The Wind and Beyond

A Documentary Journey into the History of Aerodynamics in America

Volume 1: The Ascent of the Airplane

James R. Hansen, Editor
with D. Bryan Taylor, Jeremy Kinney, and J. Lawrence Lee

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Foreword

Airplane travel is surely one of the most significant technological achievements of the last century. The impact of the airplane goes far beyond the realm of the history of technology and touches upon virtually every aspect of society, from economics to politics to engineering and science. While space exploration often claims more public glory than aeronautics research, many more individuals have been able to fly within the Earth's atmosphere than above it. Thus, aeronautics and air travel have had an enormous practical impact on many more individuals. For this reason, if no other, it is certainly an appropriate time to document the rich legacy of aeronautical achievements that has permeated our society. It is especially timely to do so during the centennial anniversary of the Wright brothers' historic flight of 1903.

Dr. James R. Hansen and his collaborators do more than just document the last century of flight. They go back and expertly trace the historical origins of what made the first heavier-than-air, controlled, powered airplane flight possible on 17 December 1903. Some names covered in this volume, such as Isaac Newton and Leonardo da Vinci, are familiar to even the most casual reader. Other heralded, but less well-known, early pioneers of flight such as George Cayley, Otto Lilienthal, Theodore von Kármán, and Theodore Theodorsen will come alive to readers through their original letters, memos, and other primary documents as they conjoin with the authors' insightful and elegantly written essays.

This first volume, plus the succeeding five now in preparation, covers the impact of aerodynamic development on the evolution of the airplane in America. As the six-volume series will ultimately demonstrate, just as the airplane is a defining technology of the twentieth century, aerodynamics has been the defining element of the airplane. Volumes two through six will proceed in roughly chronological order, covering such developments as the biplane, the advent of commercial airliners, flying boats, rotary aircraft, supersonic flight, and hypersonic flight.

This series is designed as an aeronautics companion to the *Exploring the Unknown: Selected Documents in the History of the U.S. Civil Space Program* (NASA SP-4407) series of books. As with *Exploring the Unknown*, the documents collected during this research project were assembled from a diverse number of public and private sources. A major repository of primary source materials relative to the history of the civil space program is the NASA Historical Reference Collection in the NASA Headquarters History Office. Historical materials housed at NASA field centers, academic institutions, and Presidential libraries were other sources of documents considered for inclusion, as were papers in the archives of private individuals and corporations.

The format of this volume also is very similar to that of the *Exploring the Unknown* volumes. Each section in the present volume is introduced by an overview essay that is intended to introduce and complement the documents in the section and to place them in a chronological and substantive context. Each essay contains references to the documents in the section it introduces, and many also contain references to documents in other sections of the collection. These introductory essays are the responsibility of Dr. Hansen, the series' author and chief editor, and the views and conclusions contained therein do not necessarily represent the opinions of either Auburn University or NASA.

The documents included in each section were chosen by Dr. Hansen's project team from a much longer list initially assembled by the research staff. The contents of this volume emphasize primary documents, including long-out-of-print essays and articles as well as material from the private recollections of important actors in shaping aerodynamic thinking in the United States and abroad. Some key legislation and policy statements are also included. As much as possible, the contents of this volume (and the five volumes to come) in themselves comprise an integrated historical narrative, though Dr. Hansen's team encourages readers to supplement the account found herein with other sources that have already or will come available.

For the most part, the documents included in each section are arranged chronologically. Each document is assigned its own number in terms of the section in which it is placed. As a result, for example, the fifteenth document in the second chapter of this volume is designated "Document 2-l5." Each document is accompanied by a headnote setting out its context and providing a background narrative. These headnotes also provide specific information and explanatory notes about people and events discussed. Many of the documents, as is the case with Document 2-15, involve document "strings," i.e., Document 2-15(a–e). Such strings involve multiple documents—in this case, five of them (a through e) that have been grouped together because they relate to one another in a significant way. Together, they work to tell one documentary "story."

The editorial method that has been adopted seeks to preserve, as much as possible, the spelling, grammar, and language usage as they appear in the original documents. We have sometimes changed punctuation to enhance readability. We have used the designation [. . .] to note where sections of a document have not been included in this publication, and we have avoided including words and phrases that had been deleted in the original document unless they contributed to an understanding of the writer's thought process in making the record. Marginal notations on the original documents are inserted into the text of the documents in brackets, each clearly marked as a marginal comment. Page numbers in the original document are noted in brackets internal to the document text.

Copies of all documents in their original form are available for research by any interested person at the NASA History Office or Auburn University.

While the *Exploring the Unknown* series has been a good model in many ways, this volume indeed represents the beginning of a yet another new undertaking into uncharted waters. I am confident that Dr. Hansen and his team have crafted a landmark work that will not only be an important reference work in the history of aeronautics, but will be interesting and informative reading as well. We hope you enjoy this useful book and the forthcoming volumes.

Stephen Garber
NASA History Office
October 2003

ACKNOWLEDGMENTS

This volume represents the collected efforts of many members of an outstanding team. At Auburn University, a number of individuals provided generous assistance to Dr. James R. Hansen's project team. Dr. Paul F. Parks, former University Provost, strongly encouraged and supported the project from its inception, as did Dr. Michael C. Moriarty, Vice President for Research. To undertake his leadership of the project, Dr. Hansen gave up his job as Chair of the Department of History, something he would not have felt comfortable doing without being certain that the administration of his department would be in the capable hands of worthy successors—first, Dr. Larry Gerber, and then Dr. William F. Trimble. Both Gerber and Trimble gave hearty and vocal support to Auburn's NASA history project. A number of colleagues in aerospace history gave help to the project, including Distinguished University Professor Dr. W. David Lewis and Dr. Stephen L. McFarland. Dr. Roy V. Houchin, who earned a Ph.D. under Hansen, lent aid and comfort to the project team from his vantage point inside the U.S. Air Force. A number of Hansen's current graduate students helped the project in various ways, notably Andrew Baird, Amy E. Foster, and Kristen Starr, as did Dr. David Arnold, also of the USAF, who earned a Ph.D. in aerospace history during the time period when this project was being conducted.

Historians and archivists at a number of other facilities also aided the project. Most of these are acknowledged in the "Series Bibliographic Essay," which appears early in this volume.

At NASA Headquarters, a number of people in the NASA History Office deserve credit. M. Louise Alstork painstakingly edited the essays and proofread all the documents. Jane Odom, Colin Fries, and John Hargenrader helped track down documents from our Historical Reference Collection. Nadine Andreassen provided much valuable general assistance and helped with the distribution. In the Office of Aerospace Technology, Tony Springer served as an invaluable sounding board on technical aeronautics issues. We also owe a special debt to Roger D. Launius, the former NASA Chief Historian, who provided the initial impetus and guidance for this worthy project.

At Headquarters Printing and Design Office, several individuals deserve praise for their roles in turning a manuscript into a finished book. Anne Marson did a careful job in copyediting a lengthy and detailed manuscript. Melissa Kennedy, a graphic designer, performed her craft in an exemplary manner. Jeffrey McLean and David Dixon expertly handled the physical printing of this book. Thanks are due to all these devoted professionals.

The Wind and Beyond

Series Introduction

Talking with the Wind, Collaborating with Genius

Aerodynamics is not, strictly speaking, about the wind. Rather, it concerns the motion of the air (or other gaseous fluid) plus the forces acting on a body in motion relative to the airflow.[1] Still, in choosing a title for this multivolume documentary history of aerodynamics development in the United States, we ultimately concluded that no title would be more suggestive than *The Wind and Beyond*.

Historically, the most basic instrument of aerodynamic research, by far, has proved to be the wind tunnel. Many of the scientists and engineers who achieved vital discoveries in aerodynamics described their breakthroughs in terms of a special capacity to "talk with the wind." By this, they meant visualizing what the air was doing—using the mind's eye as part of a creative process by which the air virtually told them what needed to be done in order to make an airplane fly effectively. "Beyond the wind" suggests many salient themes: the profound human curiosity that gave birth to the science of aerodynamics and, before that, to the dream of flight itself; the countless puzzles and mysteries hidden deep within all natural phenomena, both in macrocosm and microcosm, plus the myriad theories and concepts devised to fathom the forces at work; the countless technological forms resulting from inventiveness as human ingenuity moved toward mastering those natural forces, enabling humanity to leave the ground and soar above the clouds; and the potential for flight above the atmosphere and into space, where the ambitions of humankind may someday result in colonization of other worlds and perhaps contact with extraterrestrial—mythically speaking, even a sort of divine—intelligence. All this, and much more, is evoked by the title *The Wind and Beyond*.

The poetry in the title is not original to this publication. In 1967, writer Lee Edson selected it for the autobiography of Theodore von Kármán, one of the most brilliant thinkers to make the sojourn into aerodynamics during the twentieth century. (Von Kármán had just died, in 1963, at age eighty-two; Edson became his co-author.) Recounting in the first person the amazing life story of the colorful Hungarian-born

1 Webster's *Third New International Dictionary* defines "aerodynamics" as "the branch of dynamics that deals with the motion of air and other gaseous fluids and with the forces acting on bodies in motion relative to such fluids."

scientist who moved to the United States in 1930, only to tower over much of its aeronautical science for the next four decades, *The Wind and Beyond: Theodore von Kármán, Pioneer in Aviation and Pathfinder in Space* (Boston and Toronto: Little, Brown and Company) quickly became a classic. Behind its popularity, which lasts to this day, was von Kármán's restless intellectual dynamism; his humor and eccentricities (which were at least as awesome as his intellect); and his ability to express himself with extreme cogency (even amid his thick accent), whether mathematically or verbally. He made a number of fundamental breakthroughs in aerodynamic theory and, from his post at the Guggenheim Aeronautical Laboratory at the California Institute of Technology (GALCIT), he exerted massive influence over American aeronautical and early space research and development (R&D), especially during the adolescence of the United States Air Force. These facts encouraged readers to care about his remarkably storied career. As American aerodynamicist and aerospace historian John Anderson has written, "The name von Kármán has been accorded almost godlike importance in the history of aerodynamics in the United States, and that aura existed well before his death in 1963 and continues today because of the magnitude of his contributions to, and advocacy for, aerodynamic research and development. Also, his influence is seen today in the contributions of his students, many of whom have gone on to leadership roles in the field."[2] Besides his autobiography, two biographies of von Kármán have been written.[3] This coverage reveals his powerful place in the field, because certainly no other aerodynamicist has enjoyed such a spotlight. Most are still in the figurative dark, not yet having been chosen by a single biographer.

What audacity, then, we have in redeploying the title The Wind and Beyond! When we first suggested to colleagues in aerospace history and to the NASA History Office that we wanted to use it for our documentary study of aerodynamic development in the United States, thoughtful people raised eyebrows and asked serious questions about the propriety of using a title so closely identified with another book, especially one as adored as von Kármán's autobiography. Even though nearly forty years had passed since its original publication, reverence for the book was too great, some said, to adopt its title.

In the end, however, we decided that we could pay no greater respect to von Kármán's memory and to the vibrant intellectual passions of his extraordinary life than by using his title once again. In this way, we hope to refresh the memories of those already aware of his book and his other legacies—for some individuals

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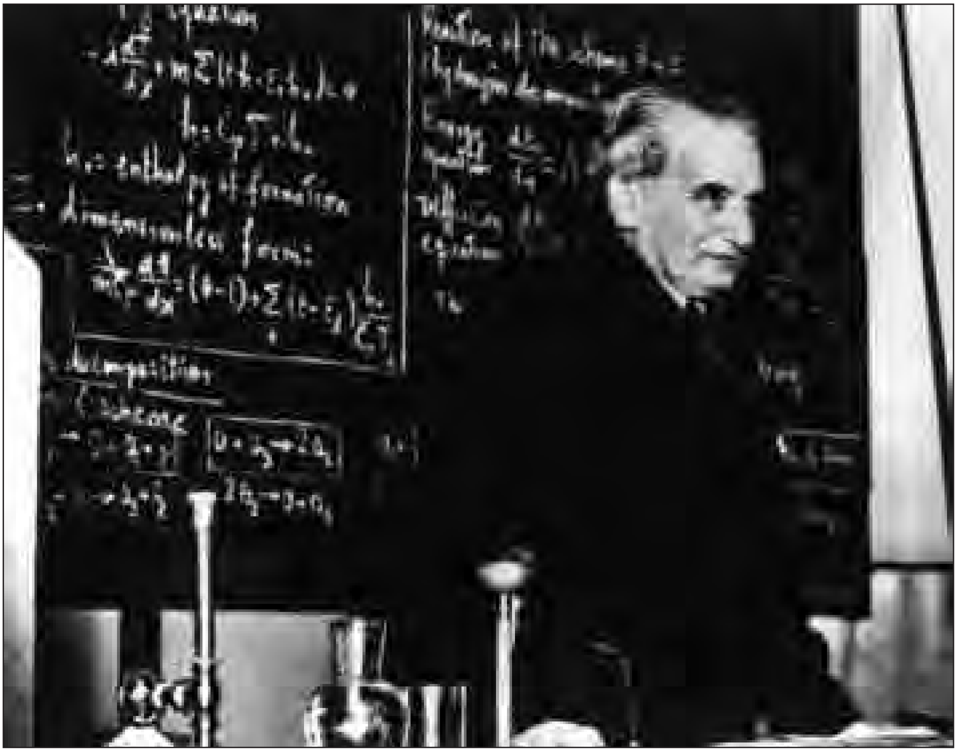
2 John D. Anderson, *A History of Aerodynamics and Its Impact on Flying Machines* (Cambridge, MA: Cambridge University Press, 1997), p. 420.

3 See Paul Hanle, *Bringing Aerodynamics to America* (Cambridge, MA: MIT Press, 1982) and Michael H. Gorn, *The Universal Man: Theodore von Kármán's Life in Aeronautics* (Washington, DC: Smithsonian Institution Press, 1992).

now in their golden years, memories of a teacher that are quite personal. But even more importantly, we thought it desirable to bring *The Wind and Beyond* to the attention of a new generation of students now that we find ourselves in the twenty-first century—some forty years since von Kármán's death. We feel that the great aerodynamicist, a very generous spirit, would approve.



Dr. Theodore von Kármán (1881–1963), shown here at his blackboard at the California Institute of Technology, personified the restless intellectual dynamism that turned the study of aerodynamics into one of the classic expressions of 20th century science and technology. NASA Image #P30570B (JPL)

Anyone with the curiosity, and the fortitude, to venture into a serious study of aerodynamics—or, as in this publication, into its marvelously intricate historical development—will certainly keep wonderful company. For somewhere deep in the heart of the adventure moves the spirit not just of von Kármán but also of many of the greatest geniuses of all time. Roughly 500 years ago, during the period of great intellectual and cultural growth in Europe known as the Renaissance, the prototypical "universal man," Leonardo da Vinci, became obsessed with the problems of flight. No subject fascinated him more. Not his study of the circulation of the blood and the action of the eye; not his discoveries in meteorology and geology; not his insights into the effects of the moon on tides; not his conceptions of continent formation; not his schemes for the canalization of rivers; not any of his other myriad inventive ideas; not even the brilliant artistic compositions for which people most remember him today—*Mona Lisa*, *The Adoration of the Magi*, *The Last Supper*. Art historian Kenneth Clark once called Leonardo "undoubtedly the most curious man who ever lived." And his greatest curiosity—and the curiosity left most unfulfilled—centered on the preconditions of flight.[4]

As we shall see in Chapter 1 of this work, what da Vinci, the quintessential artist-engineer, lacked was hardly imagination or ingenuity. He made amazing sketches of birds in flight and, on paper, designed remarkable flying machines, including a flapping-wing "ornithopter," a parachute, and a helicopter. What the great maestro and all other aeronautical conjurers of the next four centuries lacked was a *science* of flight that could turn fantasy into reality. As von Kármán would explain in his autobiography: "For advances in aviation in any real sense it was necessary for science to catch up with the dreamers and experimenters and set a basis for further development in a rational manner."[5]

In critical ways the Scientific Revolution of the seventeenth and eighteenth centuries primed the pump for the emergence of the science of flight; but in at least one key respect, that great intellectual fermentation, one of the greatest in all human history, also retarded it. With his monumental writings of the late 1600s, Isaac Newton, the culminating figure of the Scientific Revolution, gave birth to the science of mechanics. But in doing so he made calculations and expressed ideas about "upward forces" (what later scientists would call "lift") and "forces preventing motion" (later called "drag") that many would read to mean that human flight by means of a supporting wing was impossible. And, of course, everyone took Sir Isaac's conclusions very seriously, almost as divine guidance.

