Birth of U.S. Naval Aeronautical Engineering and Phenomenal Rise to Excellence

David J. Haas
Eric J. Silberg
Judah H. Milgram

Naval Surface Warfare Center, Carderock Division
Sea Based Aviation Group, Code 5300

AIAA Paper 2011-408
Presented at the 49th AIAA Aerospace Sciences Meeting
4 – 7 January 2011, Orlando, Florida

Celebrating 100 years of Naval Aviation
SEA BASED AVIATION
NSWC CARDEROCK

Birth of U.S. Naval Aeronautical Engineering and Phenomenal Rise to Excellence

David J. Haas,[*] Eric J. Silberg,[†] and Judah H. Milgram[‡]
Naval Surface Warfare Center, Carderock Division, West Bethesda, Maryland, 20817

In January of 1911, a small airplane landed on a specially prepared wooden platform on the cruiser *Pennsylvania*, then a few hours later took off. The following month, near the coast of San Diego, a small hydroplane took off directly from the surface of the water, landed back on the water, and was hoisted from the water aboard ship. With these early demonstrations, Naval Aviation in the United States was born. Thousands of miles away at the Washington Navy Yard, then Captain David W. Taylor and his assistants were beginning work in aeronautics that would lead to a wind tunnel larger than any in the world at that time. Within a few short years, Taylor's vision brought the U.S. Navy to the forefront of aeronautical engineering and naval aircraft design. His focus on rigorous scientific methods and state-of-the-art experimental facilities was rooted in his earlier experience as an accomplished naval architect, and his pivotal role in the establishment of the Experimental Model Basin at the Washington Navy Yard in the late 19th century. The wind tunnel facility would form the foundation of the Navy's Aerodynamics Laboratory and began a new era in aeronautics in the United States. Early tests at the Aerodynamics Laboratory covered a broad range of models including airplane control surfaces, semi-span wing models, and complete aircraft, as well as battleships and flat deck carriers. Less than nine years after those early demonstrations, the U.S. Navy would rise to become a world leader in sea based aviation. The spectacular progress in the design of flying boats by Taylor and his team culminated in 1919 with the first crossing by air of the Atlantic Ocean. This paper highlights the early development of aeronautical engineering and scientific methods for aircraft model testing within the U.S. Navy, and the extraordinary successes achieved in the short span of history from 1911 to 1919. It is written from the authors' present perspective as Aerospace Engineers at the Navy's David Taylor Model Basin located at the Carderock Division of the Naval Surface Warfare Center.

I. Introduction

In November, 1910, a Curtiss biplane took off from the USS *Birmingham* near Newport News, Virginia, and two months later made successful landings aboard and takeoffs from the USS *Pennsylvania* moored in San Francisco Bay. The following month, near the coast of San Diego, a small hydroplane took off directly from the surface of the water, landed back on the water, and was hoisted onto the deck of the *Pennsylvania*. By May of 1911, the U.S. Navy had prepared requisitions for two Curtiss biplanes. These events marked the birth of Naval Aviation[1] and demonstrated the combined operation of two of mankind's greatest vehicles – the ship and the airplane.

The aircraft used in these demonstrations were not very far advanced technologically beyond the Wright Flyer that first flew seven years earlier. Yet, over the subsequent seven years, the Navy would succeed in rapidly advancing the state of the art in aeronautical engineering, culminating in the design of an aircraft capable of self deploying across the Atlantic Ocean. This aircraft, the NC flying boat, represented an enormous leap in technology

[*] Aerospace Engineer, Sea Based Aviation Group, 9500 MacArthur Blvd code 5301, West Bethesda, MD 20817, Associate Fellow, AIAA.
[†] Aerospace Engineer, Sea Based Aviation Group, 9500 MacArthur Blvd code 5301, West Bethesda, MD 20817, Member, AIAA.
[‡] Aerospace Engineer, Sea Based Aviation Group, 9500 MacArthur Blvd code 5301, West Bethesda, MD 20817.

over the Navy's first aircraft, the Curtiss A-1. This paper tells the story of the birth of aeronautical engineering in the U.S. Navy and its phenomenal rise to excellence culminating in the successful mission of the NC-4 in 1919.

Figure 1. *RADM David W. Taylor, naval architect and aeronautical visionary*

A. Naval Ship Engineering Comes of Age

The development of aeronautical engineering and aircraft design capabilities in the U.S. Navy was closely intertwined with and paralleled the development and maturation of naval architecture and ship design methodologies in this country.[2,3,4] Near the close of the 19th century, ship design capabilities in the U.S. Navy lagged behind those of Great Britain and other European nations. Ship hull design in particular was based largely on trial and error. A U.S. naval officer, David W. Taylor (Fig. 1), recognized that a rigorous scientific approach would be required to transform naval architecture from an art to an engineering science. To achieve this, advanced experimental facilities along with appropriate instrumentation and techniques for carefully controlled and repeatable testing would be required. Taylor was instrumental in convincing Congress to appropriate funds for the construction of an Experimental Model Basin (EMB) at the Washington Navy Yard in Washington D.C.[5] In 1898, with CDR Taylor in charge, the EMB opened, marking the rise of the United States in naval architecture. The model basin, shown in Fig. 2, was a world class facility. At 14 feet deep, 42 feet wide, and 470 feet long, it was the longest of its kind. The EMB provided a technical and scientific means to propel the U.S. Navy to the forefront of naval architecture and ship design. Although Taylor couldn't have realized it at the time, he would some fourteen years later play a pivotal role in the development of aeronautical engineering as well. In the same year that the EMB opened, the War Department provided a grant of $50,000 to Dr. Samuel Langley, secretary of the Smithsonian Institution, to build a manned flying machine based on his earlier successful flights of a scaled model. However, it would be another five years before the Wrights' famous first flight that placed the United States at the forefront of aviation. Figure 3 is a photograph of the Washington Navy Yard in 1918 that shows the EMB (a long narrow building) as well as the building next to it that housed the Navy's (and the Government's) first wind tunnel facility.

Figure 2. *The Experimental Model Basin (EMB), was established in 1898 at the Washington Navy Yard, for the testing of ship hulls.*

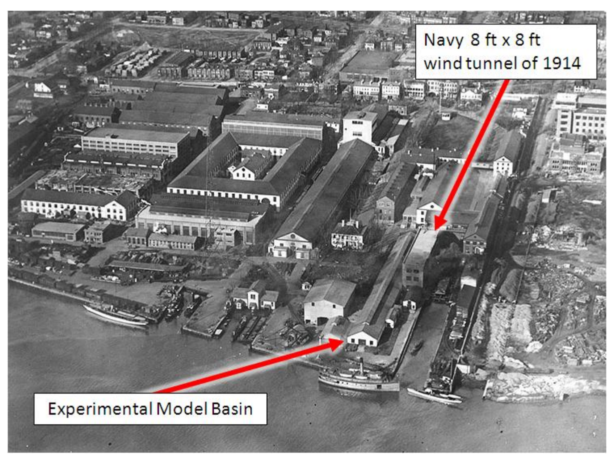


Figure 3. *The Washington Navy Yard in 1918, showing the EMB and the Navy's Aerodynamics Laboratory building housing its wind tunnel.*

David Taylor was born in 1864 and entered the United States Naval Academy in 1881. An exceptional student, he graduated first in his class with the highest grade point average of any midshipman up to that time. Following graduation in 1885, the Navy sent Taylor to the Royal Naval College in Greenway, England for graduate studies in naval architecture. He graduated with highest honors in 1888, again setting a record for scholarship. After graduating he was assigned to work as a naval constructor (naval architect). In 1893, he wrote his first book, *Resistance of Ships and Screw Propulsion*. The following year he was assigned to the Bureau of Construction and Repair in Washington as the principal assistant to the Chief Constructor. In that position he went on to establish the Experimental Model Basin in 1898. Once the EMB entered operation, he made use of the facilities to conduct pioneering research in ship propellers and hull resistance, culminating in the publication of a seminal work on the subject, *Speed and Power of Ships*.[6] In the ten years following the opening of the EMB, David Taylor greatly advanced the state of naval architecture in the U.S., developing new methods based on data collected from model tests at the EMB, and firmly established American leadership in naval architecture (for additional information on David Taylor's life see Refs. 5 and 7).

B. The Navy's First Steps in Aviation

By the end of the first decade of the 20th century, European aeronautical achievements were beginning to overshadow the early success of the Wright Brothers. In 1909 French aviator Louis Bleriot gained world-wide attention by becoming the first to fly across the English Channel. It was about this time that the U.S. War Department began to take an interest in the military potential of the airplane. In 1908 the Army Signal Corps started demonstration trials of the Wrights' Flyer across the river from Washington D.C. at Fort Myer, Virginia. U.S. Navy LT Willian McEntee, a naval architect working for David Taylor was one of the two observers sent by the Navy. At this point in time, advancements in airplane design were largely based on trial and error much as had been the case with naval ship design years earlier. No significant wind tunnel test facilities were in operation in the United States to aide the advancement of aeronautics.

