Impact Acceleration and the Human Response

A History of the Naval Biodynamics Laboratory

By James P. Rife and Eric P. Nardi

U.S. Army Aeromedical Research Laboratory
Fort Rucker, Alabama

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Foreword

One summer day in 2007, two tractor trailers and a couple of pickup trucks arrived at Fort Rucker, Alabama, to deliver forty tons of magnetic tapes, research notebooks, photographs, consent forms, microfiche, paraffin blocks, books, case reports, histology slides, and physiology tracings. The U.S. Naval Biodynamics Laboratory (NBDL) data set had a new home.

NBDL was a remarkable institution that existed from 1971 until 1996. Over the course of its lifetime, NBDL evolved from a cavernous void in NASA's massive Michoud Assembly Facility in New Orleans, Louisiana, to a world-class center for the study of human response to impact acceleration. The story of how twenty-five years of ground-breaking science came to arrive at Fort Rucker is the subject of this book. However, this book was not written as a tribute to the researchers who contributed so much to this field, as noble an endeavor as that would be, nor was it written to memorialize what occurred at Michoud during this period. This book was commissioned for the benefit of current and future researchers in order to provide context and perspective to the material those researchers generated. By fully understanding the study objectives, unique equipment, tailored methods, and social and political times themselves, future researchers may be able to better interpret the NBDL data set and use it to inform current and future research issues.

NBDL was the fruition of Dr. Channing L. Ewing's dream to establish a laboratory dedicated to developing protection standards and strategies for humans exposed to impact accelerations. Toward that aim, the studies performed at this lab focused on the head and neck and were designed to yield three principal products: 1) a mathematical model of biomechanical dynamics; 2) a biofidelic anthropomorphic test device (ATD); and 3) an injury model that could accurately evaluate protective systems.[i] Experiments used human research volunteers (HRV), ATDs, and non-human primates (NHP). Well over 7,000 impact runs were conducted on both horizontal

[i] Ewing C.L., Thomas D.J., Sances A., and Larson S.J., eds., *Impact Injury of the Head and Spine*, (Springfield, Illinois: Charles C. Thomas, 1983).

and vertical accelerators, over half of them using HRV. Massive volumes of data were collected from these runs, including pre- and post-run medical evaluations of HRV and NHP subjects, somatosensory evoked potentials, electroencephalograms, electrocardiograms, and electromyograms. High-speed video kinematics were obtained during Gx, Gy, Gz, and off-axis accelerations. Reports of these data were published in multiple journals, texts, and symposium proceedings, but much went unpublished.

Ewing realized that the complex nature of the impact acceleration problem demanded an integrated, multidisciplinary team of "specialists in biomechanics, bioengineering, and medical specialties."[ii] As it turned out, he needed even more than that—research cinematographers, veterinarians, administrators, technicians, and computer scientists, among many others. This book tells their story too. It is also an account of coordinated efforts with other labs such as the Medical College of Wisconsin, U.S. Army Aeromedical Research Laboratory, Duke University, and University of New Orleans. Oral histories were obtained from key team members, though, sadly, Ewing died on September 27, 2011. These original insights and perspectives impart a richness and depth to the text as well as an understanding of the human dimension that was so much a part of this organization over the years.

The heritage of this lab, however, extends beyond stories of its people and events. The legacy of NBDL lies within the promise of this unique, robust, meticulously collected, and irreplaceable data set. That is why this book is not as much a historical account as it is foundational to future impact acceleration research. It is our hope that an understanding of context surrounding the development of these data will be a lens through which its value is magnified. The U.S. Army Aeromedical Research Laboratory is the current custodian of this material. It is being digitized and organized into an electronically accessible system, known as the Biodynamics Data Resource, to facilitate its utility for all researchers in this field. This book is the gateway to that new and enduring resource. As Dr. John P. Stapp wrote of Ewing's efforts in 1983, "May our crusade prosper."

James S. McGhee, MD, MPH
COL (RET), US Army
USAARL Commander, 2003-2008

[ii] Ibid.

Acknowledgments

This book could not have been completed without the help of many people, including U.S. Army Aeromedical Research Laboratory (USAARL) and Biodynamic Resource (BDR) staff, History Associates colleagues, and former Naval Biodynamics Laboratory (NBDL) commanders, scientists, engineers, and technicians throughout this twenty-four-month project. Consequently, a round of acknowledgments is in order for those who helped make this work possible.

First, we would like to thank Dr. Carol Chancey, the chief of USAARL's Injury Biomechanics Division, who provided direction, feedback, and expert guidance to us throughout the project to ensure the focus and accuracy of the history. She also shared her knowledge and insight into NBDL's history and legacy through an oral history interview conducted in October 2016. We are also indebted to former USAARL commander and contracting officer's representative Dr. Jim McGhee, who served as the USAARL point of contact and was a true collaborator in this effort, contacting oral history interviewees to secure their cooperation, assisting in research scheduling, handling administrative and contractual matters for the government, and participating in an interview himself. He and Dr. Chancey also sat on the project's steering committee, alongside Dr. Barry Shender, Dr. Adrianne Noe, and Christine Beltran, which reviewed all chapter drafts and provided vital feedback for manuscript tone and revision. Ms. Beltran likewise provided research support for the project at USAARL and shared her expertise concerning the documentation and photographic imagery contained within the BDR database. Additionally, during a site visit, Joe McEntire shared his recollections about the 2007-2008 equipment and data recovery effort at Michoud and gave us a tour of USAARL's new facility housing the refurbished vertical accelerator tower. We would also like to thank BDR staff members Ardyn Olszko and Kimberly Vasquez for their support and assistance throughout this effort, as well as contracting officer, John Niziolek, who managed the contract on behalf of USAARL.

Dr. Angus H. Rupert also served as an advisor to the project, sitting for an oral history interview and patiently answering many questions through email messages and telephone calls concerning the 2007 transfer of NBDL's equipment and data from New Orleans and Pensacola to USAARL. Dr. Rupert also arranged for our attendance at the Spatial Orientation Modeling Expert Workgroup (SOMEW) at Pensacola in January 2017 to meet and interview Dr. Robert S. Kennedy, NBDL's officer in charge from 1976 to 1979, who provided critical information about both his research and administration at the laboratory during his tenure there and its elevation to military command.

NBDL's last commanding officer, Dr. Dan Dolgin, also provided invaluable insight into the Base Realignment and Closure (BRAC) transfer of NBDL to the University of New Orleans in 1996. He recounted the discussions concerning the decision at that time to move important data and documentation from NBDL to the Naval Aerospace Medical Research Laboratory (NAMRL) in Pensacola. Dr. Dolgin not only sat for an oral history interview but also answered numerous other questions later concerning his time as NBDL commander. He also graciously allowed us to scan his personal photograph collection and to use select images for the book.

Special thanks go to Dr. Dan Thomas, who provided critical guidance and insights into NBDL's history from his perspective as one of NBDL's founders and earliest scientists. He participated in two oral history interviews and composed ten highly detailed personal histories focusing on the early experiments at Wayne State University and then on NBDL's creation, its operations from 1971 to 1984 (when he departed), and the efforts from 2004 to 2008 to save and preserve NBDL's equipment and data from permanent disposal. Further, Dr. Thomas was always available to answer scientific questions by email and telephone, and he assisted in compiling the project's oral history interview list and in contacting his friends and former colleagues to arrange for their participation. He also kindly contributed a number of key documents and photographs from his personal files to aid in the preparation of this history. Consequently, this project would have been very difficult to complete without his help, and for that we are very grateful.

We also wish to thank other oral history participants for sharing their memories pertaining to NBDL's history, including Dr. Dave Gillis, Bill Muzzy, Art Prell, Dr. Patrick Walsh of the Medical College of Wisconsin, and Dr. Tom Dobie of the University of New Orleans (UNO). Dave Gillis was particularly helpful, sending to us several of his personal documents and photographs concerning his Vietnam War service and his research at USAARL, the Naval Aerospace Medical Institute (NAMI), and Wayne State University. And Dr. Dobie took time from his busy schedule to carefully review and ensure the accuracy of his oral history transcript, while instructing his staff to comb through remaining NBDL materials at UNO and make them available for this history project. We also appreciate Dr. Dobie showing us the Mobile Biodynamics Laboratory, which survived both NBDL's closure and Hurricane Katrina and currently sits outside the UNO College of Engineering. Mike Lilienthal and Andre Rog likewise provided important historical information about NBDL by telephone, as did Ed Becker by email. And Dr. Ewing's daughter Russ Wiley and his son-in-law Russ Davis not only communicated with us by telephone and email to answer questions about Dr. Ewing but they also sent us very useful biographical materials concerning his life and naval career.

On the research front, we also want to extend our thanks to André Sobocinski, the historian for the Naval Bureau of Medicine and Surgery (BUMED), who answered many historical questions about his organization and was able to locate and send to us several useful documents and photographs concerning Dr. Ashton Graybiel and Dr. Chan Ewing. BUMED historian Jan Herman likewise shared biographical information with us concerning the chief of the Office of Naval Research (ONR), Dr. Joe Pollard. Thanks also go out to archivists Andrew Mullins and Sean Benjamin of the Louisiana Research Collection at the Howard-Tilton Memorial Library at Tulane University. They assisted us in identifying and reviewing relevant materials within the Felix Hebert and Bob Livingston papers that are held at Tulane in their care.

At History Associates, we also want to thank History services director Dr. Ken Durr and senior director of operations Andy Bart for their assistance in project supervision and contract management. Dr. Durr and manuscript specialist Gail Mathews clarified and improved our prose and identified and corrected typographical errors in the manuscript. Additionally, our historian colleague Matt Goguen served as an outstanding research assistant in this project, locating and capturing key documents, reports, and publications from the National Archives and online government databases. Research historian Matt Coletti provided photograph scanning support, while historian Jennifer Giambrone beautifully designed and laid out the book. And our longtime partner, Sandi Schroeder of Schroeder Indexing Services, Inc., professionally indexed the final product.

History Associates' front office support staff members Camille Regis and Nancy Crenca also provided logistical support for the project, making travel arrangements and handling routine administrative functions at our Rockville, Maryland, office. We likewise want to extend our sincerest thanks to History Associates' president emeritus and board chairman Phil Cantelon, president Brian Martin, and senior historians Mike Reis and Jason Gart, who shared their wisdom and guidance with us, based on their own unique experiences as professional historians and researchers in the federal arena.

Finally, we want to express our gratitude to Dr. Dallas Hack, who foresaw the need to prepare this history to provide context for the data and how it was created, and then helped arrange the funding for this project.

James P. Rife
Eric P. Nardi

Chapter One

The Foundations of Impact Acceleration Research, 1917-1966

On January 31, 1974, scientists at the Naval Aerospace Medical Research Laboratory-Detachment (NAMRL-D) strapped a thirty-one-year-old enlisted man into a 3,679-pound sled mounted on a 700-foot-long horizontal track. Secure in his seat, the human volunteer stared straight at the 225,000-pound thrust accelerator mechanism prepared to propel the sled down the track extending behind him. There was reason to be apprehensive in the moments leading up to the test. The accelerator had been test fired many times but never configured for a human occupant. But if the thought of activating the handheld kill switch flashed through the volunteer's mind, he ignored it. After completion of a thorough safety protocol, the "all-systems-go" green lights appeared on the monitoring console. Engineers initiated the firing sequence. The sled jolted backward: in a split second it reached a maximum velocity of nearly 70 miles per hour. Although his torso was secured, the volunteer's head and neck were not—they lurched forward during the rapid acceleration to 3.06 G.* For just a few seconds, the sled roared down the long track but then decelerated and coasted to a smooth stop. It was over. Medical professionals examined the volunteer, and an extensive post-run physical found him unharmed.[1]

The 1974 test was the direct result of an effort begun three years earlier, when, tucked away at the National Aeronautics and Space Administration's highly secure Michoud Assembly Facility in New Orleans, Louisiana, NAMRL-D researchers quietly established a first-rate facility to conduct experiments (called "runs") in the biodynamic response of the human head and neck to impact acceleration. During the intervening years, NAMRL-D researchers had successfully completed runs using test dummies and rhesus macaques (*Macaca mulatta*); the successful human run marked the start of a new era of impact acceleration research. Over the next twenty-two years, NAMRL-D (later designated the Naval Biodynamics Laboratory, or NBDL) conducted another 3,613 human tests. Along with information obtained from thousands of runs using non-human primates and anthropomorphic test devices, the human test

*This abbreviation represents the force of gravity (32 ft/sec^2) multiplied by the number given.

results created an enormous body of experimental data. That data is priceless, not only because of its broad scope and high quality but also because—given contemporary human and animal testing restrictions—it cannot be duplicated.

This landmark effort rested on firm foundations that extended back not three years but more than thirty. At bedrock was a tradition of crash injury research that emerged from World War I. Twin cornerstones—realization that accurate and actionable data necessitates use of primates and human volunteers—were laid in the years directly following World War II. The cement that made this foundation firm was the determination, arrived at during the 1960s, that the key research question was not what happened to a body under direct impact but what happened during indirect impact—when the effects of acceleration or deceleration left a human being vulnerable to hazards he or she would otherwise be able to withstand. These foundations were laid by three generations of military researchers, men who had seen the hazards of flight firsthand and were determined to do something about mitigating them.[2]

Crash Injury Origins

It was a combination of harrowing experience and unusual occupation that set an aspiring engineer onto the path to become the father of crash injury research in the United States. Hugh DeHaven was born in 1895 to a well-to-do New York family. He studied mechanical engineering at Cornell and Columbia Universities but cut his studies short. As American involvement in the Great War grew more likely, DeHaven, like many of his Ivy League brethren, fostered dreams of glory and a dashing officer's career. DeHaven had his heart set on being a pilot but was rejected by the U.S. Army Air Corps. Instead, in 1917 he volunteered for the Canadian Royal Flying Corps. Again, things went wrong—DeHaven was involved in a mid-air collision with another airplane and plummeted 500 feet to the ground. He miraculously survived. A safety belt might have saved his life, but its poorly designed pointed buckle seriously injured his abdominal region.

His flying career over, DeHaven served out his enlistment as a clerk with an unusual task—to collect and record the bodies of accident victims less fortunate than he had been. As he began to recognize similarities in injury patterns, he developed what would become a lifelong interest in crash injury prevention. In the 1920s and 1930s, based at Cornell Medical College in New York City, DeHaven worked to design safer cockpits and pilot restraints. During World War II, DeHaven and his colleagues at Cornell worked with researchers in the Safety Bureau of the Civil Aeronautics Board reviewing crash injuries from civil and military airplane accidents. They determined that most serious injuries were sustained at the head and that many of those injuries were the result of seat or harness failures upon impact. From case studies of human survival after falls from immense heights, DeHaven postulated that if suitable restraints and cockpits could be designed to protect aviators from direct impact, they could survive tremendous forces.[3]

With the onset of World War II, however, the locus of crash research shifted from DeHaven's group to the military as part of the burgeoning field of aviation medicine. The scale of the mobilization had brought aviation safety front and center—by the time the war was over, U.S. Army Air Force flight training schools had lost some 15,530 aviators to fatal accidents in the continental United States alone. It was during the war that the Army began to establish the fundamentals of the new discipline of "biodynamics." Rapid acceleration or deceleration can cause injury or death by propelling the body into a resistant object (direct impact) or by causing displacements beyond the elastic limits of internal organs (indirect impact). As early researchers discovered, the human anatomy is composed of body segments with different stress limits. Variations in how force is applied to the body can elicit changes in dynamic response. Studies in biodynamics seek to predict the effects of mechanical force occasionally on living tissue but are more often done on cadaveric specimens.[4]

Up until 1945, however, there was little good evidence as to what the limits of those effects were, though the general assumption was that humans could not survive significant impact. DeHaven thought that the limits were higher than assumed, and during the war, military researchers began to agree that the tolerance of the human body to impact forces had been underestimated. Airplane seats were at the center of the debate. During the war, the standard seat in a military airplane was capable of withstanding impact forces up to 15 G. Above that, the seat was liable to break, sending the pilot into collision with physical structures in the cockpit. When military officials recommended that harnesses and seats be designed to withstand at least 40 G, airplane manufacturers balked at undertaking expensive comprehensive redesign programs without solid quantitative evidence showing that humans could survive impact forces up to 40 G.

The manufacturers had a point. Neither DeHaven nor the military had as yet conducted the kind of studies that could answer these questions. Nazi Germany had conducted some, and during the war, captured German documents suggested a tolerance limit to frontal impact of roughly 18 G. After 1945, many German biodynamics research programs drew to a close. The initiative was figuratively on the shoulders of the United States and literally on the shoulders of the intrepid John Paul Stapp.[5]

John Paul Stapp and Human Impact Experiments

By the end of the war, the Aeromedical Laboratory at the U.S. Army's Wright-Patterson Air Development Center (WPADC) had become the leading aviation medicine research organization. Now-famous researchers including Dr. Harry Armstrong, Colonel Otis Benson, Colonel W. Randy Lovelace, and David Bruce Dill instilled a pragmatic bent into WPADC efforts. In the aftermath of Pearl Harbor, the Army Air Corps gave researchers at WPADC three critical assignments: develop breathing

Colonel John Paul Stapp (1910-1999) pioneered impact research at Edwards and Holloman Air Force Bases during the late-1940s and 1950s. (U.S. Air Force)

oxygen equipment usable at up to 40,000 feet; produce effective suits for personnel in unpressurized bombers in the event of catastrophic depressurization; and find a way to protect pilots from gravitational forces resulting from fighter plane combat maneuvers. By 1945 WPADC had succeeded in producing early oxygen-breathing systems and anti-G suits. Having established an enviable reputation during the war, WPADC continued to take the lead in the postwar years as the expansion of civil aviation and the development of high-performance jet aircraft made the study of biodynamics ever more imperative.[6]

In 1946 Colonel Edward Kendricks, chief of the Biophysics Branch at WPADC, selected a young flight surgeon, Captain John Paul Stapp, to determine human tolerance limits to impact by studying the controlled effects of impact acceleration, then commonly known as deceleration. Over the next decade, working at Edwards Air Force Base in California and Holloman Air Force Base in New Mexico, Stapp conducted thousands of deceleration studies with test dummies, human volunteer subjects, and chimpanzees. Along the way he attained a measure of national fame, and, as one scholar has noted, if "DeHaven initiated the [crash injury research] studies…John P. Stapp brought them into the Space Age."[7]

John Paul Stapp was born on July 11, 1910, to missionary parents in Brazil. The Stapps soon returned to their native Texas, where John Paul grew up and, at age thirteen, enrolled in the San Marcos Baptist Academy. He earned an English degree and then went on to obtain a master's in zoology at Baylor University, a Ph.D. in biophysics at the University of Texas, and a medical degree at the University of Minnesota. Stapp joined the Army Air Force in 1944 and trained as a flight surgeon at the Army's School of Aviation Medicine at Randolph Field, Brooks Army Air Base in Texas. If anyone had the credentials to undertake the deceleration project, it was John Paul Stapp.[8]

Stapp's first initiative was Project MX-981 ("Effects of Deceleration Forces of High Magnitude on Man"). He was probably encouraged when WPADC obtained a site at Edwards Air Force Base in the Mojave Desert and contracted with Northrop

Aircraft to build a deceleration device. He was definitely discouraged when he arrived to find "a desolate area with a 2,000-foot track, few buildings, no electricity except from a generator, no water except from a tank car, and an interesting crew of people from Northrop." Administrators at WPADC and Edwards did a poor job of providing consistent support for the program. As a result, Stapp admitted to resorting to "moonlight requisitioning, horse trading, and personal contributions" to keep his program running. Northrop's "interesting crew" did a better job, building a deceleration device that consisted of a rocket-propelled 1,500-pound sled mounted on the 2,000-foot-long track. Forty-five independent sets of pneumatic brakes effectively brought the speeding sled to a sudden stop to simulate impact.[9]

Project MX-981, like Stapp's later experiments, utilized a variety of test subjects in many different configurations. Although from the start the study was premised on the necessity of human volunteers, Stapp was determined to expand its scope by using test dummies and animal subjects, choosing chimpanzees due to their "close approximation to human masses, dimensions and reactions." Human volunteers participated in runs in the forward-facing and backward-facing positions; runs with chimpanzees were conducted in six different positions. From April 1947 to June 1951, Stapp's team carried out 222 runs (73 human, 88 chimpanzee, and 61 dummy). Perhaps it was to demonstrate his confidence in the equipment and in the project that Stapp himself became the first human to ride the decelerator sled on December 10, 1947. But he soon developed a taste for pushing his own limits while determining those of humankind. In the following fifty months, Stapp served as a volunteer subject for twenty-five more runs. On April 6, 1950, Stapp exposed himself to 37.9 G in the forward-facing position and suffered a fractured wrist. In response, officials at WPADC prohibited any more runs in excess of 30 G. That, Stapp decided, made no sense—his assignment had been to test human tolerance to 40 G impacts. He continued testing beyond 30 G deceleration levels, altering the figures in his weekly reports to WPADC while meticulously recording his own accurate and unprecedented information on human limits.[10]

In 1953 WPADC reassigned Stapp, then a lieutenant colonel, to Holloman Air Force Base to continue the human tolerance experiments. Northrop reconfigured a 3,500-foot-long track originally built for testing missiles to accommodate the experiments. The company also developed a sled that could be powered by up to twelve solid fuel rockets, each of which produced 4,500 pounds of thrust for five seconds. Water brakes along the track provided abrupt deceleration. The new sled was capable of reaching Mach 1 and could generate up to 100 G of deceleration in anywhere from 100 G per second to 5,000 G per second. Appropriately enough, the designers named it *Sonic Wind*.[11]

On December 10, 1954, Stapp tempted fate once again with a –Gx run (facing forward to simulate frontal impact). Reaching a maximum speed of 638.8 miles per hour—faster than a pistol-fired .45 caliber bullet—Stapp overtook and passed the Lockheed Shooting Star jet trainer that was tracking the test overhead. At the beginning of the run, the windblast pressure on the sled exceeded 1,100 pounds per square foot. At the end, the water brakes created deceleration reaching 40 G. Stapp experienced temporary loss of vision and suffered abrasions from the restraint harness, but there were no permanent injuries. The run earned Stapp a spot on the covers of *Collier's* and *Time* magazines and national fame as the "Fastest Man on Earth." The sobriquet stayed with him for the rest of his life.[12]

WPADC officials may not have begrudged Stapp the fame gained on *Sonic Wind*, but they were none too happy that he had taken what the Air Force considered an unreasonable risk. It was not merely the 40 G. Everyone realized that using rocket power always created the possibility that an experiment might spin out of control—indeed, in one instance a sled carrying a chimpanzee subject left the tracks. And all of those rockets were expensive. What was required was something with neither the unpredictability nor the expense of rockets. The solution, implemented in 1954, was the *Daisy Decelerator*, Stapp's most lasting legacy to Holloman Air Force Base and biodynamics testing.[13]

Stapp's December 10, 1954, run aboard the Sonic Wind *rocket sled. During the run Stapp experienced over 40 Gs and earned distinction as the "Fastest Man on Earth. (U.S. Air Force)*

Colonel Stapp's Daisy Decelerator *at Holloman Air Force Base. This view captures a human run in an omnidirectional sled. The airgun accelerator mechanism was housed in the building to the right. The tower to the left held high-speed cameras. (U.S. Air Force)*

The *Daisy Decelerator* used an air gun to accelerate the sled (the name was derived from comparison to a popular youth air rifle model produced by Daisy Air Rifle Company). It included a 120-foot-long track (later extended to 240 feet) with water brakes that could create closely calibrated rates of deceleration up to 200 G and produce impact velocities anywhere from 10 to 76 feet per second. From 1954 to 1970, more than 5,000 tests were performed on the *Daisy Decelerator* using human volunteers, anesthetized chimpanzees, and dummies. In its sixteen-year period of operation, many researchers made names for themselves working on the *Daisy Decelerator*. More than a few of them ended up at NBDL.[14]

It was also in 1954 that Stapp forged a vital link between two biodynamics research groups. Along with Don Blanchard of the Society of Automotive Engineers, he began planning a conference. At the May 1955 event, held at Holloman Air Force Base, Stapp demonstrated runs using anthropomorphic dummies to an audience of both military and civilian researchers. The event was the first of the annual symposiums on crash injury research that became known as the "Stapp Car Crash Conferences." Over the years, a community of like-minded scientists interested in all aspects of protective equipment development and crash simulation—NBDL researchers included—coalesced around the conferences. The proceedings, published annually by the Society of Automotive Engineers, became the authoritative reference work on biodynamics. Eventually, the participation of NBDL grew to the point that it hosted the 1977 conference in New Orleans.[15]

The research of John Paul Stapp had proven that humans could survive short-duration impact forces up to and beyond 40 G and, in so doing, underscored the need for safer harnesses, seats, helmets, and cockpits. Also, Stapp set a precedent for complex research projects utilizing dummies, chimpanzees, and especially human subjects. "John Paul Stapp is the index case for human impact experiments," noted former NBDL deputy director Dr. Daniel J. "Dan" Thomas. Perhaps most importantly, Stapp left his successors with a research agenda. He was able to measure velocity using telemetry, for instance, but he could never accurately measure angular movement of the head during impact—during the 1950s, neither helmet nor sensor technology made it possible. Advances on that front would await a new day and new technology. Fortunately, Stapp had trained a generation of researchers ready to seize both.[16]

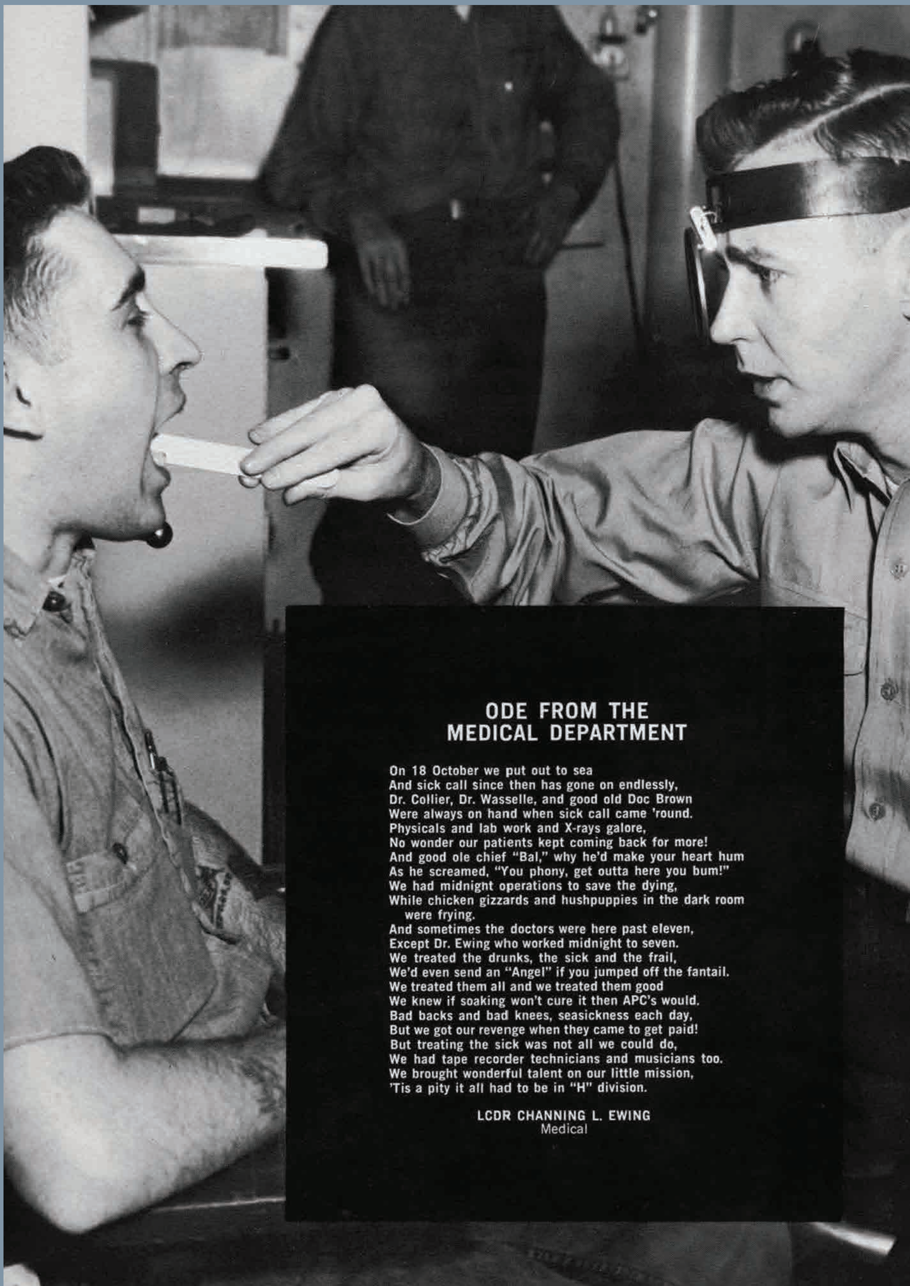
Chan Ewing and ACEL

In the summer of 1942, the Naval Bureau of Aeronautics expanded the Naval Aircraft Factory in Philadelphia into a larger complex called the Naval Air Material Center. Just over a year later, on November 30, 1943, the Department of Aviation Medicine and Physiological Research was established within the center. The department's objectives were broad: to not only ensure the personal safety of aviators but also to promote better performance in the cockpit. Its methods were wide-ranging as well, including biology, physiology, and human engineering. During the next decade, the department developed into a first-rate research facility, and in January 1954 it was renamed the Air Crew Equipment Laboratory (ACEL). ACEL pioneered studies on oxygen masks, thermodynamics, and pressure suits. The laboratory's work on helmets and ejection seats fed directly into the stream of scientific inquiry that would eventually flow through NBDL.[17]

To the layman, all helmets are "crash" helmets—there only for protection in crisis. But through the late 1940s, the Navy issued no standard fighter pilot helmet, and those employed were usually intended to protect the human head only from non-critical impact with the airplane canopy. Helmets of this variety were called "anti-buffeting" helmets and were distinct from "crash" helmets. The first standardized helmet was the H-1, developed at ACEL in 1948 by Dr. Edwin Hendler and Captain John R. Poppen, MC, USN. This anti-buffeting helmet consisted of a fiberglass shell with chamois-covered foam padding on the inside. The H-1 was designed to accommodate goggles, an oxygen mask, and a headset. Most importantly, however, the H-1 weighed only 1.75 pounds. During the course of their work, Hendler and Poppen had developed an insight that would be key to all future helmet research: a helmet should be strong, but it must also be as light as possible, not only to prevent fatigue from extended wear but also so that, as they wrote, "the load which must be supported by the tissues of the head and neck under conditions of positive G is diminished."[18]

As Hendler and Poppen worked on helmets, other ACEL researchers were improving ejection seats. The effort began in 1946 with the erection of a 105-foot-tall test fixture by Martin-Baker Aircraft, Ltd., a pioneer ejection seat manufacturer. In these early experiments, human volunteers were accelerated vertically (+Z) by detonation of a powder charge catapult mechanism positioned underneath the seat. With John Paul Stapp's work only beginning, knowledge of human tolerance to rapid acceleration remained poorly understood, so human volunteers were exposed to increasing accelerations only in small increments. Velocity was measured using sensors ("accelerometers") attached to the hip, shoulder, and head of the volunteers. Investigators believed that vertebral injuries were likely to occur between 23 and 25 G, so during the forty-eight early ejection experiments, the maximum acceleration reached only 22 G, which the researchers believed represented "the practical upper limits for seat ejection experiments." Drawing on the results of these early tests, ACEL engineers developed an ejection seat launch mechanism capable of producing a maximum acceleration of 18 to 20 G. An aviator later used the device to successfully eject moving at 250 miles per hour.[19]

By 1955 ACEL had undertaken major studies on the biomechanics of aviation crash injuries and human tolerance to parachute opening shock and developed new oxygen systems and anti-exposure suits. Under director Captain Roland A. Bosee, MSC, USN, ACEL built up a talented staff of ninety-four civilian employees and twenty-five naval researchers. Among the latter was a young Navy flight surgeon, Lieutenant Commander Channing L. "Chan" Ewing.[20]



ODE FROM THE MEDICAL DEPARTMENT

On 18 October we put out to sea
And sick call since then has gone on endlessly,
Dr. Collier, Dr. Wasselle, and good old Doc Brown
Were always on hand when sick call came 'round.
Physicals and lab work and X-rays galore,
No wonder our patients kept coming back for more!
And good ole chief "Bal," why he'd make your heart hum
As he screamed, "You phony, get outta here you bum!"
We had midnight operations to save the dying,
While chicken gizzards and hushpuppies in the dark room
were frying.
And sometimes the doctors were here past eleven,
Except Dr. Ewing who worked midnight to seven.
We treated the drunks, the sick and the frail,
We'd even send an "Angel" if you jumped off the fantail.
We treated them all and we treated them good
We knew if soaking won't cure it then APC's would.
Bad backs and bad knees, seasickness each day,
But we got our revenge when they came to get paid!
But treating the sick was not all we could do,
We had tape recorder technicians and musicians too.
We brought wonderful talent on our little mission,
'Tis a pity it all had to be in "H" division.

LCDR CHANNING L. EWING
Medical

Senior Medical Officer Lieutenant Commander Channing L. Ewing examines a sailor in 1962 aboard the USS Essex. *(Naval History and Heritage Command)*

Chan Ewing was born on May 28, 1927, in Jefferson City, Missouri, a doctor's son. Indeed, achievement in medicine was something of a birthright: when Ewing was two years old, his father Channing B. Ewing served as vice president of the American Ophthalmology and Otolaryngology Society. In the mid-1930s, the family moved to East Lake, Florida, where Ewing attended high school. In 1944, a day after his eighteenth birthday, Ewing joined the Navy. Participating in the Navy's V-12 College Training Program, Ewing enrolled in the University of Richmond's pre-med program. Upon completing his pre-med studies in October 1946, Ewing received commission as a Navy Ensign. After an interlude on active duty, Ewing enrolled at the Medical College of Virginia, where he earned his M.D. in June 1952. Ewing spent a year interning at the U.S. Navy Hospital in Portsmouth, Virginia, and then attended the School of Aviation Medicine in Pensacola, Florida, to become a flight surgeon. In late 1953 the Navy assigned Lieutenant Junior Grade Ewing to Marine Air Group 14, based in Edenton, North Carolina.[21]

Within a few months, however, the Navy transferred Ewing to Marine Attack Squadron (VMA) 211, aboard the aircraft carrier USS *Wright*, which set sail from Davisville, Rhode Island, in early April 1954. After traveling through the Panama Canal and making brief stops at San Diego and Pearl Harbor, the *Wright* reached Yokosuka, Japan, in late May, where aviators in VMA-211 joined the Navy's Seventh Fleet in missions off the coasts of Japan and Korea. In June a Navy PBM Mariner carrying seventeen marines and sailors crashed at Mt. Miyanoura on the Japanese island of Yakushima. Lieutenant Ewing and Captain Joseph C. Toth were flown in by helicopter as first responders. During the ultimately futile search for survivors, Ewing helped identify the remains of twelve Navy servicemen. After a brief stopover in Hong Kong, the *Wright* arrived in San Diego in late October 1954. For his service aboard the *Wright*, Ewing received a promotion from Lieutenant Junior Grade to Lieutenant.[22]

In January 1955 Ewing reported for duty as junior medical officer aboard the USS *Ticonderoga* (CVA-14) with the 3rd Carrier Air Group. Based in Norfolk, Virginia, the *Ticonderoga* participated in pilot qualification flights and testing with the new A4D-1 Skyhawk, F4D-1 Skyray, and F3H-2N Demon fighter planes. The *Ticonderoga* set sail for the Mediterranean where, on November 23, 1955, an aviator returning to the carrier missed the tail hook, skidded across the *Ticonderoga's* flight deck, and killed six sailors. In that instance the pilot survived, but in a second instance, witnessed by Ewing around the same time, another pilot who misjudged his landing did not survive. In August 1956 the *Ticonderoga* returned to Norfolk, and Ewing began a one-year surgical residency at Strong Memorial Hospital in Rochester, New York. In July 1957 Ewing moved to Florida to serve in the active reserve as a flight surgeon in Jacksonville and to open a general practice in nearby Belleview.[23]

Chan Ewing was not destined to be a general practitioner, as he had already developed an abiding interest in aviation injury prevention research. In December 1955 the *U.S. Navy Medical News Letter* reprinted an anonymous Medical Officer's Report on a recent fatal airplane accident. The author, not named in the journal, was Ewing. The incident he described was almost certainly a crash on the *Ticonderoga*. Operating on only three hours of sleep, a young pilot misjudged the landing on the flight deck of an aircraft carrier and his landing gear struck the barrier. Upon contact, the aircraft flipped over. The pilot's helmet was the subject of the bulk of the report, in which Ewing noted that it had been modified and that the chin strap had been worn out from earlier use to the point that it could no longer be fastened. When the plane rolled over, the helmet came off, leaving the aviator's head completely vulnerable. By the time the medical crew was able to extricate him, the pilot had already died of his injuries. Based on this experience, Ewing emphasized the importance of regular inspections of pilots in their flight gear, with particular reference to harness locks and helmets.[24]

The very next year, Ewing submitted a list of standard aviation safety tips to the Naval Aviation Safety Center, Norfolk, Virginia. The Aviation Safety Center deemed the list worthy of inclusion in its monthly journal *Approach: The Naval Aviation Safety Review*. The tips stressed the need to properly wear helmets, flight suits, oxygen masks, and life-raft lanyards. Ewing also warned against flying when exhausted or sick. To underscore Ewing's points with a touch of levity, *Approach* paired each tip with a comic illustration.[25]

Ewing's comic illustration that accompanied his tips for oxygen mask use. His tip read, "Check that oxygen mask before every hop. Take it apart and clean it yourself so that you won't be afraid of it due to ignorance. If you need help, get in touch with the squadron oxygen equipment officer, or the flight surgeon." (Source: C. L. Ewing, "Helpful Hints from the Flight Surgeon," Approach *2, no. 2 (1956): 39.)*

In late 1958 Ewing's service at Jacksonville earned him promotion to the rank of Lieutenant Commander. His interest in aviation safety earned him assignment to ACEL as an aviation medicine specialist. When Ewing arrived at ACEL, the laboratory was booming. The 130,000-square-foot facility, valued at roughly $5.6 million in 1960, included three high-altitude chambers capable of simulating levels of 100,000 feet; a vertical accelerator that could reach 200 G; a horizontal accelerator for crash and crew restraint programs capable of 43 G; an underwater test tank for research on aircraft emergency escape systems; and an acoustic chamber for research on the sound attenuating properties of helmets. At first, Ewing conducted research in a variety of aviation medicine subfields. He helped develop oxygen masks and published on the dangers of hypoxia (oxygen deficiency). All the while Ewing sharpened his interest in bioengineering with a specialization in the prevention of injuries to the head, neck, and spine during aircraft ejection and crash situations.[26]

In August 1960 Ewing took time out to serve as senior medical officer aboard the aircraft carrier USS *Essex* (CV-9). As the flagship of Carrier Division 18 and Antisubmarine Carrier Group 3, the *Essex* participated in NATO and CENTO exercises in the Mediterranean and Arabian Seas in the late summer and fall of 1960 before returning to port at Naval Station Mayport in Jacksonville, Florida.[27]

During a follow-on "training cruise" in April 1961, Ewing experienced a close brush with an actual shooting war when the *Essex* steamed off the coast of Cuba in support of the failed Bay of Pigs invasion. Sworn to secrecy in the aftermath of the botched landing attempt by CIA-trained anti-Castro rebels, Ewing's high seas adventures came to an end. Back ashore, he chose a pursuit more closely related to his professional interest—a master of public health degree from Johns Hopkins University.[28]

Ewing picked up his diploma in June 1963 and returned to ACEL as a resident in Aerospace Medicine. Two months later he was promoted to the rank of Commander. In late October, Ewing, along with researchers from the Bureau of Naval Weapons, Bureau of Medicine and Surgery, Office of Naval Research, National Aeronautics and Space Administration, and Naval Aviation Safety Center, attended a "Symposium on Effective Life Support Helmets" sponsored by the Office of Naval Research in Washington, D.C. It was an opportunity to move from the backstage into the spotlight of his chosen field, and Ewing made the most of it.[29]

Near the beginning of the conference, ACEL colleague Dino Mancinelli presented a paper written by Ewing and Frank A. Catroppa that documented defects in the Navy's APH-5 helmet (which had become standard issue in 1956). Ewing and Catroppa determined that its nylon chin strap often failed under stress, allowing the helmet to loosen or come off entirely during impact or ejection. They also identified the APH-5 (which weighed 4 pounds) as a source of pilot fatigue during longer flights. Ewing and Catroppa contrasted the APH-5 with the APH-6 helmet that they had developed. This helmet's chin straps featured cotton-covered urethane pads—the additional comfort was meant to discourage pilots from unbuckling and thus improve "retention rates." The APH-6 weighed in at 3 pounds 13 ounces.[30]

Ewing followed up with a paper that discussed the design criteria of helmets in broader terms and took issue with one of the Navy's central tenets of helmet design. The Navy's long-term emphasis on anti-buffeting helmets rather than crash helmets was predicated on the assumption that a pilot should be able to eject before crashing. Not so, Ewing told the attendees—there were numerous instances where pilots had been unable to do so. As a result, he explained, 86 percent of fatal accidents among Navy pilots between 1957 and 1960 occurred during crashes in water. Therefore, Ewing concluded, helmets should be designed primarily to protect pilots during crashes rather than from buffeting during flight.[31]

This shift of emphasis would make helmet design more complicated, however, because the extra weight needed for a crash helmet threatened not only to increase fatigue but also to raise the risk of injury. Citing Stapp's research, Ewing noted that pilots could withstand 38.6 G at 1,370 G/sec. But the increased weight of a helmet, he noted, would quickly lower that threshold. "The more weight put on the helmet, the more forces will be exerted on your cervical vertebra," Ewing said. As the weight of the helmet is increased, the human tolerance limit to impact forces decreases. For this reason, he said, "cervical vertebral fracture during deceleration is the main limit on weight." Ewing recommended that helmets relying solely on the head for support (which virtually all were at that time) be kept under four pounds.[32]

The ensuing discussion suggested that Ewing had hit a nerve. Captain Richard E. Luehrs of the Naval Air Station in Norfolk stated that he had personally witnessed eleven instances in which planes crashed near a carrier with the pilot clearly visible but making no effort to get out. "I think he is breaking his neck with the weight of the helmet when the moving plane hits the water," concluded Luehrs. "They stop hard and the G-loading is tremendous." Lieutenant Commander Robert Simmons of the Naval Aviation Safety Center cautioned, however, that "our information is very sketchy. In many cases, this is a matter of postulation." Ewing readily conceded that the case was far from closed. "To understand why cervical vertebral fracture is a matter of design parameter in crash helmets, we must review the action of the head and neck under horizontal crash decelerations," he concluded. Ewing had, in effect, laid out the research agenda for his remaining life's work.[33]

Ewing and Project Gemini

Project Mercury had barely begun when, in December 1961, the National Aeronautics and Space Administration (NASA) initiated Project Gemini. Whereas Mercury capsules contained only one astronaut for relatively short-duration missions, Gemini spacecraft carried two for extended periods in orbit. Intended as a steppingstone to the Apollo program and the moon landing, the objective of Project Gemini was to conduct more lengthy missions including extra-vehicular walks and rendezvous with other capsules in space.[34]

During these rigorous missions, NASA was concerned about the effects of negative (–Gz) acceleration on astronauts re-entering the earth's atmosphere, particularly the pooling of blood in the soft tissues of the head, face, neck, and chest cavity. The space agency therefore commissioned ACEL to develop better data on human tolerance limits in negative acceleration. ACEL subsequently developed a sled mounted on a 386-foot-long horizontal track. A hydro-pneumatic mechanism capable of producing accelerations up to 45 G and a rate of onset of 1,075 G per second supplied the input force. The ACEL device simulated impact at the beginning of the run by rapidly accelerating the sled rather than at the end through sudden breaking, as Stapp's had.[35]

Five human subjects, fitted with harness restraints, wearing Project Mercury helmets, and placed in a supine position to create negative acceleration forces, were exposed to 14.5 G. These runs were successful—enough for NASA to discontinue the ACEL contract before a better measure of human tolerance limits could be established. Even so, the experience had an important influence upon Ewing. The experiment utilized high-speed photography and sled-mounted accelerometers to produce unusually precise data. Ewing would later build these two components into the foundation of his work at NBDL.[36]

Although the acceleration contract was canceled, ACEL continued to develop space suits and life support systems for NASA. It was, for a time, the only facility in the country conducting thermodynamics studies for the space program. Since Ewing specialized in development of protective equipment for aviators, he was invaluable to the NASA efforts. As Ewing explained to the press, "Space is not fit for man, so man must be fitted for space." ACEL research led to the development of the MK IV pressurized suit, used by Project Mercury astronauts as well as naval aviators flying the high-performance Vought F-8 Crusader, the North American A-3 Vigilante, and the McDonnell Douglas F-4 Phantom. Ewing also helped develop helmet ventilation systems for pilots flying in high temperature, high humidity environments.[37]

Perhaps most importantly, the NASA research gave Ewing the opportunity to work with human volunteer subjects in a variety of situations. During the early 1960s, the Navy approved the use of human subjects for studies on altitude and oxygen sickness as well as testing of water-cooled suits in support of the space program. In the course of an experiment designed to test human adaptability to high altitudes employing pure oxygen, a spark touched off a fire that left three human volunteers and a monitoring officer with first- and second-degree burns. The event convinced Ewing and other ACEL researchers that even in carefully controlled studies, accidents always remained a risk, so when human volunteers were involved, every precaution had to be taken.[38]

In early 1964 the Navy transferred Ewing from ACEL to the Naval School of Aviation Medicine in Pensacola, Florida. Established by the Secretary of the Navy in October 1946 and a component command of the Naval Aviation Medical Center (NAMC) since April 1957, the School of Aviation Medicine was then providing flight surgeons to NASA to monitor astronaut training and physical performance during orbital missions. Ewing's earlier research for NASA suited him well for this particular job, so he joined the Gemini Program.[39]

In March 1964 Ewing reported to NASA's Manned Spacecraft Center near Houston for an intensive five-day training course designed to familiarize Navy doctors with flight schedules, mission planning, spacecraft systems, and Gemini safety equipment. After he completed the course, NASA made Ewing an aeromedical flight controller for Gemini V. The mission took place that August, with Ewing serving aboard the NASA tracking ship USS *Coastal Sentry Quebec*, monitoring astronauts Gordon Cooper and

Charles "Pete" Conrad while they orbited the Earth for eight days to determine the effects of long periods of weightlessness on humans. That performance earned Ewing a return engagement as senior aeromedical flight controller for Gemini IX at NASA's tracking station in Guaymas, Mexico. During that mission, launched in June 1966, Ewing monitored astronauts Tom Stafford and Gene Cernan during a difficult three-day flight that included docking exercises and a spacewalk.[40]

Ewing's time with the Gemini Program was educational in a number of ways, but one lesson was less than welcomed. In 1964 Ewing had opined that the "Navy's needs in research on aviation medical problems are not being met with Navy funding today." By 1966 he had grown increasingly concerned over the state of naval aviation medicine. The Naval Bureau of Medicine and Surgery (BUMED), it appeared to Ewing, was increasingly acting as an investigatory arm for NASA and other agencies rather than serving its own aviation community. By then, in fact, NASA was funding most naval research in aerospace medicine. When it came to the Navy's research agenda, he noted, "a great deal of needed work is not being done because neither the funds nor trained personnel are available." Ewing could do little about funding decisions, but he did recommend that the Navy offer more residencies, train more flight surgeons, and detail general medical officers to more routine assignments so that the flight surgeons could do research.[41]

Anthropometrics and Vertebral Fracture

In between his details to NASA, Ewing carried on an intense program of research on head and neck injuries incurred during crashes. One of the subfields that earned his attention during this period was anthropometrics, the scientific measurement of the human body. He surveyed the subject in a review of work undertaken at ACEL by Edmund C. Gifford, Joseph R. Provost, and John Lazo published in the *Navy Medical Newsletter* in late 1966. That team had recently captured precise body measurements of 1,549 U.S. Navy aviators in order to reset the baseline for aircraft specifications.[42]

Military anthropometry got off to an unfortunate start. Shortly after the war, researchers at the Army's Wright-Patterson Air Development Center tabulated measurements of U.S. Army Air Force aviators who entered service between 1943 and 1944. The Navy and aircraft manufacturers then used this data to design safety equipment and cockpits. What no one took into account was that during those years, the U.S. Army Air Force had in place a maximum height limitation of 5 feet 10 inches for fighter pilots. The Air Force had since lifted the restriction, and postwar pilots could hardly be expected to come in under it. As a result, cockpits designed using these anthropometric specifications inevitably placed taller pilots at risk. In order to accommodate themselves to their cockpits, taller pilots had to slump—and slumping, because it caused the spine to assume a posture less able to handle vertical loads, meant that far less impact energy was required to produce injury.[43]

Dr. George T. Lodge of the U.S. Naval Aviation Safety Center confirmed these findings. First he established that U.S. Navy pilots were taller on average than the specifications around which cockpits for jet aircraft of the late 1950s were designed. Lodge then evaluated 680 jet accidents to find that pilots over six feet tall were disproportionately represented. Drawing upon his own research at the Naval School of Aviation Medicine, Ewing confirmed "significant correlation between disparities in sitting height accommodation in aircraft and vertebral fracture."[44]

Another problem that Ewing identified during his review of vertebral fracture injuries was related to the characteristics of ejection seats in use at the time. Ewing found that ejection seats installed in McDonnell F-3 Demon and Grumman TF-9J Cougar fighter jets raised the overall seat height to the extent that pilots could not maintain good posture and thus normal vertebral alignment. This was enough of a problem in ejection systems in which the canopy lifted and broke away just prior to ejection. But some fighters used a through-the-canopy ejection system in which a spike at the top of the ejection seat shattered the canopy glass just before the pilot reached it. Sometimes the spike failed to deploy, leaving the pilot's helmet to shatter the canopy. Slouching pilots were far more likely to suffer vertebral fractures, especially during through-the-canopy ejections. Ewing recommended particularly that pilot posture be "forcibly maintained during ejection by a suitable minimum seat angle and restraint system."[45]

The Navy subsequently made several efforts to rectify the issue. Orders came down to replace through-the-canopy ejection systems with safer lift-away canopies. Through-the-canopy ejection remained an option only as a last resort in the event of mechanical failure. In addition, the Bureau of Weapons authorized ACEL to catalog the sitting height for every type of aircraft currently used by the Navy. This was a big undertaking, considering that twenty-two different models of Navy jet fighters had been introduced between 1945 and 1959. But the data allowed the Navy to place individual aviators in squadrons using aircraft that could safely accommodate them.[46]

"The Starting Point": Concussion and Vertebral Injury

In December 1966 Ewing published an article titled "Emergency Underwater Escape from Aircraft" in the *Navy Medical Newsletter*. In the article, Ewing surveyed new equipment and flight suits designed to allow pilots trapped in submerged aircraft to continue breathing pure oxygen (O2) for a period of time. In shallow waters at a depth of around twenty-five feet, Ewing noted, a pilot could breathe pure oxygen for about seventy-five minutes before the effects of oxygen intoxication (hyperoxia) began to set in. In these situations, it appeared that pilots would have ample time to extricate themselves from the aircraft and ascend to the surface. Most crashes occurred in deeper water, however, and then the prospects were bleak. At a depth of forty feet, a panicked or physically exhausted pilot could count on a mere ten minutes of safe breathing. If able to escape from submerged aircraft in deep water, a pilot then had to ascend slowly or face the deadly dangers of decompression sickness, more commonly known as the "bends," in which dissolved gases, chiefly nitrogen, formed bubbles inside blood and body tissues during depressurization.[47]

In any case, Ewing noted, pilots in sinking aircraft had to react quickly if they were to have any chance of survival. Since jet aircraft in use during the 1960s usually remained afloat for less than sixty seconds before sinking at a rate of about one hundred feet per minute, pilots suffering incapacitating injuries during impact were essentially doomed. This accounts for the despair voiced by Captain Luehrs at the October 1963 conference when he recalled seeing pilots make no attempt to escape their sinking planes. Luehrs surmised that the force of impact probably broke their necks. Ewing was skeptical. Remains of aviators killed in crashes at sea were rarely recovered, and in the handful of cases when they were, evidence was often compromised during autopsy, frequently conducted without pre-autopsy x-rays and performed by general pathologists at hospitals nearest the accident site.[48]

What these autopsies missed, Ewing had suspected for some time, was evidence of injury due to "acceleration concussion" that could only be detected by neuropathological examination of the central nervous system. From studies at ACEL and personal experience as a fleet flight surgeon, Ewing was aware of the dangers of impact-induced central nervous system trauma, or concussion. Nevertheless, he suspected that the pilots Captain Luehrs described had not suffered a blow to the head. Instead, they had blacked out while fully restrained and with their heads free and uninjured. Perhaps they had suffered some kind of concussion, but they had likely died from drowning.[49]

Even into the 1960s, the symptomology and effects of concussion were only vaguely understood. Early work, dating back to the 1940s, was based on necropsies of brains from concussed animals. Researchers from a variety of institutions conducted experiments with different types of animals and reviewed tissue samples with an eye for microscopic trauma attributable to concussion. While a consensus was never reached, most researchers agreed that neurologic disruptions, including sudden traumatic unconsciousness and amnesia following a blow to the head, typified concussion in humans. Ewing was coming to a different definition for a new type of concussion—one that could be produced by indirect impact, which he defined as a "concussion occurring in an individual with a freely moveable head (i.e., unrestrained and not resting against anything) who does not receive a blow to the head and who does not suffer cortical injury."[50]

Ewing was building upon existing work. Dr. Reinhard L. Friede had conducted a study with anesthetized cats at the Wright-Patterson Biomedical Laboratory in the early 1960s. Friede determined that sudden deceleration of the head resulted in an abrupt stretching of the neck that produced injuries very much in line with those caused by a blow to the head. In particular, Friede observed matching lesions at the first cervical vertebra (C-1) and loss of consciousness. This "cervical stretch" theory seemed logical to Ewing. John Paul Stapp had demonstrated that considerable head-neck displacement could occur when the unrestrained head experienced abrupt deceleration; Ewing's own research indicated that heavy helmets exacerbated this displacement. Ewing had come to the conclusion that further research on the biodynamic response of the human head and neck might answer the lengthening list of questions that started with concussions and included vertebral fracture and aircraft design. Years later, Ewing referred to these questions as "the starting point for our [NBDL] experiments." Dan Thomas agreed, asserting that the NBDL project "was always related to concussion."[51]

Having recognized a previously little-known hazard, Ewing was determined to do something about it. In the short term, he encouraged the Navy to institute new autopsy policies that would allow the Naval Aviation Safety Center to collect information from the small percentage of aviators recovered from a fatal crash at sea. Over the long term, he was hoping to establish a research program. Ewing knew it would not be easy, so he started building his case, beginning by compiling data on aviator accidents with a particular eye on restraint system design. Ewing also tapped connections at the Naval Aviation Safety Center to gather statistics on recent jet aircraft accidents. The results were alarming—a testament to the toll that the growing use of jet aircraft was taking on naval aviators.[52]

From 1959 to 1963, Ewing documented a "198 percent increase in gross fracture rate for jets and a 217 percent increase in the ejection fracture rate, with a continued upward trend in both." The statistics also burst any remaining illusions that ejection was a viable means of escape. Over the entire period, Ewing found, only 27 percent of aviators in trouble ejected or bailed out. The rest hit ground or water. "Definition of an optimist: a naval aviator with a savings account," went a quip popular at the time. The Naval Aviation Safety Center statistics only confirmed what most aviators already knew. The task remained of doing something about it.[53]

Dr. Ayub Ommaya and NIH

Ewing might have set the agenda, but as fate would have it, someone else began the research. Perhaps this was to be expected. Other scientists had been doing concussion research for three decades, and some had long-standing relationships with the Navy. During World War II, the Navy funded a number of concussion research projects through the Office of Scientific Research and Development. Its successor, the Office of Naval Research (ONR), continued to do so into the late 1950s, supporting studies by Arthur G. Gross at Gross Research Laboratories, Inc., and Dr. Arthur A. Ward, Jr., at the University of Washington on impact thresholds of brain concussion for use in helmet design. Evidence suggests that sometime around 1964, Ewing submitted a proposal to the Naval Air Systems Command (NAVAIR) to study flexion, extension, and rotation of the cervical spine and neck during impact to see if concussions resulted. The Navy recognized the importance of the research but felt that Ewing should continue his work for NASA.[54]

Instead, NAVAIR sponsored collaboration between the National Institutes of Health (NIH), Bethesda, Maryland; Naval Medical Research Center, Bethesda, Maryland; Naval Air Development Center, Warminster, Pennsylvania; and David Taylor Model Basin at the Naval Ship Research and Development Center, Carderock, Maryland. The project's objective was to collect information on the causes of concussions in humans and find means of preventing them. The fact that the Naval Medical Research Center had conducted research on accelerative and decelerative forces in aviation since World War II lent credibility to the collaborative effort, but a civilian would lead the research, Dr. Ayub K. Ommaya of NIH.[55]

The concussion study, begun in 1965, investigated experimental head injury using a variety of primates as subjects to test head and neck protection for naval aviators. Its programmatic category was "ADO 43-12X: Air Crew Impact Injury Prevention," the same under which NBDL would later be approved. Working with Dr. Arthur E. Hirsch from the David Taylor Model Basin, Ommaya conducted impact acceleration experiments with primates in order to establish a concussion threshold level. A key objective of the effort was to determine whether concussion could be produced without a direct blow to the head as Friede had postulated. Ommaya developed a reproducible experimental model using lightly anesthetized rhesus macaques because their head and neck structures are similar to those of humans. Like Stapp, Ommaya recognized that higher primates would yield results directly applicable to humans.[56]

Ommaya defined concussion broadly as a condition "indicating injury to the nervous system by rapid energy loading and having as its prime index impairment of consciousness." To detect changes in central nervous system function, Ommaya relied on electroencephalogram (EEG) and electrocardiogram (ECG) readings. He later recalled that upon review of high-speed film of the impact exposures, he was "struck by the significant bending, twisting, and stretching distortions in the neck after frontal as well as occipital impacts." Accordingly, Ommaya and Hirsch began reducing these neck distortions by using cervical collars to check head and neck motion. The collars substantially raised the concussion threshold level. This finding was profound because it got Ommaya thinking about helmet design.[57]

Ommaya detailed his findings in a 1965 lecture at the Royal College of Surgeons of England. He began by noting that helmets had always been designed to absorb or reflect blows, not to secure the head. "By adding further weight and by shifting the center of gravity up and forward, a heavy helmet, such as is worn by pilots and motorcyclists, increases the moment of inertia about the cervical pivots," he found. In other words, heavy helmets can do more harm than good, particularly in cases of indirect impact. With this observation, Ommaya reached the same essential conclusion that Ewing had already been coming to.[58]

Ewing Perseveres

Undaunted by the Navy's rejection of his proposal, Ewing continued to seek support for an experimental program. In early March 1966, he attended a symposium on the prevention of head and neck injuries conducted by the Office of the Chief of Research and Development of the U.S. Army. The attendance list reflected the recent growth of the research community. Colonel Stapp and Dr. Edward J. Baldes were present. Ewing accompanied a contingent of Navy officers that he had known since his days at ACEL, including Captain Roland Bosee, Dr. Edwin Hendler, and Captain Richard Luehrs. Ommaya and colleagues Arthur E. Hirsch and Fred H. Faas also attended. Most importantly, the meeting gave Ewing a chance to talk with researchers from the Army. As it turned out, they were also acutely aware of the dangers inherent in the moments after a crash. Army aviators might not have to escape from a sinking plane, but they did have to escape from a hazard of less concern to naval aviators—fire.[59]

The problem stemmed from the generally different mission types flown by the Army aviator. Since Army aviators most often provided short-range mobility and low-level intelligence for ground forces, they relied greatly on rotary-wing aircraft. In 1961, more than 50 percent of Army light aircraft were helicopters. For obvious reasons, helicopters did not have ejection seats. Since they generally flew at low altitude, bailouts were never an option either—helicopter crew members were not issued parachutes. As Major James C. Beyer put it, there was nothing for the average Army aviator to do but "to ride his aircraft in." That accomplished, fuel tanks often burst and deadly fires followed. From 1967 to 1969, for example, the Army registered 334 aircraft accidents. Of these, 206 would have been survivable were it not for post-crash fires. These caused 155 fatalities, an additional 470 casualties, and approximately $80 million in damage.[60]

Another study, by the U.S. Army Board for Aviation Accident Research, put the survivability rate much higher—at 97 percent. But even in the absence of fire, the lack of adequate protective equipment caused aviator deaths in otherwise survivable crashes. As the Army readily admitted, it was "no easy task to put a 40-G cockpit in a light observation helicopter and still have the aircraft able to get off the ground." Nevertheless, there was more that could be done, particularly to mitigate the effects of indirect impact, prompting the Army Surgeon General's Office and the Board for Aviation Accident Research to call, in 1961, for development of an "extensive set of data on impact experience."[61]

At the beginning of the Vietnam War, Army aviators wore the Navy APH-5 model helmet. The Army was no happier with it than Ewing had been, so in subsequent years Army technicians worked hard to develop safer helmets designed specifically for helicopter crew members. Helicopter crashes were unique in yet another way. In sharp contrast to conventional aircraft, they came down more vertically than horizontally. Therefore, protective equipment had to be designed to defend against $-G_z$

acceleration (eyeballs down). The Army assigned high-priority status to deceleration (impact acceleration) studies, particularly those that could develop experimental data from human volunteers.[62]

Ewing recognized an opening when he saw one. At another time, his affiliation with the Navy might have been prohibitive since both service branches had to coordinate approval and reach an agreement on the administration of the project. But the Army, Navy, and Air Force had recently developed an effective collaborative work plan for aeromedical research. Just months earlier, in December 1965, two of the branches had created the Joint Army-Navy Coordinating Panel for Flight Medical Research. Ewing might have stuck with his service branch despite the opening with the Army if not for one other factor: it was at just this time that he was becoming disillusioned by the Navy's propensity to undertake research on contract—particularly for NASA—at the expense of naval aviation. The time was also right since Ewing's obligation to the Gemini Program would end during the summer of 1966, freeing him to undertake the new research program before the Navy could reassign him to another project. In May 1966 Ewing submitted his proposal, entitled "Determination of Human Dynamic Response to Impact Acceleration," to the U.S. Army Medical Research and Development Command. Among other things, it promised to study the displacements of the human head and neck during impact and to collect precise quantitative data that could be used in development of helmets and restraints for Army aviators.[63]

Ewing might have considered his proposal irresistible, but would the Army be compelled to fund it? Here again, Ewing's timing was fortuitous. As the Vietnam War flared from a police action to full-scale conflict, Americans—and therefore legislators—were becoming skeptical about the value of public investment in military research. Bowing to this pressure, former Ford Motor Company "Whiz-Kid" Robert McNamara steered the Department of Defense (DOD) in a new direction. DOD had recently adopted budget classifications favoring applied research programs that directly supported short-term military priorities over long-term basic research. The new scrutiny that doomed many research programs gave Ewing's agenda new life—after all, he was promising to support a critical military need by producing data that would enable the Army to roll back the ever-mounting casualties among Army aviators involved in crashes. The Joint Army-Navy Coordinating Panel for Flight Medical Research assigned the project high- priority status.[64]

Another recent shift in the nation's social and political priorities may have encouraged contracting officers to reach for the "approved" stamp. By the mid-1960s, automobile crashes were the leading cause of death for Americans under the age of forty. Roughly 49,000 Americans were killed and another 1.8 million were injured in automobile accidents in the year 1965. But these numbers alone did little to shake the American insistence on overlooking automobile casualties. Instead, it was a best seller by an unlikely crusader that started the nation on the road to automotive safety. In 1965 Ralph Nader published *Unsafe at Any Speed*, a study that started by detailing the hazards of the Chevrolet Corvair and ended by indicting General Motors for deliberately "cutting corners to shave costs." The public outcry led to legislative action, the creation of the U.S. Department of Transportation, and industry funding for studies on vehicle dynamics and crash simulation. Had they not been moved by the national tide, military appropriators might have looked closer to home. In 1965 about 40 percent of the Army's accident casualties were due to motor vehicles. Injuries from automobile accidents cost the Air Force alone some $17.5 million.[65]

Appropriately then, the fundamentals of Ewing's research agenda transcended service lines and modes of transportation. As he summed it up later, the proposal listed four central objectives: "(1) to measure precisely the dynamic response or output of the head and neck to input acceleration; (2) to measure precisely that input acceleration; (3) to develop a method of obtaining the data in such a form that automatic data processing may be used; and (4) to develop and validate a general method for the determination of the bioengineering characteristics of the human body with such precision, accuracy, and repeatability that a mathematical model of the human dynamic response to impact acceleration can be constructed." Meeting these goals would require developing an innovative experimental methodology that utilized state-of-the-art technology to provide more accurate measures of data than produced by previous studies. It would necessarily involve human volunteers, for like Stapp before him, Ewing believed that "the primary instrument for measuring the effects of mechanical force on man is man." That conviction, eight years later, led a thirty-one-year-old enlisted man to take a seat on the NAMRL-D sled to begin the final and most formidable stage of impact acceleration research.[66]

CHAPTER ONE ENDNOTES

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[8] Douglas Martin, "John Paul Stapp, 89, Is Dead; 'The Fastest Man on Earth,'" *New York Times*, November 16, 1999, B13; Craig Ryan, *Sonic Wind*, 9.

[9] Known until 1949 as Muroc Air Force Base, this account refers to it throughout by its better-known designation, Edwards Air Force Base; Quote of John Paul Stapp from Richard F. Chandler, "John Paul Stapp and Deceleration Research, Part III: Project 7850 and Other Research at Holloman Air Force Base," *Stapp Car Crash Journal* 47 (October 2003): v; Quote of John Paul Stapp from Richard F. Chandler, "John Paul Stapp and Deceleration Research," viii; J. P. Stapp, "Human Tolerance to Severe, Abrupt Acceleration," in *Gravitational Stress in Aerospace Medicine*, ed. Otto H. Gauer and George D. Zuidema (Boston: Little, Brown and Company, 1961), 168-169.

[10] John P. Stapp, "Human Tolerance to Deceleration," *American Journal of Surgery* 93 (April 1957): 735; J. P. Stapp, "Human Tolerance to Severe, Abrupt Acceleration," 169; Richard F. Chandler, "John Paul Stapp and Deceleration Research, Part II," xviii; Richard F. Chandler, "John Paul Stapp and Deceleration Research, Part III," vi. Stapp's daring on the decelerator was matched by a way with words. The struggles with superiors inspired what he called "Stapp's Ironical Paradox: The universal aptitude for ineptitude makes any human accomplishment an incredible miracle." Stapp also deserves a share in the origin of the more well-known epigram "Murphy's Law." One day in November 1949, while repairing some malfunctioning velocity sensors, Captain Edward A. Murphy, Jr., took out his frustrations on the original assembly technicians, grumbling that "If there is any way those guys can do it wrong, they will." Several weeks later, Stapp gave Murphy's remark its enduring phraseology, telling the press, "We do all of our work in consideration of Murphy's Law…If anything can go wrong, it will." Within a decade, "Murphy's Law" was common parlance and had even made the dictionaries. For discussion of Stapp's Ironical Paradox and Murphy's Law, see Graeme Philipson, "Technology Bites Back," *The Sydney Morning Herald*, April 9, 2005, http://www.smh.com.au/news/Icon/Technology-bites-back/2005/04/06/1112489536595.html; Richard F. Chandler, "Project MX-981: John Paul Stapp and Deceleration Research," xxi; Craig Ryan, *Sonic Wind*, 136-137.

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Development, supported a study at Northwestern University. For this, see W. F. Windle, R. A. Groat, and C. A. Fox, "Experimental Structural Alterations in the Brain During and After Concussion," *Journal of Surgery, Gynecology and Obstetrics* 79, no. 6 (December 1944): 561-572; Arthur G. Gross, "Impact Thresholds of Brain Concussion," *Journal of Aviation Medicine* 29 (1958): 725-732; A. G. Gross, "A New Theory on the Dynamics of Brain Concussion and Brain Injury," *Journal of Neurosurgery* 15 (1958): 548-561; Arthur A. Ward, Jr., "Physiological Basis of Concussion," *Journal of Neurosurgery* 15 (1958): 129-134. The precise nature of Ewing's original proposal is not clear. A search of Navy records at the National Archives in College Park, MD, failed to turn up a copy. Craig Ryan has stated that Ewing submitted a proposal to the Army in 1965. This appears incorrect. Dan Thomas has reflected that Ewing first submitted a proposal to the Navy but that it was rejected and Ewing was assigned to duty aboard an aircraft carrier. The research Ewing proposed to do was apparently awarded to Ayub Ommaya, according to Thomas. BUMED files seem to corroborate Thomas's statements. A letter from the Commander of the Naval Air Development Center, Warminster, PA, to the Secretary of the Navy, dated July 20, 1970, indicates that Ommaya's program began with Navy funding around 1965 and with essentially the same research objectives Ewing had in mind. A copy of Ewing's proposal to the Army, dated May 12, 1966, is enclosed as an attachment to a letter from the Secretary of the Navy to the Commanding Officer, Naval Aerospace Medical Institute, dated November 24, 1967, Subj: "Use of human volunteers in acceleration/deceleration experiments." The documents may be found on the Department of Energy digital archive at https://www.osti.gov/opennet/detail.jsp?osti-id=16005278&full-text=%22Wayne%20State%20University%22&sortby=&page-num=1&table-length=25&order-by=desc&sort-by=. Concerning Thomas's recollection that Ewing was sent to a ship assignment when his proposal was rejected, the author's feeling is that the initial proposal to the Navy occurred in 1964, when Ewing was assigned to serve aboard the NASA tracking ship *Coastal Sentry Quebec*. For Craig Ryan's statement, see *Sonic Wind*, 341. For Dan Thomas's recollections, see email from Daniel Thomas to William Thomas, dated February 19, 2016, and James Rife Oral History Interview with Daniel Thomas, July 12, 2016, 13; Ewing's service on the Gemini Project for NASA is confirmed by Anon., "Eric Liljencrantz Award – 1977," *Aviation, Space, and Environmental Medicine* (June 1977): 577; for Ommaya's project, see Department of Energy, Office of Scientific and Technical Information OpenNet at https://www.osti.gov/opennet/servlets/purl/16005582-ViBG14/16005582.pdf.

[55] Letter from Commander, Naval Air Development Center, Warminster, PA, to Secretary of the Navy, dated July 20, 1970; Subj: "Permission for the Use of Human Subjects in Investigation of Mechanism of Head Injury and Flight Crew Head Protective Processes," letter available from Department of Energy, Office of Scientific and Technical Information OpenNet at https://www.osti.gov/opennet/servlets/purl/16005582-ViBG14/16005582.pdf; C. L. Ewing, "A Study of Aviation Medical Education in the U.S. Navy, 1964," unpublished monograph, dated 1964, 13. For early studies carried out by the Naval Medical Research Center, see David E. Goldman, "Mechanical Forces Acting on Aviation Personnel," *Journal of Aviation Medicine* 17 (October 1946): 426-430; Howard R. Bierman and Victor R. Larsen, "Reactions of the Human to Impact Forces Revealed by High Speed Motion Picture Technique," *Journal of Aviation Medicine* 17 (October 1946): 407-412; Howard R. Bierman, "Design for an Impact Decelerator," *Science*, New Series, 104, no. 2709 (November 29, 1946): 510-513. Ommaya was born in Rawalpindi, Pakistan, in 1930. After graduating from King Edward Medical College in Pakistan in 1953, he attended Balliol College, Oxford University, as a Rhodes Scholar, obtaining a master's degree in 1956. In 1961 Ommaya immigrated to the United

States and began his career as a neurosurgeon at the National Institute of Neurological Diseases and Blindness. Ommaya is now well known for inventing a device to deliver chemotherapy treatments to the brain and spinal cord, but he was also a major contributor to the field of biodynamic research. He began by studying brain injuries from automobile collisions and eventually became chief medical advisor to the National Highway Traffic Safety Administration; Joe Holley, "Ayub K. Ommaya, 78; Neurosurgeon and Authority on Brain Injuries," *The Washington Post*, July 14, 2008 (http://www.washingtonpost.com/wp-dyn/content/article/2008/07/13/AR2008071301791.html).

[56] Letter from Commander, Naval Air Development Center, Warminster, PA, to Secretary of the Navy, dated July 20, 1970; Subj: "Permission for the Use of Human Subjects in Investigation of Mechanism of Head Injury and Flight Crew Head Protective Processes"; Email from Daniel Thomas to William Thomas, dated February 9, 2016. Friede was not the first person to postulate that concussion could be produced without a direct blow to the head. For earlier researchers, see A. H. S. Holbourn, "Mechanics of Head Injuries," *Lancet* II (October 9, 1943): 438-441; A. H. S. Holbourn, "The Mechanics of Brain Injuries," *British Medical Bulletin* 3, no. 6 (1945): 147-149; R. Douglas Wright, "Concussion and Contusion," *Surgery* 19 (1946): 661-667; N. Hollister, W. P. Jolley, and R. G. Horne, "Biophysics of Concussion," WADC Technical Report 58-193, ASTIA document no. AD 203305, September 1958; Ayub K. Ommaya and Paul Corrao, "Pathologic Biomechanics of Central-Nervous-System Injury in Head Impact and Whiplash Trauma," in *Accident Pathology: Proceedings of an International Conference*, ed. K. M. Brinkhous (Washington, D.C.: Government Printing Office, 1968), 163.

[57] A. K. Ommaya, "Trauma to the Nervous System: Hunterian Lecture Delivered at the Royal College of Surgeons of England on 29th of July 1965," *Annals of the Royal College of Surgeons* 39 (1966): 344.

[58] Ayub K. Ommaya, Arthur E. Hirsch, and John L. Martinez, "The Role of Whiplash in Cerebral Concussion," *Proceedings of the Tenth Stapp Car Crash Conference*, 316; A. K. Ommaya, "Trauma to the Nervous System: Hunterian Lecture Delivered at the Royal College of Surgeons of England on 29th of July 1965," 335.

[59] Wendell H. Griffith, ed., "Summary of Conference: A Study of Military Implications of Protective Devices Designed to Prevent or Ameliorate the Head and Neck Injuries," Prepared for the Life Sciences Division, Army Research Office, under U.S. Army contract no. DA-49-092-ARO-70 (Washington, D.C.: Federation of American Societies for Experimental Biology, September 12, 1966), 43.

[60] Anon., "Army to Install CRFS in 11,600 Aircraft by 1975," *Army Research and Development News Magazine* 10, no. 10 (December 1969): 2.

[61] Major James C. Beyer and Captain Anthony A. Bezreh, "Review and Forecast of Impact Studies: United States Army," in *Impact Acceleration Stress: A Symposium* (Washington, D.C.: National Academy of Sciences – National Research Council, 1962), 17-19.

[62] James C. Beyer and Anthony A. Bezreh, "Review and Forecast of Impact Studies: United States Army," 17; Wendell H. Griffith, ed., "Summary of Conference: A Study of Military Implications of Protective Devices Designed to Prevent or Ameliorate the Head and Neck Injuries," 30; C. L. Ewing, "A Study of Aviation Medical Education in the U.S. Navy, 1964," 14.

[63] Ewing's proposal to the Army and the DD-1498 form (Work Unit summary) are enclosed as attachments to a letter from the Secretary of the Navy to the Commanding Of-

ficer, Naval Aerospace Medical Institute, dated November 24, 1967, Subj: "Use of human volunteers in acceleration/deceleration experiments." The documents may be found on the Department of Energy digital archive at https://www.osti.gov/opennet/detail.jsp?osti-id=16005278&full-text=%22Wayne%20State%20University%22&sort-by=&page-num=1&table-length=25&order-by=desc&sort-by=. For creation of the Joint Army-Navy Coordinating Panel, see p. 30 of "Proposed Plan for a US Army Aeromedical Research Program," attached to a letter from W. M. Snowden (Code 5) to Code 1, dated April 26, 1968, Subj: "Proposed Plan for US Army Aeromedical Research Program." Letter is located at NARA-College Park, in Record Group 52, Entry A1-1004, Box 1805, F: ER/1301-1968; C. L. Ewing, "A Study of Aviation Medical Education in the U.S. Navy, 1964," 35.

[64] Harvey M. Sapolsky, *Science and the Navy: The History of the Office of Naval Research* (Princeton, NJ: Princeton University Press, 1990), 57, 72; Research Proposal entitled "Determination of Human Dynamic Response to Impact Acceleration," dated April 4, 1972, from Channing L. Ewing located at NARA-CP, RG 52, Entry no. UD-WW-14, Box 3, Folder: "3900 Human Volunteers."

[65] Colonel Robert Muldrow, "Welcome," *Proceedings of the Tenth Stapp Car Crash Conference*, viii-ix; Bohannon, "What Is Being Done About Collision Injuries in the Armed Forces," xxi; Ralph Nader, "Voices from the Past: Unsafe at Any Speed: The Designed-In Dangers of the American Automobile" [excerpted from: Ralph Nader, *Unsafe at Any Speed: The Designed-In Dangers of the American Automobile* (New York: Grossman Publishers, 1965)], *American Journal of Public Health* 101, no. 2 (February 2011): 254. For some of the studies by private automakers and federal agencies, see the essays located in *Proceedings of the Tenth Stapp Car Crash Conference* (New York: Society of Automotive Engineers, 1967); Colonel Robert Muldrow, "Welcome," *Proceedings of the Tenth Stapp Car Crash Conference*, viii-ix; Lt. General Richard L. Bohannon, "What Is Being Done About Collision Injuries in the Armed Forces," *Proceedings of the Tenth Stapp Car Crash Conference*, x-xi.

[66] Channing L. Ewing, "Discussion," in *Impact Injury and Crash Protection*, ed. E. S. Gurdjian, W. A. Lange, L. M. Patrick, and L. M. Thomas (Springfield, Ill.: Charles C. Thomas, 1970), 350.