No real breakthrough occurred until fellow Englishman George Cayley, more than a hundred years later, showed that the amount of lift attained by a forward-moving plate was directly proportional not to the square of the angle, as Newton

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4 On Leonardo's fascination for flight see Serge Bramley's biography *Discovering the Life of Leonardo da Vinci* (New York, NY: Harper Collins, 1991) as well as Irma Richter, ed., *The Notebooks of Leonardo da Vinci* (Oxford: Oxford University Press, 1952; "World Classics Edition," 1980). Readers interested in a psychological treatment of Leonardo's dreams of flight, see Sigmund Freud, *Leonardo da Vinci: A Study in Psychosexuality* (New York, NY: Vintage Books, 1961). Perhaps surprisingly, Freud's analysis does not try to reduce Leonardo's genius to any sort of pathology; rather, it provides a sensitive and respectful inquiry into da Vinci's creative greatness.

5 Theodore von Kármán with Lee Edson, *The Wind and Beyond: Theodore von Kármán, Pioneer in Aviation and Pathfinder in Space* (Boston and Toronto: Little, Brown and Company, 1967), p. 58.

If anyone can be known as the "father of modern aeronautics," it is Sir George Cayley (1773–1857). Not only did he set down the fundamental concepts that defined the airplane in its present-day form, but he was also the first to link a scientific study of aerodynamic principles with the actual design and operation of flying machines. SI Negative No. 75-16335

reasoned, but to the angle made by the plate. An airplane wing need not be impossibly large and heavy as Newton had posited; its weight could be sustained by the force of lift, and its drag compensated for by a propulsion device actuated by a powerful enough engine. Although it would be several decades before Cayley's principle of the modern airplane achieved the status of a paradigm, one can argue, as von Kármán himself did, that it was at this point, during the first half of the nineteenth century, that science moved "off the sharp horns of the dilemma created by Newton."[6] In this sense, Cayley's notions were truly revolutionary.

Cayley built and flew a few gliders of his own design, some of them manned, and so did several other intrepid experimenters during the 1800s. The Industrial Revolution was sweeping across Europe, America, and other parts of the globe, bringing with it greater and greater fascination for machines of all kinds. The special interest in new forms of faster transportation spurred all kinds of efforts to develop aviation into a practical technology. Piloted balloons like those originally built by the Montgolfier brothers in France had been aloft since the 1780s, and even military establishments were finding ways of deploying them. Another form of lighter-than-air craft, the steerable airship or "dirigible," proved even more practical. The impetus for learning more about what it took to fly grew ever stronger.

What brought experimenters, finally in the late nineteenth century, to the birth of a formal study of "aerodynamics" was the matter of lift—specifically the question, "Why do curved surfaces, in particular, perform so well in flight?" Cayley had shown that the curved shape of trout enjoyed low drag in water. This prompted applications of the shape to airplanes. In the 1880s and early 1890s, the great "Bird Man," German engineer Otto Lilienthal, built and flew a number

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6 von Kármán, *The Wind and Beyond*, p. 58.

of effective hang gliders with wings having large curvatures. His flight experiments showed that, compared to a flat plate of the same size, a large curved surface provided significantly greater lift for the same speed. But Lilienthal could not show why. As von Kármán himself noted, the search for this why "led to the study of what we now call aerodynamics, the science of flight."[7]

It is the birth of this science and, even more, the unfolding of the century of rapid development in flight technology that followed it that form the storyline of the volumes to come.

Quickly, and quite necessarily, aerodynamics became highly mathematical. But, as readers of our volumes will perceive, the story involves much more than abstruse theories and differential equations. Unlike other modern technological developments, in which theory mostly preceded practice (often by several decades), aeronautical practice moved largely in parallel with theory, and even occurred before the discovery of many fundamental laws and theories. It had not happened this way in other science-based fields like thermodynamics, electricity, or atomic power, but, for some reason, it did with aerodynamics. Von Kármán recognized this as "an extraordinary thing," the fact that "scientific knowledge and its technological application proceeded almost in parallel."[8] He did not begin to try to explain the phenomenon historically—nor has anyone else. Perhaps it can be explained simply by an age-old quest: we were too anxious to fly. We had dreamed about it for too long, from time immemorial, to wait around for detailed explanations. We were plunging ahead, into the wind and beyond, even if we did not yet understand in detail how it worked.

But that excited energy took us only a little way up. Not until aerodynamicists existed as professional scientists and discovered the why behind lift—and a small but growing community of aeronautical practitioners could truly benefit from "its first real understanding of what makes flight possible"—did conditions become ripe for the "amazingly swift progress" to come.[9] We are fully aware of this synergy, and a leitmotif of our study will be the critical relationship between theory and experiment. Without a fruitful interplay between the two, progress in virtually all science is spotty and can grind to a halt. That certainly proved to be true over and over again with flight technology. In aerodynamics, specifically, we will see this most clearly in the matter of wing design where designers often, especially early in the century, shaped their airfoils independent of theory, sometimes with fortunate results but often with extremely poor—even fatal—ones. As one of the documents

7 von Kármán, *The Wind and Beyond*, pp. 58–59.

8 von Kármán, *The Wind and Beyond*, p. 59.

9 von Kármán, *The Wind and Beyond*, p. 59.

(from 1933) in a later volume suggests, "A large number of investigations are carried out with little regard for the theory, and much testing of airfoils is done with insufficient knowledge of ultimate possibilities."[10] How theory came to inform experiment in constructive ways over the course of the twentieth century should become apparent in our study. But the back-and-forth between theory and experiment remains a central concern today; to discern the most helpful balance between the two approaches to gathering knowledge will perhaps forever be an issue for scientists and engineers to resolve.

In conceiving the nature of our study, we determined very early on that our documentary history of aerodynamics should not, and could not, dwell only in the realm of ideas, concepts, equations, principles, and the like. As absolutely critical as they were to the development of a science of flight, their historical evolution—apart from the social drive to turn them into the physical realities of actual flight hardware, e.g., airplanes, airships, helicopters, autogiros, missiles, and spacecraft—made no sense. Our study would then only concern "the wind," but not what lay "beyond" it in terms of technological forms or their socio-economic, political, military, and cultural contexts.

In adopting a broader approach, we felt secure knowing that John D. Anderson in his 1997 *History of Aerodynamics* . . . took exactly the same tact, as can be seen in the rest of his title . . . *and Its Impact on Flying Machines*. In the preface to his book, Anderson wrote: "In addition to examining the history of aerodynamics per se and assessing the state of the art of aerodynamics during various historical periods, the book seeks to answer an important question: How much of the contemporary state of the art in aerodynamics at any given time was incorporated into the actual design of flying machines at that time? That is, what was the impact of aerodynamic knowledge on contemporary designs of flying machines?"[11]

From the start we determined that we wanted to show through our flow of documents not a linear development of technology but rather a matrix of dynamic relationships involving not just ideas, but also organizations, social and economic forces, political influences, and more. With this in mind, and recognizing that the general perception of aviation history is focused on the evolution of aircraft, we began work, ironically, on a list of aerodynamically significant American aircraft. We consulted numerous sources, notably *Milestones of the Air: Jane's 100 Significant Aircraft* (1969), a compilation that included thirty-two American aircraft; *Progress*

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10 Theodore Theodorsen, "Theory of Wing Sections of Arbitrary Shape," NACA Technical Report No. 411, printed in *Eighteenth Annual Report of the National Advisory Committee for Aeronautics, 1932* (Washington, DC: the NACA, 1933), p. 29.

11 Anderson, *A History of Aerodynamics and Its Impact on Flying Machines* (Cambridge, MA: Cambridge University Press, 1997), p. xi.

in Aircraft Design Since 1903 (1973), prepared by the NASA Langley Research Center, which covered ninety aircraft, seventy-six of which were American designs; and *Quest for Performance: The Evolution of Modern Aircraft* (1985), which evaluated ninety-three American aircraft in addition to a large number of foreign designs.

The list of fifty-two aerodynamically significant U.S. aircraft we came up with early in our project is appended to this introduction. We used the list not as a definitive categorization that defined the contents and structure of our narrative, but as a flexible working outline that helped us organize and focus our research effort as we moved out into aerospace archives and records centers across the United States in search of significant documents. Our objective in highlighting certain aircraft was to use them as subjects in a "pedigree chart," to use a genealogical analogy, illustrating the vital interactions between people, institutions, and ideas in the historical unfolding of American aviation technology. The fifty-two aircraft we chose represented different developmental stages of particular technologies in this "family history" of the evolution of aerodynamics. Some highlighted the primogeniture of certain technological concepts, while others illustrated developments in maturity. Many of the aircraft were significant because of the knowledge and techniques engendered through their use in research, rather than simply because of their specific performance capabilities. We treated some closely related sequences of aircraft (such as the DC-1/2/3, or Convair XF92/F102/F106) as one subject because they represented a continuum of technological developments. We hoped that the research lines emanating from each identified aircraft would provide links to an equal number of *nonaircraft* highlights, such as identification of the key people involved, the development of testing facilities and programs, and the broader social impact and meaning of the machine's operation.

Throughout our research and document-collecting phase, we kept this list of aerodynamically significant American aircraft close by our side. But it never defined or handcuffed our approach to the subject. We did not want our work to become just "another wearisome airplane book."[12] We hoped to contribute to an emerging historiography committed to fostering "Aviation History in the Wider View."[13] This approach moved the scholarship beyond narrow "gee-whiz" fascination with aircraft types to the "people, ideologies, and organizations" as well as the deeper social and intellectual roots of the technology of flight.[14] This became our

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12 See Richard K. Smith's review of James Sinclair's *Wings of Gold: How the Aeroplane Developed in New Guinea* (Sydney, Australia, 1980) in *Technology and Culture* 22 (1981): 641–643. Smith praises Sinclair's book for working in economic, engineering, and social history, and for not being just "another wearisome airplane book."

13 See James R. Hansen, "Aviation History in the Wider View," *Technology and Culture* 30 (1989): 643–656.

14 See Joseph Corn's review of Roger Bilstein, *Flight in America 1900–1983: From the Wrights to the Astronauts* (Baltimore, MD, 1984) in *Technology and Culture* 26 (1985): 872.

goal—to the extent we could accomplish a significant historical treatment in a documentary study involving something as technical as aerodynamics. A careful study of aircraft themselves was, without question, critically important to a serious understanding of aerodynamic development, but aircraft, as complex and dynamic as they are, are not alive. They never, once, have made history on their own. In our study, the primary roles are played by the people who provided the aerodynamic concepts; those who designed, built, and then used the airplane; and all the institutions fundamental to those activities.

We apologize up front, especially to our international readers, for our focus on American topics. But the magnitude of the task of adequately covering aerodynamic development in the United States alone was so profound that we simply could not hope to relate the global saga that aerodynamic development actually experienced. The American story was epic enough. And one certainly does not need to apologize for the American record. From the Wright brothers to the present-day pioneers, no national community has contributed more to aerodynamics and to resulting flight technology than the United States.

Still, the American experience has always connected to a larger world, and has been influenced in many critical and formative ways, especially in the early decades of the century, by foreign—particularly European—developments. We do our best in this study to relate the most essential connections, and to give all the credit that is due to the scientists, engineers, and institutions of the many other countries that have participated in the study of flight. In our volumes, readers will find numerous references to international events and developments, relating not only to countries whose aeronautical achievements are well known, such as Great Britain, France, Germany, Italy, Russia (and the former Soviet Union), and Japan, but also to the People's Republic of China, Sweden, the Netherlands, Poland, Israel, Brazil, and several others. Certainly, the cast of featured characters in American aerodynamics will itself be international: von Kármán from Hungary; Igor Sikorsky, Wladimir Margoulis, and Alexandre Seversky from Russia; Max Munk and Adolf Busemann from Germany; Alexander Lippisch from Switzerland; Theodore Theodorsen from Norway; Antonio Ferri from Italy; Hsue-tsen Tsien from China; among others. In embarking on their new lives and careers in America, many of them brought ideas, values, and techniques learned while studying or otherwise associating with some of the world's greatest aerodynamic thinkers: Germany's Ludwig Prandtl, Switzerland's Jakob Ackeret, England's Frederick William Lanchester, Russia's Dimitri Riabouchinsky and Nicolai Joukowski, and many more. In addition to coming into contact with the work of these foreign thinkers—either directly or indirectly—native-born American aerodynamicists engaged in a professional discipline that was, like most scientific fields, increasingly international in character. They encountered books, articles, and certainly hundreds and hundreds of foreign technical reports, both translated into English and in their foreign tongues. Many of them also traveled to international meetings and symposia where they met the world's leading lights face to face. Some of these forums, such as the Volta Congress on High-Speed Aeronautics, held in Italy in 1935, proved historic in their significance for future technological developments in America and elsewhere.

Our focus had one other major limiting factor. Because the project had been sponsored by the history program of the National Aeronautics and Space Administration (NASA), we set out to highlight as much as possible the role of NASA—and its predecessor organization, the National Advisory Committee for Aeronautics (NACA)—in the development of aerodynamic theory and practice. In exploring this, we hoped to contribute additional insights into the issue of NACA/NASA's overall significance in America's "progress" into air and space. In league with a growing body of historical scholarship that has mostly affirmed the positive significance of these two related organizations, our study confirms that the NACA and NASA were a vital part of the broader spectrum of aerodynamic research activities involving both civilian and military aviation and aerospace organizations in the United States. Without direct government involvement in the form of well-equipped and rather expansive research laboratories dedicated to "the scientific study of the problems of flight with a view to their practical solution" (Law establishing the NACA: Public Law 271, 63d Congress, approved 3 March 1915), many fundamental aspects of aerospace science and technology, most involving aerodynamics, would not have been addressed as quickly or as comprehensively. In the early decades of the century, the U.S. aircraft industry was simply too fledgling to deal with a wide range of fundamental questions. Even after that industry had exploded in size and capability, the short-term financial interests of modern corporate capitalism would not engender the kind of long-term investment in research and development that NACA/NASA laboratories provided. The proper and most effective role of government in aerodynamic R&D remains a vital issue today, and we hope the historical insights provided by our study will inform contemporary discussion of it.

Within the framework of our contract with the NASA History Office, we tried to branch out from the NACA/NASA focus to include sufficient information about aerodynamic developments related to the U.S. military, universities, the aircraft manufacturing industry, the airlines, and other pertinent government agencies such as the U.S. Bureau of Standards, the U.S. Department of Transportation, and the Federal Aviation Administration (and its precursor, the Civil Aeronautics Authority). But we concede that the attention we paid to these entities is too limited. Nonetheless, we hope that, overall, readers will come away with a feel for the whole scope of aerodynamic history—NACA/NASA and otherwise, American and otherwise.

We would like to explain how even the admittedly confined scope of our study ramified beyond anything anyone had originally intended.

In 1997, the NASA History Office contracted with us (through the Science Technology Corporation) to produce a documentary history of American aerodynamic development with a focus on NACA/NASA contributions. There were at least two major reasons for the request. First, the History Office's publication of the first two volumes of *Exploring the Unknown: Selected Documents in the History of the U.S. Civil Space Program* (NASA SP-4407; Vol. 1, 1995; Vol. 2, 1996), edited by John M. Logsdon, et al., were well received both inside and outside of NASA. These extensive documentary volumes (three more volumes have since been published) quickly became an essential reference for anyone interested in the history of the U.S. space program. Given that NASA's space activities had been covered much more extensively in NASA history books than had its aeronautical activities, Dr. Roger Launius, then the NASA chief historian, wisely felt that a complementary series of documentary histories devoted to aeronautics would prove valuable. Launius chose to start with aerodynamics, the central component of all aeronautical technology. Other volumes, dedicated to propulsion, stability and control, structures and materials, supersonics, and hypersonics, will follow.

Another inspiration for what became our project was the upcoming Wright centennial. In 2003, the United States and the rest of the world will be celebrating the 100th anniversary of the historic first powered flight by the Wright brothers at Kitty Hawk, North Carolina, on 17 December 1903. Although perhaps not comparable in magnitude to the United States Bicentennial in 1976 or the fifty-year commemoration of the end of World War II celebrated in 1995, the Wright centennial will certainly be a major national and international event. All over the world scholars and aviation experts will be discussing the significance of flight, assessing the course of its historical development, and projecting aviation's future. Major conferences will undoubtedly take place on the centennial of powered flight. In October 1998 Wright State University in Dayton, Ohio, the Wright's hometown, launched the anniversary events with a National Aerospace Conference. Its theme, "The Meaning of Flight in the 20th Century," attracted some 400 historians, policy planners, aerospace professionals, and just plain interested people.[15] The following month, on 13 November 1998, President William J. Clinton signed into law the Centennial of Flight Commemoration Act (PL 105-389). This act established a commission responsible for planning all national events involved with the Wright centennial celebration.