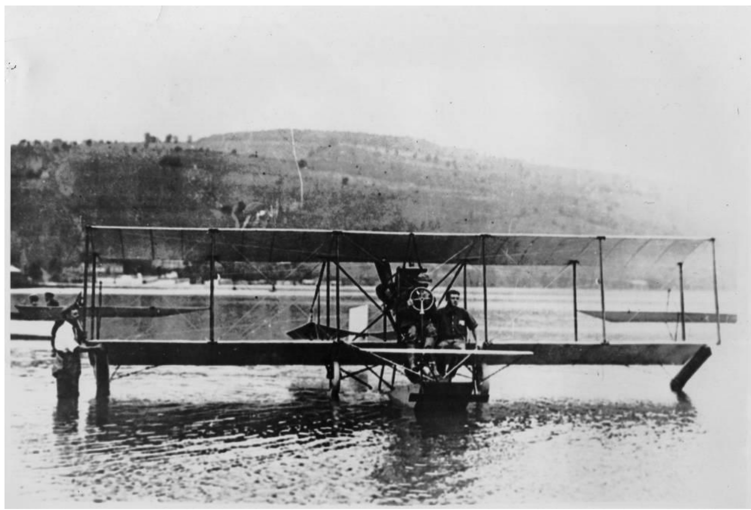


Figure 4. *The Navy's first hydroplane, the Curtiss A-1, configured with floats.*

In 1910, the Secretary of the Navy appointed CAPT Washington Chambers to answer correspondence related to aviation. Also in that year, with urging from Chambers, the Navy began experimenting with the concept of sea based aviation, conducting demonstrations that showed that airplanes could operate from ships and from the sea. Early work in this area consisted of adding a deck made of wood planking to existing navy ships or modifying existing airplanes developed by Curtiss and Wright with floats so they could take off and land on the water (Figs. 4, 5). In January 1911, a Curtiss airplane took off from and landed back on the armored cruiser *Pennsylvania* and in July of 1911 a Curtiss airplane modified with floats, designated the A-1, made a successful water takeoff and landing.[1] Seaplanes were lowered to the water by

Figure 5. *A Wright airplane was modified with floats for Navy evaluation.*

cranes, then hoisted back aboard ship after landing in the water. Techniques were also quickly developed and tested to catapult aircraft off the decks of ships (Fig. 6). These demonstrations opened new possibilities for the future of aircraft in the Navy and showed that airplanes could operate successfully from the sea in concert with naval ships. In September of 1911, Captain Chambers established the first base for Naval Aviation, an aviation experimentation station located in Annapolis, Maryland. For a detailed chronology of Naval Aviation see Ref. 1.

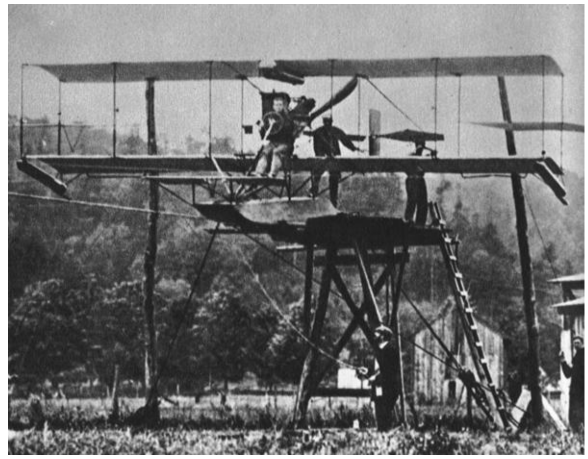


Figure 6. *Test of Curtiss seaplane on an early catapult mechanism in 1912.*

C. Hydrodynamics Facilities Applied to Aircraft

Despite the success of conventional planes modified with floats, the added weight, drag, and suction force of early floats reduced performance and in some cases prevented lift off from the water at all but the lightest gross weights. The handling and control of airplanes on the water was also a challenge, increasing the risk of accidents (Fig. 7). To improve hydrodynamic performance of seaplane floats, David Taylor utilized the expertise and facilities at the EMB.[8] A systematic set of float tests were conducted at the EMB in 1911 and 1912. Various types of float configurations were investigated including wing section floats, sled type box floats, canoe shaped floats, as well as single and twin floats with various step configurations and V-bottoms. These basin tests were of great value, providing data on hull resistance at different trim points, planing capacity, righting moments at rest, tendency of porpoising, and spray patterns.[9] Figure 8 shows a model of the Curtiss A-1 undergoing tests at the EMB. The basin tests were conducted by LT William McEntee, later joined by LT

Figure 7. *Operation of early seaplanes on the water presented unique challenges for Naval Aviation.*

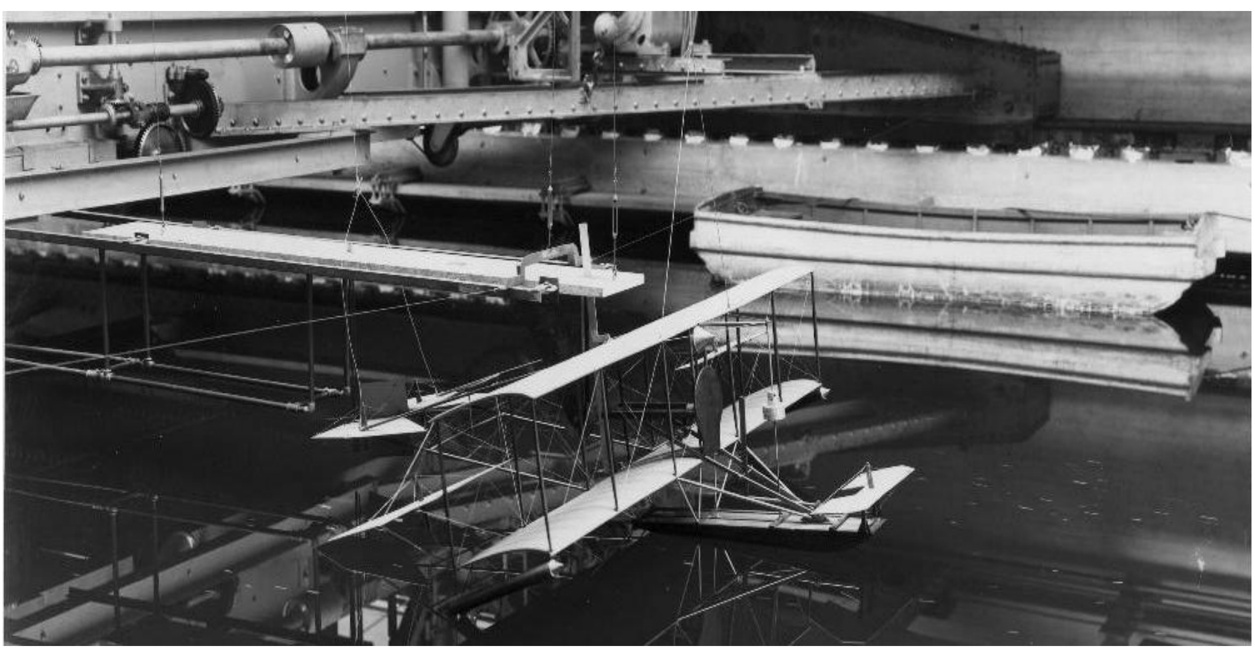


Figure 8. *Testing of seaplane floats – and entire seaplanes – began in the Navy's EMB in 1911 and led to greatly improved performance.*

Holden Richardson, both of whom were assistants to David Taylor. These experiments helped to quantify the benefits of adding a step in the float to reduce the "hump" speed where the hull can plane on the water at reduced drag, thereby increasing takeoff performance of early seaplanes significantly. The EMB would prove to be a valuable tool in the development of the Navy's seaplanes and flying boats.

II. Founding of the Navy's Aerodynamics Laboratory

Flight test trials of early Army and Navy aircraft were valuable in demonstrating the potential of aviation for military use. However, flight testing offered only limited capability to collect the data necessary to advance the state of the art of aircraft design. Based on his earlier experience with the EMB, CAPT Taylor realized that the Navy needed experimental facilities to make scientific and repeatable measurements of aerodynamic forces under controlled conditions. In 1911 Taylor obtained authorization to begin aeronautical investigations at the EMB and initiated efforts to design and build an Experimental Wind Tunnel (EWT) to serve the same purpose for aircraft as his EMB did for ships some thirteen years earlier. In 1913, funds were appropriated for the construction of what would be the world's largest wind tunnel. The use of wind tunnels as an aircraft development tool was very limited in this period of aviation. Although the Wrights' small 18-inch wind tunnel had proved useful for evaluating airfoils, most aircraft manufacturers in 1910 did not have access to a wind tunnel suitable for aircraft design and relied instead on experience and trial and error. In 1901, Dr. Albert Zahm at Catholic University in Washington D.C. built a six foot by six foot wind tunnel, at the time the largest in the United States. The tunnel, however, was taken out of operation in 1908. In France, Gustave Eiffel began testing models of complete airplanes in his 1.5-meter diameter wind tunnel in 1910.[10] He conducted a series of tests in the wind tunnel and published his research in his 1911 book, *The Resistance of the Air and Aviation*. Eiffel's work represented the state of the art in wind tunnel testing and was considered so significant that when the EMB procured a copy in 1912, Taylor's aide, now LCDR Richardson translated the book into English in his spare time.[11] Taylor, together with McEntee and Richardson (all naval architects at the Navy's Bureau of Construction and Repair), designed a closed circuit wind tunnel with an eight foot by eight foot test section. Construction began in 1913 (see Figs. 9, 10). The tunnel was constructed entirely of wood with frames spaced about three feet apart on the outside of the circuit