Chapter Two

Emplacing the First Pillar, 1966-1971

In July 1966 the U.S. Army Surgeon General's Office and the Naval Bureau of Medicine and Surgery (BUMED) approved Chan Ewing's research proposal. The funders may have expected the process they were initiating to be straightforward, specifically that Ewing would begin developing more and higher-quality information that could be used in designing better helmets and restraints. But Ewing's plans were more complicated. In order to succeed—to be able to tell with certainty the limits of human endurance under impact acceleration—he would have to put three pillars into place. First, Ewing would need to develop much better measurements of the response of human volunteers to acceleration below tolerance limits. Second, he would need to conduct animal studies starting within the same parameters as the human studies and then raising them to higher, non-survivable limits. Third, he would have to develop a mathematical model that precisely and accurately correlated the human and animal statistics and apply it to determine the threshold of human survivability. Ewing knew that this would take time and effort, and he had no expectation of being able to see his destination from the outset. But he knew that he had to move quickly to create the momentum that would help ensure the durability of his new research program: he had to emplace the first pillar.[1]

Wayne State University

The immediate task was to prove that it was possible to develop better test information, and to do that, Ewing had to buy time on an accelerator somewhere or build one. Determined to begin quickly, he began looking around for an existing facility with a suitable horizontal accelerator. Ewing started with a request to his former duty station, the Air Crew Equipment Laboratory (ACEL), and got support from colleagues Dino Mancinelli and Marvin Schulman, but it was not enough to overcome the fact that the ACEL facility was busy with other high-priority projects. If Ewing wanted to begin there, he would have to wait.[2]

Ewing could not immediately launch his project on the tide of naval research, but there was another road open in the related field of auto safety research. Wayne State University was home to the oldest university biomechanics research program in the United States and was staffed with highly regarded medical researchers and engineers. Dr. Elisha S. Gurdjian and Professor Herbert R. Lissner had begun studying impact-induced head injuries at the Detroit-based institution during the early 1940s. Their work laid the foundation for the creation of Wayne State's Biomechanics Research Center in 1964. By then, one of the leading researchers in the field was Professor Lawrence M. Patrick.[3]

As an institution, Wayne State also had close ties to the automobile industry, particularly General Motors (GM), also headquartered in Detroit. Beginning in 1963, GM and Wayne State partnered on a series of head-on collision studies using cadavers and anthropomorphic dummies. GM supplied the horizontal accelerator for these experiments, driven by compressed air and capable of achieving speeds up to 40 miles per hour. Patrick and a promising graduate student named Harold J. Mertz, Jr., worked with GM senior researchers Charles K. Kroell and Charles F. Gadd to conduct the experiments and publish the results.[4]

Captain David Schrunk, USAARL, preparing a human research volunteer for a test run at Wayne State in 1969. (Photograph courtesy of Dr. David Gillis)

By 1967 the Wayne State Engineering Department had begun building its own horizontal accelerator. This one drew upon the design characteristics of the GM accelerator as well as an earlier accelerator design that Patrick called the Wayne Horizontal Acceleration Mechanism (WHAM). Patrick's newest accelerator, called WHAM II, featured a number of innovations. Most notably, WHAM II was configured to operate in two modes. Vehicles riding on their own wheels could be accelerated to speeds up to 60 miles per hour. This configuration was extremely useful to automotive safety researchers because it allowed them to compare different car models in readily reproducible crash simulations. Alternately, the accelerator could accommodate a 1,500-pound sled riding on a track of about 100 feet in length. Seats, camera mounts, and other monitoring equipment could be bolted to the sled frame, and it could be accelerated to reach 60 miles per hour.[5]

The WHAM II sled was adjustable to accommodate cadavers, dummies, and human volunteers at different sitting heights and in any directional position along the acceleration axis. The seat harnesses were based on aviation models consisting of a lap belt, shoulder straps (of the inverted V design), and a chest safety strap. The harness system was adjustable to provide optimal safety regardless of sitting height. The WHAM II was equipped with hydraulic brakes and a variable-length cable ("snubber") to bring the sled to a stop. The maximum output of the braking system was 120,000 pounds of force. Vehicles or a sled with a gross weight of 2,000 pounds could achieve deceleration up to 60 G.[6]

Wayne State had expertise as well as equipment. Since the 1950s, Wayne State's Neurosurgery and Engineering Departments had been leaders in the study of concussion, much of their work done under sponsorship from the U.S. military. The work was led by Dr. Gurdjian, Professor Lissner, and Dr. John Webster, who subjected anesthetized dogs to direct blows to the head to induce concussions. The Neurosurgery Department then conducted necropsies to determine the effects of concussion using severity, recovery time, and the number of concussions as variables. Results of the experiments were published in leading medical journals including *Science* and the *Journal of Neurosurgery*. Wayne State also had a distinguished record in studies of the human vertebral column during $+G_z$ acceleration.[7]

Ewing and Patrick had likely become acquainted at the annual Stapp Car Crash Conferences. Both attended the Army-sponsored conference on helmet design held in March 1966. Ewing was clearly impressed with Wayne State's facilities and expertise. As an added benefit, the $+G_z$ impact acceleration program promised Ewing an opportunity to continue peripheral research related to ejection. During late 1966 and early 1967, Ewing and Patrick quietly negotiated an agreement to use the WHAM II for the joint Army-Navy project at a cost of $70,000. As part of the agreement, Patrick obligated Wayne State staff members Frank Du Pont, Kenneth Trosien, and Jerry Glinski to provide limited technical support to Ewing's program.[8]

A Web of Support

Any ambitious research program necessarily relies on a web of supporting institutions and dedicated professionals. Ewing gathered both as he started up the joint Army-Navy Wayne State project. The ultimate authority on the Army side was the Army Surgeon General's Office, which delegated control through the U.S. Army Medical Research and Development Command (USARMRDC) down to the U.S. Army Aeromedical Research Unit (USAARU) at Fort Rucker, Alabama. On the Navy side, the Office of Naval Research (ONR) acted through the Naval Bureau of Medicine and Surgery (BUMED) and the Naval Aerospace Medical Institute (NAMI) in Pensacola, Florida. NAMI was formerly the Naval Aviation Medical Center's (NAMC) School of Aviation Medicine but had been renamed in August 1965. Although Ewing himself was formally assigned to Pensacola during the Wayne State program, military necessity dictated that Fort Rucker would be the gravitational center of the project. And the Vietnam War ensured that it would be the Army that set the agenda. Due to the buildup in Southeast Asia, that branch had more aircraft, more pilots, and more aviation injuries than the Air Force and Navy combined. As Ewing had already learned, the Army also had more money to fund the research. The Navy, on the other hand, had a more established aviation medicine program and more scientists to devote to the work. It made sense, therefore, to get USAARU and NAMI—complementary commands in close proximity—working together.[9]

USAARU was founded in 1962 by Colonel Spurgeon H. Neel, Jr., and Major General Ernest Esterbrook to conduct aeromedical research for the Army. Fort Rucker was the logical location for the unit. The Army Accident Review Board, which reviewed aircraft accident reports and conducted research related to aircraft design, maintenance, standards, and crash safety, had already been established there in 1954, and in 1957 that board had been renamed the U.S. Army Board for Aviation Accident Research (USABAAR). The presence of both USAARU and USABAAR therefore made Fort Rucker the center of aviation medicine research in the Army.[10]

Captain Ashton Graybiel, MC, USN (1902-1995). (Navy Bureau of Medicine and Surgery Archives)

While the Army, through USAARU, provided most of the funding, secured human volunteers, and made support staff available for the Wayne State program, the Navy contributed the necessary technical expertise through NAMI, then led by Dr. Ashton Graybiel. A pioneer in aviation medical research since the 1930s, Graybiel was born in 1902 in Port Huron, Michigan, and graduated from the University of Southern California and Harvard Medical School. From 1936 to 1943, he worked at the legendary Harvard Fatigue Laboratory (which developed flight suits and equipment for the unpressurized bomber and fighter cabins of World War II), measuring the cardiovascular performance of pilots in stress situations. After the war, Graybiel built NAMC into a widely respected research organization, and during the 1950s the center conducted physiological research on human reactions to heat and vibration stress for NASA. In the 1960s the lab trained medical support staff to participate in the astronaut recovery teams that the Navy provided for NASA and also provided flight surgeons, including Ewing, to monitor astronauts in the Mercury and Gemini Programs.[11]

More recently, NAMI had overseen studies on weightlessness and motion sickness for NASA as well as other experiments that measured the effects of acceleration on the inner ear, circulatory system, and muscle control. Based on this extensive experience in aerospace medical research, NAMI agreed to develop the experimental design for the Wayne State project and to provide supporting technical and research personnel.[12]

Although NAMI and USAARU were the primary supporting agencies, the Wayne State program received a great deal of operational support from officials outside the chain of command. Ewing was never comfortable within the constraints of the military bureaucracy. Instead, he routinely called upon highly placed contacts in the Army and Navy who could apply leverage when and where needed. This strategy worked well during the Wayne State project because its duration was short.

Captain Joseph P. Pollard (1913-2006) was one of Ewing's most ardent supporters in the Navy. (Navy Bureau of Medicine and Surgery Archives)

One such contact, Captain Joseph P. Pollard, MC, USN, would prove to be Ewing's most influential ally for the next fifteen years. Pollard had earned a bachelor's degree from the College of William and Mary and attended medical school at the University of Virginia, graduating in 1939. During World War II, Pollard served as an aircraft carrier flight surgeon, performing heroically at the Battle of Midway by remaining aboard the stricken aircraft carrier USS *Yorktown* until all of the wounded were offloaded from the sinking ship. After the war Pollard began a long career as a military research and development officer. In the 1950s he served as a research physician on Project Strato-Lab, a high-altitude balloon flight program that took American servicemen to the upper reaches of the stratsphere. Between May 1960 and November 1964, Pollard worked as the Assistant to the Chief of Naval Research in Medical and Allied Sciences, BUMED. From November 1964 until his retirement from military service in January 1968, Pollard served as the director of BUMED's Research Division.[13]

Pollard and Ewing were both participants in a 1963 Office of Naval Research Symposium on Effective Life Support Helmets, and Ewing contributed a number of insightful comments during the conference, so it would have been hard for Pollard to have missed him. It is difficult to overstate how important Pollard would be to Ewing's work. Not only was he an expert executive, a practical administrator, and close to the Chief of Naval Research, but as Dan Thomas put it, "Joe Pollard [also] had tremendous credibility within the Department of Defense at a very high level." Pollard used this credibility to put Ewing in touch with several other influential Navy officers at BUMED. One, Captain Paul E. Tyler, had attended flight school with Thomas in the mid-1960s and continued to be a proponent of his work through the mid-1970s.[14]

Another invaluable ally, Captain Carl E. Pruett, was a close friend of Pollard and a staunch supporter of aviation medicine research. Pruett had earned a medical degree in 1943 and then attended the Naval School of Aviation Medicine in Pensacola. During the 1950s he worked as an aviation medical safety specialist, completed two tours as the senior medical officer aboard aircraft carriers, and helped establish the Pacific Missile Bioscience Office and the Life Science Department at the Naval Missile Center, Point Mugu, California, in 1958. After serving as a medical officer on Project Mercury, Pruett became Assistant for Medical and Allied Sciences for the Deputy Chief of Naval Operations.[15]

Following his retirement from the military, Pollard accepted a position as director of the Biological Sciences Division at ONR in 1968 and tasked Dr. Arthur B. Callahan with providing general support to Ewing. A former naval officer and World War II veteran, Callahan had obtained his bachelor's degree in biochemistry from Northeastern University and a Ph.D. in biophysics from Boston University. In 1965 Dr. Callahan began working at ONR, where he helped develop and manage a number of large intergovernmental and interagency medical research projects, including Ewing's. His influence would also be invaluable for the Navy's future impact acceleration research.[16]

Among Ewing's most invaluable interservice allies were officials in the Army Surgeon General's Office and USARMRDC. Lieutenant Colonel Robert T. Cutting well understood that the Wayne State program depended on "Army funding and Navy talent," and from his position within USARMRDC he made sure that was forthcoming, starting with the $70,000 to cover the cost of using the WHAM II accelerator at Wayne State. An equally invaluable ally was deputy surgeon general Major General Neel. He provided extra administrative backing for USAARU's commanding officer, Lieutenant Colonel Robert W. Bailey.[17]

Not all of Ewing's most valuable contacts were long-standing senior officers. He was fortunate to develop a number of supporters among younger military researchers. These included Captain George W. "Woody" Beeler of the U.S. Army Medical Service

Corps, who served as the chief of the Physiological Optics Branch at USAARU, and aerospace engineer and pilot Captain David G. Schrunk, MC, who had just been assigned to USAARU. All came to play important roles in the Wayne State program. Chief among the younger officers to join Ewing's team, however, was Dan Thomas, a twenty-six-year-old flight surgeon assigned by NAMI to work for USAARU at Fort Rucker.[18]

Dan Thomas had attended the Massachusetts Institute of Technology (MIT), where he was one of only four undergraduate students permitted to do a senior thesis in biophysics, earning his degree in 1959. He then graduated from Jefferson Medical College in Philadelphia in June 1963. After completing his internship, Thomas entered the Navy under the "Berry Plan" and became a flight surgeon. He arrived at the Naval School of Aviation Medicine, Pensacola, Florida, on July 1, 1964.[19]

After graduating in January 1965, Thomas served as a physician to Marine aviators and their families at the Marine Air Group in New River, North Carolina. In May 1965 he deployed with the 2nd Marine Division, serving as a helicopter lift crew member during the U.S. intervention in the Dominican Republic. Thomas returned with only six months remaining in his service commitment and so escaped assignment to Vietnam. Instead, the Navy offered him the position at Fort Rucker. The opportunity to conduct research appealed to Thomas, so he agreed to a six-month service extension, lasting until January 1967. He reported to Fort Rucker in July 1966 to serve, although still officially with NAMI, as chief of the Bioengineering Department at USAARU.[20]

A month later, Thomas stumbled upon Ewing in a hallway at NAMI. Ewing introduced himself and explained that he was establishing an experimental program to study response of the head and neck to impact acceleration. Thomas's interest was piqued, and Lieutenant Colonel Cutting encouraged him to get involved. Since his first six-month extension was set to expire in January 1967, Thomas obtained another extension in order to help Ewing. Before long, however, Thomas realized that it would take more time and effort to get the program up and running than he had expected. Torn, he told Ewing, "I will stay to help you until we get the first experiments off and we get the thing going, but then I have to leave, because I'm not going to stay in the military."[21]

A one-year extension through the Navy was out of the question—it would have landed Thomas on the deck of an aircraft carrier. He tried obtaining yet another six-month extension through the Navy but was rebuffed. Instead, Thomas sent his request through the Army chain of command, which sent it laterally to the Navy Surgeon General. Thomas was granted two additional six-month extensions at Fort Rucker, and Ewing retained the services of an invaluable assistant through June 1968.[22]

The link with Thomas also provided Ewing access to the technical expertise of Captain Beeler and administrative support from USAARU commanding officer Lieutenant Colonel Bailey. It was Bailey who provided Ewing an opportunity to work on helmet design, referring Ewing and Thomas to Long Island firm Dayton T. Brown, Inc., which was developing a fiberglass and polystyrene helmet for Army helicopter aviators. According to Thomas, Ewing's test data was used to develop a helmet that served as the military standard for more than twenty-five years. The work on helicopter helmet design, highly valued by the Army, was an invaluable part of the web of support that Thomas and Ewing were weaving beneath the Wayne State project. It raised Ewing's credibility with the Army, kept Thomas in non-permanent six-month extensions on his service, and earned Lieutenant Colonel Bailey a Legion of Merit award. As he helped Ewing build momentum for his research program, Thomas became his mentor's top lieutenant in designing an experimental protocol and grew deeply involved in almost all aspects of the program.[23]

HRVs: Human Research Volunteers

The cornerstone of the Wayne State program was the use of human research volunteers (HRVs). In April 1967, with encouragement from Lieutenant Colonel Cutting, the Army Office of Research and Development approved the recruitment of volunteers. To attract them, the Surgeon General's Office gave Lieutenant Colonel Bailey authority to make $150 per month hazardous duty pay available. Armed with this incentive, Thomas began seeking recruits among the enlisted men of the 28th Artillery Group, U.S. Army Air Defense Command, based in Detroit.[24]

The selection protocol that Thomas implemented for Wayne State remained the basis for the system later utilized by NAMRL-D and then NBDL. The first phase consisted of a series of screenings carried out at Fort Rucker's Lyster Army Hospital. Thomas and another flight surgeon carefully reviewed each prospective volunteer's medical history, personnel record, and interview responses. Those who passed the first stage of the examination were measured anthropometrically using the U.S. Naval Anthropometric Survey of 1964 as a guide. The highly regarded Anthropometry Department at the Aerospace Medical Laboratory, Wright-Patterson Air Force Base, under Charles E. Clauser, took seventy to eighty measurements from each volunteer. Volunteers with sitting heights corresponding to the 5th, 50th, and 95th percentiles of the 1964 survey (in short, servicemen of small, medium, and tall build) proceeded to the final battery of tests. These included examination by specialists in "aerospace medicine, dentistry, orthodontics, orthopedics, radiology, otorhinolaryngology, ophthalmology, neurology, psychiatry, and vestibular physiology." Only volunteers who passed through the entire process became human research subjects for the Army-Navy joint project.[25]

The meticulous selection protocol eliminated many healthy enlisted men from consideration. Thirty enlisted men originally applied for the program; only five were ultimately selected as human research subjects. During the entire course of the Wayne State program, only seventeen volunteers were ever qualified by the medical staff.

And once they were accepted, the testing had only begun. Before each experiment, volunteers underwent a physical examination, complete with a urinalysis. Post-run examinations served to detect changes in vestibular function, cardiac status, and neurological activity. Twenty-four-hour post-run follow-up surveys were required to clear each subject for participation in further tests. Two USAARU flight surgeons, Captain Barry Landfield and Captain David Schrunk, conducted the pre- and post-run medical examinations. Thomas and his fellow medical researchers on the project were particularly concerned about the use of illicit drugs by volunteers that could produce inaccurate results and therefore conducted thorough drug screenings as a part of each physical examination.[26]

Man-Rating the WHAM II

While the Wayne State crew screened volunteers, another contingent of researchers worked to ensure that the accelerator was safe for them to ride. This task, begun in January 1968, was known as "man-rating." The man-rating team was led by Lieutenant Commander David Gillis, MC, USN. A graduate of the University of North Carolina Medical School, Gillis had finished flight surgeon school at Pensacola in December 1965. The next year he spent in Vietnam, carrying out medical evacuations and troop insertions with a Marine helicopter squadron. During one particularly memorable mission, Gillis's helicopter suffered a catastrophic engine failure and crashed into a Vietnamese graveyard. He survived that harrowing experience and, as a result, became interested in aviation crash medicine. Stateside, Gillis served as a flight surgeon at Lemoore Naval Air Station, California. After six months at Lemoore, Gillis received an offer to replace Thomas as the chief of the Biomechanics Branch, Aviation Medicine Division, at Fort Rucker. The position would be opening up, NAMI officials explained, because Thomas planned on leaving the Navy to attend Harvard. "There are fifty-two flight surgeons on active duty," they said, "and there are two of those who have either a physics degree or an engineering degree, and you're one of the two, so would you like to transfer down here and do that?" Gillis accepted in November 1967.[27]

Dr. David Gillis survived this 1966 helicopter crash in Vietnam and began thinking about ways to prevent aircrew injuries during such impact acceleration events. (Photograph courtesy of Dr. David Gillis)

In his new position, Gillis worked on several joint Army-Navy aviation projects related to helicopter crashes and fires and routinely traveled to Pensacola, where Ewing was stationed, for consultations. Ewing had good reason to compare data with the helicopter crash expert—official statistics confirming the heavy cost of fixed-wing and rotary aircraft crashes justified support for the Wayne State project as well as many other military research programs. When Ewing cited those numbers to Gillis and then shared with him a list of Navy personnel supposedly killed in non-combat-related helicopter crashes obtained from the Naval Aviation Safety Center, Gillis questioned both, since the list included the names of servicemen he knew were still alive. His ensuing investigation revealed that the Safety Center had made the mistake of assuming that a fatal helicopter crash meant that everyone aboard had been killed, inflating a single death to multiple ones from the entire crew. Ewing was chagrined but glad to learn about the faulty statistics before being challenged again—and he never was.[28]

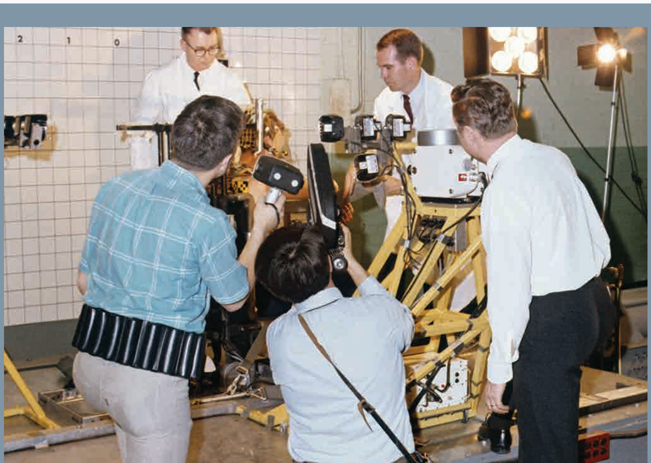
Captain Channing Ewing explains the positioning of the head and neck anatomical mounts to volunteers during the Wayne State project in 1968. (Photograph courtesy of Dr. David Gillis)

Gillis was as invested as anyone could be in the man-rating of the WHAM II. Having been prequalified by BUMED as a human experimental subject, Gillis became the first volunteer to ride the horizontal accelerator on the joint Army-Navy Wayne State project. Among the things he tested were the safety features necessary for man-rating the facility. Electrical interlocks placed in several locations on the accelerator system served to prevent unintentional firing. Four abort switches were installed throughout the lab that any operator could punch in the event of an emergency. Two different operators also held spring-locked switches, both of which had to be compressed before the system would fire. The human subject also held a palm-compressed abort switch. He could stop a run at any time prior to the onset of acceleration by relaxing his grasp on the switch. All of these switches activated lights on the master control panel. Red lights indicated unsafe conditions, while green lights signified that the system was cleared for operation. All lights on the control panel had to be green before the accelerator would fire.[29]

Standard safety policies also included the use of written countdowns, a warning horn, pressure checking at the firing console and accumulator by separate persons, and third-party inspection of reported pressures against scheduled pressure levels. In the event that an issue developed after the system had fired and induced acceleration, braking would be provided by the dual hydraulic brake cylinders, which engaged brake shoes on both sides of the sled. Polystyrene foam logs located at the end of the tracks served as an extra safety measure in case the hydraulic brakes failed. The structure of the sled system and all components were proof tested dynamically, and a two-to-one safety factor was confirmed before any human runs, meaning that WHAM II could sustain double the maximum intended impact load before any potential failure might be expected. With all these safety features in place and repeatedly tested, the man-rating process was completed in March.[30]

Runs Begin

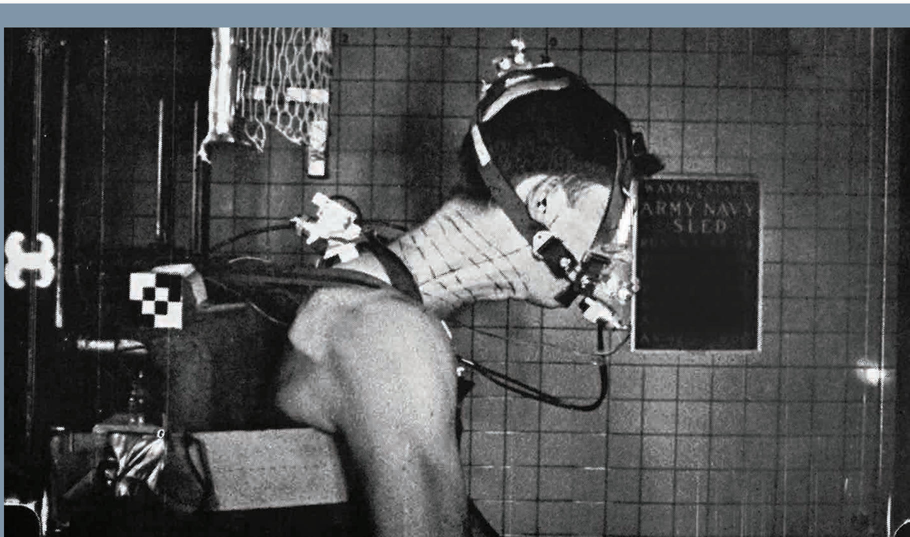
On April 4, 1968, Dan Thomas served as the human volunteer subject in the first ever experimental run at Wayne State University to measure the biodynamic response of the human head and neck to impact acceleration. Strapped into the WHAM II aluminum sled, Thomas experienced a peak acceleration of 2.8 G and came out unscathed. Follow-on human volunteer experiments continued at a steady but deliberate pace over the course of the next year. By April 27, 1969, seventeen human volunteers had completed a total of 236 runs. Thirty-seven of these were test runs: the volunteer either used a helmet or the measurements were incomplete. But 199 of the runs conducted during the year had produced fully useable data. In these runs, the human research volunteers were strapped into the sled-mounted seat backward, facing the acceleration mechanism. In this position, known as $-G_x$, the onset of acceleration simulated the effects of frontal impact on the unrestrained human head and neck. In each case, an initial acceleration impulse was applied to the sled to trigger corresponding dynamic response. The initial acceleration pulse (called the "rate of onset") was an important variable in the Wayne State experiments. To track the effects of changes in acceleration pulse levels on dynamic response data,



Dr. Chan Ewing (located in the back left against the wall) and his team prepare a human volunteer for a $-G_x$ run at Wayne State University. In the foreground Army film crew members from Walter Reed document the event. (USAARL) the investigators conducted controlled runs at 250 G/sec and 500 G/sec rates of onset. Peak sled accelerations were observed in 1 G increments from 3 G up through 10 G.[31]

The Inertial System

Another innovation in the joint Army-Navy project at Wayne State was the effective use of an inertial tracking system to precisely record linear and angular accelerations of the head and neck. Referred to as "transducers," the tracker packages consisted of several accelerometers and rate gyroscopes attached to a mount module. The idea was not new—John Paul Stapp had experimented with helmet-mounted accelerometers in 1951 but had been unable to obtain precise readings due to movement of the helmet. ACEL had more success a decade later, but successfully attaching transducers firmly yet harmlessly to the human anatomy remained a challenge. Some researchers opted to affix transducers to the sled, thus obtaining general data on the linear velocity of the sled but at the expense of quality information on the dynamic response of the occupant. Other investigators relied solely on high-speed photography to track biodynamic response to acceleration. Although a great deal of time and expense went into the processing of the film, this was an effective substitute—with one exception: film could not yield accurate three-dimensional information about angular movement of the head.[32]



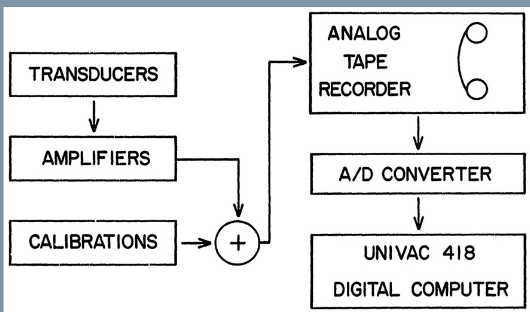
A human research volunteer exposed to acceleration impact on the Army-Navy project at Wayne State University. Peak sled acceleration for this run was 6 G with a 250 G/sec rate of onset. Transducer packages are visible at T1, the bregma, and mouth. (Source: Channing L. Ewing, "Discussion," in E. S. Gurdjian, et. al., eds., Impact Injury and Crash Prtoection *(Springfield, Ill.: Charles C. Thomas, 1970), 350.)*

The essential problem was that the module mounts had to be rigidly attached to the human anatomy and the motion of the transducers had to be held to an absolute minimum, yet the mounts also had to be completely safe for the volunteers. It was also necessary to be able to put the mounts on or take them off at short notice. Lastly, the weight of the mounted transducers had to be kept to a minimum, yet they had to be sturdy enough to withstand high levels of acceleration.

Ewing and Thomas devised a mounting system that consisted of three modules: one attached the mount to the subject, another held the transducer in a standard configuration, and another paired the first two together. To obtain the best data, Ewing and Thomas determined that three modules should be used at all times—one at the top of the head, one at the mouth, and one at the upper part of the back.[33]

To yield precise data, the transducers had to fit each individual perfectly. The mounts at the top of the head were placed at the bregma, the site where the sutures of the skull come together. The human subjects, therefore, had to be shaven and pressure molds had to be taken of the bregma area, which were used to shape the head transducer mount. Navy Dental Corps officers Captain Ralph H. Stowell and Captain Charles C. Pruitt meticulously crafted a module for the mouth mount by taking castings of the teeth, palate, and upper jaw of each subject. These castings were attached to a bite plate that held the transducer. To provide extra stability for the instrumentation at the mouth and head, Pensacola technician James L. Massey designed a harness that compressed the skull between the mouth and head mounts. To fit the third mount, located at the first thoracic (T_1) vertebra, technicians first made a pressure mold of the area from the subject's fifth cervical vertebra to the third thoracic vertebra. This was cut down to fit over T_1, which was held in place by another Massey-devised harness. This mount turned out to be particularly stable during runs because the acceleration pulse drove the T_1 mount into its spinal anchor point. Before each run, the transducers were carefully fitted onto the mounts so that all would be "midsagittal," that is, at the center of the body and on the same plane as the expected acceleration.[34]

The accelerometers used in the transducer packages were light—0.5 ounce—with a maximum nonlinearity error of 0.1 percent full scale. The gyroscopes included in the packages weighed 3 ounces and were rated ± 5,000 degrees per second with a maximum error of 0.5 percent full scale. Beeler and Thomas created a complex data acquisition system to collect transducer data from each run. Output signals from the transducers were scaled and amplified by running them through integrated circuit amplifiers that were calibrated monthly with switchable resistor networks to ensure that the degree of error did not exceed 0.1 percent. The amplified signals were captured on a tape recorder with a 53dB signal-to-noise ratio. This was the weakest link in the data system. Although the Ampex FR 1800L recorder selected was state-of-the-art at the time and used a phase-locked tape speed servo to provide relative short-term consistency, it still required frequent recalibration. The recalibration problem was exacerbated by the fact that other experimenters at NAMI had access to the recorder, so the settings were often changed. Therefore, Beeler and Thomas loaded a standardized calibration sequence prior to each experimental run. The recorded data from each run was played back through another Ampex FR 1800L recorder and sampled at 2,000 samples/second with a 10-bit accuracy level. The sampling rate was ten times the estimated maximum frequency of the dynamic response. In all, data from nine channels (eight mount derivative channels and one chair accelerometer channel) was digitized in two 100-kHz signal synchronized passes over the recording tape and transferred to a UNIVAC 418 computer for processing.[35]



Schematic of the data train system used on the Wayne State project. (Source: C. L. Ewing, et. al., "Dynamic Response of the Head and Neck of the Living Human to $-G_x$ Impact Acceleration," Army-Navy Joint Rept: NAMI-1064, USAARL Serial no. 69-6, 11.)

Data from the inertial tracking system was validated by use of an interlocking photographic system. The staff affixed photographic targets to each of the transducer packages. Focused on them were two high-precision, pin-registered, 16-mm cameras mounted to the sled at shoulder level to the right and rear of the seated subject. The cameras were positioned to document rotations of the head and neck around the x and z (front to back) axes of the torso, as well as the motion of the T_1 mount in relation to the spine. Each camera was rated at 500 frames per second and timed the shutter opening of each film frame to within ±0.1 milliseconds. By reviewing photography, investigators were able to confirm the biodynamic response of the human body at different stages of the impact event and ensure that movements of the transducers were miniscule. The film reels from each run represented the best physical record of the experiments, so the team used Ektachrome film with a 500-year shelf life to protect against degradation.[36]

Since photography was a critical part of the experiment, the lighting around the accelerator was important. Ewing's team had originally intended to duplicate the configuration used at the Federal Aviation Agency's (FAA) accelerator facility in Oklahoma City, but when it became clear that the expense for that component alone would run to about $100,000, the team decided to innovate. Gillis suggested simply mounting small photography lamps on the sled. The bulb filaments broke during initial tests, but once the bulbs were turned perpendicular rather than parallel to the acceleration force, the problem was solved at a cost of about $50.[37]

The photographic system was time-locked to the transducer data so that it could be used to determine velocities and accelerations by tracking changes in the coordinate system over time during the runs. The staff of the Mathematical Services Laboratory at Eglin Air Force Base gathered the data for position comparison by recording the positions of target points on punched cards. Afterwards, the cards were processed against the differential measures obtained from the transducer system. Photo-data was interpolated further to correspond in time to the transducer data. The final step was to develop a plot comparison. "Since the photographic and transducer data was time-locked," recalled Gillis, "the results could be reviewed and compared for validation."[38]

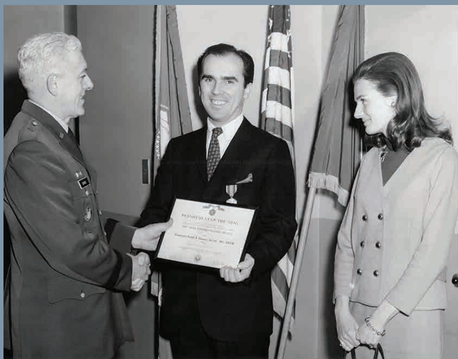
Results, Publications, and Awards: Evidence of Success

Every fully documented run conducted at Wayne State produced reported values of seventy separate variables at one-half-millisecond intervals. These early results were, as Ewing put it, "precise to a previously unknown degree," and he was exhilarated when describing the program at a research symposium on impact injury and crash protection at Wayne State. The Army and Navy were also more than satisfied with the initial results. Rear Admiral Frank B. Voris, who had ultimate authority over the project, stated that the "effort is extremely beneficial to both services and has opened up capabilities in both that would have been impossible to achieve on an individual basis."[39]

The reputation of the project continued to grow in ensuing months as the Wayne State program developed into the largest of several joint Army-Navy medical research initiatives. By October 1968, Ewing's team had fully reviewed the data from the runs completed during that spring and summer. They were sufficiently confident to present a paper at the twelfth annual Stapp Car Crash Conference, conveniently held at Wayne State. The intent of the paper, authored by Ewing, Thomas, Gillis, Beeler, and Patrick, was to present a detailed treatment of the experimental design and data acquisition systems. The paper demonstrated conclusively that the experiments were producing data of superior quality. At the next year's Stapp Car Crash Conference, held in Boston, the group presented a second installment that provided the attending group of scholars with findings rendered from analysis of processed data from eighteen runs utilizing human volunteers.[40]

Already Ewing's effort was producing insights of great import—chiefly, that current estimates of the human threshold for acceleration-induced concussion were set too low. Drawing upon his research with rhesus macaques, Ayub Ommaya posited that "in man, 30 rad/sec angular velocity and 1,800 rad/sec^2 angular acceleration are needed to produce concussion." Nevertheless, a 10 G, 250 G/sec run on a 96th percentile human research volunteer in Ewing's program had already returned a peak mouth angular velocity of 31.14 rad/sec. Clinical evaluation revealed that the run had not induced concussion. Ewing's work was important not only because it called into question existing assumptions about human acceleration injury thresholds, but also because it suggested that there had been problems with the mathematical models that other investigators had used to extrapolate data from primates to humans.[41]

Obstacles and Aspirations



Standing with his wife, Dr. Daniel J. Thomas receives the Army Commendation Award from Brigadier General Felix Gerace in 1969. (Photograph courtesy of Dr. Daniel J. Thomas)

The early results brought the Wayne State program invaluable recognition, earning Dan Thomas an Army Commendation Medal in the spring of 1969 even as he took time out to earn a master of public health degree at Harvard. But that summer, just as the project seemed to be hitting full stride, it ran off the rails. Thomas returned to the project as a civilian scientist in June. Within a few weeks, a flight surgeon who had been scheduled to report to duty as the district medical officer for the 17th Naval District in Kodiak, Alaska, died in a helicopter crash. Admiral Voris asked Ashton Graybiel if NAMI could spare Ewing to replace him. Graybiel, perhaps sensing an opportunity to exile a potential rival, agreed to send Ewing to Kodiak for a year and to take over the Wayne State project himself, appointing Thomas as his principal investigator. Graybiel's move blindsided both Thomas and Ewing. Ewing was still in uniform and under orders, so he had no choice but to comply. Thomas, however, quit in disgust and went back to Boston.[42]

With the high-profile and high-priority program in turmoil, ONR's director of Biological Sciences Joe Pollard intervened, along with Professor Ross A. McFarland of the Harvard School of Public Health, Lieutenant Colonel Cutting of USARMRDC, Commander Tyler of the Naval Medical Research and Development Command (NMRDC), and BUMED's Research Division chief Rear Admiral Ralph E. Faucett. After extensive talks held over several days, the arbiters were able to reach a settlement. Ewing had to fulfill his one-year assignment in Kodiak but otherwise got everything else he wanted. He retained control of the Wayne State project, obtained full authority over the project's funding, and stripped NAMI of any overhead responsibility. Thomas returned from Boston, and he and Ewing were given permission to travel freely to meetings with outside investigators. All Thomas had to do was break the news to Graybiel. Not surprisingly, the two never worked together again, and the fissure between Ewing and NAMI never fully healed.[43]

With Ewing stationed in Kodiak, Thomas flew up from Pensacola for repeated visits during late 1969 and 1970. Perhaps the Alaskan wilderness and the transcontinental plane trips provided more time for reflection than either man was used to. In any case, it was during this tenuous period that Ewing and Thomas began to make plans to establish a more ambitious, more permanent program. Ewing had never considered the Wayne State initiative to be more than a steppingstone. It had allowed him to build momentum and to put that first pillar into place—to collect the first large and detailed set of quantitative data on human dynamic response—but much more needed to be done. The team had to conduct comparatively documented runs with human surrogates (primates). Then it had to develop a correlative mathematical model that could allow the data from the non-human primate (NHP) runs to be extrapolated to humans. Finally, the team had to conduct primate runs beyond standards safe for volunteers in order to determine the threshold of human injury. This was too much for the rented space in Detroit. Now more fully in control, Ewing began to plan the next steps.[44]

Drs. Arthur Callahan, Channing Ewing, and Daniel Thomas (left to right), in Kodiak, Alaska, in late 1969. (Photograph courtesy of Dr. Daniel J. Thomas)

At Wayne State, Ewing and Thomas had proven that it was possible to get results far superior to anything obtained before. But they knew that they could do even better. One of the limiting factors was that at about 100 feet in length, the WHAM II track was not long enough. The sled reached peak velocity after traveling 10 feet. With only about 90 feet left on the track, braking had to begin immediately, and since in acceleration tests the experiment was over as soon as the brakes were applied, this made every run on the WHAM II unduly short. Ewing and Thomas recognized that if they could build or acquire an accelerator with a much longer horizontal track, they could further improve the quality of the data. They concluded that a larger and more sophisticated biodynamics laboratory was the solution to their problem.[45]

Ewing soon became fixated on building the new facility and turned to Joe Pollard at ONR for help. Fresh from resolving the conflict with Graybiel, Pollard once again backed Ewing and agreed to prepare a cost-benefit analysis showing how critical his research was to military aerospace medicine. Crunching the numbers, Pollard showed that the average cost of readying a Navy aviator for combat was $1.5 million (mostly in fuel for training missions). Therefore, he argued that if Ewing's quantitative data on human biodynamic response made possible the creation of new restraint systems that saved even one aviator, then that was a $1.5 million savings for the Navy. Navy bean counters could hardly fail to appreciate that value, in his estimation. Meanwhile, Ewing was boosting his reputation even further in military medical circles, co-authoring the 1968 edition of the *U.S. Naval Flight Surgeon's Manual* and designing in 1969 a head-neck safety restraint that reduced the incidence of vertebral fracture during ejection from jet aircraft.[46]

With cost-benefit figures in hand and Ewing's prominence lending instant credibility to the follow-up biodynamics program, Pollard obtained the necessary funding for a new laboratory—his first choice was to build it in Pensacola at Corry Field hangar. Graybiel, still raw from his recent bureaucratic defeat, was not interested in having a post-Wayne State project beyond his control housed on his turf, so he nipped any such discussion in the bud. With Pensacola eliminated, Ewing looked elsewhere in the southeast. The deputy surgeon general of the U.S. Army, Major General Neel, suggested the Georgia Institute of Technology (Georgia Tech) in Atlanta, so in early December 1969 Ewing visited the campus to discuss the possibility of establishing an impact acceleration program there. He met with Dr. Walter L. Bloom, who was indeed interested in Ewing's proposal but was unsure if the university was capable of hosting a new biodynamics laboratory.[47]

With Pollard's help, Ewing got a contract in place for Georgia Tech to do a feasibility study. One faculty member, Jesse D. Walton, Jr., inspected the accelerator at Philadelphia's Naval Aeronautical Engineering Laboratory for reference. Another, Professor Wilfred H. Horton, went to California to determine whether the engineering firm Monterey Research, Inc. would be able to build an accelerator that met Ewing's requirements. As negotiations continued during the early spring of 1970, representatives from nearby Emory University's Medical School and Yerkes Primate Center expressed interest in partnering with Georgia Tech.[48]

The plans soon ran aground. Georgia Tech and Emory were comfortable testing primates but not interested in research using cadavers or human volunteers. It also turned out that Monterey Research would not be able to build an accelerator that fully met Ewing's specifications. It was, perhaps, for the best. Ewing and Thomas had never been fully comfortable working within the university system at Wayne State, where unauthorized use of the accelerator had come close to endangering the project and classified information appeared to have leaked through the school's administrative channels. But there was an even better reason to cut the academic connection. In 1969 and 1970, turbulence on American college campuses caused by opposition to the war in Vietnam was reaching a boiling point. The result, as scholar Harvey M. Sapolsky has put it, was that "the military became increasingly reluctant to support university-based research."[49]

In 1969 Cornell University divested itself of the Cornell Aeronautical Laboratory. MIT followed suit in 1970 by breaking away from its largest research program, the Institute of the Charles Stark Draper Laboratory. Similar actions occurred at Stanford, Columbia, and the University of Michigan. As the trend grew, ONR finally followed suit, terminating the preliminary contract with Georgia Tech in September 1970. Ewing kept up the search, and less than a month later a better alternative appeared—there was unoccupied space available at NASA's Michoud Assembly Facility near New Orleans.[50]

The Michoud Assembly Facility

The Michoud site had seen its share of boom and bust. Located on the Intracoastal Canal roughly ten miles east of New Orleans, it began life as the Michoud aircraft plant. Built by the federal government's Defense Plant Corporation at a cost of over $31 million and dedicated on October 24, 1943, it was the second largest U.S. assembly facility completed during the war. The plan was for Higgins Industries, the company that developed the landing craft used during the war, to also produce Liberty Ships and C-46 cargo planes. As it turned out, no ships and only two planes were ever completed at Michoud.[51]

The site languished as government surplus property until the Korean War, when it was leased to Chrysler for the production of V-12 diesel tank engines. Beginning on November 28, 1951, about 2,200 Chrysler employees were producing engines at Michoud under a $30 million contract. In March 1954 Chrysler made its last delivery and returned the plant to the Army, which put it on standby status. The Michoud facility was subsequently passed from the Defense Department to the General Services Administration and then finally to the Department of Health, Education and Welfare. By 1960 the New Orleans Sewage and Water Board was planning to convert Michoud into a waste disposal plant.[52]

An aerial view of the Michoud Assembly Facility complex, near New Orleans. Building 420 is visible in the upper left-center of the photo. (U.S. Navy)

NASA ultimately saved Michoud from ignominy. Dr. Werner von Braun, one of the chief architects of America's moon landing program, took a look at the facility in mid-1961, and by early September it was slated to pressurize fuel cells for Saturn V rocket boosters with 100 percent nitrogen. Michoud began a new life as a major aerospace complex, and in time, Chrysler, Boeing, and Martin Marietta all occupied space at the facility. But as of early October 1970, when Ewing first took a look, there was room for an additional tenant—specifically, there was space in Building 420 available for lease. NASA had initially built a complex of four test cells there for pressuring fuel cells and assembling Saturn V booster rockets. The walls of the cells were blast-proof to protect the rest of the building from accidental explosions, and the cells were joined together at the center by a blast-resistant central office and control building. And there were no windows anywhere within the facility.

There had been some chance at the outset that NASA may have needed to develop four engines at a time, but as it turned out two were sufficient—the third and fourth test cells remained unused.[53]

Ewing came away from his visit impressed with the advantages that the location offered. NASA had a sizeable computer center at nearby Slidell, Louisiana, meaning that his researchers could get ready access to one of the most powerful computers in the world at a rate of only $75 per hour. The site was also in close proximity to Tulane University and its Delta Regional Primate Center, which would be vital for animal testing. And it was already equipped internally with a pressurized nitrogen supply system, something that would be equally important for operating the new laboratory. As Navy BUMED research chief Captain Lloyd F. Miller observed, "The only substantial cost item, which would be acquired at greater cost in Pensacola, is for construction of the accelerator track and housing." Moreover, the nearby city of New Orleans offered many social and cultural attractions for scientific staff and military personnel seeking diversions from an intensive impact acceleration program. Ewing decided that this was the place for his new biodynamics laboratory, and he had to have it.[54]

At 12:30 p.m. on October 29, 1970, Ewing called BUMED's assistant director for Administration and Resources Management, Captain Clifford W. Boggs, MC, and bluntly informed him that he had already requested long-term use of Michoud from NASA and that he intended to fly from New Orleans to Washington, D.C., the next day to "personally hand-walk the letter through BUMED, NAVFAC [Naval Facilities Engineering Command], and OPNAV [Office of the Chief of Naval Operations]" for official confirmation and endorsement. Ewing then told Boggs that he had already obtained tentative "telephonic approval" from Rear Admiral Oscar Gray, Jr., MC, commanding officer, Naval Aerospace and Regional Medical Center, Pensacola; Commandant, Eighth Naval District (COMEIGHT); Commandant, Sixth Naval District (COMSIX) and NAVFAC, Southern Region, and that he now desired to obtain written approval that very day from "the highest authority" in BUMED and OPNAV for the move. Whether he was awestruck or unnerved by Ewing's boldness, Boggs immediately processed the request and forwarded it to Ewing's ally at NMRDC, Commander Tyler, for action. Other plain-spoken calls within the military bureaucracy went similarly well, but it still took some time for the additional paperwork to be generated, distributed, and signed.[55]

Ewing's initiative and persistence were rewarded on January 15, 1971, when NASA officially offered a permit to "use a portion of stage test facility building (no. 420) and land for test and support facilities" at the Michoud Assembly Facility to the Navy for a period of four years with an option for renewal. The permit provided Ewing with about 10,000 square feet for administrative offices. It included the roughly 32,000 square feet of space included in the third and fourth test cells in Building 420. To accommodate the construction of a 700-foot-long horizontal accelerator track, the permit also included a 90' x 1,000' strip of land extending out of the eastern wall of the fourth test cell. NASA gave the Navy the right, after prior review and approval, to make "significant changes, additions, and modifications" to accommodate the accelerator and other testing equipment. NASA also agreed to provide basic maintenance and repair services.[56]

Important Friends and Big Plans

Ewing's immediate goal was realized on January 29, 1971, when the Navy officially accepted the permit from NASA. That same day, Navy BUMED formally established the Naval Aerospace Medical Research Laboratory-Detachment (NAMRL-D) to conduct experiments required for what was dubbed the bureau's "Human Impact Injury Prevention Program." Captain Ewing became the first officer-in-charge of NAMRL-D, and the Navy authorized a five-year, $7.5 million operating budget, set at about $500,000 for fiscal year 1972 and expected to rise to $1 million in fiscal year 1973.[57]

Administratively, much had changed since the beginning at Wayne State. In 1969 the Army had expanded the research objectives of USAARU and renamed it the U.S. Army Aeromedical Research Laboratory (USAARL). In 1970 the Navy had created the Naval Aerospace Medical Research Laboratory (NAMRL) to fund research in aerospace medicine and to take over the research and development functions of NAMI. A component of the Naval Aerospace Medical Center complex in Pensacola, NAMRL was under the direct authority of NAMI. The commanding officer of NAMRL was Captain Newton W. Allebach, MC, USN. The detachment at Michoud was therefore designated as a subordinate command under NAMRL, with Ewing reporting to Allebach. And though NAMRL-D would remain a joint Army-Navy endeavor, the branches would essentially switch roles moving forward. By the early 1970s, the Army had spent about $1 million on the Wayne State project and assumed full responsibility for obtaining human volunteer subjects. In late 1972, however, the Army, citing recent "substantial alterations…in the overall Army personnel structure," indicated that it would no longer be able to provide the volunteers. The Navy therefore took on that responsibility and became the primary supporting agency for NAMRL-D.[58]

Ewing knew that it would not be enough for the Navy and Army to remain firmly behind his project to ensure sustainability—he would also require support from Congress. Fortunately, Michoud was in the constituency of F. Edward Hébert, an inveterate cold warrior always willing to back defense appropriations—particularly if they created jobs in Louisiana's First District. Hébert was among the last generation of Democratic congressional leaders who rose to unparalleled heights of influence due to the "Solid South" and House seniority system—and from 1971 to 1974 he chaired the all-powerful House Armed Services Committee. So not surprisingly, Hébert was pleased to have the Eighth Naval District headquartered in New Orleans—in 1971 it employed 2,161 people. As Rear Admiral Robert A. McPherson, commandant of the Eighth Naval District, calculated it, the Eighth Naval District brought some $146,523,000 into the area every year during the early 1970s. This was especially welcomed because the economic impact of the space program at Michoud levelled off during the late 1960s as the development of the Saturn V booster was completed. Representative Hébert exulted over the establishment of NAMRL-D, predicting to the *Times-Picayune* that it would become, "if not the foremost impact acceleration program in the United States, at least one of the two leading such laboratories."[59]

Ewing knew that it was not sufficient to have only strong allies to secure the future for NAMRL-D. He realized that it would also be helpful to undertake other in-demand research tasks as long as they complemented rather than conflicted with his top priority of determining the human limits of impact acceleration. One such task was evaluating crew member response to shock and vibration in high-speed vessels and aircraft. Research on human response to vibration was particularly in demand by the Army because of its direct applicability to helicopter crews. Medical evacuation crews operating in adverse weather or combat conditions often encountered severe vehicular vibration and motion patterns, as Dave Gillis could personally attest. When they did, pilots instinctively reduced speed, making their craft a better target. In a proposal submitted to the Army during the summer of 1971, Ewing postulated that "if means could be developed to protect casualties against the effects of vibration, maximum vehicular speed capability could be more nearly approached without detrimental effects." Vibration studies also had the potential to yield new insights about the causes of motion sickness—an illness that particularly afflicted sailors at sea. Ewing proposed, therefore, to conduct vibration experiments using human volunteers and non-human primates to create data for comparison. Then a mathematical model would be applied that would "permit the dynamic response for man subjected to non-tolerable durations and amplitudes to be extrapolated from the animal data along with the resulting physiological response of man."[60]

The work at Wayne State had already gained attention beyond the military, and Ewing pledged that further results would be made readily available not only to the military but also to the private sector as well. There were also federal agencies beyond the military that were keenly interested in Ewing's work. The Department of Transportation (DOT), for example, believed that new data on impact acceleration would enable the department to set better standards for automobile design. On June 17, 1971, Navy BUMED's research director Captain Lloyd F. Miller authorized Ewing to share data from the Wayne State project with the DOT's National Highway Traffic Safety Administration. The staff at NAMRL-D spent a significant portion of its time during 1971-1972 preparing this data for release. The result was a long-standing relationship between NAMRL-D and the DOT that benefited both parties through the 1970s.[61]

"The Personnel Situation"

In February 1971, Joe Pollard of ONR spoke at a Defense Department conference calling attention to staffing problems at naval research facilities. It was hard enough to find qualified personnel, Pollard noted, but too often researchers—seeking higher pay and seeing no clear civilian career track in a military setting—cut their service short. "Future growth and even survival of the program depends on a favorable resolution of the personnel situation," Pollard warned. "I submit that this is an extremely critical situation." Ewing, whose new research program had been approved a month earlier, was keenly aware of these challenges. By then, he had already spent months selecting his staff, and it seemed as if the acceleration work provided just the right career paths required to attract and keep a cadre of top researchers.[62]

One of Ewing's first hires was a mechanical engineer named William H. "Bill" Muzzy III. After completing his education at Texas Western College, Muzzy had worked for the Hercules Powder Company in Salt Lake City on the Minuteman and Polaris missile systems. In the spring of 1967, Muzzy signed on with another defense contractor, Dynalectron. That company was then working for the 6571st Aeromedical Research Laboratory at Holloman Air Force Base, which was designing space suits for the Apollo mission and seats for the space shuttle, as well as testing restraint devices for the automotive industry. As operator of the venerable Daisy Decelerator and the newer Bendix HyGe vertical impact accelerator, Muzzy had already conducted approximately 3,000 volunteer tests, among them the first human test of an automotive air bag. He had also conducted hundreds of primate runs at Holloman. Consequently, in the summer of 1970, even before securing the Michoud site, Ewing offered Muzzy the position of chief mechanical engineer for the upcoming project—and invited him for a visit to New Orleans.[63]

When Muzzy arrived for a brief visit and tour, there were a number of team members already in place. Greeting him was Dan Thomas, who was slated to serve as chief of the Human Research Division responsible for managing all human and biological research at NAMRL-D. They would be working very closely together in what was the start of a lifelong friendship. Engineer Edward Becker was also there. With a master's degree in mechanical engineering from MIT, he would serve as assistant chief to the Instrumentation Branch. Scott N. Morrill, a physiologist at NAMI who had helped process data during the Wayne State project, would serve as chief of Physiological Instrumentation. Muzzy also reunited with Bobby Joe Teal, an expert animal handler who had worked at Holloman before signing on at Michoud. By January 1971, Muzzy was in New Orleans permanently and was helping to get the facility up and running. He also helped hire additional staff, including photographer Johnnie Bland and facilities and equipment technicians Willard Hunt, Roger Black, Nick Price, and Ferris Bolin, all of whom came from Holloman to work at NAMRL-D.[64]

Another early hire was Gilbert C. Willems, who headed up the Instrumentation

Division. With a master's degree in electrical engineering from Vanderbilt and expertise acquired from working on missile tracking software at Redstone Arsenal, Willems came aboard sometime during the summer of 1970. Richard Irons and Lieutenant Commander Paul Majewski, both of whom had worked on the Wayne State program, came from NAMI to join NAMRL-D. Irons assisted with data processing, and Majewski served as emergency medical officer.[65]

If the hiring of Irons and Majewski signaled continuity with Wayne State, another hire indicated a clear departure. Ewing had never even attempted to get permission to use non-human subjects at Wayne State. The objective had been only to establish a beachhead by proving that it was possible to obtain data of a high order using human volunteers. Now Ewing would be putting the next pillar of his research into place—conducting non-human primate runs that yielded equally accurate data. In order to determine the threshold of human survivability, some of those runs would be fatal; the team would require a pathologist to identify the fatal effects of impact acceleration on non-human primates.

Ewing's recruit for that position was Dr. Friedrich J. Unterharnscheidt. A native of Essen, Germany, Unterharnscheidt had grown up fast as a seventeen-year-old anti-aircraft gunner in the German army during World War II. He graduated from the University of Munich School of Medicine in 1952. The following year, Unterharnscheidt earned a doctorate in medicine at the University of Munster. Afterwards, he completed residencies at the University of Bonn's Department of Neurology and Department of Neuropathology and served as a senior research fellow at the Max Planck Institute for Brain Research, Munich, Germany. In 1966 Unterharnscheidt accepted a position as associate research professor of Pathology and Surgery at the University of Texas Medical Branch in Galveston.[66]

Unterharnscheidt had pursued a research agenda in Galveston that included determining the effects of angular acceleration on the brains of squirrel monkeys. Ewing likely met Unterharnscheidt at the Impact Injury and Crash Protection Symposium held at Wayne State in 1968. He was impressed and gratified to find a neuropathologist with rare experience in experimental biomechanics, so he was determined to hire Unterharnscheidt to perform tissue histology on non-human primates sacrificed during impact acceleration tests. However, since the German scientist was not yet a U.S. citizen, it was not until April 1973 that all of the requisite permissions were obtained. Unterharnscheidt joined NAMRL-D as chief of the Department of Neuropathology, and a little over a year later he became a United States citizen, with good friend Dan Thomas standing as his witness.[67]

Among the hires that attested to Ewing's ability to master the challenge of the "personnel situation" was that of William R. Anderson. Anderson had earned a bachelor's degree in electrical engineering from Lehigh University in 1965 and worked in the Advanced Sensors Laboratory at Redstone Arsenal. While earning a master's degree in physics at the State University of New York, Binghamton, Anderson had worked as a programmer at IBM focusing on test data generation, simulation, and advanced systems modeling. At NAMRL-D, Anderson contributed to the development of the data acquisition systems and helped analyze the results. By March 1972 Ewing had identified Anderson as "a key member of the research staff"—and, not surprisingly, he went on to become head of the Data Systems Department at the future NBDL.[68]

Tulane

As Ewing brought new and old faces to work with him in New Orleans, he also reached out to the institutions that he knew he could rely upon for support in upcoming years. None was more important than Tulane University. Ever since its founding in the nineteenth century as a medical college, Tulane cultivated a reputation as a center for research—Tulane scholars had even done work on head injuries for ONR during the 1960s. The university's biomechanics research program was spearheaded by Dr. Jack Wickstrom, chief of the Department of Orthopedics at the School of Medicine, and John L. Martinez and Edward H. Harris of the Department of Mechanical Engineering. Wickstrom's Orthopedics Department conducted impact experiments on monkeys and Belgian hares to study injuries to the cervical spine. During the course of this work, they put a great deal of effort into accurately scaling data from animals to humans. Related research ranged from specific work on the effects of whiplash from automobile collisions to more abstract mathematical modeling of the head-neck system.[69]

Martinez and Harris, meanwhile, had worked on Ayub Ommaya's concussion research project and presented at the 1966 and 1967 Stapp Car Crash Conferences. Harris followed this up with research contracts under NAMI and ONR on the inertial properties of the human head and neck based on precise anthropometric measurements from twenty male human cadavers. Harris completed the study with help from Dr. Leon B. Walker, Jr., and graduate student Uwe R. Pontius. Ewing and Thomas joined them in presenting their findings at the 1973 Stapp Car Crash Conference. By then, noted Ewing, NAMRL-D could rely on Tulane faculty for consultation in "physics, mathematics, bioengineering, medicine, anthropology, radiation, and associated disciplines."[70]

With its pre-existing expertise in biodynamics and its institutional presence, Tulane also served as a venue where researchers from NAMRL-D could engage experts nationwide. Some spoke at weekly seminars sponsored by the Tulane School of Engineering. In January 1970, for example, Henning von Gierke, head of the Biodynamics and Bionics Division of the Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base, lectured on the effects of noise, vibration, and shock on the human body. In October 1971 Ewing took the podium to discuss "dynamic response of a living human to impact acceleration." Two years later, Unterharnscheidt gave a talk on head injuries related to boxing.[71]

But it was perhaps in more practical matters that Tulane, specifically its Delta Regional Primate Center, provided the most palpable assistance. In 1971 the primate center contracted with ONR to support the NAMRL-D research effort. Maintaining lab animals and supporting primate research was a highly complex endeavor, with tasks ranging from housing and health care to surgery and quarantine. This would be a substantial undertaking, but it would be critical, because it was only in moving beyond human volunteer research to primate experimentation that Ewing would be able to put into place the second of the three pillars of his research program, as the new NAMRL-D quickly gained momentum in the early 1970s.[72]

CHAPTER TWO ENDNOTES

[1] For approvals, see the series of correspondence attached to letter from the Secretary of the Navy to Commanding Officer, Naval Aerospace Medical Institute, dated November 24, 1967, available at Dept. of Energy OpenNet https://www.osti.gov/opennet/detail.jsp?osti-id=16005278&full-text=%22Wayne%20State%20University%22&sort-by=&page-num=1&table-length=25&order-by=desc&sort-by=; see Ewing's discussion of W. Lange, "Severe Frontal Collisions and Resulting Injuries with and without Restraining Devices," *AGARD Conference Proceedings No. 88 on Linear Acceleration of Impact Type* (London: Technical Editing and Reproduction, Ltd., 1971), xli.

[2] Email from Daniel J. Thomas to William Thomas, dated February 24, 2016; Email from Daniel J. Thomas to William Thomas, dated March 1, 2016; Channing L. Ewing, Daniel J. Thomas, Lawrence M. Patrick, George W. Beeler, Jr., and Margaret J. Smith, "Living Human Dynamic Response to $-G_x$ Impact Acceleration: II. Accelerations Measured on the Head and Neck," Army-Navy Joint Report, U.S. Army Aeromedical Research Laboratory serial no. 71-11, Naval Aerospace Medical Research Laboratory report no. 1122, October 1970, 414.

[3] Werner Goldsmith, "Biomechanical Activities at Some American and European Institutions – II," *Journal of Biomechanics* 2 (1969): 471-472. Dr. Larry Patrick had completed three degrees as a student at Wayne State: a bachelor's in mechanical engineering in 1942, a bachelor's in aeronautical engineering in 1943, and a master's in mechanical engineering in 1955. He served as a biomechanics researcher there from 1946 until 1958 and took over as the director of the Biomechanics Research Center in 1965. By the end of the decade he was recognized worldwide as an authority on head injury, helmet design, and human response to collisions. He had, on numerous occasions, served as a consultant to the auto industry.

[4] Werner Goldsmith, "Biomechanical Activities at Some American and European Institutions – II," *Journal of Biomechanics* 2 (1969): 471-472; Anon., "Larry Patrick, Pioneer Auto Safety Researcher, 85," *WSU College of Engineering Exemplar*, Fall 2006, 12; Charles K. Kroell and Lawrence M. Patrick, "A New Crash Simulator and Biomechanics Research Program," *Proceedings of the Eighth Stapp Car Crash Conference* (Detroit: Wayne State University Press, 1964), 204; L. M. Patrick, H. J. Mertz, Jr., and C. K. Kroell, "Impact Dynamics of Unrestrained, Lap Belted, and Lap and Diagonal Chest Belted Vehicle Occupants," in *Proceedings of the Tenth Stapp Car Crash Conference* (New York: Society of Automotive Engineers, 1966), 51.

[5] Werner Goldsmith, "Biomechanical Activities at Some American and European Institutions – II," *Journal of Biomechanics* 2 (1969): 471; H. J. Mertz, Jr., and L. M. Patrick, "Investigation of the Kinematics and Kinetics of Whiplash," in *Proceedings of the Eleventh Stapp Car Crash Conference* (New York: Society of Automotive Engineers, 1967), 274-276; L. M. Patrick, D. J. Van Kirk, and G. W. Nyquist, "Vehicle Accelerator Crash Simulator," in *Proceedings of the Twelfth Stapp Car Crash Conference* (New York: Society of Automotive Engineers, 1968), 405.

[6] Channing L. Ewing, Daniel J. Thomas, George W. Beeler, Jr., Lawrence M. Patrick, and David B. Gillis, "Dynamic Response of the Head and Neck of the Living Human to $-G_x$ Impact Acceleration: I. Experimental Design and Preliminary Experimental Data," Joint Army-Navy Report, NAMI-1064, USAARL serial no. 69-6 (Pensacola, FL: Naval Aerospace Medical Institute, March 1969), 13.

[7] For an example of a study produced under contract with the Army Medical Research and

Development Command, see E. S. Gurdjian, V. L. Roberts, and L. M. Thomas, "Tolerance Curves of Acceleration and Intracranial Pressure and Protective Index in Experimental Head Injury," *The Journal of Trauma* 6, no. 5 (1966): 600-604; B. F. Haddad, H. R. Lissner, J. E. Webster, and E. S. Gurdjian, "Experimental Concussion: Relation of Acceleration to Physiologic Effect," *Neurology* 5 (1955): 798-800; J. L. Chason, B. F. Haddad, J. E. Webster, and E. S. Gurdjian, "Alterations in Cell Structure Following Sudden Increases in Intracranial Pressure," *Journal of Neuropathology and Experimental Neurology* 16 (1957): 102-106; E. S. Gurdjian, J. E. Webster, and H. R. Lissner, "Observations on the Mechanism of Brain Concussion, Contusion, and Laceration," *Surgery, Gynecology & Obstetrics* 101, no. 6 (1955): 680-690; F. G. Evans, H. R. Lissner, L. M. Patrick, "Acceleration-induced Strains in the Intact Vertebral Column," *Journal of Applied Physiology* 17 (1962): 405-409; A. P. Vulcan, "Response of the Lower Vertebral Column to Caudo-cephalad Acceleration" (Ph.D. dissertation, Wayne State University, 1969); Channing L. Ewing, Albert I. King, and Priyaranjan Prasad, "Structural Consideration of the Human Vertebral Column under $+G_z$ Impact Acceleration," *Journal of Aircraft* 9, no. 1 (January 1972): 84-90.

[8] Email from Daniel J. Thomas to William Thomas, dated February 24, 2016; Email from Daniel J. Thomas to William Thomas, dated March 1, 2016; Channing L. Ewing, Daniel J. Thomas, Lawrence M. Patrick, George W. Beeler, Jr., and Margaret J. Smith, "Living Human Dynamic Response to $-G_x$ Impact Acceleration: II. Accelerations Measured on the Head and Neck," 414.

[9] Email from Daniel J. Thomas to William Thomas, February 24, 2016.

[10] During the early 1960s, Neel was the Commanding Officer (CO) of the Lyster Army Hospital at Fort Rucker, AL, and Esterbrook was the CO of the Fort's U.S. Army Aviation Center. http://www.usaarl.army.mil/pages/about/history/; https://safety.army.mil/HOME/History.aspx. The Army Accident Review Board was transferred to Ft. Rucker from Ft. Sill, Oklahoma, in 1954.

[11] Ashton Graybiel, "Aerospace Medicine and Project Mercury: Navy Participation," 1195; Tim Hilchey, "Ashton Graybiel Dies at 92; Research Aided Space Flight," *New York Times*, March 3, 1995, B10; Anon., "Project Mercury," 33. For information on the Harvard Fatigue Laboratory, see G. Edgar Folk, "The Harvard Fatigue Laboratory: Contributions to World War II," *Advances in Physiology Education* 34 (September 2010): 119-127.

[12] Tim Hilchey, "Ashton Graybiel Dies at 92; Research Aided Space Flight," *New York Times*, March 3, 1995, B10; Research proposal entitled, "Determination of Human Dynamic Response to Impact Acceleration," dated April 4, 1972, from Channing L. Ewing located at NARA-CP, RG 52, Entry no. UD-WW-14, Box 3, Folder: "3900 Human Volunteers."

[13] Anon., "In Memoriam [Captain Joseph Page Pollard]," *Navy Medicine* 97 (November-December 2006): 32; Charles W. Shilling, *History of the Research Division Bureau of Medicine and Surgery, U.S. Department of the Navy* (Washington, D.C.: Bureau of Medicine and Surgery, n.d.), iii; Anon., "Random Noise," *Naval Research Reviews* (1968): 38.

[14] Biotechnology, Inc., ed., *Effective Life Support Helmets: Proceedings of an Invited Symposium Held at the International Inn in Washington, D.C. on 31 October and 1 November 1963* (Arlington, VA: Office of Naval Research and Biotechnology, Inc., 1963); James Rife Oral History Interview with Daniel J. Thomas, July 12, 2016, 18; For details on Captain Tyler, see email from Daniel J. Thomas to William Thomas, dated April 19, 2016; Channing L. Ewing, Daniel J. Thomas, Lawrence M. Patrick, George W. Beeler, Jr., and Margaret J. Smith, "Living Hu-

man Dynamic Response to –G_x Impact Acceleration," 414; D. J. Thomas and C. L. Ewing, "Human Dynamic Response to –G_x Impact Acceleration," *AGARD Conference Proceedings No. 88 on Linear Acceleration of Impact Type* (London: Technical Editing and Reproduction, Ltd., 1971), 11-12.

[15] For Captain Pruett, see Anon., "Carl Pruett, Physician in Navy, Dies," *The Washington Post*, January 26, 1991, https://www.washingtonpost.com/archive/local/1991/01/26/carl-pruett-physician-in-navy-dies/f08ff55f-e27d-4b2b-9b81-d9b6dfa3899e/; also see Dr. Pruett's brief bio from the Illinois State Society http://illinoisstatesoceity.typepad.com/photos/19611970_illinois_state_s/dr-carl-e-pruett.html.

[16] Anon., "Dr. Arthur B. Callahan Obituary," *The Frederick News-Post*, February 17, 2011, http://www.legacy.com/obituaries/fredericknewspost/obituary.aspx?pid=168499184.

[17] Letter from Brigadier General Robert T. Cutting, USA (Ret.), to Vice Admiral Don Arthur, MC, Surgeon General, USN, dated July 19, 2007 (copy of the letter is in the possession of Dr. Daniel J. Thomas); Email from Daniel J. Thomas to William Thomas, March 1, 2016; Channing L. Ewing, Daniel J. Thomas, Lawrence M. Patrick, George W. Beeler, Jr., and Margaret J. Smith, "Living Human Dynamic Response to –G_x Impact Acceleration: II. Accelerations Measured on the Head and Neck," 414; For information on Lt. Col. Cutting and the Army's funding of aviation medicine, see the NARA-CP, RG 112, entry no. A1-1038, Box 5, F: 210-01 DA Program Dev. Files, COFF 30 Sep. 67, Trf RHW Oct. 69, Ret WNRC Oct 70 PERM, "U.S. Army Medical Research & Development Command Program Data Sheets FY 1967 – FY 1969," 143; Email from Daniel J. Thomas to William Thomas, dated April 15, 2016; Email from Daniel J. Thomas to William Thomas, dated March 20, 2016; Email from Daniel J. Thomas to William Thomas, dated February 11, 2016; U.S. Army Health Services Command, "Official Biography: Spurgeon H. Neel, Jr.," May 15, 1977. The biography may be accessed at http://www.history.army.mil/news/2015/docs/bio_spurgeonNeel.pdf; Anon., "Theodore C. Lyster Award – 1977 Presented to Spurgeon H. Neel, MG, MC, USA," *Aviation, Space, and Environmental Medicine* 48 (June 1977): 576.

[18] Anon., "Aeromedical Research Unit Responsive to Vietnam," 21; Research and Development Department, U.S. Army, *Proceedings of the United States Army Human Factors Research & Development Sixteenth Annual Conference* (Fort Bliss, TX: U.S. Army Defense Center, October 1970), 293; Further details on Dr. Schrunk were obtained from his professional bios on http://lifeboat.com/ex/bios.david.g.schrunk and https://www.linkedin.com/in/davidschrunk. Additional details were provided in an email from David Gillis to William Thomas, dated November 18, 2015. In the same email, Gillis identifies Dr. Landfield as the other USAARL flight surgeon. Review of the acknowledgments from Channing L. Ewing and Daniel J. Thomas, *Human Head and Neck Response to Impact Acceleration* (Pensacola: NAMRL Monograph 21, August 10, 1972), iii, confirms the involvement of Landfield and Schrunk. The monograph can be found at http://www.dtic.mil/dtic/tr/fulltext/u2/747988.pdf.

[19] Anon., "Aeromedical Research Unit Responsive to Vietnam," 20; Email from Daniel J. Thomas to William Thomas, dated February 24, 2016; Frank B. Berry, "The Story of 'The Berry Plan,'" *The Bulletin of the New York Academy of Medicine* 52, no. 3 (March-April 1976): 280. The Berry plan provided three options to doctors: (1) joining the military right after their internship; (2) joining the military after completing their internship and the first year of their residency; and (3) completing their internship and residency and then joining the military.

[20] Email from Daniel J. Thomas to William Thomas, dated February 24, 2016; James Rife Oral

History Interview with Daniel J. Thomas, July 12, 2016, 14-15. For information on the Marines in Operation Power Pack, see Major Jack K. Ringler and Henry I. Shaw, Jr., "U.S. Marine Corps Operations in the Dominican Republic, April – June 1965," *Occasional Paper*, Historical Division, Headquarters, U.S. Marine Corps, Washington, D.C., 1970 [Reprinted 1992] digitally available at: http://www.mccdc.marines.mil/Portals/172/Docs/SWCIWID/COIN/USMC%20Counterinsurgency%20History%20Pre-2000/U.S.%20Marine%20Corps%20Operations%20In%20The%20Dominican%20Republic%20Apr-Jun%201965%20-%20USMC%20History%20Division%20(1992).pdf.

[21] James Rife Oral History Interview with Daniel J. Thomas, July 12, 2016, 15-16; Email from Daniel J. Thomas to William Thomas, dated March 1, 2016.

[22] James Rife Oral History Interview with Daniel J. Thomas, July 12, 2016, 15-16; Email from Daniel J. Thomas to William Thomas, dated March 1, 2016.

[23] James Rife Oral History Interview with Daniel J. Thomas, July 12, 2016, 4, 15-16; Email from Daniel J. Thomas to William Thomas, dated March 1, 2016; Email from Daniel J. Thomas to William Thomas, dated March 20, 2016. The collaboration with Dayton T. Brown, Inc. resulted in the publication of an article: Channing L. Ewing and A. Marshall Irving, "Evaluation of Head Protection in Aircraft," *Aerospace Medicine* 40, no. 6 (June 1969): 596-599; Email from Daniel Thomas to William Thomas, dated January 28, 2016.

[24] See pages 3-4 of Ewing's research proposal dated April 4, 1972, located at NARA-CP, RG 52, Entry no. UD-WW 14, Box 3, F: "3900 Human Volunteers." Approvals from the Army are attached to the proposal as enclosures; Email from David Gillis to William Thomas, dated November 18, 2015; Ewing et al., "Dynamic Response of the Head and Neck of the Living Human to $-G_x$ Impact Acceleration," in *Proceedings of the Twelfth Stapp Car Crash Conference* (New York: SAE, 1968), 435.

[25] William Thomas Oral History Interview with Daniel J. Thomas, March 8, 2016, 4-5; Ewing et al., "Dynamic Response of the Head and Neck of the Living Human to $-G_x$ Impact Acceleration," 435; Email from Daniel Thomas to Walt Humann, dated May 27, 2016.

[26] Email from Daniel Thomas to Walt Humann, dated May 27, 2016.

[27] James Rife Oral History Interview with David Gillis, August 16, 2016, 7-16.

[28] James Rife Oral History Interview with David Gillis, August 16, 2016, 18, 22-28; Email from David Gillis to William Thomas, dated November 18, 2015; Email from Daniel J. Thomas to William Thomas, dated March 1, 2016; Memorandum from Daniel Thomas to USAARU, dated April 18, 1968, located in the internal correspondence files at the Neel Aeromedical Center, USAARL, Fort Rucker, AL.

[29] Email from David Gillis to William Thomas, dated November 18, 2015; Letter from B. J. Semmes, Jr., Bureau of Personnel, to Lt. David B. Gillis, Jr., MC, USNR, dated March 21, 1968, confirms Gillis's designation as "human acceleration/deceleration experimental subject," from the personal files of David Gillis; James Rife Oral History Interview with David Gillis, August 16, 2016, 19-20; L. M. Patrick, D. J. Van Kirk, and G. W. Nyquist, "Vehicle Accelerator Crash Simulator," 407; Channing L. Ewing, Daniel J. Thomas, George W. Beeler, Jr., Lawrence M. Patrick, and David B. Gillis, "Dynamic Response of the Head and Neck of the Living Human to $-G_x$ Impact Acceleration: I. Experimental Design and Preliminary Experimental Data," *Proceedings of the Twelfth Stapp Car Crash Conference* (Warrendale, PA: Society of Automotive Engineers, 1968), 405.

[30] L. M. Patrick, D. J. Van Kirk, and G. W. Nyquist, "Vehicle Accelerator Crash Simulator," 407.

[31] Letter from Dan Thomas to Commanding Officer, USAARU, dated April 18, 1968, Subj: Trip Report to Eglin AFB – Assessment Section on 17 April 1968. Letter located in the internal correspondence files at the Neel Aeromedical Center, United States Army Aeromedical Research Laboratory, Fort Rucker, AL; James Rife Oral History Interview with Daniel J. Thomas, July 12, 2016, 62-63; Email from Daniel J. Thomas to William Thomas, dated March 1, 2016; Ewing et al., "Dynamic Response of the Head and Neck of the Living Human to $-G_x$ Impact Acceleration," 424; Channing L. Ewing and Daniel J. Thomas, *Human Head and Neck Response to Impact Acceleration,* 2; Ewing et al., "Living Human Dynamic Response to $-G_x$ Impact Acceleration: II. Accelerations Measured on the Head and Neck," 403; Email from Daniel Thomas to William Thomas, dated March 1, 2016; Channing L. Ewing and Daniel J. Thomas, *Human Head and Neck Response to Impact Acceleration*, 2, 14.

[32] Ewing et al., "Dynamic Response of the Head and Neck of the Living Human to $-G_x$ Impact Acceleration," 424, 428, 438. J. P. Stapp conducted several runs in 1951 in which helmet-mounted accelerometers were tested, but they were abandoned "because of angular motion of the head and instability of the helmet on the head." The quote is on page 426. Another, more successful usage of head-mounted accelerometers was conducted at the Aerospace Crew Equipment Laboratory, Philadelphia, during the early 1960s. For this, see M. Schulman, G. T. Critz, F. M. Highly, and E. Hendler, "Determination of Human Tolerance to Negative Impact Acceleration," NAEC-ACEL Report No. 510, Naval Air Engineering Center, Aerospace Crew Equipment Laboratory, Philadelphia, 1963; Channing L. Ewing and Daniel J. Thomas, "Human Dynamic Response to $-G_x$ Impact Acceleration," 11-1.

[33] Channing L. Ewing and Daniel J. Thomas, "Human Dynamic Response to $-G_x$ Impact Acceleration," 11-1.

[34] Ewing et al., "Dynamic Response of the Head and Neck of the Living Human to $-G_x$ Impact Acceleration," 424, 428, 438; Channing L. Ewing and Daniel J. Thomas, "Human Dynamic Response to $-G_x$ Impact Acceleration," 11-3 – 11-4.

[35] Email from Daniel J. Thomas to William Thomas, dated March 1, 2016; Channing L. Ewing and Daniel J. Thomas, "Human Dynamic Response to $-G_x$ Impact Acceleration," 11-3; Channing L. Ewing et al., "Dynamic Response of the Head and Neck of the Living Human to $-G_x$ Impact Acceleration," 430.

[36] Channing L. Ewing, Daniel J. Thomas, George W. Beeler, Jr., Lawrence M. Patrick, and David B. Gillis, "Dynamic Response of the Head and Neck of the Living Human to $-G_x$ Impact Acceleration: I. Experimental Design and Preliminary Experimental Data," 7; Channing L. Ewing and Daniel J. Thomas, "Human Dynamic Response to $-G_x$ Impact Acceleration," 11-4; William Thomas Oral History Interview with Daniel J. Thomas, March 8, 2016, 10-11.

[37] Email from David Gillis to William Thomas, November 18, 2015.

[38] Ewing et al., "Dynamic Response of the Head and Neck of the Living Human to $-G_x$ Impact Acceleration: I. Experimental Design and Preliminary Experimental Data," ii, 12; Ewing et al., "Dynamic Response of the Head and Neck of the Living Human to $-G_x$ Impact Acceleration," 424; Channing L. Ewing and Daniel J. Thomas, *Human Head and Neck Response to Impact Acceleration,* iii; Email from David Gillis to William Thomas, November 18, 2015.

[39] Report by RADM Frank B. Voris, MC, USN, dated December 19, 1967, Subj: 3rd Meet-

ing, Panel for Joint Army-Navy Medical Research," NARA-CP, RG 52, Entry A1-1004, Box 1790, F: 6401/Podiatry 1967; Research proposal entitled "Determination of Human Dynamic Response to Impact Acceleration," dated April 4, 1972, from Channing L. Ewing located at NARA-CP, RG 52, Entry no. UD-WW-14, Box 3, Folder: "3900 Human Volunteers"; Channing L. Ewing, "Discussion," in *Impact Injury and Crash Protection*, ed. E. S. Gurdjian, W. A. Lange, L. M. Patrick, and L. M. Thomas (Springfield, Ill.: Charles C. Thomas, [1968] 1970), 350-351.

[40] Anon., "New Captain at NAMI," *Aerospace Medicine* 39 (December 1968): 1376; Channing L. Ewing, Daniel J. Thomas, George W. Beeler, Jr., Lawrence M. Patrick, and David B. Gillis, "Dynamic Response of the Head and Neck of the Living Human to $-G_x$ Impact Acceleration," 424-439; Channing L. Ewing, Daniel J. Thomas, Lawrence M. Patrick, George W. Beeler, and Margaret J. Smith, "Living Human Dynamic Response to $-G_x$ Impact Acceleration. II. Accelerations Measured on the Head and Neck," 400-415.

[41] Channing L. Ewing, Daniel J. Thomas, George W. Beeler, Jr., Lawrence M. Patrick, and David B. Gillis, "Dynamic Response of the Head and Neck of the Living Human to $-G_x$ Impact Acceleration," 424-439; Channing L. Ewing, Daniel J. Thomas, Lawrence M. Patrick, George W. Beeler, and Margaret J. Smith, "Living Human Dynamic Response to $-G_x$ Impact Acceleration: II. Accelerations Measured on the Head and Neck," 405.

[42] Email from Daniel Thomas to William Thomas, dated April 9, 2016; Anon., "Dr. Thomas Receives Army Commendation Medal," *Aerospace Medicine* 40 (April 1969): 459; Email from Daniel Thomas to William Thomas, dated April 19, 2016; Anon., "Eric Lilgencratz Award Presented to Channing L. Ewing," *Aviation, Space, and Environmental Medicine* 48 (1977): 576-577.

[43] Faucett served as the chief of the Research Division, BUMED, from July 1969 to July 1972. For this, see Charles W. Shilling, *History of the Research Division Bureau of Medicine and Surgery, U.S. Department of the Navy*, 101; David Beach, "Ross McFarland Dies; Pioneered Study of Stress," *The Harvard Crimson,* November 13, 1976, http://www.thecrimson.com/article/1976/11/13/ross-mcfarland-dies-pioneered-study-of/; Email from Daniel Thomas to William Thomas, dated April 19, 2016.

[44] Email from Daniel J. Thomas to William Thomas, dated April 19, 2016.

[45] Email from Daniel J. Thomas to William Thomas, dated March 1, 2016.

[46] Email from Daniel J. Thomas to William Thomas, dated April 9, 2016; Chief of Naval Operations and the Bureau of Medicine and Surgery, *U.S. Naval Flight Surgeon's Manual* (Arlington, VA: Produced by Biotechnology, Inc. under contract with the Office of Naval Research, 1968).

[47] Email from Daniel Thomas to James Rife, dated September 19, 2016; Letter from Pollard to Angus Rupert, dated February 7, 2005, in the personal files of Daniel J. Thomas; Email from Daniel J. Thomas to William Thomas, dated April 15, 2016.

[48] The contract no. was N00014-67-A-0159-006; Letter from Walter L. Bloom, M.D., Georgia Institute of Technology, to ONR, ATTN: Code 444 [Pollard], Director, Medicine and Dentistry Branch, Biological Sciences Division, Subj: Monthly Status Report No. 2, dated February 11, 1970. The letter is enclosed in J. D. Walton, Jr., W. H. Horton, S. B. Chyatte, and H. Warner, "An Engineering Study of the Requirements for an Acceleration Facility for Bioengineering Research and the Feasibility of Establishing Such in the Atlanta Area," Final Report prepared for ONR under contract N000414-67-A-0159-0006, September 1970. The

report may be found at Georgia Institute of Technology, Library Service Center General Collection, Call no. TA7.G4X B57 A-1216.

[49] J. D. Walton, Jr., W. H. Horton, S. B. Chyatte, and H. Warner, "An Engineering Study of the Requirements for an Acceleration Facility for Bioengineering Research and the Feasibility of Establishing Such in the Atlanta Area," Final Report, Contract no. N00014-67-A-0159-0006 (Prepared for the Office of Naval Research, September 1970), 28-29. Report is located at Georgia Tech. Library, Archives Reading Room, call no. TA164.W23X; Letter from Walter L. Bloom, M.D., Georgia Institute of Technology, to ONR, ATTN: Code 444 [Pollard], Director, Medicine and Dentistry Branch, Biological Sciences Division, Subj: Monthly Status Report No. 2, dated February 11, 1970; Email from Dan Thomas to William Thomas, dated March 1, 2016; Harvey M. Sapolsky, *Science and the Navy: The History of the Office of Naval Research* (Princeton, NJ: Princeton University Press, 1990), 73; Project Termination Form, dated December 4, 1970. This form, which gives the contract expiration dated as September 30, 1970, enclosed in a series of documents attached to J. D. Walton, Jr., W. H. Horton, S. B. Chyatte, and H. Warner, "An Engineering Study of the Requirements for an Acceleration Facility for Bioengineering Research and the Feasibility of Establishing Such in the Atlanta Area," Final Report prepared for ONR under contract N000414-67-A-0159-0006, September 1970. The report may be found at Georgia Institute of Technology, Library Service Center General Collection, Call no. TA7.G4X B57 A-1216.

[50] Jeffrey K. Stine, *A History of Science Policy in the United States, 1940-1985. Science Policy Study Background Report No. 1, Report Prepared for the Task Force on Science Policy Committee on Science and Technology, House of Representatives, Ninety-Ninth Congress, Second Session, Serial R* (Washington, D.C.: Government Printing Office, 1986), 61-62; Roger L. Geiger, "Science, Universities, and National Defense, 1945-1970," *Osiris* 7 (1992): 45-47.

[51] Conrad L. Rein, "Defense Plant Conversion and Leading Sector Industrial Development in the Postwar South: The Slow Take-off of the Space Program in New Orleans," *Business and Economic History* 28, no. 2 (Winter 1999): 224-227.