From the start of our project, we kept the Wright centennial in mind—and not just as a deadline for publication. We believed, as NASA did, that a documentary history

15 *National Aerospace Conference Proceedings*, Wright State University, April 1999.

of aerodynamics, one which started with “The Achievement of Flight” and that took the reader through the entire twentieth century, to the present, and then beyond to our future in flight, would be a worthy contribution to the national celebration of the Wright centennial.

Originally, our contract called for a single volume incorporating between 150 and 250 documents. Initially, we planned eight chapters. Early into the project, however, we knew that this framework was too confining. In producing rough drafts of our first three chapters, we were forced to address two facts: that our resulting book would grow to become extremely large, much larger than first anticipated, and that some important topics in the overall history of aerodynamics could not be well covered in a single volume structure. For the first three chapters alone, it seemed we would need to publish in the neighborhood of 150 documents. However, the latter point became the key issue for us. Expanding the work into two volumes with a total of twelve or more chapters would result in a significantly better history of aerodynamics—as well as two volumes that were much handier for the reader.

No celebration of the Wright centennial would be complete without fully documenting the epic story of how aerodynamics progressed with such incredible speed and import, not just to the drama at Kitty Hawk on 17 December 1903, but also for the 100 years of systematic development following the historic first achievement of powered flight. NASA Image #65-H-611

At this point, a key concept emerged to guide our organization of the two volumes. The volumes would cover, respectively, "The Aerodynamics of Propeller Aircraft," and "The Aerodynamics of Jets and Rockets." In the first volume we would then have room not only to cover the mainline stories but also give adequate coverage to important aerodynamic developments in lighter-than-air research, flying boats, and rotorcraft, among others. It was evident to us, as we were sure it would be to any informed student of aviation history, that each of these areas possessed tremendous historical value and interest, and were vital components of technological developments related to propeller-driven aircraft.

The second volume would begin with the dramatic story of the high-speed research that led to the development of dedicated research aircraft and the breaking of the sound barrier. It would include chapters on transonic research facilities and supersonic flight, plus chapters covering the first generations of military and civil jet aircraft, the quest for a commercial supersonic transport, hypersonics, and the development of today's most advanced wind tunnels and other aerodynamic research tools. It would conclude with a special chapter looking ahead to the future of flight.

As bundles of photocopied documents continued to grow (and fill up our file cabinets) as a result of our research trips into archives and depositories around the country, a truly radical idea for our publication surfaced. What we were producing, whether we liked it or not (and whether or not the NASA History Office could find the funding to publish it in such an expansive format) were two multi-volume boxed sets: one, with the general introduction, series reference material, and chapters devoted to propeller aircraft; and the other, with chapters covering the aerodynamics of jets and rockets. All told, the various chapters included over 350 document strings (groups of related documents) comprising almost 1,000 individual documents—or nearly eight times as many as anticipated in the initial concept. In keeping what was in fact the original format for the one-volume concept, each volume would be introduced by a full-length analytical essay and substantial introductory headers for each document string.

At this point, the practical demands and costs of publishing intervened, and our view of the project's organization evolved into an outline of six separately bound volumes, each containing two chapters. The plan became for the first three volumes to cover the aerodynamics of propeller-driven aircraft, while volumes four through six covered the aerodynamics of jets and rockets. Also planned was a general introduction with bibliographic information included as a third section in the first volume and an epilogue included as a third section in the sixth volume.

The more we thought about this revised and greatly expanded format, the more we liked it, and came to consider it absolutely vital to the success of our publication. Besides offering much more historical content, it seemed to us most "user-friendly." We wanted the students of aerodynamics history to know by looking just at the physical makeup of our work that its authors intended for it to be *read*, that each volume in the series tells a story that can be appreciated independently of the others. A reader can start with the first volume to follow the document narrative we put together in "Chapter 1: The Achievement of Flight," or turn to the fourth volume to read "Chapter 8: The Supersonic Design Revolution." In sum, though we offer a reference work to those who want it, we also offer an integrated series of independent volumes. Each tells a story worth reading. (We were flattered beyond description when one of our referees, after reading our draft of Chapter 1, told us "it was the best single shorthand telling of the invention of the airplane" that he had ever read.) We chose the documents for every chapter to serve as critical stepping-stones through an important, often complex, narrative that would be compelling to the reader every step of the way.

Because, in the end, we wished for our readers, too, to "talk with the wind," as we felt we had been doing these past few years while engaging the history of aerodynamics. As suggested earlier in this introduction, it is our dearest hope that Dr. von Kármán himself would heartily endorse our use of his title, *The Wind and Beyond*, as a token of our great affection, and that he would warmly welcome this collection of books into his library. There, cigar in hand and with a wryly quizzical look on his face, he would spend evening after evening reading through our volumes word for word, realizing that each tells a great story full of remarkable ideas and people—and that together our volumes represent an epic intellectual journey, a crucial episode in humankind's quest to conquer nature and fly. We flatter ourselves to imagine him nodding frequently in tacit recognition and approval, perhaps even learning a few things here and there that he himself never knew—though this seems hardly possible, knowing the universal experience of the man. Optimistically, we believe he would excuse our minor errors and mistakes as instructively as he did the scientific and technical papers written by the prized pupils at Caltech who came to love him so much.

Writer Lee Edson began von Kármán's autobiography with a tribute entitled, "Collaboration with a Genius." In sum, that is what we see ourselves doing in this documentary history: collaborating not only with the genius of von Kármán but with all the other tremendously inventive minds that played a part in the development of aerodynamic theory and practice from before the Wright brothers up to the present. May there be many more in the new century at hand.

Significant Aircraft List

The list of Aerodynamically Significant American Aircraft was compiled to aid the development of a research plan for the AU/NASA History Project. As such, the list is not intended to be a definitive categorization, but rather a flexible working document to aid in organizing and focusing our research effort. The objective of highlighting certain aircraft in this way is to use them as subjects in a "pedigree chart" illustrating the dynamic relationship of people, institutions, and ideas in the history of technology.

The aircraft themselves represent different developmental stages of particular technologies in this "family history" of aerodynamics. Some highlight the primogeniture of certain technological concepts, while others illustrate developments in maturity. Many of the aircraft are more significant because of the knowledge and techniques engendered through their use in research rather than their specific performance capabilities. Along these development lines there may be other aircraft that will serve just as well, if not better, than the ones listed. Some closely related sequences of aircraft, like the Douglas DC-1/2/3, or the Convair XF92/F102/F106, are treated as one subject on the list because they represent a continuum of technological developments.

The listings on the accompanying page were prepared from a number of different sources, each representing slightly different perspectives. The different sources were compared to each other both to develop and to filter the list. Over 155 aircraft "candidates" were considered in drawing up the list, fifty-two of which appear on the following page. One of the considerations during this initial filtering was to reduce the list to a more manageable proportion.

The first source used is *Milestones of the Air: Jane's 100 Significant Aircraft* (1969). This compilation includes thiry-two American aircraft and, of this number, twenty-four are included on our list. The eight aircraft not included were deleted because there were no collaborating entries from the other sources. Two of the aircraft not listed, however, should perhaps still be considered for their aerodynamic significance: the Sikorsky VS-300 and the Lockheed U-2.

The next two sources are NASA publications: *Quest for Performance: The Evolution of Modern Aircraft*, by Laurence K. Loftin, Jr. (1985); and *Progress in Aircraft Design Since 1903*, prepared by the Langley Research Center (1974). Loftin's study of the period from 1914 to 1980 covers ninety-three American aircraft, in addition to a large number of foreign designs. One category of aircraft accorded considerable attention by Loftin, but not well represented in the other sources, is that of flying boats and amphibians. Few of these types appear on the following list, but they deserve, and will get, more attention in a later volume. The Langley publication covers ninety aircraft, seventy-six of which are American designs. Of interest is the fact that the Langley listing does not duplicate Loftin's, and includes a number of aircraft not considered in *Quest for Performance*. The aircraft from these two sources that appear on the following list are those that were also included in other lists.

The final listing of twenty-four aircraft is based on the previous lists and represents an attempt to identify flight vehicles associated with specific NACA/NASA aerodynamic research programs. The intent of this filter was to focus further recognition of the aircraft as technological representatives of a dynamic interrelated train of research and ideas. A second consideration was to help direct initial research efforts to document trails that are most likely accessible in NASA collections.

Significant Aircraft List

Aircraft	Year	Jane's	Loftin	LRC	NACA/NASA Aerodynamics
Wright Flyer	1903	✓		✓	
Curtiss JN-4	1916		✓	✓	*Flight tests*
Curtiss NC-4	1919	✓	✓	✓	
Dayton-Wright RB-1	1920	✓	✓		
Curtis R2C-1	1923	✓	✓		
Sperry Messenger	1923				*Airfoils, Full-scale wind tunnel*
Ford Tri-Motor/5-AT	1926	✓	✓	✓	
Ryan NYP	1927	✓	✓	✓	
Lockheed Vega	1927	✓	✓	✓	
Curtiss AT-5	1927				*NACA Cowling*
Lockheed Air Express	1927				
Pitcairn PCA (*Cierva)	1931	✓		✓	*Rotary-wing tests*
Taylor/Piper Cub	1931	✓	✓	✓	
Boeing 247	1933	✓	✓		
Douglas DC-2/3	1933	✓	✓	✓	
Sikorsky S-42	1934	✓	✓		
Boeing B-17	1935	✓	✓	✓	*Flaps, Cowls, Airfoil*

Aircraft	Year	Jane's	Loftin	LRC	NACA/NASA Aerodynamics
Brewster XF2A	1938	✓			*Drag clean-up*
Consolidated B-24	1939		✓	✓	
Lockheed P-38	1939		✓	✓	*Compressibility*
North American P-51	1940	✓	✓	✓	*Laminar flow*
Republic P-47	1941			✓	
Hughes H-1	1941				
Boeing B-29	1942		✓	✓	*Scale model testing, etc.*
Lockheed L 1049/C-69	1943		✓	✓	
Lockheed P-80	1944		✓	✓	
Bell X-1	1946	✓		✓	*Supersonic flight*
North American F-86	1947		✓	✓	*Swept wings*
Boeing B-47	1947			✓	
Convair XF-92/102/106	1948	✓	✓	✓	*Delta wing/area rule*
Northrup N-1M	1950				
Bell X-5	1951	✓			*Variable geometry wing*
North American F-100	1953		✓	✓	
Lockheed F-104	1954	✓	✓		*High-speed tests*
Boeing 707	1954	✓	✓	✓	
Vought F-8	1955		✓	✓	*Supercritical wing*
Convair B-58	1956	✓		✓	
Bell Model 204/UH-1	1956			✓	*Ogee tip*
McDonnell F-4	1958	✓	✓	✓	
North American X-15A	1959	✓		✓	*Hypersonic upper atmosphere*
Sikorsky S-60/64	1959	✓		✓	
Lockheed YF-12/SR-71	1963			✓	*Hypersonic flight*
General Dynamics F-111	1964		✓	✓	*TACT, Transonic research*
North American XB-70	1964		✓		*Supersonic cruise*

Aircraft	**Year**	**Jane's**	**Loftin**	**LRC**	**NACA/NASA Aerodynamics**
Northrup HL-10	1966	✓			*Lifting body*
General Dynamics F-16	1974		✓		
Rockwell B-1	1974		✓		
Rockwell STS	1977				*Space Shuttle*
Bell XV-15	1978				*Tilt-rotor*
Gates Learjet 55	1980				*Whitcomb winglet*
Grumman X-29	1984				*HiMAT, High maneuverability*
Lockheed F-117	1988				

Series Bibliographic Essay: Days on the Wing

Journeys to America's Aviation Archives

Many historians and other scholars would admit that, next to seeing their work finally appear in print, research is the most enjoyable experience of their enterprise. That was the case for all of us with this project. The comprehensive nature and scope of our documentary project required the members of the project team to travel to and spend extended periods of time in those archives and libraries across the United States that held significant materials on the development of aerodynamics. These repositories included public institutions such the National Archives and Records Administration (NARA) and the National Air and Space Museum (NASM) as well as private facilities such as the Boeing Company's Historical Archives. The "days on the wing" that members of the project team spent at these places resulted in our accumulating the bulk of the material readers will see in the following volumes. Those days of research and photocopying also provided us with some unprecedented impressions not only of the state of aerodynamics archives in the United States, but also of aeronautics archives in general.[16]

Represented in the volumes of our documentary history is a cornucopia of historical materials, of various types and in various formats. In the archives we found diverse manuscript material in the form of correspondence, journal and diary entries, meeting minutes, personal scrapbooks, and pilot reports. We also found many relevant published primary sources such as periodical and newspaper articles, autobiographies, and transcripts of oral histories. Our primary criterion in the research phase was to find documents that, either alone or in combination, could illuminate some significant point or historical moment that contributed to the development of aerodynamics in the United States. Project researchers, which included three Ph.D. students in the history of technology at Auburn University working under the supervision of project director Professor James R. Hansen, also sought related materials to support the documents—photographs, negatives, blueprints, technical manuals, motion pictures, video records, sound recordings, electronic data, etc. Though very few of these ancillary materials

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16 This section's title has been inspired by the title of the World War I memoirs of Belgian fighter ace Willy Coppens de Houthulst, *Days on the Wing* (London: J. Hamilton, 1934).

could be included in the documentary volumes to follow, given the medium of textual presentation, everything we collected helped us to see the historical development of aerodynamics in a fuller context.

We went about identifying and locating significant documents in the history of aerodynamics through several methods. First, we looked to the previous historical record by searching through the footnotes and endnotes of notable works in the field of aeronautical history. (An annotated list of significant secondary works related specifically to the history of aerodynamics is at the end of this essay.) Such a process allowed us to build a foundation for the evaluation of key documents as well as improve the research team's general knowledge of the subject. We went one step further and asked leading historians to suggest archives and document collections that they felt had been important to their research as well as to exploration of the subject in general. In recognition of their vital contribution, we have listed these individuals in our acknowledgements.

In a clear indication of the growing importance of digital information, we found the Internet to be a highly valuable resource and general research tool. The readily accessible technology in the form of our desktop PCs facilitated the search and acquisition of information pertinent to the project. This ranged from locating specific documents, to inventory listings for specific archives, to e-published articles related to aeronautical history and aerodynamic developments of the present and very recent past. The use of mainstream search engines and of keywords such as "aerodynamics," "wind tunnels," "laminar flow," "helicopters" brought us into a global matrix of information concerning the past, present, and future of aerodynamics and its social, economic, political, and military contexts. Much of this was in an electronic format that was instantaneously available. The project's specific use of Internet and other types of digital resources is mentioned at appropriate points through this essay as well as at various points in the text. E-mail also facilitated correspondence with archivists and librarians and kept us in our offices at home working at a pace that greatly helped the progress of the project.

Another valuable research tool for our process of document identification, location, and acquisition were two published descriptions of American aerospace archives. One of these was *A Guide to Sources for Air and Space History; Primary Historical Collections in United States Repositories* (1994 edition, sponsored by the National Air and Space Museum and edited by Cloyd Dake Gull), an extensive listing available in both published and digital form.[17] This guide highlights approximately 2,250 collections in over 370 repositories across the United States,

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17 Cloyd Dake Gull, ed., *A Guide to Sources for Air and Space History; Primary Historical Collections in United States Repositories* (Washington, DC: National Air and Space Museum, Smithsonian Institution, 1994), and at *http://www.nasm.edu/nasm/arch/ARCH_REPOS/gtsash1.html*

which span from the flight experiments of the nineteenth century to the space flight missions of the 1980s. First appearing in 1976, the last major edition of this bibliography, from 1994, was available to us on the Internet. Gull's listings are organized alphabetically, meaning that it takes some time for users of the bibliography to search and read through the descriptions. Also, we found that the descriptions were in no way comprehensive. Too often, Gull details a particular collection of papers thoroughly but neglects to describe other potentially significant collections found at the very same repository. Perspective researchers need to contact target archives for more specific information about their collections.

The second major bibliographical work, Catherine Scott's edition of *Aeronautics and Space Flight Collections* (1985) details the state of aerospace archives into the 1980s.[18] Scott opens the volume with a guide to regional aerospace archives across the United States; the guide is organized by subject (e.g., Wright Brothers, Charles A. Lindbergh) and by region (e.g., Northeast, Southeast). The volume includes specific essays describing the aeronautics collections in the Library of Congress, New York Public Library, United States Air Force Historical Collection, Gimble Collection at the United States Air Force Academy, National Air and Space Museum Library, and the History of Aviation Collection at The University of Texas at Dallas. Most of these essays are written by the archivists responsible for them.