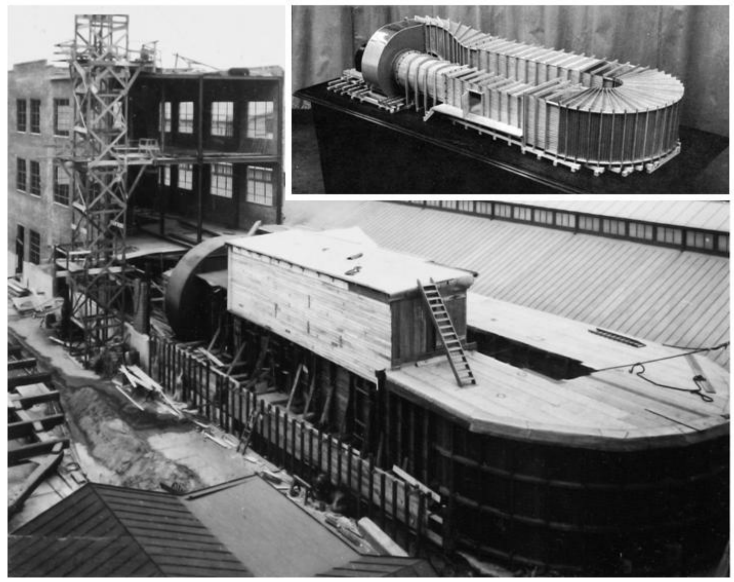


Figure 9. *Wind Tunnel under construction (c1913) for the Navy's Aerodynamics Laboratory, Washington Navy Yard (inset shows replica model).*

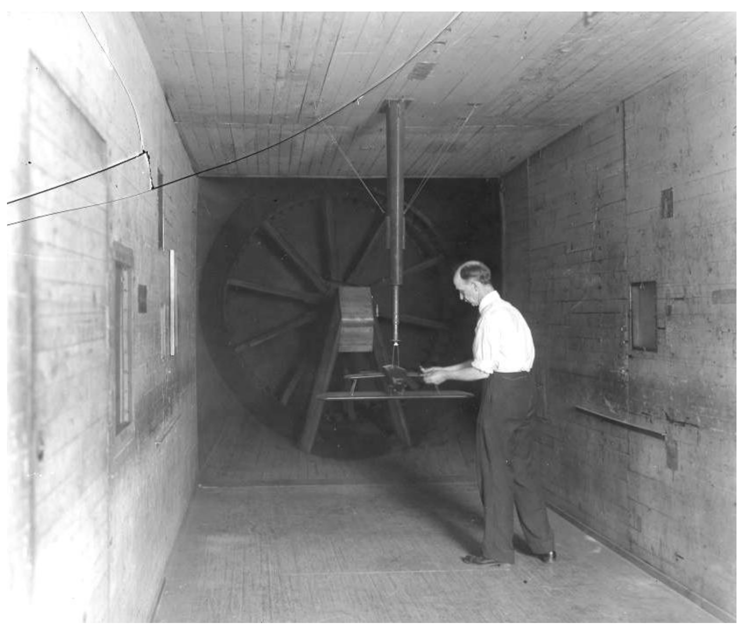


Figure 10. *The Navy's wind tunnel opened in 1914 and was the world's largest with a test section measuring 8 feet by 8 feet.*

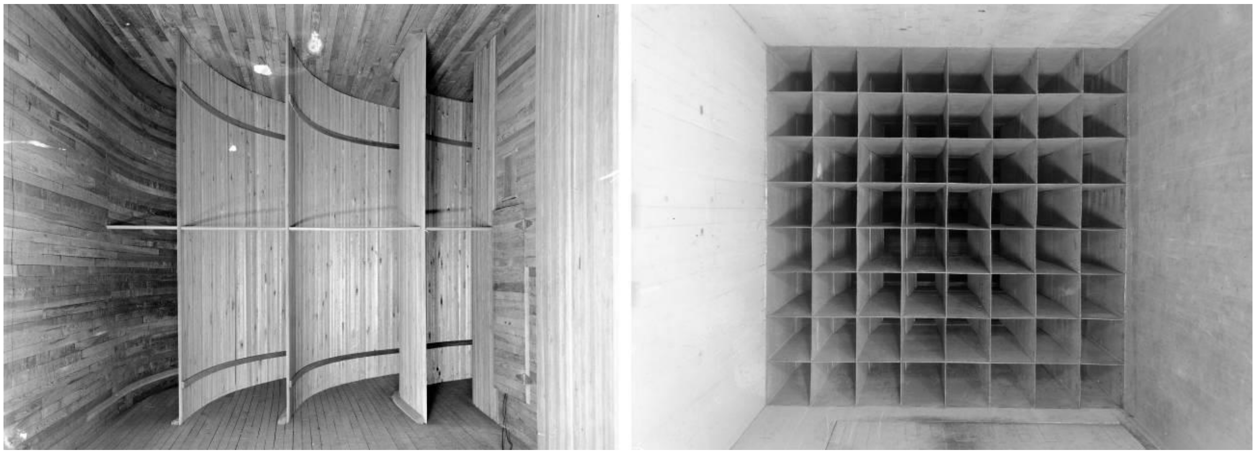


Figure 11. *Vertical "splitters" (left) and a honeycomb grid (right) were incorporated into the wind tunnel to enhance flow quality.*

(see inset, Fig. 9). The fan blower was powered by a 500 horsepower motor. A honeycomb grid of 64 one foot square ducts was installed ahead of the test section and three intermediate vertical "splitters" were installed in the return,[11] see Fig. 11. The ducts and splitters could be adjusted to enhance flow quality. Normal test speed was forty miles per hour, with a maximum of seventy five. The tunnel was completed and run for the first time in 1914, undergoing an initial period of calibration. Tests of wings used in Eiffel's experiments were also conducted in the wind tunnel as a preliminary check of tunnel accuracy.[12] During this time the Navy began design of the model 82-A, the first airplane designed and built by the government. The 82-A was also the first model of a complete airplane to be tested in the Navy's new wind tunnel in 1915[12] (Fig.12), and was later flown in 1916. Thus began the Navy's Aerodynamics Laboratory at the Washington Navy Yard.

Early tests in the Navy's wind tunnel included not only complete aircraft but also aircraft components such as control surfaces, semi-span wing models, and aircraft floats, see Fig. 13. Numerous tests were conducted in the first two years of operations (1915 and 1916), however, the exact number is unknown due to a 1918 fire in the control room that destroyed the tunnel log book. The first test in the tunnel examined the effect of varying dimensions on ships' ventilation cowling.[11,12]

By 1917, the pace of wind tunnel testing was significant and David Taylor hired Dr. Zahm from Catholic University to oversee the Aerodynamics Laboratory. Demand was such that by the summer of 1917, the tunnel was operating 16 hours per day and continued this pace for three years.[11] Models were typically two to three feet in span and fabricated from mahogany. A photo of the wind tunnel control room (c1920s) is shown in Fig. 14; note the numerous models displayed on the walls and racks. Wind tunnel testing was also conducted to study the airflow over ships. Figure 15 shows flow visualization using tufts on the battleship *Pennsylvania* and Fig. 16 shows the air flow over the deck for an early configuration of the aircraft carrier *Langley* with a flow altering device at its bow. Wind tunnel tests were used to determine the lift, drift (i.e., drag), moments, and control effectiveness of aircraft designs. In turn, these data were used to quantify power requirements and stability characteristics. Figure 17 shows lift and drag data collected during a wind tunnel test of the Burgess Speed Scout at the Washington Navy Yard in early 1917.

