Developing the Navy's NC Flying Boats: Transforming Aeronautical Engineering for the First Transatlantic Flight

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When Rear Admiral David Taylor proposed building a flying boat with the capability to cross the Atlantic Ocean in 1917, it was not for national glory, winning a race, or even achieving a world's first. The aircraft's purpose was to support the critical wartime mission of combating German U-boats that were wreaking havoc on transatlantic shipping. The aircraft available at the time had numerous limitations for anti-submarine duty. Seaplanes did not have the ability to operate over the open ocean without a support ship and were not seaworthy enough to survive the harsh conditions of the North Atlantic. The large, land based bombers did not have the range, duration, or payload required for the extended patrols required over water, nor could they safely land on the water if necessary. Rear Admiral Taylor understood that a self-deploying anti-submarine aircraft could be transformative in the battle for control of the seas. Intended for combat, the design was to be reliable, survivable, and maintainable, and had to operate both in the air and on the open ocean. It could not be a fragile vehicle designed for the singular purpose of crossing the ocean, or optimized for long duration flight in ideal conditions. The result was the largest flying boat ever built, featuring an unusual shape, advanced engineering, cutting edge technology, and unsurpassed sea-worthiness. By late 1918, the first of these craft, the NC-1 (the "N" for Navy and the "C" for Curtiss), had been constructed and was undergoing testing, but the war ended before testing was complete, and the military necessity for their unique capability quickly vanished. Navy leadership, however, was undeterred and refocused the efforts of the NC flying boat team to do what many still thought impossible – cross the Atlantic Ocean by air. Significant development was still required to prepare the aircraft for the transatlantic voyage, and with renewed focus the team set about the task of becoming the first to fly across the ocean. In May of 1919, NC Seaplane Division One set off from Rockaway, New York on a voyage to make history. Of the three flying boats that began the journey, only the NC-4 completed it. The other NC's, one lost at sea and the other heroically brought into port via the ocean, achieved a version of success as well. This paper chronicles the engineering advancements and technological achievements that went into the development of these aircraft, and the lasting legacy of the first aircraft to cross any ocean.

I. Introduction

May 27, 1919. The NC-4, commanded by Lieutenant Commander Albert C. Read, United States Navy, lands in the harbor of Lisbon, Portugal. This event marks the first time in history that any ocean of the world is crossed by air. Their voyage began eighteen days earlier, but the journey begins earlier still. In August of 1917, Rear Admiral David Taylor, Chief Constructor of the Navy, penned a memorandum to his assistant, Lieutenant Jerome Hunsaker. It was the height of the World War I, and German U-boats were wreaking havoc on the North Atlantic shipping lanes. Aircraft were being used in an attempt to find and neutralize this threat, but the limited range, payload, and sea-keeping abilities of these early seaplanes yielded only limited success. Add to that the logistical

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difficulties in transporting the aircraft via cargo ship to the European theater, where they were at risk from the very threat they were intended to combat. RADM Taylor saw a better way:

> The United States motor gives good promise of being a success, and if we can push ahead on the aeroplane end, it seems to me the submarine menace could be abated, even if not destroyed, from the air.
>
> The ideal solution would be big flying boats or the equivalent, that would be able to keep to the sea (not air) in any weather, and also able to fly across the Atlantic to avoid difficulties of delivery, etc.
>
> Please think it over very carefully, particularly as to the method of procedure to develop something as close to the ideal as possible.[1]

Taylor made two specific recommendations: the employment of a "flying boat" and the use of the "United States motor". A flying boat is a particular construction of seaplane where the fuselage is a sea-worthy hull. This is differentiated from other forms of seaplane where floats or pontoons are attached in lieu of landing gear. A flying boat was the best suited vehicle for this mission as it, uniquely, could navigate rough seas and still operate effectively as an aircraft. The United States motor, later known as the Liberty engine, was the United States' attempt to build a powerful engine that could be used in a variety of aircraft. However, it was far from certain in 1917 that the motor would be successful. As Chief Constructor of the Navy and a brilliant engineer, RADM Taylor had the ability to envision the possibilities that the engine program offered. The motor had just passed a major milestone, a 50 hour test, and Taylor was confident that the program would not fail.

Born in 1864, David W. Taylor was one of the Navy's preeminent naval architects and engineers. At the top of his class – and with the highest marks recorded up to that time at the Naval Academy and then again at the Royal Naval College in Greenway, England – his scholarly credentials were impeccable.[2] As a commander, Taylor convinced Congress of the need to construct a facility to scientifically test ship hulls. The standard method of ship design at the time was based largely on trial and error. Taylor realized that using modern methods of analysis, testing, and experimentation, a design could be objectively evaluated and superior results obtained. In 1898, the Experimental Model Basin was built at the Washington Navy Yard, with Taylor in charge. It was the largest facility of its kind in the world, and brought the United States to the forefront of ship design. Fifteen years later, Taylor did the same for aeronautical engineering. Under his direction as Chief Constructor of the Navy, the Experimental Wind Tunnel was built – again the largest facility of its kind in the world.[3]

In response to Taylor's memorandum, Hunsaker set about designing a series of flying boats that could satisfy the requirements laid out by Taylor. Jerome Hunsaker, like Taylor, graduated at the top of his class from the Naval Academy and went on to earn a PhD while detailed by the Navy to MIT (MIT's first awarded doctorate in aeronautics). He was instrumental in establishing the engineering discipline of aeronautics both at MIT and for the Navy, and as head of the Aeronautical Division of the Navy's Bureau of Construction and Repair, he was one of the Navy's preeminent aerodynamicists and aeronautical engineers. Hunsaker quickly narrowed the possibilities to a design with three engines and 20,000 to 25,000 pounds gross weight. This first concept was known as the TH-1, for "Taylor-Hunsaker"[‡]. In just a few months, models were being tested and refined in the towing basin and wind tunnel – the very facilities that Taylor himself had envisioned and realized.[4]

Prior to the war, there were attempts from around the world to cross the Atlantic by air. London's *Daily Mail* had created a prize of ₤10,000 for the first successful crossing by air. In the United States, Glenn Curtiss was commissioned to build a new class of aircraft to achieve this goal – and win the prize. The result was the *America* (Fig. 1) and the Model H class of flying boats that followed. Though not a Navy program, the Navy had an interest and detailed Lieutenant John Towers to observe and report on the feasibility of the project, and possibly be one of the pilots in a transatlantic attempt.[5,6] While many were trying to fly across the Atlantic, equally many believed that it could not be done, as portrayed in a period cartoon in Fig. 2. Once hostilities in Europe began in 1914 these attempts quickly ceased, as all efforts were focused on winning the war.