There were limitations to using both Gull's and Scott's work. Neither one mentions aerodynamics specifically, meaning that further inquiry by the project team was necessary. In neither work is there a specific listing of aerodynamics archives per se. The closest thing we found to an aerodynamics archive cited in Scott's bibliography involved the volumes of wind tunnel test reports housed in the GALCIT Aero Library of the California Institute of Technology in Pasadena. But this facility was closed in the early 1990s and most of its holdings turned over to the Caltech Archives (although some went to aerospace corporations). As a result of such institutional transitions, along with corporate downsizing and loss of funding for records keeping, the archival landscape surveyed by Gull and by Scott had changed significantly by the time we started our project in 1997. Not just for our purposes but also generally speaking, by the mid-1990s both guides were woefully out-of-date and in need of revision and updating. Despite their limitations, however, these guides still qualify as points of departure for any individual starting a research project in aerospace history in the United States.

The research methodology of utilizing the previous historical record, suggestions from leading historians, and published guides to American aerospace archives

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18 Catherine D. Scott, ed., *Aeronautics and Space Flight Collections* (New York, NY: Haworth Press, 1985).

provided the preliminary foundation for building what would become a vast documentary collection related to the development of aerodynamics in America. From it we successfully moved forward to collecting many documents of known value and significance and many others that were forgotten or completely unknown. Our objective was not only to make the most important of them available to historians and present them to readers in an accessible form, but also to make sense of them, to contextualize them, to interpret them, and to place them within a meaningful narrative—telling the story of the development of aerodynamics in America, from before the Wright brothers up to the present.

Members of the project team visited private, corporate, and both civilian and military government archives to amass the documents that made the completed volumes possible. Virtually all of the repositories we visited employed enthusiastic caretakers dedicated to the preservation of aviation history, even though they all represent different interests, outlooks, and agendas in their records keeping. We found that the governmental, military, and corporate memory of American aerodynamics was principally alive and well. No one in the project experienced the typical horror stories about tyrannical and paranoid archivists hindering historical research. All of the archivists and specialists we met were open to the promise of our project. At each archive, the project team not only found many important documents but we also benefited from conversations with archivists and, in the process, learned considerably more about the aviation history we were researching.

Many of these repositories are located near historic places related to U.S. aeronautics. This enhanced our overall research experience greatly. We visited Huffman Prairie where the Wright brothers developed their aircraft after going back to Dayton from Kitty Hawk. We toured the dry lakebeds of Edwards Air Force Base in the Mojave Desert, where the Bell X-1 and so many other important experimental aircraft had test flown. We explored Boeing Field in Seattle, and we stood in the vast test section of the thirty- by sixty-foot Full-Scale Tunnel at Langley Research Center in Virginia. All of these first-hand experiences made the importance of the project all the more apparent and committed us anew to documenting the history of aerodynamics in America.

Although we specify the bibliographic origin of the many hundreds of documents reproduced and analyzed in our study, we have included a general exposition on the state of those American archives containing collections pertinent to the development of aerodynamics. We believe this would be helpful to scholars wishing to expand upon the themes and topics presented in our volumes. The following descriptive essay therefore discusses the primary institutions holding significant collections of these records. It begins by taking a look at the NACA/NASA materials we examined and is followed by summary inventories of what we found in military, corporate, and academic libraries and repositories.

NASA

NACA/NASA collections predominate in this documentary history. The very nature of our work's overarching theme—the development of aerodynamics in the United States—meant that considerable time would be spent in archival repositories maintained by the National Aeronautics and Space Administration (NASA). Throughout the twentieth century, NASA and its predecessor agency, the National Advisory Committee for Aeronautics (NACA), founded in 1915, have been the constant in aerodynamics research in the United States.

The NASA History Office at NASA Headquarters in Washington, D.C., directs an extensive history and archival program dedicated to the preservation of both NACA and NASA involvement in the development of flight.[19] NASA created its history office in 1959 and assigned it the duty of widely disseminating information about the agency's activities and about aerospace developments generally, under the mandate of the 1958 National Air and Space Act. A commitment to serving both governmental and public interests has ensured that NACA/NASA involvement in the development of aerodynamics has been preserved. The Headquarters History Office perpetuates this mission through its direction of history offices at all of NASA's field installations. This includes offices at Langley Research Center in Hampton, Virginia; Ames Research Center at Moffett Field, California; Glenn Research Center at Lewis Field in Cleveland, Ohio; and Dryden Flight Research Center at Edwards Air Force Base in California. These are the NASA facilities that have been most directly involved in aeronautics research. For a detailed synopsis of the NASA History Program and its archival holdings across the United States, see *Research in NASA History: A Guide to the NASA History Program* (1997), which is also accessible via the Internet.[20]

As an archival repository, the NASA History Office itself maintains extensive biographical and subject files. The biography files cover approximately 5,000 individuals from the 1800s to the present and comprise 180 linear feet of archival space. Arranged alphabetically, these files contain speeches, correspondence, articles, clippings, press releases, and photographs. The aeronautics collection is thirty-two linear feet and focuses on NACA/NASA activities from 1945 to the present. These records contain photographs, newspaper and *Congressional Record* clippings, articles, speeches, news releases, reports, studies, pamphlets, and brochures on specific topics such as SST, V/STOL, X-aircraft, aerodynamics, wind tunnels, and NACA contributions to historic aircraft.

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19 NASA History Office, Code IQ, NASA Headquarters, 300 E Street SW, Washington, DC 20546-0001, *http://history.nasa.gov/*

20 *Research in NASA History: A Guide to the NASA History Program* (Washington, DC: NASA History Office, NASA HHR-64, June 1997), and at *http://www.hq.nasa.gov/office/pao/History/hhrhist.pdf*

The archival core of our documentary project, however, proved to be the substantial collections housed in the Historical Archives at Langley, the original and the oldest NACA/NASA laboratory.[21] The collections housed at Langley are immensely valuable to the study of the development of aerodynamics and are the closest thing to a dedicated "aerodynamics archive" in the United States. The collections possess materials dating back to the creation of the laboratory in 1917 and include technical reports and data logs, internal correspondence and memoranda, personal papers of leading engineers, programs and minutes of technical conferences, transcripts of oral histories, and numerous special files, such as the one compiled on the flight testing of the North American XP-51 Mustang. Members of our project team concentrated most of their efforts in four important collections: the NACA research authorization (RA) files; the Milton Ames collection; and the papers of research engineers John Stack and Fred E. Weick. Detailed finding aids for these and other collections at Langley are available in the archives and also appear in bibliographies at the end of James R. Hansen's two works on the history of NACA/NASA Langley, both of which are referenced later in the "Secondary Sources" portion of this essay.

In our view, the over 2,000 research authorization (RA) files housed in Langley's Historical Archives compose the single most valuable collection for the study of the NACA's involvement in the development of aerodynamics—and one of the most important intact collections in all of American aeronautics history. Through the voluminous materials in these RA files, historians are able to trace the evolution of a research program from the original idea to the completed project featured in a NACA publication. A clerk began an RA file whenever a research authorization was signed by the NACA chairman in Washington, D.C., authorizing one of the laboratories to pursue a specific research project. An RA file thus should exist for each and every authorized research program the NACA ever conducted. A typical RA file consisted of the RA sheet itself, which officially authorized the research, specified its title and sequential number, and delivered a statement indicating the reason and method of research. Following this cover sheet in every RA file one finds copies of all correspondence, memoranda, blueprints, drawings, and reports that NACA file clerks designated as related to the RA. Copies of a large number of original items such as this would also be placed in other related RA or correspondence files. This records-keeping scheme, invented by the NACA in the early 1920s, resulted in a truly historic and extremely extensive documentary collection. Researching the NACA RA files allows the historian to gain both a broad perspective and a very detailed picture of the NACA's process of selecting research problems

21 Historical Program Manager, Mail Stop 446, Langley Research Center, Hampton, VA 23681-0001.

and then exploring ways to solve them. The RA files also illuminate the interaction between the NACA committee structure and the NACA executive office in Washington, D.C., and between those bodies and the field centers such as Langley. They also provide an almost day-to-day picture of the research life of the laboratory and of the social, intellectual, and professional dynamics taking place within it. Typically, there are also indications in the RA files of which RA contributed to a particular NACA publication. Still, quite a bit of time needs to be spent in the RA files before a historical researcher can become adept at following the many intricacies involved in the administration and contents of the RA files. Many documents that follow in our volumes come from the RA files at Langley. Many more, which we approximate to be in the neighborhood of some two million,[22] might have been included had we time to examine them all.

Another critical assembly of documents we fully utilized in the Historical Archives at NASA Langley was the Milton Ames Collection. These files resulted from an attempt made in the 1970s by the former Langley research engineer (1936–1941) and staff member in the NACA's Washington Office (1949–1958) to write a technical history of NACA Langley laboratory, from its establishment in 1917 to the birth of NASA in 1958. By this time Ames was serving as the NACA's chief of aerodynamics. What made this collection so important to us was that it embodied dozens of documents that Ames, a veteran researcher and aerodynamics specialist, had personally identified as historically significant. Organized into seven boxes, the Ames Collection spans from the Wright-brother era to Langley laboratory's involvement in the Apollo program and includes hundreds of significant aerodynamics documents. Specific themes that the Ames Collection highlights include the establishment of government aeronautical research establishments in Europe and North America; the construction of the Variable Density Wind Tunnel (VDT); the contributions of significant individuals to NACA research; NACA research programs related to low-drag engine cowlings, the design and operation of wind tunnels and other aerodynamic research facilities, airfoils and propellers, boundary-layer control, and the potential of laminar flow; the design of airships, flying boats, and rotary wing aircraft; NACA research contributions to the aircraft that fought in World War II; the establishment of other NACA laboratories and field stations, notably what became NACA/NASA Ames, Lewis, Wallops Island, and Dryden installations; post–World War II developments in high-speed flight, including the breaking of the mythical sound barrier; and Langley researcher Richard T. Whitcomb's conception of the so-called "area

22 For more information about the holdings of the Langley Research Center Historical Archives, specifically the RA files, see James R. Hansen's *Engineer in Charge: A History of the Langley Aeronautical Laboratory, 1917–1958* (Washington, DC: NASA SP-4305, 1987), pp. 567–588.

rule." Virtually all of the papers in the Ames Collection deserved our attention as potential items for publication in our documentary history.

A third major collection we reviewed systematically in the Historical Archives at NASA Langley involved the business papers of Langley research engineer and supersonics pioneer John Stack. Divided into six major sections, the Stack Collection documents Stack's deep and diverse involvement in major aerodynamic research projects from the 1930s to the 1970s. A pioneering specialist in high-speed aerodynamics, Stack is considered by all aeronautical historians to be one of the world's most significant aerodynamic researchers. Many of his activities proved crucial to the achievement of flight at transonic and supersonic speeds. He was one of the driving forces behind the Bell X-1 and North American X-15 research airplanes; the slotted-throat transonic wind tunnel; the national SST program; and the General Dynamics F-111 (TFX) variable-sweep wing program. Stack received both the prestigious Collier Trophy (twice) and the Wright Brothers Memorial Trophy. Topics in the Stack papers cover wind tunnel design, operation, and test techniques; research problems related to airfoils, compressible flow, and the boundary layer; reports of important meetings such as NACA-sponsored conferences on aerodynamics in the late 1940s; memoranda and correspondence related to high-speed aerodynamics during World War II and the immediate postwar period; and aircraft development projects such as the North American P-51, Republic P-47B, SST, V/STOL, and the TFX (F-111). Regrettably, no biography of Stack has ever been attempted. When it is, the papers in the Stack Collection will be an important starting place. Unfortunately, the collection includes almost no papers of a personal nature.

Another collection we reviewed at NASA Langley held the papers of American aeronautics pioneer Fred E. Weick, a prolific NACA Langley researcher well known for his work at the laboratory in the 1920s and 1930s. After leaving government employment permanently in 1936, Weick went on to a highly successful career in academia and industry. The thousands of items in this collection (donated by the Weick family to the Langley archives after Weick's death in 1994) include extensive correspondence, reports, memos, articles, newspaper clippings, speeches, and oral histories. These papers document his work with the navy's Bureau of Aeronautics, the NACA, the United Aircraft and Transport Corporation, the Engineering Research Corporation (ERCO), Texas A&M University, and the Piper Aircraft Corporation. In searching through the Weick papers, we gained numerous critical insights into major aeronautical developments from the 1920s to the 1970s, including propeller design; the drag-reduction experiments that resulted in the NACA's famous Collier Trophy–winning program of the late 1920s; the design of pioneering general aviation aircraft such as the Weick W-1A and the Ercoupe; and the refinement of agricultural aerial application (i.e., crop-dusting) aircraft such as the Piper Pawnee. Occasionally in the volumes to follow, we have also reproduced excerpts from Weick's published autobiography, *From the Ground Up: The Autobiography of an Aeronautical Engineer* (Washington, DC, and London: Smithsonian Institution Press, 1988), which was coauthored by project director James R. Hansen.

On the grounds of the Langley Research Center we also reviewed the contents of the Old Dominion University Experimental Aerodynamics Library. Housed within Langley's Full-Scale Wind Tunnel building, this library is the repository for the bound volumes on the history of wind tunnels compiled by Langley aerospace engineer and cryogenic wind tunnel pioneer Robert Kilgore, an individual whose work is much discussed in our study.[23] Kilgore's volumes contain countless manuscripts and published primary documents, arranged chronologically and devoted to specific subjects related both to his own career and to the development of wind tunnels in general. The titles of these volumes are *Development of Cryogenic Wind Tunnels* (Black Volumes 1969–1989) and the *ETB Weekly Briefs* (1980s–1990s). The latter documents Langley's Experimental Techniques Branch, the organization that Kilgore directed while working to develop the cryogenic wind tunnel concept. Kilgore also compiled a similar multivolume general history of wind tunnels that he donated to Langley's Floyd L. Thompson Technical Library.

Without question, we have included more documents from Langley than from any other archives, repository, or library. This is due both to the integrity of the collections at this particular NASA center, and to the extraordinary historical significance of the aerodynamics research activities that have taken place at this, the oldest of the NACA/NASA facilities, over ten decades of operation.

But documents from many other major facilities also play a critical role in our research story. One of the most important of these was the NASA Dryden Flight Research Facility History Office located on Edwards Air Force Base in the Mojave Desert of California, northeast of Los Angeles, which serves as the central repository documenting NACA/NASA's involvement in high-speed flight research.[24] Since fall 1946, the NACA and NASA have maintained a collaborative presence at Edwards with the Air Force and the Navy in the experimental testing of research aircraft. NACA/NASA pilots, engineers, and managers played leading roles in the success of state-of-the-art R&D projects that extended humankind's presence into both the air and space. Dryden's history office maintains thirty linear feet of materials

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23 Old Dominion University, Department of Aeronautical Engineering, The Langley Full-Scale Tunnel, P.O. Box 65309, Langley Air Force Base, VA 23665-5309, and at *http://www.lfst.com/*

24 Office of External Affairs, Mail Stop TR-42, NASA Dryden Flight Research Center, Edwards, CA 93523, and at *http://www.dfrc.nasa.gov/History/*

concerning the X-series aircraft (X-1 through X-43) and D-558 program; Century series fighters (F-100, F-101, F-102, F-104, F-105, F-106, F-107); lifting bodies; the North American XB-70 supersonic research platform; the supercritical wing on the modified F-8; and the Highly Maneuverable Aircraft Technology (HiMAT) research vehicle. The office also sponsors an extensive oral history program covering important pilots and engineers in the history of flight research at Dryden.

To the north of Dryden at the mouth of the San Francisco Bay is NASA Ames Research Center. Founded in 1939, the Ames laboratory established the NACA's presence on the West Coast, which contributed greatly to the success of the aircraft manufacturing industry during World War II and the Cold War era. The Ames Research Center Library maintains a history collection documenting the activities of the center from December 1939 through August 1998, when the collection was formally created.[25] The collection measures twenty-eight linear feet and consists chiefly of published primary materials, including promotional brochures, newspaper clippings, and programs from official ceremonies. Other components of the collection are the manuscript and research materials used in the writing of Elizabeth A. Muenger's *Searching the Horizon: A History of Ames Research Center, 1940–1976*.[26] The library also maintains extensive Web-based resources describing the location, scope, and content of other archival collections concerning the history of Ames.[27] The majority of the Ames records are held by the National Archives and Records Administration, specifically at the Pacific Region Office at San Bruno, California. There are also materials about Ames housed at the NASA Headquarters History Office in Washington, D.C.