[52] The Michoud plant was second only to Ford's Willow Run facility in manufacturing area. Conrad L. Rein, "Defense Plant Conversion and Leading Sector Industrial Development in the Postwar South: The Slow Take-off of the Space Program in New Orleans," 226-228; War Assets Administration, *Plant Finder: Listing of Government-Owned Industrial Plants, September, 1946* (Washington, D.C.: Office of Real Property Disposal, WAA, 1946), 64; Civilian Production Administration, *War Industrial Facilities Authorized, July 1940-August 1945: Listed Alphabetically Company and Plant Location* (Washington, D.C.: Industrial Statistics Division, CPA, July 30, 1946). The facility is identified as Plancor 1569 in U.S. House of Representatives, *Utilization of Government-Owned Plants and Facilities: Hearings Before the Subcommittee for Special Investigations of the Committee on Armed Services – Eighty-Fifth Congress, Second Session Under the Authority of H. Res. 67, Hearings Held December 2-3, 1958* (Washington, D.C.: Government Printing Office, 1959), 1109. This is confirmed by review of Plancor books located at the National Archives. See RG 234, Entry 352, Box 07, F: "Plancor Book 1-4"; George C. Marshall Space Flight Center, "Michoud Assembly Facility," undated NASA manuscript, 9. A copy is located in the vertical files at the New Orleans Public Library.

[53] According to Conrad Rein, Chrysler was awarded a contract to produce S-I boosters at Michoud in November 1961, and Boeing arrived in December of the same year with a five-year, $300 million contract to develop and test 24 S-IC Saturn advanced stage boosters. Mar-

tin Marietta, Inc. came to Michoud after they were awarded a contract to build Saturn shuttle external tanks at the facility in July 1972. See Rein, "Defense Plant Conversion and Leading Sector Industrial Development," 230-232; James Rife Oral History Interview with Daniel J. Thomas, July 12, 2016, 6, 46-48; Memorandum from Lloyd F. Miller to Code 1, dated February 8, 1971, Subj: Air Crew Impact Injury Prevention Development Project (ADO 43-12X); relocation to NASA spaces, New Orleans, NARA-CP, RG 52, Entry A1-1004, Box 1964, F: "EE14/NASA – 1970."

[54] Memorandum from Lloyd F. Miller to Code 1, dated February 8, 1971, Subj: Air Crew Impact Injury Prevention Development Project (ADO 43-12X); relocation to NASA spaces, New Orleans, NARA-CP, RG 52, Entry A1-1004, Box 1964, F: "EE14/NASA – 1970."

[55] Memorandum from Capt. C. W. Boggs (Code 71-2), to Capt. L. F. Miller (Code 71), Director of Research Division, BUMED, dated October 29, 1970, Subj: "Procurement of NASA Building in New Orleans for Acceleration-Sled Used for the Impact Injury Studies," NARA-CP, RG 52, Entry no. A1-1004, Box 1964, F: "EE14/NASA-1970." For biographical information on Captain Boggs, see his obituary, "Boggs – Clifford," Albuquerque Journal, Saturday, January 20, 2007, http://obits.abqjournal.com/obits/2007/01/20. The rank and position of RADM Gray was obtained from Anon., "Change of Command at Pensacola," *Aerospace Medicine* 41 (October 1970): 1219. For CDR Tyler's credentials and affiliation with the program, see the acknowledgments in Channing L. Ewing et al., "Living Human Dynamic Response to $-G_x$ Impact Acceleration," 414.

[56] A copy of the permit may be found attached to a letter from C. F. McCord, Director, Real Estate Division, NAVFAC, Southern Division, to Mr. Arthur V. Daly, Assistant Director for Facilities, George C. Marshall Space Flight Center, NASA, dated January 29, 1971, NARA-CP, RG 52, Entry A1-1004, Box 1964, F: "EE14/NASA-1970." The figure of 42,000 sq. ft. includes 10,000 sq. ft. of storage area in building 420. Test cells 3 and 4 equated to roughly 32,000 sq. ft. The Navy endorsed and accepted the permit on January 29, 1971.

[57] Charles W. Shilling, *History of the Research Division Bureau of Medicine and Surgery, U.S. Department of the Navy*, 170; For the funding figures, see Anon., "Michoud to Get 5-Year Project," *The Times-Picayune*, January 30, 1971; Letter from Edward B. Becker to Dr. Davis, Office of Patent Counsel, Naval Coastal Labs, dated September 27, 1972. Letter located in the internal correspondence files, Neel Aeromedical Center, USAARL, Ft. Rucker, AL.

[58] Anon., "USAARL Expands Research to Meet Needs Generated by Role of Helicopters," *Army Research and Development Newsmagazine* 11, no. 6 (September-October 1970): 18-19; http://www.usaarl.army.mil/pages/about/history/; Charles W. Shilling, *History of the Research Division, Bureau of Medicine and Surgery*, 138; Letter from Major General Richard R. Taylor, MC, Special Assistant for Research and Development, Office of the Surgeon General, Department of the Army, to Chief, BUMED, dated December 7, 1972. The letter is located at NARA-CP, RG 52, Entry UD-WW 14, Box 3, F: 3900 Human Volunteers.

[59] Stephen S. Rosenfeld, "Rep. Hébert: A Sense of Power," *The Washington Post*, April 5, 1974, A30; James Rife Oral History Interview with Daniel Thomas, July 12, 2016, 55-56; Anon., "Michoud to Get 5-Year Project," *The Times-Picayune*, January 30, 1971; Conrad L. Rein, "Defense Plant Conversion and Leading Sector Industrial Development in the Postwar South: The Slow Take-off of the Space Program in New Orleans," 232-233; Anon., "Naval Activity Importance to New Orleans Stressed," *The Times-Picayune*, December 14, 1971, section 1, 11; Dale Curry, "Michoud – A $1.5 Billion 'Ghost,'" *The States Item*, July 31, 1970, C1, 21.

[60] Research and Technology Work Unit Summary (DD 1498 Form), "Development of a Means for Protecting Amphibious Warfare Casualties from Vehicular Vibration," dated July 1, 1971, located in NARA-CP, RG 52, Entry UD-04W1, Box 10, F: NBDL MF58.524.02E-0001 (NEW).

[61] Anon., "Human and Primate Accelerator Facility, U.S. Navy Michoud Accelerators," NAMRL-D internal document, dated March 9, 1973, located in Internal Correspondence Files, Neel Aeromedical Center, USAARL, Fort Rucker, AL; Letter from Captain Lloyd F. Miller to Officer in Charge, NAMRL, Subj: Release of research data; authorization for; dated June 17, 1971, located at NARA-CP, RG 52, Entry UD-WW 14, Box 3, F: 3900 Human Volunteers; Anon., "Flight Surgeon Discusses Protection for Head, Neck," *The Times-Picayune*, October 10, 1971, section 1, 6.

[62] Pollard is quoted in Shilling, *History of the Research Division Bureau of Medicine and Surgery*, 87-89.

[63] James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 1-3.

[64] James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 2.

[65] James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 3; For information on Becker and Morrill, see Channing L. Ewing's research proposal "Determination of Human Dynamic Response to Impact Acceleration," dated April 4, 1972. This proposal is located at NARA-CP, RG 52, Entry UD-WW 14, Box 3, F: 3900 Human Volunteers; Memorandum from Gilbert Willems, Chief, Instrumentation Division, to Channing Ewing, Officer in Charge, NAMRL-D, dated February 12, 1973, Subj: Change in Job Series Title, Internal Correspondence Files, Neel Aeromedical Center, USAARL, Ft. Rucker, AL. For Willems' work prior to his arrival at NAMRL-D, see his publications "A Note on PACTOLUS," *Simulation* 3, no. 5 (1964): 3-4; "High Sensitivity Sample-and-Hold Circuit," *Simulation* 4, no. 3 (1965): 140-141; "Optimal Controllers for Homing Missiles," Report No. RE-TR-68-15, U.S. Army Missile Command, Redstone Arsenal, AL, September 1968; "Optimal Controllers for Homing Missiles with Two Time Constants," Report No. RE-TR-69-20, U.S. Army Missile Command, Redstone Arsenal, AL, October 1969; For Majewski's work on the Wayne State project, see the acknowledgments section of Channing L. Ewing and Daniel J. Thomas, *Human Head and Neck Response to Impact Acceleration*, iii. For his position at NBDL, see Majewski, "The Naval Biodynamics Lab," *U.S. Navy Medicine* 72, no. 8 (August 1981): 4, and email from Daniel J. Thomas to James Rife, dated November 22, 2016.

[66] William Thomas Oral History Interview with Daniel J. Thomas, March 8, 2016, 20-21.

[67] Email from Daniel J. Thomas to William Thomas, dated April 12, 2016; William Thomas Oral History Interview with Daniel J. Thomas, March 8, 2016, 20-21. A copy of Unterharnscheidt's CV is enclosed in a letter from Unterharnscheidt to Thomas Dobie dated May 27, 1997. The letter is located in the correspondence files of the Neel Aeromedical Center, USAARL, Ft. Rucker. For some of Unterharnscheidt's publications, see Friedrich Unterharnscheidt and Lawrence S. Higgins, "Pathomorphology of Experimental Head Injury Due to Rotational Acceleration," *Acta Neuropathologica* (Berlin) 12 (1969): 200-204; F. J. Unterharnscheidt, "Translational versus Rotational Acceleration – Animal Experiments with Measured Input," *Proceedings of the Fifteenth Stapp Car Crash Conference* (Warrendale, PA: Society of Automotive Engineers, 1971): 767-770; Friedrich J. Unterharnscheidt and Lawrence S. Higgins, "Neuropathologic Effects of Translational and Rotational Acceleration of the Head in Animal Experiments," in *The Late Effects of Head Injury*, ed. A. Earl Walker, William F. Caveness, and

Macdonald Critchley (Springfield, Ill.: Charles C. Thomas, 1969): 158-167; Friedrich Unterharnscheidt and Lawrence S. Higgins, "Traumatic Lesions of Brain and Spinal Cord Due to Non-Deforming Angular Acceleration of the Head," *Texas Reports on Biology and Medicine* 27, no. 1 (Spring 1969): 127-166; Friedrich J. Unterharnscheidt, "Discussion," in *Impact Injury and Crash Protection*, ed. Elisha S. Gurdjian, William A. Lange, Lawrence M. Patrick, and L. Murray Thomas (Springfield, Ill.: Charles C. Thomas, 1970), 43-62.

[68] For the biographical information on Anderson, see an undated copy of his resume on file at the Neel Aeromedical Center, USAARL, Ft. Rucker, AL; Letter from Channing L. Ewing to Commanding Officer, U.S. Army Administration Center, dated March 20, 1972. Letter located in the March 1972 reading files at the Neel Aeromedical Center.

[69] Werner Goldsmith, "Biomechanical Activities at Some American and European Institutions – II," *Journal of Biomechanics* 2 (1969): 469-470; John L. Martinez, Jack Wickstrom, and Brian T. Barcelo, "Tulane University Studies of Acceleration Injuries in Animals," *Proceedings of the Ninth Stapp Car Crash Conference* (Warrendale, PA: Society of Automotive Engineers, 1966), 129-141.

[70] Ayub K. Ommaya, Arthur E. Hirsch, and John L. Martinez, "The Role of Whiplash in Cerebral Concussion," *Proceedings of the Tenth Stapp Car Crash Conference* (Warrendale, PA: Society of Automotive Engineers, 1967), 314-324; A. K. Ommaya, P. Yarnell, A. E. Hirsch, and E. H. Harris, "Scaling of Experimental Data on Cerebral Concussion in Sub-Human Primates to Concussion Threshold for Man," *Proceedings of the Eleventh Stapp Car Crash Conference* (Warrendale, PA: Society of Automotive Engineers, 1968), 73-80; Quote from Research and Technology Work Unit Summary (DD 1498 Form), "Development of a Means for Protecting Amphibious Warfare Casualties from Vehicular Vibration," dated July 1, 1971, located in NARA-CP, RG 52, Entry UD-04W1, Box 10, F: NBDL MF58.524.02E-0001 (NEW); Leon B. Walker, Edward H. Harris, and Uwe R. Pontius, "Mass, Volume, Center of Mass, and Mass Moment of Inertia of Head and Head and Neck of Human Body," *Proceedings of the Seventeenth Stapp Car Crash Conference* (Warrendale, PA: Society of Automotive Engineers, 1973), 524-537; Letter from Captain M. D. Courtney, MC, USN, Commanding Officer, NAMI, to the Honorable F. Edward Hébert, dated July 6, 1971, located at NARA-CP, RG 52, Entry A1-1104, Box 1964, F: EE14/NASA-1970.

[71] Werner Goldsmith, "Biomechanical Activities at Some American and European Institutions – III," *Journal of Biomechanics* 3 (1970): 125; Anon., "Noise Effects on Body, Topic," *The Times-Picayune*, dated January 15, 1970, section 2, 12; Anon., "Flight Surgeon Discusses Protection for Head, Neck," *The Times-Picayune*, October 10, 1971, section 1, 6; Anon., "Boxing Lecture," *The Times-Picayune*, dated November 18, 1973, section 1, 2.

[72] Werner Goldsmith, "Biomechanical Activities at Some American and European Institutions – II," 469-470; Letter from Capt. M. D. Courtney, CO, NAMI, to Hon. F. Edward Hébert, House of Representatives, dated July 6, 1971, located at NARA-CP, RG 52, Entry A1-1004, Box 1964, F: EE14/NASA-1970.

Chapter Three

Building the Machine–Beginning the Model, 1971-1975

The work at Wayne State had been foundational. It had demonstrated the potential of more rigorous, better documented acceleration experimentation, brought the first of a growing team of specialists into Chan Ewing's orbit, and—perhaps most importantly—provided a springboard for the creation of a freestanding program at Michoud. Now, after years of work gaining approval, obtaining funds, and engaging personnel for his new operation at Michoud, Ewing found himself, in some respects, beginning anew. He had an enormous empty space that had to be transformed into a first-rate research facility. That done, NAMRL-D detachment had to prove its equipment and protocol by running human volunteer tests of the same nature already conducted at Wayne State but this time capturing measurements in three dimensions. These measurements, Ewing hoped, would in turn allow for the construction of a digital model of a human head and neck injury prediction, along with a correlated non-human primate model—the ambitious third pillar of his research plan. As an ultimate goal, incremental non-human primate tests from sub-injurious to fatal could be scaled to provide insight on the limits of human survivability. NAMRL-D researchers accomplished much during the first four years at Michoud, building the horizontal accelerator device and beginning to gather the information that they hoped, in the end, would answer all the questions.

Infrastructure

Chan Ewing knew that everything to come would revolve around one all-important piece of infrastructure, the horizontal accelerator. And he had good reason to want to build it right: "I want to run it so much I want to wear it out," he told Bill Muzzy, whose responsibility it was to devise, construct, and maintain the facility. Muzzy and his team built well, for during a quarter-century of hard use, the horizontal accelerator—with meticulous maintenance—met all challenges from first to last.[1]

This is all the more remarkable because the Navy initially provided only $250,000 for construction of the horizontal accelerator. Ewing called upon his connections to

The enclosure for the horizontal impact accelerator's 700-foot-track extends into the marshy area outside building 420 at Michoud. (USAARL)

obtain essential equipment from NASA's surplus stocks. Muzzy cut costs everywhere he could. Construction and fabrication that would typically have been contracted out, for example, was instead undertaken in a NAMRL-D machine shop, woodshop, or welding shop. These shops were all outfitted with government surplus equipment and staffed by a highly resourceful team that included Ferris Bolin, Roger Black, and Willard Hunt, all of whom had worked previously with Muzzy at Holloman Air Force Base. This was a "very talented group of technicians," Muzzy recalled, able to produce "anything you wanted out of wood, fiberglass, [or] any kind of metal."[2]

It was not an entirely home-grown initiative, of course. Ewing, Muzzy, and representatives from the Southern Division of the Naval Facilities and Engineering Command (NAVFAC) negotiated technical support agreements with contractors working at Michoud for NASA. Defense contractors Chrysler, Martin Marietta, and Boeing all provided important support during construction of the laboratory.

Muzzy brought the heart of the machine with him when he first came to Michoud, in boxes containing a disassembled Bendix HyGe model linear horizontal accelerator. The HyGe accelerator employed a twelve-inch diameter piston rod driven by 3,000 psi of compressed nitrogen gas. This was fortuitous because the old test cells at Michoud were already outfitted with access valves that could provide a ready supply of pressurized, missile-grade nitrogen. All it took was a utilities contract with NASA to provide motive power. With a yield of 225,000 pounds of thrust, the HyGe could produce sled accelerations up to 70 G and rates of onset from 100 to 4,000 g/sec. The HyGe accelerator was far superior to the decelerator devices like those used by John Paul Stapp. In order to simulate impact using a decelerator, a subject must first be accelerated and then rapidly decelerated. The problem with this approach is that it is highly unlikely that the tests would be able to replicate the exact location of sudden deceleration, making it exceedingly difficult to determine the linear and angular velocity, acceleration, and location of the head at the moment of impact. Lacking precise measurements of these initial conditions, there was no good way to accurately assess the changes imparted by the deceleration pulse. Use of an accelerator made a high degree of accuracy possible, since the sled and subject were at rest prior to the moment of impact, making the initial sled conditions reliably zero. However, the initial position of the volunteer's head was still variable, needed to be carefully determined, and was affected by the test protocol conducted.[3]

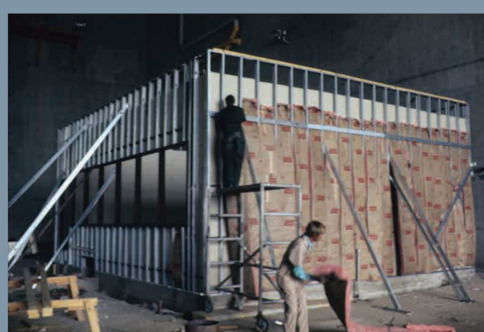
The WHAM II accelerator had shared this advantage, but the equipment being installed at NAMRL-D provided yet another leap in accuracy because Muzzy was building a longer track. Like most accelerators at the time, the Wayne State facility had a track about 100 feet in length. It was necessary, therefore, to employ brakes to rapidly decelerate the sled at the conclusion of each run. The subject's response to this braking pulse introduced an unnatural dynamic variable, or "artifact," into the data. In essence, the test was over the moment the brakes went on.[4]

Ewing and Muzzy were determined, therefore, to build a longer track so that the subject could coast into recovery from the acceleration. They were hoping to build a 1,000-foot track, but the tight budget required them to scale back their aspirations. Nevertheless, even at 700 feet, the track was sufficiently long to allow friction forces ranging from 2 to 4 meters/sec^2 to bring the sled to a stop. But if the track was shorter than Ewing and Muzzy would have liked, it was longer than Test Cell No. 4 could accommodate, requiring construction of a climate-controlled extension beyond the existing building. The rails themselves were Teflon-coated, set 39 inches apart, and bolted to 16-inch-diameter piles driven 110 feet into the ground. The entire structure rested on a foundation created by 300,000 pounds of concrete.[5]

The sleds produced for this track were equally innovative, beginning with their contact with the rails. In order to reduce friction to the greatest extent possible, they were mounted on sliders, or "pucks." The engineering team experimented with some

Left: Construction continues on the enclosure and foundation for the long-track horizontal impact accelerator. (USAARL)

Below: Construction on the control room at NAMRL-D. (USAARL)



commercially available pucks but found that they did not hold up under repeated use. Therefore, with manufacturing and testing assistance from Chrysler employees also working at Michoud, the NAMRL-D team produced a set of custom-built pucks from a mixture of Teflon and Delrin, a highly crystalline thermoplastic. The result was a slider that was durable, yet produced extremely low friction during the runs.[6]

The sleds were also positioned low to the ground, making it easier for the engineering technicians to work on them, and they were equipped with retractable rollers that could be engaged to roll the sled back up the track. At first, Willard Hunt and Bill Muzzy manually returned the sled into starting position after each run, until Muzzy injured his back in doing so. When he returned to work days later, Muzzy designed an automated return system employing a variable speed 25-horsepower motor and 1,400 feet of 1-inch chain. An added benefit of this automated return system was that it served as a safety feature: Muzzy designed a special holder with a sensor for the hitch that connected the chain and the sled. The sensor prohibited firing of the accelerator until the hitch had been disconnected and placed in the holder.[7]

Although the components were the same, there were two fundamentally different sled designs—one for use by human volunteers and one for non-human primates. It was imperative that the former never be accelerated beyond human tolerance levels. Therefore, Muzzy designed a 3.9-foot by 12.1-foot sled that weighed in at 3,680 pounds, its mass alone ensuring that the HyGe would not be able to push it beyond the human threshold. There was no similar requirement for non-human primate runs, so Muzzy produced a smaller sled that weighed about 1,000 pounds fully loaded. This created a different challenge, however. The light weight and minimal friction that would produce runs in excess of human tolerance also threatened to keep the sled moving beyond the terminus of the track. Therefore, Muzzy crafted an arresting mechanism using a wire coil to catch and decelerate the sled in emergency situations. The arresting mechanism was seldom employed over the years but performed as expected when emergencies arose.[8]

By the end of September, construction of the horizontal accelerator was complete, and on October 3, 1972, empty-sled testing began. During two months of runs, the NAMRL-D team confirmed the basic operational integrity of the horizontal accelerator while building in new redundant safety features. These included cutoff switches placed at multiple locations around the horizontal accelerator test area and an emergency hydraulic braking system. Midway through this process, on November 1-2, 1972, Captain John W. Johnson, Commander Joseph L. Graves, and Captain Robert E. Kinneman, Jr., of the Naval Bureau of Medicine and Surgery (BUMED) performed an inspection at NAMRL-D. Ewing personally led a tour that included a test firing of the horizontal accelerator. "All were very much impressed with the safety precautions employed and the gung ho attitude of Doctor Ewing's staff," Kinneman reported afterward. "The accelerator performed flawlessly and has shown exact reproducibility for subsequent runs." Johnson agreed, informing the chief of BUMED's

Research Division that the research capabilities at NAMRL-D were worth "far beyond the actual money being expended [on them]."[9]

A month later, runs utilizing anthropomorphic test dummies (ATDs) began. The earliest employed a variety of models produced by manufacturers including Alderson Research Laboratories and Sierra Engineering Company. By the end of 1972, fifty-five empty-sled and five ATD $-G_x$ runs had been completed.[10]

An early $-G_x$ ATD run at NAMRL-D, ca. 1974. (USAARL)

On January 26, 1973, Ewing hosted an open house for NAMRL-D employees and families at Michoud. The high point of the event came with a demonstration firing of the horizontal accelerator. The most basic elements of the machine were fully operational, but man-rating (i.e., ensuring safe operations for human research volunteers) of the accelerator could not begin until the entire experimental apparatus—including the inertial, photographic, and physiological measurement systems—was in place and tested.[11]

While Muzzy's team was building the horizontal accelerator, a group under Gil Willems, chief of the Bioinstrumentation Division, acquired and installed the inertial, photographic, and physiological measurement systems. Here again, budgetary constraints put a premium on patience and adaptability. As of March 1972, a minimum $95,000 investment was required to complete the instrumentation system. Also on the shopping list was expansion of the analog console of the data acquisition system (running from $30,000 to $50,000) and rate gyroscopes for the transducer packages ($4,000 to $7,000 each). Instead, Willems had to defer purchase of these and other essential items from FY 1972 to FY 1973. The federal acquisition system, with its long process of obtaining quotes and drafting justification reports, created its own unique set of delays—in some cases, it took months to obtain a critical piece of equipment. As a result, it was not until early 1973 that the data acquisition systems for the horizontal accelerator were fully installed and ready for testing.[12]

Over and above these drawbacks and delays, however, it was the technical requirements imposed by Chan Ewing and Dan Thomas that most complicated the instrumentation process. The $-G_x$ runs at Wayne State were measured two-dimensionally, but Ewing and Thomas were committed to developing a three-dimensional kinematic measurement system that would enable them to determine precisely how much lateral head movement occurred during $-G_x$ runs. There were good reasons for this. Ewing and Thomas suspected that lateral head movement had been negligible all along; if they could prove that to be the case, it would further validate the accuracy of the data from the Wayne State runs. Regardless, they recognized that three-dimensional data on human dynamic response would be invaluable because it could be paired with three-dimensional digital models of airplane cockpits and automobile cabins to evaluate safety during a variety of impact situations. In either case, the inertial, photographic, and physiological instrumentation would have to be as consistent and accurate as that used at Wayne State, yet far more complex.[13]

Inertial Instrumentation

As at Wayne State, the inertial system was composed of sled-mounted accelerometers, subject-mounted biaxial rate gyroscopes, subject-mounted transducers, and related calibration and data handling equipment. The transducer packages at Wayne State had included two piezo resistive accelerometers, and in the early runs at NAMRL-D, Ewing and Thomas continued to use this original arrangement to make two-dimensional measurements. However, in 1974 they began testing a new system at Michoud, designed by Ed Becker and Gil Willems, that incorporated six accelerometers so that they could render angular acceleration measurements in three dimensions. By 1975 the old two-dimensional system was phased out in favor of the new three-dimensional system based on the six accelerometers, which not only validated the earlier data but also ensured more precision.[14]

The six accelerometers were rigidly attached to aluminum T-plates at the mouth and T_1 vertebra in a scheme known as a 3-2-1 configuration. Three accelerometers grouped at the base of the T-plate collected data on linear (translational) acceleration. Two accelerometers were installed at one end of the horizontal bar of the T-plate, and one accelerometer was placed on the other end. Data collected from the accelerometers located at all three locations on each T-plate provided the information necessary to calculate angular (rotational) movement of the head-neck during impact.[15]

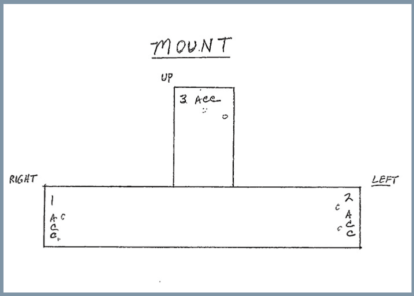
As a quality control measure, NAMRL-D purchased batches of accelerometers and tested them in-house. Only those that performed satisfactorily were sent to

Entran Devices, Inc., where they were epoxied to the T-plates within two-thousandths of an inch of the prescribed position. Wires from all six accelerometers were mated into single lines and connected to sled-mounted amplifiers. The accelerometers were calibrated regularly using an Inland Controls 800 series rate table coupled with an EAI Pacer 600® hybrid computer. To reduce weight on the head and neck, biaxial rate gyroscopes were attached to the T_1 and bregma mounts only, rather than at all three locations as done at Wayne State. As a result, the masses of the accelerometers were "virtually negligible," according to Becker and Willems, and the masses of the rate gyroscopes ranged from about 80 to 100 grams, depending on the models used. Data from the gyroscopes provided an independent measurement of angular velocity of the head and neck.[16]

It was Thomas's job to develop a theoretical methodology for translating instrument readings into three-dimensional head-neck motion that, in the long run, would be able to correlate data from human runs to non-human primate runs. Thomas worked with Dr. Arthur Callahan at the Office of Naval Research (ONR) to contract with computer and information systems firm QEI, Inc. to provide technical expertise on mathematical protocols for three-dimensional experiments. Thanks to the commitment of company president Charles Burgess, QEI became an invaluable contributor to the research carried out at NAMRL-D. "Their work was absolutely vital to the transmission of the voltage measurements to scaled, anatomically-based data," recalled Thomas. In a flurry of technical memoranda, Ewing, Thomas, and QEI personnel worked successfully to develop an instrumentation configuration that would accurately record the linear and angular accelerations registered at the head and neck during impact.[17]

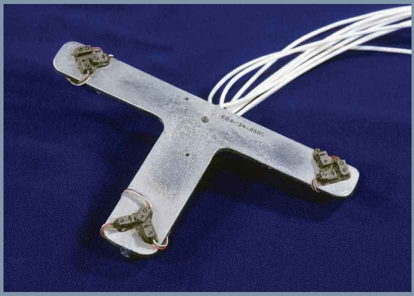
NAMRL-D retained the essentials of the inertial data acquisition system utilized at Wayne State. Information was fed from the transducer packages directly to a set of sled-mounted signal conditioning amplifiers. The amplified data traveled to the hub of the system, an analog console that transmitted buffered and amplified analog accelerometer data to a converter for digitization at a rate of 2,000 samples per/sec, per channel. Along with the inertial tracking packages themselves, the data acquisition system was calibrated prior to each experiment to provide the highest possible signal-to-noise ratio.[18]

The computer capability available at Michoud, however, was a step above the Wayne State setup. After traveling through the analog console, the data could then be fed into a UNIVAC 500 DCT terminal installed in the NAMRL-D space. The next stop in the information chain was the NASA Computer Complex at nearby Slidell, Louisiana, where a UNIVAC 1108-3G computer processed run data and calculated derived variables. To make plots to present various aspects of run data, NAMRL-D staff members utilized a Stromberg-Carlson Model 4020 microfilm printer/plotter capable of reading the half-inch magnetic tape produced by the UNIVAC 1108 and plotting at a speed of 12,500 points per second.[19]

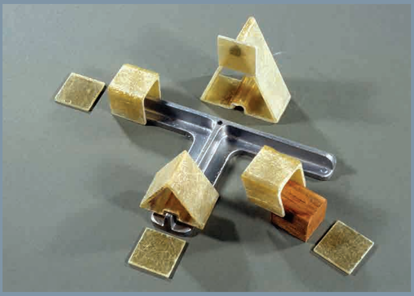


Schematic sketched by NAMRL-D staff members to document T-plate accelerometer array placement. (USAARL)

Pictured here is a functional transducer, complete with photo-targets and telemetry cabling. (USAARL)



Accelerometers and rate gyroscopes affixed to a T-plate. (USAARL)



Construction of wood photo-targets for each T-plate required meticulous detail. (USAARL)

Photographic Instrumentation

As one part of the NAMRL-D team was developing this improved inertial data chain, another was building up a strong photographic data collection capacity. This was critical because photographic information did not merely provide a pictorial record and allow investigators to study individual reactions to acceleration—it was also necessary to validate the kinematic measurements rendered by the transducers. Much of the work was conducted by technicians Roger Black and Ferris Bolin. They began by producing thin, flat fiberglass target plates. These were painted in a black-and-white checkered pattern selected to reduce photo reflection and affixed to the subject-mounted T-plates using wooden supports.[20]

The cameras used at the outset were Milliken 16-mm high-speed, shock-resistant, pin-registered instruments, capable of recording impact experiments at a rate of 500 frames per second. Kinoptic 12.5-mm lenses gave each camera a field of view of 80 cm x 60 cm in the object plane. Four General Electric Model 4582 sealed beam lamps provided lighting. Both cameras and lighting were sled-mounted and controlled by a photo-data acquisition console capable of handling 5,600 watts on ten individual circuits. Nine camera circuits were available on the console—three for variable voltage AC cameras, three for 115-volt AC cameras, and three for 28-volt DC cameras. Once the parameters of the various experiments were programmed into the console, the entire array of lights and cameras could be controlled by two separate switches: one to switch on the lights in advance, ensuring that they reached full candlepower well before the run, and another to activate the cameras just prior to acceleration. The master console switches controlling the lights and cameras could either be operated manually or by the same EAI Pacer 600® hybrid computer system used to acquire inertial transducer data. The photo-data acquisition console included one other very important feature. So as not to expose human volunteers to impact for no purpose and to avoid wasting costly photographic film, the console provided photographer Johnnie Bland with the ability to abort a run in the event of a camera or lighting failure.[21]

As with the inertial instrumentation, precision was of the utmost importance. The cameras, therefore, integrated photo-optical numeric recording devices manufactured by L.M. Dearing Associates in which a pulse generated by shutter motion caused time and date information to be printed along the edge of each frame following. A second Dearing unit printed IRIG-B codes on each frame. This highly accurate system of presenting date and time information in 10-digit binary code, developed by the U.S. military during the 1950s, enabled technicians to precisely match photographic data with accelerometer information. Both photographic time recorders were driven by a Datametric SP-400 time code generator synchronized daily, via radio, with National Bureau of Standards clocks. The synchronization of the time code generator ensured that the photo-film would be time-locked and chronologically consistent with all other data collected during each experiment.[22]

Every test, therefore, involved an extremely complicated process of photography and documentation. One sled-mounted camera provided frontal coverage of each run, while another afforded lateral coverage. Together they collected enough data for calculation of the kinematic motion of the head. The lateral shots also determined the motion of T_1 in the midsagittal plane. Since documentation of the exact location and orientation of each camera was imperative, the photographer carefully measured and noted these factors prior to each run using a complicated and tedious process. The data acquisition system would then generate a report including camera location and corresponding run identification information; then, after every run, the photographer verified the camera reports.[23]

As it had during the Wayne State program, the Math Sciences Laboratory at Florida's Eglin Air Force Base continued to process the film now being generated at Michoud. Technicians painstakingly reviewed negatives in order to validate kinematic data acquired from the accelerometers. After processing and analysis, photo-film records of each run were archived at Michoud on Ektachrome film with a 500-year shelf life.[24]

Photography proved to be one of the most costly aspects of operations at NAMRL-D. The customized sled-mounted cameras came with an individual price tag of around $15,000. Eglin's charges for processing 375 rolls of black-and-white film exposed between June 18 and December 5, 1975, were more than $5,000. Costs only went up from there—in 1978, a year's worth of film (about 3,000 rolls) cost more than $47,000 to process.[25]

Because of its capabilities, however, high-speed photography was worth the cost. In a paper presented to the Society of Photo-Optical Instrumentation Engineers in 1975, instrumentation engineer Ed Becker explained that "the images of a number of points on a body of known dimensions as captured by a number of cameras located in fixed positions in a fixed reference frame may be sufficient to yield the complete three-dimensional position and orientation of the body in that same reference plane."[26]

Physiological Measurement Systems

The third instrumentation requirement at NAMRL-D was to measure the physiological effects of impact on living subjects, either human volunteers or non-human primates. The medical staff collected data on the electrical activity of the brain using electroencephalograms (EEGs), monitored heart rates using electrocardiograms (ECG), and tracked eye movements using electrooculograms (EOGs). In instituting this physiological measurement program, NAMRL-D relied on expert outside help. A NAMRL-D consultant on the ECG system design was Dr. Raphael F. Smith of the Vanderbilt University Cardiology Department. Beginning in August 1972, Smith provided information on best practices for placing electrodes and taking ECG readings. Smith's system involved sanitizing a subject's skin at a targeted location and then attaching the electrodes there with a conductive cream and an adhesive pad. Signals from the electrodes then passed through a conditioning amplifier and were transmitted to the control room where they were stored on analog magnetic tape. Recorded ECG data could be displayed on oscilloscope monitors located in the track-side control room or reviewed in a hard copy produced by a conventional pen recorder.[27]

To help develop, and then conduct, the EEG monitoring program, Ewing hired Tulane Medical School assistant professor of psychiatry and neurology Leonard S. Lustick to lead the Mathematical Sciences Department at NAMRL-D. Selection of a neurologist to fill a GS-13 applied mathematician position might have appeared unorthodox, but Lustick was well qualified for the work. At Tulane, he had studied with famed neurological researcher Dr. Robert G. Heath, taking EEG recordings of rhesus macaques and conducting statistical analyses of the results. From the first days at Michoud, Ewing had expected to implement an exhaustive study of acceleration impact on non-human primates, so Lustick provided the kind of expertise that the program would greatly need. Lustick was even more uniquely qualified because he had been trained as a mechanical engineer, meaning that he would be able to work seamlessly with Bill Muzzy and his fellow engineers. It was a full year, however, between early 1973 when Ed Becker recommended Lustick to Ewing and early 1974 when Lustick arrived at Michoud. By then the machine had been built, the systems had been tested, and the human volunteer experiments were ready to begin in earnest.[28]

Wayne State Legacy

As exhilarating as it may have been to build a new program at Michoud, Ewing did not lose sight of the value that still lay in the work so recently carried out in Detroit. As the new lab took shape at Michoud, his other colleagues located two hundred miles to the east at NAMRL in Pensacola were processing and analyzing data previously produced at the old lab. This analysis had been requested by the National Highway Traffic Safety Administration (NHTSA) in June 1971 when it asked BUMED for access to the results of Ewing's research at Wayne State. NHTSA associate administrator for research and development John A. Edwards indicated that the data would be used to develop new performance criteria for the head and neck complex of ATDs. The director of BUMED's Research Division, Captain Lloyd F. Miller, approved the transmittal of data.[29]

It took the better part of the next year to iron out the details, but in April 1972 NAMRLD and the NHTSA signed a formal interagency agreement. The arrangement stipulated that the NHTSA would pay NAMRL-D $45,000 to cover the costs of providing the run data. NAMRL-D also promised anthropometric information on its Wayne State volunteers, a complete description of its experimental methodology, and no less than five hundred plot charts showing sled acceleration, velocity, and displacement measurements. The NHTSA was not the only party interested in data from the Wayne State runs. In conjunction with the Society of Automotive Engineers' Crash Test Dummy Subcommittee, a representative from the General Motors Proving Ground, John E. Lahiff, contacted Ewing with a request for data on the elongation of the neck during impact.[30]

With the interagency agreement in place, NAMRL scientists Richard Irons, Betsy White, and Sharon Katona in Pensacola went to work processing the Wayne State data. Although the U.S. Army's contribution to NAMRL-D had been reduced, the Army Medical Research and Development Command also provided support, with Major Eugene H. Blackstone, M.D., chief of the Cardiovascular Medicine Branch at the U.S. Army Aeromedical Research Laboratory, helping to process and plot EEG data from the Wayne State runs.[31]

As it turned out, processing and analyzing the Wayne State data for the NHTSA yielded big returns to NAMRL-D itself. During the course of the work, the staff found a number of errors and inefficiencies and, in the course of remedying them, ensured that the data produced at Michoud would be of even higher quality. To be sure, most of the data collected from the experiments at Wayne State was of very high quality, but some types of data required further conditioning before it could be analyzed. The data recorded by the sled-mounted accelerometer, for example, was excessively noisy because the device was hard-mounted directly to the sled, which introduced unwanted resonances into the recordings. As a fix, technicians developed filtration software to reduce the noise level. This would remain a standard part of the data acquisition and processing procedure at NAMRL-D.[32]

By far the most important aspect of the Wayne State legacy was that it served as a point of reference as, early in the Michoud years, the NAMRL-D team and Tulane engineers began using the data to develop the long-sought head-neck computer model. In mid-1972 Dr. Charles Beck, Dr. Robert Drake, Dr. Harold Sogin, and Professor Louis Orth of the Tulane School of Engineering worked with Bill Anderson, Gil Willems, and Ed Becker from NAMRL-D in a joint effort to use Wayne State project data to develop a computer program capable of simulating human head-neck response to impact. This early theoretical work was indispensable in enabling the NAMRL-D team to better conceptualize how to collect the three-dimensional data required to create an accurate head-neck model.[33]

The stereotaxic jig (pictured on the left), was designed by Ed Becker to take anthropometric measurements from cadaver heads. (USAARL)

The transition to three-dimensional measurements required new, more complex studies of the dynamic properties of the human head and neck. One big challenge was to relate acceleration vectors to the geometry and mass parameters of the head and neck. To do so, Ewing and Thomas needed to be able to measure parameters including static mass, center of gravity location, and moment of inertia (a term denoting the extent to which a body resists angular acceleration). If they could do that and thus establish a functional relationship between different body segments during impact, Ewing and Thomas expected to be able to predict dynamic response of particular anatomical areas to specified input acceleration levels.[34]

To assist in this exercise in theoretical kinematics, ONR turned again to Tulane. Engineering professors Leon B. Walker, Jr., and Edward H. Harris worked with graduate student Uwe R. Pontius to study the center of gravity, total mass, volume, and mass moment of inertia of the human head-neck complex. Their findings, drawn from studying twenty human cadaver heads at the Tulane University Medical Center, were to provide the physical constants that could be used in critical analysis of data collected at Michoud.[35]

Ewing realized that these figures were important, so much so that he had Becker replicate the studies on his own, using research facilities at the Anatomy Department at Tulane and new samples including six cadaver heads and three cadaver head-necks. Becker designed and patented a stereotaxic jig with a tetrahedral frame to position and lock the head in place to take measurements to calculate the center of gravity. To determine the moment of inertia, Becker created a trifilar pendulum, suspending the heads and head-necks on a disk suspended from three parallel lightweight wires of equal length attached to the frame of the jig. The jig could be hung in ten different orientations, each allowing the head to twist back and forth in different planes of motion by imparting rotational acceleration to the disk. By measuring the amount of time that a head oscillated back and forth in the different positions, the full three-dimensional moment of inertia tensor could be calculated. Becker's findings corresponded closely with those of Walker, Harris, and Pontius. Both studies, for example, determined the average position of the center of gravity of the head—the variance between the two was only 0.055 centimeters. As a result, NAMRL-D had a workable location of the head center of gravity for the human volunteer tests.[36]

As the NAMRL-D team got ever closer to launching the first human volunteer tests, there remained an additional challenge to be surmounted. Ewing and Thomas designated the human head, first thoracic vertebra, the attached mounts, the transducers, and the photo-targets affixed to the mounts to be "rigid bodies." Unlike soft tissues, rigid bodies are presumed to remain relatively unchanged as they move through space. The kinematic measurements rendered during each experiment are, therefore, valid only to the degree that the rigid bodies of the head and neck remain rigid. The rigid bodies were tracked individually using photography and by developing several coordinate systems to understand the kinematic movements. Each coordinate system consisted of a series of "fixed" points that served as a reference plane. A laboratory reference coordinate system containing the entire field of movement during the experiment was the most basic (the origin point being located on a target on the sled chair). Within this broader coordinate system, subsystems were developed, including instrumentation (including the locations of transducers and photo-targets), anatomical (based on the anatomical landmarks of individual subjects—the spine at T_1 and the head at the superior edge of each auditory meatus and the infraorbital notches), and principal (determined by the center of gravity and principal axes of the moment of inertia). After collecting data for all four coordinate systems, Ewing and Thomas devised a means to account for the three-dimensional geometric characteristics of the human head during impact.[37]

Human Research Volunteer Program

Aerial view of the horizontal accelerator and control room, preparing for an ATD run. (USAARL)

Testing and calibration of the accelerator and instrumentation continued through the spring and summer of 1973. On November 5, 1973, a Naval Aerospace Medical Institute safety committee arrived at Michoud for an on-site inspection. As part of the process, NAMRL-D conducted five runs with 98th percentile ATDs, simulating the largest and heaviest potential human volunteers. Just over two months later, on January 9, 1974, NAMRL commanding officer Captain Newton C. Allebach informed Ewing that the Michoud detachment had passed the test—the committee determined that all known factors to ensure the safety of human volunteer subjects and operators had been accounted for. With formal approval to use the horizontal accelerator in human tests, Ewing turned his attention to the challenge of obtaining volunteers, a task that Dan Thomas had been working on for more than a year.[38]

Not only did Thomas have to recruit human volunteer subjects, but he also had to get approval to do so from the highest level—the Office of the Secretary of the Navy, an office that scrupulously demanded airtight justifications and detailed applications. Meeting those requirements, Thomas remembered, "took as much of my attention as anything else I did." NAMRL-D could be sure of support from Ewing's allies in BUMED and ONR, but first Thomas had to prove that the risks to volunteers were acceptably low and develop a comprehensive plan for recruiting and for medical supervision.[39]

The breadth of Ewing's research agenda complicated the process of obtaining human volunteers. Although the primary impetus behind the establishment of NAMRL-D was to conduct impact injury research, Ewing also envisioned expansion into tangentially related areas as well, in part to build allies and to buttress support for his program. An early priority was to determine human tolerance of severe vibration levels encountered at high speed aboard ships and helicopters. Because very little research had been done on the subject, design engineers had no way to prioritize considerations of severe vibration among other factors. It was not unusual, for example, for severe vibration to force helicopter pilots to reduce speed. But in Vietnam, this had meant that it took aeromedical evacuation crews extra precious time to evacuate wounded soldiers. Lower speeds also made helicopters much easier targets. These were reasons enough for the Navy to support Ewing's 1971 proposal to study vehicular vibration. The next year BUMED agreed to provide $575,000 in funding for a six-year research program.[40]

As a result, the first human volunteer request, made in February 1972, did not even get beyond BUMED. The problem was that Thomas had requested permission to recruit human volunteers for impact and vibration experiments in a single application. The Navy, on the other hand, viewed the two research agendas as separate and distinct, and while plans for impact acceleration studies were well developed, the vibration research agenda was less than a year old and still in its preliminary stages. Captain Miller, chief of BUMED, asked for resubmission, this time in more detail.[41]

In response, Thomas compiled an information packet for volunteers that explained the impact and vibration research programs in great detail and carefully distinguished between the two, while making it clear that the programs would share volunteers. On December 7, 1973, a month after the safety inspection, the Secretary of the Navy approved recruitment of human volunteers, making Ewing directly responsible for their safety. Ewing would rely heavily, therefore, on his medical supervision team that included NAMRL-D staff members Dan Thomas, Lieutenant Commander Paul Majewski, and Lieutenant Commander William Barry.[42]

By then Ewing had already submitted a request to establish twenty-one billets for human research volunteers at Michoud. The Navy Bureau of Personnel quickly approved the billet request and authorized NAMRL-D to recruit enlisted men from the Naval Training Center in Orlando, Florida. In February 1974 Thomas went to Orlando to convene "interest meetings" with enlisted men at the Naval Training Center. He distributed his information packets, answered questions, and showed a film of Wayne State runs to give the men an idea of what to expect. About 34 percent of those who attended the interest meeting remained interested after it was over. Some may have welcomed the physical challenge; others may have looked forward to being stationed in New Orleans. It is likely that the hazard pay that Thomas was able to offer also made up a few minds. Thomas conducted interviews with this smaller group of recruits and, from those who remained qualified after the interviews, obtained written consent for medical screening.[43]

The process moved quickly after that. Within twenty-four hours, medical staff in Orlando conducted a preliminary screening of dental, medical, and administrative records and took x-rays of the spine of each potential volunteer subject. Those who made it through preliminary screening then reported to NAMRL, Pensacola, for two weeks of more extensive medical tests administered by specialists in internal medicine, neurology, ophthalmology, orthopedics, otorhinolaryngology, audiology, and psychology. Common disqualifiers that arose during this stage included musculoskeletal conditions like excessive scoliosis, spondylolysis, and lumbarization. Stringent dental criteria also resulted in a large number of disqualifications. Candidates with periodontitis (gum disease), severe cavities, missing teeth, or severely misaligned teeth were disqualified since those conditions could interfere with correct placement of the mouth-mounted transducer packages. Those who remained were indeed part of a select group. Between 1974 and 1976, only 5 percent of the recruits who attended the original interest meetings were qualified as human research volunteers and signed on for eighteen-month tours at NAMRL-D. There was further attrition after that, however, since the volunteers remained free to withdraw from the program at any time, even after qualification and selection. Consequently, of the sixty-three men qualified between February 11, 1974, and August 23, 1976, only forty-four completed the full term of service as human research volunteers for those years, with nineteen dropping out.[44]

The task of selecting volunteers was complicated for another reason. Study of the kinematics associated with indirect impact indicated to Ewing and Thomas that dynamic response most likely varied between different human beings. Accordingly, the extent to which anthropometric differences correlated to changes in dynamic response became an important research question. The twenty-one-man cohort, therefore, had to include equal proportions of human volunteers with short, medium, and tall sitting heights. All of the early volunteers fell between the 3rd and 95th percentile in sitting height. But there were factors at work beyond height, particularly circumference of the head, so all human volunteers had to be measured anthropometrically. Ewing turned again to expert anthropometric surveyor Charles E. Clauser at Wright-Patterson Air Development Center. Clauser and his team took some seventy measurements of every volunteer, which would provide for highly detailed comparisons between different subjects.[45]

The next steps took place at NAMRL-D. Since every human volunteer had a unique physical structure, all measurements and instrumentation had to be tailored to that individual. In effect, each human volunteer had to function as his own control. The distances from anatomical landmarks to transducer packages and photographic targets had to be known for each individual subject in order to calculate acceleration and velocity at specific points. This information was acquired by taking precise x-rays and photographs of each human volunteer with transducer packages and photo-target modules in place.[46]

This documentation was done on site at NAMRL-D by technician Nick Price. Each volunteer was positioned in a corner with lead BBs fixed at his orbital ridge and auditory meatus. Radiolucent Plexiglas holders containing lead markers were placed on both of the surrounding walls; these printed orientation information on the film during the exposures. A Plexiglas prism containing thirteen lead markers was also located in the target area so that at least eight of these markers would show up in each of the x-rays and provide the laboratory reference frame. Two x-ray ultra-high-speed Machlett Dynamax Model 67 and 69 tubes driven by a Westinghouse 1000 MA 150

KVP machine were positioned 1.5 and 2 meters away from the plate-holders, respectively. One tube took an x-ray of the subject from the lateral view, and the other provided an x-ray from the anterior-posterior position. Both worked nearly simultaneously. The x-rays utilized Kodak R.P. film that was processed in a ninety-second Kodak X-omat.

After the two exposures were examined for quality assurance by a physician, the images were digitized, with the position of each of the markers measured in relation to the orientation information printed by both of the wall-mounted Plexiglas holders using a Wang Laboratories Model 762 X-Y Digitizer (accurate down to 0.25 mm). In sum, the x-ray system implemented at NAMRL-D was a highly accurate means of determining the geometric relationships between subject-mounted instrumentation and the anatomical landmarks at the head and T_1. Each volunteer was also assigned a personal subject number. It was this number that was recorded along with each run, ensuring that the subjects retained their anonymity as data was put to use and even disseminated beyond the Navy.[47]

This documentation process was just part of a regime of preparatory procedures that were made explicitly clear to volunteers. Each subject was notified at least a day in advance of a run. The day of the experiment, the subject was interviewed by a monitoring physician to identify any medical problems that might have arisen since the subject's last run. The physician also disclosed the expected acceleration level for the upcoming run. Following the interview, the doctor administered an examination that included a drug test. Drug use was of special concern to the researchers at NAMRL-D because it added an unknown variable to the response data that they were collecting and so could compromise the quality of the entire program. Therefore, volunteers testing positive for unauthorized drugs were immediately disqualified from the program. Between 1974 and 1976, twelve volunteers were lost due to drug use violations.[48]

Known as the "Lab Rat Krewe," civilian and enlisted personnel at NAMRL-D built and manned floats for Mardi Gras parades in New Orleans. This example is from the 1980s. (USAARL)

The physicians also had to contend with the youthful exuberance and rowdiness of the eighteen- and nineteen-year-old young men, fresh out of boot camp, feeling invincible, and eager to spend their first Navy paychecks in the New Orleans entertainment district. Upon learning that some of the volunteers had been showing their prowess on the mechanical bull installed at one of the bars downtown, NAMRL-D issued a stern warning about avoiding potentially injurious activities that could put them out of the program and on the next bus back to Orlando. On at least two occasions, volunteers were killed in car accidents—a sobering reminder of why the team was doing its work in the first place. Over time, members of the laboratory's professional staff developed close and enduring friendships with the young military volunteers, affectionately referring to them as "lab rats." Photographer Art Prell later reflected that "we had a good time with these youngsters coming in there," and "I got a lot of good memories of those kids."[49]

After completion of the pre-run medical interview and physical exam, the horizontal accelerator and restraint systems were tested. To ensure the integrity of the restraints, Muzzy insisted that all human and animal runs be preceded by a run using a dummy at double the expected acceleration. A steel seat of the same design used in the Wayne State experiments was bolted to the sled, and subjects were restrained to it with shoulder straps, a lap belt, and an inverted V pelvic strap. Restraint straps on the upper arms and wrists prevented flailing during impacts. After a successful dummy run, the human volunteer was strapped into the sled-mounted chair and prepared for the run.[50]

A number of persons possessed the means to stop the run. The monitoring physician, present for the entire duration of the experiment, could cancel it by activating a hand-held abort switch. The human volunteer also had a hand-held abort switch. The palm-compressed units were "dead-man's" switches: they had to be held closed—relaxation of the grip for any reason would halt the run sequence. A final safeguard was the requirement that the monitoring physician had to maintain direct visual contact and communication with the human subject up to the moment of impact. These protocols proved their worth time and again—between 1974 and 1975, they were employed to abort twenty-four human runs.[51]

At the conclusion of the run, the monitoring physician conducted a medical check and loosened the restraints before the human subject was permitted to ride with the sled as it was pulled back up the track by the return mechanism. After dismounting, the volunteer was escorted to an examination room for a complete post-run physical and medical history update. Despite the fact that the actual impact event lasted only milliseconds, the extensive safety protocol dictated that each human run took approximately thirty minutes from the time that the subject was strapped into the sled to the end of the post-run medical exam. After every run, the volunteer had to be cleared by the monitoring physician before he could participate in another test. No subject was permitted to make more than one run per day. If the run had involved a relatively low-level acceleration exposure, the volunteer was usually given a two- or three-day re-spite. After higher acceleration runs, which often left volunteers with abrasions from the restraints, the resting period was longer.[52]

Volunteers did not idly await their turns on the accelerator. Instead, they were given administrative or mechanical duties, thus learning skills that helped them progress with their Navy careers. Indeed, most of the human research volunteers became machine repairmen, electronics technicians, or hospital corpsmen after moving on from their initial assignments at NAMRL-D. The lab also benefitted from this arrangement—volunteer pay came out of the Navy Bureau of Personnel rather than the NAMRLD research budget, so funds otherwise spent on staff could be used to build up the program.[53]

There were, of course, other ways to build up the program, such as contributing to related research projects. Ironically, the very first human run conducted at Michoud on January 31, 1974, was part of another program entirely. After his visit to Michoud in 1972, Captain Kinneman from BUMED recommended that NAMRL-D might be able to contribute baseline data for a small research program on parachute opening shock then being carried out at the Naval Aerospace Recovery Facility in El Centro, California, by Lieutenant Commander Douglas W. Call (future Naval Biodynamics Laboratory commanding officer), Lieutenant James F. Palmer, and Commander Donald H. Reid. Up until then, there was very little good data on the forces encountered by the human body when parachuting. In contrast to an ejection seat, in which the human body is restrained, at the moment that a parachute is deployed, an airman's body can be in any variety of positions, especially if tumbling during freefall. If his body is incorrectly aligned with the axis of the parachute's resistance, the airman can even be injured by the initial jolt, termed "parachute opening shock." By fitting NAMRL-D type transducer packages to the head and neck of test parachutists, multi-axis acceleration data could be collected for subsequent analysis. Ewing and Thomas agreed to produce transducer packages for the paratrooper tests and also to take baseline physiological readings from runs on the horizontal accelerator at Michoud for subsequent comparison. Two Navy parachutists volunteered, went through the medical screenings, and traveled to NAMRL-D for the accelerator tests.[54]

On the day of the first run, Muzzy began with a 6.5 G "check out" run using an ATD. With all systems go, the thirty-one-year-old paratrooper volunteer was strapped in for a $-3G_x$ run. He emerged unscathed. It was a good start, but the follow-through was less successful. During the next week of testing with the two paratrooper volunteers, there was a series of equipment malfunctions and one run had to be aborted. By February 7, 1974, the test runs were complete and the data was forwarded to the Naval Aerospace Recovery Facility. The paratroopers also returned to El Centro to prepare for the live jumps that would be documented and compared with the baseline data. Dan Thomas flew out to ensure that the attending medical staff knew how the equipment worked and how to take the proper measurements. He personally fitted the volunteers with inertial tracking packages. Although Thomas lamented that he "never really saw the final data and the outcome of the work," there can be little question that by supporting the parachute study even before its own testing had begun, NAMRL-D did something to demonstrate the value of its research methodology and to build support within the Navy research and development establishment.[55]

Back at Michoud, the first runs with the Orlando volunteers were beginning, putting into place the second pillar of Ewing's program. The initial group rode the sled during the Wayne State-style two-dimensional test runs, but now it was necessary to begin gathering three-dimensional data, measuring, as Ewing put it, "increments of peak acceleration, rate of onset of acceleration, duration at peak, for numerous different vector directions, and subject sizes up to the limit of voluntary human tolerance and then to model the living human response envelope."[56]

The initial human runs at NAMRL-D were carried out at low acceleration levels in the $-G_x$ vector and essentially validated the work already conducted at Wayne State. "We decided to do the safest runs first," Thomas recalled, adding that "we thought the –X runs were the safest, from the point of view [that] we knew more about that than anything else." The testing was carried out at a brisk tempo, so that by the end of 1974, the researchers had conducted 282 human runs. The tempo significantly increased the following year, with another 404 test runs on the accelerator. By then, however, NAMRL-D had finished determining the "living human response envelope" and had long since embarked on the next part of its journey, modeling the non-human primate response.[57]

Non-Human Primate Research Program

It was in developing the non-human primate research program that Ewing was closest to starting from scratch; there had been no animal experiments at Wayne State.* Since the ultimate goal was to correlate the human head-neck model with that of a non-human primate, the chief requirement was that the animals would make effective "human analogs," with comparable physical structure, particularly makeup and mass distribution, as well as biological function. At the outset, therefore, Ewing hoped to use several different species of non-human primates. Rhesus and Assam macaques, baboons, and chimpanzees all met much of the criteria and had a long history of use in biodynamic studies in the United States. But in addition to physiological similarities, availability and cost would also help determine which animals were used in experiments at NAMRL-D over the years.[58]

As he began to make these decisions regarding the logistical aspects of animal research, Ewing was fortunate to draw upon the expertise of staff members who had

*Author's note: Although non-human primate testing ended in the U.S. Navy in the early 1990s, the issue is still extremely sensitive for those veterinarians and animal neurosurgeons who participated in such studies and experiments at NAMRL-D and NBDL in the 1970s and 1980s, especially those now retired from government service and engaged in private practice. As a result, the surviving members of the former NBDL animal handling staff whom we contacted during the research phase of this project declined to participate, leaving large gaps in the recorded history of non-human primate research at Michoud, particularly concerning the issue of animal ethics and oversight boards.

come from Holloman Air Force Base, where researchers had worked with a wide variety of animal subjects, including chimpanzees and monkeys. One task was building accommodations for the animals. The facilities at Michoud, therefore, were based on drawings of the animal holding cages formerly used at Holloman Air Force Base. Since NAMRL-D intended to use several very different species of primates, Muzzy began constructing one area to contain rhesus and Assam macaques and another to hold both chimpanzees and baboons. These were not long-term accommodations. BUMED and ONR had already contracted with the Tulane Delta Regional Primate Center, under director Dr. Peter Gerone, to provide animals from its facility for Ewing's experiments. Instead, these were holding facilities where staff at NAMRL-D could safely prepare animals for experiments, in accordance with the standards of the American Association for Laboratory Animal Care.[59]

The Air Force provided not only the designs for the holding facilities but also the resident primate expert, assigning veterinarian Major Morris Eugene "Gene" Jessop, Jr., to be head of animal resources at NAMRL-D. An active duty officer since 1964, Jessop had earned a master's degree in medical science at Tulane and a doctorate in veterinary medicine at the University of Georgia. When Jessop arrived at Michoud in 1972, he immediately began working with Muzzy and private contractors to construct the track-side animal holding facility at Test Cell 4. Soon he was also coordinating closely with Dr. Gerone at Delta Regional to select the best test subject animals for the accelerator runs, and just like their human counterparts, the non-human primates underwent an exhaustive screening process including x-rays and blood work.[60]

Female primates were necessary to maintain the population of experimental animals, so at Delta Regional, as elsewhere, they were highly valuable and only used in experiments when necessary. In nearly all cases, males were chosen to participate in the acceleration experiments, and these had to be healthy and free from any physical deformities. From this pool, Jessop selected animals with a wide variety of sitting heights. To ensure these heights did not change during the period of experimentation, only mature adults were selected, and their body masses were managed through carefully planned diets so that their weights remained stable for testing. By 1973 Jessop had made the first macaque and chimpanzee selections from the population at Delta Regional. The primate center agreed to transport the animals to Michoud on an as-needed basis, where they spent at most a day at the holding facility and engaged in experimental runs before being returned to Delta Regional.[61]

Jessop and the NAMRL-D researchers had to take special precautions after assuming responsibility for the selected animal subjects, which behaved far less predictably than the human research volunteers (HRVs). Rhesus and Assam macaques, and especially chimpanzees, are powerful and cunning creatures that can be dangerous—and even deadly—to humans and to each other. Consequently, the primates were always anesthetized before they were taken out of their cages and directly handled. This ensured both the safety of the researchers and the animals during the experiments.

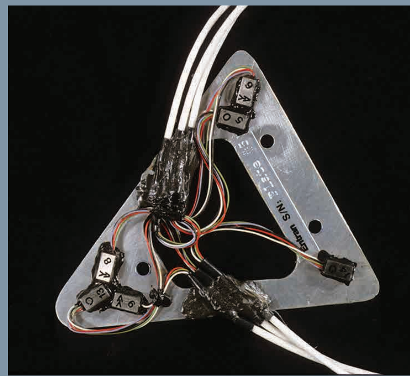
Once the animal handling procedures were implemented, Jessop then developed an experimental protocol that would produce animal data that was as reliable as that collected from human subjects. Specifically, he needed to return data quality comparable to that from the HRV tests so that it could then be scaled up to human level for analysis. Therefore, the instrumentation setups for HRVs and non-human primates had to be as similar as possible.[62]

Because of the physical size differences among the various species used during testing, the mounting configurations necessarily varied. Being the largest primates used for testing at NAMRL-D—and the closest to humans in size and physiology—chimpanzees were outfitted with stainless steel mouth mounts, custom built for each test subject from upper jaw castings taken while the animals were anesthetized. Once attached, these mounts were equipped with a variety of different T-plates to hold the instrumentation in place, comprised of the same six accelerometer and photo-target setups that were used for the HRV runs. These plates were also largely identical to those used with human volunteers, with the chimpanzees always anesthetized throughout their runs and their head positions maintained with external straps. The six accelerometers were later increased to nine, however, "for redundancy to capture all the motion," Bill Muzzy later explained.[63]

The T-plates were used freely and interchangeably so that different ranges of accelerometers could be used as different acceleration levels were applied during chimpanzee exposures. This system proved to be a reliable, dependable, and effective way of gathering impact acceleration data, so all three chimpanzees ultimately used at NAMRL-D were fitted with mouth mounts. "With the chimpanzees, we fitted the stainless steel mouth mount to them and just ran them in the lateral direction," said Muzzy, but "we never ran any chimps in the fore and aft direction." ECG activity was measured in the same fashion with animals and humans—electrodes were attached to shaven and sanitized points on their bodies.[64]

The method for capturing motion at T_1 on the anesthetized chimpanzees was the surgical implantation of mounting plates directly to that vertebra, through incisions on the backs of their necks, to which the transducer packages were then attached just before tests. After the experiments were complete, the T_1 mounts were always surgically removed from the chimpanzees, and the incisions were closed and left to heal properly before the animals were used again in further tests. Jessop and Muzzy built an operating room into the holding facility where these surgeries could be conducted.[65]

Since the mouths and vertebral columns of the macaques were much smaller than those of chimpanzees, they could not be fitted with the same mouth and T_1 mounts as their larger cousins. Instead, the researchers used "cranial pedestals," or skull caps, which were mounted to the top of subjects' heads (or calvarium). The pedestals held small "A-plate" devices, also designed by Muzzy and implanted by Jessop, which held the accelerometers in place as well as an array of electrodes that were placed directly on the rhesus macaques' brains. Due to the stability that this A-plate mounting system offered for the instrumentation packages, Thomas and Jessop declared it as "foolproof" for macaque runs. From a surgical point of view, Thomas considered the cranial pedestal and A-plate technology as "the most innovative part of the entire research program."[66]



"A-Plate" used to measure accelerations at T1 during non-human primate runs. (USAARL)

Following the pre-run surgery, the test subjects had to be restrained on the primate sled. This is where a significant challenge arose. Human subjects could be counted on to sit still in the sled—animal subjects could not. The first attempt to solve this problem involved use of a form-fitting fiberglass shell. First, technicians made a mold of each individual animal from clavicle to toes in the seated position. This was then cut into two halves like a clamshell. By placing the animal in the shell and locking the halves together, the animal would remain at rest with the head and neck unrestrained. It soon became evident, however, that the fiberglass shell caused a rise in body temperature, which influenced the physiological readings. The second attempt, devised by technician Ferris Bolin, was to produce a Kevlar body harness custom-tailored to fit each individual animal. The harnesses tightly restrained the torso, pelvis, and limbs and left only the head and neck unrestrained. This was the solution used in the majority of the rhesus macaque experiments.[67]

With this infrastructure in place, before NAMRL-D even had permission to call for human research volunteers, the first non-human primate tests began using rhesus macaques. On July 30, 1973, the team conducted three runs. Two more runs were conducted in August, again in a single day. There were good reasons to do the animal testing in blocks. For one thing, the heavy human volunteer sled had to be removed from the track and the lighter primate sled substituted. For another, surgical implantation of the instrumentation made it far more efficient to conduct multiple tests before removing the T_1 accelerometers. Nevertheless, partly due to the difficulties of devising an effective restraint system, there were still few animal runs in the early years—only forty-three between 1973 and 1975.[68]

Most of those runs were conducted using rhesus macaques. Compared to other non-human primates, they were more widely available, less costly to maintain, and easier to handle. They were also widely used in many other laboratory environments, so their anatomy, neuroanatomy, and neurophysiology were exhaustively documented. The lab did use three chimpanzees in a series of runs at relatively low acceleration levels to evaluate data acquisition and restraint systems, and data from twenty-six $+G_y$ chimpanzee runs were provided to the NHTSA under a $200,000 contract. Eight $-G_y$ chimpanzee runs were also carried out between 1974 and 1976. Those experiments only helped convince the team to settle on rhesus macaques—chimpanzees were larger, more expensive, stronger, and potentially more dangerous. They were also on the Endangered Species List during the mid-1970s. In any case, there was plenty of work to do in the rhesus macaque program. "We didn't want to run the chimps until we finished the work with the rhesus," said Thomas, and also "until we reached the points where we had neurophysiological limits on what we were doing in human subjects." For these reasons, chimpanzees were abandoned as test subjects after 1976, and baboons were never used.[69]

Under Jessop's guidance, NAMRL-D made every effort to minimize animal discomfort during its research, scrupulously adhering to guidelines laid down by the American Association for Laboratory Animal Care and administering analgesics to animals thought to be in pain. In the spring of 1973, even before animal testing began, Jessop got help with his expanding duties when Air Force Major Richard A. Boster was assigned to the lab. With a doctorate in veterinary medicine and a Ph.D. in physiology, Major Boster served as the head of the Animal Physiology Branch at NAMRL-D. Together, Jessop and Boster monitored all animals closely, making sure that they were not needlessly stressed at any point in the testing and keeping detailed medical records that could be cross-checked and correlated when necessary.[70]

From the start, however, it was understood that non-human primates would be sacrificed in the course of testing. In fact, once the living human response envelope was modeled and replicated in non-human primates, the next step was always going to be to exceed their survivability envelope in a carefully planned and clinical way. High G runs, dangerous to humans, began with Test LX0454 on October 3, 1974, with a single rhesus macaque designated Subject Number AO3146. The specific objective, Thomas and Jessop reported later, was to "identify the parameters of fatal injury and the approximate sled acceleration level of the injury." The point was not to simply find the threshold of fatal injury for non-human primates, but to determine through scaling these thresholds for humans so that sufficient models could be developed and applied in the design and manufacture of life-saving crash and ejection equipment for aviators. Subject Number AO3146 survived eight additional tests in January 1975 at increasing G levels, including 109 G and 107 G runs carried out on January 16 and January 21, respectively. However, a fatal separation at the atlanto-occipital joint occurred during a 158 G run on January 23. As a result, the researchers at NAMRL-D had their first measure of a potential injury threshold for the unrestrained head and neck in the $-G_x$ direction. But one fatal run would not be enough to confirm an injury threshold. More test runs, accounting for many more variables, were necessary.[71]

By the 1970s, animal testing had become highly controversial—after all, animals could not provide informed consent. But like all animal research scientists, the NAMRL-D leadership had fully engaged this and other ethical questions. Dr. Albert I. King, founder of the Department of Biomedical Engineering at Wayne State, tackled the issue in a volume edited by Thomas and Ewing. "The use of these surrogates can be justified if one assesses the situation with logic and utilizes commonly accepted values of human life. Animal life is taken by man for food and other necessary reasons. Surely the elimination of countless needless deaths on American highways is an essential reason for their use." In the end, King concluded, "The conviction that human life is of far greater value than any other life form is an essential aspect of biomedical research." Looking back a few years later, Ewing himself was quick to cite 51,000 accidental deaths due to vehicular trauma in 1978 alone as reason enough for this work. Along with his NAMRL-D staff and John Paul Stapp before him, Ewing strictly subscribed to the principles well articulated by King.[72]

Early Results

Even as they completed the laboratory and began implementing their long-term research agenda, the NAMRL-D staff members remained committed to sharing results that could make a difference in the shorter term. They were regular presenters at the annual Stapp Car Crash Conferences and NATO-sponsored Advisory Group for Aerospace Research and Development (AGARD) conferences. As information from the first human runs became available in 1974 and 1975, NAMRL-D researchers were able to provide some preliminary answers to problems that had bedeviled researchers in the field for some time. The questions were how changes in input force variables like rate of onset, the initial position of the head-neck prior to impact, and duration at peak acceleration influenced output dynamic response. These three variables in particular had been the subject of much discussion but little quantitative analysis. Papers given at the Stapp Car Crash Conferences in 1975 and 1976 addressed all three of them. The initial results, for example, indicated that the rate of onset variable had been overstated because restraint systems properly worn greatly attenuated its effect on dynamic response. Any acceleration applied to the sled, Thomas noted, "did not get directly transmitted to the human being because he was in a restraint system. So it was not a significant variable."[73]

NAMRL-D presenters did stress the importance of the other two variables in question: head-neck initial position and duration at peak acceleration. A presentation by Ewing and colleagues compared results from four different initial head-neck positions in $-G_x$ human runs—neck up, chin up; neck up, chin down; neck forward, chin up; and neck forward, chin down. They found that measures of angular velocity, acceleration, and torque depended entirely on the starting position of the head and neck. They also made clear that duration (defined as the amount of time spent above 75 percent of peak sled acceleration) was also an important factor in determining human response. Although in all cases the entire measured response occurred in less than one second, NAMRL-D researchers were able to break this into short and long durations and to show that these differences produced measurable differences in response. To show how quantitative data had been acquired and validated, Ed Becker and Gil Willems presented papers that reviewed the photographic and inertial data acquisition systems in use at NAMRL-D.[74]

One of the most important findings to come out of the early research at Michoud was that the ATDs then widely used in the automotive industry had serious limitations. Although the 1966 National Traffic and Motor Vehicle Act required automakers to put seat belts in all cars manufactured after January 1, 1968, public concern fell short of legislative action. Through the 1970s, not a single state required their use, and drivers and passengers generally ignored them. Indeed, contemporary studies found that, on average, only around 25 percent of those with safety belt-equipped cars actually used them. Further, public health officials and social activists charged that automakers were only making half-hearted efforts to raise awareness and were not developing sufficient buzzer systems to alert passengers that they were not wearing their seat belts. Even in cars equipped with these alert systems, however, there was little improvement in seat belt use.[75]

Ewing had an idea about what was going on. During the 1960s he had seen pilots reject new, safer helmets merely because they were less convenient, less comfortable, or simply unfamiliar. Automobile drivers and passengers were exhibiting the same behavior for undoubtedly the same reasons. Consequently, by the mid-1970s, as the potential for airbags to provide some measure of protection even without a seat belt became clearer, researchers became ever more determined to obtain good information about the relative value of each of these safety measures to change public minds—and that raised questions about how effective ATDs were.

Bill Muzzy and Leonard Lustick answered some of these questions at the 1976 Stapp Car Crash Conference. They had recently conducted an experiment at NAMRL-D to accurately compare dummy response to real human data and found troubling inconsistencies. For the experiment, the NAMRL-D staff had purchased several state-of-the-art General Motors Model Hybrid II ATDs, making sure to test different anthropomorphic sizes, and then outfitted them with the same instrumentation used on the human volunteers and put through identical $-G_x$ runs. The results were alarming, and Muzzy reported that "the kinematic response of the dummy is significantly different from that of human subjects in all variables measured." The critical result was that the linear and angular acceleration levels generated during the runs caused greater head-neck extension and flexion in human volunteers than in the Hybrid IIs. Although Muzzy and Lustick allowed that the Hybrid II appeared to be an improvement over older ATD models, it clearly did not mirror the response of human subjects to impact, and therefore its utility in crash-tests remained limited. This was the first major challenge issued by NAMRL-D to the research conducted by the automotive industry, and it would not be the last.[76]

Even in these early years, the lab's impact was felt far beyond the Navy and the automotive industry. For instance, NAMRL-D funded head-neck biodynamic modeling studies by Dr. Theodore Shugar at the Naval Civil Engineering Laboratory

(NCEL), Port Hueneme, California. NAMRL-D also underwrote electrode research for advanced telemetry units conducted by Dr. Sid Deutsch at Rutgers University.[77]

Additionally, Ewing acted as the personal emissary for the lab and its research. He was a regular speaker at seminars held throughout the New Orleans area, including those hosted by the Eighth Naval District, and regularly entertained visitors, including senior BUMED research and development officers. Some calls came from even farther afield. Dr. Norman H. Watts from the University of Sheffield's Department of Mechanical Engineering and squadron leader David C. Reader from the Royal Air Force Institute of Aviation Medicine took particular interest in the research at NAMRL-D. In 1973 Reader visited the laboratory to study the new horizontal accelerator and to consult with Muzzy.[78]

Not surprisingly, then, NAMRL-D contributed to nascent efforts to develop broader guidelines for impact injury research. Leading researchers in the United States formed the Ad Hoc Committee on Human Subjects for Biomechanical Research in 1973, with Dan Thomas serving as the chairman of the Subcommittee on Guidelines for the Comparison of Human and Human Analog Biomechanical Data. During the 1974 and 1975 meetings of the subcommittee, Thomas worked with Albert I. King, Rolf H. Eppinger, Robert P. Hubbard, Herbert M. Reynolds, and D. Hurley Robbins to develop a set of guidelines "considered to be the minimum requirement for comparability of databases." The development and use of laboratory, anatomical, instrumentation, and right-hand orthogonal coordinate-systems, as well as specification of initial conditions for each, made the list. In the course of their work, Thomas and his counterparts from the University of Michigan Highway Safety Research Institute, National Highway Traffic Safety Administration, Wayne State University, General Motors Research Laboratories, Renault-Peugeot, Volkswagen, Southwest Research Institute, and West Virginia University were, in essence, creating a common set of standards that would turn acceleration studies from a set of disparate and idiosyncratic efforts into a strong and unified field with shared tools and a common language.[79]

In just four short years, the young NAMRL-D was already making its presence felt in the field of acceleration impact research and injury prevention, within both the military and the public sector. It had thus far proven to be quite successful in engineering state-of-the-art impact acceleration test equipment and developing procedures for acquiring test subjects and then gathering data through carefully conducted, measured, and recorded experimental runs. Chan Ewing and his colleagues had high hopes for achieving even greater results and prominence in the years to come for their quickly maturing program at Michoud, as they strove to fulfill Ewing's cherished dream of building a mathematical model of the human dynamic response to impact acceleration. Although they were aiming high and ultimate success appeared to be just over the horizon, the lab would ultimately come up short and at great cost to Ewing and his researchers, as NAMRL-D reached independent command status but then faltered in the next stage of its existence.

CHAPTER THREE ENDNOTES

[1] James Rife Oral History Interview with Daniel J. Thomas, July 12, 2016, 48-49; James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 19.

[2] James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 35.

[3] James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 3, 13; Email from Daniel J. Thomas to William Thomas, dated March 1, 2016; Email from Daniel J. Thomas to James Rife, dated November 22, 2016; David H. Glaister, ed., "A Catalogue of Current Impact Devices," AGARD Report no. 658 (London: Technical Editing and Reproduction, Ltd., 1977), vii-viii; C. L. Ewing, D. J. Thomas, and L. Lustick, "Multi-Axis Dynamic Response of the Human Head and Neck to Impact Acceleration," *AGARD Conference Proceedings no. 253: Models and Analogues for the Evaluation of Human Biodynamic Response, Performance, and Protection* (London: Technical Editing and Reproduction, Ltd., 1979), A5-4; Paul L. Majewski, "Naval Biodynamics Lab," *U.S. Navy Medicine* 72 (August 1981): 4; Allison L. Schmidt, Alexandria E. Austermann, Kimberly B. Vasquez, Barry S. Shender, and Valeta Carol Chancey, "Establishing the Biodynamics Data Resource (BDR): Human Volunteer Impact Acceleration Research Data in the BDR," USAARL Report no. 2010-014 (Fort Rucker, AL: United States Army Aeromedical Research Laboratory [hereinafter USAARL], Warfighter Protection Division, October 2009), 4.

[4] James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 9, 28; Email from Daniel J. Thomas to William Thomas, dated March 1, 2016.

[5] James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 9, 28; C. L. Ewing, D. J. Thomas, L. Lustick, W. H. Muzzy III, G. Willems, and P. L. Majewski, "The Effect of Duration, Rate of Onset, and Peak Sled Acceleration on the Dynamic Response of the Human Head and Neck," *Proceedings of the Twentieth Stapp Car Crash Conference* (Warrendale, PA: Society of Automotive Engineers [hereinafter SAE], 1976), 4; C. L. Ewing and D. J. Thomas, "Torque versus Angular Displacement Response of Human Head to $-G_x$ Impact Acceleration," *Proceedings of the Seventeenth Stapp Car Crash Conference* (New York: SAE, 1973), 311-312; C. L. Ewing, D. J. Thomas, L. Lustick, E. Becker, G. Willems, and W. H. Muzzy III, "The Effect of the Initial Position of the Head and Neck on the Dynamic Response of the Human Head and Neck to $-G_x$ Impact Acceleration," *Proceedings of the Nineteenth Stapp Car Crash Conference* (Warrendale, PA: SAE, 1975), 491; R. C. Grunsten, Norman S. Gilbert, and Stephen V. Mawn, "The Mechanical Effects of Impact Acceleration on the Unconstrained Human Head and Neck Complex," *Contemporary Orthopaedics* 18, no. 2 (February 1989): 200; NAMRL-D, "Information for Volunteers in the Impact and Vibration Acceleration/Deceleration Research and Development Program," dated January 10, 1973, 1, located at NARA-CP, RG 52, Naval Medical Research and Development Command [hereinafter NMRDC] Project Files and Reports, 1967-1982, Entry UD-04W1, Box 10, F: "NBDL MF58.524.02E-0001 (NEW)."

[6] James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 46; Ewing et al., "The Effect of Duration, Rate of Onset, and Peak Sled Acceleration on the Dynamic Response of the Human Head and Neck," *Proceedings of the Twentieth Stapp Car Crash Conference*, 4; Memorandum from William Muzzy, Chief, Engineering Division, to Mechanical Engineer Technician – Mr. Roger Black, dated January 15, 1973, Subj: "Sled Slipper Material Evaluation," located in the FY 1973 Reading Files, Neel Aeromedical Center, USAARL.

[7] James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 23.

[8] James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 3, 8-10; Ewing et al., "The Effect of Duration, Rate of Onset, and Peak Sled Acceleration on the Dynamic Response of the Human Head and Neck," *Proceedings of the Twentieth Stapp Car Crash Conference*, 4.

[9] R. E. Kinneman, Jr., Briefing Report on Visit to NAMRL Detachment, New Orleans, 10/31-11/2/72," dated December 15, 1972, NARA-CP, RG 52, NMRDC Project Files and Reports, 1967-1982, Entry no. UD-04W1, Box 10, F: "NBDL MF58.524.02E-0001 (NEW)"; Memorandum from J. W. Johnson (Code 49-7114) to Code 71, dated November 6, 1972, Subj: "Visit to Naval Aerospace Medical Research Laboratory Detachment, Michoud Station, LA; report of," NARA-CP, RG 52, NMRDC Project Files and Reports, 1967-1982, Entry no. UD-04W1, Box 10, F: "NBDL MF58.524.02E-0001 (NEW)."

[10] James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 21-22; NBDL Run Index located at the Neel Aeromedical Center, USAARL. For information on early test dummies, see Margalit Fox, "Samuel Alderson, Crash-Test Dummy Inventor, Dies at 90," *New York Times*, February 18, 2005, A25; North Atlantic Treaty Organization (NATO), Advisory Group for Aerospace Research & Development, "Anthropomorphic Dummies for Crash and Escape System Testing," AGARD Advisory Report 330 (Quebec: Canada Communication Group, July 1996); Jessica Gall, Tim Michnay, David Winkelbauer, and Suzanne Phillips, "The Anthropomorphic Test Device (ATD) or Test Dummy," *MGA News* 18, no. 4 (March 2004).

[11] Memorandum from Bill Muzzy, Chief, Engineering Division, to Officer in Charge, NAMRL Detachment, dated January 26, 1973, Subj: "Weekly Status Report – 22 Jan thru 26 Jan 1973," located in the FY 1973 Reading Files, Neel Aeromedical Center, USAARL; C. L. Ewing et al., "The Effect of the Initial Head Position of the Head and Neck on the Dynamic Response of the Human Head and Neck to $-G_x$ Impact Acceleration," 492-493; Memorandum from William H. Muzzy III, Chief, Engineering Department, to Officer in Charge, NAMRL Detachment, dated January 12, 1973, Subj: "Engineering Work Load," located in the FY 1973 Reading Files, Neel Aeromedical Center, USAARL.

[12] Memorandum from Gil Willems, Chief, Bioinstrumentation Division, to Officer in Charge, NAMRL Detachment, dated March 17, 1972, Subj: "Equipment Requirements for Bioinstrumentation Division," located in the FY 1972 Reading Files, Neel Aeromedical Center, USAARL; James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 3, 5.

[13] William Thomas Oral History Interview with Daniel J. Thomas, March 8, 2016, 11-12, 28; Edward B. Becker, "A Photographic Data System for Determination of 3 Dimensional Effects of Multiaxis Impact Acceleration on Living Humans," *Proceedings of the Society of Photo-Optical Instrumentation Engineers* 57 (1975): 69; Channing L. Ewing, "Injury Criteria and Human Tolerance for the Neck," in *Aircraft Crashworthiness,* ed. K. Saczalski, G. T. Singley III, W. D. Pilkey, and R. L. Huston (Charlottesville, VA: University of Virginia Press, 1975), 8; Channing L. Ewing, "Biodynamics: What are the Problems Presently being Faced and What is the Progress in the Past Two Years [abstract]," *Presentation to the Committee on Hearing, Bioacoustics, and Biomechanics* (1981), 2. Ewing's presentation focused on biodynamics problems faced by the Navy. Col. Stanley C. Knapp, USAARL, followed Ewing with a presentation focused on the Army side. Neither presentation was published in the official proceedings, but an abstract of Ewing's is available at the Neel Aeromedical Center, USAARL.