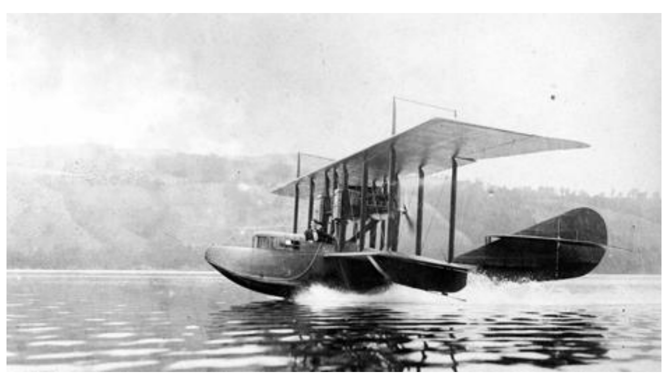

Figure 1. The Curtiss *America*. *The America was Glenn Curtiss' first attempt at building a flying boat to cross the Atlantic. Built in 1914, the start of World War I prevented any attempt, however it was unlikely that this version would have been capable of making the flight.*

[‡] Glenn Curtiss was the designer of the TH-1 concept, and there is some question as to the origin of the name.

When Taylor sent his memorandum three years later, the ocean was the equal obstacle it had been before the war. However, with better technology and methods available, Taylor was convinced that this obstacle was not insurmountable. Furthermore, he believed that flight across the ocean could be achieved in an aircraft not built for the sole purpose of setting a record, but rather with a warplane, ready to fight. Nearing the transatlantic mission after the war, Glenn Curtiss, the constructor of the NC series, was quoted as saying:

> The difference between the American entry in the flight and the ships entered by European or Canadian interests lies in the fact that the N C (Navy Curtiss) boat has not been specially constructed. With the exception of the increased power and certain alterations in interior construction of the hulls, the ships are the same as when designed for submarine chasing. Yet they have demonstrated a big factor of safety, they can carry an enormous useful load and they can land safely in a heavy sea.[7]

To be sure, Taylor reasoned that the aircraft, as originally envisioned, would be configured for the transatlantic ferry flight and then reconfigured with weapons and equipment for combat operations. The structure of the aircraft, however, with all of the necessary redundancies, allowances for maintenance, and sea-worthy ruggedness would remain. Furthermore, it had to operate in less than ideal weather conditions, and be serviceable through the course of battle.

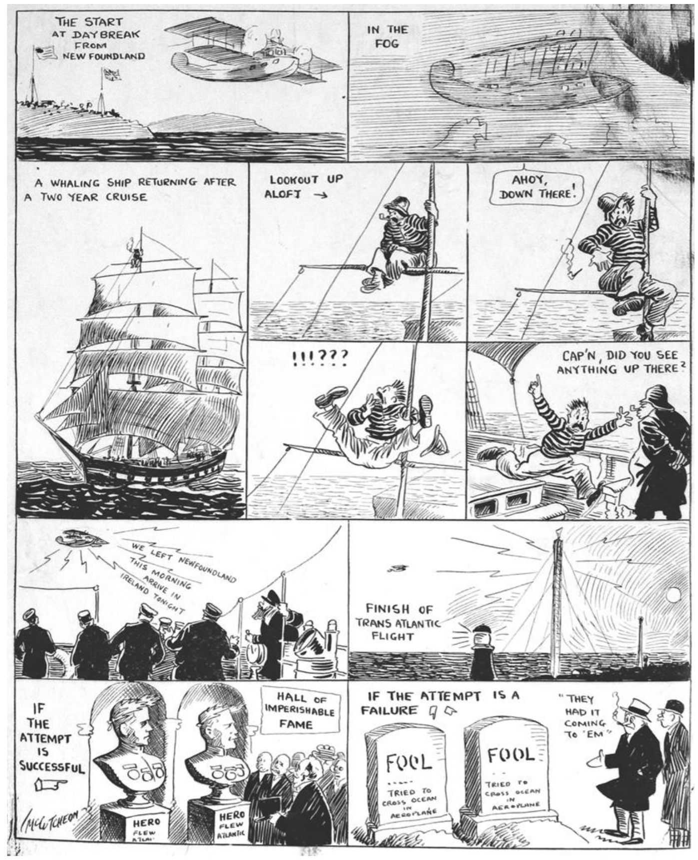

Figure 2. Cartoon featured in the February 20, 1914 issue of *Aero and Hydro*. *In 1914, and until the successful completion of NC Seaplane Division One's mission in 1919, many people did not believe that the Atlantic could be crossed by air.*

II. The Flight of NC Seaplane Division One[§]

NC Seaplane Division One, led by CDR Towers, was commissioned on May 3, 1919 (Fig. 3). The four NC flying boats of the division were the first aircraft brought into regular commission by the Navy, and consequently the first aircraft in the Navy to have their own, unique identities. As naval aviator number three, Towers was one of the most experienced pilots in the Navy. Additionally, Towers already possessed numerous aviation records for distance and endurance. He pioneered the use of aircraft for submarine hunting, and with his involvement in the prior transatlantic attempt in 1914, Towers was uniquely suited to command the division whose first mission would be to fly across the Atlantic for the first time.[8]

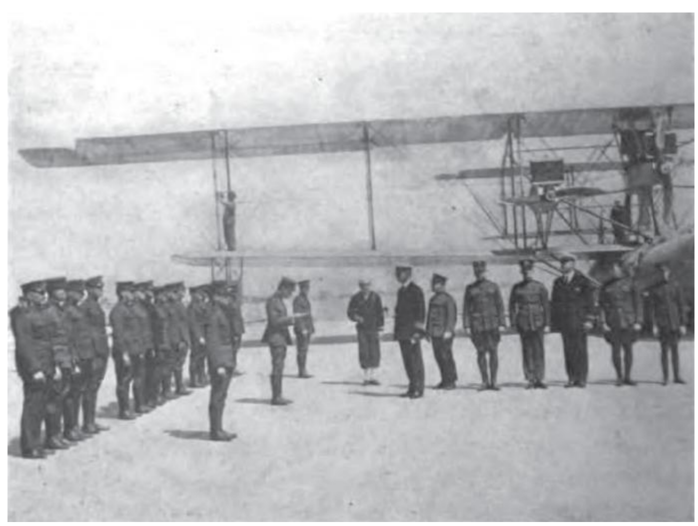

Figure 3. Commissioning ceremony of NC Seaplane Division One. *CDR John Towers reads his orders as he takes command of the Navy's first division of regularly commissioned aircraft on May 3, 1919.*

[§] While this paper deals primarily with the engineering achievements of the NC flying boats, a brief account of the flight is presented.

Less than one week after the commissioning of NC Seaplane Division One, on May 8, the NC-1, NC-3, and NC-4 left Rockaway Naval Air Station to set off across the Atlantic. The planned route would take them from Rockaway, New York, to Halifax, Nova Scotia, and then on to Trepassey Bay, Newfoundland, which would be the jumping off point for the ocean crossing. From the coast of North America, the longest leg was 1,200 nautical miles to the Azores, and then on to Lisbon, Portugal to complete the crossing. Lisbon would not be the final port though; the division would continue to Plymouth, England from where the Pilgrims left for the North American continent nearly 300 years earlier (Fig. 4). Of course, things did not go exactly to plan. Originally, the entire division of four *Nancies*, as the NC flying boats were known, was supposed to make the flight. The NC-1, however, was severely damaged in a storm and it was decided to use the NC-2 as a testbed while repairs and updates were made to the NC-1. The NC-2 was then cannibalized for the remaining parts required. Towers took the NC-3 as his flagship, LCDR Patrick Bellinger commanded the NC-1, and LCDR Albert Read commanded the NC-4.