National Archives and Records Administration

A major part of our research necessarily involved the National Archives and Records Administration (NARA), which at its various facilities around the country maintains and preserves the largest collection of aerospace history archival records in the United States.[28] The federal government's extensive civilian and military involvement in aeronautical research and development since the late

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25 Research Information Resources, Library, Mail Stop 202-3, NASA Ames Research Center, CA 94035-1000, and at *http://mainlib.arc.nasa.gov/*

26 Elizabeth A. Muenger, *Searching the Horizon A History of Ames Research Center, 1940–1976* (Washington, DC: NASA SP-4304, 1985).

27 Sources for Researchers of Ames History at *http://history.arc.nasa.gov/research.htm*

28 National Archives and Records Administration, 700 Pennsylvania Avenue NW, Washington, DC 20408, and at *http://www.nara.gov/research/*

nineteenth century has ensured the survival of significant collections. Organized into record groups (RG), these collections document the activities of particular federal agencies and departments involved in the development of American aeronautics. For our purposes, the most important record group was RG 255, which holds documents of the NACA and NASA from 1915 to 1988. RG 255 measures a gargantuan 5,182 cubic feet; however, the files are not located in one place but are distributed among various NARA facilities across the United States.[29] RG 255 consists of correspondence, technical and administrative reports, blueprints and drawings, photographs, meeting minutes, and memoranda from NACA and NASA committees, subcommittees, research units and facilities, and national and international offices. The primary NARA facilities holding files of interest to our project were the NARA Mid-Atlantic Region Office (City Center Philadelphia) in Philadelphia, and the NARA Pacific Region (San Francisco) Office at San Bruno, California.

An effort to integrate portions of the archival collections of NACA/NASA into the National Archives in the early 1990s resulted in, among other things, the move of NASA Langley's correspondence files (dating from 1917 to 1958) to the NARA facility in Philadelphia.[30] These files are also very significant historically. The NACA's manner of "correspondence control"—wherein all memoranda, letters, and notices went through Langley's engineer-in-charge before being sent out to NACA Headquarters or to any outside addresses—led to a very effective historical archive, one that enables historians to follow the business of the laboratory as it routinely unfolded, virtually day by day. In our view, however, it was a mistake for NARA to remove these correspondence files from Langley, where they not only were being well preserved but also fit into a complete network of archival materials involving the NACA research authorization (RA) files and a vast collection of library holdings. Documents in RA files, for example, routinely include cross-references to items in Langley's correspondence files. Previous to NARA's acquisition of the correspondence files, researchers could simply move from one part of the Langley historical archives to another to check the cross reference; now, unfortunately, they must travel from Hampton, Virginia, to Philadelphia, Pennsylvania.

The other NARA facility that contributed to our research was the NARA Pacific Region (San Francisco) Office at San Bruno, California, the central repository for the records of the Ames Research Center from 1939 to 1988.[31] Finding

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29 Guide to Federal Records in the National Archives of the United States—Record Group 255, *http://www.nara.gov/guide/rg255.html#255.2*

30 NARA Mid Atlantic Region (Center City Philadelphia), 900 Market Street, Philadelphia, PA 19107-4292, and at *http://www.nara.gov/regional/philacc.html*. This facility contains a total of 347 cubic feet of NACA records, and finding aids are available. A portion of the collection is indexed by subject.

31 NARA Pacific Region, 1000 Commodore Drive, San Bruno, CA 94066-2350, and at *http://www.nara.gov/regional/sanfranc.html*

aids are available for most of the 1,025-cubic-foot collection. Interspersed in the center's central files are correspondence, data sheets, meeting minutes, memoranda, and technical reports pertaining to aerodynamics, high-performance aircraft technology, and wind-tunnel tests of such notable World War II aircraft as the P-51 Mustang and P-38 Lightning. The materials from 1939 to the early 1960s are processed, well organized, and readily accessible while those from 1970 have not been fully integrated into the collection.

United States Air Force

The inextricable link between the technical development of flight and the military's participation in that quest has been a persistent theme throughout the twentieth century—and through our documentary history as well. The Air Force History Support Office (AFHSO), at Bolling Air Force Base, Washington, D.C., oversees the writing and publication of books, monographs, and professional studies and reports that document Air Force history.[32] These efforts are primarily for the benefit of Air Force leadership, but the program also exists for scholars of the military's role in aerospace. The History Support Office also directs the history of the various facilities of the Air Force as well as an extensive museum program across the nation. We reviewed several of these works in our research and they helped provide an important context for the development of aerodynamics.

Wright-Patterson Air Force Base (1948–present)—and its predecessors, McCook Field (1917–1927) and Wright Field (1927–1948), near Dayton, Ohio—has been a major center for the technical development of American military aviation. In addition to its importance as a research facility, Wright-Patterson Air Force Base is also the home of two important archival repositories. Since 1917, the successive incarnations of the Air Force Aeronautical Systems Center (ASC), have worked to enhance the performance of military aircraft and their abilities to achieve successful completion of military missions. The ASC History Office maintains and preserves not only the records of that organization, but also the individual papers of important Wright Field engineers who worked at the Air Force Flight Dynamics Laboratory.[33] Of particular importance to aerodynamics researchers are the William Lamar Files, which include many documents regarding the development of supersonic and hypersonic research aircraft and spacecraft between 1949 and 1978. Some finding aids are available. We reviewed the contents

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32 Air Force History Support Office, AFHSO/HOS, Reference and Analysis Division, 200 McChord Street, Box 94, Bolling Air Force Base, Washington, DC 20332-1111, and at *http://www.airforcehistory.hq.af.mil/*

33 United States Air Force Aeronautical Systems Center History Office, 2275 D Street, Suite 2, Wright-Patterson Air Force Base, OH 45433-7219.

of these collections, though admittedly we could have done much more with them. Two of the primary problems of working in military archives, of course, are document classification and security clearance.

The Research Division of the United States Air Force Museum in Dayton maintains an extensive collection of archival materials supporting the exhibition of Air Force history.[34] The museum's collection approximates 200,000 documents. It is comprised of photographs, technical manuals, drawings, reports, and other materials, most of them dealing with specific artifacts in the museum's collection. Many of the documents are organized by subject airplanes, which facilitates a researcher's study of milestone aircraft such as the Martin B-10 of the 1930s and the Century series fighters of the 1950s and 1960s.

While Wright-Patterson AFB has served the Army, and later the Air Force, as its major center for aircraft research and development, Edwards AFB in the Mojave Desert of California has, since the early years of the Cold War, been the more broadly based center of high-performance flight research and testing. The Air Force, Navy, and NACA/NASA have used this remote location to perform the stunning aerospace trials related primarily to high-speed flight. The Air Force, through its Flight Test Center, has also used the facility to evaluate experimental and prototype military aircraft. The United States Air Force Air Force Flight Test Center History Office (AFFTC/HO) is responsible for documenting the activities of this organization.[35] The history office preserves important material on the X-series aircraft, with a particularly strong collection documenting the Bell X-1, fighter aircraft from the air force inventory, biographical files on leading test pilots and military officers, and general documents on high-speed flight research.

Because it is located so close to Auburn University and holds such a major collection of aerospace archives and library materials, Maxwell Air Force Base in Montgomery, Alabama, the home of the Air Force's Air University (which trains the service's officers for higher command and staff duties), was a mainstay of our research project. On base at Maxwell is the Air Force Historical Research Agency (AFHRA), which is the central repository for Air Force historical documents.[36] Unit histories, command and theater of operations records, and personal papers of leading military engineers and personnel document the air force's continued involvement in the aerodynamic development of the airplane.

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34 United States Air Force Museum/MUA, Research Division, 2601 E Street, Wright-Patterson Air Force Base, OH 45433-7609, and at *http://www.wpafb.af.mil/museum/mua.htm*

35 United States Air Force Air Force Flight Test Center History Office, 305 E. Popson Avenue, Edwards Air Force Base, CA 93524-6595, and at *http://www.edwards.af.mil/history/index.html*

36 Air Force Historical Research Agency, 600 Chennault Circle, Bldg 1405, Maxwell Air Force Base, AL 36112-6424, and at *http://www.maxwell.af.mil/au/afhra/*

National Air and Space Museum

Of course, no research project related to aeronautical development in the United States would be complete without examination of the collection at the National Air and Space Museum (NASM) in Washington, D.C., one of the premiere aerospace archives and libraries in the world.[37] NASM collections represent government, military, corporate, and academic involvement in humankind's journey through air and space. Overall, NASM possesses over 1,400 archival collections amounting to some 10,000 cubic feet of material. The different types of collections include personal and professional papers, corporate and institutional records, and "artificial" collections created from published sources to serve as reference files for a particular subject. A good point of departure before embarking upon any research at the museum is Paul E. Silbermann and Susan E. Ewing's *Guide to the Collections of the National Air and Space Archives*,[38] which describes 250 of the individual, corporate, government, military, and artificial collections acquired by the museum through 1989. Readers should be aware that this guide is not exhaustive, however, as NASM holds more than the 250 collections described therein.

One of the more useful collections consulted by the project team was the NASM Technical Files, which consists of 1,300 cubic feet of aviation and space-related materials arranged as a vertical file. Initially organized for the use of the museum's curatorial staff, these records are organized by subject, aircraft, individuals, organizations, events, and objects to include correspondence, reports, brochures, press releases, clippings, and photographs. A particularly helpful document was the original 1934 Douglas Aircraft Company report on the development of the DC-1 and DC-2, the first truly modern aircraft to emerge from the airplane design revolution of the 1920s and 1930s. In addition to its huge collection of manuscript material, the NASM archives also maintains an estimated 1.5 million photographs; 700,000 feet of motion picture film; and 2 million technical drawings.

United States Navy

Members of the project team also visited the Naval Historical Center at the Washington Navy Yard in Washington, D.C. Here, for example, we researched the

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37 Smithsonian Institution, National Air and Space Museum, National Air and Space Archives, MRC 322, Seventh Street and Independence Avenue SW, Washington, DC 20560, and at *http://www.nasm.edu/nasm/arch/archdiv.htm* or *http://www.nasm.edu/nasm/arch/ARCH_REPOS/GUIDE.PT7.html#NASM*

38 Paul E. Silbermann and Susan E. Ewing, *Guide to the Collections of the National Air and Space Archives* (Washington, DC: National Air and Space Museum, April 1991).

Navy's participation in the development of early wind tunnels.[39] Records of U.S. Navy aviation are located in two buildings within the Navy Yard. The main History Center, located in Building 57, contains Navy organizational archives and transcripts of interviews with several captains and admirals before their retirements, including individuals prominent in naval aviation. The Aviation History Office in Building 157 maintains other naval aviation records. These include documents, published and unpublished manuscripts, and photographs concerning Navy aircraft programs and facilities. Finding aids are available.

Industrial and Corporate

A primary objective of our documentary research was to visit archival centers based in the aircraft industry and to fully integrate the industry's contribution to aerodynamics development into our larger study. Unfortunately, records-keeping realities within the private sector made it very difficult for us to reach this goal. Economic and financial transitions within the aerospace industry have doomed some important collections to be closed forever. Fortunately, some of the succeeding corporate entities have been able to secure the integrity of some vital archival collections.[40] Most notably, through a series of mergers in the 1990s, the Boeing Company of Seattle, Washington, has been able to integrate into its own historical memory the archives of North American Rockwell, Inc., as well as that of the McDonnell-Douglas Corporation. As a result, Boeing now maintains the preeminent aerospace corporate archives in the United States.

The Boeing Company's Historical Archives represents an unprecedented commitment at the corporate level to preserve aviation history.[41] The program maintains archival facilities in Seattle; Long Beach, California; and St. Louis, Missouri. These facilities are principally organized and maintained to serve the company's needs rather than those of the general historian—and the company must give its permission for access to and use of its materials. Boeing's Historical Archives are not actually equipped to handle and provide service to general researchers, though its directors will do their best to respond to outside inquiries

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39 Naval Historical Center, Naval Aviation History Branch, Washington Navy Yard, 805 Kidder Breese, SE, Washington, DC 20374-5060, and at *http://www.history.navy.mil/index.html* or *http://www.history.navy.mil/branches/nhcorg4.htm*

40 The following aerospace manufacturers that had no archival program or did not open their doors to this scholarly study included Lockheed-Martin, Northrop-Grumman, members of the United Technologies conglomerate (Sikorsky, Vought), Piper, and Cessna.

41 Historical Archives, The Boeing Company, MS4H-0Z, P.O. Box 3707, Seattle, WA 98124, and at *http://www.boeing.com/history/*

and research objectives. Overall, the Boeing Company was very generous in its assistance to our conduct of research, and we are happy to have the company's permission to reproduce some of the historically significant documents we found in its collection. If our documentary history does nothing more than inspire the aerospace industry to provide a greater commitment to archival collection and to scholarly research, we shall have provided a critically important service to the history of aeronautics and space in America.

Because Boeing's materials were so helpful to us, more about its archival collections should be said here. Seattle lumber magnate William E. Boeing started manufacturing aircraft in 1916. By the 1920s, his company produced passenger and mail airplanes as well as military fighters and bombers. Boeing's enterprise was one of the first manufacturing concerns to benefit from the innovations brought forth by the airplane design revolution when the company moved toward specialization in multi-engine aircraft. The Boeing Company pioneered the all-metal "modern" airplane, the Model 247, as well as the Boeing B-17 Flying Fortress and B-29 Superfortress of World War II. At the dawn of the jet age, the company produced the first successful jet bombers, the B-47 Stratojet and B-52 Stratofortress plus the prototype Model 367-80, the ancestor of the long running 707 series of modern commercial jetliners. In the 1950s and 1960s, Boeing won the contract for the ill-fated SST and introduced the "jumbo-jet" 747. In the 1990s, Boeing innovated the "paper-less" 777 airliner, the first aircraft to be designed entirely with digital imaging technology. All of these aircraft developments are detailed in our study.

Boeing made important business acquisitions over the course of the twentieth century that greatly enhanced its prominence as an aircraft manufacturer. In the 1920s, Boeing's control of the Stearman Company ensured a strong position in the general aviation segment of the aviation industry. In 1960, Boeing acquired the Vertol Aircraft Company of Philadelphia, Pennsylvania, manufacturers of the CH-46 Sea Knight and CH-47 Chinook military helicopters. This made Boeing a power in the manufacture of rotary-wing aircraft. These company developments, too, make the Boeing archives critically important to any research into the history of American aeronautics.

The Boeing Company Historical Archives facility in Seattle is the main repository for the company's archival collections. Ninety percent of the archival and microform material held there is organized around specific aircraft designated by the Boeing model number; all of these numbers are indexed on computer. Researchers need to be aware of the Boeing model number in order to access the records successfully. For example, if a researcher wants to find records on the famous B-17 Flying Fortress, one must know that Boeing's designation for the aircraft was Model 299. Materials that the project team consulted at Boeing included its extensive collection of aircraft engineering reports; personal and company correspondence from the 1920s to the present; subject and biography files; aircraft project files; personal and professional papers; and oral history interviews of leading engineers and managers such as Claire Egtvedt, Maynard Pennell, Ed Wells, and William Cook.

From 1929 to 1934, Boeing Aircraft was part of United Aircraft and Transport Corporation, which included America's leading airlines and manufacturers and was one of the three major aviation conglomerates to emerge.[42] The corporation sponsored a technical advisory committee that included many leading aeronautical engineers such as Igor Sikorsky, Jack Northrop, and Fred E. Weick. In the papers of Claire Egtvedt, one of Boeing's leading managers and engineers, survives the only available transcriptions of the immensely valuable meeting minutes from 1929 to 1934. Nowhere else can a historian have the opportunity to see the verbatim discussion of the technical development of the products from America's most powerful aviation corporation. Readers will find an outstanding example of the importance of these meeting transcripts in Volume 1.