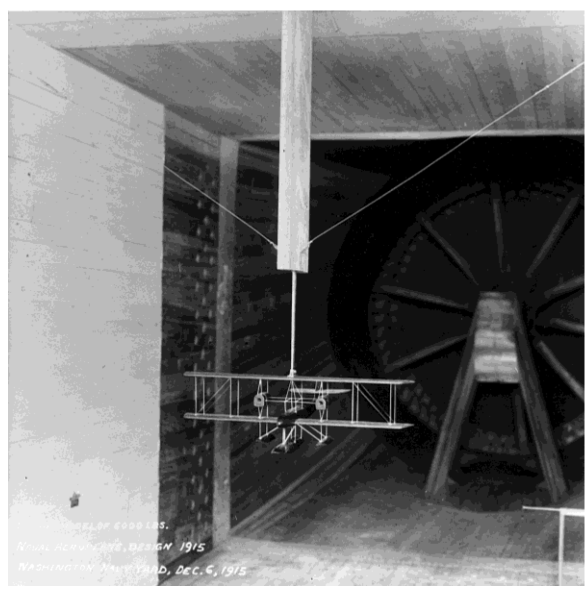


Figure 12. *The 82-A, the first airplane designed and built by the Navy, was tested at the Navy's Aerodynamics Laboratory in 1915 and later flew in 1916.*

Figure 13. *Numerous types of models were tested in the Navy's wind tunnel, including: isolated control surfaces (left), semi-span wing models (upper middle), and floats (lower middle), as well as full-span wing sets (lower right) and complete aircraft (upper right).*

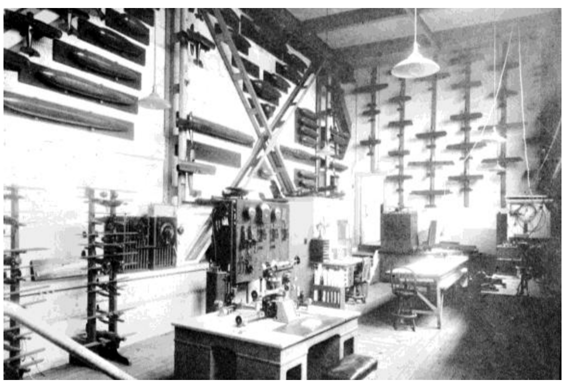


Figure 14. *Wind tunnel control room at the Aerodynamics Laboratory – by 1917, the tunnel was operating 16 hours a day for several years.*

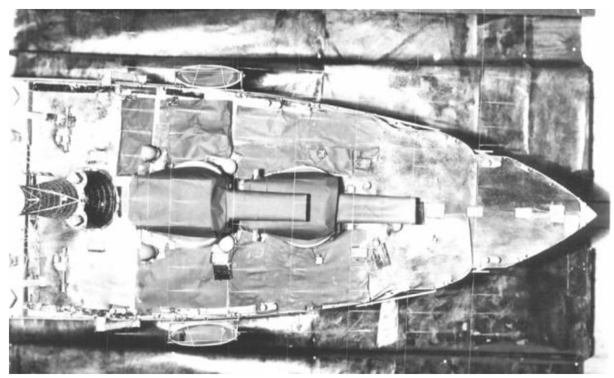


Figure 15. *The Navy's wind tunnel was also used for ship airflow visualization (test of battleship Pennsylvania, 1919).*

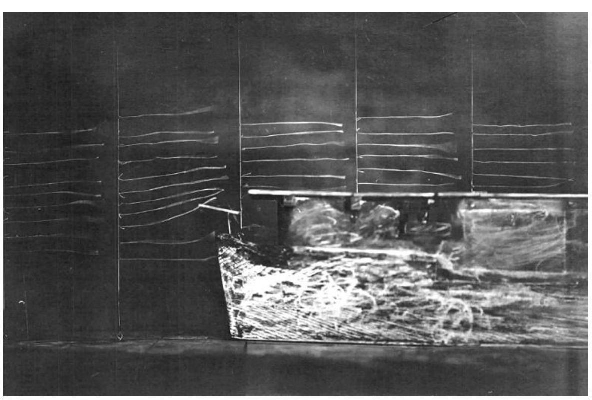


Figure 16. *Airflow visualization in a wind tunnel test of an early aircraft carrier design (1920), to study flow over the ship's bow with a wind diverter at positive incidence.*

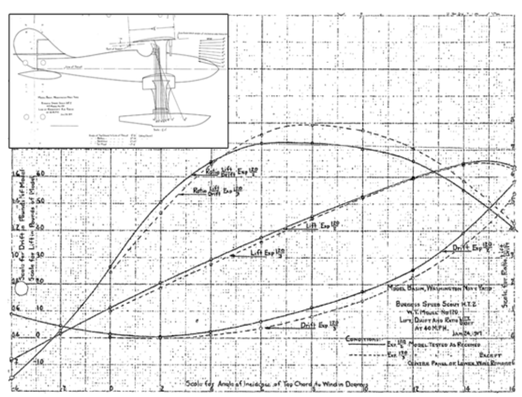


Figure 17. *Typical data collected in the Navy's wind tunnel showing lift, drift (i.e., drag), and L/D similar to today (1917 test of Burgess Speed Scout, Type H.T. 2).*

III. Preparing For War – Development of the NC "Flying Boat"

In 1914 Taylor was promoted to rear admiral and assumed the position of Chief Constructor for the Navy. In this capacity, he was responsible for the construction of all ships and airplanes for the Navy. His strong convictions regarding the importance of developing aeronautics and Naval Aviation carried over to his new position. With World War I underway, the German U-boat threat proved to be a serious menace. Early seaplanes were used to patrol for U-boats but these aircraft were small and had limited range and payload. Although useful in this role for the increasingly important anti-submarine warfare (ASW) mission, a major difficulty of these early airplanes was the challenge of shipping the fragile, bulky machines from the United States to the European war zone. Among other things, the airplanes required a considerable amount of valuable cargo space. Taylor envisioned large, long range, and high endurance aircraft that could self-deploy from the United States to the European theatre and then operate over the ocean without the need for a supporting ship. The aircraft would have to be fully seaworthy in all weather to enhance safety for long voyages across the Atlantic and long ASW patrols in the seas off of Europe.[13]

To accomplish his vision, Taylor and his handpicked team began designing a flying boat that could cross the Atlantic. Taylor's team included some of the best and most promising naval architects and aeronautical engineers of the day. CDR Jerome Hunsaker, at the time head of the Aeronautical Division of the Navy's Bureau of Construction and Repair, was placed in charge of the project. Hunsaker, like Taylor, graduated at the top of his class from the Naval Academy, and subsequently was detailed to MIT where he earned a Ph.D. CDR George Westervelt, also a naval constructor, was charged with overseeing final design and construction. Taylor selected the Curtiss Aeroplane and Motor Company to manufacture the airplane. Its founder, Glenn Curtiss, had earlier proven his exceptional abilities and innovativeness in his work with seaplanes and flying boats and showed a willingness to adapt to meet the unique challenges of Naval Aviation. The final addition to the team was naval constructor CDR Holden Richardson who had worked closely with Taylor and possessed significant expertise in hull design. Richardson later went on to pilot one of the flying boats on the transatlantic mission (Fig. 18).

While the naval constructors were at all times responsible for design and construction, Taylor gave significant autonomy to Curtiss for the details, leveraging the capabilities of his team to the greatest extent possible. Furthermore, during construction, many of the major assemblies were subcontracted, with Curtiss serving as the integrator. This was made possible through the pioneering use of detailed design drawings and component testing to ensure that all of the sub-assemblies fit together and functioned correctly, much in the manner of modern design practice.[14] This is in stark contrast to the typical trial and error processes of the day where entire assemblies were roughly designed, then built and tested. Optimization consisted of changing parts thought to contribute negatively towards performance, followed by building and testing again.

Figure 18. *The team responsible for design and construction of the NC flying boats and contributing to the rapid development of sea based aviation in the United States (photo from Ref. 17).*

As part of the methodical design effort, extensive testing was conducted in the Navy's wind tunnel and EMB facilities at the Washington Navy Yard. In 1917, initial tests were conducted in the wind tunnel to quantify control forces, stability, and power requirements. Significant issues were found, primarily with the tail design. The wind tunnel model is shown in

Fig. 19. After consideration of the problem, several potential design solutions were tested in the wind tunnel in early 1918. In 1917, the hull design was also tested in the EMB for drag and spray characteristics as ship hulls of the day typically were. Finally, in 1918, three hull designs were tested in the wind tunnel for their independent contribution to the forces and moments imparted on the entire vehicle. The facilities that David Taylor had commissioned just a few years earlier proved invaluable to the team for the resolution of problems encountered during the design and test phases in an accelerated wartime development schedule.

While some members of the team initially wanted to designate the new patrol plane series the "DWT" in honor of Taylor, they settled on "NC" – the N for Navy and the C for Curtiss – which became known simply as the *Nancy*.[15] The NC was a very large aircraft with a wing span of 126 feet and a maximum gross weight of 28,000 pounds (Figs. 20, 21). It was the largest flying boat of its day, and only a very few land based aircraft were larger. Initially the plane was powered by three of the new 400 horsepower Liberty engines, but the design was modified during testing to include a fourth. In keeping with the military role that the NC was initially designed for, the flying boat had to be able to survive the rigors of naval operations and wartime service. This included multiple redundancies to allow for combat inflicted damage, added factors of safety for key components, considerations for maintenance and repair, and the ability to carry weaponry and communications gear. Furthermore, the NC had to have sufficient seakeeping abilities to survive in rough seas while maintaining the low drag necessary to take off from the water under full load. It was truly a seaworthy boat that could fly (Figs. 22, 23).

The design process instituted by Taylor and the excellence demonstrated by the entire team produced a highly capable machine, meeting or exceeding design requirements that many thought at first to be impossible. There was such confidence in the design that it was decided to attempt a world record prior to the airplane even being put into regular service. On November 27, 1918 at Rockaway Beach Naval Air Station, New York, the NC-1 carried 51 people aloft, the 51st person being the first "stow away" in aviation history.[15] Prior to this, the world record was 40 persons carried aloft.