The NC-1 and NC-3 easily made the trip to Trepassey Bay, but the NC-4 experienced engine troubles and was forced to stop and make repairs. Nicknamed the “Lame Duck”, the NC-4 barely made it to Trepassey Bay in time to depart with the other two *Nancies*. For the transatlantic legs of the flight, the Navy had positioned ships approximately fifty nautical miles apart like a string of pearls across the ocean. Fifty-three specially outfitted ships were used in total. Some had special weather and radio gear installed, some were set up as tenders, and all had star shells for use during the night, and made smoke during the day. Departing around nightfall, the *Nancies* would fly through the night to make the Azores the next day. The three flying boats intended to fly in a loose formation, keeping each other in sight, but quickly found this to be impossible in the quickly deteriorating weather. Each then had to make its way alone across the vast expanse of open ocean. Even with only three aircraft operating over the entirety of the ocean, the airspace became crowded – in the darkness of the night the NC-1 and NC-3 nearly collided!

All three *Nancies* made the distance to the Azores, but the weather conditions had deteriorated and visibility was very poor. The NC-1 and NC-3 each landed in order to conserve fuel while obtaining a more accurate fix on their position, but were damaged landing in the very rough seas and were unable to resume their flights. The NC-4 would have done the same, but LCDR Read happened to catch a glimpse of coastline through a small break in the clouds and fog, and the NC-4 made it safely to the island of Horta. Bellinger’s crew was shortly rescued by a passing Greek freighter, but while attempting to tow the stricken NC-1, the lines broke in the heavy seas and the original *Nancy* was lost. Towers and the NC-3 had a much rougher time. With the fleet unaware of their location, and the NC-3 unable to get a radio message out due to the overwhelming volume of chatter on the airwaves, they were effectively

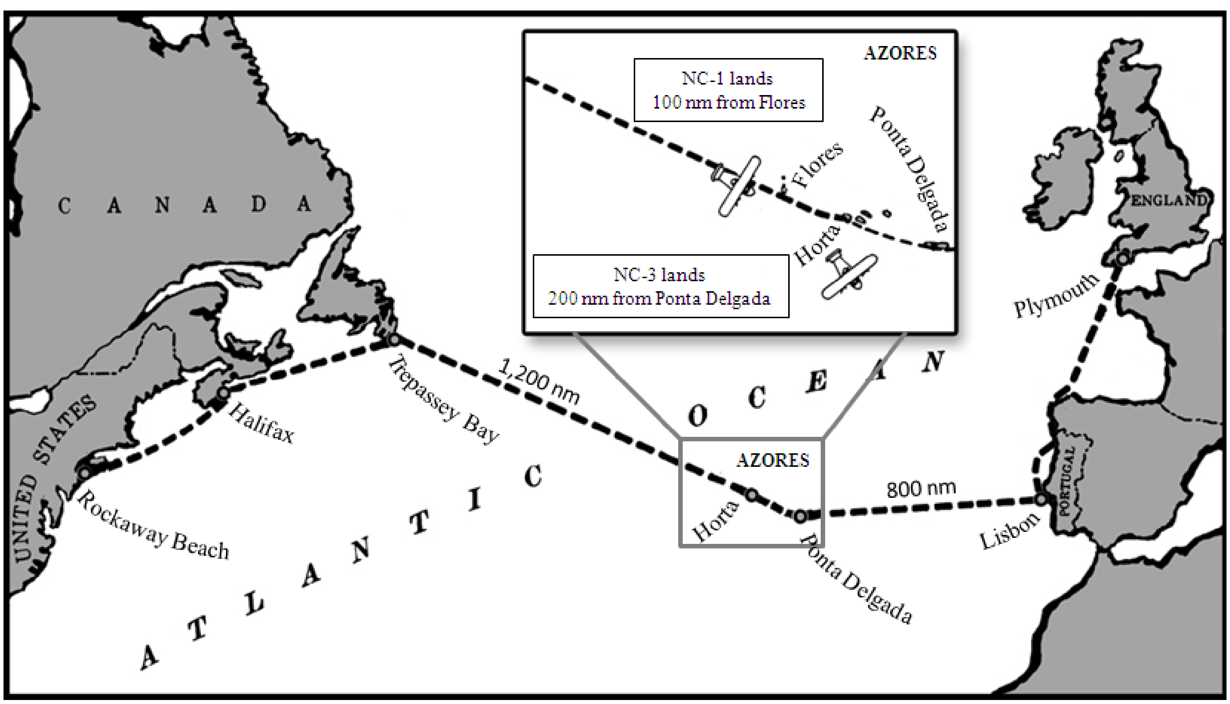

Figure 4. The flight of NC Seaplane Division One. *The transatlantic route of the flying boats from Rockaway, New York, to Plymouth, England. Only the NC-4 was able to complete the entire flight. The NC-1 and NC-3 landed near the Azores after losing their bearing in poor weather and were unable to get away again.*

Figure 5. NC-3 at Ponta Delgada, Azores. *After an overnight 200 nm voyage through 30 – 40 ft seas and gale force winds, the NC-3 brought her crew safely to the Azores. Though unable to complete the flight, the NC-1 and NC-3 had set the record for the longest flights to date.*

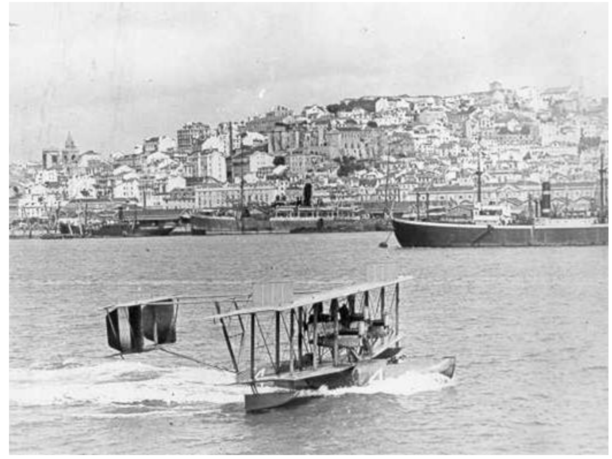

Figure 6. NC-4 arriving at Lisbon, Portugal. *The NC-4 taxis into the harbor after completing the first transatlantic crossing by air. The NC-4 had flown 2,000 nm over the open ocean on its way from Trepassey Bay to Lisbon.*

on their own in a damaged flying boat, 200 nautical miles from land. The crew survived a hellish night of gale force winds and thirty to forty foot seas, and successfully made it to Ponta Delgada on their own (Fig. 5). The inset of Fig. 4 shows roughly where the NC-1 and NC-3 put down in the ocean.

From Horta, the NC-4 made the short hop to Ponta Delgada where the NC-3 had arrived by sea, and then completed the voyage to Lisbon and Plymouth (Fig. 6). In total, the NC-4 covered 3,936 nautical miles flying 52 hours and 31 minutes over the course of 19 days. While the NC-1 and NC-3 were not successful in completing the transatlantic flight, their third leg from Trepassey Bay was longer than that of the NC-4, or any flight previously recorded.[9] Furthermore, the NC-3 demonstrated the *Nancies'* ability to survive tremendous seas and brought her crew safely to port, just as RADM Taylor had intended.