The Seattle location also maintains the records of North American Rockwell Corporation. In 1934, North American Aviation, Inc., emerged from the nucleus of the General Aviation Manufacturing Corporation of Dundalk, Maryland. The resulting company specialized initially in the design of small, single-engine trainers—notably the NA-16, BT-9, and AT-6 airplanes. By the early 1940s, North American had set its sights higher and manufactured its highly successful P-51 Mustang fighter and B-25 Mitchell medium bomber. The corporation's highly profitable transition into the design, production, and manufacture of high-performance military jet aircraft included the F-86 Sabre, FJ-1 Fury (the navy's first swept-wing jet), and the F-100 Super Sabre. North American became the corporate partner with the air force and NACA/NASA in the hypersonic X-15 research airplane and the experimental supersonic, delta-wing XB-70 Valkyrie. In 1966, North American Aviation merged with the Rockwell Standard Corporation and became North American Rockwell Corporation. In 1973, North American Rockwell became Rockwell International to reflect the company's widening range of businesses. It introduced the B-1 Bomber with variable-geometry wings. Rockwell's pioneering work on flight research and experimental design continued with its work on the tail-less X-31 enhanced-fighter maneuverability demonstrator. In December

[42] Member companies of the United Aircraft and Transport Corporation included airframe manufacturers Avion (Northrop), Boeing, Sikorsky, Chance Vought, and Stearman; engine and propeller makers Pratt and Whitney and Hamilton Standard; and the commercial operators United Airlines and Boeing Air Transport. The airline component of the corporation included United Airlines, Boeing Air Transport, National Air Transport, Pacific Air Transport, and Varney Air Lines. The corporation also controlled the Boeing School of Aeronautics, United Aircraft Exports, and the United Airports Company.

1996, the space and defense divisions of the Boeing Company and Rockwell International merged and the Rockwell contingents operated as a subsidiary under the name Boeing North American.

The overwhelming majority of North America's archival collection is not catalogued and remains unprocessed due to the relatively recent acquisition of the materials. As in the case of the Boeing files, effective evaluation of this collection requires extensive knowledge of North American's model number system, which can be acquired from secondary sources. The largest component of the collection is project correspondence recorded on microfilm—especially of late 1930s and 1940s projects such as the first trainer, the NA-16; Model NA-73 (P-51 Mustang); and the prototype XFJ-1 Fury. The collection also includes photographs, blueprints, and a small number of promotional materials from North American's earliest ancestor, General Aviation.

The Boeing Company, along with its North American component, merged with the McDonnell Douglas Corporation in August 1997. Itself the product of a 1967 merger of two eminent aerospace companies, McDonnell Douglas was a world leader in the design and production of high-performance jet fighter aircraft and commercial airliners. Due to the proprietary and military nature of its products, the records documenting the aerodynamic development of McDonnell-Douglas's fighter aircraft could not be made accessible to our project, and their size and importance is thus unknown.[43] As a result, we were able to research only the former Douglas Company's involvement in the aerodynamic development of its products.

Donald W. Douglas founded the company that bore his name in 1920, and the small enterprise quickly rose to prominence when it helped initiate the onset of the airplane design revolution with its introduction of the pioneering DC series of transports in 1933. Douglas employed such leading aeronautical engineers as James H. "Dutch" Kindelberger, John K. Northrop, and Edward H. Heinemann.

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41 It is unfortunate that the documentary project was unable to access the archival records of McDonnell Aircraft, due to its important position in aerospace history. After working for various aircraft manufacturers, such as the Aviation Division of the Ford Motor Company and the Glenn L. Martin Company, McDonnell established his own company in St. Louis, Missouri, in 1939. An early project McDonnell pursued was his Doodlebug of 1927, which the NACA latter used as a research vehicle for STOL experiments. Primarily a component manufacturer during World War II, the company submitted pioneering designs such as the twin-engine, long-range XP-67 fighter. The postwar period and the emergence of jet aircraft, specifically fighters, would catapult McDonnell to a prominent position within the world aerospace industry. The FH-1 Phantom was the first military jet aircraft to operate from an American aircraft carrier and was quickly followed by the F2H Banshee. The highly versatile F-101 Voodoo and F-4 Phantom II of the 1950s and 1960s led to the even more adaptable F-15 Eagle and F/A-18 Hornet. Hughes Helicopters became part of McDonnell Douglas in January 1984 and produced the important OH-6A Cayuse light observation helicopter and the AH-64 Apache advanced attack helicopter.

During World War II, the company produced the A-20 Havoc and A-26 Invader light bombers, the C-47 Skytrain and C-54 Skymaster transports, and the TBD Devastator and SBD Dauntless naval aircraft. The Cold War era saw it manufacture the military aircraft A4D Skyhawk and C-17 Globemaster III, the experimental high-speed research aircraft of the D-558 series and the X-3 Stiletto, and the commercial airliners MD-90 and MD-11.

The Boeing Company's Historical Archives at Long Beach, California, maintain primarily the corporate memory of the Douglas Aircraft Company.[44] Archival materials housed there include internal correspondence, engineering data, photographs, press releases, GALCIT wind tunnel reports, personal papers, the company newspaper *Airview*, and files organized by model number and subject. A collection that proved crucial to the success of the documentary history was the group of nine boxes containing the professional papers of Richard T. Cathers, who served as chief of the Advanced Design Group at McDonnell Douglas from the 1970s to the 1980s. Cathers's materials included documents related to developmental work on commercial airliners such as the DC-10, proposed SST and HSCT aircraft, and STOL transports.

The N. Paul Whittier Aviation Library and Archives of the San Diego Aerospace Museum preserves the history of the various incarnations of two other significant West Coast aircraft manufacturers, Convair and Teledyne Ryan.[45] The museum holds the surviving papers of Consolidated-Vultee and Convair from the 1930s to the 1960s and Ryan Aircraft and Teledyne Ryan from 1925 to 1960. These records are organized by aircraft project and are in the form of scrapbooks, technical reports, project correspondence, letters, memoranda, and GALCIT tests. The Convair files were especially helpful in illuminating the aerodynamic development of high-lift devices and big aircraft, primarily the B-24 and the B-36. There were also records related to the development of the jet-powered XF2Y Sea Dart seaplane interceptor; the VTOL XFY-1 Pogostick; and the Convair 240, 340, 440, 880, and 990 series airliners. The Ryan scrapbooks cover the development of the NYP *Spirit of St. Louis*, the Fireball FR-1 hybrid jet-piston engine aircraft, the Dragonfly YO-51 STOL observation plane, the X-13 Vertijet and Vertiplane V/STOL projects, and the ducted-fan SV-5A and SV-5B. The museum also maintains extensive subject files, which include entries on "aerodynamics" and "wings."

Another useful collection found at the San Diego Aerospace Museum was of the papers of Edward H. Heinemann (1908–1991), a prolific aircraft designer

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44 Historical Archives, The Boeing Company, 3855 Lakewood Boulevard, Mail Code D036-0038, Long Beach, CA 90846.

45 San Diego Aerospace Museum Archives, 2001 Pan American Plaza, Balboa Park, San Diego, CA 92101-1636, and at *http://www.aerospacemuseum.org/library.htm*

who primarily worked for the Douglas Aircraft Company. Heinemann was personally responsible for the design of over twenty aircraft, which included the SBD Dauntless, A-20 and A-26 bombers, A-1 Skyraider, F4D Skyray, A4 Skyhawk, and D-558 Skystreak. Twelve boxes, ranging from 1926 to 1986, include correspondence; biographical articles; and materials related to Heinemann's designs, patents, speeches, and involvement in specific aircraft projects.

Back in the country's heartland, the Henry Ford Museum and Greenfield Village Archives in Dearborn, Michigan, also contributed to our project. There, we found records documenting Henry Ford's and the Ford Motor Company's involvement in aeronautics from 1925 to 1936.[46] Interested in doing for aviation what he had already succeeded in doing for the automobile industry, Henry Ford bought the Stout Metal Airplane Company and its idea for an all-metal airplane; he hoped this would be the foundation for his new aviation enterprise. The Stout Metal Airplane Company Collection, with some ninety linear feet of records in 169 boxes, documents Ford's earliest activities and their precursors. The internal correspondence, technical reports, and photographs pertaining to the highly successful Tri-Motor transport proved the most illustrative from the standpoint of aerodynamic development during the airplane design revolution. Another valuable resource found at the Henry Ford Museum and Greenfield Village Archives was the oral history of Harold Hicks, the engineer behind the development of the Ford Tri-Motor.

We also visited the Missouri Historical Society Archives in St. Louis, Missouri. It maintains records pertaining to regional involvement in aviation, some of which relates to aerodynamic development.[47] Under the Graeco-Byzantine dome of the renovated Historic United Hebrew Temple at Forest Park, researchers can evaluate the papers of Lloyd Engelhardt (1905–1973), who served from 1924 to 1970 as an aeronautical engineer for the Curtiss-Wright Corporation, McDonnell Aircraft Corporation, and McDonnell Douglas Corporation. The approximately seven linear feet of materials include Engelhardt's engineering papers for specific airplanes; inter-office memoranda; and published primary articles on V/STOL, supersonic and hypersonic design, and commercial airliners.

Academic Sources

Along with the governmental, military, and industrial archives we visited in the course of our project, we also sought to identify significant materials located

46 Henry Ford Museum, Archives and Research Library, Dearborn, MI 48121, and at *http://www.hfmgv.org/research/index.html*

47 Missouri Historical Society Archives, Jefferson Memorial Building/Forest Park, St. Louis, MO 63112-1099, and at *http://www.mohistory.org/*

in the libraries and archives of America's universities. We soon realized that one of the most important academic collections to examine was at the California Institute of Technology (Caltech) in Pasadena, California.

The philanthropic Guggenheim Fund for the Promotion of Aeronautics catapulted the Caltech to a preeminent position within the aeronautical community in the late 1920s, a position the institution retains today. The institute's archives maintain materials related to key individuals associated with the university's aeronautical engineering program and the operation of the GALCIT.[48] Organized by individual collection, these papers include fifteen linear feet of the personal and professional correspondence, government files, manuscripts, technical papers, and personal diaries of Dr. Clark B. Millikan; a twenty-page oral history along with the papers for the 1928–1934 period of Dr. Arthur E. Raymond, equaling approximately one linear foot; and the two linear feet of oral history and papers from 1928–1974 of Dr. Arthur L. Klein. Perhaps the most meaningful collection at Caltech is the eighty-one linear feet of Theodore von Kármán's 145,000 pages of letters, scientific manuscripts, reports, unpublished speeches, and lecture notes that span from the 1880s to 1960. GALCIT and its aeronautical library closed in the early 1990s. The library's voluminous collection of wind tunnel test reports of specific aircraft was distributed among members of the aerospace industry in lieu of complete disposal.

Our research also took us to The University of Texas at Dallas History of Aviation Collection at The University of Texas at Dallas Eugene McDermott Library. There we found an archive containing over 200 private collection items and 2.5 million items pertaining to aviation history.[49] Of particular interest to aeronautical researchers is the library's Lighter-Than-Air Collection. Included in this are the Rosendahl Collection, with almost 350 boxes of dirigible and blimp materials, and the Robinson Collection, which contains forty-five boxes of materials dealing with dirigible operations and, surprisingly, also with B-58 bomber development. The General Aviation Collection includes two boxes of personal papers and documents regarding Edwin A. Link and Link flight trainers, as well as other documents dealing with general aviation, but few of these are directly related to aerodynamics. Good finding aids are available.

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48 California Institute of Technology, Institute Archives, Mail Code 015A-74, Pasadena, CA 91125, and at *http://broccoli.caltech.edu/~archives/*

49 University of Texas at Dallas, History of Aviation Collection, Eugene McDermott Library, Special Collections, P.O. Box 830643, Richardson, TX 75083-0643, and at *http://www.utdallas.edu/library/special/aviation/*

Primary Sources—Published

In addition to the primary archival and manuscript material that was central to our documentary history, our project team also consulted a large number of published primary sources in the form of articles, reports, and memoranda from national and international agencies, trade groups, and the popular aviation media. The team found these materials at three major libraries. The Floyd L. Thompson Technical Library at NASA Langley Research Center holds complete series of the major NACA and NASA publications—Technical Report (TR), Technical Note (TN), Technical Memorandum (TM), Advanced Confidential Report (ACR), and the Wartime Confidential Report (WCR).[50] Several of these publications, or selections from them, are reproduced in the documentary collection to follow. The Thompson library also maintains a comprehensive card-file index to all types of aeronautical literature that dates back to the early days of the NACA; much of this has not been computerized and is therefore not available online. Most of these publications, such as professional papers generated by the American Institute of Aeronautics and Astronautics (AIAA) and the North Atlantic Treaty Organization's (NATO's) Advisory Group for Aircraft Research and Development (AGARD), are accessible through the library system.

An enormous amount of NACA/NASA information has become increasingly available via the Internet. The NASA Center for Aerospace Information (CASI) Technical Report Server,[51] the NACA Report Server,[52] and the NASA Technical Report Server[53] provide full-text FTP reproductions of major technical documents. At a certain point, all NACA/NASA publications should be available online and will be an extraordinary resource of research into the history of aeronautics and space exploration.

The Air University Library (AUL) at Maxwell Air Force Base, Alabama,[54] and the Auburn University Library, Auburn, Alabama,[55] are both outstanding repositories for primary aeronautical periodicals and secondary works. These libraries possess full or partial series of the various incarnations of *Aviation Week and Space*

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50 The Floyd L. Thompson Technical Library, Langley Research Center, Hampton, VA 23681-0001.

51 NASA Center for Aerospace Information Technical Report Server, *http://www.sti.nasa.gov/RECONselect.html*

52 NACA Report Server, *http://naca.larc.nasa.gov/*

53 NASA Technical Report Server, *http://techreports.larc.nasa.gov/cgi-bin/NTRS*

54 Air University Library, 600 Chennault Circle, Building 1405, Maxwell Air Force Base, AL 36112-6424, and at *http://www.au.af.mil/au/aul/aulv2.htm*

55 Auburn University Libraries, 231 Mell Street, Auburn University, AL 36849-5606, and at *http://www.lib.auburn.edu/*

Technology, *Journal of the Royal Aeronautical Society*, *Aero Digest*, *Flight*, and *The Aeroplane* as well as publications from professional societies such as the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the AIAA. The Auburn University Interlibrary Loan Office provided access to materials that were not otherwise available in a timely and efficient manner.

Naturally, our project benefited from considerable documentation pertaining to the achievement of the Wright Brothers. In much the same spirit of this documentary history, Marvin W. McFarland edited *The Papers of Wilbur and Orville Wright, Including the Chanute-Wright Letters and Other Papers of Octave Chanute*. This work from 1953 reproduced seminal documents from the development of the first practical heavier-than-air aircraft.[56]

An individual who was intimately connected with several of the successful aerodynamics programs at Langley was Fred E. Weick. His memoirs, *From the Ground Up: The Autobiography of an Aeronautical Engineer*, co-written by James R. Hansen, provide remarkable insights into the story of early aeronautical development in the United States that are not just associated with the NACA or Langley, but with the navy and the aircraft industry as well.[57] Weick went on to successful careers in academia and industry and his autobiography illuminates those aspects of his career as well.

One of the most prolific and important aerodynamicists of the twentieth century was Theodore von Kármán. As noted in our introduction, von Kármán's autobiography, *The Wind and Beyond: Theodore von Kármán, Pioneer in Aviation and Pathfinder in Space* (co-written with Lee Edson) inspired our study in many ways, including our choice of an overall title.[58]

Because our project focused on the history of aerodynamics in America and not the world—and because our budget would not have allowed it anyway—we did very little research outside of the United States. Wanting to place American developments in global context, we did review a significant amount of secondary literature related to the worldwide story and also located a number of non-American (mostly European) reports and articles, some of which are reproduced in this study. We did take the opportunity to explore the contents of one European library, however. The library of the Royal Aeronautical Society (RAeS) in London provided valuable information on the development of the early wind

56 Marvin W. McFarland, ed., *The Papers of Wilbur and Orville Wright,Including the Chanute-Wright Letters and Other Papers of Octave Chanute* (New York, NY: McGraw-Hill, 1953).

57 Fred E. Weick and James R. Hansen, *From the Ground Up: The Autobiography of an Aeronautical Engineer* (Washington, DC: Smithsonian Institution Press, 1988).

58 Theodore von Kármán with Lee Edson, *The Wind and Beyond: Theodore von Kármán, Pioneer in Aviation and Pathfinder in Space* (Boston and Toronto: Little, Brown and Company, 1967).

tunnel, primarily the activities of society members Francis Wenham and Horatio Phillips in the late nineteenth century. The RAeS is one of the oldest institutions devoted to aeronautical and aerospace engineering, and it maintains the oldest library in the world dedicated to the study of aeronautics and astronautics. Its collection includes all of the society's earliest records, dating back to its first meeting in 1866. The early Annual Reports are a goldmine of papers containing the thoughts and ideas of prominent European researchers in the field. Finding aids and excellent assistance are available, but access for non-RAeS members is expensive, 10£ per day.[59]

Secondary Sources

The project team looked to the work of other historians and scholars not only to formulate our research plan but also to inform our overall perspective. The topics, themes, and interpretations offered in these volumes represent our collective reflection upon what has become a vigorous field of aerospace history. As a result, a growing body of substantial research into the history of flight and its technical development has guided us through our deliberations. Much of this work has been produced with the help of the NASA History Office. Since establishment in 1959, this office has sponsored a steady stream of important historical works discussing NACA/NASA's involvement in the development of aeronautics and space. Many of these works are now out of print, but are available online.[60] Information on how to access them and other resources created by the NASA History Office records are provided in footnotes at appropriate points within this bibliographical essay.