[14] Will Thomas Oral History Interview with Daniel J. Thomas, March 8, 2016, 44-47; E.

Becker and G. Willems, "An Experimentally Validated 3-D Inertial Tracking Package for Application in Biodynamic Research," *Proceedings of the Nineteenth Stapp Car Crash Conference* (Warrendale, PA: SAE, 1975), 899-906.

[15] D. J. Thomas, C. L. Ewing, P. L. Majewski, and N. S. Gilbert, "Clinical Medical Effects of Head and Neck Response During Biodynamic Stress Experiments," *AGARD Conference Proceedings no. 267: High-Speed, Low-Level Flight Aircrew Factors* (London: Technical Editing and Reproduction, Ltd., 1980), 15-3.

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[17] Email from Daniel J. Thomas to James Rife, dated September 19, 2016; Email from Daniel J. Thomas to William Thomas, dated April 13, 2016; William Thomas Oral History Interview with Daniel J. Thomas, March 8, 2016, 18-19; Working Memorandum from G. H. Sloan to Captain C. Ewing, Dr. A. B. Callahan, Dr. D. Thomas, and Dr. A. L. Slafkosky, dated January 29, 1971, Subj: "3-D Data Simulation – Memo B – Coordinate System Conventions and Misalignment Corrections." Copies of the working memos between QEI, Ewing, and Thomas may be found in the reading files at the Neel Aeromedical Center, USAARL.

[18] E. Becker and G. Willems, "An Experimentally Validated 3-D Inertial Tracking Package for Application in Biodynamic Research," 906, 909.

[19] Channing L. Ewing and Daniel J. Thomas, "Human Head and Neck Response to Impact Acceleration," NAMRL Monograph 21 (Pensacola, FL: NAMRL, 1972), 9-10.

[20] William H. Muzzy III and Arthur M. Prell, "Targets for Three-Dimensional (3-D) Tracking of Human Impact Test Subjects," *Proceedings of the International Society for Optical Engineering* 291 (1981): 106-108.

[21] Edward B. Becker, "A Photographic Data System for Determination of 3-Dimensional Effects of Multiaxes Impact Acceleration on Living Humans," 70.

[22] Edward B. Becker, "A Photographic Data System for Determination of 3-Dimensional Effects of Multiaxes Impact Acceleration on Living Humans," 70.

[23] Edward B. Becker, "A Photographic Data System for Determination of 3-Dimensional Effects of Multiaxes Impact Acceleration on Living Humans," 71; Memorandum from William Anderson, Leading Electronics Engineer, to Officer in Charge, NAMRL Detachment, dated April 3, 1974, Subj: "Data Acquisition System Documentation for Photographic Data," FY 1974 Reading Files, Neel Aeromedical Center, USAARL; Ed Becker, Memorandum for File, dated July 16, 1976, Subj: "Camera Locating Routine," FY 1976 Reading Files, Neel Aeromedical Center, USAARL.

[24] Edward B. Becker, "A Photographic Data System for Determination of 3-Dimensional Effects of Multiaxes Impact Acceleration on Living Humans," 70; William Thomas Oral History Interview with Daniel J. Thomas, March 8, 2016, 10-11.

[25] James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 5, 7; Memorandum from Bill Muzzy, Chief, Engineering Division, to Officer in Charge, NAMRL Detachment, dated December 5, 1975, Subj: "Film Processed through Eglin AFB," FY 1975 Reading Files, Neel Aeromedical Center, USAARL; Memorandum from Bill Muzzy, Chief, Engineering Division, to Scientific Director, dated September 1, 1977, Subj: "Black & White Film Processing

Cost – FY 78," FY 1977 Reading Files, Neel Aeromedical Center, USAARL.

[26] Edward B. Becker, "A Photographic Data System for Determination of 3-Dimensional Effects of Multiaxes Impact Acceleration on Living Humans," 70.

[27] Letter from Raphael F. Smith, M.D. Cardiology Division, Vanderbilt University, Department of Medicine, School of Medicine, to Officer-in-Charge, NAMRL-D, Attn: Commander Majewski, dated August 4, 1972, FY 1972 Reading Files, Neel Aeromedical Center, USAARL; P. L. Majewski, T. J. Borgman, Jr., D. J. Thomas, and C. L. Ewing, "Transient Intraventricular Conduction Effects Observed During Experimental Impact in Human Subjects," *AGARD Conference Proceedings no. 253: Models and Analogs for the Evaluation of Human Biodynamic Response, Performance and Protection* (London: Technical Editing and Reproduction, Ltd., 1979), A6-2; D. J. Thomas et al., "Clinical Medical Effects of Head and Neck Response during Biodynamic Stress Experiments," 15-3.

[28] Letter from John K. Cullen, Jr., to Dr. Leonard Lustick, Department of Psychiatry and Neurology, Tulane University School of Medicine, dated January 13, 1969, located in the FY 1969 Reading Files, Neel Aeromedical Center, USAARL; Memorandum from Chief, Instrumentation Division, to Officer in Charge, NAMRL Detachment, dated February 13, 1973, Subj: "Applied Mathematician Position – GS-13," FY 1973 Reading Files, Neel Aeromedical Center, USAARL; Memorandum from Ed Becker, Assistant for Inertial Instrumentation, to Officer in Charge, NAMRL Detachment, dated April 6, 1973, Subj: "Mathematician," FY 1973 Reading Files, Neel Aeromedical Center, USAARL; Werner Goldsmith, "Biomechanical Activities at Some American and European Institutions – II," *Journal of Biomechanics* 2, no. 4 (1969): 470; Bernard Saltzberg, Leonard S. Lustick, and Robert G. Heath, "Detection of Focal Depth Spiking in the Scalp EEG of Monkeys," *Electroencephalography and Clinical Neurophysiology* 31 (1971): 327-333; L. S. Lustick and R. G. Heath, "Comparative Study of Intracranial Electrodes for Stimulation and Recording [abstract]," *Biophysics Journal* 11, Supplement (1971): 165a; Bernard Saltzberg and Leonard S. Lustick, "Signal Analysis: An Overview of Electroencephalographic Applications," in *Brain Function and Malnutrition: Neurophysiological Methods of Assessment*, ed. J. W. Prescott, M. S. Read, and D. B. Courin (New York, London, Chichester, Sidney, and Toronto: John Wiley and Sons, 1975), 129-140; Nick Ravo, "Robert G. Heath, 84, Researcher Into the Causes of Schizophrenia," *The New York Times*, September 25, 1999.

[29] Letter from Captain Lloyd F. Miller, Director, Research Division, Bureau of Medicine and Surgery, to Mr. John A. Edwards, Acting Associate Administrator for Research & Development, Research Institute, NHTSA, dated June 17, 1971, located at NARA-CP, RG 52, Entry no. UD-WW 14, Historical and Reference Files, 1942-1982, Box 3, F: "3900 Human Volunteers."

[30] A copy of the signed interagency agreement is attached to a letter from A. F. Glagola, Contract Specialist, NHTSA, U.S. Department of Transportation, to Captain N. W. Allebach, Naval Aerospace Medical Research Laboratory, dated April 24, 1972, Subj: "Enclosed executed copy of Interagency Agreement DOT-HS-187-2-295," FY 1972 Reading Files, Neel Aeromedical Center, USAARL; Letter from John E. Lahiff, Performance Specifications Group, Crash Test Dummy Subcommittee ("Address Writer at General Motors Proving Grounds"), to Capt. Channing L. Ewing, MC, USN, Commander, Naval Aerospace Medical Dept., Michoud Station, NASA Missile Facility, dated July 15, 1971, Subj: "Request for Neck Data," letter located in the FY 1971 Reading Files, Neel Aeromedical Center, USAARL.

[31] Letter from Major Eugene H. Blackstone, M.D., to Captain Channing Ewing, MC, USN, OIC, NAMRL Detachment, dated October 6, 1971; Letter from Lieutenant Colonel Arlie D. Price, Acting Commander, USAARL-AM, to Commanding Officer, NAMRL, NAMC, ATTN: CPT Channing L. Ewing, dated March 19, 1971, Subj: "Acceleration Project," both letters are located in the FY 1971 Reading Files, Neel Aeromedical Center, USAARL; Memorandum from W. R. Anderson to Capt. C. L. Ewing, dated March 30, 1972, Subj: "Status report of physiological data and software from WSU work," located in the FY 1972 Reading Files, Neel Aeromedical Center, USAARL. For some general discussion of the Army's interest in the research at NAMRL-D and the funding given to the Navy for joint medical research projects, see the U.S. Army Medical Research and Development Command [hereinafter USARMRDC] Program Data Sheets located at NARA-CP, RG 112, USARMRDC, Ft. Detrick, MD, Comptroller Division, Program Development Files, FY 1967-1975, Entry no. A1-1038, Box no. 6.

[32] Channing L. Ewing and Daniel J. Thomas, "Human Head and Neck Response to Impact Acceleration," 128.

[33] See correspondence located at the Neel Aeromedical Center, USAARL. Examples include, Assistant Dean, John L. Martinez to Captain Channing Ewing, dated April 28, 1972; W. Anderson to Officer in Charge, NAMRL Detachment, dated May 4, 1972, Subj: "Technical Assistance at Tulane University"; W. Anderson to Officer in Charge, NAMRL Detachment, dated June 1, 1972, Subj: "Initiation of Head-Neck Modeling Support from Tulane University"; Robert L. Drake to Captain Channing Ewing, dated June 6, 1972; Daniel J. Thomas to Capt. C. L. Ewing, dated June 6, 1972, Subj: "Modeling by Beck and Drake"; Robert L. Drake, Professor, to Captain Channing Ewing, dated June 13, 1972; Robert L. Drake, Professor, to Captain Channing Ewing, dated June 26, 1972; Assistant Dean John L. Martinez to Captain Channing Ewing, dated June 30, 1972; Robert L. Drake, Professor, to Captain Channing Ewing, dated July 5, 1972; Robert L. Drake, Professor, to Captain Channing Ewing, dated July 10, 1972; Robert L. Drake, Professor, to Captain Channing Ewing, dated August 5, 1972.

[34] William Thomas Oral History Interview with Daniel J. Thomas, March 8, 2016, 5, 45; Channing L. Ewing and Daniel J. Thomas, "Human Head and Neck Response to Impact Acceleration," 1.

[35] Walker et al. found that mean head-neck weight was just over 13 lbs., with the head accounting for 9.5 lbs. and the neck 3.5 lbs. Leon B. Walker, Jr., Edward H. Harris, and Uwe R. Pontius, "Mass, Volume, Center of Mass, and Mass Moment of Inertia of Head and Head and Neck of Human Body," *Proceedings of the Seventeenth Stapp Car Crash Conference* (Warrendale, PA: SAE, 1973), 525; Letter from Captain M. D. Courtney, Commanding Officer, NAMI, to Hon. F. Edward Hébert, House of Representatives, Washington, D.C., dated July 6, 1971, NARA-CP, RG 52, General Correspondence of the Administrative Division, 1952-1971, Entry A1-1004, Box 1964, F: "EE14/NASA-1970."

[36] Edward B. Becker, "Measurement of Mass Distribution Parameters of Anatomical Segments," *Proceedings of the Sixteenth Stapp Car Crash Conference* (Warrendale, PA: SAE, 1972), 160-185; Email from Edward Becker to James Rife, dated November 18, 2016; Edward B. Becker, "United States Patent: 3841148 – Tetrahedral Stereotaxic Jig," October 15, 1974. There is some discussion of the findings of the data from studies by Walker, Harris, Pontius, and, separately, by Becker, in Channing L. Ewing and Daniel J. Thomas, "Human Head and Neck Response to Impact Acceleration," 52-55, but the numbers of cadavers studied by both

groups appear to be misreported. The mistakes might be attributed to the fact that the findings of Becker and of the Tulane group had not yet been formally published at the time of the composition of Ewing and Thomas's monograph.

[37] Channing L. Ewing and Daniel J. Thomas, "Human Head and Neck Response to Impact Acceleration," 16-23.

[38] See letters from Captain R. C. McDonough, Commanding Officer, Naval Aerospace Medical Institute, to Officer in Charge [N. W. Allebach], Naval Aerospace Medical Research Laboratory, dated January 9, 1974, Subj: "Approval of linear accelerator for use with human subjects," and N. W. Allebach, Officer in Charge, Naval Aerospace Medical Research Laboratory, to Head, Bioengineering Department [Ewing], dated January 9, 1974, Subj: "Approval of linear accelerator for use with human subjects," FY 1974 Reading Files, Neel Aeromedical Center, USAARL; for evidence of the dummy runs, see the run index located at the Neel Aeromedical Center, USAARL.

[39] James Rife Oral History Interview with Daniel J. Thomas, July 12, 2016, 5-6; Letter from Jack R. Schmidt, Ph.D., Acting Director, Research Division, Code 71, BUMED, to the Secretary of the Navy, dated August 16, 1973, Subj: "Permission to utilize human volunteers in acceleration/deceleration experiments, request for," NARA-CP, RG 52, Entry UD-WW 5, General Correspondence, 1972-1976, Box 17, F: "6420."

[40] Research and Technology Work Unit Summary, "Development of a Means for Protecting Amphibious Warfare Casualties from Vehicular Vibration," dated July 1, 1971, located at NARA-CP, RG 52, NMRDC Project Files and Reports, 1967-1982, Entry no. UD-04W1, Box 10, F: "NBDL MF58.524.02E-0001 (NEW)." BUMED correspondence files show that Ewing submitted the proposal to do vibration research on June 21, 1971. See Letter from Capt. C. L. Ewing, Officer-in-Charge, NAMRL-D, to Chief, BUMED (Code 7114 [J. H. Stover, Jr.]), dated June 21, 1971, Subj: "Research and Development Proposal, forwarding of," NARA-CP, RG 52, NMRDC Project Files and Reports, 1967-1982, Entry no. UD-04W1, Box 10, F: "NBDL MF58.524.02E-0001 (NEW)." The proposal itself is missing.

[41] Letter from Captain Lloyd F. Miller, Chief, BUMED, to Officer in Charge, NAMRL, Pensacola, dated February 16, 1972, Subj: "Permission to utilize Human Volunteers in acceleration/deceleration experiments; request for," Department of Energy, OpenNet database, https://www.osti.gov/opennet/detail.jsp?osti-id=16005657&full-text=%22ADO%2043-12X%22&sort-by=&page-num=1&table-length=25&order-by=desc&sort-by=.

[42] NAMRL-D, "Information for Volunteers in the Impact and Vibration Acceleration/Deceleration Research and Development Program," dated January 10, 1973, located at NARA-CP, RG 52, NMRDC Project Files and Reports, 1967-1982, Entry UD-04W1, Box 10, F: "NBDL MF58.524.02E-0001 (NEW)"; Research and Technology Work Unit Summary, "Development of a means for protecting naval warfare casualties from vehicular vibration," dated July 1, 1974, located at NARA-CP, RG 52, NMRDC Project Files and Reports, 1967-1982, Entry no. UD-04W1, Box 10, F: "NBDL MF58.524.02E-0001 (NEW)"; Letter from Chief, BUMED, to Chief of Naval Operations, dated March 18, 1973, Subj: "Establishment of Military Billets in Support of ADO 43-12X and ADO 43-11X; request for," located at NARA-CP, RG 52, Historical and Reference Files, 1942-1982, Entry no. UD-WW 14, Box 3, F: "3900 Human Volunteers"; Letter from Secretary of the Navy to Commanding Officer, Naval Aerospace Medical Center, dated December 7, 1973, Subj: "Authorization to use human volunteer subjects in impact acceleration and vibration acceleration experiments," 1973 Reading Files,

Neel Aeromedical Center, USAARL; Letter from C. J. Boyd, Commander, Naval Sea Systems Command, to the Secretary of the Navy, dated July 2, 1974, Subj: "Permission to utilize human volunteers in vibration acceleration tests; request for," Department of Energy, OpenNet database, https://www.osti.gov/opennet/detail.jsp?osti-id=16005751&full-text=%22Channing%20L.%20Ewing%22&page-num=1&table-length=25&order-by=desc&sort-by=.

[43] Letter from N. W. Allebach, Officer in Charge, NAMRL, to Chief of Naval Operations, dated December 13, 1972, Subj: "Establishment of Military Billets in Support of ADO 43-12X and ADO 43-11X; request for," Department of Energy, OpenNet database, https://www.osti.gov/opennet/detail.jsp?osti-id=16010017&author=ALLEBACH,N.W.&sort-by=&page-num=1&table-length=25&order-by=asc&sort-by=; Letter from Secretary of the Navy to Commanding Officer, Naval Aerospace Medical Center, dated December 7, 1973, Subj: "Authorization to use human volunteer subjects in impact acceleration and vibration acceleration experiments," 1973 Reading Files, Neel Aeromedical Center, USAARL; Letter from Secretary of the Navy to Commanding Officer, Naval Aerospace Medical Center, dated December 7, 1973, Subj: "Authorization to use human volunteer subjects in impact acceleration and vibration acceleration experiments," 1973 Reading Files, Neel Aeromedical Center, USAARL; Letter from C. J. Boyd, Commander, Naval Sea Systems Command, to the Secretary of the Navy, dated July 2, 1974, Subj: "Permission to utilize human volunteers in vibration acceleration tests; request for," Department of Energy, OpenNet database, https://www.osti.gov/opennet/detail.jsp?osti-id=16005751&full-text=%22Channing%20L.%20Ewing%22&page-num=1&table-length=25&order-by=desc&sort-by=; D. J. Thomas, P. L. Majewski, C. L. Ewing, and N. S. Gilbert, "Medical Qualification Procedures for Hazardous-Duty Aeromedical Research," *AGARD Conference Proceedings no. 231 on Prospective Medicine Opportunities in Aerospace Medicine* (London: Technical Editing and Reproduction, Ltd., 1978), A3-2.

[44] D. J. Thomas et al., "Medical Qualification Procedures for Hazardous-Duty Aeromedical Research," A3-2 – A3-4; Terie Hynish, "Lab studies human response to impact," *Crescent City Currents*, December 4, 1987; Memorandum from Daniel J. Thomas, M.D., Human Research Division, to C. L. Ewing, Capt., MC, USN, Officer in Charge, dated January 11, 1974, Subj: "Human Experimentation," 1974 Reading Files, Neel Aeromedical Center, USAARL; D. J. Thomas et al., "Medical Qualification Procedures for Hazardous-Duty Aeromedical Research," A3-2.

[45] William Thomas Oral History Interview with Daniel J. Thomas, March 8, 2016, 12-13; C. L. Ewing et al., "Multiaxis Dynamic Response of the Human Head and Neck to Impact Acceleration," A5-2. Anthropometric measurements taken by Clauser became the focus of two unpublished reports. The anthropometric data from the Wayne State project appeared in C. Clauser, "An Inquiry into the Ranges of Values Existing in the U.S. Navy Acceleration Study," 6570th Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, June 17, 1969. Measurements taken of the volunteers at NAMRL-D appeared in C. Clauser and K. Kennedy, "An Inquiry into the Ranges of Values Existing in the U.S. Navy Acceleration Study," 6570th Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, April 1975.

[46] Channing L. Ewing and Daniel J. Thomas, "Human Head and Neck Response to Impact Acceleration," 50-54.

[47] E. Becker, "Stereoradiographic Measurements for Anatomically Mounted Instruments," *Proceedings of the Twenty-First Stapp Car Crash Conference* (Warrendale, PA: SAE, 1977), 477-496; James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 4-5, 15-16.

[48] P. L. Majewski et al., "Transient Intraventricular Conduction Defects Observed during Experimental Impact in Human Subjects," A6-2 – A6-3; D. J. Thomas et al., "Medical Qualification Procedures for Hazardous-Duty Aeromedical Research," A3-9; Email from Daniel J. Thomas to James Rife, dated September 19, 2016; Channing L. Ewing and Daniel J. Thomas, "Human Head and Neck Response to Impact Acceleration," 50-66.

[49] James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 5, 31; James Rife Oral History Interview with Art Prell, August 18, 2016, 3-4.

[50] Reporting in 1975, NAMRL-D researchers noted that the "same seat as that previously used at Wayne State University and a restraint system of the same geometry with wider straps" was used in human $-G_x$ experiments at NAMRL-D. See C. L. Ewing et al., "The Effect of the Initial Position of the Head and Neck on the Dynamic Response of the Human Head and Neck to $-G_x$ Impact Acceleration," 491; C. L. Ewing et al., "The Effect of Duration, Rate of Onset, and Peak Sled Acceleration on the Dynamic Response of the Human Head and Neck," 4; James Rife Oral History Interview with Daniel J. Thomas, July 12, 2016, 54-55; James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 22-26.

[51] P. L. Majewski et al., "Transient Intraventricular Conduction Defects Observed during Experimental Impact in Human Subjects," A6-2; NBDL Run Index, Neel Aeromedical Center, USAARL.

[52] Memorandum from Scott Morrell, Assistant for Physiological Instrumentation, to Chief, Human Research Division, dated May 24, 1973, Subj: "Count-down from subject call-up (after subject is mounted on sled)," FY 1973 Reading Files, Neel Aeromedical Center, USAARL; William Thomas Oral History Interview with Daniel J. Thomas, March 8, 2016, 36-38; James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 8.

[53] Terie Hynish, "Lab studies human response to impact," *Crescent City Currents*, December 4, 1987.

[54] Research and Technology Work Unit Summary, "Human Head and Neck Response to Multi-Axis Accelerations During Military Escape," dated July 1, 1974, NARA-CP, RG 52, Historical Records, Projects, and Reports Files, 1942-1980, Entry no. UD-04W2, Box 3, F: "R&D Technical Reports Annual Progress for FY75"; Douglas W. Call, James F. Palmer, and Channing L. Ewing, "Human Head and Neck Response to Multi-Axis Accelerations During Military Parachuting," *Preprints of the Annual Aerospace Medical Association Meeting* (San Francisco, CA, May 1, 1975), 112-113; R. E. Kinneman, Jr., "Briefing Report on Visit to NAMRL Detachment, New Orleans, 10/31-11/2/72," dated December 15, 1972, NARA-CP, RG 52, NMRDC Project Files and Reports, 1967-1982, Entry no. UD-04W1, Box 10, F: "NBDL MF58.524.02E-0001 (NEW)"; NBDL Run Index, Neel Aeromedical Center, USAARL. Significant evidence supports the contention that the first human runs at NAMRL-D were done with parachutists from the Naval Air Recovery Facility (NARF). NAMRL-D did conduct baseline runs on the horizontal accelerator for NARF, and it is known that NARF provided two volunteers for it. Also, the volunteer that participated in the first run was thirty-one years old—much older than the average volunteers recruited by NAMRL-D. Comparison of volunteer personal information in two letters from 1974 verifies the story. If further evidence is needed, it may be found in the fact that the two earliest volunteers only participated in a few runs and then disappeared entirely from the run indexes. Lastly, and importantly, Daniel J. Thomas et al., "Medical Qualification Procedures for Hazardous-Duty Aeromedical Research," does not mention recruitment of volunteers prior to February 1974. For the evidentiary corre-

spondence, see letter from Gilbert Willems, Chief, Instrumentation Division, to Dr. D. Call, Naval Air Recovery Facility, El Centro, CA, dated May 17, 1974, and memorandum from Bill Muzzy, Chief, Engineering Division, to Officer in Charge, NAMRL Detachment, dated February 11, 1974, Subj: "12" Hyge Accelerator Incident – Safety Pin Malfunction," both located in the FY 1974 Reading Files, Neel Aeromedical Center, USAARL.

[55] Douglas W. Call et al., "Human Head and Neck Response to Multi-Axis Accelerations During Military Parachuting," 112-113; William Thomas Oral History Interview with Daniel J. Thomas, March 8, 2016, 6; Research and Technology Work Unit Summary, "Human Head and Neck Response to Multi-Axis Accelerations During Military Parachuting," NARA-CP, RG 52, Historical Records, Projects, and Reports Files, 1942-1980, Entry no. UD-04W2, Box 3, F: "R&D Technical Reports Annual Progress for FY75."

[56] NBDL Run Index, Neel Aeromedical Center, USAARL; Channing L. Ewing, "Injury Criteria and Human Tolerance for the Neck," 8.

[57] William Thomas Oral History Interview with Daniel J. Thomas, March 8, 2016, 40; Email from Daniel J. Thomas to James Rife, dated November 22, 2016; NBDL Run Listing, Neel Aeromedical Center, USAARL; NBDL Run Listing, Neel Aeromedical Center, USAARL. In 1974, 289 human experiments were set up—seven of these were aborted. In 1975 there were 421 human experiments, including 17 aborts.

[58] Daniel J. Thomas and M. Eugene Jessop, "Experimental Head and Neck Injury," in *Impact Injury of the Head and Spine*, ed. C. L. Ewing, D. J. Thomas, A. Sances, and S. J. Larson (Springfield, Ill.: Charles C. Thomas, 1983), 191.

[59] James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 1-2; James Rife Oral History Interview with Art Prell, August 18, 2016, 6-7; Memorandum from M. Eugene Jessop, Jr., Major, USAF, VC, Chief, Animal Resources Branch, to Capt. C. L. Ewing, MC, USN, Officer in Charge, dated November 16, 1972, Subj: "Telecom with Lt/COL Ralph Zeigler re: Assignment of Veterinary Officers to NAMRL Detachment," NARA-CP, RG 52, NMRDC Project Files and Reports, 1967-1982, Entry UD-04W1, Box 10, F: "NBDL MF58.524.02E-0001 (NEW)"; Email from Daniel J. Thomas to James Rife, dated November 22, 2016.

[60] U.S. Air Force, Office of the Directorate of Personnel Program Actions, *Air Force Register, Volume 1: Active Lists* (Washington, D.C.: Government Printing Office, 1968), 604; http://www.riverridgeveterinaryclinic.com/AboutUs/DrGeneJessop.aspx; http://www.zoominfo.com/p/Gene-Jessop/1045572117; Memorandum from Major M. Eugene Jessop, Jr., USAF, VC, Chief, Animal Resources Branch, to Capt. C. L. Ewing, MC, USN, Officer in Charge, dated November 16, 1972, Subj: "Telecon with Lt/COL Ralph Ziegler re: Assignment of Veterinary Officers to NAMRL Detachment," NARA-CP, RG 52, NMRDC Project Files and Reports, 1967-1982, Entry no. UD-04W1, Box 10, F: "NBDL MF58.524.02E-0001 (NEW)"; Letter from Captain M. D. Courtney, MC, USN, Commanding Officer, NAMI, to Rep. F. Edward Hébert, dated July 6, 1971, located at NARA-CP, RG 52, General Correspondence of the Administrative Division, 1975-1971, Entry no. A1-1004, Box 1964, F: "EE14/NASA-1970."

[61] Daniel J. Thomas and M. Eugene Jessop, "Experimental Head and Neck Injury," 191. There are two exceptions worthy of mention in regard to the gender of the animals. Two rhesus monkeys later used at the lab were old adult females that were no longer capable of breeding.

[62] Daniel J. Thomas and M. Eugene Jessop, "Experimental Head and Neck Injury," 191-192.

[63] C. L. Ewing, D. J. Thomas, L. Lustick, G. C. Willems, W. H. Muzzy, E. B. Becker, and M. E. Jessop, "Dynamic Response of Human and Primate Head and Neck to +G_y Impact Acceleration," Report no. DOT-HS-803-058 (Washington, D.C.: Department of Transportation, January 1978), 9-13; James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 8.

[64] C. L. Ewing, D. J. Thomas, L. Lustick, G. C. Willems, W. H. Muzzy, E. B. Becker, and M. E. Jessop, "Dynamic Response of Human and Primate Head and Neck to +G_y Impact Acceleration," Report no. DOT-HS-803-058 (Washington, D.C.: Department of Transportation, January 1978), 9-13; James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 8.

[65] C. L. Ewing et al., "Dynamic Response of Human and Primate Head and Neck to +G_y Impact Acceleration," 10.

[66] James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 8; Daniel J. Thomas and M. Eugene Jessop, "Experimental Head and Neck Injury," 191-192; James Rife Oral History Interview with Daniel J. Thomas, July 12, 2016, 30-31.

[67] William Thomas Oral History Interview with Daniel J. Thomas, March 8, 2016, 42-43; James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 9-12; Daniel J. Thomas and M. Eugene Jessop, "Experimental Head and Neck Injury," 180-181.

[68] NBDL Run Index, Neel Aeromedical Center, USAARL. The 43 runs included 22 rhesus macaques and 21 chimpanzees.

[69] C. L. Ewing et al., "Dynamic Response of Human and Primate Head and Neck to +G_y Impact Acceleration," 8; James Rife Oral History Interview with Daniel J. Thomas, July 12, 2016, 49; Email from Daniel J. Thomas to James Rife, dated November 22, 2016; Email from Daniel J. Thomas to James Rife, dated September 19, 2016; William Thomas Oral History Interview with Daniel J. Thomas, March 8, 2016, 14-15; C. L. Ewing et al., "Dynamic Response of Human and Primate Head and Neck to +G_y Impact Acceleration," cover, 9; for a chronological listing of chimpanzee runs, see NBDL Run Index, Neel Aeromedical Center, USAARL.

[70] C. L. Ewing et al., "Dynamic Response of Human and Primate Head and Neck to +G_y Impact Acceleration," 9; Memorandum from M. Eugene Jessop, Jr., Major, USAF, VC, Chief, Animal Resources Branch, to Capt. C. L. Ewing, MC, USN, Officer in Charge, dated November 16, 1972, Subj: "Telecom with Lt/COL Ralph Zeigler re: Assignment of Veterinary Officers to NAMRL Detachment," NARA-CP, RG 52, NMRDC Project Files and Reports, 1967-1982, Entry UD-04W1, Box 10, F: "NBDL MF58.524.02E-0001 (NEW)"; Memorandum from Richard A. Boster, Head, Animal Physiology Branch, to C. L. Ewing, Officer in Charge, dated October 2, 1974, Subj: "Development and verification physiologic parameters for animal vibration studies," and Memorandum from Bill Muzzy to Dr. Ewing and Dr. Jessop, dated April 3, 1974. Both memos are located in the FY 1974 Reading Files, Neel Aeromedical Center, USAARL. Letter from G. M. Lawton, Chief, Bureau of Medicine and Surgery, to Navy Audit Service Headquarters, dated September 30, 1975, Subj: "Breakdown of veterinary support furnished to naval activities, request for," NARA-CP, RG 52, Administrative Division, General Correspondence, 1972-1976, Entry no. UD-WW-7, Box 33, F: "6321."

[71] The details on the run are from Daniel J. Thomas and M. Eugene Jessop, "Experimental Head and Neck Injury," 177-217 [quote is on p. 199].

[72] Albert I. King, "Human Analogues in Biomechanical Research," in *Impact Injury of the Head and Spine*, 388; Channing L. Ewing, "Preface," in *Impact Injury of the Head and Spine*, vii-x.

[73] William Thomas Oral History Interview with Daniel J. Thomas, March 8, 2016, 2, 38, 40; C. L. Ewing et al., "The Effect of Duration, Rate of Onset, and Peak Sled Acceleration on the Dynamic Response of the Human Head and Neck," 35.

[74] C. L. Ewing et al., "The Effect of the Initial Position of the Head and Neck on the Dynamic Response of the Human Head and Neck to $-G_x$ Impact Acceleration," 491; William Thomas Oral History Interview with Daniel J. Thomas, March 8, 2016, 45-46; C. L. Ewing et al., "The Effect of the Initial Position of the Head and Neck on the Dynamic Response of the Human Head and Neck to $-G_x$ Impact Acceleration," 5, 35, 39; David C. Viano and Charles W. Gadd, "Significance of Rate of Onset in Impact Injury Evaluation," *Proceedings of the Nineteenth Stapp Car Crash Conference* (Warrendale, PA: SAE, 1975), 808; M. Kornhauser, "Theoretical Prediction of the Effect of Rate-of-Onset on Man's G-Tolerance," *Aerospace Medicine* 32 (May 1961): 412; E. Becker and G. Willems, "An Experimentally Validated 3-D Inertial Tracking Package for Application in Biodynamic Research," 899-930; E. B. Becker, "A Photographic Data System for Determination of 3-Dimensional Effects of Multiaxis Impact Acceleration on Living Humans," 69-78.

[75] Leon S. Robertson, "Safety Belt Use in Automobiles with Starter-Interlock and Buzzer-Light Reminder Systems," *American Journal of Public Health* 65, no. 12 (December 1975): 1319-1325; William Haddon, Jr., "Perspective on a Current Public Health Controversy," *American Journal of Public Health* 65, no. 12 (December 1975): 1342-1344.

[76] William H. Muzzy and Leonard Lustick, "Comparison of Kinematic Parameters Between Hybrid II Head and Neck System with Human Volunteers for $-G_x$ Acceleration Profiles," *Proceedings of the Twentieth Stapp Car Crash Conference* (Warrendale, PA: SAE, 1976), 43-74; Email from Daniel J. Thomas to James Rife, dated November 22, 2016; James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 21-22.

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Chapter Four

The Limits of Flexible Informality, 1976-1984

In January 1976, after more than thirty years in the Navy, Chan Ewing retired from active duty. To the casual observer, this may have appeared to be a straightforward event. After more than twenty years of full engagement in acceleration impact studies and more than a decade of promoting, building, and administering a cutting-edge laboratory, Ewing was ready to leave the work to a new generation. But that observer would not have known Chan Ewing, who had no intention of stepping back. Instead, the retirement allowed Ewing to adroitly offload the part of the job he liked the least—the administrative and military duties of a naval officer-in-charge. After an extended vacation, Ewing returned to NAMRL-D as civilian scientific director in June 1976.[1]

Exchanging his Navy uniform for a civilian suit and white physician's coat underscored one of Ewing's particular strengths: his ability to use contacts and knowledge of the Navy bureaucracy to accomplish his goals in an informal, flexible way. But in ceding administrative authority over his work to other naval officers likely to be uncomfortable with his approach to leadership and laboratory management, Ewing was unknowingly creating a potential source of friction and perhaps cause for conflict. The unintended consequences later became apparent when Ewing made another key move—getting his lab elevated to an independent command, which brought about unanticipated administrative expectations and unwanted levels of accountability from higher Navy authorities. As the lab made the rocky transition to more formal arrangements, Ewing's old support network broke down, his researchers were left without work for months at a time, and he found himself directly opposed to the superiors he had expected merely to lighten his administrative load. Most importantly, the transition to independent command status cast unwanted light on a hitherto unexposed shortcoming: Ewing may have built a remarkably innovative and productive experimental lab, but he had not yet had the time or capability to transform the raw scientific data into mathematical models. The years between 1976, when Ewing opted for civilian status, and 1984, when he left the lab for good, were therefore highly productive yet disappointing. They established the limits of the informal flexibility through which Ewing had accomplished so much.

Vibration and Ship Motion Studies

Commander Robert S. Kennedy, an aerospace experimental psychologist, succeeded the retired Dr. Chan Ewing as the officer-in-charge of the NAMRL-D, serving in that role from 1976 to 1979. (Photograph courtesy of Michael Lilienthal)

These limits were not yet visible in 1976. Indeed, the reorganized NAMRL-D appeared to get off to a good start both scientifically and administratively. During the first half of 1976, Dan Thomas served as acting officer-in-charge of NAMRL-D. After Ewing returned, he filled the slot until the Navy could assign a replacement. Commander Robert S. Kennedy, who arrived in December 1976, most likely met all of Ewing's expectations. A New Yorker who grew up in the Bronx, Kennedy joined the Navy in 1959 and went on to earn a Ph.D. in experimental psychology from the University of Rochester in 1972, majoring in sensation and perception. He then dedicated his career to aerospace experimental psychology and studies on motion sickness and disorientation. In fact, just a year earlier while working at the Naval Missile Center at Point Mugu, California, Kennedy had developed a test that could be used to predict aviator susceptibility to motion sickness.[2]

Kennedy and Ewing had known each other since the 1960s when they were both stationed at NAMI in Pensacola, and they shared a mutual respect. Kennedy was always more interested in research than administrative details. After coming to NAMRL-D, he met regularly with Ewing and Thomas, more often to talk about research than to spread red tape. He had no desire to micromanage the impact acceleration research. Instead, Kennedy focused closely on what was, during the late 1970s, a growth industry for the laboratory: vibration, motion sickness, and performance evaluation studies, part of a growing body of "human factors" research that studied the interactions between individuals and technology in complex systems.[3]

The earliest NAMRL-D experiments related to vibration began in 1974 to help solve a problem created by emerging ship technology. Combat personnel had always been highly vulnerable during transit to and from landing beaches. In the 1960s, to make tactical insertion and casualty evacuation safer and more efficient, the Navy had begun developing high-speed vessels called Surface Effect Ships (SES). An unusual combination of hovercraft and catamaran, these vessels were highly prone to severe vibration problems. Although they were capable of reaching speeds up to 100 knots, the vessels could rarely achieve them because extreme vibration made operators either sick or physically incapable of controlling the vessel. This was particularly a problem in large SESs, but designers had completely failed to appreciate how increases in mass affected the vibration profile. NAMRL-D's assignment was to research the effects of ship vibration on humans, establish detrimental vibration levels, and then send the data to the Naval Sea Systems Command, Naval Air Systems Command, U.S. Marine Corps, and Bureau of Medicine and Surgery for use in SES design evaluation.[4]

The chief concern was the difficulty of casualty evacuation, so NAMRL-D planned to measure the vibrations from an SES prototype, reproduce them in the laboratory, and expose first animal subjects and then human volunteers in the supine position. This was the same basic conceptual methodology as impact acceleration research, but instead of reproducing the experience of an aviator hitting the water, it replicated the sensation of a casualty being taken off the beach. "We started vibration research intending the same instrumentation approach," wrote Thomas.[5]

The approach and instruments might have been the same, but the prime movers were different. To begin the vibration studies, Ewing obtained the right to use an MB Electronics model C-210 vibration system, which was already installed at Michoud's Chrysler Engineering Test Lab. Used during the early Apollo program to test the Saturn S-1 and S-1B rocket boosters, the C-210 was capable of generating fourteen tons of force. It had a 2,800-pound aluminum "shake table" driven by an audio amplifier consisting of three high-power stages that could produce frequencies ranging from 5 Hz to 2 kHz and oscillating motion ranging from 3 Hz to 2 kHz. Since it was owned by the federal government, NAMRL-D could use the C-210 at low cost.[6]

Vibration tests on rhesus macaques began in early 1974. Rhesus Number 3148 was the first animal subject. Over the course of one week, it was exposed to vibration frequencies from 10 to 40 Hz and acceleration levels from 0.57 to 10 G. These early tests provided an opportunity to troubleshoot and adapt the restraint systems and instrumentation originally developed for acceleration impact studies. Ed Becker and Bill Muzzy, for example, produced stiffer T-plate mouth mounts for larger primate subjects and human volunteers after detecting an unusual degree of resonance during some of the initial vibration tests.[7]

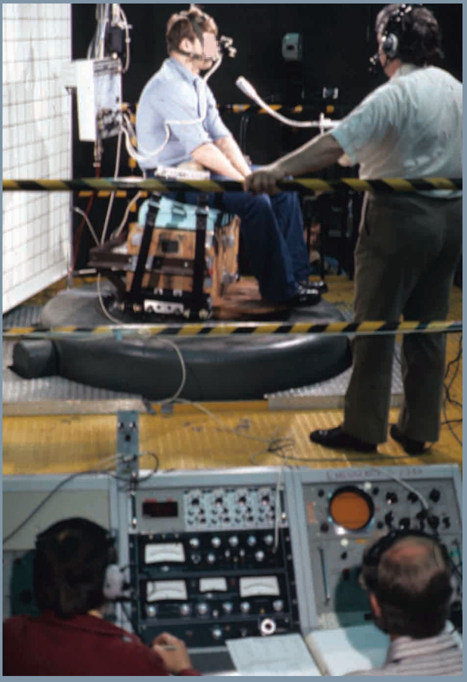
As work with rhesus macaques continued into 1975, the capabilities of the vibration program expanded with the installation of a 5,000-pound force capacity electrohydraulic vibrator manufactured by Minneapolis Test Systems Corporation (MTS). The MTS device allowed NAMRL-D to conduct studies at lower frequencies than formerly possible, down to 1 Hz. The team also developed new equipment and procedures for use in the MTS experiments. These included a fiberglass couch specially molded to restrain a macaque securely and creation of small Teflon-lined tunnels in the craniums of the macaque subjects. These tunnels allowed the technicians to insert pressure transducers through the skull to rest firmly against the dura.

The chief objective was to correlate vibration with intracranial (brain tissue and cerebrospinal fluid) pressure changes in the macaques. Researchers outfitted the rhesus subjects with three pressure transducers to measure intracranial pressure and three accelerometers to measure motion. High-speed cinematography found that the acceleration of the couch was more or less in line with the rhesus's restrained torso, so the fiberglass couch was also fitted with an accelerometer positioned close to the neck. The macaques were exposed to vibration frequencies ranging from 2 to 35 Hz, with acceleration amplitudes of 5, 10, 20, and 40 m/s^2 on the MTS electrohydraulic shaker. One of the most startling findings from these experiments was that at frequencies below 10 Hz and amplitudes below 40 m/s^2, acceleration caused the rhesus's head to strike the neck, creating the possibility of spinal injury if prolonged. The results of these first experiments were never deemed reliable enough to use, but the work did demonstrate that it would be possible to develop a model to predict response to vibration.[8]

Ewing's next step was to recruit Dr. John C. Guignard to spearhead subsequent rounds of vibration research. Born in England, Guignard obtained his medical degree from the University of Edinburgh and conducted human factors research at the Royal Air Force Institute for Aviation Medicine and the University of Southampton. In 1969 Guignard moved to the United States and conducted research on vibration, noise, and human performance under stress for the U.S. Air Force Aerospace Medical Research Laboratory in Dayton, Ohio, using a C-5 electrodynamic vibration machine similar to the C-210 at Michoud. While there, Guignard evaluated the International Organization for Standardization's (ISO) boundaries for whole-body vibration exposure. In Guignard's study, eight human male volunteers were seated in a "vehicle-driving posture" and exposed to vertical vibration levels between 8 and 16 Hz. During the vibration tests, which lasted up to eight hours, the seated subjects had their heart rates monitored and movements tracked with a mouth-mounted accelerometer. Guignard found that the exposure had "practically no significant effect upon a wide variety of physiological indicators or upon several varieties of central and peripheral performance," thus proving the sufficiency of the ISO boundaries.[9]

Guignard arrived at Michoud in 1975. A year later, he came under the nominal supervision of Commander Kennedy who, in addition to being named officer-in-charge, was also designated director of the newly created Human Performance Sciences Division at NAMRL-D. By then the team was preparing to man-rate the C-210, fitting the device with numerous failsafe mechanisms and interlocks designed to stop the entire system in the event of a malfunction. These failsafe mechanisms worked by cutting off the oscillator signal produced by the amplifier and by removing power from the vibration exciter and the amplifier. This instantaneous halting of the equipment, however, had the potential to generate an entirely new hazard—a system-generated high-voltage electrical transient that could reach the shake table and seriously harm the occupant. Bill Muzzy developed an automatic servo-cycling oscillator, equipped with an interlock circuit, in conjunction with a control signal monitor to remedy the problem. In the event of a loss of power, the interlock circuit allowed the machinery to step down rather than stop abruptly, allowing the electrical transient to decay.[10]

By 1977 the C-210 was ready for man-rating by an independent team of safety technicians and engineers. They pored over documentation, interviewed personnel, and tested the machinery at a variety of stress levels. "They would deliberately try and stop the test in an unauthorized manner and see what would happen," recalled Muzzy, pleased that his safety features performed as expected. In November 1977 the C-210 passed the test. Work with human volunteers could begin.[11]



The C-210 hydraulic shaker in use with a human research volunteer. (USAARL)

The first series of tests focused on the inertial response and psychophysiological reactions to whole-body vibrations at 2 Hz (the dominant frequency encountered aboard early SES prototypes) and above. Navy human research volunteers had accelerometer arrays like those used in the impact program mounted to their first thoracic vertebra, upper jaw, and pelvis. Their seats, fixed to the shake table, also had a reference accelerometer attached. The vibration was applied to the buttocks and feet of the seated subject in a vertical sinusoidal direction (oscillating up and down). The data measured by the seat reference and subject-mounted transducers was recorded initially on analog magnetic tape and later converted to consistent and precise digital form. The human volunteers were exposed to steady-state sinusoidal vibration for three minutes and to up-and-down fluctuating frequencies, or sweeps, for approximately one minute.[12]

Guignard was pleased with the accuracy and reliability of these first human subject vibration tests. A look at the literature, he told a group at a 1979 Aerospace Medical Panel Specialists meeting, indicated that "use of man-mounted inertial instrumentation in such a manner that meaningful and repeatable observations of skeletal motion can be reliably made, and related to a precise inertial frame of reference, has rarely been attempted and even more rarely achieved." By then NAMRL-D had completed 80 human experiments covering a vibration frequency range of 5 to 32 Hz with no one harmed. The next year the lab undertook 157 vertical axis vibration runs with seated human volunteers. This series of experiments employed a subjective vibration severity rating scale to determine the human threshold of tolerance. The team supplied volunteers with a nine-point vibration severity scale that they used to identify their level of discomfort. Although the scale covered increments running from imperceptible motion (level 1) to intolerably severe (level 9), exposure was terminated if any volunteer rated a level 6. But even as the team at Michoud accomplished the "rarely achieved," NAMRL-D staff were working simultaneously on another front to better document tolerance to ship vibration.[13]

It began in early 1973 when Ewing met with officials from the Navy and Bell Aerospace Company to discuss results of an intriguing trial. That March, Bell Aerospace had outfitted a 1,000-ton production model SES-100B with more than 300 motion sensors and accelerometers. The chief of the Naval Material Command, Admiral Isaac C. Kidd, Jr., then rode the 100B for approximately twenty minutes in Sea State 2, typically characterized by smooth water conditions with occasional waves just over a foot high. Kidd and his crew exceeded what was considered the voluntary tolerance threshold of 2 Hz vibration, and they did so longer than previously believed possible. This finding, Ewing noted subsequently, "raises the question of what the correct figures are." With no good information on vibrations created by the 1,000-ton SES and with the Navy and Bell already anticipating a 2,000-ton model, this brought the entire SES program into question.[14]

Ewing decided that given adequate resources, NAMRL-D could provide the needed answers. First, the team would require access to a better hydraulic shaker—one that could perform at frequency levels below 1 Hz and produce higher amplitudes of motion than the C-210 and even the MTS. This, in turn, would necessitate new instrumentation to provide accurate measurements at lower frequencies. Finally, to effectively capture the human factors aspect of the tests—documenting the long- and short-term effects of the vibration exposure far beyond the shake table—NAMRL-D would need a dedicated cadre of human volunteers unaffected by impact acceleration testing.[15]

The ship motion simulator (SMS) at Goleta, California, before its transfer to NBDL. (USAARL)

There was one location where these requirements were available, and in late 1973 Ewing proposed to make use of the Office of Naval Research (ONR) ship motion simulator (SMS) facility in Goleta, California, operated by Human Factors Research, Inc. (HFR), for vibration experiments in the 0.1 to 0.4 Hz spectrum. ONR approved the proposal, and from July to September 1975 Ewing worked in Goleta along with several staff members and nineteen human research volunteers conducting motion simulation experiments on the SMS. The motions were intended to replicate the effects of a 2,000-ton SES running in a bow quartering sea in three separate conditions: 1) Sea State 3 at 80 knots; 2) Sea State 4 at 60 knots; and 3) Sea State 5 at 40 knots. Pairs of subjects were exposed for forty-eight hours to each of these conditions, with intervals given over to performance of tasks representing shipboard activities, resting, and static control. Sixteen of the nineteen human volunteers aborted the runs due to severe nausea or vomiting. There was little consistency in onset; it varied from twelve hours to fifteen minutes. Only the remaining three volunteers could function for the entire duration of the test period.[16]

Working with HFR staff members Michael E. McCauley and James F. O'Hanlon, Kennedy and Guignard used data from the Goleta experiments to develop a mathematical model drawing upon motion frequency, acceleration, and duration of exposure to predict incidence of motion sickness. The model showed that the frequency most likely to induce motion sickness was 0.166 Hz.[17]

The Goleta experiments paved the way for sustained human factors research at Michoud. Even before Ewing's sojourn, NAMRL-D's Paul Majewski had acted briefly as observing medical officer for a series of studies on the SMS. He documented a number of effects of motion sickness, including vomiting, sleep disturbance, fatigue, loss of appetite, headache, vision disturbance, and decline in work performance. It was the decline in work performance finding that intrigued Ewing the most and resulted in the shipboard activities element in the 1975 Goleta tests. Afterward, he decided that his team should develop a test battery that, when taken before, during, and after ship motion experiments, could determine in greater detail how work performance was affected by motion. Moreover, Ewing believed, this battery of tests could prove useful in a variety of dynamic experiments, including impact research.[18]

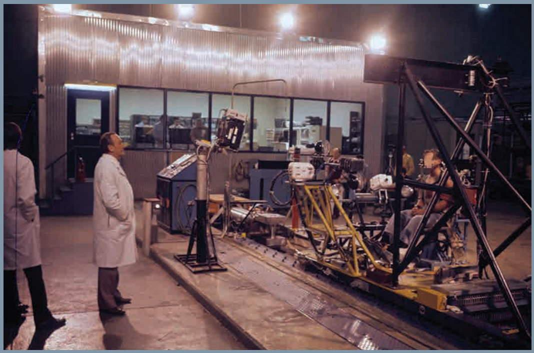
This desire to get into human factors research subsequent to the interlude in Goleta strongly suggests that Ewing may have exerted some influence in the process of making Commander Kennedy, an expert in human factors, his successor as officer-in-charge at NAMRLD. Upon his arrival at Michoud, Kennedy enthusiastically advanced a research project ultimately entitled Performance Evaluation Tests for Environmental Research (PETER). With a team including Dr. Alvah C. Bittner, Jr., Lieutenant Commander Robert C. Carter, MSC, USN, and a few research assistants, Kennedy reviewed psychological literature to evaluate different types of human volunteer performance tests. Some, like the Halstead-Reitan Battery and the Stroop Test, were well known. Others appeared more appropriate for identifying performance task areas that might degrade under ship motion. The team used the results from NAMRL-D vibration tests to, in effect, "test" the various tests. They then divided the performance tasks that were shown to degrade under motion into two broad categories: cognitive tasks (decision-making, information processing, or judgment-related) and motor tasks (tracking and reaching). Each performance test battery was administered to human volunteers Monday through Friday for three consecutive weeks, and the results were carefully reviewed for consistency. Over the course of the PETER program, 112 test measures were studied and evaluated based on consideration of the task's stability and definition. In the end, 30 of these 112 measures were deemed useful for studying the effects of motion on human task performance.[19]

As the PETER project unfolded at Michoud, the SMS was being disassembled in Goleta, since in late 1976 ONR had decided to transfer it to NAMRL-D. With scientific staff as well as human volunteers readily available in Michoud, ONR decided that the SMS could be operated more efficiently there. There was understandable resistance in Goleta. Kennedy described "factions with the Navy and outside that didn't want it to go there." But in March 1977, the SMS was shipped to the Naval Civil Engineering Laboratory in Port Hueneme, California, for refurbishing. When it arrived at NAMRL-D, it remained crated up—there was no funding available for the reassembly. Finally, in the fall of 1980, the SMS was reassembled in Test Cell 3 at Michoud by general contractor J.L. Rumold, Inc. On November 1 it was test operated for the first time since leaving Goleta. Now that it was assembled and functional, Ewing and his team looked forward to man-rating the SMS.[20]

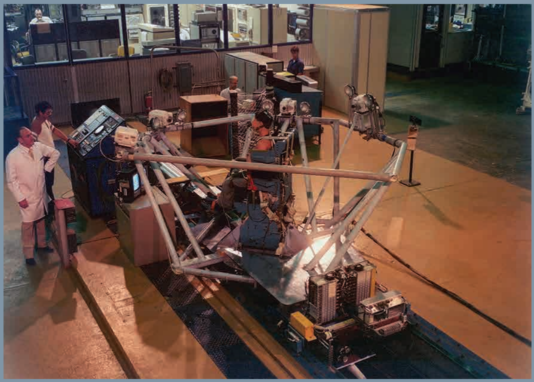
Expansion of Impact Acceleration Research

On March 3, 1972, Mohawk Airlines Flight 405, a twin-engine turboprop, lost power while approaching the Albany, New York, airport. It careened off a street and came to rest in a house. Most of the passenger seats failed on impact, either coming loose from their tracks or their legs collapsing. The loose seats, with occupants still fastened in, were thrown together into a forward compartment. There were seventeen fatalities altogether—fourteen passengers, two crew members, and an occupant of the house. The National Transportation Safety Board (NTSB) estimated that the G forces generated during the accident should have been survivable. The agency recommended that the Federal Aviation Administration (FAA) require seats to be built in excess of the forces that human beings could endure; however, the FAA rejected the recommendation. As aircraft cabin safety questions piled up in the 1970s, Congress decided to act, with California Democratic Congressman Norman Mineta leading the investigation. Among the experts Mineta consulted was Chan Ewing. By then Ewing had more than a decade of research and testing to draw upon, the most significant of which had been conducted during the last four years as the human and non-human primate impact studies increased in frequency and variety.[21]

Ewing made sure that the venture into vibration and human factors research did not distract the core staff from its impact acceleration research, particularly the effort begun at mid-decade to expand the vectors under investigation. The first of these initiatives was to conduct human runs in the $+G_y$ vector to obtain information on the consequences of lateral impacts, such as those encountered when an automobile is hit broadside. There was some foundation work to build upon. During the early 1960s, $+G_y$ experiments using human volunteers had been carried out by John Paul Stapp and Major Ellis R. Taylor at Holloman Air Force Base and also by Captain Edmund



Preparing for a $+G_y$ run with a human research volunteer. (USAARL)



Dr. Gilbert looks on as a human volunteer is readied for an off-axis G_{-x+y} run. (USAARL)

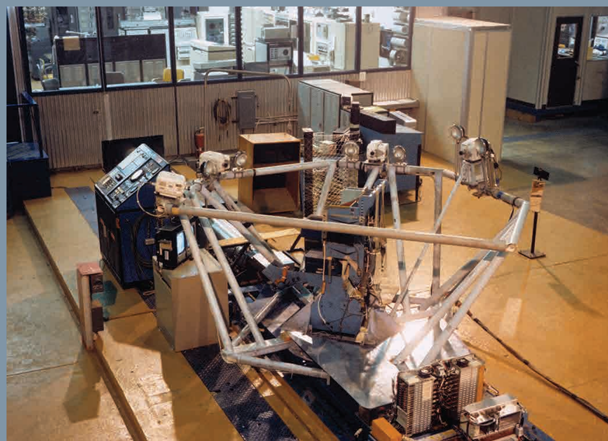
B. Weis, Jr., Captain Neville P. Clarke, and James W. Brinkley at Wright-Patterson Air Force Base. The data, however, was clearly inadequate for use in mathematical modeling. Stapp had employed subject-mounted accelerometers, but the results were compromised because the human subjects wore Project Mercury helmets. The Wright-Patterson researchers used no subject-mounted instrumentation at all.[22]

The NAMRL-D team members were able to adapt the existing instrumentation systems to the new configuration, but they had to develop a new restraint configuration that included an additional safety belt wrapped around the chest and a padded wooden board mounted on the carriage to stop lateral trunk movement. Subjects were positioned so that the acceleration thrust would hit them on the right side. Since force would drive from right to left across the body, the unrestrained head and neck would respond by moving laterally to the right. The $+G_y$ runs began on May 6, 1976, and remained the primary focus of human impact exposures into the spring of 1977. By the fall of 1977, NAMRL-D personnel had conducted one hundred human volunteer $+G_y$ runs. Their most notable preliminary conclusion was that the initial position of the head was directly related to the dynamic response output. When the head and neck were bent, for example, forward (or "pitch") increases were realized in angular acceleration and velocity. The NAMRL-D team members presented these findings when they hosted the 21st Annual Stapp Car Crash Conference that October in New Orleans. In early 1978 the lab began conducting oblique runs in order to simulate airplane crashes with the seat pitched upwards. In these vectors, known as G_{-x+y}, human volunteers were positioned 45º to the accelerator. In both the $+G_y$ and G_{-x+y} runs, the NAMRL-D research staff measured the same variables (rate of onset, duration at peak acceleration, and initial position of the head) as they had in the $-G_x$ runs conducted in 1974 and 1975.[23]

The most notable medical finding from these rounds of experiments was in regard to syncope, the temporary loss of consciousness due to a fall in blood pressure. A total of 1,621 fully instrumented human experiments were carried out between January 31, 1974, and July 12, 1979. Following 655 of these runs, the medical staff under Thomas noted symptoms including neck pain, headache, restraint abrasions, and syncope. There were twenty-nine cases of syncope in all, usually occurring among new volunteers on the first or second run. It seemed likely at the time that the condition had been induced in part by tight restraint straps. In all cases, volunteers were removed from the restraints and promptly recovered. But there was clearly another factor at work in these human subjects, later identified by the medical team as "the additional stress of his first experiment." Sure enough, as volunteers learned how to breathe diaphragmatically and to anticipate and adapt to the physical stress, the likelihood of syncope decreased. Only four volunteers suffered more than one syncopal episode. On several very rare occasions, intraventricular conduction abnormalities and bradycardia showed up on ECG readings. All of the electrocardiographic abnormalities were resolved within three minutes following the run.[24]

An example of the fiberglass pelvic mounts devised and used at the lab. (USAARL)

Throughout these years there were steady improvements in the original instrumentation and equipment. In January 1976, in order to collect information on the movement of the human torso in relation to the head and neck, the Engineering Department took plaster impressions from each volunteer to construct a close-fitting fiberglass pelvic ring. Accelerometers and photo-targets were attached to a steel mount on the ring. In order to ensure that the mount remained rigid, the fiberglass pelvic ring was integrated into the restraint system, serving as the fastening point for the standard over-the-shoulder straps. The lap belt also fastened to the pelvic ring. During safety testing, the pelvic region of a 220-pound Alderson 95th percentile anthropomorphic test dummy (ATD) was replaced with one of the fiberglass rings, and it withstood 17 G runs with no deficiency. This new instrumentation allowed NAMRL-D engineers to study the amount of pelvic rotation that occurred during an experiment and to relate that information to readings measured at the head and neck. The pelvic measurements also provided more data with which to evaluate the functionality of different restraint configurations.[25]



The omnidirectional sled configured for an off-axis run. (USAARL)

As the pelvic rings proved their utility and research in new vectors continued, Bill Muzzy began developing specifications for an adjustable sled carriage for human runs. This promised not only to be a more optimal arrangement for multi-vectorial runs but would also relieve the lab of the task of switching out and maintaining a growing collection of special-use sleds. The accepted maximum acceleration level for human volunteers was 15 G. For safety, Muzzy doubled that number, designing a sled that could handle impact forces up to 30 G. The design included provisions for a rotatable seat that could accommodate G_x, G_y, and G_z runs. The plans also included three onboard cameras that could be positioned 1.2 meters from the test subject. Like the carriages produced earlier, the multi-vectorial model was equipped with independent pneumatic brakes. After painstaking negotiations, the contract for the new carriage went to CVC Products, Inc. at a value of approximately $45,000. Construction and man-rating took several years. Dry runs were conducted with 750 pounds of weight in the carriage to account for the expected total weight of the human subjects and the additional test equipment. NAMRL-D conducted its first runs with the new sled carriage in November 1980. The carriage greatly reduced the amount of time and effort required to switch between different impact vectors.[26]

The lab also implemented a system for processing photography during these years that was more efficient than previous arrangements. At first, film exposed during runs was mailed to Eglin Air Force Base for developing; it was usually returned within three days. After trimming and quality checking, the film was then "digitized." This involved using an automatic photo film reader and a computer to record on magnetic tape the frame-by-frame position of each photo target along with the associated time data. In 1980 NAMRL-D switched from using developers at Eglin to employing two local vendors: Pan American Films, Inc. and the Naval Support Activity in New Orleans. To better process ever-increasing amounts of photographic data, William

Anderson developed an automatic photo-digitizing system composed of a film reader connected to a Nova 800 computer and Tektronix 4051 operating console. Imported photo-data was carefully evaluated to ensure that it matched the inertial data from the accelerometers. Afterward, the digitized photo-data was recorded on magnetic tape and kept on file with the original film. These upgrades enabled the team to analyze all photographic and inertial data within five days of an experiment. They also resulted in a cost savings of nearly $50,000 in 1980 alone.[27]

It was about this time that Congressman Mineta tapped the expertise being developed at NAMRL-D to help compel the FAA to take action on airplane seat specifications. Mineta informed Ewing that hearings before the Congressional Committee on Public Works and Transportation, which were held in June and September 1980, had only produced "conflicting testimony." He hoped that Ewing would help resolve the conflict by answering a series of incisive questions. Many were specific to the FAA seat question, but Mineta also asked specifically about the limits of human capability to withstand inertial forces and the utility of mathematical modeling to identify those limits. Ewing sent back a comprehensive reply in late October, which was included in the official record. The most important question was whether human beings were capable of withstanding higher G forces than standard airplane seats could. "The tolerance limits listed," Ewing insisted, "are far too low and are belied by published data." The FAA's limit for frontal impact, for example, was 9 G. Ewing pointed out that human subjects in his experiments had endured 15 G with no harm, thoroughly discrediting the FAA's safety standards.[28]

While Mineta was calling the FAA to account, Ralph Nader associate Joan Claybrook, appointed director of the National Highway Traffic Safety Administration (NHTSA) by President Jimmy Carter, was pressuring automakers by pushing for tough new regulations, including a requirement for airbags in vehicles. The automakers, struggling with foreign competition and skyrocketing fuel costs, pushed back hard. President Ronald Reagan's election in the fall of 1980 resolved the conflict in favor of the automakers—for a time—but as Dr. Carol A. MacLennan, a participant on the NHTSA side, noted later, the "controversy centered on the issue of scientific precision. Were anthropomorphic dummies sophisticated enough to measure the relationship between crash forces and human injuries?"[29]

Ewing's answers to Mineta revolved around the same question. Given the number of variables involved, as Ewing explained, the only good way to understand the dynamics of a seat failure during a crash would be through use of an ATD. The best ATD then available, GM's Hybrid III, was far from accurate, however. "This is one of the central problems at the U.S. Department of Transportation, as well as the Department of Defense, in attempting to specify performance criteria for evaluation of restraint/protective systems for ejection seats, crash protective systems for other aircraft, and protective systems for automobiles sold in the United States," Ewing concluded.

But there was good reason for this problem, as the task of developing the required criteria was Herculean. Ewing informed Mineta that although NAMRL-D researchers had data available from 1,759 human volunteer runs in three different vectors, they still did not know enough to develop an ATD that would match human dynamic response, let alone validate it with a "math model" of a human being. In the end, Ewing could not help putting in a plug for his own work. Given the required resources, Ewing assured Mineta, his lab planned not only to develop performance criteria but also "to prepare designs and to construct a family of dummies (manikins) which will act dynamically as a man does, as measured by comparison to the performance criteria." Ewing expected to reach that goal by 1987, "depending on availability of staff and funds." But he never attained it, and Mineta's efforts, like Claybrook's, were turned back by the change in administration, but only for a time. In 1988 airplanes were finally required by the Department of Transportation to have 16 G seats installed.[30]

Non-Human Primate Program Expansion

As the pace of human experimentation increased during the late 1970s, so did the extent of non-human primate research. In non-human primate studies as in human impact research, NAMRL-D made innovations both in the vectors of runs and in equipment and instrumentation. Injurious, occasionally fatal high acceleration level $-G_x$ non-human primate runs, begun early in the decade to locate an injury threshold, were stepped up, and by the early 1980s preliminary results began to appear. One of the most notable findings was that the fatality threshold was similar for both $+G_x$ and $-G_x$ runs. In contrast to forward-facing $-G_x$ runs, $+G_x$ runs replicated a collision from behind, inducing a whiplash response from the unrestrained head. Ewing and Thomas had previously considered $+G_x$ runs to be especially dangerous, and there was little or no pre-existing human volunteer research in that vector. There was precedent in non-human primate research, however, since Ayub Ommaya had conducted $+G_x$ runs with rhesus macaques at NIH during the late 1960s and early 1970s. Further, since NAMRL-D had provisions in place for fatal $-G_x$ runs with non-human primates, Ewing decided that the team was prepared to conduct potentially fatal $+G_x$ runs.[31]

The first step was to set a threshold level for forward impact that would establish a basis for comparison. Based on twenty-three high level (85 to 180 G) $-G_x$ rhesus runs, which had produced thirteen fatalities, Dan Thomas and Gene Jessop set the threshold for fatal injury at the head-neck junction at acceleration levels between 110 and 120 G. This finding roughly corresponded to the threshold set by Thomas Clarke and Bill Muzzy years earlier at Holloman, where fatal head-neck injuries were observed in baboons around 100 G. NAMRL-D personnel consulted with Clarke on comparability between different species of non-human primates. The next step was to conduct the tests replicating impact from behind. These first $+G_x$ runs were supervised by Thomas and Jessop in the early 1980s. The results were startling, indicating that the fatal injury threshold was at a force of around 140 G—far higher than anticipated.[32]

This threshold injury value, however, applied only in impacts where the non-human primate's head was aligned with the torso and facing the impact vector. In runs where the head was not positioned straight forward, the fatal threshold was lower. For example, in 1980 an 88 G peak sled acceleration run in which the initial position of the primate's head was displaced by 60º on the Z-axis resulted in a fatal neck injury. Human subjects could be instructed how to position their heads during experiments, but rhesus behavior could not be controlled to this extent. The NAMRL-D staff worked to develop a "breakaway restraint system" to hold the head in a specific position until the moment of impact, at which point the impact force would break the restraint. In the end, the team was unable to come up with a device strong enough to provide sufficient initial restraint but fragile enough to break on impact without interfering with the dynamic response. Thomas was deeply disappointed about the lack of control over the initial conditions of the animal runs, but NAMRL-D nevertheless collected a dataset containing a great deal of information about initial head position.[33]

Determining non-human primate head position upon impact, wherever it may have been, was made easier when the lab developed new photographic procedures for collecting data on high G animal runs. The old Milliken cameras were replaced with new 16-mm PhotoSonics, Inc. model 1B cameras that could better withstand high acceleration levels. The frame rate of the PhotoSonics devices was also doubled to 1,000 frames per second in order to collect the same quantity of measurements at double the acceleration.[34]

As fatal non-human primate runs increased, histologic research, conducted by Dr. Friedrich Unterharnscheidt, became increasingly important to the lab's work. If the acceleration experiments established when fatalities occurred, it was Unterharnscheidt's study of the patterns of structural tissue damage that explained how they occurred. Unterharnscheidt identified the most common cause of fatal injury in both the $\pm G_x$ vectors as disarticulation at the atlanto-occipital junction. He did, however, find differences between the patterns of traumatic lesions and hemorrhages caused by fatal $-G_x$ and $+G_x$ runs, thus concluding that "each vector direction of impact acceleration produces a different and predictable type of injury in regard to quality and distribution."[35]

Among the most important tasks undertaken by Unterharnscheidt was to prove or disprove one of the theories that had been formative to pioneers of impact acceleration studies: the "cervical stretch" theory put forth by Dr. Reinhard L. Friede in the early 1960s. This theory held that abrupt stretch and flexion of the cranio-cervical junction could cause a concussion that may or may not be fatal. The idea had once led Ewing to postulate that pilots lost after hitting the water may have died not from crash impact but by drowning after losing consciousness. During the testing at NAMRL-D, there were no outward signs of concussion induced by cervical stretch and, most importantly, no instance in which impact resulted in a temporary loss of consciousness. Non-human primates exposed to high G impacts either survived or died. Unterharnscheidt was tasked with looking for internal changes that might be associated with the condition. Existing pathological literature indicated that a concussion could occur without leaving any trace of microscopic alteration. The NAMRL-D team, however, believed that more proof was required, so Unterharnscheidt carefully examined tissue from the fatalities for microscopic alterations to cellular structure. In the end, he reported "no pathomorphological findings detectable using the classical light microscopical staining techniques," thus disproving the notion of cervical stretch.[36]

If NAMRL-D had closed the book on Friede's theory, the clinical criteria for concussion remained open for debate. Unterharnscheidt's histological research became an important part of this ongoing debate because it provided information on non-human primates that could be compared with the results of autopsies of humans killed in airplane and automobile accidents—that is, as long as the latter were detailed enough. Ewing and Unterharnscheidt became strong advocates of new military autopsy procedures requiring uniform and careful examination of the spinal cord and craniospinal junction.[37]

Somatosensory Evoked Potentials

By the late 1970s, work at Michoud indicated that concussion was not solely produced by trauma to the brain or spinal cord. The question remained, how else was it caused? Ewing and his colleagues postulated that impact might cause a temporary disruption in the central nervous system. That led to increased focus on neurophysiological monitoring on the assumption that it might be possible to detect these temporary disruptions to a sustained electrical impulse received from the central nervous system during an impact experiment. These electrical impulses were known as "somatosensory evoked potentials" (SEPs). To observe changes, Ewing and his team thought of stimulating the median nerve percutaneously and monitoring the resulting SEPs before, during, and after runs.[38]

Drs. Marc S. Weiss and Michael Berger spearheaded the SEP research at NAMRL-D. Both men had earned a Ph.D. from the University of Rochester. Weiss held a position in the Department of Psychology at Washington State University before coming to NAMRL-D in 1972 to help with data system design, and he stepped up to lead the SEP research as it grew from a small initiative into a sizeable program. Berger was a member of the University of Maryland Physiology Department before becoming assistant neurophysiologist under Weiss in September 1973.[39]

The SEP program is a good example of NAMRL-D working flexibly and informally with outside experts, although it was ONR rather than Ewing that made the connection with the pioneering researchers at the Biomedical Engineering and Neurosurgery Departments at the Medical College of Wisconsin (MCW) in Milwaukee. Headed by Drs. Sanford J. Larson and Anthony Sances, Jr., the MCW team had extensive experience in electrophysiological monitoring and developing clinical applications for SEPs. Among these applications was using SEPs to monitor patients undergoing surgery for spinal injuries. In order to monitor SEPs with precision, it was necessary to implant electrodes directly into the cortex, a task not among the in-house capabilities of NAMRL-D. Jessop, therefore, arranged for non-human primates to be transported to MCW, where Drs. Patrick Walsh and Joel Myklebust performed the necessary implantation surgeries. The primates were then flown back to Michoud for experimentation.[40]

An NBDL neurophysiologist monitors EEG readings. (USAARL)

In a series of 1977 experiments, eight rhesus macaques with implanted cortical reading electrodes were exposed to a range of $-G_x$ impact accelerations. EEG and SEP readings were taken from the macaques before, during, and after the impact tests. Berger and Weiss found that the SEP readings were a better indicator of inertial load on the brain than EEG information and concluded that it might be possible for short-term brain dysfunction to increase in severity proportional to increases in impact acceleration levels. Furthermore, they postulated that there could be a "threshold for the interruption of the transmission of neurophysiological signals through the central nervous system of the animal." They made these preliminary findings public in a paper presented at a November 1978 International Aerospace Medical Panel Specialists' meeting in Paris.[41]

Berger and Weiss followed up that work with a new set of experiments in 1978 and 1979 that used SEP information obtained from electrodes implanted in the cervicomedullary junction between the skull and brainstem. These sensors indicated that amplitude dropped and latency increased following a non-lethal impact event. Berger and Weiss again found that the higher the peak acceleration, the higher the latency shifts in the evoked potential. Based on these experiments, Berger and Weiss postulated that a threshold for neurophysiological dysfunction in the rhesus might exist in the range of 700-800 m/s^2. This research involving rhesus macaques held enormous potential as a safe means of confirming that low G impact exposures caused changes in the functioning of the human central nervous system. Not only did it support that hypothesis, but it also provided a body of data to use as a point of reference in human experiments.[42]

Neurophysiologist Lieutenant Commander David M. Seales, MC, USN, joined the NAMRL-D team to lead the transition to human volunteer SEP experimentation. The first challenge was determining the best means of positioning the electrodes. There could be no implantation directly on the brain surfaces of the human subjects, so it was expected that human readings were going to be less accurate. Seales worked with human volunteers to come up with an optimal placement scheme for electrodes affixed to the skin.[43]

In 1981 Seales and Weiss began a round of $-G_x$ impact runs with five human volunteers during which SEP readings were taken from the top of the head, the brachial plexus (near the left clavicle), the iliac crest of the right hip, and the midline of the neck 4 cm from the inion. Runs were conducted reaching 20, 100, and 150 m/s^2 accelerations for each volunteer with SEP readings taken before, during, and after each run. During the entire period, the median nerve running through the left arms of the subjects was stimulated percutaneously at the wrist with 5 μV rectangular pulses lasting 2ms. In analyzing the readings, Seales and Weiss looked for disruptions in the stimulus-produced SEP caused by acceleration. They found that the SEP was not altered in any clinically significant way during these runs. This was not unexpected—rhesus macaques had experienced central nervous system disruptions only at much higher accelerations between 700-800 m/sec^2. While the findings were negative, these first human SEP experiments helped refine placement of electrodes; the restraints, it turned out, caused the hip and neck electrodes to create excessive noise. Seales did not remain to continue the work, however. In 1982 he left NBDL and took a position at the Department of Neurology at Louisiana State University, returning direction of all SEP research at the lab to Marc Weiss.[44]

An Independent Command

In some respects, 1979 was the high-water mark for the laboratory at Michoud. The first results from the SEP research were coming in, the acceleration impact research with both non-human primates and human volunteers was going full bore, vibration research was under way, and the ship motion simulator from Goleta was awaiting assembly. Ewing had every reason to be proud of his work and sure of his plans, so bolstered by his success, he conceived the idea of having his lab elevated to an independent command. Seeking higher institutional status seemed like a logical next step, one that might yield greater visibility and open new funding streams for Ewing's research programs. Buried deep within the military organizational structures, both the Wayne State and NAMRL-D operations had too often been overlooked. As a result, NAMRL-D was almost entirely dependent upon its parent NAMRL command in Pensacola and had difficulty obtaining supplemental funding outside of ONR and BUMED. Further, the civilian scientists at NAMRL-D suffered from lack of recognition by their military counterparts, and Ewing believed that they were not properly rewarded or compensated for their hard work. His mind made up, Ewing began working his contacts in ONR and BUMED to make it happen, and by mid-year the process of creating the new command was well under way. What may have been unrealistic was Ewing's apparent expectation that even as an independent command, the laboratory would continue to operate much as it always had—with minimal supervision, maximum flexibility, and an informal culture.[45]

The first indication that this might not be the case came early when the Navy set an important precondition for the transition. Since Ewing's lab conducted human experiments, protocol required that its ultimate administrator be a medical doctor. Commander Kennedy, however, was only a Ph.D. and an aerospace experimental psychologist. No matter how well he had performed as officer-in-charge of NAMRL-D or how well respected he was within his professional field, he could not hold the same position in an independent naval command. Kennedy did not mind. He was happy to transition to a full-time position as head of the Human Performance Sciences Division—the job that had formerly occupied most of his time anyway. In the meantime, a new commanding officer would be selected for the billet.[46]

In August 1979 Captain James E. Wenger arrived at NAMRL-D to assume command from Kennedy. Wenger had joined the Navy in 1966, after graduating from the Indiana University School of Medicine. By the time of his assignment to NAMRL-D, Wenger had done tours as senior medical officer aboard the USS *Bennington* (CV-20) and USS *John F. Kennedy* (CV-67). Wenger had first become familiar with NAMRL-D in early 1978 during a stint as a staff medical officer at BUMED and had met Ewing, Kennedy, and Thomas while serving on an inspection team.[47]

On February 28, 1980, while Wenger was still settling in, the Chief of Naval Operations officially established NAMRL-D as a separate command under a new name—the Naval Biodynamics Laboratory (NBDL). The official notice stated that NBDL was "To be the principal Navy Activity to conduct biomedical research on the effects of mechanical forces (motion, vibration, and impact) encountered in ships and aircraft on naval personnel; to establish human tolerance limits for these forces; and to develop preventive and therapeutic methods to protect personnel from the deleterious effects of such forces." The commissioning ceremony was held on August 14, 1980, with more than three hundred military and civilian personnel in attendance. Wenger was formally named as NBDL's first commander, while Ewing's title changed from scientific director to chief scientist.[48]

The reorganization at Michoud was part of a larger ongoing transition within BUMED as responsibilities for the administration of research programs were consolidated within the Naval Medical Research and Development Command (NMRDC). NBDL, now commanded by Wenger, fell under NMRDC in the reshuffled organizational chart, with Wenger reporting to NMRDC's skipper, Captain James F. Kelly. In earlier years, organizations outside of BUMED, such as NAVAIR and NAVSEA, had communicated directly with Ewing and Kennedy. But in August 1979, around the time of Wenger's arrival, the Navy Surgeon General informed NAVAIR's commander that medical laboratories were henceforth expected to route communications through the aviation medicine program manager, Captain Ronald K. Ohslund at NMRDC. As the designated liaison officer, Ohslund would then forward all communications to the intended recipients. The flexible administrative system that Ewing had taken advantage of for so long was beginning to stiffen.[49]

Captain James E. Wenger and Dr. Chan Ewing were all smiles when NBDL was elevated to command status in 1980. In the ensuing months their working relationship sharply deteriorated. (USAARL)

Just as NBDL began adjusting to its new status, it was left without its top civilian scientific leaders when both Chan Ewing and Dan Thomas had to take simultaneous medical leave. Ewing had developed heart trouble and underwent coronary artery surgery in 1980. His recovery required several months of hospital care and home bedrest. Meanwhile, Thomas was severely injured in car accident near Michoud and was hospitalized for several weeks. He likewise required an extended period of recovery and therapy before his physicians cleared him to return to work. Consequently, their lengthy absences at such a critical juncture made NBDL's transition from a detachment to a command even more difficult.[50]

With both Ewing and Thomas away from NBDL, Wenger had to ease the lab into the new administrative structure alone, something that required both tact and patience in dealing with the lab's previously autonomous civilian staff. Wenger's stern personality and tough command style worked against him, however, and the researchers resented the brusque and unyielding manner in which he imposed the chain of command over NBDL. He was a by-the-book administrator, and his vision of a well-defined and tightly controlled operational structure for NBDL clashed with the flexible, informal laboratory culture that had flourished under Ewing. Kennedy's tenure had been placid because he identified more with NBDL's scientists than his military peers and instinctively gave scientific priorities precedence over organizational imperatives. Wenger, as long-time NBDL photographer Art Prell put it, "really struggled with the professional scientist versus the administrator" relationship. Consequently, relations between the captain and the civilian researchers rapidly deteriorated. Ewing himself, having returned to work after his surgery to find NBDL drastically changed, inevitably grew restless, and finally rebellious, under Wenger's command. Rumors began to circulate that his days as chief scientist were numbered.[51]

The talk seemed to be confirmed when Wenger finally took disciplinary action against Ewing for insubordination. The charge, one of the most serious in a military command, was based on Ewing's refusal to begin his work days at standard military early morning hours. He instead preferred to arrive at Michoud closer to noon but then work late into the night, contrary to Wenger's repeated orders. Ewing, as NBDL's founder and driving force, had simply ignored his skipper, determined to continue running NBDL as he saw fit. So Wenger moved against him. Effective August 3, 1981, at Wenger's request, Captain Kelly at NMRDC suspended Ewing for two weeks without pay. Acting executive officer Paul Majewski announced the punishment at a meeting of NBDL department heads the next day. Amid the resulting outrage, Majewski could do little but insist that Ewing would remain chief scientist, despite his temporary suspension. Ewing stayed home and officially served out his punishment, but undeterred, he refused to stop working and remained in daily contact with NBDL using his personal telephone. He ultimately appealed his suspension through bureaucratic channels, and Secretary of the Navy John Lehman eventually ordered it struck from his record.[52]

It was natural for lab veterans to blame the controversy on differing personalities, approaches, and, ultimately, Wenger's inflexibility. But during these transition years, NBDL encountered a host of challenges that turned otherwise negotiable differences into insurmountable barriers. Most importantly, NBDL was suddenly exposed at a very bad time. During the Vietnam years, every branch of the military had been amply funded for mission-critical work. The funding, now more discretionary, still flowed for a few years, but by the last half of the decade, the energy crisis, inflation, and recession had curtailed much of the Navy's former "buying power"—even as the transition to an all-volunteer force was raising labor costs. Now out from under the protective wing of NAMRL in Pensacola, NBDL had to compete for increasingly scarce resources and found itself outmatched. Wenger had requested $386,130 to fund equipment acquisition for FY 1982, but the Navy allocated less than half that amount. During the same funding cycle, BUMED's dispersal of $815,000 to NBDL for the impact program was delayed. Then the Navy cut the number of billets for civilian NBDL employees from fifty-eight to forty-eight. In the end, Wenger managed to obtain funding for fifty-three billets, but NBDL was nevertheless essentially in a hiring freeze.[53]

All during 1981 Wenger had been fighting for NBDL on an even more important front. In January the Chief of Naval Operations failed to approve billets for new human volunteer recruits, the essential components to the biodynamics research. Wenger notified his superiors of this new hurdle, but in the fall the problem remained unresolved. NBDL continued human testing until the current crop of volunteers' eighteen-month assignments expired, but without new billets, recruitment of replacements stalled. In October 1981 Wenger warned NMRDC that "without the volunteers, all human research ceases, thereby causing significant programmatic delays." The Navy finally renewed the billets.[54]

While Wenger fought his superiors for more resources, his subordinates blamed his administration for the holdups caused by the lack of funding. Gil Willems was perturbed to find that a large number of critical supply orders had been delayed, despite personal assurances that they were on the way. As Bill Muzzy remembered, "There were long periods there where we couldn't do anything at all." In August 1981, at the height of the controversy, an exasperated Leonard Lustick wrote to Commander Lewis E. Waldeisen, NBDL director of Plans and Programs: "We are not doing the experiments. That is the purpose of this laboratory. We are not running, why not?" Work stoppages and delays made it ever more difficult to maintain a coherent research plan.[55]