III. Concept of the NC Flying Boats

Most worlds' firsts are accomplished with specialized and optimized equipment, unable to do anything but the minimum required to succeed in completing the task at hand. The result would be achieved using inventive, often untested concepts, in the pursuit of glory. In addition to the dangers inherent in breaking new ground, safety was often overlooked and significant risk accepted in the quest to be the first in accomplishing a feat of this magnitude. During the 1910's, while trying to be first to cross the ocean, most of the attempts were being made using land based aircraft. Flying boats had yet to demonstrate the range needed for the trip, and were still a niche in aviation. While large, land based aircraft had proven their capabilities during the war, there were still significant risks in using these aircraft to attempt a transatlantic crossing. As the aircraft had no option but to take off and land on the ground, a non-stop flight was the only feasible approach, and they were at the limits of the proven ranges of these aircraft. If, for any reason, the crew was unable to make the complete trip, ditching into the North Atlantic was the only option. Not only would the aircraft provide no protection from the water, they would be at the mercy of ships finding them in the vast expanse of open ocean. Engines of the day were notoriously unreliable, and losing engines in flight was commonplace. Navigation over the water presented a new problem. Most navigation was done visually, but without land as a reference, transatlantic fliers would have to rely on instruments to find their way. Weather patterns and winds were not precisely known over the ocean and the techniques for determining ground speed and position while over the water were experimental.

The NC flying boats were "the result of organized engineering rather than invention"[10] according to Hunsaker in 1919. The NC flying boats' "design and construction made use of available talent both in and out of the service, the facilities of parts makers and the new materials developed during the war". This was no science project or research program. That said, there was still significant inventiveness on the part of the design team in search of solutions to engineering problems, and numerous patents[**] resulted from their work. The NC's were originally envisioned as

[**] Example of an invention made during the design of the NC flying boats: Freund, Carl. Patent No. 1,364,431, "Airplane-Wing Structure", assigned to Curtiss Aeroplane and Motor Company. Filed March 31, 1919, assigned January 4, 1921. This technology enabled a more efficient wing structure, improving strength and reducing weight.

combat aircraft, and their design and construction had to support that mission. Their specifications included performance that had yet to be proven possible and at the same time be produced in large quantities. To achieve these diverse goals, aeronautical engineering was about to come of age. Decades earlier, David Taylor modernized naval architecture through the rigorous application of analysis, experimentation, and design. In 1919, the team he charged with building the greatest flying boats ever constructed would complete the same transformation for aeronautical engineering. The result was the NC flying boat (Fig. 7).

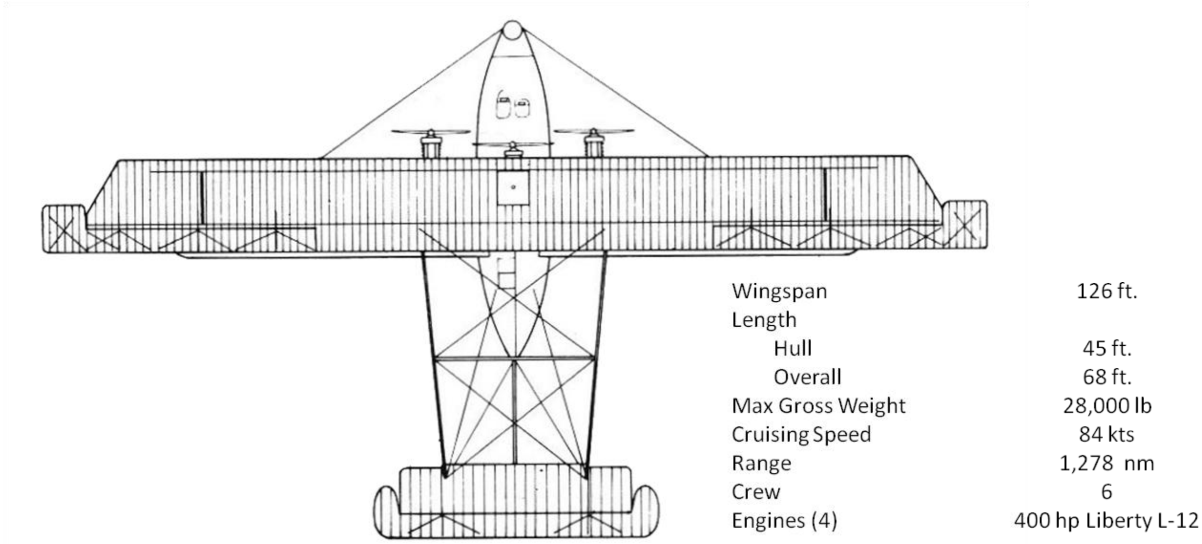

Figure 7. The NC flying boat. *In 1919, the NC flying boats were the largest in the world, and are still impressively large vehicles by today's standards.*

IV. Engineering and Building the NC Flying Boats

In the years leading up to 1917, the design process for aircraft, as it had been for ships a few decades earlier, could be described as largely trial and error. The entire vehicle would be designed and roughly analyzed, then immediately a prototype would be built. This prototype would be tested and then aspects re-designed in order to address shortcomings in performance. The changes were based mostly on the experience of the designer, and would continue until the result was satisfactory, or the design was deemed to be ineffective. This method was not only risky, but also highly inefficient. For an aircraft the size of the *Nancy*, it was wholly impractical, and a better way was needed. The designers of the NC flying boats implemented the more modern method that had been adopted as standard for ship design by the Navy and was recently being tried for aircraft. Every component was designed in detail, optimized, and tested before anything was built for the prototype. Certainly, many changes were made once the vehicle was built and underwent flight testing, but the design had already been proven and there was no question, at least to the designers, as to the air and sea-worthiness of the vehicle.[11] While the NC-4 was still in the Azores, an article was published in the *Aircraft Journal* describing the famous flying boats as:

> …designed from theoretical and model experimental, data, combined with the practical experience of a half dozen or more people, performed in every way so close to her designed characteristics as to completely justify the methods of the Naval Architects here applied to the design of a flying machine.[12]

This approach has more in common with modern systems engineering than early aircraft design, and was transformational in allowing increasingly larger and more complex vehicles to be built.

A. A Team Effort

The design of the NC series was fundamentally a team effort. While certain individuals made singular contributions to the concept or design, no one person could be credited for designing the entire vehicle. Ideas from all members were given equal consideration, chosen on the basis of merit alone. As Hunsaker writes, "no one man can be said to have designed these craft, although the Chief Constructor of the Navy, Admiral Taylor was at all times responsible".[13] Even the name of the series, NC – "N" for Navy and "C" for Curtiss – bears out the unified nature of this project. Hunsaker goes on to describe the design as the "organized result of what we had learned from previous experience, what we could deduce as to the future by application of aeronautical engineering theory and methods, and what we could learn from foreign practice." Today, this is commonplace, but in the early 20th century, these “best-practices” techniques were newly being applied to aircraft design. After Taylor and Hunsaker’s initial studies into the feasibility of the aircraft that was to be known as the NC, the development and design team was quickly completed with Glenn Curtiss and Navy Commanders George Westervelt and Holden Richardson. Each of these men had significant and unique experience and were some of the best and most promising aeronautical engineers of the day (Fig. 8).[14]

Glenn Curtiss, the founder of the Curtiss Aeroplane and Motor Company, was the first to successfully build a seaplane and remained at the forefront of seaplane design. His company had worked with the Navy since the beginnings of naval aviation in 1911, and had a proven record of innovation. Furthermore, while his *America* was never able to attempt transatlantic flight as intended, the Model H series of flying boats that followed were some of the most successful designs of the war. Curtiss was one of the pioneers of aircraft design and manufacturing in the Unites States; as Taylor said: “The Curtiss Engineering Corporation is the only firm in position to undertake this development at the present time”.[15] Curtiss was therefore chosen as the contractor to build and integrate the *Nancies* and his company was responsible for many of the design details.