But many fine works in aerospace history have come from places other than NASA. Products of rigorous independent scholarship, these works have appeared in books and articles published by academic and commercial presses. One of the most fundamental studies that we utilized in our project was John D. Anderson, Jr.'s *A History of Aerodynamics and Its Impact on Flying Machines*, published by Cambridge University Press in 1997. Anderson's was the first work of its kind to directly address the emerging practice of aerodynamics from the nineteenth century to the present.[61] Heavily footnoted and written in a context that benefits both aerodynamic

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59 The Royal Aeronautical Society, 4, Hamilton Place, London, W1V 0BQ, United Kingdom, and at *http://www.raes.org.uk/*

60 NASA Histories Online, *http://www.hq.nasa.gov/office/pao/History/online.html*

61 John D. Anderson, Jr., *A History of Aerodynamics and Its Impact on Flying Machines* (Cambridge, MA: Cambridge University Press, 1997).

practitioners and historians, we viewed this work as our main point of departure. It was our goal that our volumes would read profitably side-by-side with Anderson's.

Lawrence K. Loftin, Jr.'s *Quest for Performance: The Evolution of Modern Aircraft*[62] helped us enormously to understand some of the arcane aspects of aircraft engineering and aerodynamic design. His book also aided us in identifying, classifying, and describing the major eras in heaver-than-air powered flight. Similarly, *The Technical Development of Modern Aviation*,[63] by Ronald Miller and David Sawers, assisted us by addressing aerodynamic issues within the overall system of the airplane. The essays by John D. Anderson, Jr., James R. Hansen, Richard K. Smith, and Terry Gwynn-Jones that appeared in John T. Greenwood's edition of *Milestones of Aviation* elaborated on different technological trends in aeronautics crucial to aerodynamic development.[64] Walter G. Vincenti's *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History*,[65] challenged us to apply epistemological and sociological notions to what we were discovering in the empirical evidence. A general work that was immensely valuable to the less technically literate in our group (and thus to any nonspecialist's understanding of the mechanics of flight) was Theodore A. Talay's *Introduction to the Aerodynamics of Flight*.[66]

In our study of the Wrights, we placed tremendous value on the work of the National Air and Space Museum's Dr. Tom D. Crouch, the world's leading scholar of the early flight period. In *A Dream of Wings: Americans and the Airplane, 1875–1905* and *The Bishop's Boys: A Life of Wilbur and Orville Wright*, Crouch has brilliantly recreated the international and personal environment in which the Wrights developed their aircraft.[67] Another major work that deserves special consideration is NASM's Peter L. Jakab's book, *Visions of a Flying Machine: The Wright Brothers and the Process of Invention*, which successfully tackles the Wrights' creative engineering approach to solving the design challenges they faced.[68]

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62 Lawrence K. Loftin, Jr., *Quest for Performance: the Evolution of Modern Aircraft* (Washington, DC: NASA SP-468, 1985), *http://www.hq.nasa.gov/office/pao/History/SP-468/cover.htm*

63 Ronald Miller and David Sawers, *The Technical Development of Modern Aviation*, (New York, NY: Praeger, 1970).

64 John T. Greenwood, ed., *Milestones of Aviation* (New York, NY: Macmillan, 1989).

65 Walter G. Vincenti, *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History* (Baltimore, MD: Johns Hopkins University Press, 1990).

66 Theodore A. Talay, *Introduction to the Aerodynamics of Flight* (Washington, DC: NASA SP-367, 1975), *http://history.nasa.gov/SP-367/cover367.htm*

67 Tom D. Crouch, *A Dream of Wings: Americans and the Airplane, 1875–1905* (Washington, DC: Smithsonian Institution Press, 1989) and *The Bishop's Boys: A Life of Wilbur and Orville Wright* (New York, NY: W.W. Norton and Co., 1989).

68 Peter L. Jakab, *Visions of a Flying Machine: The Wright Brothers and the Process of Invention* (Shrewsbury, England: Airlife, 1990).

General histories of the NACA and NASA proved valuable to the conceptualization of our documentary project. A fine overall survey of the two organizations, including coverage of their research commitment to aeronautics, is Roger E. Bilstein's *Orders of Magnitude: A History of the NACA and NASA, 1915–1990*.[69] There are two important histories that focus on the NACA specifically as well. Alex Roland's history, *Model Research: The National Advisory Committee for Aeronautics, 1915–1958*, provides a useful and provocative critique of the NACA style of research.[70] The fact that our work questions the validity of many of Roland's interpretations does not detract from the overall esteem we have for his insightful, shrewdly argued book.

A work that we include here as a secondary source but in truth serves more usefully as a primary document is George W. Gray's 1948 book, *Frontiers of Flight: The Story of NACA Research*. Readers will find that we have used it primarily as the latter, reproducing selections from it as actual documents. The book does celebrate the NACA's achievements, especially in regard to the Committee's contributions to the outcome of World War II.[71] But Gray's technical discussions are so exceptional in communicating difficult engineering concepts and activities to a lay readership that we have incorporated them as a referenceænot as propaganda in the service of the NACA's historical reputation.

No single body of work underpins our entire study more than the histories of NACA/NASA Langley Research Center provided by James R. Hansen. Langley has been one of the epicenters—some might even argue the epicenter—of American aerodynamics research since the 1920s, and thus its history informed our study throughout. Hansen's two books, *Engineer in Charge: A History of the Langley Aeronautical Laboratory, 1917–1958* and *Spaceflight Revolution: NASA Langley Research Center from Sputnik to Apollo*,[72] examine the nature of aerodynamics research activities at Langley. The books cover the laboratory's establishment in 1917 through the transition to space and into the 1960s—with thoughts on what has happened beyond and into the 1990s. Hansen's goal was to present more than just an institutional history of an important aeronautics research facility.

69 Roger E. Bilstein, *Orders of Magnitude: A History of the NACA and NASA, 1915–1990* (Washington, DC: NASA SP-4406, 1989), *http://www.hq.nasa.gov/office/pao/History/SP-4406/cover.html*

70 Alex Roland, *Model Research: The National Advisory Committee for Aeronautics, 1915–1958*, 2 vols. (Washington, DC: NASA SP-4103, 1985).

71 George W. Gray, *Frontiers of Flight: The Story of NACA Research* (New York, NY: Alfred A. Knopf, 1948).

72 James R. Hansen, *Engineer in Charge: A History of the Langley Aeronautical Laboratory, 1917–1958* (Washington, DC: NASA SP-4305, 1987) and *Spaceflight Revolution: NASA Langley Research Center from Sputnik to Apollo* (Washington, DC: NASA SP-4308, 1995).

In these books, he more broadly interprets the events within a government research laboratory devoted to a technological development. As director of our documentary project, he worked to expand—and to correct—some of the coverage he provided in his two-volume study. For example, he delved into the history of NACA/NASA research on helicopters and rotary-wing aircraft, mainly to correct his previous neglect of that topic. An excellent illustrated history of Langley based largely on Hansen's books is James Schultz's *Winds of Change: Expanding the Frontiers of Flight, Langley Research Center's Seventy-Five Years of Accomplishment, 1917–1992*.[73]

After establishment in 1940, NACA Ames Aeronautical Laboratory (later renamed NASA Ames Research Center) became an important center for aerodynamics research, one that directly benefited from the high concentration of aviation manufacturers on the West Coast. Over the past thirty years, considerable effort has been made to document the Ames contribution to aeronautics. Edwin P. Hartman, a NACA/NASA official and leading aeronautical engineer and educator, contributed the first appraisal of the center's activities in *Adventures in Research: A History of Ames Research Center, 1940–1965*.[74] Elizabeth A. Muenger provided another detailed account in *Searching the Horizon: A History of Ames Research Center, 1940–1976*.[75] The latest update, *Atmosphere of Freedom: Sixty Years at the NASA Ames Research Center*, by Glenn E. Bugos, focuses on the history of the center during the last quarter of the twentieth century.[76]

One of the more important research programs conducted at the Ames Research Center has concerned Vertical and Short Takeoff and Landing (V/STOL) aircraft. In the last section of Volume 3 of our documentary history, we study the history of V/STOL research as it has related to helicopter and other rotary-wing aircraft development, as well as the NACA/NASA role in that history. Readers will find that one type of modern rotary-wing aircraft, the tilt rotor, has been a pet subject for NASA research, especially at Ames laboratory. We will make significant use of a 2000 NASA publication on tilt rotor development entitled *The History of the XV-15 Tilt Rotor Research Aircraft: From Concept to Flight*, authored by three Ames researchers who have worked prominently in this field.[77] Selections from this book will also be used as part of our documentary story. A recent book

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73 James Schultz, *Winds of Change: Expanding the Frontiers of Flight, Langley Research Center's Seventy-Five Years of Accomplishment, 1917–1992* (Washington, DC: NASA, 1992).

74 Edwin P. Hartman, *Adventures in Research: A History of Ames Research Center, 1940–1965* (Washington, DC: NASA SP-4302, 1970).

75 Elizabeth A. Muenger, *Searching the Horizon: A History of Ames Research Center, 1940–1976* (Washington, DC: NASA SP-4304, 1985).

76 Glenn E. Bugos, *Atmosphere of Freedom: Sixty Years at the NASA Ames Research Center* (Washington, DC: NASA SP-2000-4314).

that proved tremendously useful for our discussion of helicopter development was Eugene K. Liberatore's *Helicopters Before Helicopters*.[78] So taken were we with the conceptually stimulating epilogue to this book that we reproduced it as the final document in that section.

The highly successful flight research programs at the NACA's High-Speed Flight Research Station at Muroc, California, (later renamed NASA Dryden Flight Research Center) have produced many of the most memorable moments in aviation history, including the flight of the Bell XS-1, which broke the mythical "sound barrier" in October 1947. Historian Richard P. Hallion provides an exhaustive survey of the high-flying, high-speed activities over the Mojave Desert in *On the Frontier: Flight Research at Dryden, 1946–1981*.[79] A helpful companion to Hallion's work is Lane E. Wallace's *Flights of Discovery: An Illustrated History of the Dryden Flight Research Center*.[80] Michael H. Gorn documents the career of a former director of the center and the man for whom the center is now named in *Hugh L. Dryden's Career in Aviation and Space*.[81] An important part of Gorn's biography is the inclusion of facsimile reproductions of key documents from Dryden's career.

Some of the flight research programs conducted at Dryden have garnered their own histories. J. D. Hunley's edition of *Toward Mach 2: The Douglas D-558 Program* documents the joint NACA–navy quest to break the sound barrier in the late 1940s.[82] Two notable histories of lifting bodies come from former NASA employees. R. Dale Reed, a former Dryden engineer, and Milton O. Thompson recount their involvement in *Wingless Flight: The Lifting Body Story* and *Flying Without Wings: NASA Lifting Bodies and the Birth of the Space Shuttle*, respectively.[83]

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77 Martin D. Maisel, Demo J. Giulianetti, and Daniel C. Dugan, *The History of the XV-15 Tilt Rotor Research Aircraft: From Concept to Flight* (Washington, DC: NASA SP-2000-4517, NASA Monographs in Aerospace History, No. 17, 2000).

78 E. K. Liberatore, *Helicopters Before Helicopters* (Malabar, FL: Krieger Publishing Co., 1998).

79 Richard P. Hallion, *On the Frontier: Flight Research at Dryden, 1946–1981* (Washington, DC: NASA SP-4303, 1984), *http://www.dfrc.nasa.gov/History/Publications/SP-4303/*

80 Lane E. Wallace, *Flights of Discovery: An Illustrated History of the Dryden Flight Research Center* (Washington, DC: NASA SP-4309, 1996).

81 Michael H. Gorn, *Hugh L. Dryden's Career in Aviation and Space* (Washington, DC: NASA, *NASA Monographs in Aerospace History*, No. 5, 1996), *http://www.dfrc.nasa.gov/History/Publications/Monograph_5/*

82 J.D. Hunley, ed., *Toward Mach 2: The Douglas D-558 Program* (Washington, DC: NASA SP-4222, 1999), *http://www.dfrc.nasa.gov/History/Publications/D-558/*

83 R. Dale Reed, *Wingless Flight: The Lifting Body Story* (Washington, DC: NASA SP-4220, 1998), *http://www.dfrc.nasa.gov/History/Publications/WinglessFlight/*; Milton O. Thompson and Curtis Peebles, *Flying Without Wings: NASA Lifting Bodies and the Birth of the Space Shuttle* (Washington, DC: Smithsonian Institution Press, 1999).

Computers Take Flight: A History of NASA's Pioneering Digital Fly-by-Wire Project documents an important episode in the refinement of aircraft control systems.[84] Albert L. Braslow's *A History of Suction-Type Laminar-Flow Control with Emphasis on Flight Research* addresses an ongoing effort at Dryden to further refine aerodynamic efficiency through the application of new technology.[85] We found Braslow's insights extremely useful as we endeavored to accept the esoteric nature of the subtle aerodynamic conditions in the so-called "boundary layer."

Often overlooked is the fact that women played (and continue to play) a part in the success of aerodynamics in the United States. Sheryll Goecke Powers, in *Women in Flight Research*, tells the story of the unnamed women who in the early days of Dryden—and at other NACA laboratories before them—worked as "human computers" and were responsible for processing and analyzing wind tunnel and flight research data.[86]

Several important works addressing the development of hypersonic aerodynamics in the United States informed our study. *In Hypersonics Before the Shuttle: A Concise History of the X-15 Research Airplane*, Dennis R. Jenkins analyzes the highly successful flight research program of the late 1950s and 1960s that, in key respects, led technologically to the Space Shuttle program of the 1970s and beyond.[87] Wendell H. Stillwell's *X-15 Research Results with a Selected Bibliography* provides an analysis and exhaustive listing of reports and other "lessons learned" materials drawn from the X-15 program.[88] In "Transiting from Air to Space: The North American X-15," which appeared in *The Hypersonic Revolution: Case Studies in the History of Hypersonic Technology*, Robert S. Houston, Richard P. Hallion, and Ronald G. Bostonis detail many crucial aspects of our country's prototype transatmospheric vehicle or "spaceplane."[89] A definitive source listing for the Space Shuttle appears in Roger D. Launius and Aaron K. Gillette's *Toward a History of the Space*

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84 *Computers Take Flight: A History of NASA'a Pioneering Digital Fly-by-Wire Project* (Washington, DC: NASA SP-2000-4224), *http://www.dfrc.nasa.gov/History/Publications/f8ctf/*

85 Albert L. Braslow, *A History of Suction-Type Laminar-Flow Control with Emphasis on Flight Research* (Washington, DC: NASA, *NASA Monographs in Aerospace History*, No. 13, 1999).

86 Sheryll Goecke Powers, *Women in Flight Research* (Washington, DC: NASA, *NASA Monographs in Aerospace History*, No. 6, 1997), *http://www.dfrc.nasa.gov/History/Publications/WIFR/contents.html*

87 Dennis R. Jenkins, *Hypersonics Before the Shuttle: A Concise History of the X-15 Research Airplane* (Washington, DC: NASA SP-2000-4518, *NASA Monographs in Aerospace History*, No. 18).

88 Wendell H. Stillwell, *X-15 Research Results with a Selected Bibliography* (Washington, DC: NASA SP-60, 1965), *http://www.hq.nasa.gov/office/pao/History/SP-60/cover.html*

89 Bolling Air Force Base, *The Hypersonic Revolution: Case Studies in the History of Hypersonic Technology*, 3 vols. (Washington, DC: Air Force History and Museums Program, 1998), *http://www.hq.nasa.gov/office/pao/History/hyperrev-x15/cover.html*

Shuttle: An Annotated Bibliography.[90] All of these works gave us a framework for our profile of development in hypersonic aerodynamics.

One of the keys to the success of NASA, and the NACA before it, has been the ability to design and construct world-class facilities in support of pioneering research programs. In *The Wind Tunnels of NASA*, veteran NACA/NASA wind tunnel engineer Donald D. Baals and technical writer William R. Corliss provide the standard reference for NASA's preeminent research tools.[91] Those looking for detailed technical information on the operation and use of wind tunnels may find Alan Pope's *Wind-Tunnel Testing* useful.[92] Pope later collaborated with Jewel B. Barlow and William H. Rae, Jr., on *Low-Speed Wind Tunnel Testing*,[93] and he co-authored *High-Speed Wind Tunnel Testing* with Kennith L. Goin.[94] These books contain a wealth of information on the ways engineers have used wind tunnels to develop aircraft designs over several decades.