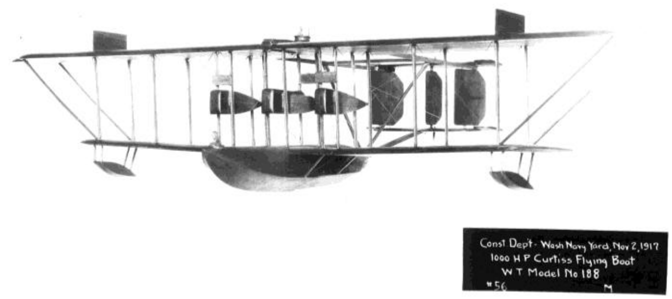


Figure 19. *First model of NC flying boat tested in Navy wind tunnel (1917).*

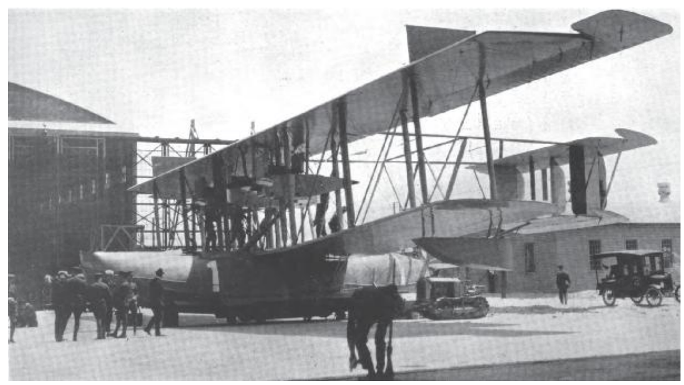


Figure 20. *With a 126' wingspan, four 400 hp Liberty engines, and the ability to lift off of the water at 28,000 lbs, the NC flying boats were the largest of their time.*

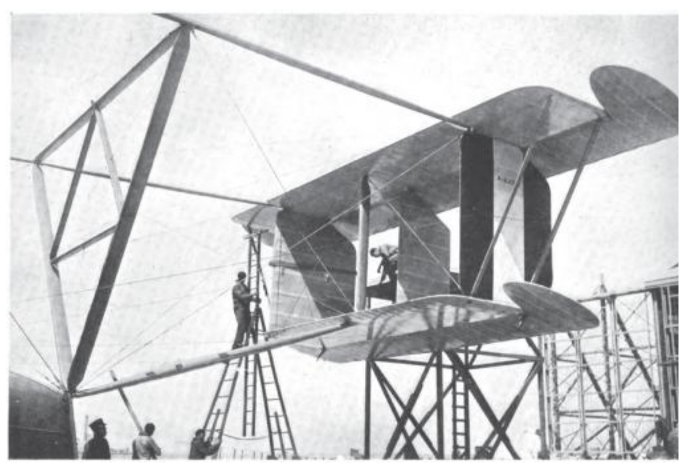


Figure 21. *The horizontal stabilizers of an NC flying boat were larger than the wings of an A-1.*

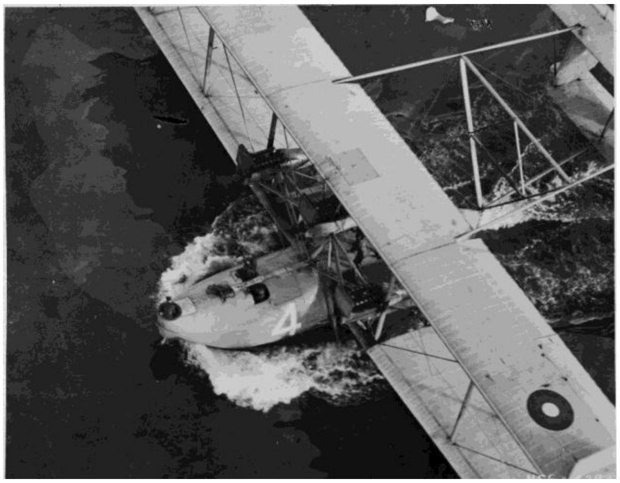


Figure 22. *The NC flying boats were seaworthy and airworthy – veritable boats with wings.*

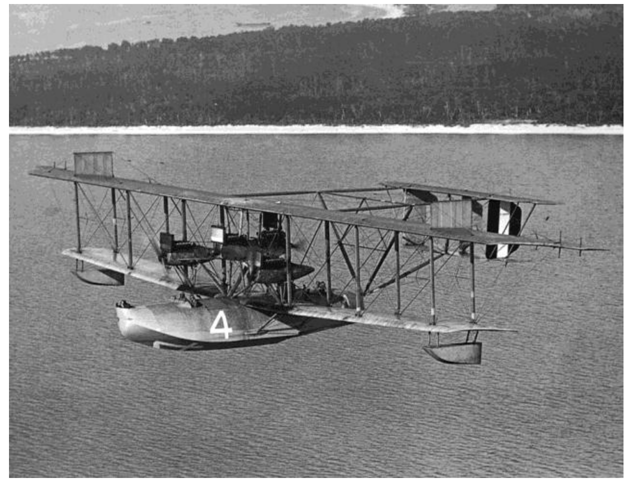


Figure 23. *NC flying boats were amazing aircraft for their time, setting several world records.*

IV. Rise to Glory – the 1st Transatlantic Crossing

Construction of the first NC flying boat began in 1918 and the NC-1 was first test flown later that same year – barely one year after the start of design. In late 1918, however, the armistice was signed and the urgent threat of German U-boats disappeared. This did not stop the Navy from developing and building the NC flying boats, but rather refocused the effort in pursuit of a new goal. David Taylor continued his vision of developing an airplane that could fly across the Atlantic, the goals now being to expand the nation's aeronautical and scientific capabilities, to re-establish the United States as a preeminent force in aviation, and perhaps even to pave the way for regular transatlantic air operations. Other parties at the time were also attempting to be the first to fly across the Atlantic, spurred on by a prize offered by London's *Daily Mail*. Australian Harry Hawker and Scotsman Kenneth Grieve were staging for an attempt at the same time as the NCs, and after reports of the U.S. Navy's initial successes, they made a dash to cross the ocean non-stop. Unlike the operation undertaken by the U.S. Navy, Hawker and Grieve left little margin for error in their attempt. They were unsuccessful and rescued only because they were able to ditch their aircraft near a freighter which plucked them out of the ocean.[16]

After construction and testing were complete, the NC flying boats were placed into regular commission as NC Seaplane Division 1 on May 3, 1919 with CDR John Towers as commanding officer. They were ready to undertake the transatlantic mission. This mission was not pursued by the Navy as a publicity stunt to establish a record (the team never even registered the attempt with the *Daily Mail*) but rather as an organized naval operation to fly across the ocean with minimal risk and a high probability for success. In preparation for the crossing, the Navy developed a plan whereby 53 specially outfitted ships of various types would be stationed approximately 50 nm apart along the planned route of the NCs. These ships would provide radio and visual navigation, communication relays, and weather updates for the NC crews. These too were pioneering efforts, testing and improving the latest available technologies, and further served to increase the chances of rescue should an aircraft go down at sea.

The route chosen was not the shortest, but rather was selected to provide the best chance of success with the least risk given the capabilities of the aircraft. It was divided into several legs, with alternate landing sites if needed. The flight plan started at Naval Air Station Rockaway, New York with the first leg of 540 nm taking them to Halifax, Nova Scotia. The second leg ran 460 nm to Trepassey Bay, Newfoundland which was the jumping off point for the transatlantic journey. From Trepassey Bay, the route took them across 1,200 nm of open ocean to the Azores, first to Horta, then another 150 nm to Ponta Delgada. Lisbon, Portugal was the target on the European continent, 800 nm from Ponta Delgada, then a final 775 nm to Plymouth, England. In total, 3,925 nm from New York to the coast of England, with the longest leg being 1,200 nm to a series of small islands in the middle of the ocean.[17] Figure 24 shows a map of the transatlantic route.