There was little that Wenger could have done about the external challenges facing the lab, but in going ahead with wholesale internal reforms despite the difficulties, he clearly made things more difficult for his researchers and himself. During the Ewing and Kennedy years, the structure and responsibilities of the various departments had changed little. Every researcher knew what his duties were and how to carry them out. By bringing about sudden changes in work responsibilities, Wenger changed all of that. As an efficiency measure, Wenger considered moving data processing from Lustick's Math Sciences Department to William Anderson's Data Systems Department. Anderson vented to acting executive officer Majewski, who had been a Ewing confidant for years, although he was now Wenger's deputy. "Management has placed a very real priority on presenting a good image to the Navy chain of command," Anderson wrote, "even to the extent of compromising the efficiency of the research work. One gets the very definite impression that laboratory management neither appreciates nor understands the people or work being done at this facility." Anderson concluded that "if the situation is not turned around, this laboratory is going to lose its capacity to perform biodynamics research."[56]

One of Ewing's goals in seeking an independent command had been to obtain more recognition for civilian scientists. Instead, as Wenger reshaped the lab to correspond to prevailing expectations about military formality, the civilians began to feel slighted. Several NBDL department heads wrote that they "felt intimidated" because they were expected to adhere to Navy protocol and to address senior officers just as if they themselves were military men—and to stand up whenever the commanding officer entered their offices, work areas, and meeting rooms. Lustick believed that "there should be a distinction between military and civilians."[57] Whether Ewing had expected any of this when he set the lab on the path to independent command is unknown, but it is clear that the genie could not be put back in the bottle. In May 1982 Wenger, ever the outsider, rotated out of NBDL to another posting but died just two months later of a heart attack. Majewski, the veteran insider, departed the lab too. A new command team, Captain Loys E. Williams and Commander Wilton W. McIntosh, took NBDL's helm and continued the reorganization that Wenger had started.[58]

Unfortunately, NBDL lost its chief ONR patron in 1982 when Joe Pollard retired as director of the Biological and Medical Sciences Division. Over the years Pollard had negotiated agreements with subcontractors, including the Tulane Delta Regional Primate Center, QEI, and MCW, and found the money to support NBDL's projects. His retirement, perhaps forced due to changing times and internecine Navy politics, left a gaping hole in the support network that had sustained Ewing's enterprises since Wayne State.[59]

In 1983 NBDL suffered yet another heavy blow when Dr. Arthur Callahan, who had long served as managing liaison between Ewing's lab and its subcontractors, transferred from ONR to a position as director of the Biomedical Sciences Department at the Naval Submarine Base in Groton, Connecticut. Callahan had been one of Ewing's fiercest defenders ever since the Wayne State project. His departure, coming on the heels of Pollard's, effectively left NBDL without ONR protection and vulnerable to NMRDC's budget cuts and scientific meddling. The stress on Ewing undoubtedly became overwhelming. During this turmoil, he suffered his first heart attack, requiring yet another period of emergency leave just when NBDL needed his leadership and iron will the most. As a result, the Navy was able to set NBDL's research agenda with little regard to Ewing and his civilian scientists, with Captain Williams coming aboard as NBDL's second commander and revising its priorities and reallocating resources.[60]

Mission and Modeling

As a flight surgeon, Captain Williams had undertaken some impressive missions. He was previously the senior medical officer aboard the USS *Enterprise* (CVN-65) and at the Crew Systems Division, NAVAIR. Now at NBDL, he was intent on aligning the mission of the lab more closely with the priorities of the naval establishment. In official terms the mission was: "1) Develop procedures and guidelines to improve the health, safety, and well-being of naval personnel; 2) Evaluate the operational capability of U.S. Navy combatants in rough seas; and 3) Develop equipment and procedures to improve human operation of combat systems under the biodynamic stresses imposed by naval operations in adverse weather and sea conditions." Unofficially, this meant eliminating the vibration program, refining the ship motion simulation work, and building up the lab's non-human primate study capacity. One mission that Williams—and his two predecessors and Ewing—had not carried out, however, at least in the estimation of an independent evaluation and NMRDC's Captain Kelly, was to make sufficient progress on what was always the lab's ultimate goal: mathematical modeling.[61]

Indeed, the creation of the independent command had led the Navy to take a closer look at its investment. One high-level conclusion was that since the Air Force and Army both had similar initiatives, funding for the human response to vibration program was unnecessary, so Williams ended it. The decision to terminate was made easier when the C-210 electrodynamic device was badly damaged by a water leak at Michoud. In 1983 NBDL returned the C-210 to NASA, cutting its rental expenditures by about $14,000 per year. At that point the MTS had finally been certified for use, but with the vibration program shelved, it was used primarily to study the response of seated humans to shocks caused by underwater explosions.[62]

The Navy retained high hopes for the ship motion simulation studies at Michoud, but the program suffered a few setbacks of its own during the early 1980s. Although NBDL planned to have the SMS assembled and ready to run by 1980, repeated equipment failures and the need to acquire computerized data collection equipment delayed the man-rating process indefinitely. Also during that period, the experts who were expected to conduct the research departed NBDL. In 1981 Robert S. Kennedy left to conduct human performance work at the Canyon Research Group in California. His replacement lasted only a year before being reassigned to the Naval Medical Research Institute in Maryland. Lieutenant Commander Robert Carter, principal investigator in the PETER program, also rotated out of Michoud, taking invaluable institutional memory with him.[63]

John Guignard, who remained despite the closure of the vibration program, helped fill this void, as did another British researcher who arrived in 1984, Dr. Thomas G. Dobie. An Officer of the Order of the British Empire (OBE), Dobie had lived a very interesting life up to that point. He had served as a bomber pilot in the Royal Air Force (RAF) during World War II and then developed an interest in motion sickness research during the postwar years while serving as a test pilot and working with other aviators who had been grounded for exhibiting signs of the disorder. After earning his medical degrees from the University of Leeds and retiring as a group captain from the RAF, he had gone on to serve as chief medical officer for Saudi Airlines before he was recruited to head up motion sickness research at NBDL. Dobie soon became the mainstay of that program when the SMS finally received its man-rating certification in March 1985, while on the side he taught classes in human factors engineering at the University of New Orleans.[64]

Other NBDL staff members undertook a variety of productive tasks while they waited out the budget crunches and equipment delays of the early 1980s. "We did a lot of building maintenance," Bill Muzzy recalled, "and we built soundproof rooms up on the third floor for some of the psychology tests." One of the most ambitious projects in the period was conversion of the animal holding facility from a temporary care facility to a long-term vivarium. In tenor with the times, the move was justified as a way to provide semi-permanent care to laboratory animals on a more cost-effective basis than was possible when constantly shuttling them between Tulane and Michoud. On November 2, 1983, representatives from the American Association for Accreditation of Laboratory Animal Care visited the vivarium for inspection and accreditation. Henceforth, NBDL obtained animals through commercial purchase and participation in DOD and NIH primate recycling programs. Ultimately, the initiative resulted in an estimated savings of roughly $1,000 per month.[65]

But there was more than cost savings at stake since the expansion was also directly related to the lab's 1980s agenda. NBDL had determined that in order to scale data up from rhesus macaques to humans, an intermediate step would be necessary—testing with larger primates. The plan was to use chimpanzees (*Pan troglodytes*) or, in the event that they became scarce, baboons (*Papio*) for the next phase of impact acceleration research. In a work unit summary for FY 1984, NBDL informed Captain Kelly that to resume and sustain chimpanzee research would require approximately thirteen chimps per year. Kelly frowned on the request. Not only were chimps expensive and an increasingly endangered species, but Kelly was growing pessimistic about the outlook for NBDL's modeling efforts.[66]

There can be no doubt that construction of a mathematical model of human head and neck injury had always been Ewing's ultimate objective. But it is equally clear that up to the early 1980s, Ewing had applied only a small fraction of his laboratory's resources toward that work. NBDL, and NAMRL-D before it, had always kept some modeling-related initiatives going, but those had generally been left to contractors. QEI, Inc. had been there from the beginning, developing the methodology and hardware for the three-dimensional data acquisition upon which successful models would depend. QEI also developed the software package called EZFLOW that was used to digitize, compile, and time-lock anthropometric, photographic, and accelerometer data from analog tapes. So dependent was NBDL on QEI, in fact, that when the lab faced a contract lapse in early 1983, William Anderson warned that the consequences could include delays in digitization of instrumentation film, calibration of photographic systems, reduction of x-ray anthropometry, and conversion of accelerometer data to UNIVAC format.[67]

While QEI worked to help NBDL improve its data, another pair of researchers helped develop information that would be at the center of the mathematical model: accurate establishment of the center of gravity, moment of inertia, and mass of the human head and neck. NAMRL-D's Ed Becker and Tulane professors Leon Walker and Edward Harris had done invaluable work on these measurements in the early 1970s. But there was one deficiency recognized at the time—the measurements were taken from embalmed cadavers. Becker had been aware of the problem from the beginning, reporting that "the specimens themselves are changed considerably from the living state as a result of the embalming procedures." To improve upon these results, Ewing reached out to Dr. Wolfgang Spann and Dr. Gundolf Beier at the University of Munich's Forensic Institute. The institute was in the unusual position of having access to "fresh," unembalmed cadavers, mostly car crash victims, and was well known in Europe for its unique brand of impact injury research and data collection based on the thousands of autopsies it performed over the years.[68]

Under contract to ONR, Spann and Beier began replicating the earlier work with fresh cadavers. Since prior research had shown that there was no detectable difference in brain weight of cadavers kept at 4 to 6º C (39.2 to 42.8º F) during the first one hundred hours after death, Spann and Beier took all of their measurements within five days using a stereotaxic jig like the one designed earlier by Becker. A study of twenty-one cadaver heads between 1975 and 1977 determined the mean weight of the human head to be 4,305 g, closely conforming to Walker's finding of 4,376 g. However, Spann and Beier noticed a "significant difference" in the form of a 1 cm variation in the mean center of gravity located in Walker's study. Impressed by the Germans' diligence, Ewing used the updated information on anatomical constants in the impact program at NBDL.[69]

The contractor most directly involved in modeling was Desmatics, Inc., based in State College, Pennsylvania. Starting in 1979, Desmatics began developing statistically based models using the data from both human and rhesus runs. Desmatics even began grappling with the problem of scaling the experimental results of the $-G_x$ rhesus runs to other species. It had been Desmatics that recommended that NBDL undertake chimpanzee testing in the early 1980s after it determined that the effective scaling of data from rhesus macaques to humans would require "injury data for at least two species of subhuman primates in order to construct a statistical injury prediction model for humans." By then, Desmatics had helped identify integral variables (initial position and rotational forces, in particular), but as yet there was no progress—nor even a compelling plan—for scaling a full mathematical model.[70]

While his lab was working with a variety of contractors, Ewing was in close touch with military researchers working on another front. The Naval Air Development Center (NADC) Aircraft and Crew Systems Technology Directorate spent much of the 1970s developing a simulator to determine how and when a human pilot would make contact with structures in the aircraft cockpit during crash or ejection. The effort was immensely collaborative—NADC worked with the Naval Engineering Center, the Naval Weapons Center, and the FAA on the project. Enormous amounts of data were required to create computer models to study human response within the context of an aircraft cockpit. Required input included not only three-dimensional geometric data on the structure of the cockpit but also anthropometric and dynamic response data, which was forthcoming from NBDL.[71]

The entrance to the Naval Biodynamics Laboratory at Michoud. (USAARL)

Georg D. Frisch, NBDL's representative at NADC during the early 1980s, had access to NADC computers running crash simulation software produced by Calspan Corporation, Ultrasystems, Inc., and Boeing. His work showed that large pilots were most likely to hit the instrument panel, particularly with their feet. He also found that some of the aircraft ejection seats contributed to poor cervical spine alignment, which increased the probability of injury. Most importantly, Frisch compared the predicted responses of humans during crashes generated by the NADC software with the actual results developed by NBDL. None of the programs were able to closely replicate the test data developed by NBDL. Whether this was best attributed to the shortcomings of the software or the limitations of the informational input was a matter of contention.[72]

By the 1980s, however, the lab's lack of progress in modeling had also become a cause for concern, both within and outside NBDL. Working with its vendors, NBDL was building critical components necessary to produce and validate a three-dimensional model of human dynamic response to impact. But more could be done in bringing the information together and building potential models for evaluation, and it required close and consistent coordination. William Anderson and Ed Becker routinely interfaced with QEI and Desmatics, but neither they nor anyone else at NBDL ever had direct responsibility for the modeling effort. In 1980 Becker resigned, admitting that he was "frustrated in that we were collecting lots of data but the intent seemed to be creating a resource for study rather than studying that resource directly."[73]

Four years later NMRDC commissioned an independent review by the American Institute of Biological Sciences (AIBS). The reviewers led with the good news, lauding what was "probably the most comprehensive and well-documented collection of human head and neck data in the world." But AIBS also pointed out that "the collection of data alone is not a biomechanical endpoint for injury-criteria research or for manikin development." AIBS went on to note that NBDL had apparently conducted much of its impact research "in an isolated atmosphere," making little effort to study, let alone use, head-neck models developed at other institutions. A year later, Captain Kelly of NMRDC was even less charitable, questioning the rationale that had underpinned Ewing's project almost from the beginning. "The entire biodynamics protocol pivots upon the establishment of scaling factors," Kelly wrote. "While there are obvious intuitive generalizations which can be made for scaling between rhesus macaques, to chimpanzees, to humans, the justification presentation within the protocol itself must include a greatly expanded discussion of the scaling issue."[74]

Chan Ewing's lab had been highly productive in the late 1970s, and despite the budget cuts and administrative reforms of the early 1980s, it had continued to pile up invaluable and ultimately irreproducible data. Due to time and technological constraints, however, Ewing had been unable to bring the same level of systematic effort to the modeling process that he did to his experimental regime. By 1983 his inability to put his third and final pillar into place, coupled with the increasingly negative consequences of NBDL's elevation to independent command, had raised questions about the lab's future.

As the uncertainties mounted, so did NBDL's personnel losses. In July 1983 Fred Unterharnscheidt followed Kennedy, Majewski, and Becker out the door, although he continued to work for NBDL as a contractor. In early January 1984, Ewing himself retired, still ailing from his heart trouble and fed up with Navy interference and criticism of the lab he had done so much to create and lead. "He just couldn't put up with it anymore," Dan Thomas later remembered. Similarly frustrated and disillusioned, Thomas exited alongside Ewing. Once he was out the door, he informed Senators Jeremiah Denton of Alabama and Russell Long of Louisiana that "many of the scientists have left NBDL in a state of dissatisfaction" due to the "deterioration" that had happened since 1980. "I no longer believe that the Medical Research and Development Command (MRDC) is capable of effective internal self-criticism and scientific leadership," Thomas wrote.[75]

Ewing landed a job as the president of the American Biodynamics Corporation and continued promoting his research interests in the private sector for years to come. Thomas, for his part, went to work for the Celanese Corporation, also in the private sector. Although they were out of government service, Ewing and Thomas never entirely gave up on NBDL. Now on the outside looking in, but not without some influence within Navy and scientific circles, they maintained a strong mutual concern for the facility's precious data and never hesitated to speak out on its behalf.

In the meantime, NBDL faced the second half of the 1980s and the early 1990s with lots of data and little institutional memory. And it remained to be seen whether the AIBS assessment would stand as an indicator for forward progress or an inventory of past shortcomings as NBDL lurched through the final years of the Cold War and toward its ultimate fate in the following era of military lab closures and consolidation.

CHAPTER FOUR ENDNOTES

[1] NBDL, *Naval Biodynamics Laboratory Initial Command History: Calendar Years 1980 and 1981* (New Orleans: NBDL, 1982), 4; NBDL, *Command History for Calendar Years 1984 and 1985* (New Orleans: NBDL, 1986), 3.

[2] Letter from D. J. Thomas, Acting Head, Bioengineering Sciences Department, NAMRL-D, to Contracting Officer, Code 19P10, ATTN: Mrs. Laura Subel, Naval Air Station, Pensacola, dated March 19, 1976, Subj: "N00203 76 RQ 00149 (CVC Products)," FY 1976 Reading Files, Neel Aeromedical Center, USAARL; Robert S. Kennedy, CV; NBDL, *Naval Biodynamics Laboratory Initial Command History: Calendar Years 1980 and 1981*, 4; Anon., "CDR Robert S. Kennedy, MSC, USN," *Journal of Aviation, Space, and Environmental Medicine* 48 (1977): 391.

[3] James Rife Oral History Interview with Robert S. Kennedy, January 20, 2017, 2-5.

[4] Letter from Channing L. Ewing, Capt., MC, USN, to Capt. J. W. Johnson, MC, USN, Department of the Navy, Bureau of Medicine and Surgery, dated August 29, 1972, Subj: "BuMED-49-dll of 16 Aug 1972," NARA-CP, RG 52, Naval Medical Research and Development Command [hereinafter NMRDC] Project Files and Reports, 1967-1982, Entry no. UD-04W1, Box 10, F: "NBDL MF58.524.02E-0001 (NEW)"; BUMED DD-1498 form for OIC/NAMRL, dated January 9, 1974, Subj: "MF51.5241017-0001 Change," NARA-CP, RG 52, NMRDC Project Files and Reports, 1967-1982, Entry no. UD-04W1, Box 10, F: "NBDL MF58.524.02E-0001 (NEW)"; Email from Daniel J. Thomas to William Thomas, dated April 13, 2016.

[5] Email from Daniel J. Thomas to William Thomas, dated April 13, 2016; James Rife Oral History Interview with Robert S. Kennedy, January 20, 2017, 3.

[6] NBDL, *Naval Biodynamics Laboratory Initial Command History: Calendar Years 1980 and 1981*, 5; Letter from L. D. Holmes, Manager, Contract Administration, Space Division, Chrysler Corp., to NAMRL Detachment, ATTN: Captain C. L. Ewing, dated April 4, 1972, Subj: "Chrysler Corporation Space Division Proposal MK-73; Technical Support for the Naval Aerospace Medical Research Laboratories Detachment," NARA-CP, RG 52, NMRDC Project Files and Reports, 1967-1982, Entry no. UD-04W1, Box 10, F: "NBDL MF58.524.02E-0001 (NEW)"; William H. Muzzy III, Channing L. Ewing, and Perry W. Seal, "Industrial Electrodynamic Vibrator for Human Experimentation – A Feasibility Study," in *Proceedings of the Eighth Human Response to Vibration Conference* (University of Salford, England, September 17-19, 1973), 1-6 [copy of the paper available at the Neel Aeromedical Center, USAARL]; for more on M.B. Electronics, Inc. as a pioneer in vibration technology and its work with the Navy and NASA, see John Judd and George Fox Lang, "MB Electronics – A Nearly Forgotten Important Piece of Our History," *Sound and Vibration* 47 (April 2014): 10-15.

[7] Gil Willems, Memorandum for Record, dated January 29, 1974, Subj: "Rhesus 3148 Vibration Tests, 10-17 January 1974," Neel Aeromedical Center, USAARL; Memorandum from Ed Becker, Assistant for Inertial Instrumentation, to Chief, Instrumentation Division, dated April 9, 1974, Subj: "T-Plate Vibration," Neel Aeromedical Center, USAARL.

[8] NBDL's command histories are misleading in that they indicate that the MTS shaker was not installed until the 1980s. The MTS shaker was installed in 1975 and was used for rhesus ma-

caque runs. The confusion in the command histories likely stems from the fact that the MTS shaker was not man-rated until the early 1980s. For evidence of the MTS in the 1970s, see NBDL, "Physiological Effects of Ship Motion on Crew Members," DD-1498 form, RTWUS, dated October 1, 1976, NARA-CP, RG 52, NMRDC Project Files and Reports, 1967-1982, Entry no. UD-04W1, Box 10, F: "NBDL MF58.524.02E-0001 (NEW)"; W. R. Anderson, R. A. Boster, and G. C. Willems, "Empirical Model of Intracranial Pressure and Head Motion Resulting from a Vibrating Seated Rhesus," *Aviation, Space, and Environmental Medicine* 49, no. 1 (1978): 240-252; NBDL, *Command History for Calendar Year 1982* (New Orleans: NBDL, 1983), 2.

[9] Anon., "Obituary Listing," *Journal of Aviation, Space, and Environmental Medicine* 85, no. 6 (June 2014): 686.

[10] William H. Muzzy III, Channing L. Ewing, and Perry W. Seal, "Industrial Electrodynamic Vibrator for Human Experimentation – A Feasibility Study," 1-6.

[11] James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 15; William H. Muzzy III, Channing L. Ewing, and Perry W. Seal, "Industrial Electrodynamic Vibrator for Human Experimentation – A Feasibility Study," 5.

[12] NBDL, *Naval Biodynamics Laboratory Initial Command History: Calendar Years 1980 and 1981*, 5; J. C. Guignard, C. L. Ewing, G. C. Willems, W. Anderson, W. H. Muzzy III, D. J. Thomas, and P. L. Majewski, "A Method for Studying Human Biodynamic Responses to Whole-Body Z-Axis Vibration," in *AGARD Conference Proceedings no. 267 on High-Speed, Low-Level Flight: Aircrew Factors*, ed. David H. Glaister (London: Technical Editing and Reproduction, Ltd., 1980), 9-1 – 9-2.

[13] J. C. Guignard et al., "A Method for Studying Human Biodynamic Responses to Whole-Body Z-Axis Vibration," in *AGARD Conference Proceedings no. 267 on High-Speed, Low-Level Flight: Aircrew Factors*, 9-1 – 9-7; NBDL, *Naval Biodynamics Laboratory Initial Command History: Calendar Years 1980 and 1981*, 32.

[14] See letter with enclosures from C. L. Ewing, Capt., MC, USN, Officer in Charge, to Captain John Johnson, MC, USN, Bureau of Medicine and Surgery (Code 7114), Navy Department, Washington, D.C., dated April 13, 1973, NARA-CP, RG 52, NMRDC Project Files and Reports, 1967-1982, Entry no. UD-04W1, Box 10, F: "NBDL MF58.524.02E-0001 (NEW)." Ewing misspelled Hiatt's name. Dr. Edwin Peele Hiatt (M.D., Duke University; Ph.D., University of Maryland) was a professor of physiology at Ohio State University at the time. See OSU, "College of Medicine: School of Allied Medical Professions, School of Nursing," *The Ohio State University Catalog* 1, no. 13 (Columbus, OH: The Ohio State University, April 17, 1969), 10.

[15] See letter with enclosures from C. L. Ewing, Capt., MC, USN, Officer in Charge, to Captain John Johnson, MC, USN, Bureau of Medicine and Surgery (Code 7114), Navy Department, Washington, D.C., dated April 13, 1973, NARA-CP, RG 52, NMRDC Project Files and Reports, 1967-1982, Entry no. UD-04W1, Box 10, F: "NBDL MF58.524.02E-0001 (NEW)."

[16] Anon., "Summary Concerning NAMRL letter L6/ver of 30 August 1973 to the Project Manager, Surface Effect Ships Project," Subj: "SES Man/Machine Effects," FY 1973 Reading Files, Neel Aeromedical Center, USAARL; H. R. Jex, R. J. DiMarco, and W. F. Clement, "Effects of Simulated Surface Effect Ship Motions on Crew Habitability – Phase II. Volume 3: Visual-Motor Tasks and Subjective Evaluations," Technical report no. 1070-3 (Bethesda, MD:

Department of the Navy, May 1977), i, v, 9; D. J. Thomas, P. L. Majewski, J. C. Guignard, and C. L. Ewing, "Effects of Simulated Surface Effect Ship Motions on Crew Habitability – Phase II. Volume Five: Clinical Medical Effects on Volunteers," Technical report 1070-5 (Bethesda, MD: Department of the Navy, May 1977), iii. In publications of the era, the ONR motion generator was known as the "MOGEN." Since the staff at NBDL subsequently referred to it as the Ship Motion Simulator (SMS), the author has opted to use the latter acronym to avoid confusion.

[17] James Rife Oral History Interview with Robert S. Kennedy, January 20, 2017, 1; J. C. Guignard and Michael E. McCauley, "Motion Sickness Incidence Induced by Complex Periodic Waveforms," in *Gateways to the Future: Proceedings of the Human Factors Society 21st Annual Meeting,* ed. Alan S. Neal and Robert F. Palasek (Santa Monica, CA: Human Factors Society, 1977), 197; R. J. DiMarco and H. R. Jex, "Effects of Simulated Surface Effect Ship Motions on Crew Habitability – Phase II. Volume 2: Facility, Test Conditions, and Schedules," TR-1070-2 (Hawthorne, CA: Systems Technology, Inc., 1977), v.

[18] James Rife Oral History Interview with Robert S. Kennedy, January 20, 2017, 1, 3-6; Paul L. Majewski, "Final Report on the Medical Effect of Simulated 2000 Ton Surface Effect Ship Motions on Human Volunteer Subjects, August and October 1974," Letter report dated July 29, 1975, 5, copy located at the Neel Aeromedical Center, USAARL; Mary M. Harbeson, Michele Krause, Robert S. Kennedy, and Alvah C. Bittner, Jr., "The Stroop as a Performance Evaluation Test for Environmental Research," *The Journal of Psychology* 111 (1982): 224.

[19] James Rife Oral History Interview with Robert S. Kennedy, January 20, 2017, 3-6; R. S. Kennedy and A. C. Bittner, Jr., "Progress in the Analysis of a Performance Evaluation Test for Environmental Research (PETER)," in *Proceedings of the 22nd Annual Meeting of the Human Factors Society* (Santa Monica, CA: Human Factors Society, 1978), 29; Alvah C. Bittner, Jr., Robert C. Carter, Robert S. Kennedy, Mary M. Harbeson, and Michele Krause, "Performance Evaluation Tests for Environmental Research (PETER): Evaluation of 112 Measures," NBDL-84R006 (New Orleans: NBDL, September 1984), ii.

[20] DD 1498 form, Subj: "Work Unit Number ZF51.524.026-3000 Change physiological effects of ship motion on crew members," dated August 14, 1978, NARA-CP, RG 52, NMRDC Project Files and Reports, 1967-1982, Entry no. UD-04W1, Box 10, F: "NBDL MF58.524.02E-0001 (NEW)"; James Rife Oral History Interview with Robert S. Kennedy, January 20, 2017, 3-6; NBDL, *Naval Biodynamics Laboratory Initial Command History: Calendar Years 1980 and 1981*, 26; William H. Muzzy III, "Ship Motion Generator Upgrade Study," NBDL-83R012 (New Orleans: NBDL, 1983), ii.

[21] National Transportation Safety Board, "Aircraft Accident Report, Mohawk Airlines, Inc., Fairchild Hiller, FH-227B, N7818M, Albany, New York, March 3, 1972," Report Number NTSB-AAR-73-8, April 11, 1973, http://libraryonline.erau.edu/online-full-text/ntsb/aircraft-accident-reports/AAR73-08.pdf; House Committee on Public Works and Transportation, *Cabin Safety "SAFER Committee" Update (Aircraft Passenger Seat Structural Design): Hearings Before the Subcommittee on Oversight and Review of the Committee on Public Works and Transportation, June 3-5, and September 10, 1980,* 96th Cong., 2nd sess., 1980, 9.

[22] For examples of other studies on lateral impact acceleration, see Edmund B. Weis, Jr., Neville P. Clarke, and James W. Brinkley, "Human Response to Several Impact Acceleration Orientations and Patterns," *Aerospace Medicine* 34, no. 12 (December 1963): 1122-1129; J. P. Stapp and E. R. Taylor, "Space Cabin Landing Impact Vector Effects on Human Physiology,"

Aerospace Medicine 35, no. 12 (1964): 1117-1132; A. V. Zaborowski, "Lateral Impact Studies, Lap Belt Shoulder Harness Investigations," in *Proceedings of the Ninth Stapp Car Crash Conference* (Warrendale, PA: SAE, 1966), 93-127; A. V. Zaborowski, "Human Tolerance to Lateral Impact with Lap Belt Only," in *Proceedings of the Eighth Stapp Car Crash Conference* (Detroit: Wayne State University Press, 1966), 34-70. After Stapp's time at Holloman, R. W. Sonntag, Jr., conducted some lateral runs using the Daisy Decelerator; C. L. Ewing, D. J. Thomas, L. Lustick, W. H. Muzzy III, G. C. Willems, and P. Majewski, "Dynamic Response of the Human Head and Neck to $+G_y$ Impact Acceleration," in *Proceedings of the Twenty-First Stapp Car Crash Conference* (Warrendale, PA: SAE, 1977), 550-551.

[23] NBDL Run Index, Neel Aeromedical Center, USAARL; C. L. Ewing et al., "Dynamic Response of the Human Head and Neck to $+G_y$ Impact Acceleration," 549-586; C. L. Ewing, D. J. Thomas, L. Lustick, W. H. Muzzy III, G. C. Willems, and P. Majewski, "Effect of Initial Position on the Human Head and Neck Response to +Y Impact Acceleration," in *Proceedings of the Twenty-Second Stapp Car Crash Conference* (Warrendale, PA: SAE, 1978), 136; Email from Daniel J. Thomas to James Rife, dated November 22, 2016; SAE, ed., *Proceedings of the Twenty-First Stapp Car Crash Conference* (Warrendale, PA: SAE, 1978).

[24] Eighteen of the syncope cases occurred before impact, and all of the runs were aborted by the monitoring physician. Eleven instances of syncope occurred after impact. See D. J. Thomas, C. L. Ewing, P. L. Majewski, and N. S. Gilbert, "Clinical Medical Effects of Head and Neck Response During Biodynamic Stress Experiments," in *AGARD Conference Proceedings no. 267 High-Speed, Low-Level Flight: Aircrew Factors*, 15-1, 15-12; P. L. Majewski, T. J. Borgman, Jr., D. J. Thomas, and C. L. Ewing, "Transient Intraventricular Conduction Defects Observed During Experimental Impact in Human Subjects," in *AGARD Conference Proceedings no. 253: Models and Analogues for the Evaluation of Human Biodynamic Response, Performance and Protection*, ed. Henning von Gierke (London: Technical Editing and Reproduction, Ltd., 1979), A6-1 – A6-11; for information on Dr. Gilbert, see his obituary, "Dr. Norman S. Gilbert, medical researcher," *The Times-Picayune*, January 5, 2002; for the responsibilities of Ewing and Thomas in regard to volunteers, see "Recommendation of the Committee for the Protection of Human Subjects," attached to DD-1498 form "Physiological effects of ship motion on crew members," dated August 11, 1978, NARA-CP, RG 52, NMRDC Project Files and Reports, 1967-1982, Entry no. UD-04W1, Box 10, F: "NBDL MF58.524.02E-0001 (NEW)."

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[26] NBDL, *Naval Biodynamics Laboratory Initial Command History: Calendar Years 1980 and 1981*, 24; Invoice from CVC to Navy Regional Financial Center, Norfolk, VA, dated November 9, 1976, Neel Aeromedical Center, USAARL; Memorandum from R. S. Kennedy, Officer in Charge, NAMRL-D, to Assistant Chief of Supply Services, NARMC, Attn: S. M. Brodsky, Lt., MSC, USN, dated November 18, 1977, Subj: "Omnidirectional Impact Acceleration Sled (Contract no. N00204-76-B-0008)," Neel Aeromedical Center, USAARL.

[27] James Rife Oral History Interview with Art Prell, August 18, 2017, 7-8; Memorandum from Bill Muzzy, Head, Engineering Department, to Administrative Officer, dated September 15, 1980, Subj: "Photography Laboratory Support – FY 81, Eglin AFB," Neel Aeromedical Center, USAARL; NBDL, *Naval Biodynamics Laboratory Initial Command History: Calendar Years 1980 and 1981*, 24; Patricia D. Kilgore and Joseph H. Gottbrath, "Photodigitizing Pro-

cedures," NBDL-84R002 (New Orleans: NBDL, 1984), 4; G. Willems, W. Muzzy, W. Anderson, and E. Becker, "Cinematography Data Systems at the Naval Biodynamics Laboratory," in *Proceedings of SPIE – The International Society for Optical Engineering vol. 291: Second International Symposium of Biomechanics Cinematography and High Speed Photography*, ed. Juris Terauds (Bellingham, WA: SPIE, 1981): 91.

[28] House Committee on Public Works and Transportation, *Cabin Safety "SAFER Committee" Update (Aircraft Passenger Seat Structural Design): Hearings Before the Subcommittee on Oversight and Review of the Committee on Public Works and Transportation, June 3-5, and September 10, 1980*, 96th Cong., 2nd sess., 1980, 668-677; NBDL, *Naval Biodynamics Laboratory Initial Command History: Calendar Years 1980 and 1981*, 2.

[29] Carol A. MacLennan, "From Accident to Crash: The Auto Industry and the Politics of Injury," *Medical Anthropology Quarterly*, new ser., 2, no. 3 (September 1988): 242, 244, and 248; Thomas O. McGarity, *Freedom to Harm: The Lasting Legacy of the Laissez Faire Revival* (New Haven, CT: Yale University Press, 2013), 149.

[30] Emphasis reproduced from source. See U.S. House Committee on Public Works and Transportation, *Cabin Safety "SAFER Committee" Update (Aircraft Passenger Seat Structural Design): Hearings Before the Subcommittee on Oversight and Review of the Committee on Public Works and Transportation, June 3-5, and September 10, 1980*, 96th Cong., 2nd sess., 1980, 670, 672.

[31] William Thomas Oral History Interview with Daniel J. Thomas, March 8, 2016, 40-41. Whiplash is a poorly defined and often misused term. As Stapp has noted, whiplash has been used to indicate a mechanism that can produce injury but should not be used as a diagnostic term. See John P. Stapp, "Historical Review of Impact Injury and Protection Research," in *Impact Injury of the Head and Spine*, ed. C. L. Ewing, D. J. Thomas, A. Sances, Jr., and S. J. Larson (Springfield, Ill.: Charles C. Thomas, 1983), 24; Philip Yarnell and Ayub K. Ommaya, "Experimental Cerebral Concussion in the Rhesus Monkey," *Bulletin of the New York Academy of Medicine* 45 (January 1969): 39-45.

[32] Daniel J. Thomas and M. Eugene Jessop, "Experimental Head and Neck Injury," in *Impact Injury of the Head and Spine*, 201, 205, 215; Email from Daniel J. Thomas to James Rife, dated November 22, 2016; T. D. Clarke, D. C. Smedley, W. H. Muzzy, C. D. Gragg, R. E. Schmidt, and E. M. Trout, "Impact Tolerance and Resulting Injury Patterns in the Baboon Air Force Shoulder Harness-Lap Belt Restraint," in *Proceedings of the Sixteenth Stapp Car Crash Conference* (Warrendale, PA: SAE, 1972), 365-411; D. J. Thomas and M. E. Jessop, "Experimental Head and Neck Injuries from Inertial Forces," in *Proceedings of the Thirty-Seventh Annual Conference of Engineering in Medicine and Biology* (Los Angeles, CA, September 17-19, 1984), 291; D. J. Thomas and M. E. Jessop, "Experimental Head and Neck Injuries in the Rhesus Monkey from +X Impact Acceleration [abstract]," *Symposium on Mechanisms of Head and Spine Trauma* (Marco Beach, FL, November 15-20, 1983).

[33] Daniel J. Thomas and M. Eugene Jessop, "Experimental Head and Neck Injury," 201, 205, 215; William Thomas Oral History Interview with Daniel J. Thomas, March 8, 2016, 43; James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 9-11.

[34] NBDL, "Procedure for Digitizing High Acceleration Animal Film," dated March 20, 1980, Neel Aeromedical Center, USAARL.

[35] Friedrich Unterharnscheidt, "Neuropathology of Rhesus Monkeys Subjected to $-G_x$ Impact Acceleration," AD A089829, Office of Naval Research contract N00014-78-C-0800 (New

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[36] William Thomas Oral History Interview with Daniel J. Thomas, March 8, 2016, 22-24, 26; Email from Daniel J. Thomas to James Rife, dated February 23, 2017; Email from Daniel J. Thomas to William Thomas, dated February 11, 2016; Friedrich Unterharnscheidt, "Neuropathology of the Rhesus Monkey Undergoing $-G_x$ Impact Acceleration," in *AGARD Conference Proceedings no. 322 on Impact Injury Caused by Linear Acceleration: Mechanisms, Prevention and Cost*, ed. J. L. Haley, Jr. (London: Technical Editing and Reproduction, Ltd., 1982), 17-14.

[37] Channing L. Ewing and Friedrich Unterharnscheidt, "Neuropathology and Cause of Death in U.S. Naval Aircraft Accidents," B16-1 – B16-6.

[38] William Thomas Oral History Interview with Daniel J. Thomas, March 8, 2016, 29-30, 33; David L. Matson, "Naval Biodynamics Laboratory Research in Human Response to Impact Acceleration," *Shock and Vibration Technology Review* 1, no. 11 (November 1991): 3.

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[40] William Thomas Oral History Interview with Daniel J. Thomas, dated March 8, 2016, 29-30; Michael D. Berger and Marc S. Weiss, "Effects of Impact Acceleration on Somatosensory Evoked Potentials," in *Impact Injury of the Head and Spine*, 324.

[41] Marc S. Weiss and Michael D. Berger, "The Effect of Impact Acceleration on the Electrical Activity of the Brain," in *AGARD Conference Proceedings no. 253: Models and Analogues for the Evaluation of Human Biodynamic Performance and Protection*, A20-1 – A20-9; see Dan Thomas's comments during the Round Table Discussion published in *AGARD Conference Proceedings no. 322 on Impact Injury Caused by Linear Acceleration: Mechanisms, Prevention and Cost*, RTD-5.

[42] Marc S. Weiss and Michael D. Berger, "Neurophysiological Effects of –X Impact Acceleration," in *AGARD Conference Proceedings no. 322 on Impact Injury Caused by Linear Acceleration: Mechanisms, Prevention and Cost*, 14-1 – 14-6.

[43] William Thomas Oral History Interview with Daniel J. Thomas, March 8, 2016, 13, 31-32.

[44] D. M. Seales, A. C. Bittner, Jr., M. S. Weiss, and S. N. Morrill, "'Short-Latency'" Somatosensory Evoked Potentials during Experimentally Induced Biodynamics Stress in Humans," NBDL-85R002 (New Orleans: NBDL, 1985). The 1985 report is a reprint of a paper presented at the 2nd International Evoked Potentials Symposium held in October 1982 in San Diego, CA; David L. Matson, "Human Short-Latency Somatosensory Evoked Potentials in Impact Acceleration Research: Equipment, Procedures and Techniques," NBDL-89R001 (New Orleans: NBDL, October 1990); David L. Matson, "Naval Biodynamics Laboratory Research in Human Response to Impact Acceleration," *Shock and Vibration* 1, no. 11 (November 1991): 7.

[45] James Rife Oral History Interview with Daniel J. Thomas, July 12, 2016, 32-33.

[46] James Rife Oral History Interview with Robert S. Kennedy, January 20, 2017, 6-7.

[47] Officer Biography Sheet for James Edward Wenger, dated June 18, 1970, Naval History and Heritage Command [hereinafter NHHC] Archives; *USS John F. Kennedy, 1975-1976 Cruisebook*, NHHC Library; Capt. J. E. Wenger, MC, USN, Briefing Report, dated February 8, 1978, Subj: "Visit to Naval Aerospace Medical Research Laboratory Detachment, Michoud, LA," NARA-CP, RG 52, Entry no. UD-WW 10, Central Correspondence Files, 1/1978-12/1978, Box 1, F: "NAMRL 1978."

[48] OPNAV Notice 5450 announced the elevation of NAMRL-D to command status under the new name of NBDL. See NBDL, *Naval Biodynamics Laboratory Initial Command History: Calendar Years 1980 and 1981*, 1, 18.

[49] NMRDC was founded on July 1, 1974. See Charles W. Shilling, *History of the Research Division of the Bureau of Medicine and Surgery, U.S. Department of the Navy* (Washington, D.C.: Department of the Navy, 1975), iv; Department of the Navy, *RDT&E Management Guide* (Washington, D.C.: Government Printing Office, 1983), 1-3. Captain Ohslund had additional duty as the head of Aeromedical Research at BUMED. See letter from W. P. Arentzen, Chief, Bureau of Medicine and Surgery, to Commander [Capt. J. B. Wildman], Naval Air Systems Command, dated August 13, 1979, Subj: "Human Impact Injury Prevention Program," NARA-CP, RG 52, Entry no. UD-WW 11, Central Correspondence Files, 1/1979-12/1979, Box 4, F: "3900 1979."

[50] Email from Daniel J. Thomas to James Rife, dated March 27, 2017.

[51] James Rife Oral History Interview with Art Prell, August 18, 2016, 12-13; P. L. Majewski, "Naval Biodynamics Laboratory Department Head Meeting Minutes," dated August 4, 1981, Neel Aeromedical Center, USAARL.

[52] P. L. Majewski, "Naval Biodynamics Laboratory Department Head Meeting Minutes," dated August 4, 1981, Neel Aeromedical Center, USAARL; James Rife Oral History Interview with Robert S. Kennedy, January 20, 2017, 8-9; James Rife Oral History Interview with Art Prell, August 18, 2016, 11-12.

[53] J. E. Wenger, Commanding Officer, NBDL, to Commanding Officer, NMRDC, dated October 15, 1981, Subj: "Quarterly Report," Neel Aeromedical Center, USAARL. For perspective on military-wide challenges during the late 1970s and early 1980s, see Andrew Feickert and Stephen Daggett, "A Historical Perspective on 'Hollow Forces,'" Congressional Research Service Report for Congress R42334, January 31, 2012.

[54] J. E. Wenger, Commanding Officer, NBDL, to Commanding Officer, NMRDC, dated Oc-

tober 15, 1981, Subj: "Quarterly Report," Neel Aeromedical Center, USAARL. For Wenger's explanations of the volunteer billet issue during the fall of 1981, see Joan Holland, "Minutes of NBDL Staff Meeting – 3 Sept. 1981," and Margaret Carter, "Naval Biodynamics Laboratory Department Head Meeting," dated August 4, 1981, Neel Aeromedical Center, USAARL.

[55] P. L. Majewski, "Naval Biodynamics Laboratory Department Head Meeting Minutes," dated August 4, 1981; "Department Head Meeting, Naval Biodynamics Laboratory," dated July 21, 1981, Neel Aeromedical Center, USAARL; James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 27; Email from Edward Becker to James Rife, dated November 18, 2016.

[56] Memorandum from William Anderson, Head, Data Acquisition Systems Department, to Executive Officer, dated October 9, 1981, Subj: "Reorganization of Data Processing," FY 1981 Reading Files, Neel Aeromedical Center, USAARL.

[57] James Rife Oral History Interview with Daniel J. Thomas, July 12, 2016, 32; P. L. Majewski, "Naval Biodynamics Laboratory Department Head Meeting Minutes," dated August 4, 1981; "Department Head Meeting, Naval Biodynamics Laboratory," dated July 21, 1981, Neel Aeromedical Center, USAARL.

[58] Captain James E. Wenger Obituary, http://peacetime-casualties.mooseroots.com/l/15939/James-Edward-Wenger; NBDL, *Naval Biodynamics Laboratory Initial Command History: Calendar Years 1980 and 1981*, 55; Anon., *USS Enterprise (CVN 65) WestPac Cruise Book 1978* (n.p.: American Yearbook Co., 1978?), 178; Sandy Russell, "Oak Leaf Golden Wings," *Naval Aviation News* 64 (January 1982): 11; "Newsmakers [L. Eugene Williams]," *The Palm Beach Post* (West Palm Beach, FL), December 1, 1985; "Medical Department Roster," *Navy Medicine* 75, no. 1 (January-February 1984): 4.

[59] "Joseph P. Pollard," *Aviation, Space, and Environmental Medicine* 77, no. 12 (December 2016): 1308; James Rife Oral History Interview with Daniel J. Thomas, July 12, 2016, 25, 29, 42, 57.

[60] "Dr. Arthur B. Callahan," *The Frederick News-Post* (Frederick, MD), February 17, 2011; Email from Daniel J. Thomas to James Rife, dated March 27, 2017.

[61] NBDL, *Command History for Calendar Years 1984 and 1985*, 20.

[62] NBDL, *Command History for Calendar Year 1983* (New Orleans: NBDL, 1984), 2; J. E. Wenger, Commanding Officer, NBDL, to Commanding Officer, NMRDC, dated October 15, 1981, Subj: "Quarterly Report," Neel Aeromedical Center, USAARL; NBDL, *Command History for Calendar Year 1986* (New Orleans: NBDL, 1987), 2.

[63] NBDL, *Command History for Calendar Years 1984 and 1985*, 1; NBDL, "Physiological and Performance Effects of Ship Motion on Crew Members," DD-1498 Form, Research and Technology Work Unit Summary (hereinafter RTWUS), dated October 1, 1982, NARA-CP, RG 52, NMRDC Project Files and Reports, 1967-1982, Entry UD-04W1, Box 10, F: "NBDL MF58.524.02E-0001 (NEW)"; for Shannon's departure, see NBDL, "Human Performance Effects of Ship Motion," DD-1498 Form, RTWUS, dated November 30, 1982, NARA-CP, RG 52, NMRDC Project Files and Reports, 1967-1982, Entry UD-04W1, Box 10, F: "NBDL MF58.524.02E-0003"; James Rife Oral History Interview with Robert S. Kennedy, dated January 20, 2017, 6-7, 10; also see Robert S. Kennedy's resume located at http://rskassessments.com/index_files/Page440.htm.

[64] Dr. Thomas G. Dobie Biography and Resume, http://www.uno.edu/coe/naval-architec-

ture-marine-engineering/faculty/dobie.aspx; James Rife Oral History Interview with Thomas G. Dobie, October 25, 2016, 3-4; James Rife Oral History Interview with Daniel J. Thomas, dated July 12, 2016, 24; Email from Daniel J. Thomas to William Thomas, dated April 14, 2016; Terie Hynish, "Lab Studies Human Response to Impact," *Crescent City Currents*, December 4, 1987.

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[66] Letter from R. S. Kennedy, Officer in Charge, to Commanding Officer, NMRDC, dated March 13, 1978, Subj: "Request for veterinary services," NARA-CP, RG 52, Entry no. UD-WW 10, Central Correspondence Files, 1/1978 - 12/1978, Box 8, F: "6400 1978"; NBDL, "Determination of Human Dynamic Response to Impact Acceleration," DD-1498 Form, RTWUS, Neel Aeromedical Center, USAARL; Letter from James F. Kelly, Commanding Officer, NMRDC, to Commanding Officer, NBDL, dated April 15, 1985, Subj: "Experimental Protocol for Biodynamic Research with Chimpanzees," Neel Aeromedical Center, USAARL; American Institute of Biological Sciences, "Report to the Department of the Navy: Evaluation of the Biodynamics Research Program of the Naval Biodynamics Laboratory, Naval Medical Research and Development Command" (Arlington, VA: September 19-20, 1984), 10-13.

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[69] Memorandum from E. B. Becker, Assistant for Inertial Instrumentation, to Scientific Director, dated September 14, 1979, Subj: "Mass distribution measures of the human head and neck," Neel Aeromedical Center, USAARL; G. Beier, E. Schuller, M. Schuck, C. L. Ewing, E. B. Becker, and D. J. Thomas, "Center of Gravity and Moments of Inertia of Human Heads," in *Proceedings of the 1980 International IRCOBI Conference on the Biomechanics of Impact* (Birmingham, England, September 9-11, 1980), 218-228; G. Beier, M. Schuck, E. Schuller, and W. Spann, "Determination of Physical Data of the Head: I. Center of Gravity and Moments of Inertia of Human Heads," Scientific report no. 1 for Office of Naval Research contract

N00014-75-C-0486 (Arlington, VA: Office of Naval Research, April 1979). For Beier's background in automobile crash injury research and the work of the University of Munich's Forensic Institute, see his remarks in the "Minutes of the Round Table Discussion" at the Aerospace Medical Panel Specialists' Meeting held in Cologne, Germany, on April 26-29, 1982. The remarks are printed in *AGARD Conference Proceedings no. 322 on Impact Injury Caused by Linear Acceleration: Mechanisms and Costs*, RTD-4-5.

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[72] Georg D. Frisch and Charles Cooper, "Mathematical Modeling of the Head and Neck Response to $-G_x$ Impact Acceleration (Minimum Articulation Requirements)," *Aviation, Space, and Environmental Medicine* 49 (January 1978): 196-204; William Thomas Oral History Interview with Daniel J. Thomas, March 8, 2016, 35. The crash simulation programs were Calspan's "3D Computer Simulator of a Motor Vehicle Crash Victim," Ultrasystems' "Crash Victim Simulator – Light Aircraft," and Boeing's "Prometheus." See Georg D. Frisch, Joseph O'Rourke, and Louis D'Aulerio, "The Effectiveness of Mathematical Models as a Human Analog," in *Mathematical Modeling Biodynamic Response to Impact* (Warrendale, PA: SAE, 1976), 61; Georg D. Frisch, "Simulation of Occupant-Crew Station Interactions during Impact," 534.

[73] Email from Ed Becker to James Rife, dated November 20, 2016.

[74] Letter from James F. Kelly, Commanding Officer, NMRDC, to Commanding Officer, NBDL, dated April 15, 1985, Subj: "Experimental Protocol for Biodynamic Research with Chimpanzees," Neel Aeromedical Center, USAARL; American Institute of Biological Sciences, "Report to the Department of the Navy: Evaluation of the Biodynamics Research Program of the Naval Biodynamics Laboratory, Naval Medical Research and Development Command," 10-13.

[75] James Rife Oral History Interview with Daniel J. Thomas, dated July 12, 2016, 38; "In Memoriam Channing L. Ewing, M.D., M.P.H.," *Aviation, Space, and Environmental Medicine* 82, no. 12 (December 2011): 1172; see Unterharnscheidt's CV attached to a letter from Unterharnscheidt to Thomas Dobie, M.D., dated May 27, 1997, Neel Aeromedical Center, USAARL. Unterharnscheidt suggested to Captain Williams that histopathology technician Jeff Hamby help complete the remaining histological work. See letter from Friedrich Unterharnscheidt, Neuroscience, Inc., to Commanding Officer, NBDL, dated July 2, 1984, Neel Aeromedical Center, USAARL. Thomas's last day was January 13, 1984. See Memorandum from D. J. Thomas, Head, Biomedical Research Department, to Commanding Officer, dated January 5, 1984, Subj: "Future Experiments," Neel Aeromedical Center, USAARL; Dan Bennett, "Reflex: Fast Move Saves Doctor," *The Times-Picayune*, January 28, 1988, confirms that Ewing retired in 1984; NBDL, *Command History for Calendar Years 1984 and 1985*, 3; Dr. Daniel J. Thomas to Senators Jeremiah Denton and Russell Long, January 7, 1985, in the personal files of Dr. Daniel J. Thomas.

Chapter Five

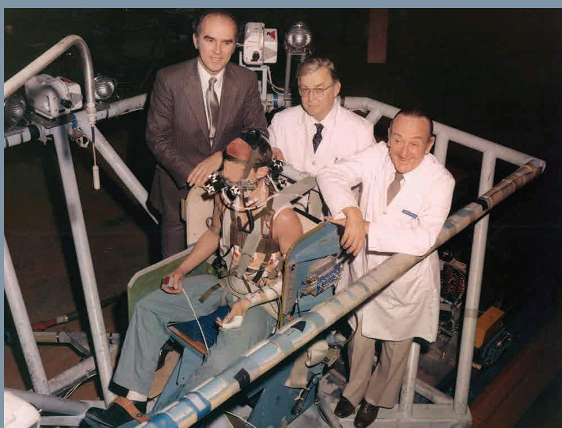
Decline and Transfer, 1984-1996

When Chan Ewing and Dan Thomas left in January 1984, NBDL suddenly lacked overall senior civilian scientific leadership. The commanding officer, Captain Loys Williams, was primarily an administrator and was subject to regular military rotation, so he could offer little long-term research direction or planning. John Guignard was the highest level civilian employee remaining, but his expertise was in vibration and ship motion research rather than impact acceleration. No senior physician, researcher, or engineer could match Ewing's breadth of vision or management experience. And no one had the personal contacts so crucial to maintaining favor and funding from higher naval authority.[1]

Realizing that he and Ewing were creating a leadership vacuum, Thomas left Williams some recommendations for reorganizing the lab. He suggested putting veterinarian Eugene Jessop in charge of the upcoming animal experiments and leaving physician Norman Gilbert in charge of medical support and assuring the safety of the human research volunteers. "He is the only one capable to do this for impact acceleration," Thomas wrote. He recommended that Williams "personally retain supervision" of future experimental design decisions and responsibility for the human test subjects. Instead, Williams gave mathematician Leonard Lustick responsibility for the impact testing program on an acting basis.[2]

However, Williams was gone within a few months. His replacement was Captain Robert J. Biersner, a research psychologist with an undergraduate degree from Central Washington State College and a Ph.D. from McGill University, who took over as CO on August 31, 1984. Biersner had served with the Navy Experimental Diving Unit from 1967 to 1970. After a stint with the Navy Medical Neuropsychiatric Research Unit, in 1974 Biersner became a human factors analyst for the Chief of Naval Education and Training Support. Most recently, Biersner had served as the program manager for NBDL on the staff of the Naval Medical Research and Development Command (NMRDC). He well understood the lab's ongoing challenges, noting shortly after his arrival that NBDL was "still trying to get its bearings as the youngest command within the Navy medical research and development community."[3]

As the reassigned staff members got their bearings, Biersner made technological upgrades a priority. To improve data acquisition and analysis for the impact acceleration program, he replaced an old EAI Pacer 600 hybrid computer with new Hewlett-Packard 9000/220 and 9000/835 model computers. The HP9000/835 interfaced with an HP9872T plotter. To provide better information on the effects of motion on Navy combat operations, particularly the loading of weaponry, the Ship Motion Simulator (SMS) was outfitted with a Baltimore Therapeutic Equipment model work simulator. Upgrades also included installation of a laser-generated artificial horizon in the SMS cabin as well as replacement of outdated Apple II computers with new Zenith models. Among the most important equipment upgrades, however, were NBDL's own efforts to improve anthropomorphic test dummies (ATDs).[4]



Left: Drs. Dan Thomas (left), Chan Ewing (middle), and Norman Gilbert with a human research volunteer prepared for a test run in 1979-1980. Medical supervision of the impact accelerator runs fell to Gilbert after Thomas and Ewing left NBDL in January 1984. (Photograph courtesy of Dr. Daniel J. Thomas)

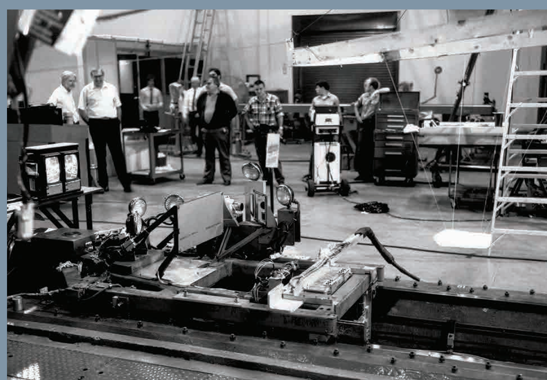
Right: Captain Robert J. Biersner, MSC, USN (USAARL)

Change and Continuity in the Impact Program

Following the departure of Ewing and Thomas, Lustick kept the horizontal impact acceleration program on track, conducting regular human, rhesus macaque, and Hybrid III ATD runs throughout 1984. There were two related priorities: to develop new information on the $+G_z$ vector and to prove the accuracy of the ATDs. During the 1984 runs, most human and Hybrid III subjects were placed in the supine position, simulating vertical acceleration forces like those encountered during ejection from aircraft. By the summer, Hybrid III tests had proven that the spinal structures in the ATDs were "unequivocably" insufficient for replicating human dynamic response. The new data enabled the NBDL team to push forward in creating a validated, state-of-the-art ATD that accurately represented the biodynamic head-neck response of a human being.[5]

The ATD head-neck design research was part of an ongoing joint effort with Georg Frisch at the Naval Air Development Center (NADC), whose three-dimensional crash simulation research won the Scientific Achievement Award from the Navy in 1987. The joint NBDL-NADC effort was focused specifically on designing a more accurate head-neck system for use with the body of the Hybrid III. By June 1988 Frisch had made progress on development of a 50th percentile male head-neck, but his work was cut short after he was diagnosed with terminal lung cancer and died in August 1989.[6]

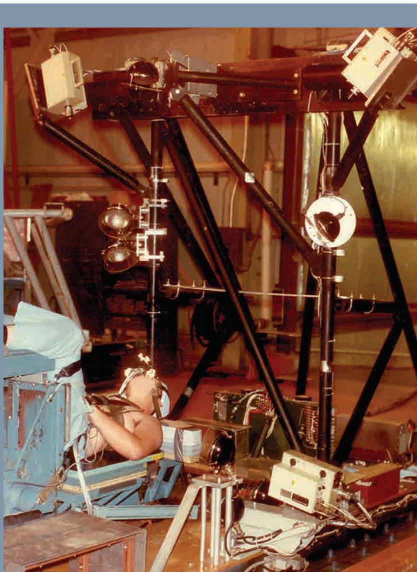
In January 1986 the space shuttle *Challenger* disaster led the acceleration experimentation team into a few months of unusual work for NASA. The post-accident investigation suggested that an icicle may have punctured one of the *Challenger*'s external rocket booster tanks. NASA subcontractor Martin Marietta tried dropping icicles down a vertical shaft onto booster tank panels, but the experiment was inconclusive because the investigators could not control the orientation of the icicles upon impact. Martin Marietta had an office at Michoud and called upon Bill Muzzy for help. In March 1986, booster tank panels affixed to the front of a lightweight sled were accelerated at varying velocities up to 90 miles per hour to make contact with icicles suspended by a thread. Muzzy determined conclusively that icicles could not have penetrated the booster tank panels. Eventually, the cause was identified as a cold temperature-induced failure in one of the rubber rings used to seal the tanks.[7]



Bill Muzzy (far left) awaits the start of a horizontal impact accelerator test to determine if an icicle could penetrate space shuttle booster tank panels. (USAARL)

Another project more directly related to human impact acceleration was an effort to anticipate how the additional mass of night-vision systems or helmet-mounted displays changed dynamic response. The work included tests with five human volunteers wearing fiberglass helmets during $-G_x$ runs between 3 and 10 G. The researchers attached weights ranging from 275 to 600 grams to different locations on a rack mounted on top of the helmet to change overall mass and center of gravity of the head. In the end, Lustick and his team found that weighted fiberglass helmets (with attached mounts to hold accelerometers) resulted in up to a 30 percent increase in total head mass. At the 30th Stapp Car Crash Conference, held in San Diego in October 1986, NBDL personnel presented the findings from ninety-six $-G_x$ runs with human volunteers wearing helmets. They noted that the additional mass resulted in "increased head angular travel, as well as increased torques and forces on the neck." The military had long understood that pilot helmet mass was directly related to dynamic response, but as Muzzy explained, the research at NBDL "provided the first objective data on the effects of increased mass on the head-neck response."[8]

The highlight of the mid-1980s was the completion of the lab's first vertical accelerator. This had been years in the making. Ewing and Muzzy had been considering the engineering requirements for a vertical accelerator since 1971, and Ewing had worked diligently to fund and build it. The tower for the accelerator was finished in 1982, but another four years passed before the entire apparatus was ready for experimentation. The structure included a Bendix HyGe nitrogen-powered accelerator with a six-inch cylinder capable of producing 40,000 pounds of thrust to accelerate a sled carriage with a payload in excess of 500 pounds up the 42-foot-tall tower track. Perhaps most strikingly, the vertical accelerator, located in Test Cell 4, was designed to serve as something of a gigantic x-ray machine. Outfitted with lead-lined walls and a high-speed 35-mm x-ray camera, the apparatus was capable of recording objects in motion at a rate of 250 frames per second. As with the horizontal accelerator, the sled carriage was decelerated by gravity and friction forces of 5 m/sec^2. Bill Muzzy designed locking brakes to keep the sled from crashing back down the tracks at the end of each run. The first empty sled runs with the vertical accelerator began on July 31, 1986.[9]



A human research volunteer in the supine position is prepared for a $+G_z$ run on the horizontal accelerator. (USAARL)

The vertical accelerator provided an accurate means of simulating ejection forces ($+G_z$) in a realistic military posture without the compromise of placing subjects in the supine position on the horizontal accelerator. It also allowed for data from $+G_z$ runs on the vertical accelerator to be compared to information from earlier $+G_z$ horizontal accelerator runs to fully validate those readings. The vertical accelerator data was also available to Frisch at NADC for his ejection simulation programming. In addition, the vertical accelerator could be used to simulate sudden shocks, like those resulting from underwater explosions.[10]

During the next two years, the vertical accelerator was used primarily for ship shock simulations using ATDs. The tests were intended to estimate the response of seated humans to sudden upward ship shock motions (simulating motions resulting from underwater explosions) between 3 and 30 G. After conducting runs with a variety of both cushioned and hard seats, NBDL found that cushioned seats could "significantly attenuate the shock input into the body." The information was sent to the Naval Sea Systems Command (NAVSEA) for comparison to data collected during ship shock trials at sea.[11]

In the fall of 1986, Lustick retired, leaving the acceleration impact program to Marc Weiss, who served as de facto scientific director until his appointment as chief scientist in 1988. To take over Lustick's other responsibilities as head of the Mathematical Sciences Department, NBDL hired Dr. Salvadore J. "Sal" Guccione, Jr. After completing a Ph.D. in mathematics at the University of Missouri–Rolla in 1977, Guccione taught mathematics at the University of Southwestern Louisiana and the University of New Orleans. After joining NBDL in 1986, Guccione became responsible for analyzing the impact program data.[12]

In the late 1980s, NBDL continued to set the standard for acceleration impact research nationwide. In a series of presentations and reports released between 1986 and 1989, Weiss provided guidelines for safe human exposures to impact acceleration based on findings at NBDL over many years. The reports provided a ready resource of findings from NBDL's experiments in multiple vectors. In the $-G_x$ direction, Weiss and his colleagues noted that human volunteers had safely experienced accelerations up to 15.9 G with a rate of onset up to 1,522 g/sec. They reported similar exposures up to 11.3 G in the $+G_y$ and 13 G in the $-G_{x+y}$ vectors. In 1989 NBDL physicians noted that "clinical and radiologic examinations in 45 volunteers two to twelve years after impact have revealed no apparent structural neck injuries." The publications also provided information on how measurements were taken and profiled experimental protocols.[13]

Somatosensory Evoked Potentials (SEP) Research

In SEP research, as with other areas of research, the mid-1980s was a period of rebuilding. Those who left the SEP team included David Seales and long-time assistant researcher Michael Berger. Newcomers included neurophysiologist Dr. David L. Matson. With a Ph.D. in physiological psychology from the University of California, Irvine, Matson became primary collaborator with Weiss in SEP-related studies.[14]

Their first major challenge resulted from a 1985 review of the impact research program at NBDL by the American Institute of Biological Sciences (AIBS). The controversy arose over proper use of anesthesia. NBDL routinely anesthetized animals subject to impact exposures on runs where SEP readings were not taken, but in conducting SEP experiments, reasoning that anesthesia introduced an uncontrolled variable that could alter SEP data, the lab did not anesthetize its rhesus macaque subjects. The AIBS reviewers claimed to be "deeply concerned with the impact testing of conscious non-human primates" and called for substantial documentation to justify the decision not to use anesthesia in SEP research. One of Lustick's last projects was to determine whether anesthetic agents did indeed affect electrophysiology. The plan was simple—run tests with anesthetized rhesus macaques and compare the results with those obtained from runs with unanesthetized macaques.[15]

In a 1987 study carried out by Matson and Weiss, a group of anesthetized rhesus macaques were accelerated to peak levels ranging from 95 to 870 m/sec² in the $-G_x$ vector. Runs were followed by x-rays and medical examinations. The macaques were monitored for twenty-eight days following the tests and were then euthanized. A necropsy report was prepared for each animal. When Matson and Weiss compared this data, they found that it did not differ greatly from data produced by 1984 experiments with unanesthetized macaques, validating the premise that anesthetized macaques could be used for SEP impact research. NBDL subsequently anesthetized all macaques used in this research.[16]

These experiments also confirmed that nervous system disruptions were evident at impact acceleration levels around 550 m/sec² in the $-G_x$ vector. This was an important finding because the threshold for detection of SEP disruption was well below the point at which actual physical injury could be distinguished, which was 800 m/sec². SEPs, therefore, could serve as a predictor of neuropathological damage before such damage occurred. The experiments also substantiated Dr. Friedrich Unterharnscheidt's earlier finding that the cervico-medullary junction was the site most sensitive to stress during impact acceleration. Overall, the mid-1980s research conducted by Weiss and Matson indicated that SEPs continued to hold "promise as an index of pre-pathological injury levels in impact research."[17]

Captain Loys E. Williams (far left) and Captain James F. Kelly (center) outside NBDL at Michoud during the change of command ceremony in August 1984. (USAARL)

As the AIBS review suggested, animal testing became increasingly controversial during the 1980s. As early as 1985 there was evidence that the Navy's stance on animal experimentation had shifted. When NBDL applied for permission to use twelve chimpanzees that it already owned in testing, Captain James F. Kelly, the commanding officer at NMRDC, flatly told Biersner that "the fact that NBDL already owns 12 chimpanzees cannot serve as an additional argument for their use in this or other potentially noxious experiments."[18]

Whether or not the results justified the testing, Kelly's use of the term "noxious" was apt since the Navy was increasingly wary of the potential political repercussions should the non-human primate research become a matter of public debate. That concern was vindicated two years later when the Navy confirmed that three animal handlers at NAMRL in Pensacola had contracted the rare and deadly Simian B virus from one or more rhesus macaques at the institution's primate center. One of the handlers, a thirty-seven-year-old biological technician with thirteen years of experience, had also transmitted the virus to his wife through a shared tube of hydrocortizone ointment with which she was treating him. He died from his infection, but she recovered.[19]

The chief of primate research at the NIH Animal Center noted after the event that "when you work with these primates like they do and we do, the odds catch up… it could happen to anybody any time." Dr. Norman Bernstein, the infectious disease specialist who treated the sick animal handlers, noted that as many as 60 percent of rhesus macaques are carriers of the virus. As a result of the infections, NBDL began a policy of blood testing all of its staff members that were likely to come into contact with animals. This was an unusual outbreak of a rare disease—physical injury among animal handlers was far more common—but it helped strengthen the case against animal testing that was then being built up nationwide.[20]

As the controversy grew in the late 1980s, animal testing at NBDL waned. The last rhesus macaque run was conducted on July 14, 1989, and in mid-1990 NBDL decided to discontinue animal research entirely. Its animals were dispersed to the U.S. Army Medical Research Institute of Infectious Disease at Frederick, Maryland, the Armed Forces Radiobiology Research Institute in Bethesda, Maryland, and the Centers for Disease Control in Atlanta, Georgia. With the conclusion of the animal program, there was no need to retain veterinary staff members, and those billets were terminated. After being disinfected and painted, the vivarium was turned into storage space. In this case, the lab's timing was apt. Less than two years later, in congressional testimony, animal rights activists charged a number of military institutions, NBDL among them, with "providing grossly inadequate veterinary care" to research animals.[21]

Whether or not the charges of the activists were entirely warranted, or whether the human costs of animal experimentation were justified, there can be no disputing that animal testing at Michoud resulted in a trove of invaluable experimental information. Between 1973 and 1989, NBDL conducted four hundred non-human primate acceleration test runs. This constitutes the only set of three-dimensional response data on rhesus macaques and chimpanzees ever developed.[22]

Sal Guccione underscored the importance of the non-human primate data in his October 1990 research report entitled "A Statistical Analysis of –X Rhesus Head Kinematics" in which he addressed the question of rhesus kinematic behavior and developed statistical relationships from a database of fifty-three $-G_x$ rhesus macaque tests from the 1984, 1985, and 1987 series, linking key head kinematic variables to anesthetic condition, sled acceleration, and initial head orientation. Guccione also compared qualitative and quantitative kinematic response between humans and rhesus macaques and assessed repeated exposures of the animals and their out-of-plane responses. His analysis ultimately showed that human and rhesus –X head kinematics were not only similar in shape but, more importantly, depended on the same sled and head initial position parameters. Guccione also found that the anesthetic state of rhesus macaque subjects had no significant statistical effect on their kinematic output, based on comparisons of unanesthetized runs in the 1984 series and the anesthetized runs of the 1985 and 1987 series. Thus, it made no difference whether the rhesus macaque was asleep or awake during the experiments for the generation of reliable kinematic data. Moreover, Guccione determined that the effects of repeated tests could be reasonably explained through restraint interaction or anatomical constraints in the rhesus head-neck areas.[23]

Perhaps Guccione's most significant finding was that human and rhesus kinematic response curves were remarkably similar. Consequently, he recommended that methods for scaling human and rhesus macaque response be developed and that "future human and animal experimental series should be jointly planned to facilitate statistical modeling." Despite Guccione's call, due to contemporary legal and ethical considerations limiting animal research, it is unlikely that similar experiments will be replicated in the near future.[24]

Human SEP Readings

As non-human primate SEP research declined during the mid- to late 1980s, NBDL built on these results in an attempt to fine-tune its approach and instrumentation for human studies. The aim was to determine the extent to which impact acceleration compromised human cervico-cortical neural pathways. While the NBDL team had earlier obtained striking results—detecting regular latency shifts in rhesus macaques—the problem was that those shifts occurred at an acceleration of about 550 m/s^2, far too high for human exposure. The goal, therefore, was to adapt the experimental model in hopes of picking up much smaller latency shifts at far lower acceleration levels, with the team anticipating eventually reaching the 15 G_x level. Rather than stimulating the median nerve at the wrist, NBDL transitioned to percutaneous stimulation of the medial phalange of the index and middle fingers on the left hand. Researchers at the lab also began taking readings from the lower limbs by stimulating the posterior tibial nerve at the ankle, a location that Matson wrote was most appropriate to "assess the effects of diseases and injury as well as normal functioning." In order to mitigate the problem that had arisen earlier of excessive noise at the hip electrode, the new procedures relocated the electrode to the left kneecap where it would not be adversely affected by seat restraints.[25]

With these improvements in place, NBDL took SEP measurements during select human runs in a variety of vectors between 3 and 15 G. The SEP data was recorded on analog tape, which could be digitized by processing the tape with an 80286-based AT-type microcomputer paired with a Data Translation, Inc. DT-2821 A/D converter capable of processing 150,000 samples per second. Digitized output data was saved using a Qualstar nine-track tape system at 1,600 BPI. After high-density 1,600 BPI data tapes were produced, the analog tapes were archived. To analyze EEG data, NBDL used a customized evoked potential analysis program called REPANL (Revised Evoked Potential Analysis system) run on a Data General Eclipse computer.[26]

Despite these initial tests, Weiss and Matson continued to fine-tune their electrode array and auxilary equipment. In 1990 Matson posited that adding more EEG channels would enable the research team to use a "spatiotemporal mapping approach" that he hoped would be more sensitive to transient disruptions of the neural pathways. The team also upgraded its digital filtration software in attempts to reduce the disparity between averaged SEPs from humans (averages computed every one or two minutes) and rhesus macaques (averages computed every two seconds). Building upon some of his own research dating back to the 1970s, Weiss evaluated various statistical functions that might be used to better correlate data, with particular focus on variations of the Kolmogorov-Smirnov test, commonly used to draw comparisons between two samples.[27]

In the end, however, Weiss and Matson's team was unable to come up with changes in equipment, procedure, or computation that would enable it to detect latency interruptions in humans at acceptable acceleration levels. In 1989 NBDL physicians Russell Grunsten, Norman Gilbert, and Stephen Mawn flatly stated that "no alteration in somatosensory evoked potentials has been found at impact levels up to 15 G." It was unclear whether there really was no effect at all or whether there was an effect but the instrumentation was just not sensitive enough to record it, based on the technology limitations of the time. Years later Bill Muzzy mused that "we did a lot of EEG work but never got it analyzed to the point that we could say this [impact] is affecting the EEG." In its efforts to obtain heightened detection of human SEPs, the NBDL team most likely helped lay the groundwork for more successful work to come. But its failure to successfully do so most certainly increased the vulnerability of a command that was arguably, at this late date, "still trying to get its bearings."[28]

Crests and Troughs in Motion Research

By the time non-human primate research stopped and human SEP research stalled, a third research priority at NBDL had come to a different, but equally disappointing, end. When he came in as CO, Robert Biersner believed that he had a sure-fire solution for making NBDL freshly relevant to the Navy's mission. He began, almost at once, to shift the lab's priorities more decisively toward ship motion research. The

The freshly painted SMS at NBDL. (USAARL)

timing seemed good. The Navy was then carrying out President Ronald Reagan's 600-ship expansion program, which required the recruitment, training, and retention of thousands of new sailors and officers, many of whom would dread the seasickness exacerbated by the development of faster and more nimble oceangoing vessels. The instrument best suited to help quantify and qualify those forces—the SMS—was man-rated about six months after Biersner's arrival, and in March 1985 experiments with human research volunteers began by studying the effect of vertical heave motion on cognitive performance. These and subsequent efforts were underwritten by the more than $800,000 that the Navy set aside for NBDL ship motion studies in fiscal year 1985. It was a good start.[29]

At the outset of the program, NBDL, the U.S. Coast Guard (USCG), and the David Taylor Naval Ship Research and Development Center, Carderock, Maryland, conducted a wide-ranging effort to acquire data on ship motion levels and seasickness incidence experienced by fleet sailors. Between 1984 and 1985, NBDL personnel deployed with ships in the Atlantic and Pacific fleets, ultimately collecting data from five frigates, six destroyers, three USCG vessels (two monohulls and a Surface-Effect Ship), and a commercial Small Waterplane Area Twin Hull, a vessel designed for high stability.[30]

At the same time, construction went forward on a three-axis shake/tilt chair for use in motion sickness research under the supervision of Dr. Thomas G. Dobie. Completed in 1986, the device, known as the tilt chair or "Dobie Chair," became a staple for motion sickness desensitization research. In more direct terms, it was work intended to help human volunteers become more tolerant of motion sickness.[31]

Dobie's interest in motion desensitization grew out of his experiences in the Royal Air Force. He had noticed that while many people could inevitably adjust to disorienting motion—gaining their "sea legs," so to speak—some never could. Dobie's hypothesis was that the problem stemmed not from strictly physical limitations but from anxiety and anticipatory fear that rendered its victims unable to adjust to disorienting motion. During an early 1970s experiment, Dobie had provided therapy to fifty airmen permanently grounded due to severe susceptibility to motion sickness. During several weeks of therapeutic sessions, Dobie helped the aircrewmen to come to terms with their anxiety and to rebuild their confidence. By coupling the psychological counseling with brief simulations of the coriolis effect (using a rotating drum painted with black and white stripes to give the illusion of circular self-motion), Dobie obtained excellent results: 86 percent of the airmen returned to service and exhibited no further significant signs of airsickness. A lengthy follow-up, carried out over a period of seven years, showed that most of the aircrewmen remained desensitized to motion sickness.[32]

After coming to NBDL, Dobie continued his research in cooperation with Dr. James G. May from the Psychology Department at the University of New Orleans (UNO). On campus, May had access to a rotating drum similar to the one Dobie had devised years earlier. The drum was five feet in diameter and four feet in height, and the inner surface was painted with alternating black and white stripes, each six inches wide. Dobie and May had volunteers sit on the tilt chair and stare at the spinning drum to try to induce motion sickness. Each volunteer was tested twice. The first established a baseline reading for the amount of time that it took to induce nausea. After this initial test, each volunteer participated in ten sessions of cognitive-behavioral counseling, administered by thirteen specially trained counselors over a period of three to four weeks. During these sessions the counselors worked to promote confidence among the volunteers that they could get over their fears of motion sickness and thus be better able to tolerate disorienting motion environments.[33]

After the counseling sessions, volunteers were tested again with the rotating drum and tilt chair. On average, Dobie and May found that the mean tolerance of volunteers improved from about 2.5 minutes of exposure to almost 10. Volunteers also reported less severe nausea in post-counseling tests. Based on these experiments and others, Dobie and May reported that "the most beneficial treatment involved counseling which sought to increase an individual's confidence in their ability to tolerate disorientation during motion, coupled with controlled exposure to such motion to reinforce those beliefs."[34]

Despite Dobie's advances in motion sickness research, the lab suffered another setback in January 1986 when John Guignard submitted his resignation, dealing a blow to human factors research at NBDL. A letter of recognition submitted by Lustick, Muzzy, Weiss, and Gil Willems to Biersner attested to Guignard's contributions to the laboratory. The four department heads noted that Guignard "made outstanding contributions to laboratory scientific research and program planning as well as performing key scientific administrative duties within the Laboratory." Guignard's "efforts were in no small part responsible for the transfer of the Ship Motion Simulator…to NBDL and establishing the current laboratory Ship Motion program."[35]

With the departure of Ewing in early 1984, NBDL's influence and reputation had begun to wane. Guignard's resignation ensured that the erosion continued. More than any other NBDL researcher, Guignard was internationally recognized as an expert in his field, and he appeared prominently in high-profile conferences. Guignard, the department heads concluded, "has been instrumental in presenting laboratory research to higher and interagency authorities and to the international scientific community." Among his efforts on behalf of NBDL had been helping to bring the 1981 annual meeting of the International Organization for Standardization (ISO) to New Orleans. Delegates from twenty-eight countries attended and presented findings on human exposure to vibration and shock. To complement the ISO meeting, Guignard organized a three-day international workshop on research methods in human motion and vibration studies.[36]

By 1986 the institutional support for NBDL was beginning to wear thin. The first props to go had been Ewing's old allies at ONR and BUMED. By the time Ewing left, the Navy research establishment—under pressure from new political priorities and ever-tighter budgets—was cooling toward NBDL's type of basic research, preferring to invest in applied research with a quick payoff. At that point, NBDL's chief proponent was not in the Navy but on Capitol Hill, in the person of Republican Congressman Robert Livingston of Louisiana's 1st District. Livingston sat on the powerful House Appropriations Committee and was doggedly determined to keep Michoud, and the jobs that it generated for the East New Orleans area, running full bore. Livingston, as Art Prell put it, "liked the lab. He believed in the lab and he supported the lab, and he did a lot of political maneuvering to keep the lab open."[37]

Consequently, in 1984 Livingston began publicly extolling the virtues of NBDL to his fellow members of the House Subcommitttee on Department of Defense Appropriations during that year's budget hearings. As a defense appropriator, he controlled the Pentagon's purse strings, and his most useful manuever was to procure regular line item funding for NBDL, specifying how much of the Navy's total allotment had to go to NBDL each year (usually amounting to several million dollars). Beginning in 1984, Livingston's line items were a life line for NBDL but an irritant to the Navy program managers who wanted to decide for themselves where the dollars should go. Therefore, quite contrary to Livingston's intent, they began quietly diverting the dollars to other programs, leaving NBDL chronically short of operational and maintenance funds for further impact acceleration and SMS testing.[38]

Livingston's subcommittee finally noticed in 1987. In a report that year, the Subcommittee on Department of Defense Appropriations noted that "since fiscal year 1984 the Navy has ignored Congressional intent and direction regarding funding of the Aircrew Impact Injury Prevention project and other projects conducted at the Naval Biodynamics Laboratory." By that time, NMRDC had already terminated the NBDL ship motion program and diverted its funds to the Bone Marrow Registry and Transplantation Program, which the Navy deemed to be more important than seasickness at that time.[39]

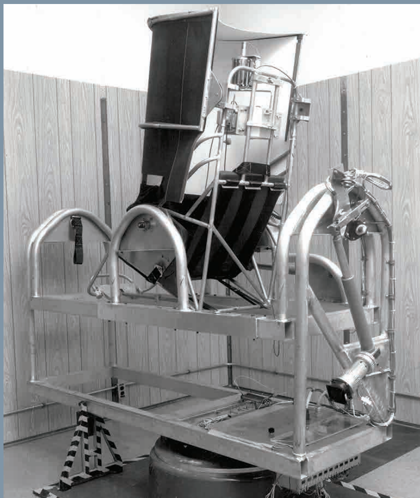
NMRDC believed that there was good reason for cutting the ship motion program. While the effort to improve sailor performance was laudable on its own merits, NMRDC suspected that it was not getting its money's worth. As the Navy bureaucratically explained, the program had "limited application for materially improving the operational readiness of fleet personnel," and by the tough, quantitative standards that the Navy applied, it was not succeeding even in that. During fiscal year 1986, NBDL produced eight publications on ship motion at an average cost of $100,000 each. NMRDC's other laboratories produced publications at an average cost of $77,000 each. More telling, during 1986 NBDL provided no data to other Navy organizations, so it seemed that no one else was benefitting immediately or directly from its research.[40]

The Navy may have been obsessed with efficiency, but Livingston was acutely aware of whether or not the Navy dollars he appropriated were getting back home. During hearings on the fiscal year 1988 budget, Livingston questioned Secretary of the Navy John Lehman directly about funding cuts. Lehman cited "prudent management of limited fiscal resources necessitated investment in high priority, high payoff programs." The tone was being unequivocally set at the top: research programs would produce quick, high-yield results or they would lose funding. By then, the possibility of shuttering NBDL had been openly broached in Congress and at the highest levels of the Navy. When the Navy's list of RDT&E priorities was drawn up for fiscal year 1990, research on blood substitutes, hypothermia, and radiation were all at the top. Impact acceleration and ship motion were both at the bottom. But at that point in time there was only so much the Navy could do to counter Livingston's line items, and through the late 1980s he made sure that impact acceleration research retained its own specific appropriations.[41]

The loss of the ship motion program was not the only change at NBDL. In April 1987 commanding officer Biersner left abruptly following a Navy investigation into his alleged misallocation of resources at NBDL. He was temporarily replaced by Commander Don M. Herron, USN, and then by Captain Douglas W. Call, who arrived in May 1987. With a Ph.D. in anatomy from the University of Louisville, Captain Call had been an aerospace physiologist and test parachutist and had been head of the Aircrew Systems Department, Naval Air Test Center, at Patuxent River, Maryland. Call had known NBDL and its scientific and engineering staff for years. During the 1970s he had worked directly with Ewing and Thomas on the parachute opening shock tests at the Naval Air Recovery Facility in El Centro, California.[42]