Two other histories highlight the correlation between advanced research tools and successful research programs. *The High Speed Frontier: Case Histories of Four NACA Programs, 1920–1950*, was written by NACA/NASA engineer John V. Becker, one of John Stack's chief associates and the man who many regard as the "father of the X-15." In his book, Becker offers both first-hand and historical insights into the story of the NACA's work in the 1930s, 1940s, and 1950s on high-speed airfoils, propellers, cowlings, internal-flow systems, and transonic wind tunnels.[95] An anthology of scholarly articles entitled *From Engineering Science to Big Science: The NACA and NASA Collier Trophy Research Project Winners*, edited by Clemson University historian of technology Pamela Mack, cover the processes by which NACA and NASA scientists and engineers successfully employed wind tunnels, aerodynamics, and other types of experimental tools and theoretical methods to generate successful research programs.[96]

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90 Roger D. Launius and Aaron K. Gillette, *Toward a History of the Space Shuttle: An Annotated Bibliography* (Washington, DC: NASA, *NASA Monographs in Aerospace History*, No. 1, 1992), *http://www.hq.nasa.gov/office/pao/History/Shuttlebib/cover.html*

91 Donald D. Baals and William R. Corliss, *The Wind Tunnels of NASA* (Washington, DC: NASA SP-440, 1981), *http://www.hq.nasa.gov/office/pao/History/SP-440/cover.htm*

92 Alan Pope, *Wind-Tunnel Testing*, 2d ed. (New York, NY: John Wiley & Sons, 1954).

93 Jewel B. Barlow, William H. Rae, Jr., and Alan Pope, *Low-Speed Wind Tunnel Testing*, 3d ed. (New York, NY: John Wiley & Sons, 1999).

94 Eugene E. Bauer, *Boeing in Peace and War* (Enumclaw, WA: TABA Publishing, 1991).

95 John V. Becker, *The High Speed Frontier: Case Histories of Four NACA Programs, 1920–1950* (Washington, DC: NASA SP-445, 1980), *http://www.hq.nasa.gov/office/pao/History/SP-445/cover.htm*

96 Pamela Mack, ed., *From Engineering Science to Big Science: The NACA and NASA Collier Trophy Research Project Winners* (Washington, DC: NASA SP-4219, 1998).

Two biographical studies explore von Kármán's role in the American academic and scientific community. The first of these, Paul A. Hanle's *Bringing Aerodynamics to America*, examines the dramatic steps taken by proponents of American aeronautics to transfer European knowledge of aerodynamics from Ludwig Prandtl and his talented group of students at the University of Göttingen to the United States. This initiative led to the importation of two of Prandtl's prize students: von Kármán to Caltech, and Max M. Munk to the NACA.[97] The work of both of these individuals is covered in our text and documents to come. The second of the biographies, *The Universal Man: Theodore von Kármán's Life in Aeronautics*, by Michael H. Gorn, provides another important picture of von Kármán's career as an aerodynamicist and aeronautical research leader.[98] Whereas Hanle's book concentrates on the era of the 1920s and 1930s, Gorn's study spends more time looking at von Kármán's career during and after World War II to his death in the early 1960s.

No single definitive history of the U.S. Air Force's commitment to aeronautical research exists; one is badly needed. Works featuring research from the bountiful Sarah Clark collection in the National Archives have started to appear, but none of them discuss the American military's involvement in aerodynamic development. In *From Huffman Prairie to the Moon: The History of Wright-Patterson Air Force Base*, Lois E. Walker and Shelby E. Wickam provide a valuable introduction to the aeronautical research activities that have taken place at the army and—later—air force installations near Dayton, Ohio.[99]

Project members found value in several secondary works on the history of the Boeing Company. Boeing Historical Services, the unit that manages the firm's historical archives, published *A Brief History of the Boeing Company*, which provides a useful and condensed introduction to the individuals, aircraft, and programs of Boeing, North American Rockwell, and McDonnell Douglas.[100] In *Boeing's Ed Wells*, Mary Wells Geer presents insightful biographical reminiscences of her engineer father, which highlight Boeing's important activities in aircraft design and manufacture during the 1940s.[101] Two popular histories, Robert J. Serling's *Legend and Legacy: The Story of Boeing and Its People* and Harold Mansfield's *Vision: The Story of Boeing*, present the company in a very favorable light while providing a

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97 Paul A. Hanle, *Bringing Aerodynamics to America* (Cambridge, MA: MIT Press, 1982).

98 Michael H. Gorn, *The Universal Man: Theodore von Kármán's Life in Aeronautics* (Washington, DC: Smithsonian Institution Press, 1992).

99 Lois E. Walker and Shelby E. Wickam, *From Huffman Prairie to the Moon: The History of Wright-Patterson Air Force Base* (Washington, DC: General Printing Office, 1986).

100 *A Brief History of the Boeing Company* (Seattle, WA: Boeing Historical Services, 1998).

101 Mary Wells Geer, *Boeing's Ed Wells* (Seattle, WA: University of Washington Press, 1992).

basic survey of the company's history.[102] The standard reference for Boeing aircraft over the decades is *Boeing Aircraft Since 1916* by Peter M. Bowers.[103] Another work we consulted was Eugene E. Bauer's *Boeing in Peace and War.*[104]

North American Aviation and Rockwell have yet to find their historians. Norm Avery's two-volume *North American Aircraft 1934–1998* assists readers mostly in determining the model numbers of individual aircraft and exciting them with stunning photographs.[105] Wagner's *Mustang Designer: Edgar Schmued and the P-51* focuses on the design environment at North American in which the famous World War II fighter gestated. Wagner also highlights the careers of contemporary fellow designers, such as Don Berlin of Curtiss-Wright, to illustrate the existence of an American design community.[106]

Two works were especially helpful in studying the history of the Douglas Company. Douglas J. Ingells, a prolific historian of the aviation industry, in *The McDonnell Douglas Story*, traces the development of two separate companies and the path they followed after their historic merger in 1967.[107] In the same format as Bowers's book on Boeing, Rene Francillon's *McDonnell Douglas Aircraft Since 1920* rates as the major point of departure for any serious study of the corporation's aircraft.[108] Fully half of Henry M. Holden's *The Legacy of the DC-3* delves into the early history of Douglas and the development of the DC-1/2/3 airplanes.[109]

For our epilogue on thoughts about the future of flight, Joseph J. Corn's *The Winged Gospel: America's Romance with Aviation, 1900–1950* offered critical social and cultural insights.[110] Corn's classic little book focuses on America's popular infatuation with the airplane rather than on technological enthusiasm and concepts within the aircraft industry and the aeronautical engineering community.

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102 Robert J. Serling, *Legend and Legacy: The Story of Boeing and Its People* (New York, NY: St. Martin's Press, 1992); Harold Mansfield, *Vision: The Story of Boeing* (New York, NY: Popular Press, 1966).

103 Peter M. Bowers, *Boeing Aircraft Since 1916* (Annapolis, MD: Naval Institute Press, 1989; reprint, New York, NY: Funk and Wagnalls, 1966).

104 Eugene E. Bauer, *Boeing in Peace and War* (Enumclaw, WA: TABA Publishing, 1991).

105 Norm Avery, *North American Aircraft 1934–1998*, 2 vols. (Santa Ana, CA: Narkiewisc/Thompson, 1998).

106 Ray Wagner, *Mustang Designer: Edgar Schmued and the P-51* (Washington, DC: Smithsonian Institution Press, 2000).

107 Douglas J. Ingells, *The McDonnell Douglas Story* (Fallbrook, CA: Aero Publishers, Inc., 1979).

108 Rene Francillon, *McDonnell Douglas Aircraft Since 1920*, 2 vols. (London: Putnam Aeronautical Books, 1990).

109 Henry M. Holden, *The Legacy of the DC-3* (Niceville, FL: Wind Canyon Publishing, 1997).

110 Joseph J. Corn, *The Winged Gospel: America's Romance with Aviation, 1900–1950* (New York, NY: Oxford University Press, 1983).

Nonetheless, it provides an overarching thesis illuminating the dynamics between American culture and ideology and American technological belief and outlook.

Points of Departure

Despite what we feel was a rather comprehensive examination of aeronautics libraries and archives countrywide, without question we left many stones unturned in our endeavor to document the history of aerodynamic development in the United States, in terms of both topics and archival facilities. There was simply no way to visit every potentially interesting repository or engage every related topic. For example, we recognize that more needs to be done to cover general aviation aircraft's aerodynamic design and to explore aerodynamics in university research. It is our hope that our documentary collection will provoke others to add to our research and to create collections of their own. Readers should remember, however, that the NASA History Office contracted with Auburn University to document the history of aerodynamics in America as it related most specifically to the contributions made by the NACA and NASA. Such a focus demanded that we emphasize certain archives and topics, and minimize others.

As mentioned above, one area we regret to have neglected involves general—or private—aviation. A leading general aviation manufacturer during the period of the airplane design revolution of the 1920s and 1930s, well known for its "Mystery Ship" and Model R air racers, was The Travel Air Company. We had hoped to visit the special collections and archives of Wichita State University Library, where the papers of Walter E. Burnham and Herb Rawdon are stored. These materials document the engineering development of Travel Air general aviation and racing aircraft during the 1920s and 1930s.[111]

Given the enormous scope of our project we were not even able to cover relevant NACA/NASA materials as exhaustively as we had hoped. One set of records we regret to have minimized involves the activities of NASA John H. Glenn Research Center at Lewis Field in Cleveland, Ohio, and the original NACA Aircraft Engine Research Laboratory (AERL), which later became NASA Lewis Research Center. While primarily concerned with problems pertaining to propulsion systems, the Glenn center has sponsored numerous projects pertinent to the relationship between aerodynamics and propulsions systems. Work in this facility's historic icing tunnel plus many other issues certainly relate to compromised aerodynamic integrity, a problem that has had an important impact on the study

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111 Special Collections and University Archives, Wichita State University, 1845 Fairmount, Wichita, KS, 67260-0068, and at *http://www.twsu.edu/library/specialcollections/sc.html*

of aerodynamics for both commercial and military aircraft.[112] Given our focus on NACA/NASA contributions, we could have done more to illuminate the importance of the work done at this installation, whose work dates back to 1941. Many of NASA Glenn's retired administrative files rest within six boxes at NARA's facility at Suitland, Maryland, or are still in storage at the center's Plum Brook Station, located on Lake Erie near Sandusky. There were also nineteen boxes of documents (mostly speeches, talks, and papers by center authors) accessioned from NASA Glenn to the NARA center in Dayton, Ohio, plus four additional boxes of center records stored at the federal records center in Chicago, Illinois. For more description of NASA Lewis's records situation, readers should consult Virginia P. Dawson's *Engines and Innovation: Lewis Laboratory and American Propulsion Technology*.[113]

Even within NARA, the project team concentrated on documenting NACA and NASA involvement in the development of aerodynamics as it related to Langley, Ames, and Dryden centers. This brought us to the NARA facilities at Philadelphia and San Bruno but not to the other NARA facilities where the Glenn center records are kept. Our focus also took us to the NARA facility at College Park, Maryland, where a significant, if not the largest, portion of the previously mentioned NACA Record Group 255 exists.[114]

Another important collection that NARA College Park maintains is RG 342, the Records of the United States Air Force Commands, Activities, and Organizations. Within that organization rests the well-known Sarah Clark Collection, named after the clerk who processed the documents in preparation for their transfer from the air force to NARA. Officially known as the research and development project files of the Engineering Division, Material Command of Wright-Patterson Air Force Base in Ohio, this collection features an extensive record of the military's pursuit of aeronautical excellence from 1917 to 1945. The post-1945 version of the Sarah Clark collection is located at NARA's National Personnel Records Center in St. Louis.[115]

Other facilities where our project could have profitably spent more time include the NASA Marshall History Office in Huntsville, Alabama;[116] the NARA Southeast

112 History Office, Mail Stop 21-8, Glenn Research Center, 21000 Brookpark Road, Cleveland, Ohio, 44135, and at *http://www.grc.nasa.gov/WWW/PAO/html/history.htm*

113 Virginia P. Dawson, *Engines and Innovation: Lewis Laboratory and American Propulsion Technology* (Washington, DC: NASA SP-4306, 1991), and at *http://history.nasa.gov/SP-4306/sp4306.htm*

114 National Archives at College Park, 8601 Adelphi Road, College Park, MD 20740-6001, and at *http://www.nara.gov/nara/dc/Archives2_directions.html*

115 NARA's National Personnel Records Center, Military Personnel Records, 9700 Page Avenue, St. Louis, Missouri 63132-5100, and at *http://www.nara.gov/regional/mpr.html*

Regional Office at East Point, Georgia, near Atlanta;[117] and the Arnold Engineering Development Center (AEDC) History Office at Tullahoma, Tennessee.[118] At each of these facilities, we are sure we could have found additional materials related to the development of hypersonic aircraft and high-speed wind tunnels.

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The preceding bibliographic essay includes references from archives, libraries, printed materials, primary sources, and secondary literature that proved most influential to our study. We apologize to authors of other major works in aerospace history if we have neglected to include references to them in this essay. Not mentioning them does not mean that we were not aware of them, or failed to take them into account in preparation of our study. We have, in fact, cited many other works in our footnotes. But in a project of this magnitude, there was simply not enough time and energy on our part to locate, read, and completely digest every last document, every last article, and every last book that may have been relevant to the development of aerodynamics in America. As detailed and voluminous as this overall study became, just in terms of documents, it still only scratches the surface of what is available out there. Somewhere, on some dusty shelf, in someone's file drawer, hidden in some crumpled box, or some garage container, there are works waiting for other curious historians and scholars to discover, analyze, and interpret them.

What we offer, in the end, is not the final or penultimate "documentary journey through the history of aerodynamics in America," but our own unique journey along the rivers and streams running through our massive country. We invite you to retrace our steps and see what we found, what we mapped, the detours we took, and the locales we found most engaging. We hope you enjoy the adventure as much as we did, and that you are equally stimulated and informed by it, even though you may have chosen to follow a different route. We are sure to revisit this one incredible trip over and over again as we look back through these volumes, like a family browsing over the photo albums of their memorable cross-country vacation to the Grand Canyon. We are relieved the journey is over, and we feel

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116 George C. Marshall Space Flight Center History Office, CN22, Marshall Space Flight Center, Alabama 35812, and at *http://history.msfc.nasa.gov/*

117 NARA Southeast Region (Atlanta), 1557 St. Joseph Avenue, East Point, Georgia 30344-2593, and at *http://www.nara.gov/regional/atlanta.html*

118 Arnold Engineering Development Center History Office, 100 Kindel Drive, Suite B-330, Arnold Air Force Base, Tennessee 37389-2330, and at *http://candice.arnold.af.mil/aedc/history.htm*; E-mail: *history@hap.arnold.af.mil*

thankful that our own "family," the Auburn University project team, made it home in one piece. We are immensely proud of the contributions we made individually and collectively to what we hope will serve, for many years to come, as a standard reference work in the history of aeronautics.

Biographies of Volume 1 Contributors

James R. Hansen, Professor of History at Auburn University, has written about aerospace history for the past twenty-three years. His two-volume study of NASA Langley Research Center—*Engineer in Charge* (NASA SP-4305, 1987) and *Spaceflight Revolution* (NASA SP-4308, 1995)—earned critical acclaim, as did his *From the Ground Up* (Smithsonian Institution Press, 1988), the life story of aviation pioneer Fred E. Weick. His newest book, *The Bird Is on the Wing* (Texas A&M University Press, 2003), explores the role of aerodynamics in the American progress of the airplane from before the Wright brothers to the present. Currently, Hansen is at work on the authorized biography of Neil A. Armstrong.

D. Bryan Taylor is Instructional Technology (IT) Coordinator for the College of Liberal Arts at Auburn University. He holds an M.A. in history from Brigham Young University and is working on his Ph.D. in the history of technology at Auburn.

Jeremy R. Kinney is a curator in the Aeronautics Division, National Air and Space Museum, Smithsonian Institution. He holds a Ph.D. in the history of technology from Auburn University, with a specialization in aerospace history. Prior to joining NASM, he served as the American Historical Association NASA Fellow in Aerospace History.

J. Lawrence Lee holds B.M.E., M.A., and Ph.D. degrees from Auburn University. Following a lengthy career in mechanical engineering, Lee changed his focus to the history of technology, where his primary interests are transportation technology and engineering issues.