Though four NC flying boats were originally built, the NC-1 was severely damaged in a storm a few months before the transatlantic flight was scheduled. It was decided to use that as an opportunity to refit the original *Nancy* to the specifications of the later craft. For the next few months, the NC-2 was used as a testbed, and then

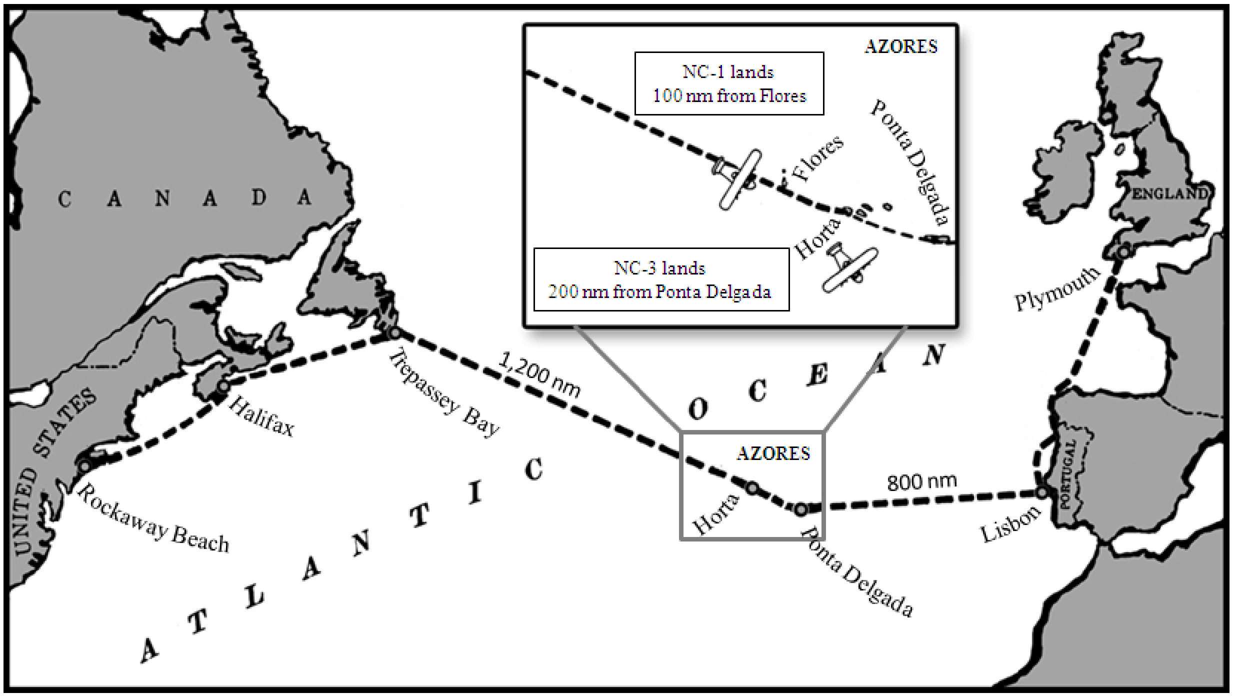


Figure 24. *The transatlantic route of NC Seaplane Division 1 took them from Rockaway, NY to Plymouth, England. The NC-4 successfully completed the 3,936 nm voyage. The NC-1 and NC-3 nearly made it to the Azores, but landed after losing their positions in dense fog and were unable to takeoff again (inset).*

cannibalized for the remaining parts needed to complete the NC-1. On the morning of May 8, 1919, the NC-1, NC-3, and NC-4 departed from Naval Air Station Rockaway heading for Nova Scotia (Fig. 25). The NC-1 and NC-3 arrived at Halifax soon after, but the NC-4 had mechanical trouble and diverted to an alternate port at Chatham, Massachusetts. Five days behind the others, the NC-4 finally reached Halifax, and then made it to Trepassey Bay in time for NC Seaplane Division 1 to start the transatlantic flight together, on May 15. Nearing the end of the long flight to the Azores, the crews of the NC-1 and NC-3 lost their way in dense fog and decided to land at sea to conserve fuel while they determined their locations. The seas where very rough and both *Nancies* were damaged upon landing, unable to resume flight even if the conditions would have allowed it. The crew of the NC-1 was rescued by a passing freighter after surviving for six hours in very difficult conditions. While attempts were made to take the stricken NC-1 in tow, the lines broke in the heavy seas and the original NC was lost. Though unable to take off, the NC-3 survived gale force winds and thirty to forty foot seas (sea state eight conditions), successfully sailing over 200 nm to safety. The *USS Harding* finally sited the NC-3 as it was nearing the coast of Ponta Delgada in the Azores, but CDR John Towers, the mission's commander, was determined to sail the damaged flying boat to port and declined assistance. The crew arrived to a hero's welcome (Fig. 26). These efforts demonstrated not only the courage of these early naval aviators but also the seaworthiness of their flying boat's design.

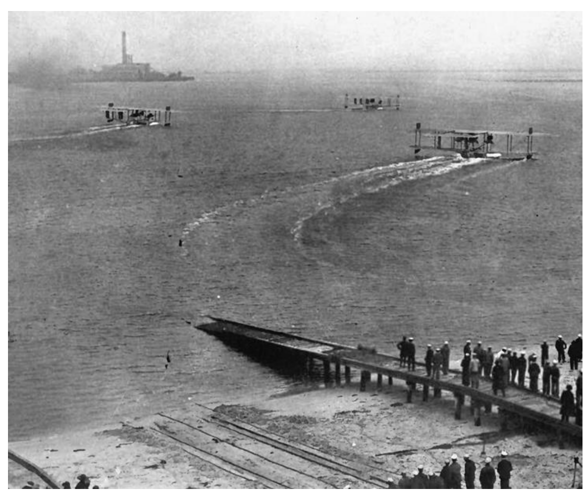


Figure 25. *Three NC flying boats depart from Rockaway, NY for their mission across the Atlantic.*

The NC-4, commanded by LCDR Albert Read, landed safely at Horta in the Azores after flying more than 15

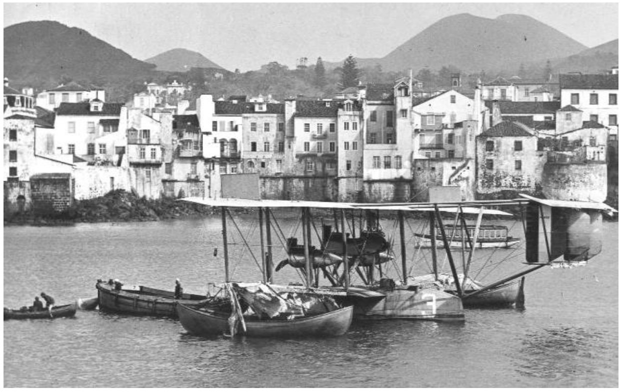


Figure 26. *The NC-3 landed at sea, surviving sea state eight conditions, and sailed over 200 nm to safety.*

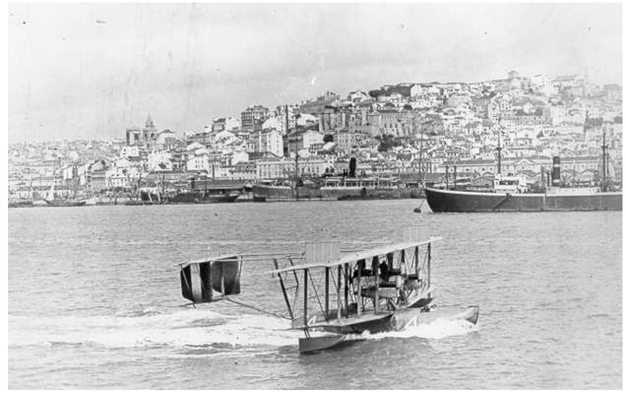
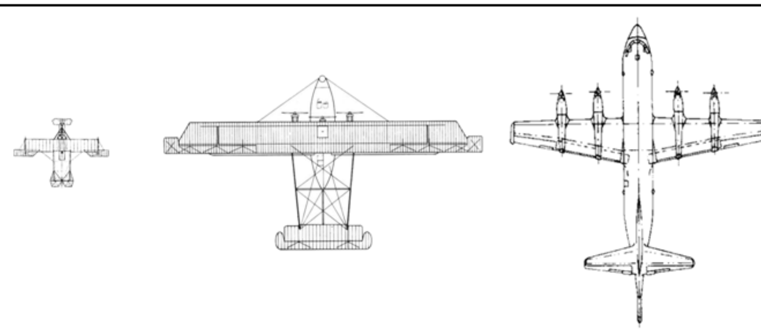


Figure 27. *The NC-4 arrives at Ponta Delgada in the Azores after a flight covering 1,200 nm over water.*

hours nonstop over 1,200 nm of ocean below. A short stop was made before continuing on to Ponta Delgada (Fig. 27), where the NC-3 had arrived by sea just a day earlier. A week later, the NC-4 completed the ocean crossing, reaching Lisbon on May 27. The crew was once again heralded, but they were not yet finished. Four days later, they completed the mission, landing at Plymouth, from where the Pilgrims launched almost 300 years earlier. The triumphant crew was commended by officials from all over the world. Total flying time for the voyage was 52 hours and 31 minutes covering 3,936 nm, just 11 nm more than planned. At a time when the prestige of U.S. aeronautics was waning, the masterfully conceived and executed mission of the NC flying boats was a major victory for U.S. Naval Aviation and propelled the United States to a leading position in the development of sea based aviation.

V. The Navy's Progress in Perspective

The progress in the development of sea based aviation in the eight years from the birth of Naval Aviation in May 1911 to the first transatlantic crossing by air in May of 1919 was phenomenal. In 1911, Naval Aviation consisted of small, two-seat airplanes with very limited endurance and payload. Development and design of airplanes were largely trial and error, and the United States did not have the experimental facilities needed to further the development of airplane design. By 1919 this had all changed. The U.S. Navy had established an Aerodynamics Laboratory collocated with the Experimental Model Basin at the Washington Navy Yard. The Navy could design its own aircraft and had successfully flown across the Atlantic in a flying boat that could carry 51 people aloft and survive sea state eight conditions. By 1919 the Navy had over 2,000 aircraft (mostly sea planes and flying boats) with training facilities in San Diego and Pensacola. This success can be attributed to the vision, expertise, and courage of the Navy team of aeronautical engineers and naval aviators working together during this time to advance the state of research, development, and flight operations related to sea based aviation. Figure 28 shows the A-1 seaplane of 1911 and the NC flying boat of 1919 in perspective to the Navy's current ASW patrol aircraft the P-3 Orion.