Captain Douglas W. Call, MSC, USN, served as NBDL's commanding officer from May 1987 to May 1992. (USAARL)

With new leadership in place, NBDL appeared to bounce back out of its trough, with NMRDC announcing in 1988 that it would resume funding of the ship motion program. But the rebound was weak. Most of the ship



The motion desensitization chair at NBDL. (USAARL)

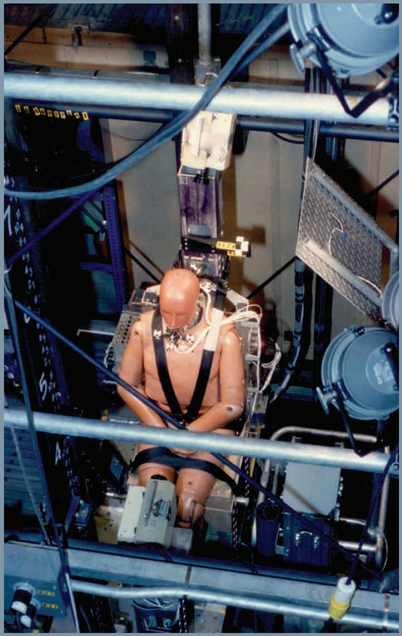
motion research continued to focus on motion desensitization, work that Dobie had been able to keep going despite the funding lapse due to his collaboration with UNO. The next year the ship motion research program received only 16 percent of the $3,214,000 provided to the lab. In 1990 the allocation fell to just 10 percent. It was enough to fund a traveling lab, formally known as the Mobile Biodynamics Laboratory, a twenty-onefoot-long utility trailer hauling a three-axis tilt chair that could be transported to any Navy installation wishing to conduct motion studies onsite. Within another five years, the impact acceleration program would be packing as well—with nowhere to go.[43]

Final Stages of Impact Acceleration Research at NBDL

On April 7, 1988, an inspection team from NAMRL arrived at Michoud. This was an auspicious occasion: the inspectors were there to begin the process of man-rating the vertical accelerator, which up to this point had only performed non-human primate and ATD runs. The inspectors departed on April 8, leaving behind some homework for Bill Muzzy's team. The chief concern was the braking system, specifically the emergency backstop system to keep the sled from falling back down from the top of the tower at the end of each run. It had to be improved. Another requirement was that NBDL establish an emergency exit floor plan and a formal protocol for training the operators of the accelerator. Perfecting the braking system and satisfying the other requirements took months, particularly since Muzzy's team had to do its work in between ongoing animal experiments, but on February 8, 1990, the vertical accelerator was formally man-rated.[44]

Between 1990 and 1991, NBDL conducted a series of 129 human $+G_z$ runs ranging from 3 to 12 G on the vertical accelerator intended primarily to measure the effects of added head mass and changes in the head center of gravity caused by helmets. Human research volunteers in the 1990 runs were tested without helmets, but in the 1991 runs they wore personalized, tight-fitting, fiberglass "skullcaps" with weight-carrier frames that could mount adjustable weights in a variety of configurations to simulate mass additions caused by night-vision goggles and other common attachments. Findings by researchers Stephen V. Mawn, James J. Lambert, and Joseph L. Catyb, Jr., published in January 1992 in *Aviation, Space, and Environmental Medicine* confirmed a correlation between head and neck anthropometry and dynamic response.[45]

James Lambert and Sal Guccione conducted another study, sponsored by NMRDC, that was based on those same $+G_z$ vertical impact accelerator tests and augmented by 95th percentile Hybrid III manikin runs, in which they analyzed linear regression of the kinematic responses of humans and ADTs under the same conditions. Lambert and Guccione found that the correlations for displacement models used for human $+G_z$ tests were low for both test series, with two distinct response patterns, either a unimodal trace with one positive peak or a bimodal trace characterized by a negative peak followed by a positive peak. Among the factors contributing to the discrepancies in the displacement regressions were inherent inaccuracies in estimation of the center of gravity within the human research volunteer heads and inertial moments of the unencumbered human heads. Meanwhile, the correlations for displacement models used for manikin $+G_z$ tests were somewhat higher since the Hybrid III manikin neck is not designed to hyperextend and is unable to simulate the observed human response of backward rotation, thereby limiting the range of kinematic response.[46]



An ATD prepared for a run on the vertical impact accelerator. (USAARL)

Around the same time that these vertical accelerator tests were taking place, NBDL was using the horizontal accelerator to simulate aircraft crash dynamics for the U.S. Army Aeromedical Research Laboratory (USAARL). USAARL had determined that crew members who perished in AH-1 Cobra and AH-64 Apache helicopter crashes were often killed after their heads made contact with the cockpit telescopic sighting unit (TSU) or optical relay tube (ORT). The question was how to stop it. NBDL simulated these crashes by conducting 35º impacts at 25 G using instrumented Hybrid III ATDs. In one round of tests, the ATDs were protected by harnesses and crash-activated air bags, while another round used harnesses alone. The tests determined that the air bags kept acceleration at safe levels, minimizing damage from contact with instrumentation, and established that restraints alone could not prevent potentially lethal impacts. The research helped confirm to USAARL that air bags were a promising means of reducing injuries and deaths from helicopter crashes.[47]

In mid-1990 Gil Willems completed work under contract for the National Highway Traffic Safety Administration (NHTSA) on a six-degree of freedom transducer package. This was the first such transducer developed at NBDL and promised to greatly reduce the number of data calculations required. NBDL had long employed six-accelerometer arrays, but the sensor used an array of nine linear Entran Devices, Inc. EGA series subminiature accelerometers arranged in a non-coplanar 3-2-2-2 configuration. To hold the accelerometers, Willems designed an aluminum mount with three 2.75-inch arms, and to ensure accuracy he devised a standardized calibration sequence. NBDL tested the new configuration against the traditional setup in sixty-five runs on the horizontal accelerator using a range of variables. The tests confirmed that the nine-accelerometer transducer package accurately provided signals directly proportional to angular acceleration levels, relieving technicians of the need to estimate angular velocities.[48]

Willems shared this innovation with biodynamics researchers worldwide at the 35th Stapp Car Crash Conference held in San Diego in 1991. Soon afterward, the Navy acknowledged Willems with the Meritorious Civilian Service Award for his nearly twenty years of work handling the design of the data acquisition systems and selection and calibration of accelerometers at NBDL.[49]

As Willems worked on his transducer, Bill Muzzy was absorbing bad news. Muzzy had long been a member of the Tri-Service Working Group on Biodynamics (TWG), which brought together researchers from NBDL, Wright-Patterson Air Force Base, NADC, and USAARL twice a year. "We could talk over our projects and our problems and progress," Muzzy recalled, "and it was a good old meeting that we did without interference from the COs." But one of the 1990 meetings was not so good, where Muzzy first heard that plans were being laid to consolidate the research functions of NBDL and USAARL at Wright-Patterson. Shortly thereafter, the assignment of producing a detailed plan for NBDL's role in the consolidation landed on Muzzy's desk. He saw it as a clear harbinger of things to come.[50]

In his twenty years at Michoud, Muzzy had left his stamp on nearly every piece of NBDL equipment and took pride in being one of the last remaining members of Ewing's original team. He had also been a source of stability during the turbulent 1980s. But with NBDL's survival now in doubt, Muzzy made the tough decision to take the next big step in his professional life and get out before it closed. He retired from federal service effective January 1, 1991, and became a private industry consultant, joining the forensic engineering firm ARCCA, Inc., founded by former NADC researcher Louis D'Aulerio.[51]

Although consolidation was uncertain officially, it seemed likely to happen given the ongoing debate about the fate of NBDL. As a frustrated Bob Livingston said of NBDL in 1988, "Every year there is a battle to shut it down or not to shut it down, reduce funding or not reduce funding." By the early 1990s, Livingston appeared to have lost the battle. In July 1991, after confirming the plans in a visit to NMRDC in Bethesda, Maryland, Captain Call informed the NBDL department heads that the command was tentatively expected to transfer its billets and research programs to the

Armstrong Aeromedical Laboratory at Wright-Patterson between October 1996 and April 1997. But NBDL was not entirely out of allies. According to NBDL research engineer Andre Rog, at this point Louisiana Congressman William J. Jefferson intervened to block the effort. He was assisted by Air Force officials who wished neither to pay for the relocation of the acceleration equipment nor the modification of the existing plant at the Armstrong Aeromedical Laboratory to accept it. NBDL appeared to have a reprieve, if not a new lease on life.[52]

After May 1992, NBDL had new military leadership as well when Captain Call retired after five years as commanding officer, the longest tenure of any of its commanders. He was succeeded by Commander Robert W. Rendin, who had been Call's executive officer since 1990. With an M.S. degree in environmental health from East Tennessee State University, Rendin had joined the Navy in 1974 and had served as chief of the Occupational and Preventative Medicine Service at the Naval Regional Medical Center in Great Lakes, Illinois, as head of the Environmental Health Service at the Navy Environmental and Preventative Medicine Unit No. 2 in Norfolk, Virginia, and as a medical administrative officer at the Fourth Marine Division Headquarters.[53]

Rendin assumed command at a time when the Navy had to come to terms with a demographic transformation of naval aviation. Historically, the data produced by NBDL, as well as other testing entities, and utilized by aircraft designers was all derived from young enlisted adult males. Little, if any, accurate data existed for other sectors of the general population, including children, the elderly, and women. It was the latter category that presented a new challenge by the 1990s. In 1974 the Navy qualified its first female aviators. Nine years later the first female test pilots went on duty. By the early 1990s, the Navy was preparing to deploy female fighter pilots to aircraft carriers. During these years the Navy was aware of a growing problem—that female aviators were physiologically different from male aviators—and the aircraft they were operating had all been designed for men. This provided NBDL with an invaluable new mission to reproduce the acceleration impact studies already conducted with male volunteers using a female cohort and then compare the results. In 1993 the Navy approved eight billets for female research volunteer subjects. Like the male volunteers, all the female volunteers were selected from the Recruit Training Command in Orlando, Florida.[54]

However, the project soon ground to a halt. On March 22, 1994, NBDL was testing new restraint harnesses designed for females when the horizontal accelerator's load cylinder exploded, hurling fragments of stainless steel across the test cell. No one was seriously injured. NBDL hired two independent contractors to investigate the rupture. One was ARCCA, and Bill Muzzy led its forensic team. The official explanation by the team's metallurgist was that leaking water from overhead air conditioning lines had corroded the accelerator's stainless steel load cylinder and caused the failure. But having spent years maintaining the equipment at Michoud before his retirement, Muzzy unofficially believed that the true cause was a simple lack of maintenance in his absence. Willems set immediately to work rebuilding the horizontal accelerator, but it was clear from the outset that the process would be lengthy, as he had to procure a sizeable inventory of custom-built parts.[55]

By September, Willems had spent $112,354 on new components. In December he was still awaiting delivery of the most critical part, the new load cylinder. The manufacturer of the load cylinder could provide no firm delivery date, noting only that the delay would be "substantial." While slowly rebuilding the horizontal accelerator, NBDL's engineers and maintenance men also repaired the damage to Test Cell 4 itself, replacing the windows, doors, and electrical circuit panels that had been damaged by the explosion. The mishap spurred a longer look at the facilities overall, with the team repairing other items that had deteriorated over the years. The close call also prompted the engineers to construct containment enclosures around both accelerators. The repairs and upgrades took engineering technician Leslie Lorig most of the second half of 1994 to complete.[56]

It was imperative throughout these months that the vertical accelerator stay fully operational. Accordingly, in July 1994 the NBDL team disassembled, cleaned, reassembled, and hydrostatically tested the accelerator by pressurizing the system up to 4,500 psi (three times the maximum operating pressure level used during runs) for twenty minutes. In August and early September, the vertical accelerator was inspected by certified contractor Owensby & Kritikos, Inc. It passed the inspection. Between September 12 and December 12, 1994, a total of forty runs were conducted, reaching acceleration levels up to nearly 23 G. Upon completion of this series, Roger Black and Ferris Bolin again disassembled, inspected, and reassembled the vertical accelerator.[57]

Meanwhile, retrenchment elsewhere in the Navy obliged the Engineering Department to take on new tasks formerly handled by the Naval Aviation Depot in Pensacola. The depot had long provided critical support to NBDL in the manufacture of custom mouth mounts for human volunteers. In September 1994, word came that the depot would be closing, so NBDL began to procure the needed materials and machinery in order to manufacture the mouth mounts in-house. Robin Roth and Leslie Lorig fabricated the mounts and kept the impact research experiments going. Roth and Lorig were also drawn into an emergency construction project for NBDL's "sister command," NAMRL, in Pensacola. The closure of the Naval Aviation Depot left NAMRL in its own bind, unable to replace shock absorbers on its Coriolis Acceleration Platform. The acceleration platform was scheduled to be used by some of NAMRL's international partner institutions in early 1995. Accordingly, all of the fabrication and installation work at NAMRL had to be completed between mid-October and December 1994. The fact that the deadline was met is a testament to the capabilities and skill of NBDL's remaining engineering technicians and support staff.[58]

By early 1995, the vertical accelerator was fully rebuilt and had undergone a second man-rating process. On January 11, 1995, just a few months after the first female fighter pilot had been deployed to the aircraft carrier USS *Eisenhower*, the first impact acceleration tests with female research volunteers began. Experiments with female volunteers required several adjustments from the male protocol. Testing revealed that the torso restraint belts used by men were too large, so new ones fitted for women's smaller frames had to be designed and made. The new women volunteers also requested that a female human research volunteer be assigned to the Biomedical Support Department and act as a standby in the medical prep room and during the experiments. "The women said everyone acted appropriately," acknowledged Navy Hospital Corpsman Second Class Gail Seaman, "but it was intimidating on the sled with so many males and it made it better to have a female there." Over the next few months, NBDL conducted fifty-nine female runs on the vertical accelerator, reaching exposures exceeding +9 G. During the runs, the female volunteers wore instrumentation at the mouth and at T_1. Runs were also monitored using three high-speed cameras at 500 frames per second.[59]

The project suffered briefly because, even years after Muzzy's departure, NBDL had never adequately restructured its internal chain of command when it came to equipment safety issues. When Muzzy left, Willems had taken on the formal responsibility of overseeing the employees in the Engineering Department's Photography, Maintenance, and Facilities Branches, all the while keeping his former duties. Since Roger Black was the designated command safety officer, Willems expected him to deal with safety and maintenance issues and involve him only as needed. But Black clearly believed that equipment safety required more leverage than he personally could provide. In mid-December 1994, Black sent a report on the vertical accelerator to Willems recommending the improvement of the pins that prevented premature firing. Willems deemed the upgrade unnecessary since fourteen other fail-safes already prevented accidental firing. "This has been found acceptable to the Horizontal Accelerator man-rating committee in 1974 and to the Vertical Accelerator one in 1989 and I have no plans to make changes now."[60]

Concerned with productivity as well as safety, Willems deemed the equipment approved by the man-rating committees good enough. When Black adopted this approach himself, however, it ended up shutting down the female runs for an entire month. In early April 1995, Black mentioned to Captain Rendin during a routine written communication that there were further safety measures that could be implemented. But he downplayed their importance, noting that they were not part of the current safety protocol and that "the vertical accelerator is as safe as it was the last time we ran humans." Rendin came down hard in his reply. "Your memo implies that we are not doing everything possible to achieve a safe and professional operation," Rendin wrote. "We will not run the vertical accelerator again until these issues are addressed." Stung by the skipper's displeasure, Black and Bolin began making the safety upgrades on the vertical accelerator in mid-April, and in May the runs resumed. The female dynamic response tests were concluded on June 6, 1995, when the last run in the series was completed and data analysis began.[61]

BRAC and Transfer to the University of New Orleans

The Navy was not alone in facing ever-diminishing budgetary prospects during the late 1980s. In 1988 Congress instructed the Secretary of Defense to create a bipartisan commission tasked with making recommendations to Congress for base closures and consolidations throughout the armed services. The selection process was politically charged, since every cut threatened the economic well-being of some particular community, so the bipartisan commission was soon mired in controversy. In November 1990 Congress passed the Defense Base Realignment and Closure Act that was intended to ensure fairness in the closure of military establishments. The result was the establishment of the Base Realignment and Closure (BRAC) Commission, consisting of members appointed by the President to evaluate and recommend bases for closure or merger. The collapse of the Soviet Union just over a year later created even more pressure for cuts in defense expenditures, with the Bush administration seeking to cash in on the "peace dividend" by slashing defense funding. In 1993 the succeeding Clinton administration announced its intention to strip a further $60 billion from the Defense Department budget through fiscal year 1997.[62]

On February 28, 1995, Secretary of Defense William Perry submitted recommendations for base closures and realignments to the BRAC Commission. The list included 146 military installations, closure of which was expected to save taxpayers about $1.8 billion every year, and NBDL was on it. Closing down the lab at Michoud was expected to cost $600,000, but it was anticipated that the step would save the government almost $3 million per year. The termination date was initially set for September 1995 but then moved back a year to 1996. News that NBDL was up for closure reached the lab even before Perry's report reached the BRAC Commission—there was little reason to be surprised. As Andre Rog later attested, "NBDL was an oddball organization. It was an offshoot of naval medicine and not really under ONR, so the Navy did not see a lot of value in preserving the organization, and no command was interested in taking on new facilities at that time."[63]

The disposition of the personnel and equipment at NBDL was just as certain as its closure. By all accounts, members of Louisiana's congressional delegation were determined to see that NBDL's jobs and resources remained in New Orleans. A number of military installations in the state of Louisiana had already been closed during the late 1980s and early 1990s. In 1987 Livingston and fellow Louisiana Representatives Lindy Boggs and Billy Tauzin questioned Navy proposals to close the Naval Investigative Service Regional Office in New Orleans. Closure of England Air Force Base, Alexandria, Louisiana, in 1992 was followed in 1994 by closure of the Army's New Orleans Military Ocean Terminal. The Navy's Reserve Readiness Command in New Orleans was also identified for closure along with NBDL in September 1996. If the large scale of some of the other closures made a good outcome improbable, in one respect at least, the small scale of NBDL gave it an advantage. Its equipment and research personnel could at least be relocated from the military to another institutional framework locally. None seemed more appropriate than the University of New Orleans (UNO).[64]

For one thing, UNO's Engineering Department and NBDL had a history of cooperative research programs. Its personnel already knew well the dynamic testing devices, the research programs, and the existing data. For another, Tom Dobie had given lectures and taught courses at UNO as an adjunct professor for years. Beginning in 1994, as it became evident that NBDL's days were numbered, UNO faculty members Dr. Edit Kaminsky Bourgeois, Dr. Russell Trahan, and Clifford Mugnier, among others, visited the lab regularly. Therefore, the director of NBDL's Research Department, Commander Daniel L. Dolgin, recalled that "when BRAC came down, it was already a foregone conclusion that UNO was in the sights." On February 7, 1995, two weeks before Perry's list became public, Rendin informed his department heads and executive officer of the goal to have the "lab readied for transition to UNO by 1 Oct."[65]

Lieutenant Christopher Miller (left) and Commander Daniel L. Dolgin (right) at Michoud. The departure of Lieutenant Miller, NBDL's medical monitoring officer, in June 1995 effectively ended human testing at NBDL. (USAARL)

In order to prepare the laboratory for transfer to the UNO Engineering Department, Rendin set the staff to work cataloging the biodynamic response dataset (particularly the human data) already collected. Rendin also hoped to get the horizontal accelerator man-rated in time to conduct female $-G_x$ runs that could be compared to $-G_x$ male run data. But while equipment and data remained, human resources were a vanishing asset. Historically, NBDL had maintained about twenty billets for human research volunteers. In 1992, however, the Navy began scaling them back. By early 1995, there were only eight human research volunteers left at Michoud. The final human runs on the vertical accelerator were conducted on June 6, 1995; female volunteers were never run on the horizontal accelerator. Later in the month, Lieutenant Christopher Miller, the only remaining medical officer, departed, precluding any possibility of conducting further human experiments. Between 1971 and 1995, NBDL had collected data from 3,430 non-injurious runs with 211 human research volunteers, out of a total pool of nearly 300 qualified sailors.[66]

The mood at Michoud had long since turned dreary. Ever since the early 1980s, NBDL's personnel had been accustomed to budget cuts and program terminations, but now they came more quickly than before. The non-operational horizontal accelerator stood in mute testimony to the inability of the researchers to pursue their mission, while the steady decline in publications coming from the lab created a more palpable record. More than anything else, however, the steady stream of staff departures—with openings filled by temporary investigators—sapped morale. Not surprisingly, a number of long-time NBDL employees decided that it was time to retire. Gil Willems and Ferris Bolin dutifully remained on for several months after the news came and then, after decades of distinguished service, retired. Commander Rendin had initially expected to oversee the closure, but ultimately NBDL outlasted him. After Rendin left the lab in November 1995, Commander Dolgin was elevated to commanding officer. A native of Chicago, Dolgin had obtained his Ph.D. in psychology from the Illinois Institute of Technology and was designated as a naval aerospace experimental psychologist. After serving as head of the Aviation Selection Division, NAMRL, Pensacola, he transferred to NBDL in January 1994.[67]

Surprisingly, Dolgin's tasks were not limited solely to closure, since funded research at NBDL continued until the very end. In a continuation of his earlier linear regression analysis, Sal Guccione further evaluated human versus Hybrid III response to rapid $+G_z$ vertical acceleration, this time for NAVSEA, which wanted to determine whether the manikins could be used to produce roughly accurate data on human response to shocks from underwater explosions. In his report, submitted in October 1996, Guccione noted that the Hybrid III was of limited value because it could only simulate certain types of head-neck motion and did not absorb energy as well as the human neck. "These results obviously call into question the ability to assess the potential of head-neck injury to humans in shipshock scenarios based on Hybrid (or any purported biofidelic) manikin responses," Guccione warned.[68]

But the lab's main work now was to catalog and ensure the integrity of the equipment and data that would be NBDL's legacy to UNO. To begin, Dolgin "talked to everyone at NBDL, from the E1 human research volunteer to Dr. Weiss, about what the latest information was from NMRDC, ONR, and the University of New Orleans, and nothing was held back." Dolgin also oversaw in-house efforts to ensure that raw photo and sensor data was converted to American Standard Code for Information Exchange II (ASCII) and archived on disks. Responsibility for processing raw data was left to UNO. Dolgin's administration also assessed and cleaned all of the analog tapes containing physiological data, some of which were beginning to deteriorate, so that they could be transferred to a new recording format. After Willems retired, much of this work fell to Mark Lotz, the new head of the Technology Department. "He got along with everyone," said Dolgin, "and he was very efficient and extremely knowledgeable of the unique NBDL data."[69]

Data not only went to UNO but was also made available to military researchers at Wright-Patterson Air Force Base and the Naval Air Warfare Center in Warminster, Pennsylvania. NBDL likewise made some data available to civilian institutions through the NMRDC Technology Transfer program. The Federal Technology Transfer Act of 1986 provided for "strategic alliances between Federal laboratories and universities, nongovernment laboratories, and industry" and allowed NBDL to enter into a Cooperative Research and Development Agreement (CRADA) with civilian institutions to share federal research assets (excluding money) with value to the civilian researchers. The CRADA mechanism allowed NBDL to transfer data to Snell Memorial Foundation for use in helmet design and to Harvard Medical School for ECG analysis.[70]

The Snell Memorial Foundation, in particular, had close ties to NBDL. Snell was founded in 1957 after William "Pete" Snell died from head injuries incurred in a racing accident despite wearing a helmet. The non-profit organization, which focused on impact injury protection through development of helmets and restraints, grew under the direction of Dr. George Snively, and by 1995 Dan Thomas had become its president. Moreover, Chan Ewing, Bill Muzzy, and Ed Becker were all on Snell's board of directors.[71]

NBDL's collaboration with Snell had begun in the early 1990s. Ewing and Thomas had remained in touch with Gil Willems and even visited the lab on occasion. The CRADA allowed NBDL to transfer data to the foundation as long as Snell paid for all expenses incurred processing the requests. Data transferred to Snell was used in a collaborative effort with the Netherlands Organization for Applied Scientific Research (TNO). NBDL had worked with TNO since the mid-1980s and had hosted a visit by TNO official Dr. Jan Thunnissen. Between 1992 and 1995, Snell and TNO worked together to develop new specifications for ATDs and crash helmets. In addition, the two organizations used data from a handful of human impact runs to develop a "two-link" mathematical model (a theoretical model with two pivots: one link represents the head and neck, and one link the torso) with the hope that it could eventually be expanded and validated by including data from all of the human runs at NBDL. The initiative ended in disappointment, however, for after NBDL closed, the models developed by TNO were never validated.[72]

By 1996 it was clear that there would be a number of loose threads left hanging when the transfer occurred. In February 1996 Art Prell expressed regret that pathology reports produced by Dr. Unterharnscheidt years earlier remained unpublished even though they required very little editing. Prell volunteered to prepare Unterharnscheidt's reports for publication, calling it "our moral responsibility to report on as much as we possibly can for the taxpayers' money we expended." But there was too much other work to be done, so the reports remain unpublished. The horizontal accelerator also sat idle, with only about 75 percent of the required repairs having been completed. UNO would have to oversee the remainder of the reassembly.[73]

In August 1996 ONR and UNO reached an agreement by which the university would take over NBDL. The official Navy transfer ceremony took place on September 30, 1996, with both Chan Ewing and Robert Kennedy in attendance along with

The crowd listens to a speech at the NBDL closure ceremony in September 1996. In the background is Dr. Tom Dobie's Mobile Biodynamics Laboratory. (USAARL)

other current and former employees. During the proceedings, Dr. John N. Crisp, the dean of UNO's College of Engineering, which would now have operational and administrative control over the lab, named Tom Dobie as NBDL's new director. Crisp also announced that it was being rechristened the National Biodynamics Laboratory. This name change reflected NBDL's new constituencies, both nationwide and globally, as anticipated in the transfer agreement.[74]

As the senior leading scientist at NBDL prior to the transfer, Marc Weiss had expected to make the jump to UNO and lead the lab from there as a faculty member. However, when he learned of Crisp's decision at the ceremony, he was stunned. "It was like the rug had been pulled out from under him," Dolgin later recalled. Although Weiss had been with NBDL since 1972 and had helped keep it running through the post-Ewing 1980s and early 1990s, Dobie was an obvious choice for director given his connections to the Navy and UNO, his extensive scholarship and publication record, and his standing as an internationally renowned scientist. Disappointed at this outcome, Weiss took a position in the Biomedical Engineering Department at Tulane University and later retired to the Northeast.[75]

On October 1, 1996, the Naval Biodynamics Laboratory was officially transferred to UNO and became the National Biodynamics Laboratory. If the acronym remained the same, much else had changed in the years between 1984 and 1996 due to internal strains created by the revolving door of commanding officers, funding shortfalls, loss of key scientists, external threats posed by changes in military research objectives, and the end of the Cold War. Despite these years of turmoil, the lab still made important research findings, including work with SEPs, motion desensitization, and production of the first precise data set on female dynamic response to $+G_z$ acceleration. This latter asset joined the now imposing body of information at UNO, where it was expected to remain. But anyone who had been paying attention would know that when it came to NBDL, the unexpected was a distinct possibility.[76]

CHAPTER FIVE ENDNOTES

[1] Naval Biodynamics Laboratory [hereinafter NBDL], "Command History for Calendar Years 1984-1985" (New Orleans: NBDL, 1985), 2-4; James Rife Oral History Interview with Dr. Daniel J. Thomas, July 12, 2016, 35-38; Obituary for Dr. John Guignard, *Aviation, Space, and Environmental Medicine* 85, no. 6 (June 2014): 686; Memorandum from Dr. John Guignard to Civilian Staff Members, NBDL, dated January 24, 1986, Subj: "Message of Farewell and Thanks," Neel Aeromedical Center, USAARL, Fort Rucker, AL.

[2] Memorandum from Head of the Biomedical Research Department Dr. DanThomas to Commanding Officer Captain Loys Williams, dated January 5, 1984, Subj: "Future Experiments," Neel Aeromedical Center, USAARL. Norman S. Gilbert, M.D., joined NBDL in 1976. After obtaining his medical degree from Louisiana State University (LSU), from 1950-1976 Dr. Gilbert worked at the LSU Medical Center.

[3] NBDL, "Command History for Calendar Years 1984-1985," 1-6. In December 1985 Williams left the Navy and joined the staff at Jensen Beach Emergency Center located in Florida. See "Newsmakers [L. Eugene Williams]," *The Palm Beach Post*, December 1, 1985, 31. Evidence of Biersner's prior visits is found in NBDL, "Initial Command History: Calendar Years 1980 and 1981" (New Orleans: NBDL, 1982), 50, 53.

[4] NBDL, "Command History for Calendar Years 1984-1985," 13; NBDL, "1989 and 1990 Command History" (New Orleans: NBDL, July 1991), 11; Dorothy Francis, "X-Ray Anthropometry Digitization Program for the Hewlett-Packard 9000/835 Computer," NBDL-90R003 (New Orleans: NBDL, 1990), 1; NBDL, "Command History for Calendar Years 1984-1985," 20; NBDL, "Command History for Calendar Year 1986" (New Orleans: NBDL, 1987), 10.

[5] NBDL, "Command History for Calendar Years 1984-1985," 1-2; "NBDL Run Index for Human, Primate, and ADT Runs, 1972-1996," Neel Aeromedical Center, USAARL.

[6] "Scientific Achievement Award [Georg D. Frisch]," *NADC Reflector* (July 1987): 4; Email from Daniel J. Thomas to James Rife, dated March 27, 2017; NBDL, "Determination of Human Dynamic, Injury, and Performance Response to Impact Acceleration & Development of Validated Manikin Components," DD-1498 Form, dated October 1, 1988, Neel Aeromedical Center, USAARL; John J. Quartuccio, "Ejection Seat and Body Dynamic Simulation Model Considering the Effects of Changing Inertial Properties on the System Dynamics" (master's thesis, Lehigh University, December 5, 1996), iii; Georg D. Frisch Death Notice, US Social Security Death Index, Ancestry.com, *U.S., Social Security Death Index, 1935-2014* [database on-line], Number: *085-36-4039,* Issue State: *New York*, Issue Date: *1962* (Provo, UT: USA: Ancestry.com Operations Inc., 2011).

[7] Diane Vaughan, *The Challenger Launch Decision: Risky Technology, Culture, and Deviance at NASA* (Chicago: University of Chicago Press, 1996, 2016); Storer Rowley and Ronald Kotulak, "Weather Prime Suspect in Shuttle Inquiry: Cold Believed Catalyst for Data; 'Burnthrough,'" *Chicago Tribune*, February 19, 1986, 1, 4; NBDL, "Command History for Calendar Year 1986," 9; James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 33-34.

[8] William H. Muzzy III, Marjorie R. Seemann, Gilbert C. Willems, Leonard S. Lustick, and Alvah C. Bittner, Jr., "The Effect of Mass Distribution Parameters on Head/Neck Dynam-

ic Response," *Proceedings of the 30th Stapp Car Crash Conference* (Warrendale, PA: Society of Automotive Engineers [hereinafter SAE], 1987), 167-168; W. H. Muzzy III, "Summary of Current Research in Head Injury Mechanisms at the Naval Biodynamics Laboratory," in *Symposium on Head Injury Mechanisms* (Des Plaines, Ill.: American Association for Automotive Medicine, 1987), 2; Allison L. Schmidt, Alexandria E. Austermann, Kimberly B. Vasquez, Barry S. Shender, and Valeta Carol Chancey, "Establishing the Biodynamics Data Resource (BDR): Human Volunteer Impact Acceleration Research Data in the BDR," USAARL report no. 2010-01 (Fort Rucker, AL: USAARL, 2010), 12-13.

[9] NBDL, "1989 and 1990 Command History," 13; G. C. Willems, W. H. Muzzy III, D. Knouse, and F. Gilreath, "Dynamic Response of the Hybrid III Dummy to $+G_z$ Simulated Ship Shock – Cushioned vs. Hard Seats," NBDL-91R002 (New Orleans: NBDL, November 1991), 4; James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 14-15; David L. Matson, "Naval Biodynamics Laboratory Research in Human Response to Impact Acceleration," *Shock and Vibration* 1, no. 11 (November 1991): 9; "NBDL Run Index for Human, Primate, and ADT Runs, 1972-1996," Neel Aeromedical Center, USAARL, Fort Rucker, AL.

[10] Allison L. Schmidt et al., "Establishing the Biodynamics Data Resource (BDR): Human Volunteer Impact Acceleration Research Data in the BDR," 7; James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 16, 25-26. For early mention of the vertical accelerator, see Memorandum from W. Muzzy to Capt. Ewing, dated December 14, 1971, Subj: "Six Inch Vertical Accelerator Foundation Estimate – Updated," Neel Aeromedical Center, USAARL.

[11] G. C. Willems et al., "Dynamic Response of the Hybrid III Dummy to $+G_z$ Simulated Ship Shock – Cushioned vs. Hard Seats," 20.

[12] For Lustick's retirement, see William H. Muzzy III et al., "The Effect of Mass Distribution Parameters on Head/Neck Dynamic Response," 167; "Alums," *The Times-Picayune*, December 30, 1987, E-4; Bio for Salvadore J. Guccione, Jr., Ph.D., Neel Aeromedical Center, USAARL. For Weiss's promotion to scientific director, see NBDL, "1996 Command History: Final Report," NBDL-96R002 (New Orleans: NBDL, September 1996), 8.

[13] Marc S. Weiss and Leonard S. Lustick, "Guidelines for Safe Human Experimental Exposure to Impact Acceleration," NBDL-86R006 (New Orleans: NBDL, 1986); Marc S. Weiss and Leonard S. Lustick, "Safe Human Experimental Exposure to Impact," *Sixteenth International Workshop on Human Subjects for Biomechanical Research* (Atlanta, GA, October 16-19, 1988), 135-164; Marc S. Weiss, David L. Matson, and Stephen V. Mawn, "Guidelines for Safe Human Exposure to Impact Acceleration, Update A," NBDL-89R003 (New Orleans: NBDL, 1989), 4; Marc S. Weiss, "Standards for Human and Human Surrogate Impact Testing," *The Journal of the Acoustical Society of America* 88, Suppl. 1 (Fall 1990): S64; Email from Daniel J. Thomas to James Rife, dated February 23, 2017.

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[15] American Institute of Biological Sciences, "Report to Department of the Navy: Evaluation of the Biodynamics Research Program of the Naval Biodynamics Laboratory, Naval Medical Research and Development Command" (Arlington, VA: American Institute of Biological Sciences, September 19-20, 1984), 12; Memorandum from Leonard S. Lustick, Head, Mathematical Sciences Department, to Scientific Staff, dated January 31, 1985, Subj: "Suggested Protocol

for Animal Experiments Comparing Anesthetized and Unanesthetized Rhesus Subjects," Neel Aeromedical Center, USAARL.

[16] David L. Matson, "Impact Injury and Evoked Potentials: II – Somatosensory Evoked Potentials in Rhesus Monkeys," NBDL-89R002 (New Orleans: NBDL, November 1990), 2.

[17] David L. Matson and Marc S. Weiss, "Evoked Potential Analysis of Impact Acceleration Experiments," in *AGARD Conference Proceedings no. 432 on Electric and Magnetic Activity of the Central Nervous System: Research and Clinical Applications in Aerospace Medicine* (London: Technical Editing and Reproduction, Ltd., 1988), 28-1 – 28-13.

[18] Letter from James F. Kelly, Commanding Officer, NMRDC, to Commanding Officer, NBDL, dated April 15, 1985, Subj: "Experimental Protocol for Biodynamic Research with Chimpanzees," Neel Aeromedical Center, USAARL.

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[21] See "NBDL Run Index for Human, Primate, and ADT Runs, 1972-1996," Neel Aeromedical Center, USAARL; NBDL, "1989 and 1990 Command History," 33; NBDL, "Naval Biodynamics Laboratory 1st Interim Report FY-91: 1 October 1990 – 1 February 1991" (New Orleans: NBDL, 1991), 5; Memorandum from G. Willems, Head, Technology Dept., to Commanding Officer, dated January 22, 1991, Subj: "Animal Facilities Spaces," Neel Aeromedical Center, USAARL; House Committee on Armed Services, *The Use of Animals in Research by the Department of Defense: Hearing before the Research and Technology Subcommittee*, 103rd Cong., 2nd sess., 1994, 218.

[22] Review of the NBDL run index compiled at the Neel Aeromedical Center, USAARL, shows a total of 331 non-human primate impact acceleration test runs; see also Thomas G. Dobie, "Archiving and Databasing of Non-Human Primate Impact Data," Final Technical Report (New Orleans: University of New Orleans, November 2001), 2, which gives a figure of 389 animal runs. In 2000 a proposal to the Office of Naval Research put the figure at 405. See National Biodynamics Laboratory, "Archiving and Databasing of Non-Human Primate Impact Data: Proposal to the Office of Naval Research" (New Orleans: University of New Orleans, February 3, 2000), 4.

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[26] David L. Matson, "Naval Biodynamics Laboratory Research in Human Response to Impact Acceleration," 10-11.

[27] David L. Matson, "Human Short-Latency Somatosensory Evoked Potentials in Impact Acceleration Research: Equipment, Procedures and Techniques," 15; Marc S. Weiss, "Testing Correlated 'EEG-Like' Data for Normality Using a Modified Kolmogorov-Smirnov Statistic," *IEEE Transactions on Biomedical Engineering* 33 no. 12 (December 1986): 1114-1120; Marc S. Weiss, "Modification of the Kolmogorov-Smirnov Statistic for Use with Correlated Data," *Journal of the American Statistical Association* 73, no. 364 (December 1978): 872-875; M. S. Weiss, "Kolmogorov-Smirnov Goodness-of-Fit Test: Corrected for Use with 'EEG-Like' Data," NBDL-84R003 (New Orleans: NBDL, April 1984); M. S. Weiss, "Testing EEG Data for Statistical Normality," *Proceedings of the Eleventh International Conference of the IEEE Engineering in Medicine and Biology Society* 11, no. 2 (1989): 704-705; David L. Matson, "Impact Injury and Evoked Potentials: II – Somatosensory Evoked Potentials in Rhesus Monkeys," 2.

[28] Russell C. Grunsten, Norman S. Gilbert, and Stephen V. Mawn, "The Mechanical Effects of Impact Acceleration on the Unconstrained Human Head and Neck Complex," *Contemporary Orthopaedics* 18, no. 2 (February 1989): 202. Dr. Grunsten was an associate professor of orthopaedics surgery at Tulane University and a consultant at NBDL. David Matson also reported to members of the Aerospace Medical Association in 1990 from analysis of $+G_z$ human runs on the horizontal accelerator that "$+G_z$ impact acceleration up to 12 G does not compromise somatosensory pathways"; see D. L. Matson, "$+G_z$ Impact Acceleration Experiments: Human Evoked Potentials [abstract]," paper presented at the 61st Annual Meeting of the Aerospace Medical Association (New Orleans, LA, May 13-17, 1990), Publication Library, Neel Aeromedical Center, USAARL; James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 26-27.

[29] NBDL, "Command History for Calendar Years 1984-1985," 1-2; U.S. Congress, House of Representatives, 100th Cong., 1st sess., 1987, House Reports Nos. 392-432, U.S. Congressional Serial Set, Document 13809, "Aircrew Impact Injury Prevention," 231; American Institute of Biological Sciences, "Report to Department of the Navy: Evaluation of the Biodynamics Research Program of the Naval Biodynamics Laboratory, Naval Medical Research and Development Command," 13; NBDL, "Command History for Calendar Year 1986" (New Orleans: NBDL, 1987), 10; House Subcommittee on the Department of Defense, *Department of Defense Appropriations for 1986: Hearings before a Subcommittee of the Committee on Appropriations*, pt. 7, 99th Cong., 1st sess., 1985, 428-429.

[30] NBDL, "Command History for Calendar Year 1983" (New Orleans: NBDL, 1984), 8; NBDL, "Command History for Calendar Years 1984-1985," 20.

[31] NBDL, "Command History for Calendar Year 1986," 10.

[32] Thomas G. Dobie, "Teaching the Right Stuff – the Heart of the Matter," *Aviation, Space, and Environmental Medicine* 60 (February 1989): 195-196.

[33] NBDL, "1989 and 1990 Command History," 17; Thomas G. Dobie and James G. May, "Generalization of Tolerance to Motion Environments," *Aviation, Space, and Environmental Medicine* 61 (1990): 707-711; Thomas G. Dobie and James G. May, "Motion Sickness Prevention: A Course of Instruction in Cognitive-Behavioral Counseling," *Proceedings of the Twelfth Psychology Symposium in the Department of Defense* (Colorado Springs: United States Air Force Academy, April 1990), 87-91; T. G. Dobie, J. G. May, W. D. Fisher, S. T. Elder, and K. A. Kubitz, "A Comparison of Two Methods of Training Resistance to Visually-Induced Motion Sickness," *Aviation, Space, and Environmental Medicine* 58 (1987): A31-41; T. G. Dobie, J. G. May, W. D. Fisher, and N. B. Bologna, "An Evaluation of Cognitive-Behavioral Therapy for Training Resistance to Visually-Induced Motion Sickness," *Aviation, Space, and Environmental Medicine* 60 (1989): 307-314; Thomas G. Dobie, "Teaching the Right Stuff – the Heart of the Matter," 195-196.

[34] Ibid.

[35] Memorandum from Dr. John Guignard to Civilian Staff Members, Naval Biodynamics Laboratory (NBDL), dated January 24, 1986, Subj: "Message of Farewell and Thanks," Neel Aeromedical Center, USAARL; Letter from Undersigned Scientific Staff [Lustick, Willems, Muzzy, and Weiss], Naval Biodynamics Laboratory, New Orleans, to Commanding Officer, Naval Biodynamics Laboratory, dated January 17, 1986, Subj: "Letter of Recognition for Dr. John Guignard," Neel Aeromedical Center, USAARL.

[36] Ibid.; NBDL, "Initial Command History for Calendar Years 1980 and 1981," 19; Citations for papers presented by Guignard during his time at NBDL may be found in Mary M. Harbeson, "Bibliography of NBDL Publications," NBDL-87R001 (New Orleans: NBDL, 1987).

[37] The records of the House Subcommittee on Department of Defense Appropriations indicate that congressional interest for supporting NBDL began in FY 1984. For example, in 1990 the Committee on Appropriations noted, "Since fiscal year 1984, this Committee has expressed special interest in and had closely monitored the funding of the Aircrew Impact Injury Prevention project and other research projects conducted at the Naval Biodynamics Laboratory (NBDL)." See House Committee on Appropriations, *Department of Defense Appropriations Bill, 1991: Report of the Committee on Appropriations*, Rpt. No. 101-822, 101st Cong., 2nd sess., 1990, 181; James Rife Oral History Interview with Art Prell, dated August 18, 2016, 14.

[38] Ibid.

[39] House Reports nos. 392-432, Serial Set no. 13809, 100th Cong., 1st sess., January 6-December 22, 1987, 231.

[40] House Subcommittee on the Department of Defense, *Department of Defense Appropriations for 1988: Hearings before a Subcommittee of the Committee on Appropriations*, 100th Cong., 1st sess., 1987, 478.

[41] See letter from James N. Woody, Commanding Officer, NMRDC, to Distribution, dated March 31, 1989, Subj: "FY90 Program Guidance," enclosure number six, "List of Tentative Medical Requirements by Priority Level," Neel Aeromedical Center, USAARL; House Subcommittee on the Department of Defense, *Department of Defense Appropriations for 1988: Hearings before a Subcommittee of the Committee on Appropriations, House of Representatives*, 100th Cong., 1st sess., 1987, 253-255.

[42] James Rife Oral History Interview with Bill Muzzy, dated August 17, 2016, 30; NBDL, "1991 and 1992 Command History" (New Orleans: NBDL, August 1993), 1.

[43] NBDL, "Department Head Meeting," January 8, 1988, Neel Aeromedical Center, USAARL; NBDL, "1989 and 1990 Command History," 5; David L. Matson and Daniel L. Dolgin, "Training Program for the Prevention of Motion Sickness," *Navy Medicine* 82, no. 2 (March-April 1995): 7; NBDL, "1994 Command History," NBDL-95R003 (New Orleans: NBDL, March 1995), 15.

[44] See chain of correspondence and notes attached to Bill Muzzy, Head, Engineering Div., to Distribution, dated March 18, 1988, Subj: "Vertical Accelerator Man-Rating," Neel Aeromedical Center, USAARL.

[45] NBDL, "1991 and 1992 Command History," 17; Stephen V. Mawn, James J. Lambert, and Joseph L. Catyb, Jr., "The Relationship Between Head and Neck Anthropometry and Kinematic Response During Impact Acceleration," *Aviation, Space, and Environmental Medicine* 63, no. 1 (January 1992): 32.

[46] J. J. Lambert and S. J. Guccione, Jr., "Linear Regression Analysis of Human and Manikin Head Kinematic Response to $+G_z$ Impact Acceleration, NBDL-95R004 (New Orleans: NBDL, October 1995), 1, 5-7.

[47] NBDL, "1989 and 1990 Command History" (New Orleans: NBDL, July 1991), 35; Nabih M. Alem, Dennis F. Shanahan, John V. Barson, and William H. Muzzy III, "The Airbag as a Supplement to Standard Restraint Systems in the AH-1 and AH-64 Attack Helicopters and Its Role in Reducing Head Strikes of the Copilot/Gunner," USAARL report no. 91-6, vol. 1 (Fort Rucker, AL: USAARL, July 1991); Stephen V. Mawn, James J. Lambert, and Joseph L. Catyb, Jr., "The Relationship Between Head and Neck Anthropometry and Kinematic Response During Impact Acceleration," *Aviation, Space, and Environmental Medicine* 63, no. 1 (January 1992): 32.

[48] NBDL, "1989 and 1990 Command History," 19; Gilbert Willems and Gordon R. Plank, "Calibration of a Six-Degree-of-Freedom Acceleration Measurement Device," DOT-HS-808-189 (Washington, D.C.: U.S. Department of Transportation, December 1994).

[49] NBDL, "1991 and 1992 Command History," 65.

[50] James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 37. Muzzy's statements regarding the plan to consolidate NBDL and USAARL with operations at Wright-Patterson are confirmed in the minutes of NBDL department head meetings. See Douglas W. Call, "Department Head Meeting, 11 January 1991," and Call, "Department Head Meeting, 19 July 1991," both documents located at the Neel Aeromedical Center, USAARL.

[51] William H. Muzzy III, Alan E. Cantor, Donald K. Eisentraut, Louis A. D'Aulerio, "Seat-Back Yielding and Collapse: A Danger to Occupants during Real-World Collisions," in *Proceedings of the 20th Annual Workshop on Human Subjects for Biomechanical Research* (Warrendale, PA: SAE, 1992), 237.

[52] House Subcommittee on the Department of Defense, *Department of Defense Appropriations for 1989: Hearings before a Subcommittee of the Committee on Appropriations, House of Representatives*, 100th Cong., 2nd sess., 1988, 811; Douglas W. Call, "Department Head Meeting, 11 January 1991," and Call, "Department Head Meeting, 19 July 1991," Neel Aeromedical Center, USAARL; James Rife telephone conversation with Andre Rog, March 27, 2017; Memorandum from Douglas W. Call to Department/Division Heads, dated September 26, 1991, Subj: "Department Head Meeting"; and Call, "Department Head Meeting, 19 July 1991," Neel Aeromedical Center, USAARL.

[53] For Call's retirement, see NBDL, "1991 and 1992 Command History," 70-71; for Rendin's full bio, see NBDL, "1994 Command History," 5.

[54] On February 22, 1974, Lt. Barbara A. Allen became the Navy's first designated female aviator. Mark L. Evans and Roy A. Grossnick, *United States Naval Aviation, 1910-2010, vol. 1, Chronology* (Washington, D.C.: Naval History and Heritage Command, 2015), 406, 443; Margaret Conrad Devilbiss, *Women and Military Service: A History, Analysis, and Overview of Key Issues* (Maxwell Air Force Base, AL: Air University Press, November 1990), 21-22. According to Devilbiss, women began flying as Army aviators (often as helicopter pilots) in 1974. The Air Force did not accept female pilots until 1977; Mark L. Evans and Roy A. Grossnick, *United States Naval Aviation, 1910-2010, vol. 1, Chronology*, 506; Traci A. Keegan, "Study of Factors Affecting the Retention Decisions of Sea-Going Female Naval Aviators and Naval Flight Officers" (master's thesis, Naval Postgraduate School, May 1999), 4; James Rife Oral History Interview with Daniel J. Thomas, July 12, 2016, 61-62; NBDL, "1993 Command History," 17; NBDL, "1994 Command History," 9; R. W. Rendin and L. W. Schoenberg, "Women Volunteers Engage in Impact Acceleration Research," *Navy Medicine* 86, no. 4 (July-August 1995): 5-7.

[55] Bill Muzzy indicated in his oral history that engineering technician Ferris Bolin may have suffered temporary hearing loss. James Rife Oral History Interview with Bill Muzzy, August 17, 2016, 20, 39; Memorandum from G. Willems, Head, Technology Dept., to Research Psychologist, dated April 19, 1994, Subj: "Interim Report Inputs," Neel Aeromedical Center, USAARL; Memorandum from Gil Willems, Head, Technology Dept., to Commanding Officer, dated December 20, 1994, Subj: "CY-94 Vertical Acceleration Operation and Maintenance Summary," Neel Aeromedical Center, USAARL; NBDL Run Index with Dates, Neel Aeromedical Center, USAARL.

[56] See memos, Gil Willems, Head, Technology Department, NBDL, to Phillip Cheng, NMRDC, dated August 24, 1994, Subj: "'Pig II' Project for NAMRL"; Gil Willems, Head, Technology Dept., to Commanding Officer, dated September 7, 1994, Subj: "Cost of Horizontal Accelerator Repair"; Memorandum from Gil Willems, Head, Technology Dept., to Distribution, dated December 28, 1994, Subj: "Horizontal Accelerator"; S. J. Guccione, Jr., Principal Investigator, Impact Acceleration Program, to Distribution, dated December 20, 1994, Subj: "Input for 4th Incremental Report FY 1994," Neel Aeromedical Center, USAARL; Memorandum from Gil Willems, Head, Technology Dept., to Commanding Officer, dated January 13, 1995, Subj: "Restoration of Leave," Neel Aeromedical Center, USAARL.

[57] Memorandum from Gil Willems, Head, Technology Dept., to Commanding Officer, dated December 20, 1994, Subj: "CY-94 Vertical Acceleration Operation and Maintenance Summary," Neel Aeromedical Center, USAARL.

[58] Memorandum from Gil Willems, Head, Technology Dept., to Commanding Officer, dated January 13, 1995, Subj: "Restoration of Leave"; R. W. Rendin, Commanding Officer, Naval Biodynamics Laboratory, to Defense Finance and Accounting Services, Defense Accounting Office/Cleveland Center (ATTN: Code BLN), Charleston, SC, dated January 27, 1995, Subj: "Restoration of Annual Leave Hours for Leave Year Ending 7 Jan 95, ICO Mr. Leslie Lorig and Mr. Robin Roth," Neel Aeromedical Center, USAARL.

[59] Memorandum from HM2 Gail Seaman to Committee Chairman, Female Human Research Volunteer Feasibility Study Committee, dated November 16, 1992, Subj: "Strapping of Female Subjects," and "NBDL Run Index for Human, Primate, and ADT Runs, 1972-1996,"

Neel Aeromedical Center, USAARL; R. W. Rendin and L. W. Schoenberg, "Women Volunteers Engage in Impact Acceleration Research," 7.

60 Emphasis reproduced from source. Memorandum from Gil Willems, Head, Technology Dept., to Chief, Operations Branch, dated December 14, 1994, Subj: "Vertical Accelerator," Neel Aeromedical Center, USAARL.

61 See series of letters, Roger Black, Command Safety Manager, to Commanding Officer, dated April 7, 1995, Subj: "Vertical Accelerator Safety"; R. W. Rendin, Commanding Officer, to Command Safety Manager, dated April 7, 1995, Subj: "Vertical Accelerator"; and Roger Black, Command Safety Officer, to Commanding Officer, dated April 12, 1995, Subj: "Vertical Accelerator Safety"; Memorandum from S. J. Guccione, Jr., Head, Mathematical Sciences Division, to CDR Dolgin, dated February 2, 1995, Subj: "Top Ten Goals for NBDL (CY' 95)," Neel Aeromedical Center, USAARL.

62 David E. Lockwood and George Siehl, "Military Base Closures: A Historical Review from 1988 to 1995," Congressional Research Service Report for Congress (October 18, 2004).

63 United States General Accounting Office, *Military Bases: Analysis of DOD's 1995 Process and Recommendations for Closure and Realignment: Report to the Congress and the Chairman, Defense Base Closure and Realignment Commission* (Washington, D.C.: General Accounting Office, 1995), 2; James Rife Oral History Interview with Daniel L. Dolgin, January 19, 2017; Andrew Feickert and Stephen Daggett, "A Historical Perspective on 'Hollow Forces,'" Congressional Research Service Report for Congress R42334 (January 31, 2012), 10-11; U.S. Congress, *Defense Base Closure and Realignment Commission Report to the President*, 104th Cong.,1st sess., 1995, H. serial 14300, 6, 81. BRAC Commission members were former Illinois Senator Alan J. Dixon (Chairman), Vietnam veteran and business owner Alton W. Cornella, former director of the White House Office Public Liaison Rebecca G. Cox, former finance chairman of the Democratic National Committee S. Lee Kling, Wendi L. Steele, General James B. Davis, USAF (Ret.), Major General Josue Robles, Jr., USA (Ret.), and Rear Admiral Benjamin F. Montoya, USN (Ret.). James Rife telephone conversation with Andre Rog, March 27, 2017.

64 House Subcommittee on the Department of Defense, *Department of Defense Appropriations for 1988: Hearings before a Subcommittee of the Committee on Appropriations, House of Representatives*, 100th Cong., 1st sess., 1987, 256; James Rife Oral History Interview with Daniel Dolgin, January 19, 2017, 3, 9, 35; Email from Daniel J. Thomas to James Rife, dated March 27, 2017; James Rife telephone conversation with Russ Wiley (Chan Ewing's daughter) and Russ Davis (Ewing's son-in-law), dated March 24, 2017.

65 Memorandum from S. J. Guccione, Head of Research, to Distribution, dated October 10, 1996, Subj: "1st Meeting on Database Project," Neel Aeromedical Center, USAARL. Many of the visits to the lab over the years are evidenced by copies of visitor badge requests preserved at the Neel Aeromedical Center, USAARL. James Rife Oral History Interview with Daniel L. Dolgin, January 19, 2017, 9; Memorandum from R. W. Rendin, Commanding Officer, Naval Biodynamics Laboratory, to XO, Department Heads, Chief Scientist, dated February 7, 1995, Subj: "Goal Review," Neel Aeromedical Center, USAARL.

66 Douglas W. Call, "Department Head Meeting 8 May 92," Neel Aeromedical Center, USAARL; NBDL, "1994 Command History," 14; Memorandum from R. W. Rendin, Commanding Officer, Naval Biodynamics Laboratory, to XO, Department Heads, Chief Scientist, dated February 7, 1995, Subj: "Goal Review," Neel Aeromedical Center, USAARL; NBDL, "1996 Command History: Final Report," 15. The Command History does note that NBDL

could make arrangements to use a NASA-employed physician to provide the necessary temporary medical monitoring support. However, the NBDL run listing at the Neel Aeromedical Center, USAARL, lists June 6, 1995, as the final occasion when humans were run on the vertical accelerator. Based on this evidence, it does not appear that NBDL acted on the option to use a NASA physician. Although almost 300 human research volunteers were qualified, 211 were exposed to impact. Allison L. Schmidt et al., "Establishing the Biodynamics Data Resource (BDR): Human Volunteer Impact Acceleration Research Data in the BDR," iii, 8.

[67] James Rife telephone conversation with Andre Rog, March 27, 2017; NBDL, "1996 Command History: Final Report," 6; James Rife Oral History Interview with Daniel Dolgin, January 19, 2017, 1-2.

[68] James Rife Oral History Interview with Daniel Dolgin, January 19, 2017, 14; S. J. Guccione, Jr., "Human vs. Manikin Neck Response to High-Onset $+G_z$ Vertical Acceleration" (New Orleans: NBDL, October 15, 1996), 11.

[69] James Rife Oral History Interview with Daniel Dolgin, January 19, 2017, 6-7; NBDL, "1996 Command History: Final Report," 13.

[70] NBDL, "1996 Command History: Final Report," 12; Jerry C. Patee, Daniel L. Dolgin, and Michael H. Mittelman, "Naval Medical Research and Development Command and Technology Transfer," *Navy Medicine* 86, no. 1 (January-February 1995): 21, 23.

[71] For the Snell Memorial Foundation, see http://www.smf.org/who.

[72] Memorandum from Gil Willems, Head, Technology Dept., to Commanding Officer, dated October 19, 1990, Subj: "Phonecon with Dr. Ewing"; Memorandum from Gil Willems, Head, Technology Department, to Commanding Officer, dated October 23, 1990, Subj: "Memorandum of Understanding (MOU) NAVBIODYNLAB and Snell Memorial Foundation (SNELL)," Neel Aeromedical Center, USAARL. For evidence of the visits, see the listings of notable visitors in the 1989-1990, 1991-1992, and 1994 Command Histories and in the copies of the visitor badge requests to Martin Marietta, preserved at the Neel Aeromedical Center, USAARL. Douglas W. Call, "Department Head Meeting, 7 February 1992," Neel Aeromedical Center, USAARL; Jerry C. Patee et al., "Naval Medical Research and Development Command and Technology Transfer," 23; NBDL, "1994 Command History," 34; J. Thunnissen, J. Wismans, C. L. Ewing, and D. J. Thomas, "Human Volunteer Head-Neck Response in Frontal-Flexion: A New Analysis," in *Proceedings of the 39th Annual Stapp Car Crash Conference* (Warrendale, PA: SAE, 1995), 439-460. Some of the modeling draws upon earlier work completed by Ed Becker while working for QEI, Inc. during the 1980s. See Edward B. Becker, "Head and Neck Kinematics for Frontal, Oblique, and Lateral Crash Impact," in *Mechanisms of the Head and Spine*, ed. Anthony Sances, Jr., D. J. Thomas, C. L. Ewing, S. J. Larson, and F. J. Unterharnscheidt (Goshen, NY: Aloray Publishers, 1986), 117-132; Daniel Thomas, "Important Data on Impact Injury Prevention Needs Protection and Further Analysis with a Long Term Strategy for this National Treasure," n.d., 6, 14, paper in the possession of Daniel J. Thomas.

[73] NBDL, "1996 Command History: Final Report," 16; Memorandum from Art Prell to Commanding Officer, dated February 9, 1996, Subj: "Publish Reports and Other Things We Should Accomplish Before the Lab Closes," Neel Aeromedical Center, USAARL.

[74] NBDL, "1996 Command History: Final Report," 7, 16; James Rife Oral History Interview with Daniel Dolgin, January 19, 2017, 3-8, 43-44.

[75] James Rife telephone conversation with Andre Rog, March 27, 2017; James Rife Oral History Interview with Daniel Dolgin, January 19, 2017, 11-12; Jack Curry, Jr., "Weiss Left His Mark on Cycling," *The Times-Picayune*, July 8, 1998. For Weiss's affiliation with Tulane, see Susan S. Margulies, Q. Yuan, S. J. Guccione, and Marc S. Weiss, "Kinematic Response of the Neck to Voluntary and Involuntary Flexion," *Aviation, Space, and Environmental Medicine* 69, no. 9 (October 1998): 896-903.

[76] NBDL, "1996 Command History: Final Report," 7, 16.

Chapter Six

Saving the Legacy, 1996-2017

In the days before the closing ceremony that marked NBDL's last day as a Navy command, Dan Dolgin and John Crisp, dean of the College of Engineering at the University of New Orleans (UNO), hammered out a Cooperative Research and Development Agreement (CRADA) intended to define a path forward for the soon to be rechristened National Biodynamics Laboratory. Although the Department of Defense (DOD) and the Base Realignment and Closure (BRAC) Commission expected UNO to maintain the lab on an "as-needed" basis, the university had visions of an enduring mission comprising three main goals. The first was preserving, assessing, archiving, and transforming the existing NBDL impact acceleration data into an updated National Crash Survival Data Bank for future researchers and modelers. The second was to continue the Ship Motion Simulator (SMS) program under NBDL director Dr. Tom Dobie. The third goal was for UNO to maintain and upgrade as necessary all of NBDL's equipment, including the SMS, the horizontal and vertical accelerators, and a host of other devices. In subsequent months, all of these goals would be challenged in one way or another.[1]

One of the challenges was the result of a cultural shift that had begun about the same time that Ewing developed his vision for impact acceleration research. Animal rights activism had its roots in the cultural ferment of the 1960s and began to crystallize as a movement, with the founding of both fringe and mainstream organizations in the 1970s. In the 1980s came escalating protests, malicious break-ins, and a series of high-profile campaigns against laboratories that used animals in experiments, most notably one in Silver Spring, Maryland, that resulted in criminal charges against a researcher, which were later overturned. While few Americans sympathized with extremists, a sizeable percentage of the public was unreflective about the need for animal research and generally sympathetic toward the movement. By the early 1990s, this broader cultural shift had obliged universities, corporations, and the military to greatly tighten restrictions on animal testing. Therefore, the films from NBDL's almost four hundred test runs, as well as physical specimens, photographs of test animals, veterinary medical records, x-rays, and physiology strip charts, amounted to much dynamite with the potential to blow a big hole in the Navy's reputation. As he oversaw the closure of NBDL, Dolgin became acutely aware of this. "My concern was that it would be problematic if these images were released to the public," he recalled, "especially without an appropriate interpretation."[2]

Representatives from the U.S. Navy and the University of New Orleans complete the lab's transfer and the National Biodynamics Laboratory is established. (USAARL)

The pending transfer made an explosion especially likely. While most of the research staff could expect to relocate to other military or university labs, the hourly employees at Michoud were left high and dry—and they were bitter about it. Dolgin was particularly worried that one of them might turn old experimental records over to animal rights activists out of spite or for profit. Even if the animal testing records made the transfer without exposure, Dolgin did not believe that the University of New Orleans constituted the safest of repositories—most of the attacks in the 1990s were on university labs—nor was UNO enthusiastic about accepting the data. At Dolgin's request, chief of the Office of Naval Research (ONR) Rear Admiral Paul G. Gaffney II, accompanied by Navy legal counsel, visited Michoud to review samples of the primate test imagery and decide how to deal with it. Although the ONR lawyers never directly suggested disposing of the records altogether, that unstated option was clearly on the table. Dolgin took the initiative and argued that the primate films should be preserved since they could never be replicated in the future, given the Navy's tighter regulation of animal and human testing in its labs. Captain Tom Jones at the Naval Medical Research and Development Command (NMRDC) in Bethesda, Maryland, backed Dolgin. Torn between protecting the Navy from a potential reputational crisis and the need to preserve irreplaceable scientific data, Gaffney decided to "lock it up" at NAMRL in Pensacola, away from UNO and out of public reach.[3]

The decision made, Dolgin began working the phone to get things under way before anyone could change their mind. Everyone along the chain of command understood the gravity of the situation; every answer was "yes, yes, and yes." Dolgin was amazed. It was one of the rare times in the Navy that such a move was actually "fast tracked." The data at NBDL had always been stored in standard government gray filing cabinets protected only by perfunctory locks. Dolgin invested in two large, heavy-duty, fireproof safes as a permanent repository for the animal data. "They were very heavy," he remembered, "but we were able to get them on one rental truck." As the truck pulled out from Michoud and turned east onto Interstate 10 toward Pensacola, two hundred miles away, Dolgin and his colleagues took a collective deep breath.[4]

Three long hours later came word that the truck was at NAMRL and the data was in good hands. Dolgin was ecstatic. "It was a great phone call to receive," he later declared, "knowing that everything was fine at the other end, and that it had arrived safely, because there was no replacing that data." Just a few days later, Dolgin handed over the keys to what remained behind to John Crisp. Dolgin was soon reassigned as an international sciences programs director for the Navy, based in Arlington, Virginia.[5]

Restarting Research

UNO began its stewardship of NBDL with the best of intentions, with remaining staff members, including Dr. Salvadore "Sal" Guccione, Mark Lotz, and Andre Rog, taking up quarters in consolidated offices at UNO and Michoud. The veteran staff then launched a comprehensive training program to teach the academic personnel how to actually run and maintain the test equipment. The UNO scientific team next evaluated the condition of the equipment, repaired the SMS, and tested the vibration platform, which had not been operated in years. Finally, Dobie prepared a comprehensive plan and schedule for deliverables, achieving desired staffing levels, and new equipment acquisition.[6]

NBDL Command group photograph from July 1991. Seated in the front row are Commander Robert W. Rendin (third from the left), Commander Douglas W. Call (fourth from the left), Dr. Marc S. Weiss (fifth from the left), and Dr. Thomas G. Dobie (second from the right). Photographer Art Prell stands to the right. (USAARL)

But it soon became clear that, despite expectations, NBDL would not be able to perform as expected under the new arrangements—resources available from UNO could not make up for the Navy line-item appropriations that had kept the lab going for so long. Even worse, the staffing reductions brought about by BRAC, approximately 65 percent from 1995 to 1996, crippled NBDL's ability to resume research and testing. Dobie had only about ten to twelve staff members, including those who had transitioned from the Navy to UNO, to bring NBDL back to life. The dismissal of the hourly workers left NBDL with few machinists, mechanics, electricians, or maintenance men. And with Marc Weiss's departure, there was no one remaining who was qualified to supervise human research volunteer and non-human primate test runs on the impact accelerators. But human test runs would have been out of the question anyway. For although the lab had an impressive array of machinery, there were not enough people to safely operate it. As Andre Rog recalled, "There were no test runs—just occasional shots for maintenance and to retain the capability."[7]

Maintenance was a problem, because much of the equipment, including the vibration platform, the photo digitizing system, and the SMS, was in poor condition. Although the horizontal accelerator had been repaired over the winter of 1996-1997, upgrades and repairs of smaller devices were more expensive and time consuming than anticipated. As of March 1997, few of the test devices were fully operational, and the price tag for repairs was an estimated $925,000.[8]

Dobie was undaunted. By September 1997, he had augmented his staff with students, got the SMS running reliably, and renewed his motion sickness research. What Rog called Dobie's "boundless enthusiasm and energy for his ship motion sickness research" went on to yield a few final academic achievements for NBDL, with major academic papers published in 2003 and 2004 about the role of vision in motion sickness. Dobie also presented an important paper entitled "Critical Significance of Human Factors in Ship Design" at the 2003 Research Vessel Operators Committee meeting, in which he argued that naval architects needed to do a better job of designing vessels with respect to human responses to moving platforms. A third doctoral degree, based on this groundbreaking NBDL work, was forthcoming in 2005 when Dobie presented his two-volume research thesis to the University of Leeds entitled "Motion Effects on the Human Body."[9]

Although the motion research was important from both academic and applied engineering perspectives, the greatest accomplishment of NBDL at UNO was expected to be creation of a National Crash Survival Data Bank (NCSDB). The intent was to build a modern, fully searchable database on the foundation of the vintage 1970s and 1980s database developed under Ewing and Thomas. UNO believed that the NCSDB would have real commercial value and planned to offer access to it to clients in both the government and private sectors. This was theoretically true, but there was much to be done before any value could be realized, namely, to make sense of—and provide access to—some twenty-three tons of medical records, some 10,000 rolls of human research volunteer films, physiologic paper readouts, and bulky analog and digitized tapes, all stored in cabinets and boxes covering 399 square feet at Michoud. Every bit of this vast amount of material would have to be digitized and entered into the new data bank.[10]

UNO designated Dr. Edit J. Kaminsky Bourgeois as principal investigator for the NCSDB. Bourgeois was an Argentinian electrical engineer specializing in digital communications and signal and image processing who had worked for Sverdrup Technologies and Lockheed Martin before joining the UNO faculty in 1995. Sal Guccione, Andre Rog, and Mark Lotz were slated to assist her.[11]

In a proposal submitted in December 1996, Bourgeois described the expected end-product as "a user-friendly, relational data base for impact acceleration data from anthropomorphic mannequins and human volunteers" that contained "all recoverable data collected by the Naval Biodynamics Laboratory in the last 25 years." The data bank was expected to utilize Oracle software and be compatible with the Microsoft Windows 95 operating system so that personal computer users could easily access and retrieve the data. The raw digitized data was expected to be archived on tapes and CD ROMs. Additionally, NBDL planned to develop a proprietary impact data analysis program called EZFLOW to compute the three-dimensional trajectory of selected anatomical segments of test subjects. The initial cost for the entire archiving and data bank project was estimated at $196,626.[12]

ONR funded construction of the data bank through "Human and Manikin" contract N00014-98-1-0335. Following delays due to space consolidation, replacement of obsolete computers and software, data network reconnection and reorganization, and slow staff recruitment, work began on February 1, 1997. During the next three years, Bourgeois and her team made steady progress, even after finding that the magnetic coatings on the aging tapes had started to disintegrate and that this data had to be first transferred to more stable electronic storage media. In the meantime, UNO established a web address for NCSDB on the Internet, www.nbdl.org, and filed for intellectual property copyright protection with the Library of Congress for any data digitized by NBDL.[13]

In May 1999 Bourgeois and Rog introduced the NCSDB to the world at the Digital Human Modeling for Design and Engineering International Conference and Exhibition in The Hague, Netherlands, with a technical paper entitled "The National Crash Survival Data Bank: A Resource for Modelers." In December 1999 UNO dean John Crisp asked ONR to formalize a licensing agreement between the Navy and UNO allowing the university to move forward with the NCSDB's public release, with customers to be charged based on the level of service required.[14]

In 2000 UNO sought both permission and funding from ONR to evaluate, preserve, digitize, archive, and enter into the data bank the non-human primate medical records in the lab's possession. ONR agreed but only if access to the sensitive information was restricted to approved onsite NBDL users. On July 15, 2000, ONR allocated $970,000 to enable UNO to integrate the non-human primate information under contract N00014-00-1-0546 with a one-year period of performance. The amount was reduced by $4,000 to $966,000 that September.[15]

NBDL subsequently scanned the clinical medical records for 118 animal subjects—115 rhesus macaques and 3 chimpanzees through 311 test runs—into portable document format (PDF) electronic files. The PDFs were then processed and uploaded into the NCSDB, along with 288 sets of sensor data, 283 sets of photographic data, and 336 sets of three-dimensional (3D) motion data, all similarly preserved and scanned. The task was completed by November 30, 2001, although a funding shortfall forced NBDL to work during the last four months on a no-cost extended contract basis. In his final technical report to ONR, Dobie concluded that "with the inclusion of non-human primate response to indirect impact, the already valuable NCSDB becomes even more valuable to the scientific community." This was especially true in his estimation because "similar impact tests using non-human primates are not likely to be performed today or in the near future due to funding limitations and the concerns of using animals in testing programs." The concerns were so great that ONR still refused to allow the non-human primate data to be accessed on the Internet.[16]

Leaving New Orleans

Despite the technical progress in building the NCSDB, UNO's expectations for commercialization were not met. NAMRL was the sole customer for the data bank and leased the digitized data as it became available. Continued access restrictions to the all-important non-human primate data remained a hurdle for further analysis, while the impact accelerators sat quietly in Test Cell 4 at Michoud, producing no new data. The only thing of import happening at NBDL was in Test Cell 3 at Michoud, where Dobie continued running the SMS and preparing publications on motion sickness.[17]

Six years after the 1996 transition, it was abundantly clear that NBDL was not likely to live up to expectations under UNO control. Under those circumstances, UNO grew weary of maintaining NBDL at Michoud, as operating and maintenance costs outstripped NCSDB revenue and ONR funding dried up, with Navy resources reallocated to U.S. warfighters overseas during Operations Enduring and Iraqi Freedom. Further congressional appropriations were also out of the question since NBDL's long-time patron, Bob Livingston, had resigned in 1999 due to an exposed extra-marital affair, and Louisiana Congressman William Jefferson did not have the clout to secure new funding alone. Therefore, in 2002 UNO instructed Dobie to wind down his SMS testing and to begin clearing his equipment and records out of Michoud. Since UNO did not have the space on its campus to store any of this material, permanent disposal was authorized. Dobie was stunned and looked for alternatives. He called a friend at NAMRL, Captain Angus Rupert, to see if the Navy could help.[18]

Rupert was a highly regarded naval flight surgeon, inventor, and scientist, specializing in studies of spatial disorientation in aviators and astronauts. Born in Madoc, Ontario, in 1947, Rupert had earned a Ph.D. in neurophysiology from the University of Illinois, Urbana, in 1979 and an M.D. from the University of Toronto in 1982 before joining the Navy's Medical Corps in 1984. As a researcher, Rupert was best known for developing a Tactile Situation Awareness System, an advanced flight suit designed to reduce spatial disorientation accidents and to improve the performance of pilots, astronauts, and divers.[19]

Captain Angus H. Rupert (right) talks with Captain Douglas W. Call (center) during one of his early visits to NBDL between 1987-1992. (USAARL)

Rupert had spent most of his Navy career at Pensacola and had known Dobie for years. When Dobie's call came, Rupert immediately grasped the enormity of the threat. "I thought it was just a terrible, terrible tragedy, since there was no place else that this work could be carried out," Rupert recalled. "It was simply going to go into storage in a salt mine somewhere. I then wanted to find some way to salvage that, so it could at least be analyzed." Rupert turned for help to Commander Michael Lilienthal, an experimental psychologist and action officer working for Dr. Charles Holland in the Acquisition, Technology, and Logistics (AT&L) Office of the Deputy Undersecretary of Defense (Science and Technology) at the Pentagon. Lilienthal needed no convincing and went to colleague Dr. Robert Foster, the director of the BioSystems Office of the Deputy Under Secretary of Defense (Science & Technology), for support. Foster was also appalled at the prospect of losing the data and promised to bring his own DOD resources to bear on the situation. The orders finally came down to the ONR program officer for the Aviation Medicine Program, Lieutenant Commander David R. Street, Jr., to authorize and provide funding for NAMRL to transfer the data to Pensacola.[20]

Street allocated $36,000 to pay for the rescue, part of which would be used for purchasing NBDL's digitized human data. Rupert was not content to just obtain the funding and hand the job over to somebody else—he wanted to personally ensure that all of the physical data was collected from NBDL and transported back to NAMRL. In 2002 he rented two moving trucks, mustered some enlisted personnel to do the moving, and accompanied them to New Orleans to pack up the twenty-three tons of material and bring it back to NAMRL. The impact accelerators, SMS, vibration fixture, and other supporting laboratory equipment were too large to be disassembled on short notice and transported, and NAMRL did not have space for them anyway. Rupert expected them to be retrieved at some point in the future once a new home could be found elsewhere.[21]

IIP: A Second Chance Lost

Rupert realized that getting those twenty-three tons back to NAMRL presented researchers with a golden opportunity. Not only could the data be reunited with the non-human primate films already shipped down by Dolgin, but the evaluation and digitization efforts started at UNO could be completed and the mathematical modeling first begun in the late 1970s could be restarted. Rupert again contacted Lilienthal, who arranged for Foster to personally review the data. Foster was impressed and assured Rupert that even though he could not underwrite the work himself, he would "try and lean on a few people to provide some funding." Foster began with the Army's Military Operational Medicine Research Program at Fort Detrick, Maryland, but research area director Colonel Karl Friedl, unaware of NBDL's joint Army/Navy origins, turned the opportunity down as a Navy concern. Foster next approached Dr. James Sheehy, the chief scientist of the Naval Air Systems Command (NAVAIR) Air-4.6 Humans Systems Department, based at Patuxent River, Maryland. Sheehy embraced the opportunity, agreeing to provide roughly $400,000 per year to evaluate, digitize, and analyze the data under a 6.4 "Medical Engineering and Manufacturing Development" line item grant in DOD's Research, Development, Test, and Evaluation budget. The funding in place, the project was named the Impact Injury Prevention (IIP) program. Although undertaken at NAMRL, NAVAIR became its primary sponsor.[22]

Rupert had made the most of the opportunity; however, he did not have the time to supervise the large and complex 6.4 IIP project. So he hired someone else eminently qualified, Dan Thomas, who had done so much to generate the data in the first place. Thomas had retired from consulting in 2000 and was then serving as president of the Snell Memorial Foundation. In order to be able to continue his work with Snell, Thomas agreed to take the position on a half-time basis. Rupert arranged for the creation of a limited GS-14 research medical officer position for Thomas. Working twenty hours per week, Thomas would serve as the project's principal investigator, while Rupert would serve as the project's "figurehead."[23]

Thomas came aboard in early September 2004. That same week he submitted his 6.4 proposal for organizing and performing the work over a three-year period, which NAVAIR approved and which became the IIP program's governing document. The plan was "to establish a completely analyzed biodynamic database (BDB) at NAMRL using all the research data from NBDL and the ancillary research conducted in support of NBDL." As Thomas later explained, the basic purpose was to "get [the data] to a form with enough documentation that it could be used by any skillful physiologist or engineer in this area of endeavor." Further, the data would be "made available to all qualified users by NAMRL under procedures appropriate for widespread dissemination of government research results."[24]

Thomas clearly believed that those who created the data were best suited to analyze it. The team he put together included Bill Muzzy, Friedrich Unterharnscheidt, Gene Jessop, Ed Becker, David Seales, Robert Kennedy, and Alvah Bittner. Thomas even persuaded Chan Ewing to play a small role in the project, although he was then in declining health. Additionally, Thomas brought into the project the Snell Memorial Foundation, the Visual Instrumentation Corporation, and the Bioengineering Group from the Medical College of Wisconsin, under long-time non-human primate research collaborator Dr. Anthony Sances. Outside colleagues, such as Dr. Ints Kaleps, retired chief of the Acceleration Effects and Escape Branch of the U.S. Air Force Research Laboratory, and Professor Jac Wismans of TNO Crash-Safety Research Centre in the Netherlands, likewise joined the team as consultants. Information technology expert Dr. Carl Cole drew the job of managing IIP's computer operations and integrating UNO's digitized data into a new database. NAMRL provided floor and office space at its 51 Hovey Road headquarters in Pensacola, while the Navy issued a sole-source contract to Muzzy's consulting firm, WHMuzzy Consulting, LLC, to administer the project.[25]

Scene of wreckage in front of "Admiral Row" at the Naval Air Station, Pensacola, caused by Hurricane Ivan. The storm reportedly damaged 90 percent of the buildings on the base. (U.S. Navy)

No sooner had the effort gotten under way when nature intervened to stop it. On September 16, 2004, Hurricane Ivan crashed ashore across the Florida panhandle and devastated Pensacola. Although the NAMRL facility was severely damaged, the IIP team had wisely stored its data on its upper floors, saving it from destruction. Ivan, however, made the 51 Hovey Road site all but unlivable. The building was a half-century old, built during Ashton Graybiel's tenure at Pensacola, and after being soaked to the foundations by the storm, it developed a serious mold problem. Rupert believed that they had to get the data offsite as soon as possible. With most of Pensacola savaged by the storm, however, that was easier said than done, and the IIP team had to make do in the soggy, moldering building, at least for the time being. The effort began with an inventory of all the physical data that had been transferred from NBDL. The team then evaluated select digitized samples with somatosensory/EEG information to determine if it was worth obtaining further electronic data from NBDL.[26]

That process stalled when researchers were unable to make the Oracle database compatible with 2004 computer technology. In early 2005, IT expert Cole traveled to UNO and worked directly with Edit Bourgeois and the original digitizers to solve the problem. Cole was ultimately successful in extracting the data, but as Rupert reported

Damage to the horizontal accelerator building enclosure caused by Hurricane Katrina. (USAARL)

to Sheehy and his NAVAIR colleague Barry Shender in May 2005, "it was still not in a form that one could access as a relational database to make it useful to ourselves or any customer." Nevertheless, given what Cole and Bourgeois were able to make available, IIP director Thomas decided to lease from UNO the digitized human anthropometric data and the portion of animal data that had also been included in the NCSDB.[27]

This digital setback was followed by yet another natural disaster when Hurricane Katrina, a Category 5 storm with sustained winds of over 175 miles per hour, struck the Gulf Coast in late August 2005. New Orleans was virtually destroyed by severe flooding following the failure of its levee system. Pensacola was again submerged under the storm surge. UNO suffered widespread damage across its campus, but the Michoud Test Facility was largely spared due to its heavy-duty construction. Unfortunately, NBDL's roof was open for repairs when Katrina made landfall, exposing Test Cells 3 and 4 to the driving rain. The impact accelerators and the SMS were soaked but not destroyed, although in the storm's chaotic aftermath, looters broke into Michoud and stole or damaged some of their custom-built parts.[28]

Once Katrina dissipated and the roads out of New Orleans became passable again, Dobie drove to Michoud to assess the damage. He found both test cells drained of water and the test equipment mostly undamaged, although damp and rusting. Unfortunately, the equipment would have to remain that way for the time being—UNO's budget was already overextended just getting its campus reopened and classes restarted. Instead, Dobie and his assistants went around the test cells marking what had to be fixed when time and funding returned, which was likely to be no time soon.[29]

Hurricane Katrina inflicted a second heavy blow to the IIP project farther east, as Bill Muzzy's home and office in Ocean Springs, Mississippi, located near the storm's epicenter, were demolished. Gone were his records and drawings from his old NBDL days, as well as WHMuzzy Consulting's paperwork for the IIP program in Pensacola. "Katrina was a life and lifestyle changer," said Muzzy. "Everything is measured from that day, before or after." The project was again put on hold while Muzzy rebuilt and Pensacola cleaned up for a second time. Yet another delay occurred four months later when Muzzy suffered a heart attack, knocking him out of the project for several more months.[30]

By June 2006, Muzzy had recovered and the IIP project could finally move ahead. The months-long hiatus had not been spent idly, however, since Rupert was able to find new space for IIP through one of his colleagues, a vestibular researcher named Bill McBride, who owned a new building at 2415 North Pace Boulevard in Pensacola. The 3,000-square-foot facility was an ideal data center, and Rupert was able to arrange a multi-year lease through the Henry Jackson Foundation, with additional support from NAMRL and NAVAIR. With plenty of floor space now available, Thomas also took the opportunity to build up his support staff, hiring independent contractor Dottie Dubuisson, who started work in July, and Jan Mauldin, who reported in August. These two professionals came to understand the data's organization as well as anyone else involved in the project. Thomas also called former colleague Art Prell out of retirement to assist in preserving the old film and analyzing the photography data that he had helped produce. Prell's wife, Margaret, also joined the team to scan the xray data and assist with the inventory. It was a three-hour weekly commute from Pearl River, Louisiana, to Pensacola, but Prell was pleased to have another chance at making the most of the work to which he had devoted much of his career.[31]