Figure 8. NC Design Team. *The team charged with designing and building the NC flying boats were some of the Navy’s and industries’ most talented aircraft and ship engineers.*

Commander George Westervelt was a naval constructor, specializing in structural design. He too had a history with aviation and seaplanes. In 1914, Westervelt was stationed in Seattle, Washington, overseeing shipbuilding efforts. He became interested in aviation in general and seaplanes in particular, along with a local lumber supplier and boat builder. This man decided that he wanted to purchase a seaplane, and asked Westervelt to recommend a type. After researching the available aircraft, Westervelt could find none to recommend, and so the man offered to build two aircraft if Westervelt could come up with a good design. While he had never attempted to design an aircraft before, Westervelt agreed to the challenge, enlisting as much help as possible from every source he could find. Eventually, he settled on a design, and as promised, two were built (Fig. 9). This was the lumber-man’s first foray into aircraft manufacturing, but would not be his last; William Boeing decided to become a manufacturer of airplanes. Based on this experience, CDR Westervelt was placed in charge of aircraft inspection and construction by RADM Taylor. One of Westervelt’s early contributions to the effort was suggesting a name for the new flying boat; his proposal was “DWT” for David W. Taylor. On further consideration, it was decided that Taylor would not take kindly to this, and the NC designation was adopted.

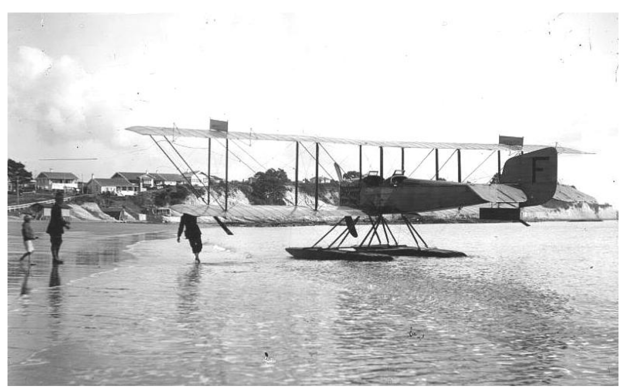

Figure 9. The B & W Seaplane. *Naval Constructor George Westervelt designed this seaplane for a lumber-man who had become interested in aviation. William Boeing built two of these aircraft, and then a few more later on.*

Commander Holden Richardson, also a naval constructor, was another one of Taylor’s prodigies. Richardson became involved with naval aviation in 1911 as the Navy’s first engineering and maintenance officer for aviation. In 1912, Richardson translated Gustave Eiffel’s aeronautical research data and began the process, along with Taylor, of designing and building the Navy’s large scale wind tunnel, which was the foundation of the Navy's newly established Aeronautical Laboratory.[16,17] A few years later, Richardson used this tunnel to evaluate the government's first in-house designed aircraft, the 82-A or Richardson Seaplane. While an accomplished aerodynamicist, he had unparalleled expertise in the design of flying boat hulls and seaplane floats, and this is what he was brought to the NC design team to do. In addition to being an accomplished engineer, Richardson was also a pilot. He was naval aviator number thirteen, and the first engineering test pilot. CDR Richardson served as a test pilot on the NC project, and he personally tested the sea-worthiness of his hull design while sailing the 200 nm to Ponta Delgada as pilot of the NC-3.

B. Designed for Combat

Per Taylor's direction, the NC series was to be a serviceable, combat-ready, flying boat. This required building a vehicle that could withstand the rigors of combat deployments, protect the crew, complete its intended mission in non-ideal conditions, be maintainable and repairable in theater, and be built in accordance with standard Navy practice. These requirements all tend to have the undesirable side effects of adding weight, cost, and complexity. For a vehicle that was already the largest and heaviest flying boat ever built, these challenges were compounded. Examples of these considerations are: multiple redundancies on flying wires and landing wires in order to maintain integrity in the event that wires were cut by enemy fire; extra factors of safety on critical components, where needed, to survive maneuvering and rough landings; control rigging hidden under a hinged leading edge to allow ease of inspection as well as reduced drag; and, of course, the ability to carry and deploy weaponry.

Taylor's requirement that the *Nancy* handle foul weather in the water put additional requirements on the overall design. The entire vehicle, but especially the hull, would need to be robust enough to take a pounding from the ocean and then continue with the mission. Corrosion was also a significant consideration in the design of a vehicle intended to serve its useful life in salt water. Wood and fabric treatments were well developed by that point, though the fabric covering on the wings would need to be changed every six months to one year. Improvements were necessary in order to protect the highly stressed and weight-optimized metal components. A new process of electro-galvanization prior to painting was developed for steel. This was considered a significant advance in corrosion protection. Aluminum was also used for certain components in the design. Given that this was the first time aluminum was used in quantity on heavier-than-air aircraft, and due to its reactive nature to salt water, methods of protection were necessary before it could be utilized. The coatings developed were very successful and used later for strength members of dirigibles.[10]

C. The Incredible Hull

Designing a flying boat as large as the NC series required re-envisioning what the shape of the aircraft should be. Flying boats of the day were built on a single hull extending from the bow to the tail surfaces, directly supporting all of the vehicle's components. Due to the unprecedented size of the *Nancy*, though, Curtiss had a different idea. His concept was a shorter hull with the tail supported not by the hull itself but by a system of booms, struts, and outriggers anchored to the hull and the upper wing[18] (Fig. 10). While somewhat unusual looking, this highly visible aspect of the design helped to meet the sea-worthiness requirements by keeping the tail as high above the waterline as possible. This would allow for operation in higher seas without the waves hitting the tail. Curtiss' concept not only allowed the tail to be mounted high up, but also saved a significant amount of weight.