	A - 1	NC - 4	P - 3
Year	1911	1919	Current
Wingspan	37 ft.	126 ft.	99 ft. 8 in.
Max Gross Weight	1,575 lb	28,000 lb	139,760 lb
Cruising Speed	51 kts	84 kts	330 kts
Range		1,278 nm	2,070 nm

Figure 28. *Comparison of the A-1, the NC flying boat, and the P-3 in operation today.*

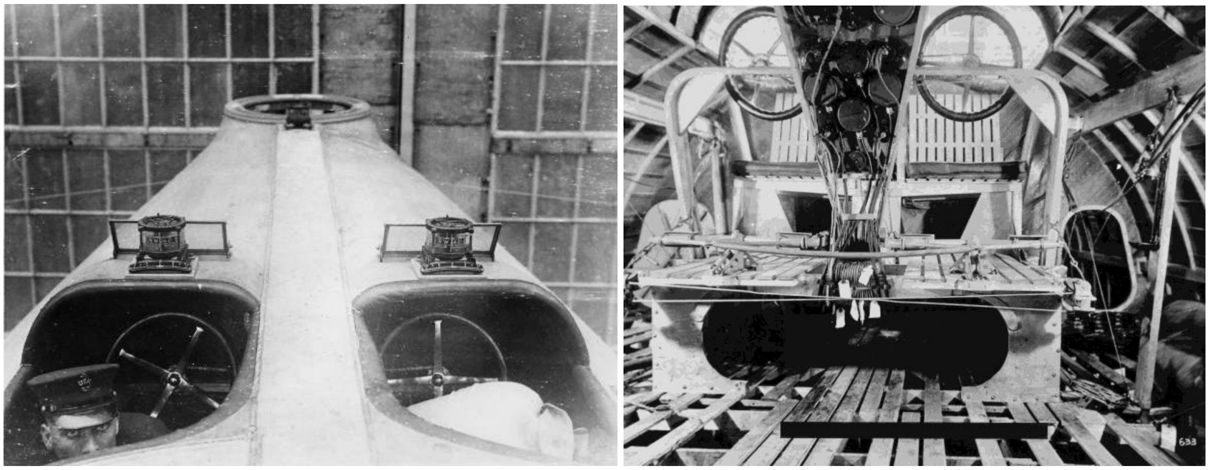


Figure 29. *The cockpits, instrumentation, and radio equipment of the NC flying boats demonstrated the dramatic advancements made since the A-1.*

In addition to aerodynamic design and construction, the Navy had made great strides in other technologies critical to sea based aviation. Instrumentation was developed for navigation over the featureless expanse of the open ocean, radios were available for long range communication, and radio navigation techniques were pioneered. The airplane had become a vehicle capable of carrying heavy loads over long distances – and in relative comfort. The NC flying boats offered its normal crew of six (navigator, two pilots, radio operator, and two mechanics) the ability to move around, and even lay down, within its hull. Figure 29 shows interior and exterior views of the cockpits of the NC flying boat as well as the navigator and aircraft commander's station at the nose of the aircraft.

VI. Legacy of RADM David Taylor and the Navy's Aerodynamics Laboratory

RADM David Taylor and his team of early Naval Aviation pioneers made lasting contributions to the field of aeronautics and sea based aviation. The noted aeronautical researcher Dr. William Durand (himself a formal naval officer), on the occasion of the award of the John Fritz Medal to Taylor in 1930 stated, "Admiral Taylor, as Chief Naval Constructor, bore from 1915 until 1921 … the entire responsibility for the design and construction of naval aircraft, which were carried brilliantly forward under his direction" and finished by saying, "Admiral Taylor has made a deep and lasting imprint on the development of Aeronautics in the United States."[7] Many years later, in 1971 at MIT, another aeronautics pioneer who had worked under Taylor and established the first aeronautics curriculum in the U.S., Professor Jerome Hunsaker, said of Taylor that he had single-handedly brought the Navy into the modern technical world.[18]

Taylor's contributions impacted a number of organizations. He realized the need for an independent bureau in the Navy Department to handle the great expansion of aviation that he foresaw. Due in large part to his vision, the Bureau of Aeronautics was established in 1921 for the procurement of aircraft for the Navy. Taylor was also involved with the formation and early years of the National Advisory Committee for Aeronautics (NACA), the predecessor to today's NASA, as were other naval officers involved in aeronautics at the time. Chambers was an early proponent of establishing a national laboratory for conducting aeronautics research to benefit the entire country[19] and both Taylor and Richardson where involved in the initial studies for a national aeronautics laboratory. Congress established NACA in 1915 by adding funding to that year's Navy appropriation. Richardson served as the Navy's representative on the initial committee. Taylor became a member in 1917, served as the secretary after his retirement from the Navy in 1923, and was appointed vice chairman in 1927. Figure 30 shows RADM Taylor in 1922 with Orville Wright and other members of NACA.

In 1939, the Navy's Aerodynamics Laboratory and the Experimental Model Basin began relocating from the Washington Navy Yard to Carderock, Maryland, a few miles to the northwest. The facilities were significantly expanded and a complex of wind tunnels and a larger model basin were constructed. With Taylor present, the new Center was dedicated as the David W. Taylor Model Basin shortly before his death in 1940. Subsequently, the name was changed to the David W. Taylor Naval Ship Research and Development Center and shortened to the David Taylor Research Center. CAPT Richardson, having been a key designer of the NC flying boat while at the EMB and a pilot of the NC-3, was recalled to Navy service to head the Navy's Aerodynamics Laboratory at Carderock from 1942 to 1944. CDR Hunsaker, who as a naval officer had founded the first aeronautics program in the country at MIT, went on to serve as the chairman of NACA for 15 years from 1941 to 1956. For further information on Chambers and Hunsaker see Refs. 20 and 18 respectively.

In the years following the move to Carderock, the Center expanded its aerodynamics facilities to include transonic, supersonic, and hypersonic wind tunnels. Focus areas included aircraft store separation, numerous VSTOL and rotary wing aircraft concepts, wing in ground effect vehicles, surface effects ships, and circulation control for both air and underwater applications. Today the David Taylor Research Center is known as the Naval Surface Warfare Center (NSWC), Carderock Division (Fig. 31). It is still home to the

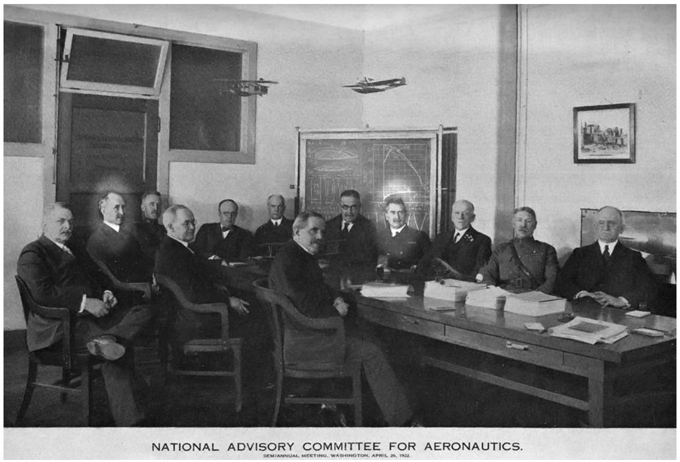


Figure 30. *RADM Taylor (fourth from right) at NACA meeting in 1922 with Orville Wright (second from left) and other aeronautical pioneers.*