Ensconced in the new data center, the team began the arduous task of editing and digitizing all the data, beginning with 10,000 rolls of film that Thomas personally unpacked and examined for damage. The group fell back into their old NBDL routines and made major headway. Rupert later recalled that IIP "was producing material for the Naval Air Systems Command, and Dr. Jim Sheehy was quite happy with it. The data was moving very well." That fall, Thomas and Rupert entered negotiations with dean Russell E. Trahan, Jr., at UNO, who had succeeded dean John Crisp in 2003, for NAMRL to merge the NCSDB into the new IIP database. They also wanted to jointly complete data quality control and then release it all to the public using the 6.4-funded IIP program. Trahan indicated that UNO was interested in reaching an agreement on their proposal.[32]

Before further discussions took place, the IIP project came to a halt due to a dispute between NAMRL's commanding officer, Commander David Street, and Dan Thomas. Street had recently transferred to Pensacola from ONR, and his mission was to prepare NAMRL for transfer to Wright-Patterson Air Force Base at Dayton, Ohio, under BRAC 2005 so that it could be merged with BUMED's Environmental Health Effects Laboratory to create a new Naval Medical Research Unit. Intent on getting the move done, he saw the IIP program, being conducted on his base but supported by NAVAIR, as a distraction at best. Working at cross purposes, Thomas's and Street's professional relationship was strained from the start and worsened throughout 2006.[33]

In January 2007, the simmering conflict finally boiled over. Commander Street was presiding over an all-hands meeting in cramped quarters at NAMRL. The group of about fifteen was gathered in a circular room that had once housed a centrifuge and was now full of boxes, which was a palpable reminder that the move was Street's main priority. Then, Thomas's cell phone rang. As Rupert recalled, "He got up to answer it and walked in front of Dave Street and walked out." Thomas may have believed that he was being polite, but Street considered it a gross insult for someone to take a phone call during a meeting. As Rupert described it, "His face was just full of anger, and I went, 'Uh-oh. Here's a real problem about to happen.'" Street soon opened an administrative investigation, citing a potential conflict of interest in Thomas's relationship with Snell, the expiration of the UNO digitized data license, and Muzzy's sole-source contract.[34]

Thomas marshaled formidable forces in defense of himself and IIP, including retired Chief of Naval Research Joe Pollard, retired Dr. Richard G. "Jerry" Snyder (an Air Force counterpart who had fought a similar battle to keep from losing his own impact acceleration materials), and retired Army Brigadier General Robert T. Cutting (who had originally helped Ewing establish NAMRL-D in 1971), all of whom pledged their support. Ultimately, the administrative investigation went nowhere. In November 2007, Captain Kerry Thompson, the commanding officer of the Naval Health Research Center in San Diego (and Street's superior), and his executive officer, Captain Gregory Utz, cleared Thomas of any wrongdoing and prepared an official letter for the record attesting to his "good standings with NAMRL, Navy R&D, and Navy Medicine." Thompson also promised to "call some folks at the University to state the same."[35]

By then it was too late. Street may not have had the power to fire Thomas outright, but he could launch a "reduction-in-force" action, an official downsizing process that typically took several months to complete but achieved the same effect. In May 2007 Street cancelled the IIP project, abruptly returning NAVAIR's funding and disappointing Jim Sheehy at NAVAIR. He also terminated the lease for the data center on Pace Boulevard and cancelled Muzzy's consulting contract. Street then had the data packed up and dispersed throughout Naval Air Station Pensacola and denied Thomas and Rupert further access.[36]

Enter USAARL

Appalled at the closure of the IIP project, Rupert began planning his retirement from the Navy. But when it became evident that Street intended to dispose of the impact acceleration data rather than ship it to Dayton, he and Thomas sprang into action. The only alternative, it appeared, would be to transfer the data to yet another military installation where perhaps the project could be restarted. The Naval Air Station at Patuxent River in Maryland seemed like a suitable candidate—NAVAIR, after all, had funded the previous effort—but to the regret of Sheehy and Shender, there was not sufficient space there to house the materials. With no other Navy facility interested, Thomas suggested that they "send it to where the impact acceleration program began, the Army." Rupert agreed that this was a fine idea, and they took it with them to the meeting of the Aerospace Medical Association held in New Orleans shortly after the shutdown. There he made the proposition to Colonel James S. "Jim" McGhee, commanding officer of the U.S. Army Aeromedical Research Laboratory (USAARL).[37]

A native of Newport News, Virginia, McGhee was a senior Army flight surgeon who held master's degrees in environmental sciences and engineering from Virginia Tech and in public health from The Johns Hopkins University. In 1998 McGhee was appointed consultant to the Army Surgeon General for Aerospace Medicine and dean of the U.S. Army School of Aviation Medicine (USASAM), tasked with reinvigorating the Army Aerospace Medicine Program. Five years later he took over command of USAARL. McGhee was now at the right place at the right time to save the NBDL data.[38]

In New Orleans, Rupert and Thomas explained their dilemma to McGhee over coffee. To their surprise, McGhee took no time to think it over—he immediately accepted their proposal. "We've got a big warehouse on our campus, and we've got a place we can at least put it temporarily, and it's already in boxes, so it's not going to be a big issue," McGhee told them. "If they want to put it in trailers and bring it up here, that's fine with me." McGhee was confident that he had the clear authority to make such a deal. "It was a local commander's decision, as I saw it."[39]

Located in Fort Rucker, Alabama, USAARL was convenient, being only three hours away from NAMRL. But despite McGhee's cooperation, there was more to be overcome than distance. It would take some political skill to wrest the data from NAMRL. Advocates such as Sheehy and Shender at NAVAIR once again began pulling strings. But no one had more pull than Chan Ewing's old friend and benefactor, Brigadier General Robert T. Cutting, long ago retired but still living in Georgia. In a letter to Vice Admiral Donald C. Arthur, Jr., the surgeon general of the Navy, Cutting skillfully played off one service against another. "I recently learned that one of your officers, Commander David Street of Pensacola, may be intending to give all the data to the USAF," he wrote. "This is doubly unfortunate because the person with intimate knowledge and interest in the project, Captain Angus Rupert, has, as a result, hinted at retirement from the USN." Cutting suggested to Arthur that the best solution was to transfer Rupert, along with the data, to Fort Rucker.[40]

Arthur approved the idea, and in June 2007 Sheehy, Captain Thompson, and Commander Street met in Washington to iron out the details. McGhee also negotiated with Street at the commanders' level but encountered none of the bad blood that had undermined the earlier arrangements. "He didn't seem to care, it was fine with him," McGhee later remembered. Thus, the plans were laid, and in August 2007 NAMRL shipped the data to USAARL. McGhee accepted delivery personally. "It arrived here in two eighteen-wheeler trailers and two pickup trucks," he recalled, and "was literally about 40 tons." As he monitored the unloading of the vehicles, it became clear to McGhee that the volume of material was matched only by its lack of organization. It would take years to sort everything out. Meanwhile, as one team saved the informational legacy of NBDL, another secured the equipment.[41]

While Thomas and Rupert attempted unsuccessfully to make the most of the data in Pensacola, Tom Dobie presided over what was left of the National Biodynamics

Laboratory. By 2002, he was doing so in solitude. His students and colleagues having moved on, Dobie was director—and the only staff member. Therefore, when NASA decided to evict NBDL from its historic home at the Michoud Assembly Facility, there was little that he could do. That move was the result of a presidential initiative launched in early 2004, in which President George W. Bush had decided that Americans would return to the moon, presumably by 2020. He wanted robotic missions to begin much earlier though, by 2008. That left NASA scrambling to find facilities capable of building the next generation of moon rockets under the resulting Constellation program, and not surprisingly, the agency soon fixed on Michoud, where the booster rockets for the first moon missions had been built. It would be the perfect site for assembling and testing the planned Ares rockets that would launch astronauts toward the moon in Orion spacecraft and, later, a new super-heavy lift launch vehicle, to be named the Space Launch System (SLS).[42]

NASA decided it needed every inch of space at Michoud, so it notified UNO that NBDL's long-standing lease was cancelled and that it had two weeks to move all the remaining records and test equipment out. This was easier said than done. The SMS was two stories tall and partially embedded in the thick walls of the facility, the two accelerators were large, complex machines, and UNO had neither the funds nor the facilities for any of them. Nevertheless, Dobie recalled, "they were pushing us daily to get out." Dobie managed to gather up a few smaller pieces of equipment and documentation and store it at UNO. The Mobile Biodynamics Laboratory was easiest to move, and Dobie simply parked it outside of the College of Engineering. But it was too big of a job to move the rest. "We'd done all we could," Dobie recalled, "and the thing just folded." Word was that NASA would simply scrap the rest of the equipment. Before handing the keys over to NASA, however, Dobie informed Thomas about what was happening at Michoud. He, in turn, contacted Dr. Valeta Carol Chancey, a research biomechanical engineer and rising star in USAARL's Injury Biomechanics Branch.[43]

Born and raised on the family farm in Ozark, Alabama, Chancey had earned bachelor's degrees in applied mathematics and mechanical engineering at Auburn University. During that time, she interned at USAARL under former NBDL researcher Dr. Nahib Alem and with B. Joseph "Joe" McEntire. Chancey then earned a master's degree in rotor dynamics at Auburn, specializing in neck injuries. Desiring to develop an interest in biology, Chancey enrolled at Duke University in North Carolina to study under former USAARL researcher Jim McElhaney. She earned a Ph.D. in biomechanical engineering and returned to USAARL in early 2005, joining McEntire in the Injury Biomechanics Branch.[44]

Chancey had first learned of the work at NBDL in the early 2000s while researching her Ph.D. dissertation on neck injury as related to air bag interactions. Among her tasks was to build a computational model as well as a finite element rigid body model, and to validate those she required data. Her advisors told her that it had been generated by NBDL in years past, but the challenge was getting access which, despite all the effort in building the NCSDB, was close to impossible. "It really wasn't quite functional at that time," she recalled, "so finally I had to go and find old papers that had been published and then hand-digitize the plots to get the data out of it so that I could finish up my Ph.D."[45]

With an abiding appreciation of the NBDL legacy, Chancey was the right person for Thomas to call. She knew that USAARL had to try to save the NBDL test equipment. Having received a similar call from Mark Lotz at UNO, McEntire was also onboard. Together they requested McGhee's permission to go to New Orleans and evaluate the condition of the impact accelerators. "If we're going to recover all the data, which we've already started doing," McGhee agreed, "then we ought to take the equipment that generated it as well."[46]

On a Friday in August 2007, Chancey and McEntire rented a passenger van and drove to New Orleans for a weekend reconnaissance trip. Both engineers were astounded during their first look at the Michoud test cells. Chancey later described the scene: "The facility was just incredible," she said later, "the size of it alone was enormous." But more striking to Chancey was being face to face with "the equipment that

Piles of materials at Michoud, as encountered by Dr. Carol Chancey and her recovery team in 2007. (USAARL)

Loading the trailers and trucks with salvaged NBDL data and equipment during one of the trips organized by Dr. Carol Chancey. (USAARL) had collected this research for decades that we had known about but had never before been able to see." Once the initial impact wore off, Chancey and McEntire set to work inspecting the horizontal and vertical accelerators. The only significant damage was a hole in the metal shielding covering the horizontal accelerator's 700foot track, caused by flying debris during the hurricane. With the electricity to the test cells long since cut off, there were no air conditioners to regulate temperature and humidity, which left the accelerators covered with superficial surface rust. With the impact accelerators structurally sound—and NASA happy to have them removed—the decision seemed like an easy one to make.[47]

The following Monday, Chancey and McEntire were in McGhee's office recommending that USAARL retrieve and refurbish the equipment. McGhee agreed with the idea but believed that the Army would require a second opinion as to whether or not the accelerators were in fact recoverable. Chancey contacted the original manufacturer, HyGe, which arranged for some technicians to visit Michoud and make the evaluation. Having swarmed over Muzzy's thirty-five-year-old masterpieces, the HyGe experts began the conversation by asking what would happen to the equipment if USAARL did not take it. "We knew right then that the equipment was good," Chancey recalled, because they clearly wanted the impact accelerators for their company. When Chancey pressed for an answer to her question, HyGe finally conceded that "there's nothing wrong with them, just some surface rust, and it would be no problem to get them back in shape again."[48]

In front of the Neel Aeromedical Science Center at Fort Rucker, Alabama, USAARL commanding officer Colonel James S. McGhee tries out the famous custom built "Liberty bike," plated with left-over copper from the Statue of Liberty's centennial restoration in 1986. The motorcycle, seen on the television show American Chopper, *was then on a morale/publicity tour of military bases. Several of the soldiers who helped salvage the impact accelerators from Michoud stand around it and Colonel McGhee. (USAARL)*

Second opinion in hand, McGhee put together a funding package through the U.S. Army Medical Research and Development Command (USARMRDC) and NAVAIR to pay for disassembly and transport of the accelerators. NAVAIR also agreed to provide USAARL with the services of Pensacola-based contractor Dottie Dubuisson, formerly of IIP, to provide administrative support to the recovery effort. As NAVAIR negotiated the disassembly with HyGe, Chancey and McEntire began removing as much additional equipment as they could from the test cells at Michoud. "We didn't have enough money to hire anybody," Chancey remembered, so "we had to pretty much do it ourselves." Her team consisted of herself, McEntire, and four or five others from USAARL, who made the grueling five-hour, 300-mile trips back and forth from Fort Rucker to Michoud. Dubuisson located a U-Haul dealer in East New Orleans that had reopened following Katrina that provided the trucks used by the team to haul the smaller equipment back to Fort Rucker. Each trip lasted two to three days, with the team working non-stop with little assistance and few conveniences in storm-ravaged East New Orleans. "It was still a big mess down there," she said. The roads were overgrown with weeds, and "there was at that time only one place to stay and only one place to eat." The swampy wetland around Michoud was treacherous too, as one team member learned when he tried to drive a vehicle off the main entrance way around to a better door. "It just sank down to the axles," Chancey ruefully noted. Toward the end of the effort, when Chancey's team had exceeded the limits of its freight hauling abilities, Dubuisson hired a long-haul trucking company to move the larger pieces of equipment using tractor-trailer rigs.[49]

NASA added to Chancey's worries with its unrelenting demands to remove the test cells, telling her each trip that "We are going to kick you out next week." She was in a clear race against time to recover the equipment since NASA had already contracted with a salvage company to empty the test cells. Fortunately at the time, every salvage company on the Gulf Coast had weeks of backlog, so in that respect, at least, Katrina was a blessing. Nevertheless, every time they pulled away from Michoud, the members of Chancey's team did so with trepidation. There was no way of knowing what would remain when they returned because NASA work crews continuously and indiscriminately threw away small items, such as manuals, binders, report copies, and books. During one visit, McEntire encountered a dumpster sitting in the outside parking lot, and upon investigation he found important documentation. McEntire and another team member were soon in the dumpster recovering NBDL data.[50]

Chancey had a more positive experience on one occasion when she met with Dan Thomas, Bill Muzzy, and Art Prell for lunch at a nearby sandwich shop. During the ensuing discussion, they recounted the history of NBDL and provided pointers on what to look for at Michoud during her recovery mission. To Chancey, it was "interesting to meet them all in that context, and to get their impressions on work undone." Speaking with the old-timers was also motivating for her. "To know that we were picking up the material and the equipment and the data, and that we had a chance of continuing their research," she added, "kept us going back in there."[51]

In January 2008 HyGe disassembled both impact accelerators and transported them, as well as three hundred of the original seven hundred feet of track, back to Fort Rucker. The SMS had to remain behind; it was too large to be removed intact from Test Cell 3, and USAARL had little use for it. At USAARL, soldiers unloaded and stored the accelerator pieces in the same warehouse as the data and other materials recovered from Michoud. Colonel McGhee later described the scene: "The whole floor was covered with a mishmash of all sorts of gears and tools and pieces of equipment and boxes of data." Meanwhile, Chancey and McEntire made one last visit to Michoud to retrieve any remaining moveable items before NASA and Corps of Engineers contractors took over the test cells. It had all been stripped clean, and there was nothing left to recover, so Chancey's immediate mission was accomplished.* But the question remained: What was to be done with all the disorganized data and rusty disassembled equipment now that the Army had it all?[52]

Building the BDR

Retrieving the accelerators had been something of a categorical imperative and had to be done. But the overriding concern to all involved in the USAARL reclamation project—just as it had been for Rupert, Thomas, and Ewing before them—was to put the existing data to good use. Those past efforts, however, had all suffered from an excess of ambition. The intent had been not only to make the raw data available to interested researchers, but also to conduct further analysis and to ultimately come up with a mathematical model that provided solid information about human responses to impact acceleration based on actual animal experiments. In reaching too far, all of those efforts had ultimately foundered before accomplishing the simple goal of effectively sharing information. USAARL intended not to repeat that mistake and to succeed where others had failed.

Even before the equipment arrived at Fort Rucker, the coalition that would get this done had begun to come together. In 2007 NAVAIR's Barry Shender and Jim Sheehy visited USAARL to see the rescued data and to discuss the possibility of either restarting IIP or initiating a successor project at Fort Rucker. In 2008, as Chancey took on an ever greater role in the effort, she continued to work closely with Shender and Sheehy. The result of their talks was the conception of the Biodynamics Data Resource (BDR). From the outset, the objective was a limited but realizable goal of restoring and digitizing physical records and data from the NBDL experiments and making it available in a digital archive accessible to researchers. When complete, the BDR should contain sensor, photographic, and physiological data from almost 7,800 human volunteer, non-human primate, and anthropomorphic test dummy (ATD) runs.[53]

The BDR effort was spearheaded by Dr. Chancey at USAARL with additional funding by NAVAIR. Among the team members was Dottie Dubuisson, who had worked with the material at Pensacola and helped make possible its move to Fort Rucker. Starting in early 2008, Dubuisson and other USAARL staff members began

*In the end, the Obama administration canceled the Constellation program in 2010, and to help cover facility maintenance costs, NASA began renting the empty former NBDL site to motion picture studios for filming large-scale scenes in major action and science fiction productions.

going through the material as time allowed. As with all previous efforts, the first task was to take stock. NBDL, Chancey observed, "did a wonderful job of labeling everything, labeling it by run, labeling it by subject, so we could put it back together." Unfortunately, however, the labeling on the containers holding those labeled boxes was less accurate. Labels once applied by Dobie or Chancey had often been removed by NASA personnel, only to be reapplied by USAARL. There was nothing to do but separate out all of the materials and take a close inventory. "It took us a considerable amount of time just to get it organized again the way it needed to be to know what we needed to do," said Chancey.[54]

Once USAARL staff could begin processing data, the effort primarily focused on the human volunteer data, although non-human primate data documenting impact exposures up to 192 G were also included in the BDR. This data is not likely to be replicated in the future and could play a critical role in studies on interspecies scaling and head injury neuropathology. By 2010, enough progress had been made for USAARL to publish a preliminary report that provided an overview of human volunteer data collected from 3,430 runs using the horizontal and vertical accelerators at NBDL in impact exposures up to 15 G. Still, the cataloging process continued on a very limited budget, and the effort moved slowly. Creating a detailed metadata structure for the database so that researchers could locate materials of interest quickly took time and careful consideration.[55]

An unexpected result of the recovery of the NBDL data was the transfer of Angus Rupert to USAARL. "Serendipity and luck," as he called it, once again placed Rupert in a position to help. After the termination of IIP at NAMRL and retirement from military service, Rupert called deputy assistant secretary of the Army for research and technology Dr. Thomas H. Killion. As the Army's chief scientist, Killion was responsible for about 10,000 researchers in that service branch. Rupert informed Killion that although he had left the Navy, he still retained DOD funding and suggested that he might move his work to Fort Rucker. Killion was amenable and called his Navy counterpart, deputy assistant secretary of the Navy for research, development, test and evaluation Dr. Michael F. McGrath, and asked for the favor. "The two of them shook hands," Rupert recalled, and he arrived at USAARL unimpeded by interservice politics.[56]

Rupert was happy to be at Fort Rucker but unhappy about the slow pace of the digitization effort. The death of Chan Ewing on September 27, 2011, in New Orleans underscored the fact that decades of institutional knowledge could slip away while the digitizing project proceeded as a spare-time effort.** Dan Thomas was having similar thoughts. Unbeknownst to each other, in March 2013 he and Rupert met separately with Colonel Dallas C. Hack, a leader in traumatic brain injury research and director of the Combat Casualty Care Research Program at USARMRMC at Fort Detrick,

**Following his death, Dr. Ewing bequeathed his large collection of personal and professional papers to the Snell Memorial Foundation, which currently stores and protects them at a secure facility in Harahan, Louisiana.

Maryland. Hack soon became a proponent of the work at Fort Rucker. "I think that one-two punch convinced him," said Rupert. Following the meetings, Hack and Dr. John Frazier Glenn, principal assistant for Research and Technology, USARMRDC, agreed to help Rupert obtain the necessary funding through higher authorities. In due course, Rupert kept Chancey informed of his activities.[57]

Hack, Glenn, and Rupert contacted DOD and engaged with the director and assistant director of the Human Performance, Training, and BioSystems Directorate, Dr. Patrick Mason and Dr. Fred Pearce, respectively, convincing them of the BDR's value. In another round of meetings, Rupert briefed Captain Sean Biggerstaff (USN), program director for Medical Modeling and Simulation and Military Operational Medicine at the Defense Health Agency (DHA), about the project. Biggerstaff then brought Rear Admiral Bruce A. Doll, the dual-hatted deputy commander of USARMRMC and head of the DHA Research, Development and Acquisition Directorate, into the discussion.[58]

The culmination of this work came when the representatives from USARMRDC, DOD, and DHA all agreed that the BDR was indeed worth developing and should be funded in FY 2014. As a result, Hack and Glenn secured $10 million over five years for the BDR, to be alternately funded at $2 million per year by RAD II (Combat Casualty Care) and RAD III (Military Operational Medical Research Program, or MOMRP).[59]

The new funding stream led to a more concerted effort and allowed Chancey to hire eight to ten staff members and contractors to work on the BDR full time. The staff focused not only on scanning and digitizing but also on creating and linking the metadata in the database. The new funding also allowed USAARL to bring in one of NBDL's long-standing former subcontractors, the Medical College of Wisconsin, to help with analysis of medical images and x-rays. At Rupert's urging, in 2014 Jim McGhee, since retired, returned to USAARL as a civilian research physician to help administer the project.[60]

During his discussions with Thomas and Rupert, Colonel Hack proposed that a portion of the funding be set aside for the writing of a formal history of NBDL. His intent was to convey to data users the original mission of NBDL and to provide the historical context required to understand the research methodology employed and the findings made over the years. Given the breadth of the complex and innovative research carried out at NBDL, Hack also insisted that oral history interviews with former lab employees be included in the history. Hack's emphasis on the importance of oral histories in preserving the institutional memory of NBDL was underscored not only by the death of Ewing but also by the recent loss of other lab veterans, among them Gilbert Willems, Norman Gilbert, John Guignard, and Leonard Lustick. In 2016 and 2017, historians captured the personal insights and experiences of the remaining key players in the NBDL story, and the resulting recordings and transcripts became a permanent part of the BDR.[61]

While Chancey took prime responsibility for the BDR, mechanical engineer Joe McEntire worked to rebuild the horizontal and vertical accelerators. Funding for this effort also came from USARMRDC as a result of McGhee's networking with Hack and Glenn. The first step was to ship both accelerators back to HyGe for refurbishing. When the accelerator parts left the base, as Chancey later recounted, the enlisted men doing the loading treated the pieces as if they were junk because they looked it. When the parts returned, the same soldiers were hesitant to handle the bright, shiny, and expensive-looking hardware. "Guys, all it was, was surface rust," Chancey explained to them. "Whatever damage you were going to do the first time, it's the same damage you do now, so you've got to unload it."[62]

The recovered and refurbished Vertical Acceleration Tower (VAT), now installed at USAARL for the continuation of research into human response to impact acceleration. (USAARL)

The reinstallation effort began with the 42-foot-tall vertical accelerator. During the summer of 2016, McEntire's team finished rebuilding it in a brand new laboratory facility constructed near USAARL. The lab housed not only the refurbished and upgraded accelerator but also x-ray machines and new fabrication shops equipped with many of the tools recovered from NBDL. The Vertical Accelerator Tower (VAT), as it is called, is now regularly employed in biodynamic experiments with ATDs. However, on July 20, 2017, the first whole body cadaver test was completed at USAARL using the VAT, with its cameras and data acquisition systems triggering successfully. This was a momentous occasion since it was the first time an entire human cadaver had ever been tested in an impact acceleration experiment using NBDL equipment. Chancey witnessed the run and was pleased with its outcome. She immediately informed USAARL and NAVAIR stakeholders and congratulated her staff on the culmination of their recovery and rebuilding efforts: "Today's test was the result of the work of numerous dedicated individuals over the past ten years from the time we first learned that the vertical accelerator was scheduled to become scrap metal after the hurricanes that hit New Orleans, the University of New Orleans, and the NASA Michoud Assembly Facility. A huge thank you to the current and past team members for making this possible! A special thank you to the current team, their dedication, and long hours that made this first ever event possible!"[63]

Meanwhile, work continued on refurbishing and reinstalling the horizontal accelerator, which will utilize a 300-foot track instead of the original 700-foot track at the former NBDL. This older machine is expected to come online sometime in the next few years.

Conclusion

Pointing to the successful human cadaver test as a major milestone in the modern USAARL version of Chan Ewing's old aircrew injury prevention program, and in light of the current regulatory restrictions against human and primate testing, Dr. Chancey often describes the original NBDL data as "the gold standard" for validating mathematical models of human biodynamic response. Since no validated model yet exists, it is increasingly important that the data be analyzed and released. Outside of the research that NBDL scientists originally published in their papers, the data has been mostly inaccessible to researchers worldwide since 1996. As the only extant set of three-dimensional head-neck biodynamic response data on humans, non-human primates, and ATDs ever developed, when the BDR is complete, it will serve as a vital resource for new generations of bioengineers and researchers who choose to follow the same impact injury prevention trail that Ewing and his team members began blazing over fifty years ago.

In their pioneering work, Ewing's generation of impact acceleration researchers also created something unique. Today, "when you say NBDL," Dr. Chancey points out, "everybody is in awe. They may not know exactly what happened, but they know it was one-of-a-kind amazing stuff." After many years of uncertainty, NBDL's "amazing stuff" will finally be preserved, a public resource at the disposal of any scientist or researcher determined—as Chan Ewing once was—to seek answers about the ability of humans to survive impact acceleration and to find ways to prevent injuries from happening during ejections and high-G crashes.[64]

It is perhaps fitting to add that the data generated by NBDL is already informing current scientists as they tackle present-day issues by reaching back to the original research, thereby proving its enduring value. In 2009 researchers from Southwest Research Institute in San Antonio collaborated with NAVAIR and USAARL to produce a study using the NBDL data set, entitled "Modeling Female Response to Impact Acceleration," the results of which were presented at the 47th Annual SAFE Symposium in San Diego, California. Since then, several other studies have been conducted using the BDR data set, with NAVAIR and USAARL scientists spearheading the research and analysis. Later joint efforts focused on head kinematic response to combined loading in unhelmeted male volunteers and the effect of posture on head kinematic response to rapid +Z acceleration, with the results reported at the 86th and 88th Aerospace Medical Association Conferences in 2015 and 2017, respectively.[65]

Most recently, a team of researchers from the University of Virginia (UVA), comprised of biomechanics professors and their students, further demonstrated the BDR's value as a lens through which to evaluate current standards, regulations, and biomechanical concepts. In their study entitled "Evaluation of Head and Brain Injury Risk Functions Using Sub-Injurious Human Volunteer Data," the UVA team used the NBDL data set to confirm previously published information by the original researchers to assist the National Highway Traffic Safety Administration (NHTSA) in developing and evaluating new regulations. Specifically, the UVA researchers looked at fourteen existing brain injury risk functions and attempted to predict non-injurious response using six degree-of-freedom head kinematics data from 335 human research volunteer sled tests conducted at NBDL in the 1970s with relatively low peak loads of 16 G.[66]

The results were striking, with the UVA team reporting that several injury risk functions substantially over-predicted the likelihood of concussion and diffuse axonal injury. Among other things, this meant that past modeling of brain injury was very poor; that controlled laboratory experiments applicable to humans to either improve or validate brain injury models are currently lacking; that the detailed understanding of brain injury is still insufficient for improved intervention; and that past disruption of impact acceleration research was a serious mistake, considering the extensive length of time required to fully understand the epidemiological, clinical, and event data from test runs. "This work is an important first step in assessing the efficacy of existing brain risk functions and highlights the need for a more predictive assessment model," the team declared, perfectly echoing Chan Ewing's arguments some fifty years ago.

Thus, Ewing's dream of building an accurate mathematical model of the human dynamic response to impact acceleration endures through the research of these young scientists and their peers. As the original generation of NBDL passes, the next one is already emerging that will carry forth NBDL's legacy, as that laboratory's successors in science continue Ewing's cherished quest to save human life from impact acceleration injury.[67]

CHAPTER SIX ENDNOTES

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Notes About Sources

Although the Naval Biodynamics Laboratory (NBDL) has been closed for many years now, it left behind an extensive documentary record through official publications, reports, correspondence, internal written communications, and command histories that we were able to compile and consult during the preparation of this history. Much has been digitized and preserved in the Biodynamic Data Resource (BDR) at the U.S. Army Aeromedical Research Laboratory (USAARL) at Fort Rucker, Alabama. Fortunately, we were able to utilize this invaluable resource during our research with the assistance of USAARL BDR staff, collecting numerous textual documents and photographic images from internal files for use in this book.

For supplemental documentation, we performed research at the National Archives and Records Administration in College Park, Maryland, and at the Federal Records Center in Suitland, Maryland, focusing on the records of the Naval Bureau of Medicine and Surgery in Record Group 52. The Department of Energy's OpenNet database likewise yielded a number of important primary documents and reports concerning the early history of impact acceleration research and human and non-human primate testing. Meanwhile, the Naval History and Heritage Command as well as the Navy Medical Department Office of the Historian and Publications also provided important biographical information and photographs for key early personnel at NBDL, including Dr. Channing Ewing and Dr. Ashton Graybiel.

Further, we performed extensive congressional, publication, and periodical research at the Library of Congress and the National Library of Medicine and collected a variety of relevant reports as well as news and journal articles from both onsite and online databases. During our local research, we collected material from the New Orleans Public Library as well as from the Louisiana Research Collection of the Howard-Tilton Memorial Library at Tulane University.

Several individuals also stepped forward to provide private documents and photographs for inclusion in the project. These included Dr. David B. Gillis, Dr. Daniel J. Thomas, Dr. Daniel L. Dolgin, and Mrs. Russell E. Wiley. Dan Thomas in particular shared a great deal of information with us though extensive email correspondence and telephone calls, and he composed a series of ten detailed personal histories recounting the history of NBDL from his perspective as one of its founders and original researchers. Dan Dolgin, NBDL's last commanding officer, kindly allowed us to review and scan his personal collection of photographs from his brief time there before the 1996 BRAC.

During the project, we scheduled and conducted ten oral history interviews with the following people who had important personal knowledge or insights into NBDL and its history:

Dr. Daniel J. Thomas	March 8, 2016 and July 12, 2016
Dr. David B. Gillis	August 16, 2016
William H. Muzzy III	August 17, 2016
Arthur M. Prell	August 18, 2016
Dr. Angus H. Rupert	August 31, 2016
Dr. Valeta Carol Chancey	October 18, 2016
Dr. James S. McGhee, Jr.	October 18, 2016
Dr. Thomas G. Dobie	October 25, 2016
Dr. Daniel L. Dolgin	January 19, 2017
Dr. Robert S. Kennedy	January 20, 2017

These interviews were transcribed and used during the preparation of this history to not only fill gaps in the documentary record but also tell the human story of NBDL and to add color and richness to the narrative.

We also conducted telephone interviews with former NBDL research electrical engineer Andre Rog, retired Navy aerospace experimental psychologist Michael Lilienthal, and Dr. Ewing's daughter Russell E. Wiley and son-in-law Russell B. Davis, Jr., who were kind enough to share additional information with us about Dr. Ewing and his scientific career. Finally, former NBDL mechanical engineer Edward B. Becker provided key technical information on the laboratory's early years through an email interview.

Annotated Bibliography

Alem, N. M., D. F. Shanahan, J. V. Barson, and W. H. Muzzy. "The Effectiveness of Airbags in Reducing the Severity of Head Injury from Gunsight Strikes in Attack Helicopters." *AGARD Conference Proceedings No. 532 Aircraft Accidents: Trends in Aerospace Medical Investigation Techniques* 44: 1-9. Essex, UK: Specialised Printing Services, Ltd., September 1992.

This study explores the ability of airbags to reduce the incidence and severity of operator head strikes against optical gunsight systems in helicopter crashes. Using NBDL's horizontal accelerator, the authors collected data from G_{-X+Z} runs with anthropomorphic test devices up to 25 G. Subsequent data analysis revealed that airbags lowered head linear and angular acceleration levels and suggested reduced injury severity.

Anderson, W. R., G. C. Willems, and J. C. Guignard. "Analysis of Head Motion During Simulated, Rough Water Operation of a 2200 Ton Surface Effect Ship." *AGARD Conference Proceedings No. 372 on Motion Sickness: Mechanisms, Prediction, Prevention and Treatment* 38:1-14. London: Technical Editing and Reproduction, Ltd., 1984.

Nineteen enlisted Navy human research volunteers were exposed for periods up to forty-eight hours to motion environments designed to replicate those encountered aboard a 2,200-ton surface effect ship (SES). The motions of both the motion simulator device and head of each volunteer were measured during five-minute intervals, and the relationship of head motion to vomiting was studied. The time series data and the frequency spectra were examined to identify variability in head response resulting from repetitions with the same subject, repetitions with different subjects, repetitions with and without pitch and roll motions, differences between well and sick subjects, fatigue, and progression to vomiting. Heave, pitch, and roll motions in the range of 0.05 to 1.5 Hz were simulated. Results from analysis indicated that a correlation between spontaneous head motion and motion sickness exists. Additionally, the results demonstrated the viability of studying the effects of motion in a controlled laboratory environment.

Becker, Edward B. "Measurement of Mass Distribution Parameters of Anatomical Segments." *Proceedings of the Sixteenth Stapp Car Crash Conference*, 160-185. Warrendale, PA: Society of Automotive Engineers, 1972.

This study discusses the procedures used to determine three-dimensional center of mass and moments of inertia from preserved human cadaver head-neck segments. Results are presented that confirm and expand upon earlier research conducted at Tulane University. One important limitation to the data set (readily acknowledged by Becker) was the fact that the heads had been preserved through embalming. Even so, the results provided the basic anatomical reference information relied upon in subsequent experiments at NBDL.

———. "Preliminary Discussion of an Approach to Modeling Living Human Head and Neck to $-G_x$ Impact Acceleration." In *Human Impact Response*, edited by W. F. King and H. J. Mertz, 321-29. NY: Plenum Publishing Company, 1973.

This article contains discussion of a theoretical human head-neck mechanical linkage for use in modeling response to $-G_x$ impact. The required parameters include establishment of two anatomically based "hingepoints" and determination of head center of gravity and mass moments of inertia values. This theoretical model showed good agreement to data from human runs conducted at NBDL and also provided an important foundation for later work.

———. "A Photographic Data System for Determination of 3-Dimensional Effects of Multiaxis Impact Acceleration on Living Humans." *Proceedings of the Society of Photo-Optical Instrumentation Engineers* 57 (1975): 69-78.

This paper provides a discussion of the photographic system developed and used early on at the Naval Aerospace Medical Research Laboratory, Detachment. The treatment includes a complete description of the camera and lighting coverage, film processing techniques, and mathematical theory utilized to determine the position and orientation of the subject throughout experiments.

———. "Stereoradiographic Measurements for Anatomically Mounted Instruments." *Proceedings of the Twenty-First Stapp Car Crash Conference*, 477-505. Warrendale, PA: Society of Automotive Engineers, 1977.

This paper describes the stereoradiographic procedures used to determine the geometrical relationship between subject-mounted instrumentation packages and subject-anatomy at NBDL. A discussion of the radiologic equipment and calibration techniques is also provided.

———. "Head and Neck Kinematics for Frontal Oblique and Lateral Crash Impact." NBDL-80R009, Naval Biodynamics Laboratory, New Orleans, August 1980.

This report discloses findings from comparison of NBDL photographic data to output from a theoretical four-pivot mechanical head-neck linkage model. While the linkage showed promise for use in modeling human response to frontal, lateral, and oblique impact, it could not account for voluntary head yaw motion.

Becker, E. B., and G. C. Willems. "An Experimentally Validated 3-D Inertial Tracking Package for Application in Biodynamics Research." In *Proceedings of the Nineteenth Stapp Car Crash Conference*, 899-930. Warrendale, PA: Society of Automotive Engineers, 1975.

This paper provides a detailed discussion of the six-accelerometer inertial tracking packages used at NBDL to measure response to impact acceleration. The presentation includes a discussion of component equipment, design considerations, calibration techniques, and the associated data acquisition system. This publication provides an authoritative reference resource for information on the telemetered instrumentation systems developed and relied upon at NBDL.

Beier, G., E. Schuller, M. Schuck, C. L. Ewing, E. Becker, and D. J. Thomas. "Center of Gravity and Moments of Inertia of Human Heads." *Proceedings of the 1980 International IRCOBI Conference on the Biomechanics of Impact*, 218-28. Bron, France: IRCOBI, 1980.

This study reports on anatomical research conducted on fresh, unpreserved human male and female cadaver heads to determine the three-dimensional center of gravity location and the mass moments of inertia of the human head-neck system. This information was collected for comparison to Becker's earlier findings with preserved cadaver heads. Following the procedures previously utilized by Becker, the heads were fixed for measurements within a tetrahedral frame that allowed for measurement of the center of gravity and the calculation of the inertial properties from the rotational oscillations of the trifilar suspended frame. The findings closely conformed to the earlier research conducted by Becker and provided further information on anatomical constants for use in experiments at NBDL.

Berger, Michael D. "Analysis of Sensory Evoked Potentials using Normalized Cross-Correlation Functions and Polyexponential Regression." NBDL-82R015, Naval Biodynamics Laboratory, New Orleans, July 1982.

This report discusses some aspects of neurophysiological monitoring of impact acceleration exposures. Somatosensory evoked potentials (SEPs) produced by stimulation of the dorsal columns were recorded from the cervico-medullary junction of adult rhesus macaques and were analyzed using normalized cross-correlation functions (NCCFs), simple peak-detection, and amplitude measurement. The NCCF provided measures of latency shift and waveshape change, while the simple peak-detection method provided measures of peak latency and peak amplitude. The results of these procedures were plotted as functions of time relative to the impact exposure. Analysis by means of the NCCF was found to be a highly versatile and effective method because of its ability to detect subtle waveshape changes and accurately measure latency shifts, and its consistency in a wide variety of noise conditions. Polyexponential regression analyses were conducted on some plots and proved to be an effective way of reducing neurophysiological data.

Berger, Michael D. "A High-Performance Analog-to-Digital Conversion Subsystem Suitable for the Study of Evoked Potentials, With Design Considerations for the Eclipse S140 Computer." NBDL-83R001, Naval Biodynamics Laboratory, New Orleans, February 1983.

This report presents detailed specifications for a high-performance analog-to-digital conversion subsystem suitable for processing neurophysiological data from impact acceleration experiments. The system developed and presented here was devised to efficiently handle large amounts of data. In addition to the discussion of equipment already in use at NBDL, the author also provides some suggestions for further A/D conversion hardware that could be implemented.

Berger, M. D., and M. S. Weiss. "Effects of Impact Acceleration on Somatosensory Evoked Potential." In *Impact Injury of the Head and Spine*, edited by C. L. Ewing, D. J. Thomas, A. Sances, Jr., and S. J. Larson, 324-78. Springfield, Ill.: Charles C. Thomas, 1983.

This chapter contains a detailed discussion of findings from analysis of neurophysiological data collected from $-G_x$ impact acceleration runs with rhesus macaques at NBDL. Somatosensory evoked potential (SEP) readings were recorded before, during, and after the runs. The authors observed decreases in the amplitude of cortical SEP readings as a result of indirect impact and suggest the existence of an injury threshold at peak sled accelerations around 700-800 m/sec^2. Smaller latency shifts, occurring around 600 m/sec^2, were viewed as potential evidence of a pre-injury condition. This study is an authoritative source for NBDL's research objectives, methods, and findings with SEP monitoring in non-human primates.

Bishop, B. A., D. A. Francis, and G. L. Jupiter. "EZFLOW Data Reduction and Analysis System: Operating Procedures for the Hewlett Packard 9000/835 System." NBDL-92R002, Naval Biodynamics Laboratory, New Orleans, July 1992.

This report presents operating procedures for EZFLOW, a software program devised for processing, analyzing, and plotting impact acceleration data on a Hewlett Packard model 9000/835 computer. EZFLOW processing consisted of updating datasets and executing several multi-sequence computer programs to convert photographic and inertial data to calculate and plot displacements, linear and angular velocity, and acceleration of each subject's head and neck. EZFLOW was an important and lasting innovation at NBDL that served as a fundamental part of data processing and analysis at the lab.

Bittner, A. C., Jr., and R. C. Carter. "Repeated Measures of Human Performance: A Bag of Research Tools." NBDL-81R011, Naval Biodynamics Laboratory, New Orleans, November 1981.

This report describes research tools that relate to evaluation of human performance through repeated measures testing. In the first section of the report, the statistical criteria for task selection are delineated, tools for assessment are described, and examples of applications are provided. In the second section, multiple subject and single-subject analyses of intervention experiments are considered, with major focus on the methodological tools. The third and final section summarizes these tools with examples of their utility.

Bittner, A. C., Jr., J. P. Shortal III, and M. M. Harbeson. "Effects of Head Impact Acceleration on Human Performance: Overview and Preliminary Battery Identification." NBDL-83R004, Naval Biodynamics Laboratory, New Orleans, May 1983.

This report discusses the results of a review of the effects of impact acceleration on human performance as a part of a larger effort to assemble an experimental test battery. Tasks were designated for inclusion in the test battery only if deemed suitable for repeated measures applications and if sensitive to indirect impact acceleration. After experimental and clinical research, two human performance task tests, Choice Reaction Time and Manikin Spatial Orientation, met the accepted criteria and were recommended for inclusion in an impact acceleration test battery.

Bittner, A. C., Jr., R. C. Carter, R. S. Kennedy, M. M. Harbeson, and M. Krause. "Performance Evaluation Tests for Environmental Research (PETER): Evaluation of 112 Tasks." NBDL-84R006, Naval Biodynamics Laboratory, New Orleans, September 1984.

The goal of the PETER program was to identify a set of measures of human cognitive, perceptual, and motor capabilities for use in research on human response to different environments. Tasks were evaluated as suitable for repeated measures applications when their intertrial means, variances, and correlations were well behaved under constant baseline conditions. This report documents the results of the PETER program at large. In all, the PETER program identified and recommended thirty task measures for use in a performance test battery. Another fifteen measures performed acceptably but were deemed redundant. Thirty-five tasks were identified as having some desirable features, but these were outweighed by flaws. Finally, thirty-two measures were identified as totally unacceptable for inclusion in a performance battery because they were characterized by either differential instability or weak reliability.

Bittner, A. C., Jr., and J. C. Guignard. "Motion Sickness Evaluations in an At-Sea Environment: Seakeeping Trials of a USCG Cutter (WMEC 901)." NBDL-86R002, Naval Biodynamics Laboratory, New Orleans, 1986.

This paper reports on the incidence and implications of seasickness during seakeeping trials aboard the U.S. Coast Guard cutter *Bear* (WMEC 901), performed at the David Taylor Naval Ship Research and Development Center. The authors posit that, contrary to common belief, seasickness is characterized by two distinct factors: general motion illness and retching-vomiting. Analysis of data collected from individuals aboard the *Bear* show that general motion illness reflected persistent individual differences and was generally linked with vertical heave motion. Vomiting, on the other hand, was observed to be transitory and associated with high transverse and lower vertical motion that generally accompany ship roll. Importantly, the authors find that periods of rest (even short naps of less than 20 minutes) can help alleviate seasickness in some individuals.

Bowman, B. M., and L. W. Schneider. "Analysis of Head and Neck Dynamic Response of the U.S. Adult Military Population." Report No. UM-HSRI-82-29, University of Michigan Highway Safety Research Institute, Ann Arbor, MI, and NR 207-280, Naval Medical Research & Development Command, Bethesda, MD, July 1982.

This report discusses results from efforts to use human volunteer impact data from NBDL to investigate the relationships between dynamic head-neck response and the biomechanical properties of the neck. Data was used in a two-dimensional simulation model to locate the kinematic parameters that play the most important roles in dictating head-neck kinematics in $-G_x$ impact. Kinematic parameters of interest were established, and the related degree of sensitivity of biodynamic response to variation from each parameter was estimated. Based on findings from the two-dimensional model, preliminary work began on a three-dimensional model. Initial simulations using NBDL $+G_y$ data in the three-dimensional model indicated some promise.

Bowman, B. M., L. W. Schneider, L. S. Lustick, W. R. Anderson, and D. J. Thomas. "Simulation Analysis of Head and Neck Dynamic Response." In *Proceedings of the Twenty-Eighth Stapp Car Crash Conference*, 173-206. Warrendale, PA: Society of Automotive Engineers, 1984.

This paper presents findings from efforts to use NBDL data from $-G_x$, $+G_y$, and G_{-X+Y} runs in two-dimensional and three-dimensional simulation models in order to quantify biomechanical properties of the human neck. From the work, the authors noted the mechanical properties of the neck could be determined by review of impact data from the $-G_x$ and $+G_y$ vectors. G_{-X+Y} data was deemed less than necessary moving forward because the rendered information closely conformed to that provided by the $-G_x$ and $+G_y$ impacts. However, the authors did anticipate that eventual data from the G_z vector would be useful in developing improved parameter values representing the axial properties of the neck.

Carter, R. C. "Visual Search with Color." NBDL-M005, Naval Biodynamics Laboratory, New Orleans, October 1980.

This report profiles experiments that were conducted to discover how rapidly people can find a particular target when they know the color of the target. More than 14,000 searches were conducted by 212 subjects. The subjects searched for a specific colored three-digit number among other colored three-digit numbers on a circular display screen that subtended about 14 degrees of visual angle. Three factors had a profound effect on search speed. Search time increased dramatically as the number of display items of the target's color increased. Search time also increased when the number of display items of different colors from the target increased if the color of these items was sufficiently similar to that of the target. If the color of these background items was dissimilar to that of the target, then the background items had no effect on search time. A color difference calculation was shown to be moderately related to the apparent similarity of colors. An effect of patterned versus random placement of the target-colored items was also demonstrated. There was no consistent effect on search time of the target placement, the number of items adjoining the target, or the practice of the search task. None of the individual difference variables studied (parafoveal acuity, foveal acuity, stereo acuity, reading speed, age, sex, recent drug or alcohol use, smoking habits, nor color vision) were significantly related to differences of search speed.

Carter, R. C., and A. C. Bittner, Jr. "Jackknife for Variance Analysis of Multifactor Experiments." NBDL-82R013, Naval Biodynamics Laboratory, New Orleans, May 1982.

This report presents a method for analyzing effects of multifactor experimental treatments on the variance of a dependent variable. The method is based on the statistical jackknife. It enables the analyst to enhance the power of an analysis by using the degrees of freedom associated with the random factor (for example, subjects in an experiment) of a multifactor design. The method is suitable for investigating hypotheses about trends of variances. A computer program is appended that calculates the jackknife variance estimates and other useful statistics.

Carter, R. C., and M. Krause. "Reliability of Slope Scores for Individuals." NBDL-83R003, Naval Biodynamics Laboratory, New Orleans, April 1983.

This article examines reliabilities across fifteen days of repeated measurements for each of six human information processing tasks: high-speed memory scanning, proactive memory interference, semantic reasoning, letter search, typographic error search, and choice reaction time. In each case, the reliability of the slope scores (representing the rate of human information processing) proved less than the reliabilities of the mean response times for which the slopes were calculated. This proved especially interesting because the slopes include more data than each mean response time. Finally, the authors posit that in applied experimental research, it is generally unnecessary to calculate slope scores for individuals because the more reliable mean response times are enough to answer most research questions.

Clarke, T. D., J. F. Sprouffske, E. M. Trout, H. S. Klopfenstein, W. H. Muzzy, C. D. Gragg, and C. D. Bendixen. "Baboon Tolerance to Linear Deceleration ($-G_x$): Lap Belt Restraint." In *Proceedings of the Fourteenth Stapp Car Crash Conference*. Warrendale, PA: Society of Automotive Engineers, 1970.

This study reports on findings from experiments on impact tolerance with lap belt restraint systems using adult male baboons as subjects. Impact exposures ranging from 8.6 to 40 G were studied, and lethality was used as the tolerance index. Baboons survived sled deceleration levels of approximately 32 G. The predominant fatal injuries were located at the atlanto-occipital junction of the cervical vertebrae. These studies provided an important point of reference for later pathological research with non-human primates at NBDL.

Clarke, T. D., C. D. Gragg, J. F. Sprouffske, E. M. Trout, R. M. Zimmerman, and W. H. Muzzy. "Human Head Linear and Angular Accelerations During Impact." *Proceedings of the Fifteenth Stapp Car Crash Conference*, 1K-12K. New York: Society of Automotive Engineers, November 1971.

This paper reports on findings from impact experiments with fourteen adult male human volunteer subjects using three different restraint configurations (lap belt only, Air Force shoulder harness, and airbag plus lab belt). Volunteers were exposed to peak sled deceleration levels from 7.7 to 10.3 G. Results indicated that peak head linear and angular accelerations were greater in runs that utilized airbags. Nevertheless, the study concedes that the elevated accelerations could be less traumatic than the greater degree of head-neck hyperextension and flexion encountered with harness and lap belt restraints.

Clauser, E. E., J. T. McConville, and J. W. Young. "Weight, Volume, and Center of Mass Segments of the Human Body." Technical Report No. 69-70, Aerospace Medical Research Laboratory. Wright-Patterson Air Force Base, Dayton, OH, 1969.

Using measurements taken from thirteen male cadavers, this study provides center of mass approximations, information on postmortem changes in body size, differences between standing and supine anthropometry, and comparisons of the densities of fresh and preserved human cadaver tissues. This report proved to be an important reference work on the weight, volume, and center of mass of different segments of the human anatomy for research carried out at NBDL.

Dobie, T. G. "Teaching the Right Stuff – The Heart of the Matter." *Aviation, Space, and Environmental Medicine* 60 (February 1989): 195-96. Also published as NBDL-90R017, Naval Biodynamics Laboratory, New Orleans, January 1991.

This article contains Dobie's reflections on his approach to treatment of aviators who had been grounded due to motion sickness. Dobie noticed that anxiety was often a contributing factor. Based on his observations as a doctor in the Royal Air Force, Dobie implemented a method composed of cognitive confidence-building therapy and behavioral reinforcement training. Using cognitive-behavioral counseling in combination with sessions of Coriolis stimulus exposure, Dobie reported that 86 percent of a group of fifty grounded airmen were able to return to flight. A follow-up carried out six-seven years afterwards showed that, in general, the airmen continued to perform their duties.

Dobie, T. G., and J. G. May. "Generalization of Tolerance to Motion Environments." *Aviation, Space, and Environmental Medicine* 61 (1990): 707-11. Also published as NBDL-90R010, Naval Biodynamics Laboratory, New Orleans, October 1990.

This article reports on an investigation of the extent to which training tolerance to one motion stimulus would generalize other motion experiences. Twenty subjects prone to motion sickness were selected and assigned to four groups after a round of pre-testing in a Dichgans and Brandt drum to determine their susceptibility to visually induced apparent motion. They were also tested with a VDT display of an expanding surface and on a revolving/tilting chair. Subjects were assigned to groups based on their average tolerance to motion. Subjects in the first group served as controls and received only cognitive counseling regarding their motion intolerance. Subjects in the other groups received the same counseling coupled with incremental exposures to the drum, chair, or VDT, respectively. Post-tests on each device showed that the treatments using the chair and the drum provided noticeable increases in tolerance to the device used during treatment, and that the treatment involving the chair provided a generalized tolerance to visually induced motion. The authors found that these observations supported the concept that there are both specific and general components in learning to tolerate motion environments.

Dobie, T. G., J. G. May, W. D. Fisher, and N. B. Bologna. "An Evaluation of Cognitive Behavior Therapy for Training Resistance to Visually-Induced Motion Sickness." NBDL-89R008, Naval Biodynamics Laboratory, New Orleans, October 1990.

This investigation examined the techniques for reducing visually induced motion sickness. On the basis of their responses to a motion sickness history questionnaire, thirty-two subjects were selected and assigned to one of four groups based on their ability to tolerate visually induced motion (VM). One group received ten sessions of desensitization training only (DT); a second group received ten sessions of cognitive therapy only (CT); a third group received ten sessions of combined desensitization and cognitive therapy treatment (CG); and a fourth group, serving as the control, received no treatment. The results indicated that only the groups that received cognitive therapy exhibited significant increases in tolerance to visually induced apparent motion when pre-treatment measures were compared to post-treatment measures. No significant differences in pre-treatment versus post-treatment measures were observed in the desensitization only or control groups.

Ewing, C. L. "Design Criteria and Parameters of Life Support Helmets." In *Effective Life Support Helmets*, 99-121. Arlington, VA: Biotechnology, Inc., 1963.

In this paper Ewing discusses the need to focus on development of crash helmets (designed to reduce relative velocity between the head and the impact object with a minimum of injury) rather than anti-buffeting helmets. Ewing also warns against the dangers of heavy helmets, which by increasing head and neck mass loads contribute to wearer discomfort and can lead to dangerous hyperextension and flexion during impact. Most importantly, it is in this early paper that Ewing opines on the theory that the impact force of crashes might be causing concussions and preventing aviators from escaping burning or sinking aircraft.

———. "A Study of Aviation Medical Education in the U.S. Navy." Unpublished manuscript, 1964. A copy is located at the Neel Aeromedical Center, U.S. Army Aeromedical Research Laboratory, Fort Rucker, AL.

This unpublished manuscript contains Channing Ewing's appraisal of changes in Navy aviation medicine. While Ewing does discuss the education of flight surgeons, he does so in the context of important research opportunities, including but not limited to impact injury and ejection. Ewing also highlights problems hindering the development of aviation medicine in the Navy. These problems included limited funding and the tendency to loan talented research personnel to other organizations like NASA. This text provides important insight into Ewing's early mindset and research interests.

———. "Vertebral Fracture in Jet Aircraft Accidents: A Statistical Analysis for the Period 1959 through 1963, U.S. Navy." *Aerospace Medicine* 37, no. 5 (May 1966): 505-8.

This article examines vertebral fracture incidence in aircraft accidents between fiscal years 1959 and 1963 from data obtained from the Naval Aviation Safety Center. The data showed that the highest rates of vertebral fracture were associated with jet aircraft ejections. The F-3 and the TF-9J model jets, equipped with multiple catapult seats, had disproportionately high fracture rates. Sitting height accommodations of both the F-3 and TF-9J were below the 70^{th} percentile, and over 94 percent of all ejections were through the canopy. These findings suggest that the combination of seat accommodations and through the canopy ejection contributed to the incidence of vertebral fractures.

———. "A Short Review of Anthropometrics in Naval Aviation." *US Naval Medical Newsletter* 48, no. 12 (December 1966): 17-19.

This article provides a review of the major contemporary anthropometric surveys produced by the Army, Navy, and Air Force. In doing so, the article notes that the Air Force Wright Air Development Center (WADC) Technical Report No. 52-321 contained biases that skewed the data. Most of the aviators represented in the report had entered service in the U.S. Army Air Force during 1943-1944, and there was a height limit on fighter pilot recruits of 5 feet 10 inches. The Navy did not enact this restriction. A further bias to the WADC report came in the form of measurements from non-pilots (truck drivers, bombardiers, and gunners) who were lumped into the sample dataset. As a result, when the WADC report was used to design aircraft, taller pilots were placed in a potentially dangerous position. Based on these concerns, the Navy Bureau of Weapons commissioned the Air Crew Equipment Laboratory to conduct a survey of 1,659 naval aviators in 1964.

———. "Emergency Underwater Escape from Aircraft." *US Naval Medical Newsletter* 48, no. 12 (December 1966): 19-23.

This article highlights the dangers of failure to escape from an aircraft after crashing in water. Experiments with jet aircraft showed that they remained afloat for no longer than one minute. Innovative oxygen systems may give divers with SCUBA equipment a chance to free trapped aviators. Underwater ejection systems were also developed as a means of escape. Still, oxygen supply was limited, and the underwater ejection systems were hampered by the difficulty of jettisoning the canopy. For aviators submerged in deep waters, intrapulmonary gas expansion in the lungs during ascension to the surface is also a danger. If an aviator has been knocked unconscious or injured during the collision with the water, his chance of survival is even lower.

———, ed. *U.S. Naval Flight Surgeon's Manual*. Washington, D.C.: Government Printing Office, 1968.

This manual, commissioned by the Navy Bureau of Medicine and Surgery, was published to provide up-to-date information on human response to aerospace environments and to describe the duties of the flight surgeon. The massive volume was produced under the direction of Channing L. Ewing, who acted as the managing project officer and scientific editor. As one of his crowning achievements, Ewing displayed the breadth of his expertise by authoring or co-authoring sections on casualty management and aeromedical evacuation, gas physiology, environmental factors, otorhinolaryngology, vision, anthropometry, and emergency escape from aircraft.

———. "Nonfatal Ejection Vertebral Fracture, U.S. Navy Fiscal Years 1959 through 1965: Costs." *Aerospace Medicine* 42 (1971): 1226-28.

This article presents a cost analysis of seventy incidents of vertebral fracture resulting from non-fatal ejections among designated Navy aviators between fiscal years 1959 and 1965, using data obtained from the Naval Aviation Safety Center. Review of the medical records of the injured aviators was completed to ascertain the repercussions of the fractures. The average annual cost to the Navy (including hospitalization, salary costs associated with lost workdays, and replacement costs stemming from disability) between 1959 and 1965 was $6,797,718. This analysis helped serve as an additional reason to do further impact injury research.

———. "Injury Criteria and Human Tolerance for the Neck." In *Aircraft Crashworthiness*, edited by K. Saczalski, G. T. Singley III, W. D. Pilkey, and R. L. Huston, 141-51. Charlottesville, VA: University of Virginia Press, 1975.

In this chapter, Ewing provides a review of important studies of human dynamic response to impact acceleration and highlights how the research at NBDL has built upon the pre-existing work. He finds that NBDL's primary innovation has been its ability to directly measure and validate input data to the neck using telemetered sensors. Following this discussion, Ewing closes by articulating the long-term objectives for study of human dynamic response at NBDL. As explained, the approach entails exposing human subjects to impact levels up to the limit of voluntary human tolerance. Then, identically instrumented subhuman primate runs up to fatal accelerations will be conducted. The third phase requires mathematical scaling of primate data to the human anatomy and extrapolated to locate injurious acceleration levels for humans.

Ewing, C. L., and Frank A. Catroppa. "Defects of Current Navy Helmets." In *Effective Life Support Helmets*, 14-19. Arlington, VA: Biotechnology, Inc., 1963.

This paper addresses problems associated with helmets utilized by Navy aviators by examining the APH5 helmet, which became standard issue in 1956. The APH-5's poor helmet retention rate and uncomfortable weight distribution were identified as the biggest flaws. Design was complicated by the need to retain sound attenuation properties as well as provision for helmet-mounted communication, respiratory, and optical equipment. The lighter weight and more comfortable APH-6 offered some improvements.

Ewing, C. L., D. J. Thomas, G. W. Beeler, Jr., L. M. Patrick, and D. B. Gillis. "Dynamic Response of the Head and Neck of the Living Human to $-G_x$ Impact Acceleration." In *Proceedings of the Twelfth Stapp Car Crash Conference*, 429-39. NY: Society of Automotive Engineers, 1968.

This paper describes the experimental design and early results from research carried out under the joint Army-Navy project at Wayne State University. The discussion includes a description of the volunteer selection process and the instrumentation, photographic, accelerator, and data acquisition systems. The publication concludes by profiling results from a human run that registered a rate of onset of 140 G/sec and a peak sled acceleration of 2.8 G. Findings presented in this paper were reproduced the following year in a report produced in tandem by the Naval Aerospace Medical Institute and the U.S. Army Aeromedical Research Laboratory.

Ewing, C. L., and A. Marshall Irving. "Evaluation of Head Protection in Aircraft." *Aerospace Medicine* 40, no. 6 (June 1969): 596-99.

This article studies contemporary methods used to test helmet impact protection. When evaluating protective equipment, three separate requirements must be satisfied: User acceptance (will the intended user wear it); Functionality (does it protect against the anticipated threat); and Functional non-interference (does it interfere with the ability of the user to function and perform his/her duties). In testing the functionality of protective helmets, the article suggests that testing cover three different types of impact: situations where a moving object makes contact with the helmet; situations where the moving head strikes a stationary physical structure in the cockpit; and situations where impact causes flexion/hyperextension of the head-neck but does not result in contact with a physical object. The article emphasizes that no testing method exists for the third type of testing despite the fact that the presence of torso restraints makes them the most likely.

Ewing, C. L., D. J. Thomas, L. M. Patrick, G. W. Beeler, Jr., and M. J. Smith. "Living Human Dynamic Response to $-G_x$ Impact Acceleration. II, Acceleration Measured on the Head and Neck." *Proceedings of the Thirteenth Stapp Car Crash Conference*, 400-415. NY: Society of Automotive Engineers, 1969.

This paper reports on eighteen human runs carried out during the joint Army-Navy project at Wayne State University. From human 10 G runs, the authors note that peak acceleration at the mouth had been registered at 47.8 G, and peak mouth angular velocity exceeded 30 rad/sec (31.14) without causing injury or functional impairment. These findings refute earlier re-

search by Ayub Ommaya positing that angular velocity of 30 rad/sec and angular acceleration of 1,800 rad/sec^2 were needed to observe concussion in humans. Findings reported here were substantially reproduced in a joint report by the Naval Aerospace Medical Research Laboratory and the U.S. Army Aeromedical Research Laboratory the following year.

Ewing, C. L., and D. J. Thomas. *Human Head and Neck Response to Impact Acceleration*. Joint Report – Naval Aerospace Medical Research Laboratory Monograph No. 21, U.S. Army Aeromedical Research Laboratory Serial No. 73-1, Pensacola, FL, August 1972.

This monograph represents the culmination of the joint Army-Navy project at Wayne State University. It includes a detailed description of the theoretical kinematics and experimental design surrounding the impact acceleration research. In addition, the monograph reviews the unique transducer, photographic, data acquisition, and accelerator systems utilized. Experimental controls, data processing, subject selection procedures, and anthropometry are discussed. Finally, the monograph provides an expansive treatment of the results from the runs carried out at Wayne State. Run plots are accompanied by a discussion of variables, repeatability, spectral characteristics, and quality control. Some important conclusions drawn are that the response of the unrestrained human head and neck to $-G_x$ impact acceleration is two dimensional in the mid-sagittal plane; the response is characteristic and repeatable; simultaneous sensor and photographic measurement of human response permits cross validation; the utilization of the theoretical mechanics of rigid body motion is a valid experimental design basis for measuring the response of human head and neck motion; and the use of x-ray anthropometry permits X, Y, and Z coordinate description of the position of the center of gravity of the head within a head anatomical coordinate system.

———. "Torque Versus Angular Displacement Response of Human Head to $-G_x$ Impact Acceleration." In *Proceedings of the Seventeenth Stapp Car Crash Conference*, 304-42. Warrendale, PA: Society of Automotive Engineers, 1973.

This paper emphasizes the need for researchers in the field to develop and utilize standardized anatomically based, three-dimensional coordinate systems so that quantitative comparisons can be made between data derived from human impact exposures conducted at different laboratories. The authors note that differing anatomical definitions of the head and neck complex also make comparisons difficult. Using anatomical research conducted on cadavers by Edward Becker and Leon Walker at Tulane University, this paper profiles a set of theoretical anatomically based coordinate systems that could be used industry-wide.

———. "Bioengineering Aspects of Spinal Injury in OV-1 (Mohawk) Aircraft." *AGARD Conference Proceedings No. 134 on Escape Problems and Maneuvers in Combat Aircraft*, A2-1-9. London: Technical Editing and Reproduction, Ltd., February 1974.

Based on statistics provided by the U.S. Army Board for Aircraft Accident Research as of 1967, Ewing reports a non-fatal ejection vertebral fracture (NFEVF) rate of 56 percent for the OV-1

aircraft. Since this was one of the highest NFEVF rates among aircraft in the U.S. military at the time, Ewing and Thomas undertook an investigation to identify contributing factors. They found potential issues with the sitting height accommodation of the OV-1. Tall aviators might be required to slouch (and thus loosen the pelvic restraint lap belt) to operate the aircraft. Doing so would put them at greater risk of injury during ejection. Ewing and Thomas also objected to the ejection seat design, which contained a two-inch thick elastic pad over the seat pan. Ejection seat firing would cause the pad to compress and create slack in the pelvic harness as the body is pushed down onto the compressed pad. Finally, a potential issue was also found with the restraint harness design.

Ewing, C. L., D. J. Thomas, L. S. Lustick, E. B. Becker, G. C. Willems, and W. H. Muzzy. "The Effect of the Initial Position of the Head and Neck on the Dynamic Response of the Human Head and Neck to $-G_x$ Impact Acceleration." In *Proceedings of the Nineteenth Stapp Car Crash Conference*, 487-512. Warrendale, PA: Society of Automotive Engineers, 1975.

This paper presents findings from an investigation designed to quantify the role of initial head position on human dynamic response. Human volunteers were positioned for $-G_x$ runs in four different initial condition states: neck up, chin up (NUCU); neck up, chin down (NUCD); neck forward, chin up (NFCU); and neck forward, chin down (NFCD). From the experiments, the authors confirmed that initial head-neck position had a significant impact on output dynamic response. Specifically, it was determined that increasing the neck angle position significantly reduces peak angular velocity and angular acceleration. Likewise, increases in head angle (chin down) resulted in significant decreases in peak angular velocity and angular acceleration.

Ewing, C. L., D. J. Thomas, L. S. Lustick, W. H. Muzzy, G. C. Willems, and P. L. Majewski. "The Effect of Duration, Rate of Onset and Peak Sled Acceleration on Dynamic Response of the Human Head and Neck." In *Proceedings of the Twentieth Stapp Car Crash Conference*, 3-41. Warrendale, PA: Society of Automotive Engineers, 1976.

This study investigated the extent to which variables of duration, rate of onset, and peak sled acceleration influenced the dynamic response of humans. To test the variables, human subjects were exposed to $-G_x$ impact in three conditions: high rate of onset–long duration; high rate of onset–short duration; and low rate of onset–long duration at peak acceleration levels of 6, 10, and 15 G. To minimize the effects of initial conditions, each subject was run in the neck-up/chin-up position. Review of data recorded at T1 during experiments suggested that peak head angular and linear acceleration as well as angular velocity were dependent on the peak and duration of acceleration at T1. The rate of onset at T1 had no measurable effect.

Ewing, C. L., and F. Unterharnscheidt. "Neuropathology and Cause of Death in U.S. Naval Aircraft Accidents." *AGARD Conference Proceedings No. 190, Recent Advances in Aviation Pathology* B16: 1-6. London: Technical Editing and Reproduction Ltd., December 1976.

This paper discusses the possibility that aviators downed in crashes at sea may be drowning because they have been incapacitated by an "acceleration concussion" resulting from hyperextension of the cranio-cervical junction during impact. In order to investigate this possibility, the authors argue for changes to be made to the Navy's autopsy policies. In the 10 percent of cases where bodies are recovered, the article noted that usually autopsies were not carried out in a manner that included a satisfactory neuropathological examination of the central nervous system. The authors continued to argue that these particular autopsies should include a brief, but detailed, description of the tissue alterations in the brain and spinal cord deemed to be the result of the impact.

Ewing, C. L., D. J. Thomas, L. S. Lustick, W. H. Muzzy III, G. C. Willems, and P. Majewski. "Dynamic Response of the Human Head and Neck to $+G_y$ Impact Acceleration." In *Proceedings of the Twenty-First Stapp Car Crash Conference*, 477-505. Warrendale, PA: Society of Automotive Engineers, October 1977.

This paper reports on findings from runs with human volunteers in several different sled configurations to test dynamic response to lateral impact acceleration ($+G_y$). The authors found that for $+G_y$ runs, the head rotates around an axis with a fixed orientation in the mid-sagittal plane approximately normal to the neck line between the T1 anatomical origin and the head anatomical origin. It was also found that head linear acceleration in high rate of onset–short duration runs was significantly less in the $+G_y$ vector than in $-G_x$ because the effect of duration was more pronounced in $+G_y$ runs.

Ewing, C. L., D. J. Thomas, P. L. Majewski, Roger Black, and L. Lustick. "Measurement of Head, T1, and Pelvic Response to $-G_x$ Impact Acceleration." In *Proceedings of the Twenty-First Stapp Car Crash Conference*, 509-45. Warrendale, PA: Society of Automotive Engineers, October 1977; also published in *SAE Transactions* 86 (1978): 3205-20.

This paper deals with the response of the human head and neck in conjunction with the motion of the pelvis during $-G_x$ impact acceleration human runs from 2 to 7 G. To record hip measurements, a fiberglass pelvic ring outfitted with an instrumentation mount and photo-targets was custom made for each volunteer. A circumferential steel band was imbedded in the fiberglass, and the ring was integrated in the restraint harness system. Tests with and without the pelvic mount indicated that the pelvic mount did not cause any substantial differences by integrating it into the restraint. These tests meant that NBDL could continue to record hip motion without unintentioonally altering the data being recorded at T1 and the head. The pelvic measurements were useful to biodynamic researchers because it allowed them to see how acceleration was transmitted through the human structure to the head and neck.

Ewing, C. L., D. J. Thomas, L. S. Lustick, G. C. Willems, W. H. Muzzy, E. B. Becker, and E. M. Jessop, Jr. "Dynamic Response of Human and Primate Head and Neck to $+G_y$ Impact Acceleration." Report No. DOT-HS-4-00852, Washington, D.C.: Department of Transportation, 1978.

This report presents results from the first studies of human and chimpanzee response to lateral ($+G_y$) impact acceleration completed at NBDL. Measurements were taken with three-dimensional inertial instrumentation located at the head and T1. Thirty-four human experiments at peak sled acceleration levels from 2 to 7.5 G were completed and compared with data from twelve chimpanzee runs reaching peak sled acceleration levels of 6 to 20 G. The authors find considerable differences between $-G_x$ and $+G_y$ response. This report is particularly important because it is the only thorough treatment of chimpanzee experiments conducted at the lab.

Ewing, C. L., D. J. Thomas, L. S. Lustick, W. H. Muzzy, G. C. Willems, and P. L. Majewski. "Effect of Initial Position on the Human Head and Neck Response to +Y Impact Acceleration." In *Proceedings of the Twenty-Second Stapp Car Crash Conference*, 101-38. Warrendale, PA: Society of Automotive Engineers, 1978.

This study reports on the effect of the initial position of the human head and neck on head angular and linear acceleration, velocity, and displacement during $+G_y$ impact acceleration. From exposures with human volunteers in several different initial position configurations, the authors found that lateral bending of the head-neck in the direction of the motion significantly reduced the peak head angular acceleration and velocity and often produced an angular acceleration profile with a deceleration peak greater than the acceleration peak. These observations were consistent with findings for $-G_x$ runs. Increases in angular acceleration and velocity were observed in situations where the head and neck were bent forward. This was the only initial condition configuration that the authors felt they might not be able to account for accurately in a fixed-axis theoretical model.

Ewing, C. L., D. J. Thomas, and L. S. Lustick. "Multiaxis Dynamic Response of the Human Head and Neck to Impact Acceleration." *AGARD Conference Proceedings No. 253: Models and Analogues for the Evaluation of Human Biodynamic Response, Performance, and Protection* A5: 1-27. London: Technical Editing and Reproduction Ltd., June 1979.

This paper focuses on data from $-G_x$ and $+G_y$ impact acceleration runs with human volunteers carried out at NBDL from 1974-1978. The relationships of the kinematic variables are graphically presented and statistically analyzed. A previously suggested head and neck model for two-dimensional response is evaluated, as well as the approaches and constraints for a three-dimensional model, and the anthropometric effects on the dynamic response are presented.

Ewing, C. L., D. J. Thomas, A. Sances, Jr., and S. J. Larson, eds. *Impact Injury of the Head and Spine*. Springfield, Ill.: Charles C. Thomas, 1983.

This twenty-one chapter edited volume is the primary resource for consulting the major research conducted by NBDL and its affiliated partners. Broken down into four sections, the volume contains works regarding injury mechanisms and tolerances; neurophysiological and neurosurgical aspects; human analogues; and injury prevention and epidemiology.

Francis, D. A. "General Plot Subroutine Package for the Hewlett-Packard 5451C Fourier Analyzer." NBDL-84R008, Naval Biodynamics Laboratory, New Orleans, December 1984.

This paper discusses the programming tool used by NBDL with the Hewlett-Packard 5451C system to develop various plots with relative ease. Data plotting was a critical aspect of the work at NBDL because plots are useful in analyzing data and are usually much easier to interpret than tabular printouts. Paired with an HP-9872T plotter, the program allowed users to create plots with labelled axes, textual data, vector information, and graphs from data arrays (x and y), with optional scaling of either array and centered symbols denoting the location of a data point.

———. "X-Ray Anthropometry Digitization Program for the Hewlett-Packard 9000/835 Computer." NBDL-90R003, Naval Biodynamics Laboratory, New Orleans, May 1991.

This report describes a computer program developed by NBDL to calculate instrumentation origins and instrumentation-to-anatomy transformation matrices from x-ray anatomical reference data. Operational requirements are also described for its use on the Hewlett-Packard 9000/835 computer interfaced with an HP 9872T plotter/digitizer.

———. "Operating Procedures for Anthropometry and Initial Conditions Photogrammetric Program." NBDL-93R010, Naval Biodynamics Laboratory, New Orleans, March 1994.

This report describes the program used with an IBM Model 486 personal computer to process stereoradiographic anthropometry and initial condition run data. The report describes the program's subroutine operating sequence, functions, and required equipment and, in doing so, provides an important reference for users interested in the NBDL data acquisition and processing systems.

———. "Body X-Ray Anthropometry Manual." NBDL-94R003, Naval Biodynamics Laboratory, New Orleans, May 1995.

This publication provides documentation of neck x-ray anthropometry data acquisition and analysis. It also documents the anthropometry photogrammetric program used on an IBM-compatible 486 personal computer at NBDL.

Friede, Reinhard L. "The Pathology and Mechanics of Experimental Cerebral Concussion." Technical Report No. 61-256, Wright Air Development Center, Dayton, OH, March 1961.

This report provides theoretical findings regarding the neuropathology of experimental cerebral concussion. The author describes findings from two series of experiments with cats designed to simulate direct and indirect impact. In the most significant tests, Friede restrained the heads of cats using a collar and then allowed the unrestrained bodies to suddenly fall about 30 inches, inducing rapid neck hyperextension ("cervical stretch") and flexion. Histopathological studies revealed that these tests caused lesions at the first cervical vertebrae, a finding that Friede linked to cellular changes in the brain and the symptomology of concussion. Friede finds neck hyperextension and flexion to be the most important factors in experimental cerebral concussion. His hypothesis that neck stretch was the primary factor in acceleration-induced concussions was picked up by biodynamics researchers during the 1960s (including Channing Ewing) trying to understand the failure of aviators to make attempts to escape after crashing in water.

Frisch, G. D. "Simulation of Occupant-Crew Station Interaction During Impact." In *Impact Injury of the Head and Spine*, edited by C. L. Ewing, D. J. Thomas, T. A. Sances, Jr., and S. J. Larson, 485-535. Springfield, Ill.: Charles C. Thomas, 1983.

This is a study of the physical interaction between pilots and airplane cockpits ("crew station") during impact. Cockpits must be designed so they allow pilots to perform their tasks without posing a danger during crashes or ejections. From simulations using NBDL human volunteer data and dummy ejection tower tests, the study finds that large individuals are likely to strike their toes against the instrument panel during egress. In addition, the study finds that seats with a distance of more than two inches between seat backs and the headrest result in greater head rotation during impact. Higher seat backs are suggested to reduce the likelihood of cervical spine injuries.

Frisch, G. D., J. O'Rourke, and L. D'Aulerio. "The Effectiveness of Mathematical Models as a Human Analog." In *Society of Automotive Engineers Transactions SP-412, Mathematical Modeling Biodynamic Response to Impact*, 61-73. Warrendale, PA: Society of Automotive Engineers, October 1976.

This paper provides an analysis of data on the dynamic response of the human head and neck to $-G_x$ impact acceleration. Three computerized crash simulation programs (the Calspan "3D Computer Simulator of a Motor Vehicle Crash Victim," the Ultrasystems "Crash Victim Simulator – Light Aircraft," and the Boeing Computer Services "Prometheus") were used to provide estimates of the responses. Inputs were made as comparable as the different programs would allow. Results from the simulators were compared to each other as well as to the corresponding human test run data obtained from NBDL. Importantly, the authors found that the programs failed to adequately replicate human results. Inclusion of head-neck articulation information failed to improve the quality of the simulation output results.

Frisch, G. D., L. A. D'Aulerio, and M. Schultz. "Simulation of Emergency Egress from Aircraft Crew Stations." NADC Report No. 80059-60, NBDL-80R001, Naval Biodynamics Laboratory, New Orleans, March 1980.

This report demonstrates the use of the "Bioman" modeling system in evaluating the physical compatibility of crew members with crew stations under emergency egress conditions and illustrates the usefulness of this approach as both a design and evaluation criterion. Validated results for F-18 aircraft investigations based both on ejection tower and human physiological acceptance tests are presented to demonstrate the evaluation process for this crew station. These results are contrasted against those obtained from A-4, F-14, and AV-8B simulations, and the relative propensity of direct impact (between limbs and crew station interior) and head and neck (due to adverse cervical alignment) injuries is discussed.

Gennarelli, T. A., A. K. Ommaya, and L. E. Thibault. "Comparison of Transitional and Rotation Head Motions in Experimental Cerebral Concussion." In *Proceedings of the Fifteenth Stapp Car Crash Conference*, 797–803. Warrendale, PA: Society of Automotive Engineers, 1971.

This paper discusses results from indirect impact exposures with squirrel monkeys. In one set of experiments, animal heads were restrained using a "head accelerating device" (HAD) to prevent any rotational motion. In these runs, the authors reported no indication of concussion. Alternately, in a second series of experiments, heads were left unrestrained to allow for translational and rotational motion to act upon the head. Notably, the authors found that in all six cases where the head was allowed to rotate the animals were concussed. Based on this evidence, the authors argued that rotational motion of the head was a more likely mechanism to produce cerebral concussion than translational motion; however, they did note that translational motion could contribute to brain lesions and thus contribute to injury patterns associated with indirect impact.

Gifford, Edmund C., Joseph R. Provost, and John Lazo. "Anthropometry of Naval Aviators, 1964." Report No. NAEC-ACEL-533, Aerospace Crew Equipment Laboratory, Naval Air Engineering Center, Philadelphia, PA, 1965.

This study reports body size data for ninety-six measurements of 1,549 U.S. Navy aviators. The techniques used for the measurements are profiled and accompanied by schematic illustrations. Both diametral and surface measurements are included, and the dimensions are given in both centimeters and inches. The purpose of this study was to provide anthropometric data for use by engineers designing aircraft and personnel protective material. The need for this particular survey stemmed from a desire to address inconsistencies and biases found in previous surveys.

Gilbert, N. S., S. V. Mawn, S. J. Guccione, Jr., and F. E. Bolin. "Fabrication and Application of a Standardized T1/T2 Mount." NBDL-88R001, Naval Biodynamics Laboratory, New Orleans, December 1988.

This report profiles the construction and utility of a platform designed for use with sensor instrumentation to collect data from subjects during experiments. The platform consisted of an anatomical mount molded from each subject's cervicothoracic region; a fixture that is fastened to the mount and held against the subject by straps; and a T-plate carrying accelerom-

eters and photo-targets. The main issue with the platform was that kinematic measurements reflected not only the motion of the anatomical section but also any untoward movement of the platform itself. This issue was remedied in animal experiments because the platforms were surgically affixed to the desired anatomical segments, thus ensuring rigidity. In use with human subjects, however, the straps were the only steadying agent. Review of photographs from human impact exposures showed that some occasional package movement did occur. As a result, a certain degree of error in dynamic head-neck response data was always present.

Guccione, S. J., Jr. "A Statistical Analysis of –X Rhesus Head Kinematics." NBDL-89R006, Naval Biodynamics Laboratory, New Orleans, October 1990.

This report discusses the use of a statistical method to predict the head kinematics of rhesus macaques to $-G_x$ impact acceleration. Using data from fifty-three $-G_x$ rhesus runs carried out from 1984-1987, the author used statistics to link head kinematic variables to anesthetic state, sled acceleration, and initial conditions. Predictions rendered by the statistical analysis were compared to previous predictions made from analysis of human data. Some conclusions from the analysis included: (1) rhesus mid-sagittal head dynamic responses are repeatable and not significantly affected by the use of anesthesia; (2) rhesus and human volunteer head kinematic response curves are similar; (3) head angular acceleration and velocity are more sensitive to out-of-plane dynamic response than linear acceleration. After noticing some issues with gaps in the frame-by-frame photographs taken during the high G level acceleration exposures, Guccione recommended that effort be made to keep gaps to an absolute minimum in the future so that they do not impede researchers trying to model head-neck displacement.