Starting with Curtiss' idea, Richardson went about designing the shortened hull. He based the design on his previous work with seaplane floats, and the result was unlike anything that had been seen before. In fact, it was so out of the ordinary that it was made the subject of ridicule by many of the world's experts in aircraft and flying boat design. Many found it ungainly, and were not shy about expressing their doubts. As one distinguished British visitor opined, "The hull of this machine was examined, and is the design of a naval constructor. The machine is impossible, and is not likely to be of any use whatever."[19] Even CDR Towers found the design, at first, odd looking, and stated openly that he did not like it.[20] Richardson, for his part, was undeterred. He was designing a flying boat hull with unprecedented buoyancy and planing requirements that had to be operable and safe in adverse seas while being as light as possible. It was not

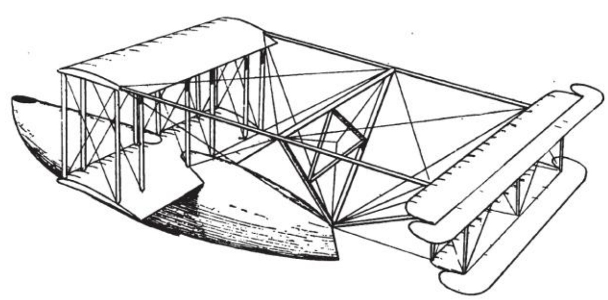

Figure 10. Curtiss' Tail. *In the early stages of design, Glenn Curtiss proposed a radical departure from the standard practice of flying boat design. His idea was to shorten the boat hull and locate the tail surfaces with booms and outriggers.*

an ordinary problem, and required an extraordinary solution.

Previous designs relied on the width of the hull to achieve planing at reasonably low speeds, often adding sponsons or pontoons to the sides of the hull to get the necessary lift. Richardson realized that this additional width would add both weight and drag, neither of which could be afforded in the design. Furthermore, the added width would be destabilizing in heavy seas, making the requirement of navigating through rough seas impossible. Instead, he designed the hull to plane with speed rather than width which was a radical departure from the standard practice. Another important feature of flying boat hulls is the "step," which both reduces the drag and can provide stability while planing. Richardson's novel design included a single step and also makes use of the stern of the hull as a second step, providing a stable platform while planing and allowing the pilots to better control the aircraft while at speed on the water. This concept was yet another significant improvement in the design of flying boats (Fig. 11).

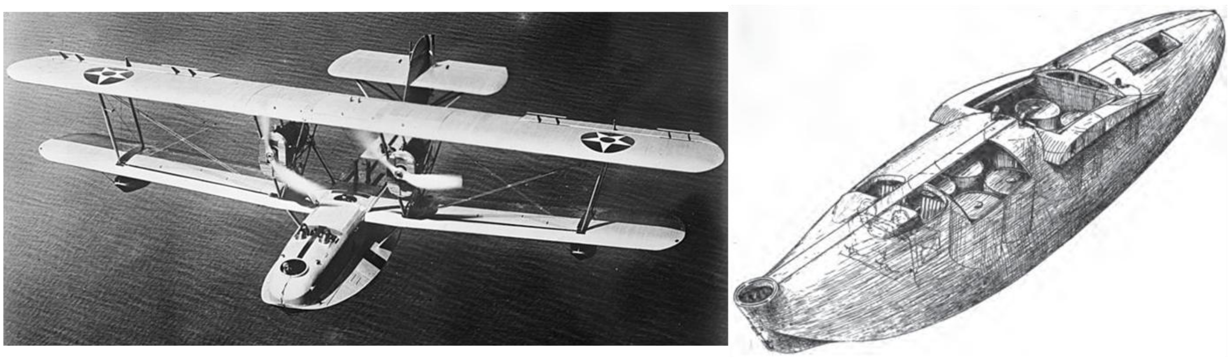

Figure 11. Richardson's Hull. *Richardson's hull design was a drastic change from the standard of the day. Hulls such as the PN (left) used sponsons to provide the extra width for the lift necessary to get away. Based on his previous work on pontoons and seaplane floats, Richardson designed the NC hull (right) to plane using speed instead. This narrower hull, which many thought strange or awkward looking, was more stable and sea-worthy than the alternative designs, and still allowed the NC flying boats to get away at and above their maximum design gross weights. The hull design was put to the test in the middle of the Atlantic when the NC-1 and NC-3 landed in heavy seas. The forward-thinking designer saved both crews, and allowed the NC-3, with Richardson himself on board as a pilot, to sail in to Ponta Delgada.*

The structure of a hull is of equal importance to its shape. Being part boat, part airplane, a flying boat must be able to withstand the loads imposed by the sea while at the same time remaining light enough to fly. For a vehicle as large as the *Nancy*, this challenge is magnified. These opposing requirements were successfully managed by careful selection and distribution of material. W. L. Gilmore, a Curtiss engineer, is given credit for much of the structural design of the hull. The keel of the hull is built up from spruce while the bottom planking is laid up from two plies of cedar separated by a waterproofing barrier of muslin set in marine glue. Ash girders braced with steel wire provide longitudinal strength. As designed, a bare hull weighs 2,800 pounds with a displacement of 28,000 pounds, an incredible-for-the-time ten-to-one ratio. Hunsaker described the *Nancy's* hull as having an "easy flaring bow so that it can be driven through a seaway to get up the speed necessary to take the air and a strong V-bottom to cushion the shock of landing on the water. The combination of great strength to stand rough water with the light weight required of anything that flies was a delicate compromise, and it is believed that a remarkable result has been obtained in this design."[10]

While small by current standards, the hull was spacious for 1918. There were six compartments separated by bulkheads, and originally watertight doors for survivability in the event of damage from battle or heavy seas, as shown in Fig. 12. Narrow passageways along the side of the hull allowed the crew of six to move between these compartments, and all but the two pilots could remain below decks and out of the weather if desired. The aircraft commander even had enough space to lie down on the planking that made up the floor of his compartment at the front of the airplane (the airplane commander also served as the navigator). In order to permit inspection and maintenance of the engines, topside hatches and non-skid walkways were incorporated to allow the engineers to move about. A "tunnel" on the aft deck was provided for an engineer to crawl through, under the centerline pusher propeller, and they used linesman's belts to secure themselves to the aircraft while moving about in flight (Fig. 13).

Curtiss and Richardson's unusual design was vindicated by its performance. It permitted the *Nancies* to get-away at weights even above the originally designed maximum gross weight, and remained stable on the water and in the air. Further, it proved rugged and sea-worthy beyond what any could have imagined during the transatlantic flight. When the NC-1 and NC-3 put down in the ocean near the Azores, the seas were rougher than anticipated at up to fifteen feet. Both aircraft suffered damage upon landing, but would not have been able to take off again regardless, due to the sea conditions. During the overnight saga of the NC-3, the seas were in excess of thirty feet and very