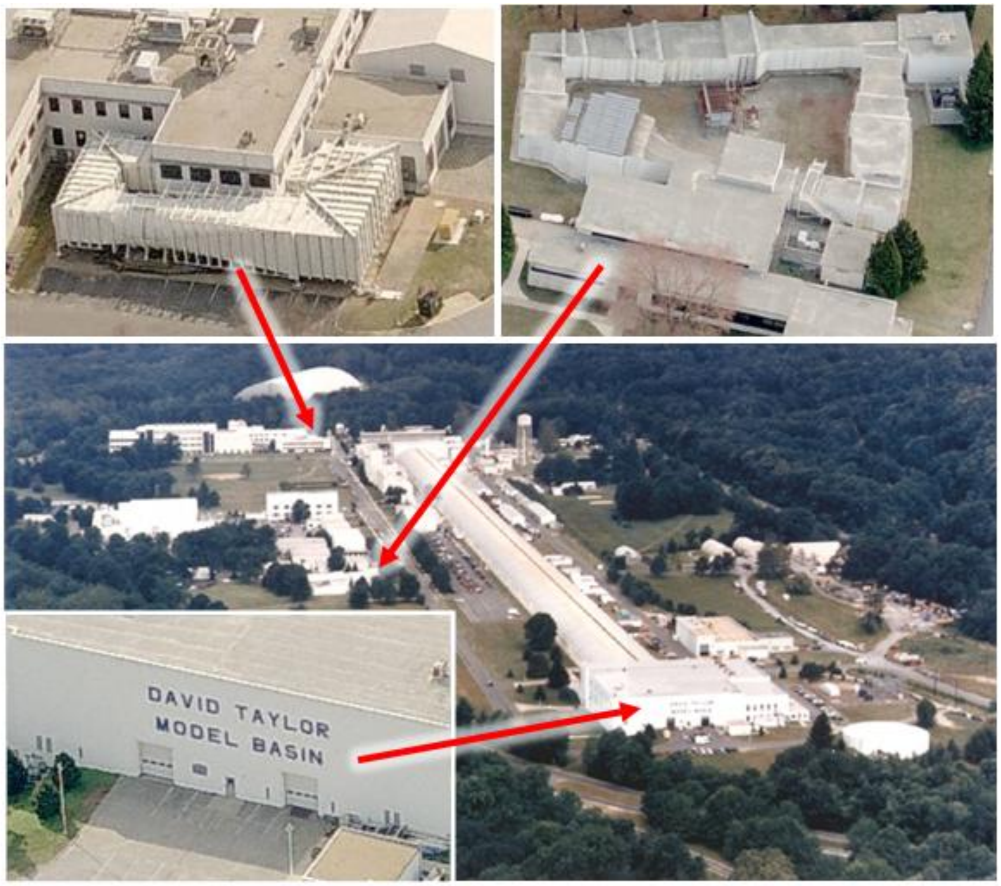


Figure 31. *Subsonic Wind Tunnel (upper left) and Anechoic Flow Facility (upper right) at the David Taylor Model Basin, NSWC Carderock Division today.*

Navy's largest wind tunnel facilities including an 8 foot by 10 foot subsonic closed circuit wind tunnel and a closed circuit Anechoic Flow Facility with an 8 foot by 8 foot closed jet test section and an open jet anechoic chamber 23 feet square by 21 feet long. These facilities are used for a broad range of experimental activities involving ships, underwater vehicles, air vehicles, wind turbines, and ducted fans, to name a few.

From its beginnings at the Washington Navy Yard, NSWC Carderock has been supporting the Navy's development of sea based aviation for 100 years. It has continuously operated wind tunnel facilities longer than any other U.S. Government organization. In addition to experimental aerodynamics, aerospace engineers at NSWC Carderock are involved with: computational fluid dynamics of ships, aircraft and rotor systems;[21] rotorcraft aeromechanics;[22] ducted fan systems for aircraft and ships;[23] and the development of Military Flight Operations Quality Assurance within the Navy and Marine Corps.[24,25] The David Taylor Model Basin at Carderock is even utilized for an occasional seaplane test (e.g., a C-130 aircraft modified with floats). For a complete history of the David Taylor Research Center see Ref. 26.

VII. Summary

Hydrodynamics and aeronautics are closely related scientific fields and their development has been intertwined to the benefit of both. This was especially true at the dawn of U.S. Naval Aviation in 1911. At that time, a naval officer, David W. Taylor, was a central figure in the scientific development of both naval architecture and aeronautics. He established the Experimental Model Basin and the Navy's Aerodynamics Laboratory, both at the Washington Navy Yard. Using these facilities and under his leadership, the U.S. Navy took an early leading role in the development of aeronautics and its application to sea based aviation. His contributions as a naval architect, aeronautical engineer, and as Chief Constructor of the Navy fueled the phenomenal rise and achievements of naval aeronautical engineering in the second decade of the 20th Century. The efforts of Taylor and his Navy team culminated in the first successful transatlantic flight by the NC-4 flying boat in 1919. His legacy in both hydrodynamics and aeronautics is profound and is most visible today in the experimental facilities at the Naval Surface Warfare Center in Carderock, Maryland, home of the David Taylor Model Basin and the Navy's large scale wind tunnel facilities.

Acknowledgements

The authors would like to acknowledge the support of Robert Roddy from NSWC, for his assistance and support in locating materials from the archives at NSWC Carderock, and the support of Curtis Utz, Roy Grossnick, and the rest of the aviation staff from the Naval History and Heritage Command for their assistance in locating materials from the archives at the Washington Navy Yard. Lastly, the authors would like to acknowledge the technical achievements of all those who worked as part of the Navy's Aeronautical Laboratory over the last 100 years.

References

[1]Grosnick, R, *United States Naval Aviation 1910-1995*, Naval Historical Center, Dept. of the Navy, Washington D.C., 1997.

[2]McEntee, Willian, "Some Applications of the Principles of Naval Architecture to Aeronautics," *Transactions of the Society of Naval Architects and Marine Engineers*, Vol. 19, Nov. 1911, pp. 287-298.

[3]Hunsaker, Jerome, "Naval Architecture in Aeronautics," *Journal of the American Society of Naval Engineers*, Vol. 32, No. 4, Nov. 1920, pp. 762-775.

[4]Ferreiro, Larrie, "The Connection Between Ship Hydrodynamics and Aircraft Aerodynamics through the mid-20th Century, in Theory and Experiment," Paper presented at the *ASHiC Conference on Fluid Resistance from Newton to the Present*, 29-30 Oct. 2010, Paris, France.

[5]Allison, D.K., Keppel, B.G., and Nowicker, C.E., *D.W. Taylor*, United States Printing Office, Washington D.C. 1986.

[6]Taylor, D.W., *The Speed and Power of Ships*, Two volumes, First Edition, John Wiley & Sons, New York, 1910.

[7]Hovgaard, W., *Biographical Memoir of David Watson Taylor 1864-1940*, presented to the National Academy of Sciences at the Annual Meeting, 1941, Published by the National Academy of Sciences, Washington 1941.

[8]Richardson, Holden. C., "Naval Development of Floats for Aircraft," *Transactions of the Society of Naval Architects and Marine Engineers*, Vol. 34, Nov. 1926, pp. 15-28.

[9]Richardson, Holden. C., "The Trend of Flying Boat Development," *Journal of the American Society of Naval Engineers*, Vol. 38, No. 2, May, 1926, pp. 231-253.

[10]Anderson, Jr., J. D., *A History of Aerodynamics*, Cambridge University Press, New York, 1997.

[11]Fresh, J, "The Aerodynamics Laboratory (The First 50 Years)," *David Taylor Model Basin Aero Report 1070*, Jan. 1964.

[12]Richardson, H. C., memorandum dtd. Dec. 10, 1941. H. C. Richardson Collection, Box III. Naval History and Heritage Command, Washington Navy Yard, Washington, D.C.

[13]Hunsaker, J.C., "Progress in Naval Aircraft". *Society of Automotive Engineers Transactions*, Part II Vol XIV, 1919, pp. 236-277.

[14]Westervelt, G.C., "Design and Construction of the NC Flying Boats". United States Naval Institute Proceedings, Vol 45, No 199, September 1919, pp. 1529-1581.

[15]Westervelt, G.C., Richardson, H.C, and Read, A.C., *The Triumph of the N.C's*. Doubleday Page and Company, New York, NY, 1920.

[16]Wilbur, Ted, *The First Flight Across the Atlantic*, Smithsonian Institution, Washington, D.C., 1969.

[17]Curtiss Aeroplane and Motor Corporation, *The Flight Across the Atlantic*, New York, NY, 1919.

[18]Trimble, W.F., *Jerome C. Hunsaker and the Rise of American Aeronautics*, Smithsonian Institution Press, Washington D.C., 2002.

[19]Chambers, W. I., "Aviation To-Day, and the Necessity for a National Aerodynamic Laboratory," *United States Naval Institute Proceedings*, Vol. 38, No. 4, Nov. 1912, pp. 1491-1528.

[20]Stein, S.K., *Torpedoes to Aviation Washington Irving Chambers and Technological Innovation in the New Navy 1876-1913*, The University of Alabama Press, Tuscaloosa, AL, 2007.

[21]Bi, N., Jiang, M and Haas, D., "Simulation of Fan-In-Wing Aircraft Aerodynamics in Hover" *Proceedings of the American Helicopter Society International Powered Lift Conference*, Oct 5-7, 2010 Philadelphia, PA.

[22]Vorwald, J., "Influence of Pitch Attitude on Tiltrotor Autorotation Characteristics," *Proceedings of the American Helicopter Society Aeromechanics Specialists' Conference*, San Francisco, CA, Jan 20-22, 2010.

[23]Bi., N. P., Kimmel, K., and Haas, D.J., "Performance Investigation of Ducted Aerodynamic Propulsors," Presented at the *First International Symposium on Marine Propulsion* , Trondheim, Norway, June 22-24, 2009

[24]Silberg, E, Haas, D., Walker, J and Kough, L, "Enhancing the Value of Data through Effective Aggregate Analytical Techniques" *Proceedings of the AIAA Aviation Technology, Integration, and Operations Conference*, 13-15 Sept 2010, Ft Worth, TX.

[25]Nguyen, P.N., Walker, J. and Pierce, B, "An Automated Approach for Objective Evaluation of Practice Autorotations using Available Aircraft Data," *Proceedings of the American Helicopter Society 66th Annual Forum*, Phoenix, AZ, May 11-13, 2010.

[26]Carlisle, R.P., *Where the Fleet Begins a History of the David Taylor Research Center*, Naval Historical Center Department of the Navy, 1998.