Guignard, J. C., C. L. Ewing, G. C. Willems, W. R. Anderson, W. H. Muzzy III, D. J. Thomas, and P. L. Majewski. "A Method for Studying Human Biodynamic Responses to Whole-Body Z-Axis Vibration." *AGARD Conference Proceedings No. 267 High-Speed, Low-Level Flight: Aircrew Factors* 9: 1-7. London: Technical Editing and Reproduction Ltd., March 1980.

This paper describes the methodology used in experiments to determine the transmissibility of mechanical vibration to major axial segments (pelvis, upper torso, head) of the seated human body vibrated in the z-axis. Factors influencing transmissibility are mentioned, and the importance of controlling such factors in experimental determinations of the human biodynamic response to vibration is discussed. The methodology described, adapted from established use in human impact studies, includes the use of standardized anatomical coordinate systems for data reference so that meaningful comparison of responses measured in different subjects or in different conditions of vibration can be conducted.

Hertzberg, H. T. E., G. S. Daniels, and E. Churchill. "Anthropometry of Flying Personnel – 1950." Technical Report No. 52-321, Wright Air Development Center, Dayton, OH, September 1954.

This report presents anthropometric data for 132 body size measurements taken from examination of over 4,000 Air Force flying personnel and includes a discussion of the tabulation and use of the statistics. This survey provided updated information on bodily dimensions on Air Force aviators for use in a host of applications. In the ensuing years, this study became the primary resource used in design of crewmember and pilot compartments in aircraft. During the 1960s, researchers from the Navy noticed potential bias in the reported figures. As a result, the Navy subsequently commissioned its own anthropometric surveys.

Hirsch, A. E., S. J. Shaibani, T. T. Nguyen, G. C. Willems, W. H. Muzzy III, and D. R. Knouse. "Response of Seated and Standing Manikin During Shock Trials on U.S.S. Mobile Bay (CG53) and U.S.S. Roosevelt (CVN71)." NBDL-89R005, Naval Biodynamics Laboratory, New Orleans, May 1989.

This study reports on findings from experiments conducted to measure the effects of shock motion on seated and standing manikins during shock trials aboard the USS *Mobile Bay* and the USS *Roosevelt*. The authors found that deck motion aboard the *Mobile Bay* was mostly in the upward (+G_z) direction but also reported oscillations around 10 Hz. The combination of oscillatory and upward motion, the authors noted, could compromise the protection offered by current seats on the *Mobile Bay*. Similar findings were reported for the *Roosevelt*, where large vertical (+G_z), surge (+G_x), and sway (+G_y) deck motions were observed.

Holcombe, F. D., and S. C. Webb. "Human Factors Assessment of USCG 47-Ft Motor Lifeboat." NBDL-91R003, Naval Biodynamics Laboratory, New Orleans, October 1991.

This two-part report provides a detailed assessment of a U.S. Coast Guard lifeboat from a human factors perspective. Part one documents the ergonomic and safety deficiencies noted during an on-site familiarization and inspection of the prototype 47-foot motor lifeboat. The following human factors operability and habitability problem areas are addressed: steps, platforms, and railings; doors, hatches, and passageways; controls, instruments and displays; workspace; and habitability considerations. Approaches to problems are indicated in the form of suggestions for possible redesign, reconfiguration, relocation, or replacement of equipment. Deficiencies fall into these categories: design of ladders; design and configuration of hatches; location and arrangement of controls, instruments, and displays; design of seating; and workspace layout. Part two contains recommendations for reconfiguration of the problematic steering stations. Mock-ups of the open and enclosed steering stations were constructed for the purpose of evaluating alternative configurations of equipment layout.

Kazarian, L. E. "The Primate as a Model for Crash Injury." In *Proceedings of the Nineteenth Stapp Car Crash Conference*. Warrendale, PA: Society of Automotive Engineers, 1975.

This article describes the biomechanical response of the rhesus macaque, baboon, and chimpanzee to impact in an attempt to establish a basis for a whole body interspecies scaling relationship among primates. In addition, it also provides information on the pathology of spinal injuries resulting from identical acceleration inputs across the three different species. These results are then compared with human spinal column structure, known injury patterns, and tolerances. This paper is an important contribution to the broader effort to devise a means to use non-human primates as analogs to help draw conclusions regarding human injury.

Kennedy, R. S., A. C. Bittner, Jr., M. M. Harbeson, and M. B. Jones. "Perspectives in Performance Evaluation Tests for Environmental Research: Collected Papers." NBDL-80R004, Naval Biodynamics Laboratory, New Orleans, November 1981.

The Performance Evaluation Tests for Environmental Research (PETER) program began at NBDL in 1977. This report includes four papers that were written between 1977 and 1980 describing progress and developments in this program. "An Engineering Approach to the Standardization of Performance Evaluation Tests for Environmental Research (PETER)" delineates the structure of the PETER paradigm, describes representative results, and discusses implications of the results to previous and future research. "Assessing Productivity and Well-Being in Navy Workplaces" explains how Jones's rate-terminal performance and theory of skill acquisition has been applied to the study of complex human performance and abilities. Examples from two tests administered under a fifteen-day repeated measures paradigm are presented to illustrate the methodological approach employed in the PETER program. Application of these methods to selection and training research is suggested. "Progress in the Analysis of a Performance Evaluation Test for Environmental Research (PETER)" describes the preliminary results of ten tests that had been completed by October 1978. "The Development of a Navy Performance Evaluation Test for Environmental Research (PETER)" describes the earliest plan for developing PETER as it was formulated in 1977 and includes the philosophy and principles upon which the PETER program was based.

Kennedy, R. S., A. C. Bittner, Jr., R. C. Carter, M. Krause, M. M. Harbeson, D. B. McCafferty, R. L. Pepper, and S. F. Wiker. "Performance Evaluation Tests for Environmental Research (PETER): Collected Papers." NBDL-80R008, Naval Biodynamics Laboratory, New Orleans, July 1981.

This is a collection of papers about the development of the Performance Evaluation Tests for Environmental Research (PETER) project at NBDL. This research focused on assessment of human mental and physical capabilities in unusual environments. As a result, provision was made to take repeated measurements of the performance of subjects before, during, and after participation in an experiment. The authors note that PETER is being developed to provide a battery of tests that can be reliably used to measure human performance. Candidate tests for inclusion in PETER were pulled from the existing body of literature on performance testing and summarized in the first paper of this collection. The results of the examinations of candidate tests are presented in the second paper in the collection. The remaining papers deal with specific tests, including code substitution, stroop, complex counting, critical tracking, time estimation, arithmetic, air combat maneuvering, digit span, four other memory tests, interference susceptibility, and item recognition, that are discussed only briefly in the first two papers. Overall, this collection of papers describes progress in the PETER project up to November 1980.

Kilgore, P. D., and J. H. Gottbrath. "Photodigitizing Procedures." NBDL-84R002, Naval Biodynamics Laboratory, New Orleans, February 1984.

This report documents the equipment, techniques, and procedures required to operate the photographic digitization system used by NBDL and provides a detailed description of the processing of photo data as well as an operators manual. The system was a critical part of operations at the lab because it digitized photographic data from experiments. Following digitization, the three-dimensional motion from runs could be reviewed and analyzed. Photo data was required to validate readings from the telemetered subject-mounted instrumentation packages.

King, A. I. "Human Analogs in Biomechanical Research." In *Impact Injury of the Head and Spine*, edited by C. L. Ewing, D. J. Thomas, A. Sances, Jr., and S. J. Larson, 381-90. Springfield, Ill.: Charles C. Thomas, 1983.

This article discusses the reasoning behind the selection and use of non-human primates as human analogs in biodynamic research programs. In addition to providing information on requirements for anthropometric and anatomical similarities, King's discussion also includes insight into the position of researchers on the ethics of animal testing in the context of growing public opposition. King's points aptly represent the attitudes subscribed to by the researchers working at NBDL and the broader field at large.

Krause, M., and J. C. Woldstad. "Massed Practice: Does it Change the Statistical Properties of Performance Tests?" NBDL-83R005, Naval Biodynamics Laboratory, New Orleans, June 1983.

This report presents findings from a study to see if massed practice (repeated testing carried out with little rest time in between) test scores compared favorably to repeated measures testing (carried out with twenty-four-hour breaks in between tasks to reduce fatigue). Paper-and-pencil and computerized versions of human performance tests known to have high reliability measures were examined under massed practice conditions. The authors found that the paper-and-pencil tests took more time to complete under massed practice conditions but generally retained high reliability. Computerized performance tests failed to maintain the statistical properties required for repeated measures analysis. As a result, the authors recommended that repeated measures testing with trials separated by at least twenty-four hours be used whenever possible.

Kroell, Charles K., and Lawrence M. Patrick. "A New Crash Simulator and Biomechanics Research Program." In *Proceedings of the Eighth Stapp Car Crash Conference,* 185-228. Detroit: Wayne State University Press, 1964.

This paper describes the crash simulator and biomechanics research program that developed at Wayne State University during the early 1960s and includes a treatment of experiments simulating automobile collisions using human cadavers as subjects. These experiments utilize restraint and measurement (xray, sensor, and photographic) techniques that were carefully honed over years of research at Wayne State and elsewhere. Within the broader context of NBDL, this paper is useful because it provides insight into the ongoing research carried out at Wayne State University prior to the start of the joint Army-Navy project.

Lambert, J. J. "A Method of Photo Data Reduction, with Design Considerations for the NOVA 800T® and UNIVAC 1100/83® Computers." NBDL-84R001, Naval Biodynamics Laboratory, New Orleans, January 1984.

Digitized photo data acquired during impact experiments at NBDL had to be scaled and converted to a format suitable for analysis. Once converted, the data required comprehensive graphical presentation (plotting) for efficient interpretation. This report presents a detailed description of the software developed to accomplish such tasks in both a production and an interactive environment. Procedures utilizing the design presented were developed and instituted at NBDL and found to be highly effective.

Lambert, J. J., and S. J. Guccione. "Linear Regression Analysis of Human and Manikin Head Kinematic Response to $+G_z$ Impact Acceleration." NBDL-95R004, Naval Biodynamics Laboratory, New Orleans, 1995.

NBDL carried out $+G_z$ vertical impact acceleration test series to develop mathematical models for risk assessment of cervical spine injuries due to whole-body acceleration. This paper documents the results of linear regression of the primary peaks of key head kinematic response variables on parameters describing sled acceleration input, initial head orientation, head and neck anthropometry, and head and helmet inertial properties.

Lodge, George T. "Pilot Stature in Relation to Cockpit Size: A Hidden Factor in Navy Jet Aircraft Accidents." Paper Presented at the Seventy-First Annual Convention of the American Psychological Association, Division of Military Psychology, Philadelphia, PA, September 4, 1963.

This paper draws attention to the importance of considering anthropomorphic data in the design of cockpit and crew station geometry. In comparing anthropomorphic data from surveys conducted separately by the Air Force and Navy, Lodge emphasizes the dangerous implications of the fact that Navy pilots possessed a taller average height. If tall Navy aviators operated planes that had been designed for smaller men, it placed them at a greater risk of suffering injury in the event of crash or egress. Analysis of 680 jet aircraft accidents found that aviators taller than six feet were disproportionately represented in "pilot-factor" accidents.

Lotz, M. L. "Physiology Data Acquisition System Description." NBDL-90R004, Naval Biodynamics Laboratory, New Orleans, October 1990.

This technical report describes the physiological data acquisition system that was used at NBDL to acquire, record, and reproduce physiologic responses from human volunteers subjected to short duration accelerations on horizontal and vertical accelerator devices. The system was used to acquire data including electrocardiograms, electromyograms, and somatosensory evoked potentials. The equipment used and the interconnection of the equipment are reviewed in detail.

Lustick, L. S., and M. R. Seemann. "Determination of Sensitivity to Error Sources and Target Configuration on Kinematic Variables Derived from Cinematography." *Proceedings of the International Society for Optical Engineering* 291 (1981): 170-77.

A target configuration attached to a T-plate and affixed to an anatomical segment is acquired by at least two cameras, and linear displacement and orientation components are derived from this data. The quality of these cinematographic solutions depends on the number of targets and on the geometry of the target configuration relative to the camera axis orientation, as well as on errors in camera location and orientation, errors in photo-target location on the T-plate, timing errors between cameras, and high frequency noise errors. This paper presents methods for statistically assessing these errors while obtaining the solution for the kinematic variables and presents plots of these errors for representative runs in the NBDL database. The possibility of using the method for dynamically eliminating poor quality solutions is also discussed.

Lustick, L. S., and H. G. Williamson. "Editing of Cinematographic Data." *Proceedings of the International Society for Optical Engineering* 291 (1981): 153-60.

This paper presents a method for plotting film coordinate data from cameras in such a way that macroscopic errors in the locations of the automatically tracked targets can be easily detected and corrected. This function proved to be yet another example of improvement in the quality of NBDL's photographic data.

Lustick, L. S., and H. G. Williamson. "Errors in Derived Kinematic Variables Determined from a Fixed Accelerometer Configuration." *ISA Transactions* 20 (1982): 35-47.

This paper presents the errors in derived linear and angular kinematic variables consistent with the 3-2-1 accelerometer array used for acceleration experiments at NBDL. Accelerometer sensitivity, linearity, and orientation related errors are explained. The statistics of the errors are derived from repetitive calibrations of the transducer packages and are consistent with the calibration techniques implemented by NBDL. By extension, some "worst case" combinations of the standard deviation errors in sensitivity, linearity, and orientation are presented. Finally, the performance of the 3-2-1 configuration is compared with the least squares solution using three triaxial accelerometers.

Lustick, L. S., H. G. Williamson, M. R. Seemann, and J. M. Bartholomew. "Problems of Measurement in Human Analog Research." NBDL-82R012, Naval Biodynamics Laboratory, New Orleans, May 1982.

This paper discusses some of the types of problems observed in the measurement of three-dimensional dynamic response of human volunteers to short duration (250 millisecond) acceleration profiles. Potential errors in the sensor and photography systems are discussed, as are measures to limit them. The authors note that use of a three triad (nine-accelerometer) transducer configuration can be more stable than the six-accelerometer 3-2-1 configuration in use at NBDL. Further, the three triad configuration also possesses some statistical advantages. Even so, the authors point out that the configurations are so close in accuracy that if the 3-2-1 setup is deemed unreliable, then the nine-accelerometer platform would be as well.

Majewski, P. L., T. J. Borgman, D. J. Thomas, and C. L. Ewing. "Transient Intraventricular Conduction Defects Observed During Experimental Impact in Human Subjects." *AGARD Conference Proceedings No. 253: Models and Analogues for the Evaluation of Human Biodynamic Response, Performance and Protection* A-6: 1-11. London: Technical Editing and Reproduction Ltd., June 1979.

This paper presents results on electrocardiographic readings taken in 923 of 1,282 human impact exposures at the lab since 1974. Particular focus is directed toward the four individual cases when transient intraventricular conduction disturbances were observed. The authors profiled the experimental methodology, data acquisition, and clinical evaluations in use at the lab. In the end, they note that the cause of the intraventricular conduction issues remained unknown since the volunteer subjects had normal cardiovascular system function prior to impact, and no evidence of permanent changes were noticed. An increase in right ventricular chamber pressure coinciding with the acceleration stroke was sighted as a possible cause but would not explain left ventricular conduction abnormalities nor changes suggestive of myocardial contusion. Another postulation was that the disturbances could have been related to the direction of the impact exposure. Despite the small number of cases, the authors did note that three of the four conduction defects were observed in a series of 194 $-G_x$ runs. Only one was noticed in the course of 729 $+G_y$ exposures.

Matson, D. L. "Impact Injury and Evoked Potentials: I - Somatosensory Evoked Potentials in Humans." NBDL-86R003, Naval Biodynamics Laboratory, New Orleans, January 1986.

This report discusses two early experiments with somatosensory evoked potential (SEP) readings conducted at NBDL using human subjects. The first experimental trial was conducted to show that heart rate increases would not confound SEP readings. The second experiment, which involved $-G_x$ impact acceleration exposures, showed that runs up to 10 G did not comprise the thalamocortical tract in humans, thus implying that the force was not great enough to disrupt the function of the central nervous system.

———. "Impact Injury and Evoked Potentials: II - Somatosensory Evoked Potentials in Rhesus Monkeys." NBDL-89R002, Naval Biodynamics Laboratory, New Orleans, 1990.

The purpose of this study was to determine the validity of using anesthetized animals to record short-latency somatosensory evoked potentials (SEPs) for impact research. The SEPs of anesthetized and unanesthetized animals during $-G_x$ acceleration were compared. Adult male rhesus macaques, seated on a sled and restrained (except for the head and neck), were accelerated at peak sled accelerations ranging from 95.5 to 870 m/sec². Somatosensory stimuli were delivered prior to, during, and after impact. Amplified SEP activity was telemetered and recorded on magnetic tape. The raw SEP data was digitized and analyzed off-line. Results for short-latency SEPs from anesthetized animals were consistent with SEPs from unanesthetized animals, showing a threshold for transitory changes in cervical SEP latencies in macaques at peak $-G_x$ sled accelerations around 550 m/sec². This threshold is below the threshold for single impact $-G_x$ neuropathological injury in macaques (700 m/sec²) and suggests a role for anesthetized animals in establishing injury criteria for humans.

———. "Human Short-Latency Somatosensory Evoked Potentials in Impact Acceleration Research: Equipment, Procedures and Techniques." NBDL-89R001, Naval Biodynamics Laboratory, New Orleans, October 1990.

This report summarizes the techniques and equipment developed for neurophysiological monitoring of impact acceleration runs and offers some possible directions for future research. Matson discusses the electrode recording sites, EEG electrode harness, EEG recording system, and control room prepared for neurophysiological monitoring at NBDL. In the same vein, consideration is given to the percutaneous stimulus input and the signal averaging process. Importantly, Matson's remarks include suggestions to improve the quality of the SEP measurements. In order to reduce the disparity between averaged SEPs from rhesus macaques and those from human volunteers, Matson recommended that improvements be made to the digital filtering system. He also notes that adding more EEG channels would enable NBDL to use a spatiotemporal mapping approach to detect transient disruptions in the nervous system with more sensitivity.

Matson, D. L., and M. S. Weiss. "Evoked Potential Analysis of Impact Acceleration Experiments." *AGARD Conference Proceedings No. 432: Electric and Magnetic Activity of the Central Nervous System: Research and Clinical Applications in Aerospace Medicine* 28: 1-13. Essex, UK: Specialized Printer Services Limited, February 1988.

This paper discusses the use of somatosensory evoked potentials (SEPs) as a tool to detect transient injury in the central nervous system of rhesus macaques subjected to $-G_x$ impact acceleration. The authors report on experiments with adult male macaques exposed to peak sled acceleration levels between 95.5 m/sec² to 1,039.6 m/sec². SEP readings were taken prior to, during, and after the runs. From analysis of the SEP data, the authors found reason to believe that a threshold for nervous system disruption in rhesus macaques existed at peak $-G_x$ sled acceleration levels around 550 m/sec². This value was significantly under the $-G_x$ threshold required to observe neuropathological trauma in macaques (800 m/sec²). This fact suggested that SEP readings could be used as a pre-index to injurious acceleration levels.

Mawn, S. V., J. J. Lambert, and J. L. Catyb. "The Relationship Between Head and Neck Anthropometry and Kinematic Response During Impact Acceleration." *Aviation, Space, and Environmental Medicine* 63, no. 1 (January 1992): 32-36.

To investigate the relation between head and neck anthropometry of individuals and linear acceleration of the head, tests involving fifteen human volunteer subjects were selected. Anthropometric variables, principally different combinations of neck length and circumference, were reviewed across runs with identical sled and vector acceleration profiles. The authors found that longer, thin necks generally allowed for a greater peak linear acceleration level along the X axis than short, broader necks. Similar findings were observed in regard to the Z axis where short, stocky necks correlated to lower peak acceleration levels. The correlation of neck stockiness to reduced peak acceleration was not as pronounced in the Y axis. The authors also touch on the effects of head mass ratio on dynamic response. In $-G_x$ run data examined, it was found that smaller head mass translated to greater downward acceleration of the head.

Morrison, T. R., S. C. Webb, and R. M. Wildzunas. "The Effects of Fatigue on 41-Ft Utility Boat Crewmembers." NBDL-90R012, Naval Biodynamics Laboratory, New Orleans, May 1991.

This report contains findings from study of the effects of fatigue on twenty U.S. Coast Guard crew members of a 41-foot utility boat. Following baseline testing, four-man crews were seated in the below deck cabin every two hours during sixteen-hour simulated missions in both calm and rough seas. During the testing period, a number of performance tests were administered including tracking, four-choice reaction, addition, memory and search, and manual assembly tasks. Subjective mood and motion sickness questionnaires were also completed. Subsequent analysis of the collected data showed that fatigue and motion associated with the below deck cabin environment increased the average amount of time that it took individuals to complete tasks. Increases in motion sickness severity were also observed over time and in rough seas. Overall, the findings supported the USCG policy to limit cumulative crew underway time during a twenty-four-hour period to ten hours for 0-4 foot seas and eight hours for 4-8 foot seas.

Morrison, T. R., T. G. Dobie, G. C. Willems, S. C. Webb, and J. L. Endler. "Ship Roll Stabilization and Human Performance." NBDL-90R007, Naval Biodynamics Laboratory, New Orleans, January 1991.

The purpose of this study was to assess possible performance enhancements due to roll stabilization. Psychomotor performance was assessed under no motion, roll stabilized, and non-roll stabilized motion conditions in the NBDL ship motion simulator using twelve human research volunteers. For comparison, real world at sea motion conditions were recorded aboard an FFG-7 class frigate outfitted with five roll stabilizers. Using performance tests and questionnaires, it was found that subject performance was not affected by roll stabilized motion compared to non-roll stabilized motion. Subjects accurately judged the non-roll stabilized motion condition to be greater than the roll stabilized condition but reported no differences in motion sickness caused by the two conditions.

Mugnier, Clifford J. "Assessment and Evaluation of the Naval Biodynamics Laboratory X-Ray Anthropometry System." NBDL-93R006, Naval Biodynamics Laboratory, New Orleans, December 1993.

This report appraises the accuracy and functionality of the x-ray anthropometry system used by NBDL and provides recommendations for potential improvements. With software composed primarily of a series of FORTRAN programs that were developed gradually over the years, the assessment praised the implementation of a number of complex analytical photogrammetry packages and subsystems to provide a reliable computational mechanism with the capability to compute the geometric values with precision. Recommendations included adding extra BB's to x-ray plate carriers to enhance the ability to compensate for any film shrinkage that might result from high development temperatures. In addition, Mugnier also suggested that NBDL purchase and utilize a Back-Lit X-Y digitizer for all x-ray anthropometric applications with an accuracy of ±0.001 inches. This equipment would allow NBDL to digitize the x-rays themselves rather than paper tracings produced with a plotter.

Muzzy, W. H. III. "Ship Motion Generator Upgrade Study." NBDL-83R012, Naval Biodynamics Laboratory, New Orleans, 1983.

This study describes modifications made to the ship motion generator after it was moved from Human Factors Research, Inc. in Santa Barbara, CA, and reinstalled at NBDL. A new heave drive piston and casing was installed that reduced system whip and decreased buffer deceleration from 6.5 G to 2 G. The piston still allowed the motion generator to maintain its original head stroke displacement of ±11 feet and retain the 17 ft/sec maximum velocity with a 2:1 safety factor. The ship motion generator tower was also increased by nine feet. In addition to discussion of upgrades, this source is also valuable because it provides a technical discussion of the device's design and capabilities.

Muzzy, W. H. III, and L. S. Lustick. "Comparison of Kinematic Parameters Between Hybrid II Head and Neck System with Human Volunteers for $-G_x$ Acceleration Profiles." In *Proceedings of the Twentieth Stapp Car Crash Conference*, 43-74. Warrendale, PA: Society of Automotive Engineers, 1976.

This paper addresses the results of a study to assess the biofidelity of the Hybrid II head and neck system by comparison to data derived from $-G_x$ impact exposures with living human volunteers at 6, 10, and 15 G. The authors found substantial differences in dynamic response output between the Hybrid II and the human volunteers. The most evident difference observed was a large negative angular acceleration spike that occurs in the dummy but is significantly attenuated in human volunteers. This spike resulted in a much smaller peak head angle value in the Hybrid II. In 6 G runs the Hybrid II registered higher peak horizontal acceleration values at T1 than found in human volunteers. This problem diminished at higher G levels, which the authors attributed to the stiff chest of the Hybrid II closely replicating human chest characteristics at high rates of onset.

Muzzy, W. H. III, and A. M. Prell. "Targets for Three-Dimensional (3-D) Tracking of Human Impact Test Subjects." *Proceedings of the International Society for Optical Engineering* 291 (1981): 106-9.

This paper discusses the photo-targets developed and utilized at NBDL. Key points focus on the purpose, construction, and location of the targets. As the authors explain, the targets had to be capable of being tracked during an experiment by at least two cameras to obtain three-dimensional displacement and orientation information. Since the photo-targets were tracked and digitized by a computerized system, attention had to be paid to select a pattern and paint scheme that would maximize recognition and minimize crossover confusion.

Muzzy, W. H. III, A. M. Prell, and P. B. Shimp. "Camera and Site Calibration for Three Dimensional (3D) Target Acquisition." *Proceedings of the International Society for Optical Engineering* 291 (1981): 161-69.

This paper describes procedures and equipment used for camera calibration, discusses problems, and compares surveying methods utilized over the years at NBDL to locate and determine camera orientation. Three camera site/orientation methods of calibration (optical rectangle, the nineball method, and the theodolite method) are compared in view of their advantages and disadvantages. This paper serves as a primary resource documenting the evolution of NBDL's cinematography system over a number of years.

Muzzy, W. H. III, M. R. Seemann, G. C. Willems, L. S. Lustick, and A. C. Bittner, Jr. "The Effects of Mass Distribution Parameters on Head/Neck Dynamic Response." In *Proceedings of the Thirtieth Stapp Car Crash Conference*, 167-83. Warrendale, PA: Society of Automotive Engineers, 1986.

This paper discusses results from experiments to investigate the effect of mass distribution variations on the dynamic response of the head and neck. Kinematic responses were measured on human volunteer subjects in three conditions: no mass addition; with a helmet equipped with weights; and with the helmet and added weights symmetrically located with response to the mid-sagittal plane of the head. The total mass addition to the head with the weights was roughly 30 percent. Analysis revealed that mass distribution changes resulted in increased head angular travel, as well as increased torques and forces upon the neck.

Muzzy, W. H. III, and A. M. Prell. "Photo Reference Target Array Scheme." NBDL-89R004, Naval Biodynamics Laboratory, New Orleans, May 1989.

This is a technical note published to document the numbering and pattern conventions used by NBDL for reference photo-target arrays. The reference photo-target location and orientation was used to identify displacement within a given coordinate system. One- to five-sided photo-targets were employed depending on the specific application and placement. Photo-targets were colored in checkered black-and-white patterns. Theodolites were used to locate the position of each target corner, which provided for calculation of each target's center even when the full target surface was not entirely visible. The technical note also includes discussion of designation of photo-target sides, corners, and centers.

Myklebust, J. B., T. A. Sances, Jr., D. J. Maiman, F. Pintar, M. Chilbert, W. Rauschning, S. J. Larson, J. F. Cusick, C. L. Ewing, and D. J. Thomas. "Experimental Spinal Trauma Studies in the Human and Monkey Cadaver." In *Proceedings of the Twenty-Seventh Stapp Car Crash Conference*, 149-60. Warrendale, PA: Society of Automotive Engineers, 1983.

This paper reports on findings from comparative evaluation of the thoracolumbar region of human cadaver and monkey spines. Compression studies were conducted on the ligamentous thoracolumbar spines of fresh human male cadavers by applying force to the posterior upper thoracic area of the spine. Since thoracolumbar flexion injury routinely involves ligament failure and vertebral body wedge compression fractures, studies were conducted on single vertebral bodies and isolated ligaments. For comparison, similar experiments were conducted in isolated monkey ligaments. The authors found that the intact and ligamentous thoracolumbar spines failed predominantly in the region of the thoracolumbar junction at forces from 1,113-5,110 N. For both the human and monkey cadavers, the anterior longitudinal ligament proved the strongest. Notably, the human ligaments were two to five times stronger than those of the monkey.

Ommaya, Ayub K., Arthur E. Hirsch, and John L. Martinez. "The Role of Whiplash in Cerebral Concussion." In *Proceedings of the Tenth Stapp Car Crash Conference*, 314-24. Alamogordo, NM: Society of Automotive Engineers, 1967.

This paper draws a correlation between potential injury mechanisms associated with whiplash and cerebral concussion resulting from indirect impact. Building upon the earlier work of R. L. Friede, the authors present research from impact experiments with rhesus macaques that show that use of a neck collar designed to restrict the flexion of the head and neck during impact raises the threshold for experimental cerebral concussion. From additional impact exposures, the authors also noticed that experimentally induced whiplash (without direct impact) can produce disruptions in neural response to external stimuli. The article suggests that multiple injury mechanisms, including rotational acceleration of the head, neck hyperextension/flexion, and intracranial pressure gradients, all contribute to cerebral concussion incidence.

Ommaya, A. K., and P. Corrao. "Pathologic Biomechanics of Central-Nervous-System Injury in Head Impact and Whiplash Trauma." In *Proceedings of the International Conference on Accident Pathology*, edited by K. M. Brinkhous. Washington, D.C.: U.S. Government Printing Office, 1970.

This article provides an extensive literature review and theoretical discussion behind the pathology of neurophysiological injuries associated with indirect head impact. A detailed discussion is included of the criteria for cerebral concussion and whiplash-related trauma. Importantly, the article contains comments from F. J. Unterharnscheidt which articulate his thoughts that translational and rotational acceleration can be traced to specific lesion patterns and that further histological studies should be conducted to link lesions characteristics to the axis of impact.

Ommaya, A. K., and T. A. Gennarelli. "Cerebral Concussion and Traumatic Unconsciousness: Correlations of Experimental and Clinical Observations on Blunt Head Injuries." *Brain* 97 (1974): 633-54.

In this article the authors present a new hypothesis to help explain cerebral concussion based on observations from a series of experiments with squirrel monkeys and rhesus macaques. The hypothesis is that a graded set of clinical syndromes following head injury (based on the severity of disruptions in consciousness) are caused by mechanically induced strains affecting the brain in a centripetal sequence of disruptive effect on function and structure. The effects of this sequence always begin at the surfaces of the brain in mild cases and extend inwards to affect the diencephalic-mesencephalic core at the most severe levels of trauma. Importantly, the authors argue that rotational acceleration produces a graded centripetal progression of diffuse cortical-subcortical disconnection phenomena, while translational acceleration is only significant in causing focal injuries. This article is important for two reasons. First, it served as a major contribution to the body of literature regarding the pathomorphology of head injuries from impact acceleration, which Unterharnscheidt engaged with in his work at NBDL. Second, the article provides insight into the research of Thomas Gennarelli prior to his subsequent collaboration with researchers from NBDL.

Patrick, L. M., D. J. Von Kirk, and G. W. Nyquist. "Vehicle Accelerator Crash Simulator." In *Proceedings of the Twelfth Stapp Car Crash Conference*, 402-23. New York: Society of Automotive Engineers, 1968.

This article provides a description of the second Wayne State University Horizontal Accelerator Mechanism (WHAM II). Accelerations and decelerations up to 60 G, velocities up to 60 mph, rates of onset of 200-2,000 g/sec, acceleration differences up to 10 feet, and deceleration distances up to 6 feet were attainable on the WHAM II. Importantly, the article also provides a detailed discussion of the device's built-in safety features. This linear accelerator was used in the joint Army-Navy project at Wayne State University headed by Channing Ewing.

Pittman, M., and C. Mugnier, GPA Associates. "Photogrammetric Tasks for +Z Vertical Added Mass Experiments." NBDL-93R005, Naval Biodynamics Laboratory, New Orleans, December 1993.

This report provides an evaluation of the x-ray anthropometry system at NBDL. A new method is proposed to analyze the x-rays using a powerful photogrammetric technique and a new Altek digitizing tablet. The anthropometry system pre-processing program (PREP) was rewritten to accommodate input from the new tablet. Evaluation of x-ray procedures and quality led the authors to recommend that a Lucite posing chair be constructed for human research volunteers to be strapped into for x-ray. This chair could be rotated to accommodate different x-ray position exposures and eliminate errors sometimes caused by the motion of moving the volunteer freely.

Pollack, J. G. "Motion Comparison Between a SWATH and a Monohull." NBDL-85R001, Naval Biodynamics Laboratory, New Orleans, February 1985.

This report contains findings from a comparative study of the seakeeping capabilities of a 64-foot SWATH and a 65-foot monohull carried out by NBDL personnel over a two-day period at the mouth of the Columbia River, in Astoria, Oregon. The trials measured the hull motions of both vessels during approximately identical sea conditions. The sea conditions were selected that were similar to the maximum in which the vessels would normally be expected to conduct hydrographic surveying missions. Measurements of pitch, roll, and vertical and transverse acceleration of the hydrographic crew's work station were collected on each vessel. The trials indicated that the SWATH hull provided a significantly more stable platform for conducting hydrographic surveying missions from a human factors perspective. Compared to the counterparts on the monohull, SWATH crew members exhibited a lower incidence of motion sickness and better performance response time.

Saltzberg, B., W. D. Burton, Jr., N. R. Burch, C. L. Ewing, D. J. Thomas, M. S. Weiss, M. D. Berger, T. A. Sances, Jr., P. R. Walsh, J. B. Myklebust, S. J. Larson, and M. E. Jessop, Jr. "Evoked Potential Studies of Central Nervous System Injury Due to Impact Acceleration." *AGARD Conference Proceedings No. 322 - Impact Injury Caused by Linear Acceleration: Mechanisms, Prevention and Cost* 16: 1-11. London: Technical Editing and Reproduction, October 1982.

This paper discusses measurements of afferent neural transmission in the rhesus macaque based on latency and amplitude variations in somatosensory evoked potential readings taken during impact acceleration exposures carried out at NBDL. The experiments exposed four macaques to lateral (G_y) impacts at 10, 30, 70, and 90 G. Only data from the 30, 70, and 90 G runs are presented in this paper because the 10 G runs did not register any significant post-impact SEP changes. The authors found that the collected data showed that neural activity from the spinal cord to the sensory-motor cortex was not only subject to severe alteration at high acceleration levels, but the alterations were more pronounced along the right pathway than the left pathway.

Saltzberg, B., W. D. Burton, Jr., M. S. Weiss, M. D. Berger, C. L. Ewing, D. J. Thomas, M. E. Jessop, Jr., T. A. Sances, Jr., S. J. Larson, P. R. Walsh, and J. B. Myklebust. "Dynamic Tracking on Evoked Potential Changes in Studies of Central Nervous System Injury Due to Impact Acceleration." In *Impact Injury of the Head and Spine*, edited by C. L. Ewing, D. J. Thomas, T. A. Sances, Jr., and S. J. Larson, 310-23. Springfield, Ill.: Charles C. Thomas, 1983.

This chapter reports on findings from analysis of somatosensory evoked potential measurements recorded from rhesus macaques during $-G_x$ impact acceleration exposures at NBDL. The authors found that brief transient latency disruptions occurred during impact runs at 80 and 100 G. Amplitude data, however, was not found to be reliable enough to correlate it with impact acceleration levels. Beyond the reported findings, this chapter serves as an important source of information on the experimental methodology developed by NBDL and the Medical College of Wisconsin for use in impact acceleration run monitoring. Particularly useful sections contain discussion of programs used to analyze averaged evoked potential data.

Sances, A., Jr., D. J. Thomas, C. L. Ewing, S. J. Larson, and F. J. Unterharnscheidt. *Mechanisms of the Head and Spine*. Goshen, NY: Aloray Publishers, 1986.

This twenty-four-chapter edited volume put together by researchers from NBDL and the Medical College of Wisconsin builds upon the work published in a similar type of volume three years earlier. This volume contains works addressing properties of the head and spine, biomechanical and injury tolerance, neurophysiology, and mathematical modeling. The collection of essays is one of NBDL's major contributions to the field of biodynamics research and a key reference work.

Sances, T. A., Jr., R. Weber, J. B. Myklebust, J. F. Cusick, S. J. Larson, P. R. Walsh, T. Christoffel, C. Houterman, C. L. Ewing, D. J. Thomas, and B. Saltzberg. "The Evoked Potential: An Experimental Method for Biomechanical Analysis of Brain and Spinal Injury." In *Proceedings of the Twenty-Fourth Stapp Car Crash Conference*, 63-100. Warrendale, PA: Society of Automotive Engineers, 1980.

This study reports on experiments with rhesus macaques carried out in collaboration between the Medical College of Wisconsin and NBDL. In these experiments, axial forces were applied between the shoulders and the skull of eight male rhesus macaques. Forces ranging from 556-1,444 N produced noticeable changes in blood pressure, heart rate, and flexion of the cervical spinal column. Somatosensory evoked potentials (SEPs) were recorded at the cortical and thalamic areas of the cerebrum. Following dorsal column or peripheral nerve stimulation, alterations in the SEP readings were observed before or during changes in heart rate or blood pressure. Similar findings were observed in the efferent responses recorded from electrodes placed on the thoracic spinal cord following stimulation of the sensorimotor cortex.

Sances, T. A., Jr., J. B. Myklebust, J. F. Cusick, R. Weber, C. Houterman, S. J. Larson, P. R. Walsh, M. Chilbert, T. Prieto, B. Saltzberg, M. Zyvolski, D. J. Thomas, and C. L. Ewing. "Experimental Studies of Brain and Neck Injury." In *Proceedings of the Twenty-Fifth Stapp Car Crash Conference*, 149-94. Warrendale, PA: Society of Automotive Engineers, 1981.

In this study, static and dynamic axial tension loads were applied to the intact and isolated cervical column of the monkey and human cadaver. Radioactive microspheres were used to evaluate brain and spinal cord perfusion in the monkey. To determine neural pathway damage, somatosensory evoked potentials were recorded with simulation of the spinal cord, in spinal cord with stimulation of sensorimotor cortex, and in spinal cord with stimulation of cauda equine. The evoked potential amplitude decreased prior to heart rate and blood pressure changes, presumably due to brainstem distention. The preliminary studies show: (1) the brain and spinal cord were well perfused as measured with the microspheres when the evoked potentials decreased, (2) the cervical isolated cadaveric monkey spinal column ligaments failed statically at approximately one-half to one-third the force required for dynamic disruption, (3) in the intact monkey, the cervical ligaments failed statically at approximately one-half the dynamic failure force, and (4) the isolated human cervical ligaments failed at loads approximately three times those observed in the isolated monkey cervical column.

Sances, T. A., Jr., J. B. Myklebust, C. Houterman, R. Weber, J. Lepkowski, J. F. Cusick, S. J. Larson, C. L. Ewing, D. J. Thomas, M. S. Weiss, M. D. Berger, M. E. Jessop, Jr., and B. Saltzberg. "Head and Spine Injuries." *AGARD Conference Proceedings No. 322 - Impact Injury Caused by Linear Acceleration: Mechanisms, Prevention and Cost* 13: 134. London: Technical Editing and Reproduction Ltd., 1982.

Neurophysiologic and biomechanical methods were used to evaluate axial tension applied to the cervical spinal cord and brain during impact or inertial loading. Because axial forces are often implicated in military accidents, these studies were designed to evaluate physiologic changes in the brain and spinal cord with cervical axial tension applied to the rhesus (Macaca mulatta) monkey. Both slowly applied (0.1 to 1 cm/s) and rapidly applied loads (greater than 100 cm/s) were studied in the isolated fresh cadaveric cervical column of the monkey and in the intact living and dead monkey. Similar investigations were conducted on fresh human cadaveric skulls and cervical spinal columns and in the fresh human cadaveric torso. Both axial tension and compression were applied to the human preparations. Thoraco-lumbar sections were also tested for failure in compression. Helmet studies were conducted to determine the effects with axial loading. A mathematical model was developed using a lumped parameter torso, head, and helmet capable of simulating displacement and time dependent applied loads. The model was compared with photographically studied football injuries for validation.

Sances, T. A., Jr., J. B. Myklebust, D. Kostreva, J. F. Cusick, R. Weber, C. Houterman, S. J. Larson, D. J. Maiman, P. R. Walsh, M. Chilbert, F. J. Unterharnscheidt, C. L. Ewing, D. J. Thomas, K. Seigesmund, K. Ho, and B. Saltzberg. "Pathophysiology of Cervical Injuries." In *Proceedings of the Twenty-Sixth Stapp Car Crash Conference*, 41-70. Warrendale, PA: Society of Automotive Engineers, 1982.

Male rhesus macaques were studied with slow application of axial forces to the vertebral column with forces that produced an approximate 50 percent reduction in the afferent or efferent evoked potential amplitude. Autoradiographic studies with ^{14}C deoxyglucose demonstrated a marked reduction in metabolic activity at the cervical-medullary junction and cervical spinal column, while other levels of the spinal column were essentially normal. Examination of the neural tissue with light microscopy was unremarkable. However, in a seven-day survival macaque, damage was observed in the central gray nervous tissue at the cervical level. Electron microscopy studies with similar force application demonstrated shrinkage of the axoplasm and disruption of the myelin lamellae in the upper and lower cervical region, while brain and thoracic spinal cord tissues were minimally altered. These preliminary findings suggest that the greatest effects occur in the cervical regions with axial distension and that ^{14}C deoxyglucose and electron microscopy may be valuable for the evaluation of early physiologic alterations following biomechanical trauma to the brain and spinal column.

Schmidt, Allison L., Alexandra E. Austermann, Kimberly B. Vasquez, Barry S. Shender, and Valeta Carol Chancey. "Establishing the Biodynamics Data Resource (BDR): Human Volunteer Impact Acceleration Research Data in the BDR." USAARL Report No. 2010-1, Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory, 2010.

This report provides a general overview of the history and objectives of NBDL, as well as a thorough profile of the data collected from human impact exposures at the lab. Particular focus is given to the experimental methodology, equipment, processing, and physical disposition of the data. The report also discusses the establishment of the Biodynamics Data Resource and the ongoing effort to make data from NBDL available to modern researchers.

Schneider, L. W., B. M. Bowman, R. E. Snyder, and L. S. Peck. "A Prediction of Response of the Head and Neck of the U.S. Adult Military Population to Dynamic Impact Acceleration from Selected Dynamic Test Subjects." UM-HSRI-76-10, Highway Safety Research Institute, University of Michigan, Ann Arbor, MI, 1976.

This study reports on research carried out to try to determine the extent to which data on the dynamic response of young military enlisted men recorded by NBDL may be representative for the head-neck characteristics of the broader general adult population (from eighteen to seventy-five years of age) of the United States. In order to compare responses, the authors created a two-dimensional simulation model using the NBDL dataset of human runs from 6 to 15 G. Subsequently, simulations for eighteen- to twenty-four-year-old females at 6 G and 15 G were made using data obtained from the Highway Safety Research Institute (HSRI). Comparison of the results from the NBDL male data and the HSRI female data showed substantial congruence. The main difference was that the females showed an increase in the maximum flexion angle of the head by approximately 40 and 25 percent at 6 G and 15 G, respectively.

Schulman, Marvin, George T. Critz, Francis M. Highly, and Edwin Hendler. "Determination of Human Tolerance to Negative Impact Acceleration." NAEC-ACEL-510, Naval Air Engineering Center, Aerospace Crew Equipment Laboratory, Philadelphia, PA, 1963.

This report presents results from a research effort carried out at the Air Crew Equipment Laboratory to study human tolerance to short-duration $-G_z$ acceleration in conjunction with NASA's Apollo project. Five human volunteers, placed in the supine position on a linear accelerator, served as test subjects. Measurements were obtained from sled-mounted accelerometers and high-speed camera coverage. Subjects reached acceleration exposures up to 14.5 G with a velocity change of 20.6 ft/sec but stopped before ever reaching a tolerance limit. This study served as an important point of reference for subsequent research at NBDL, particularly in regard to simulation of G_z motion by positioning subjects in the supine position on a horizontal accelerator.

Seales, D. M., A. C. Bittner, Jr., M. S. Weiss, and S. N. Morrill. "Short-Latency" Somatosensory Evoked Potentials During Experimentally Induced Biodynamic Stress in Humans." NBDL-85R002, Naval Biodynamics Laboratory, New Orleans, December 1985.

In this study, averaged somatosensory evoked potentials (SEPs) were used to monitor the structural and functional integrity of human nervous system pathways before and after experimentally controlled exposures to impact acceleration. SEPs were obtained from five human research volunteers using recording electrodes placed on the scalp and neck and over Erb's point. The median nerve of the left arm was stimulated percutaneously at the wrist with 5 (0.2 millisecond duration) rectangular pulses per second. Telemetered electrophysiological data was stored on magnetic tape and subsequently analyzed. Results from impact acceleration exposures up to 150 m/sec² revealed no clinically significant disruptions of central nervous system function.

Seemann, M. R. "Error in CALSPAN® 3-Dimensional Crash Vehicle Simulation Computer Program for the Case of Massless Segments." NBDL-83R013, Naval Biodynamics Laboratory, New Orleans, December 1983.

This report describes significant errors that NBDL personnel found in the "3-Dimensional Crash Vehicle Simulation" computer program designed by Calspan. The errors resulted in situations where the biodynamic response of particular anatomical segments was simulated without inclusion of information on the mass of the segment. NBDL published this report to detail the significance of the errors and to make other users aware of the program's problems.

———. "Implementation of the Marjorization Program for Computing Optimum Combined Kinematic Variables on the HP9000/835." NBDL-95R002, Naval Biodynamics Laboratory, New Orleans, April 1995.

This report describes the operating procedures for the "Marjorization" computer program designed by Marjorie Seemann at NBDL for use with the Hewlett Packard Model 9000/835 computer. The algorithmic program was developed to determine the most likely corrections to accelerometer direction cosines and sensitivities and to initial Euler angles. In the event that errors existed, these corrections would be required to bring accelerometer-derived data into agreement with corresponding photographic data. The key underlying assumption on which the Marjorization program was situated was that photographic data derived from NBDL's EZFLOW data analysis system was the best source for displacement variables, while accelerometer-derived data was the best source for acceleration variables.

Seemann, M. R., and L. S. Lustick. "Combination of Accelerometer and Photographically Derived Kinematic Variables Defining Three-Dimensional Rigid Body Motion." *Proceedings of the International Society for Optical Engineering* 291 (1981): 133-40.

This paper describes procedures developed by NBDL to measure the dynamic response of critical segments of the human anatomy to acceleration. A configuration of accelerometers and photographic targets were mounted on a T-plate that was fixed to the anatomical segment to be measured. The kinematic variables defining the linear displacement and angular orientation of the rigid body were derived independently from the accelerometer and photographic measurements. The procedure for combining the results from both sets of measurements into one consistent set of derived variables from acceleration to displacement was applicable to non-contiguous photo-derived variables. The method was ideal because it utilized the high frequency resolution capabilities of the accelerometer system while also limiting low frequency errors.

Seemann, M. R., L. S. Lustick, and G. D. Frisch. "Mechanisms of Control of Head and Neck Dynamic Response." In *Proceedings of the Twenty-Eighth Stapp Car Crash Conference*, 207-22. Warrendale, PA: Society of Automotive Engineers, 1984.

This paper reports on the observation that human volunteers participating in impact acceleration tests at NBDL could, and did, learn to control the severity of their exposures by bracing their head-neck joints in anticipation of sled firing. The authors found that volunteers who had previously participated in $+G_y$ and/or G_{-X+Y} runs exhibited atypical dynamic responses in a subsequent series of $-G_x$ runs. After checking to ensure that this was not a widespread problem in previously collected data from the lab, NBDL used this information to develop a procedure so that volunteers would have a more difficult time familiarizing themselves with the timing of sled firing.

Seemann, M. R., W. H. Muzzy III, and L. S. Lustick. "Comparison of Human and Hybrid III Head and Neck Dynamic Response." In *Proceedings of the Thirtieth Stapp Car Crash Conference*, 291-311. Warrendale, PA: Society of Automotive Engineers, 1986.

This paper presents findings from assessment of the biofidelity of the Hybrid III head-neck system through comparison to data from living human volunteers. Importantly, the authors found the Hybrid III neck to be too stiff to replicate the biodynamic response of living humans to $-G_x$ and $+G_z$ impact. On the other hand, the authors also admitted finding remarkably unexpected similarities in the human and Hybrid III head-neck response to $+G_y$ and G_{-X+Y} impact. They also noted that the Hybrid III linkage model developed by General Motors, when modified slightly, worked reasonably well to simulate dynamic response of the Hybrid III head-neck to $-G_x$ 10 and 15 G accelerations. A recommended next step was to extend the Hybrid III math model to vector directions other than $-G_x$.

Smith, D. E., and W. R. Anderson. "Predictive Model of Dynamic Response of the Human Head/Neck System to $-G_x$ Impact Acceleration." *Aviation, Space, and Environmental Medicine* 49, no. 1, sect. II (January 1978): 224-33.

This article discusses a preliminary mathematical model developed based on motion present at T_1 to predict human head response to impact. Data for the model was taken from six human volunteer runs at NBDL. The model was then evaluated against the responses of other volunteers under identical impact conditions. Overall, the model performed well but only took into account the motion at T_1.

Snyder, R. G. "Human Impact Tolerance – State of the Art." SAE Paper No. 700398, Society of Automotive Engineers, 1970.

This review of impact research discusses research problems that remained largely unaddressed around the time of NBDL's founding. Tolerance limits for sections of the population outside of young, healthy males remained largely unstudied. Little was known about human response in off-axis and lateral impact vectors. Furthermore, studies of human tolerance were often narrowly focused, ignoring the fact that the human body operates as a whole rather than in distinct segments. The problems identified here are a major part of the body of research conducted subsequently by NBDL.

Snyder, R. G., C. C. Snow, J. W. Young, W. M. Crosby, and G. T. Price. "Pathology of Trauma Attributed to Restraint Systems in Crash Impacts." *Aerospace Medicine* 39, no. 8 (1968): 812–29.

This study assesses different types of injuries associated with the lap belt, three-point harness, single-diagonal belt, double-torso harness, an experimental double-torso inverted-Y yoke with inertia reel, and an airbag restraint system. Sixty experiments were conducted for this purpose by the Civil Aeromedical Institute, using baboons on the Daisy Decelerator at Holloman Air Force Base. Results from histologic post-run evaluations are presented, with particular attention paid to the distinctive trauma patterns caused by specific restraint systems. This research effort served as an important point of reference for subsequent research carried out at NBDL.

Sonntag, R. W., Jr., W. A. Newsom, S. D. Leverett, Jr., and V. E. Kirkland. "Use of Contoured Restraint Systems in Exposure of Large Primates to –150 G_x Impact." In *Proceedings of the Twelfth Stapp Car Crash Conference*, 201-6. New York: Society of Automotive Engineers, 1968.

This paper reports findings from exposures of adult anesthetized chimpanzees on a linear accelerator. Seated chimpanzees were restrained using straps and a contoured Ensolite mold to support the neck, torso, and arms. Unlike the runs conducted by Stapp and, later, by NBDL, for each run a strap was used to hold the head of the chimpanzee firmly against a cushion. With the head and body restrained, two chimpanzees survived exposures to $-G_x$ impacts of 150 G with only minor injuries. This research demonstrated the enormous protective potential of restraints.

Stapp, John P. "Human Tolerance to Deceleration – Summary of 166 Runs." *Journal of Aviation Medicine* 22, no. 1 (February 1951): 42-45, 85.

This article presents early findings from exposures of human volunteer subjects to high-G level sudden decelerations. In a series of $-G_x$ runs, human volunteers were exposed to impacts between 10 and 35 G with durations ranging from .42 through .11 seconds. The maximum exposure reportedly reached 35.4 G with a duration of .16 seconds and a rate of onset at 1,200 G per/sec. Importantly, none of the runs resulted in any noticeably irreversible or persistent injuries. The implication of the research was that the limit of human tolerance to impact had been significantly underestimated.

———. "Historical Review of Impact Injury and Protection Research." In *Impact Injury of the Head and Spine*, edited by C. L. Ewing, D. J. Thomas, A. Sances, Jr., and S. J. Larson, 540. Springfield, Ill.: Charles C. Thomas, 1983.

This expansive review focuses on the origins and growth of scientific research on the effects of mechanical force on living tissue carried out in German, American, and British laboratories dating back to the 1920s. Diverse and interrelated projects focused on the biomechanics of blast, internal hydraulic pressure, impact, vibration, and head-neck injury pathology and modeling are profiled. As the first chapter in a volume edited by NBDL staff members, it serves as an exemplary introduction to the field at large.

Tabler, R. E. "Nicolet Med-804® Programs in the Naval Biodynamics Laboratory Evoked Potential Series." Research Report No. NBDL-84R007, Naval Biodynamics Laboratory, New Orleans, August 1984.

This report provides a complete description of five computer programs developed and used at NBDL to record, analyze, and plot somatosensory evoked potential data with a NicoletMed-804® model computer. Appendices include instructions for wiring the Med-804®, as well as flowcharts and printouts for all five programs.

Thomas, D. J. "Specialized Anthropometry Requirements for Protective Equipment Evaluation." *AGARD Conference No. 110 on Current Status in Aerospace Medicine*, edited by Walton L. Jones, C9: 1-8. London: Technical Editing and Reproduction Ltd., February 1973.

This paper describes a means to provide improvements in protective equipment through utilization of anthropometric measurements. Thomas notes that anthropometric data required to support equipment evaluation can be divided into three major categories: population descriptors, three-dimensional anatomical descriptors, and mass distribution parameters. All three categories are defined and described. Importantly, Thomas describes the standardized three-dimensional anatomical coordinate system for observations on the human head, as developed by the Naval Aerospace Medical Research Laboratory, Detachment (NAMRL-D) as a useful measure. The coordinate system, Thomas explains, had been used to determine mass distribution parameters of the head and neck through an Office of Naval Research contract with Tulane University.

Thomas, D. J., and C. L. Ewing. "Theoretical Mechanics for Expressing Impact Acceleration Response of Human Beings." *AGARD Conference Proceedings No. 88 on Linear Acceleration of Impact Type* 12: 1-7. London: Technical Editing and Reproduction Ltd., 1971.

This paper presents the theoretical requirements for expressing the kinematics of human impact acceleration experimentation, as devised by Ewing and Thomas. Two basic coordinate systems necessary for expression of the kinematic information are identified as: 1) the body reference frame, defined in terms of the experimental subject's anatomy; and 2) the laboratory reference frame, selected by the experimenter as required for each experiment. A general set of rules for deriving these coordinate systems is described, and necessary variables and parameters are defined in terms of the general set of rules.

Thomas, D. J., D. H. Robbins, R. H. Eppinger, A. I. King, and R. P. Hubbard. "Guidelines for the Comparison of Human Analogue Biomechanical Data: Report of the Guidelines Subcommittee." *Second Annual International Workshop on Human Subjects for Biomechanical Research: Committee Reports and Technical Session Papers*, 21-38. Ann Arbor: Ad Hoc Committee, 1974.

This paper contains guidelines drafted by the Ad Hoc Committee on Guidelines for the Comparison of Human and Human Analogue Biomechanical Data. A number of NBDL's innovations were added to the guidelines list for distribution to other biomechanics research institutions. The guidelines were: (1) use of a right-handed coordinate system; (2) establishment of a laboratory-fixed coordinate system; (3) use of an anatomically based subject coordinate system [preferably with application across species]; and (4) specification of the initial conditions for all four coordinate systems [laboratory, fixture, anatomical, and instrumentation]. The goal of these suggestions was to make it more possible to compare data collected at multiple different laboratories.

Thomas, D. J., D. H. Robbins, R. H. Eppinger, A. King, R. P. Hubbard, and H. M. Reynolds. "Guidelines for the Comparison of Human Analogue Biomechanical Data." *Third Annual International Workshop on Human Subjects for Biomechanical Research: Committee Reports and Technical Discussions*, 17-26. San Diego, CA: Ad Hoc Committee, 1975.

This paper contains guidelines drafted by the Ad Hoc Committee on Guidelines for the Comparison of Human and Human Analogue Biomechanical Data. A number of NBDL's innovations were added to the guidelines list for distribution to other biomechanics research institutions. Building upon the guidelines issued the previous year, the committee recommended a sixth guideline: establishment of a standard anatomical reference position to help define anatomical coordinate systems consistently. Accordingly, the committee advocated use of a pelvic anatomical coordinate system, as devised and implemented at NBDL.

Thomas, D. J., P. L. Majewski, J. C. Guignard, and C. L. Ewing. "Effects of Simulated Surface Effect Ship Motions on Crew Habitability – Phase II. Volume 5: Clinical Medical Effects on Volunteers." Technical Report No. 1070-5. Bethesda, MD: Department of the Navy, May 1977.

This report discusses findings from a series of 2,000-ton surface effect ship (SES) motion simulation experiments carried out on the Office of Naval Research-owned ship motion simulator located at Human Factors Research, Inc. in Goleta, California, between July and September 1975. Nineteen human research volunteers participated in the experiments. Test motion environments were selected to simulate conditions encountered by a 2,000-ton SES running at 80 knots in sea state three, 60 knots in sea state four, and 40 knots in sea state five. In pairs, the subjects were to be exposed to each of the three sea state conditions for forty-eight hours. During the simulations, the volunteers performed tasks representative of common shipboard activities. As it turned out, sixteen of the nineteen volunteers aborted during the experiments because of vomiting or severe nausea. The authors reported finding that in all sea state three simulations, the percentage of subjects who experienced vomiting was 22 percent. In sea state four and five simulations, the percentage of subjects who experienced vomiting increased to 62 percent and 73 percent, respectively.

Thomas, D. J., P. L. Majewski, C. L. Ewing, and N. Gilbert. "Medical Qualification Procedures for Hazardous-Duty Aeromedical Research." *AGARD Conference Proceedings No. 231 on Prospective Medicine Opportunities in Aerospace Medicine*, A3: 1-13. London: Technical Editing and Reproduction Ltd., September 1978.

This paper discloses the procedures used to screen and qualify human research volunteers for service at NBDL, carefully profiling the multi-step, multi-disciplinary physical and mental medical evaluation process. The paper notes that from a group of 1,227 prospective volunteers, only 63 were qualified to participate as human research subjects, and of these, only 44 successfully completed their full tours. Detailed discussion of the different categories of volunteers is provided as well as information on specific recruitment efforts. This paper is the primary resource for information on volunteer qualification at NBDL.

Thomas, D. J., C. L. Ewing, P. L. Majewski, and N. S. Gilbert. "Clinical Medical Effects of Head and Neck Response During Biodynamic Stress Experiments." *AGARD Conference Proceedings No. 267 – High-Speed, Low-Level Flight: Aircrew Factors* 15: 1-15. London: Technical Editing and Reproduction Ltd., March 1980.

This paper reports on clinical evaluations of human research volunteers who participated in impact acceleration exposures in the $-G_x$, $+G_y$, and G_{-X+Y} vectors dating back to 1974. Major categories of symptoms resulting from impact exposures were designated as neck pain, headache, restraint-related musculoskeletal conditions, and syncope. The nature of the symptoms was sometimes related to the direction, peak acceleration level, and duration of the impact exposures. At the time, the lab had conducted a total of 1,621 instrumented experiments with sixty-two human volunteers. Symptoms occurred in 655 (40 percent) of these experiments.

Thomas, D. J., and M. E. Jessop, Jr. "Experimental Head and Neck Injury." In *Impact Injury of the Head and Spine*, edited by C. L. Ewing, D. J. Thomas, T. A. Sances, Jr., and S. J. Larson, 177-217. Springfield, Ill.: Charles C. Thomas, 1983.

This chapter contains discussion of fatal head-neck injury mechanisms from $-G_x$ impact acceleration runs with rhesus macaques at NBDL. From post-run autopsies, the authors found atlanto-occipital separation to be the most common injury. Importantly, associated peak sled acceleration threshold for this injury was 110 to 120 G. However, in experiments where the initial position of the head was deviated by 60º or greater, the threshold was much lower. The threshold values and injuries agreed with earlier findings from $-G_x$ runs at Holloman Air Force Base with baboons. This publication is a key reference work because it reports seminal findings and provides a detailed review of the experimental methodology developed and used for testing with non-human primates at NBDL.

Thunnissen, J., J. Wismans, C. L. Ewing, and D. J. Thomas. "Human Volunteer Head-Neck Response in Frontal Flexion: A New Analysis." In *Proceedings of the Thirty-Ninth Stapp Car Crash Conference*, 439-60. Warrendale, PA: Society of Automotive Engineers, 1995.

This paper discusses errors in instrumentation readings collected at T1 in some NBDL data and presents a correction protocol. A detailed analysis of the high-speed films revealed that in some cases the volunteer T1 instrumentation mount was not firmly mounted to the spine. Untoward movement of the T1 mount introduced inaccuracies into the data. In this paper, the authors address this issue by discussing a correction procedure designed to correct the errors in the T1 rotations and to develop a set of new performance requirements that are expressed relative to a rotated T1 coordinate system.

Unterharnscheidt, Friedrich. "Translational Versus Rotational Acceleration: Animal Experiments with Measured Input." In *Proceedings of the Fifteenth Stapp Car Crash Conference*, 767-70. Warrendale, PA: Society of Automotive Engineers, 1971.

This paper addresses the effects of translational and rotational acceleration on the brain in closed head injuries. If impact is directed at the center of mass of a freely movable object, the resulting motion is a translational acceleration. If the impact is directed eccentrically, the result is a combined translational and rotational acceleration. The distinction between the two types of acceleration is important in the view of the different physical processes they initiate in the brain. Importantly, Unterharnscheidt notes that pure translational acceleration creates pressure gradients, while pure rotational acceleration produces shear strains and hemorrhages from rotation of the skull relative to the brain. The key component of Unterharnscheidt's analysis is that different injury mechanisms produce different patterns of lesions.

———. "Neuropathology of Rhesus Monkeys Subjected to $-G_x$ Impact Acceleration." In *Impact Injury of the Head and Spine*, edited by C. L. Ewing, D. J. Thomas, T. A. Sances, Jr., and S. J. Larson, 94-176. Springfield, Ill.: Charles C. Thomas, 1983.

This chapter serves as a thorough discussion of neuropathological findings from $-G_x$ impact acceleration exposures with rhesus macaques at NBDL. Histological observations showed that translational and rotational acceleration each played different and predictable roles in determination of the quality and distribution of injuries. Unterharnscheidt found that fatal injuries from $-G_x$ runs were typified by tissue damage at the atlanto-occipital junction, traumatic transection of the spinal cord, ruptures of vertebral arteries, and concomitant basilar and spinal subarachnoid and subdural hemorrhages. In addition to discussion of findings, the chapter also contains a valuable treatment of Unterharnscheidt's theories and work with Channing Ewing over the years, including discussion of the findings of R. L. Friede and a recommendation that more strenuous autopsy procedures be implemented for naval aviators killed in aircraft accidents.

———. "Pathological and Neuropathological Findings in Rhesus Monkeys Subjected to $-G_x$ and $+G_x$ Indirect Impact Acceleration." In *Mechanisms of Head and Spine Trauma*, edited by A. Sances, Jr., C. L. Ewing, S. J. Larson, and F. J. Unterharnscheidt, 565-653. Goshen, NY: Aloray Publishers, 1986.

This chapter discusses findings from neuropathological examinations of rhesus macaques after exposure to $-G_x$ and $+G_x$ impact acceleration. Comparison of injury patterns resulting from both vectors supports the author's ongoing theory that the acceleration input direction plays a role in producing a different and predictable type of injury. Accordingly, Unterharnscheidt concludes that each mechanical input to the head and neck corresponds to a predictable and typical morphological end state. This source is particularly valuable for its discussion of $+G_x$ injury mechanisms. Based on runs at NBDL, Unterharnscheidt found a threshold for atlanto-occipital separations and traumatic transection of the spinal cord at peak sled accelerations of 140 G in the $+G_x$ vector. This level is roughly 35 to 40 G higher than the injury threshold levels corresponding to $-G_x$ impact acceleration.

Unterharnscheidt, F., and K. Sellier. "Mechanics and Pathomorphology of Closed Brain Injuries." In *Head Injury*, edited by W. F. Caveness and A. Walker, 321-41. Philadelphia: J. B. Lippencott Co., 1966.

This chapter contains discussion of research efforts carried out by the authors since 1957. Attention is given to a number of subjects, including mechanics, measuring techniques, pathomorphology of cortical cavitation trauma, distinction between Duret-Berner's hemorrhages as rhectic and diapedetic hemorrhages, respectively, morphological changes from single and repeated head impacts, and scaling data from animals to humans. This particular chapter is useful because it provides insight into the work of Unterharnscheidt prior to his arrival at NBDL.

Unterharnscheidt, Friedrich, and Lawrence S. Higgins. "Traumatic Lesions of Brain and Spinal Cord Due to Non-Deforming Angular Acceleration of the Head." *Texas Reports on Biology and Medicine* 27, no. 1 (Spring 1969): 127–66.

This article discusses pathological findings from autopsies on twenty-five squirrel monkeys (*Samiri sciureus*) killed in impact acceleration experiments. The experiments were tailored specifically to investigate the role of angular acceleration in head injury and possible link to concussion. A complete micro-anatomical study of the brain and spinal cord regions of each animal was conducted, and the location and attributes of lesions were noted. The authors found subdural and subarachnoid hemorrhages, cortical layer tears, and spinal cord rhectic hemorrhages. Unterharnscheidt observed differences in the quality and distribution of hemorrhages and lesions resulting from angular acceleration when compared to findings from earlier studies on translational acceleration.

Unterharnscheidt, F., and C. L. Ewing. "Potential Relationship Between Human Central Nervous System Injury and Impact Forces Based on Primate Studies." *AGARD Conference Proceedings No. 253: Models and Analogues for the Evaluation of Human Biodynamic Response, Performance and Protection* A18: 1-8. London: Technical Editing and Reproduction Ltd., June 1979.

This paper contains a review of previous work from a number of pathological studies carried out by Unterharnscheidt using a variety of non-human primates and acceleration variables. Particular focus was paid to investigation of the roles that rotational acceleration, translational acceleration, and input vector played in the quality and distribution of injuries. The authors found that each acceleration vector produces different and predictable injury patterns, and that injuries associated with $-G_x$ impact consists of tissue damage at the atlanto-occipital junction and subdural hemorrhages over both cerebral hemispheres.

Walker, Leon B., Edward H. Harris, and Uwe R. Pontius. "Mass Volume, Center of Mass and Mass Moment of Inertia of Head and Neck of the Human Body." In *Proceedings of the Seventeenth Stapp Car Crash Conference*, 524-37. Warrendale, PA: Society for Automotive Engineers, 1973.

This paper reports on a study of the physical properties of twenty preserved human male cadaver heads carried out at the Tulane University Medical Center. Anthropometric values and anatomical landmarks were determined with measurements and x-rays. Using a compound pendulum device, the authors recorded values for the mass, volume, center of mass, and mass moments of inertia of the head-necks. This study was completed under contract with the Navy to assist the research carried out at the Naval Aerospace Medical Research Laboratory, Detachment (NAMRL-D). Channing Ewing and Daniel Thomas are thanked for their contributions and criticism in the acknowledgments. The findings from the Tulane researchers would be built upon and partially validated by the contemporaneous research carried out by Edward Becker. One potential issue with this study that NBDL would later investigate was the extent to which the embalming and preservation process altered the physical properties of the head-necks.

Walsh, P. R., and M. E. Jessop, Jr. "The Evoked Potential in Sled Impact Acceleration: Methodologic and Neurosurgical Considerations." In *Impact Injury of the Head and Spine*, edited by C. L. Ewing, D. J. Thomas, T. A. Sances, Jr., and S. J. Larson, 302-9. Springfield, Ill.: Charles C. Thomas, 1983.

This chapter provides a detailed discussion of the surgical and electrophysiological techniques utilized in somatosensory evoked potential research with rhesus macaques at NBDL. The procedures for cranial "pedestal" and spinal electrode implantation are reported in detail. This particular chapter is valuable because it provides insight into the collaborative effort between veterinarians at NBDL and surgeons at the Medical College of Wisconsin.

Watkins, T. A., and S. J. Guccione, Jr. "A Statistical Approach to Human Kinematics Response to Impact." In *Sixteenth Annual International Workshop on Human Subjects for Biomechanical Research*, 209-25. Warrendale, PA: Society of Automotive Engineers, 1988.

This report focuses on the feasibility of using a statistical approach to scaling and modeling human and rhesus $-G_x$ head kinematic data. Using data from fifty-seven human $-G_x$ runs from 6 to 15 G, Watkins and Guccione analyzed six response parameters (three measuring head linear displacement and rotation in the mid-sagittal plane with respect to the sled, and three measuring head linear and angular acceleration in the X-Y plane of the head anatomical coordinate system). Points representing each head kinematic response variable were identified through statistical regression for the sled acceleration profile and head orientation parameters. The results were promising. Visual comparisons suggested that the observed acceleration curves closely approximated the predicted ones.

Weiss, M. S. "Kolmogorov-Smirnov Goodness-of-Fit Test: Corrected for Use with "EEG-Like" Data." NBDL-84R003, Naval Biodynamics Laboratory, New Orleans, April 1984.

This report discusses Weiss's use of the single-sample Kolmogorov-Smirnov goodness-of-fitness test, which was designed for use with independent data and was proven to be highly sensitive to correlated data. The report notes that standard critical data values for the Kolmogorov-Smirnov statistical test cannot be used with data with known correlations. For data with electroencephalogram-like low-frequency, high-amplitude spectral peaks, an empirically derived correction for the Kolmogorov-Smirnov statistic provides the correct critical values. The correction is based on a quadratic expression involving a parameter computed from zero-crossing measurements.

Weiss, M. S., and M. D. Berger. "The Effect of Impact Acceleration on the Electrical Activity of the Brain." *AGARD Conference Proceedings No. 253: Models and Analogues for the Evaluation of Human Biodynamic Response, Performance and Protection* A-20: 1-9. London: Technical Editing and Reproduction Ltd., June 1979.

This paper presents findings from neurophysiological measurements taken from rhesus macaques during impact acceleration runs at NBDL. In the experiments, eight macaques with implanted cortical recording electrodes were exposed to $-G_x$ impact accelerations ranging from roughly 28 to 158 G. Electroencephalogram (EEG) and somatosensory evoked potential (SEP) readings were collected from each run and analyzed. The authors found the SEP readings to be a more sensitive index of the inertial load on the brain than the EEG. Observations during the experiments led Weiss and Berger to suggest the tentative possibility that acceleration levels could cause short-term central nervous system disruptions.

———. "Neurophysiological Effects of –X Impact Acceleration." *Aviation, Space, and Environmental Medicine* 54 (November 1983): 1023-27.

This article reports on results from nineteen runs with eight unanesthetized rhesus macaques. The macaques were restrained in the seated position with the head and neck free to move and exposed to accelerations from 42 to 963 m/sec^2. Somatosensory evoked potential readings were measured using electrodes implanted over the cortex. The input stimulus pulse was delivered through electrodes located at L1-L2 on the spine at a rate of 5 Hz. Readings were taken before, during, and after the run and later analyzed. The analysis revealed a latency increase at acceleration levels around 600 m/sec^2. This latency increase was viewed as a possible indicator of a central nervous system disruption at an acceleration level below that known to cause physical injury.

Weiss, M. S., and L. S. Lustick. "Guidelines for Safe Human Experimental Exposure to Impact Acceleration." NBDL-86R006, Naval Biodynamics Laboratory, New Orleans, April 1986.

This report provides some guidelines for fellow researchers working with human volunteers in impact acceleration experiments based on findings and procedures from NBDL. The guidelines are specifically suggested for experiments where human volunteers are torso-restrained and the head and neck remain free to move. In the $-G_x$, $+G_x$, $+G_y$, $+G_z$, $-G_z$, and G_{-X+Y}, peak sled acceleration limits of 15.6 G, 6 G, 11.3 G, 12.5 G, 9 G, and 13 G, respectively, were suggested. All of these recommendations, except those for the $-G_z$ and $+G_x$ vectors, were based on maximum exposures conducted safely at NBDL.

Weiss, M. S., S. J. Guccione, Jr., and T. A. Watkins. "A Kinematic/Dynamic Model for Prediction of Neck Injury During Impact Acceleration." *AGARD Conference Proceedings No. 471 on Neck Injury in Advanced Military Aircraft Environments* 11: 1-6. Essex, UK: Specialised Printing Services, Ltd., April 1989.

This paper reports on findings for a statistical study of six head kinematic response curves for a set of fifty-seven human and twenty-nine rhesus macaque $-G_x$ runs conducted at NBDL. Acceleration exposures ranged from 6 to 15 G for the humans and 42 to 106 G for the macaques. The kinematic responses that were analyzed included the X and Z components of the linear acceleration and displacement, as well as the Y axis angular acceleration and displacement. Each head kinematic variable was non-linearly regressed along sled acceleration profile and head orientation parameters. Regression equations for macaque and human kinematics had the same exponential functional form with correlations ranging from 0.50 to 0.95. The statistical goodness-of-fit test returned highly significant measures. The results of the tests found that the rhesus macaque head/neck was a good biomechanical human analog. Based on this confirmation, the authors postulated that the next step would be to devise a validated method for scaling kinematic data from macaques to humans.

Weiss, M. S., D. L. Matson, and S. V. Mawn. "Guidelines for Safe Human Exposure to Impact Acceleration: Update A." NBDL-89R003, Naval Biodynamics Laboratory, New Orleans, June 1989.

This report provides some updated guidelines for fellow researchers working with human volunteers in impact acceleration experiments based on findings and procedures from NBDL. The updated guidelines are again specifically suggested for experiments where human volunteers are torso-restrained and the head and neck remain free to move. In the $-G_x$, $+G_y$, and G_{-X+Y} vectors, peak sled acceleration limits of 15.9, 11.3, and 13 G, respectively, were suggested. These values were based on the most severe exposures conducted at NBDL, none of which resulted in injury.

Weiss, M. S., G. C. Willems, S. J. Guccione, C. J. Mugnier, and M. E. Pittman. "A New Instrumentation System for Measuring the Dynamic Response of the Human Head/Neck During Impact Acceleration." *AGARD Conference Proceedings No. 532 – Aircraft Accidents: Trends in Aerospace Medical Investigation Techniques* 21: 1-6. Essex, UK: Specialised Printing Services, Ltd., September 1992.

This paper describes the results from tests utilizing a new type of accelerometer (produced by Applied Technology Associates) and photogrammetry system (using an Altek® digitizer and PREP® and PC-GIANT® software packages) in Hybrid III $+G_z$ impact exposures up to 13 G. For comparison, data was collected using the new sensors and the standard NBDL nine-accelerometer package in use at the time. Analysis from the tests showed that the new sensor and photogrammetry system compared well with the traditional nine-accelerometer array and the direct photographic measurement system. The new system rendered equivalent and, in some cases, more precise measures of acceleration, velocity, and displacement.

Willems, G. C. "A Detailed Performance Evaluation of Subminiature Piezoresistive Accelerometers." *Proceedings of Instrumentation in the Aerospace Industry* 23 (1977): 531-40.

This paper is a detailed review of accelerometers from the perspective of biomechanics research. The authors examined data from hundreds of accelerometer types in the 5 to 500 G range and incorporated some general observations into this study. The paper touches on accelerometer linearity, sensitivity, long- and short-term drift, temperature sensitivity, temperature shock sensitivity, axis alignment, warmup characteristics, and hysteresis. A treatment of calibration and data acquisition aspects is also included.

———. "Some Useful Filter Forms." NBDL-80R005, Naval Biodynamics Laboratory, New Orleans, June 1980.

This report addresses the evolution of a variety of digital and analog filters developed over several years at NBDL and presents them in a "design manual format." These filters were honed and validated through use in conditioning transducer data so that the signal-to-noise ratio is optimized. The presented filters were also designed to prevent misidentification of signal fre-

quency noise during digitization procedures.

———. "A Detailed Evaluation of the Endevco Model 7302® Angular Accelerometer." NBDL-83R009, Naval Biodynamics Laboratory, New Orleans, August 1983.

This report reviews the performance of the Endevco Corporation Model 7302® miniature, single-axis angular accelerometer, which NBDL purchased in 1982 and performed a comprehensive review of its functionality. Part of this review profiles the development and validation of a reliable calibration sequence for automated operation. The accelerometer is then evaluated in regard to linearity, sensitivity, cross-axis response, temperature effects, transient and frequency response, spectral fidelity, and linear acceleration sensitivity. The angular accelerometer received generally positive marks, and the report contains recommendations that a three-dimensional package consisting, in part, of the Endevco accelerometers be developed and tested against the transducer packages in use at NBDL.

———. "Closing the Loop – Or Can the Ship Motion Simulator Simulate Ship Motion?" NBDL-89R007, Naval Biodynamics Laboratory, New Orleans, November 1989.

This report documents the procedures developed at NBDL to ensure that the simulator produces motion environments that approximately replicate those encountered aboard ships in the real world. In the same vein, the report also documents the history of the development of the ship motion simulator and cites important research findings associated with its use. Lastly, the report provides a brief description of improvements that were made to the ship motion simulator when it was moved to NBDL.

Willems, G. C., and E. B. Becker. "An Algorithm for Minimizing the Effect of Low Frequency Errors in Kinematic Variables Derived from Cinematography." *Proceedings of the International Society for Optical Engineering* 291 (1981): 119-23.

This paper describes an algorithm devised to minimize the effect of cinematography errors. The authors note that errors sometimes result from photo-target visibility problems. Low frequency error due to camera orientation, location, and calibration constants, as well as errors in the target locations on the Tplates, coupled with target visibility issues, could result in discontinuous jumps in the derived kinematic variables. In contrast to a conventional photographic data output filter, the algorithm is an improvement because it operates only on individual targets and only if an inconsistency occurs. The downside of the algorithm is that it does require careful review of final output data and possibly some editing.

Willems, G. C., W. H. Muzzy III, W. R. Anderson, and E. B. Becker. "Cinematography Data Systems at the Naval Biodynamics Laboratory." *Proceedings of the International Society for Optical Engineering* 291 (1981): 90-96.

This paper presents an overview of the entire NBDL cinematography system. It describes the hardware employed, calibration requirements and procedures, data reduction and analysis, and timing systems. At the time of publication in 1981, the system described had been in use for several years and successfully proven to render accurate measurements and validate readings from instrumented sensors.

Willems, G. C., and D. R. Knouse. "A Detailed Evaluation of the ATA Angular Motion Sensor in Realistic Simulated Crash Environments." In *Proceedings of the Thirty-Fifth Stapp Car Crash Conference*, 303-34. Warrendale, PA: Society of Automotive Engineers, 1991.

This paper presents findings from testing of an angular accelerometer sensor developed by Applied Technology Associates (ATA). After review of data collected using the sensor in impact runs with the Hybrid III manikin at NBDL, the authors found that the sensor's acceleration and velocity levels compared very well with those registered by two different nine-accelerometer packages, regularly used at the lab. Even so, the authors also found the new sensors to be insensitive to linear acceleration.

Willems, G. C., W. H. Muzzy III, D. R. Knouse, and F. Gilreath. "Dynamic Response of the Hybrid III Dummy to +G, Simulated Ship Shock—Cushioned vs. Hard Seats." NBDL-91R002, Naval Biodynamics Laboratory, New Orleans, November 1991.

This report discusses findings from experiments to see how different seats changed the effects of shock motion using Hybrid III dummies. Hybrid III dummies seated in cushioned and hard seats were exposed to accelerations from 3 to 30 G on the NBDL vertical accelerator, and the results were compared. Analysis revealed that the soft seat type provided considerable shock attenuation and kept peak $+G_z$ acceleration at the pelvis at a lower level than the hard seat types.

Willems, G., and G. R. Plank. "Calibration of a Six-Degree-of-Freedom Acceleration Measurement Device (Final Report)." Report No. DOT-HS-808-189, Washington, D.C.: U.S. Department of Transportation, December 1994.

This report describes calibration procedures for a six-degree-of-freedom inertial tracking package for using in measurement of linear and angular acceleration levels during impact tests. The calibrated device consists of nine linear accelerometers arranged in a non-coplanar (3-2-2-2) configuration. This report evidences an important transition from a six-accelerometer package to a nine-accelerometer array at NBDL.

Wismans, J., and C. H. Spenny. "Performance Requirements for Mechanical Necks in Lateral Flexion." In *Proceedings of the Twenty-Seventh Stapp Car Crash Conference*, 137-48. Warrendale, PA: Society of Automotive Engineers, 1983.

This paper presents results from research using NBDL human impact acceleration data to assess biofidelity in anthropomorphic test device (ATD) design. The authors find that an ATD head-neck system built around a two-ball and socket joint configuration would better replicate human head-neck response in lateral and forward flexion than other types of designs. Investigation of the Hybrid III head-neck system found that it was too stiff to accurately replicate human head-neck flexion.

Yarnell, P., and A. K. Ommaya. "Experimental Cerebral Concussion in the Rhesus Monkey." *Bulletin of the New York Academy of Medicine* 45, no. 1 (January 1969): 39-45.

This paper presents the evolution of concussion threshold levels following the preliminary research from the joint Army-Navy project at Wayne State University. The authors present a concussion threshold for rhesus macaques at a rotational acceleration level of 40,000 rad/sec^2 when durations are longer than 5 milliseconds. This particular paper also provides a succinct overview of the dynamic testing device and experimental methodology utilized by Ommaya and his associates to simulate indirect impact.

Comprehensive Bibliography

The following comprehensive bibliography is comprised of additional textual sources, journal articles, reports, books and other studies that were not prepared and published by the Naval Biodynamics Laboratory, but are relevant to the research performed there and the data generated during its operational history. Due to the large volume of materials identified and listed, the comprehensive bibliography is organized into nine broad sub-categories to enable easier access and consultation by interested readers and researchers. These are: 1) Impact Acceleration, 2) Anthropometry, 3) Simulation/Modeling, 4) Experimental Measurements, 5) Pathology, 6) Performance Evaluation, 7) Protection, Restraints, and Emergency Escape Systems, 8) Vibration/ Motion Studies, and 9) General Reference. While several of the listed works can be considered multi-disciplinary and may fit in two or more of the sub-categories, we have attempted to place them in the most appropriate one based on their primary subject matter and focus.

<u>Impact Acceleration</u>

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Ames, W. H., and H. E. Savely. “Motion of the Head During Simulated Seat Ejection.” MCREXD 695-661, Engineering Division, Air Materiel Command, U.S. Air Force, January 6, 1948.

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