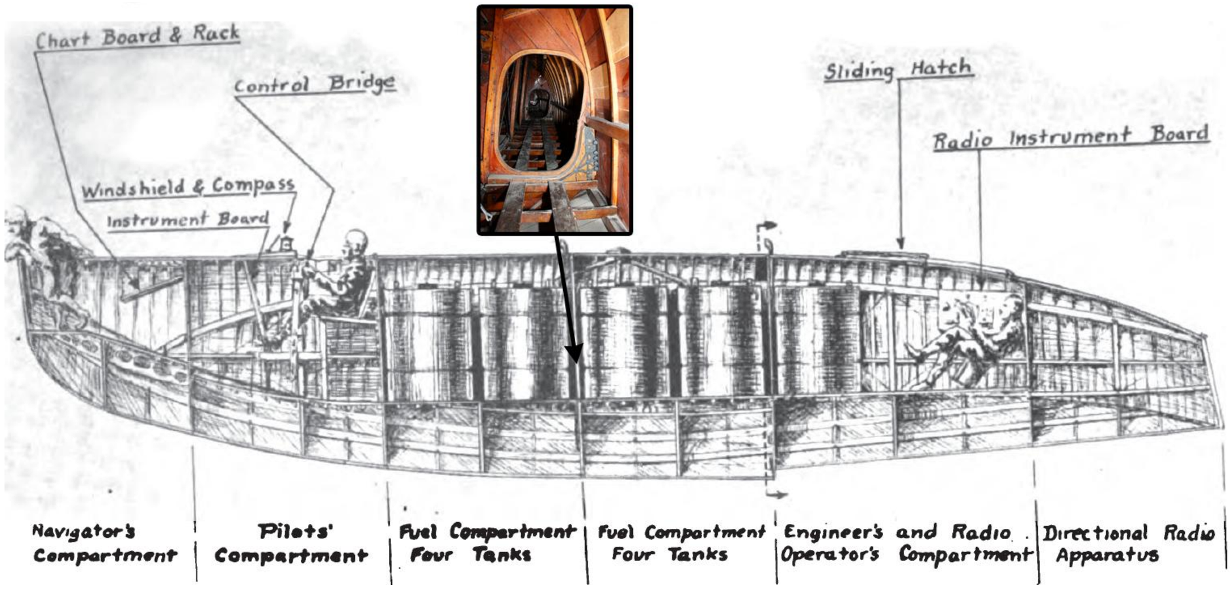

Figure 12. Inside the hull of an NC flying boat. *The hull was broken into six compartments, originally sealed off with watertight doors. Passageways along the sides allowed the crew to move about inside the hull (inset).*

steep, with gale force winds blowing, according to the first-hand accounts of Towers and Richardson. This is the equivalent to sea state eight conditions, and well beyond the sea-keeping capabilities of any other flying boat of the day. The design saved the crews of both the NC-1 and NC-3, and permitted the crew of NC-3 – including Richardson himself – to sail safely, if not comfortably, to port in unbelievably difficult conditions.[19,21]

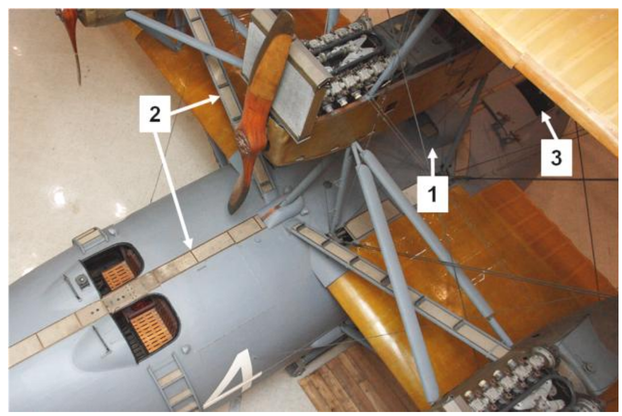

Figure 13. Overhead view of the NC-4. *The hull was built to accommodate the movement and access needed to maintain the aircraft while in operation: the "tunnel" provides a guide for safe movement and protection from the aft prop (1), non-skid walkways line the deck and struts permitting access to the engine nacelles (2), and a hatch offers the engineers access topside while underway – on the water or in the air (3).*

D. Experimentation, Analysis, and Testing

With the availability of the Experimental Model Basin and Experimental Wind Tunnel at the Washington Navy Yard, and Curtiss' own smaller facilities, the team had unprecedented access to cutting-edge experimental facilities. In 1917 and 1918 Dr. A. F. Zahm, head of the Navy's Aerodynamics Laboratory, conducted one wind tunnel test of hull designs and two tests of the complete aircraft in the Navy's large wind tunnel, as well as a special stability test. These tests validated the aerodynamic design of the vehicle and were used to tune the performance and handling with evaluations of tail size and incidence, control surface balancing, and overall stability. In 1917 and 1919, three tests of the hull were conducted in the model basin by Richardson and Naval Constructor William McEntee. During these tests, three different hull designs were tested before the final shape was decided upon, then fine tuned for best trim and performance. Richardson's earliest design had two steps with an upward curvature of the keel. The first modification removed the curvature, and the second modification removed second step creating the final shape with the unique stern that functioned as a step. Through testing, it was found that without these modifications, the *Nancy* would not have gotten off the water.[22] Finally, in late 1918 and 1919, seven tests were conducted in Curtiss' smaller wind tunnels to assess design changes and final configurations.[23] The entire design was thoroughly analyzed for lift, drag, and power required for flight; control authority and power; stability; and hull hydrodynamics and stability (Fig. 14). These tests provided the basis for the team's confidence, prior to construction of the first prototype *Nancy*.

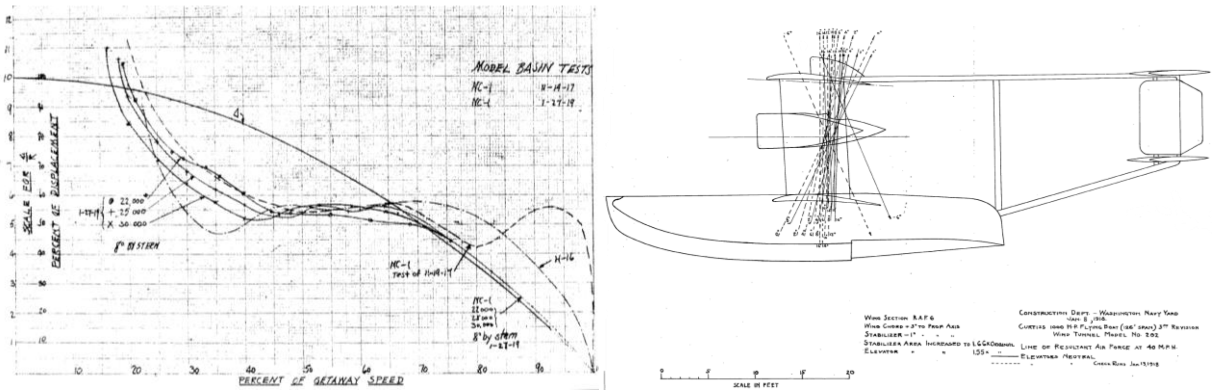

Figure 14. Sample experimental test results. *The design was tested for both hydrodynamic and aerodynamic performance in the experimental facilities at the Washington Navy Yard. The Experimental Model Basin was used to determine power required on the water (left) and the Experimental Wind Tunnel was used to determine flight power requirements along with stability and control characteristics (right).*

As the aircraft was originally intended for wartime use, the design and test schedule was highly compressed. From Taylor's initial idea in August of 1917, it took just over one year to complete the prototype aircraft and on October 4, 1918, the NC-1 flew for the first time with CDR Richardson as the test pilot. Initial tests of the NC-1 proved the design to be sound with performance that exceeded expectations. The handling of the aircraft was excellent without requiring too much effort on the part of the pilots. There had been concern that an aircraft as large as the *Nancy* would need servo assistance on the controls, but due to the careful design of the control surfaces for aerodynamic balance and fine-tuning of the tail size and incidence in the wind tunnel, the aircraft flew without much effort and was very stable. To further improve handling qualities, the center of lift was determined through wind tunnel tests and the vehicle was balanced so as to collocate it with the center of gravity, as shown in Fig. 14, right.

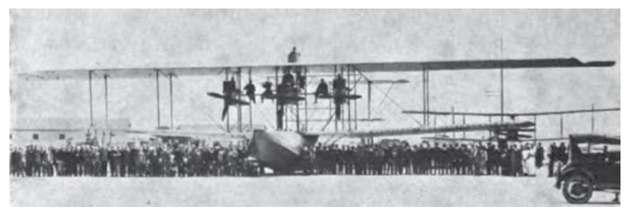

Figure 15. The NC flying boats were record setters from the start. *On November 25, 1918, with the NC-1 still in test, it made a flight carrying 51 people aloft, setting a record for the most people ever carried on an airplane.*

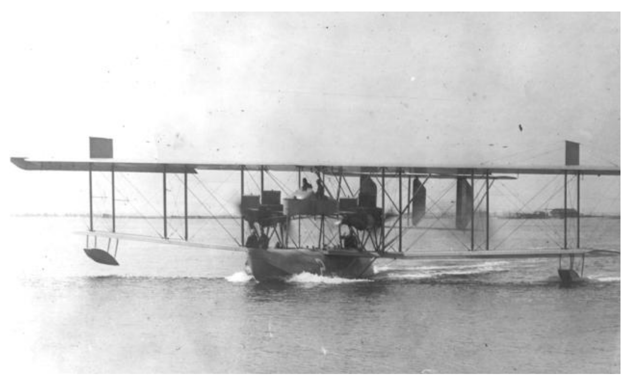

Figure 16. The NC-2. *The NC-2 was modified to a four-engine configuration with two pairs of engines on the wings, retaining the central nacelle for the pilots. This "twin-tandem" version was known as the NC-2T and was able to lift off the water at a gross weight of 28,000 lbs.*

Soon, the NC-1 was being exercised at high gross weights, even beyond the design maximum, and over extended ranges. One of these flights took the NC-1 on a trip to Washington, D.C. where it docked on the Anacostia River at the Washington Navy Yard. It was here that RADM Taylor saw the aircraft that he envisioned for the first time. It was also decided to attempt to set a record for the most people carried aloft while the NC-1 was still in test. On November 25, 1918, 51 people (one being a stowaway, hiding himself in the hull for hours wanting to be a part of the record setting flight) were crammed into the hull and the NC-1 easily lifted off (Fig. 15). This bested the record of 40 persons set just prior in a Handley-Page bomber.

The initial design was for a maximum gross weight of 22,000 pounds with three engines. During flight tests of the NC-1, the structure was determined to be capable of carrying more weight if more power was available. Consequently, the decision was made to configure the NC-2 with a fourth engine for testing (Fig. 16). This extra engine, while not explicitly necessary for flight, offered the advantages of additional redundancy in addition to greater range and payload, which was especially important for an aircraft intended to operate over vast expanses of open ocean carrying as much fuel, equipment, and weaponry as possible. The fourth engine brought the maximum gross weight up to 28,000 pounds, 12,000 of which are payload. This is a useful weight fraction of 43%, an incredible achievement. For comparison, the land based Handley-Page V/1500, or Super-Handley, while heavier, had a lower useful weight fraction of 41%. Different configurations for the three and four engine installations were tested before the final configuration was decided upon. As with the design of the rest of the vehicle, results and performance, rather than preconceived notions or personal preference, guided the process.

E. Structure

The structural design of all the various components had to be carefully engineered to carry the massive loads while remaining light enough to fly. The wings, struts, spars, tail booms, fitting, wires – everything that went into the build of the vehicle – needed to be carefully considered. While the designers utilized the standard RAF 6 airfoil for the wings, the ribs and structure had to be built to handle the enormous weight and load requirements for the 28,000 pound flying boat. In some cases, the structure had more in common with bridges than with typical aircraft construction. George Westervelt, having been assigned by the Navy to oversee final design and construction of the *Nancies*, was also responsible for the structural design and testing of all the various parts of the aircraft, and personally directed the build-up of the wing. As he did when designing his first aircraft for Boeing, CDR Westervelt gathered as much information as possible on the methods that other engineers had used to build wings for large aircraft. He traveled to England and met with Sir Frederick Handley-Page, who, after much discussion, gave Westervelt a sample of the rib used in his Super-Handley night bomber. Westervelt ended up basing his design on this rib.

Metal fittings were a challenging design problem to keep the amount of material used to a minimum. Each fitting, having unique load bearing requirements, was analyzed individually in order to ensure that it met the structural design requirements while remaining as lightweight as possible. The result were pieces that were, literally, the work of a jeweler (Fig. 17). This attention to detail at all levels exemplifies the commitment to excellence that the entire team exhibited throughout the course of the design, construction, and testing of the NC flying boats.

In addition to the aerodynamic and hydrodynamic testing, significant experimentation and analysis was done on the proposed structures of the wing, tail, and riggings, and to determine the best materials to use. Load testing rigs, able to simulate the forces exerted in flight, were used for testing wing rib designs to failure (Fig. 18). Booms were tested for strength in compression and bending, and components of different materials were tested for best performance. Through the course of this process, many different concepts were tested for the variety of load bearing components. For some of these, there were collegial disagreements over which design would be best. The result would remain objective based on testing and engineering analysis, however there would be friendly bets placed on each design as to which would be optimal. This light-hearted competition fostered both ingenuity and application of solid design principles.[19]

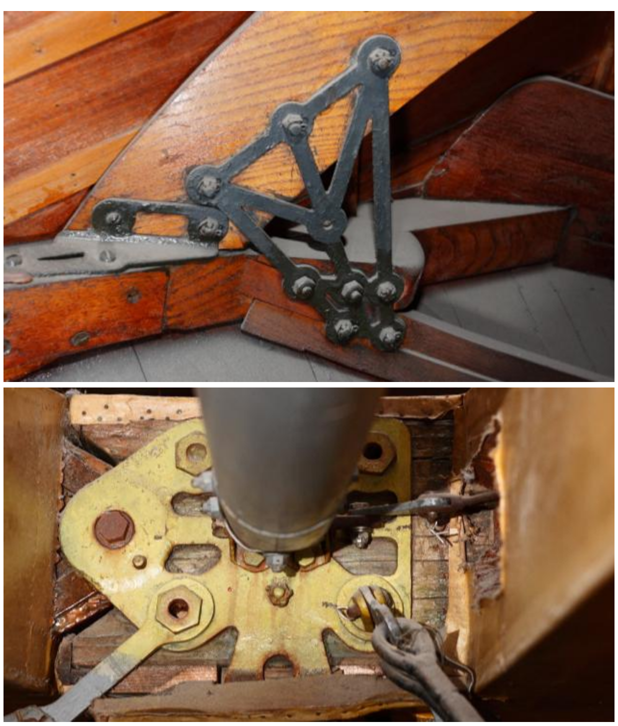

Figure 17. Metal fittings used on the NC's. *These metal fittings were designed and tested to ensure that they had the strength required while using the absolute minimum of material.*

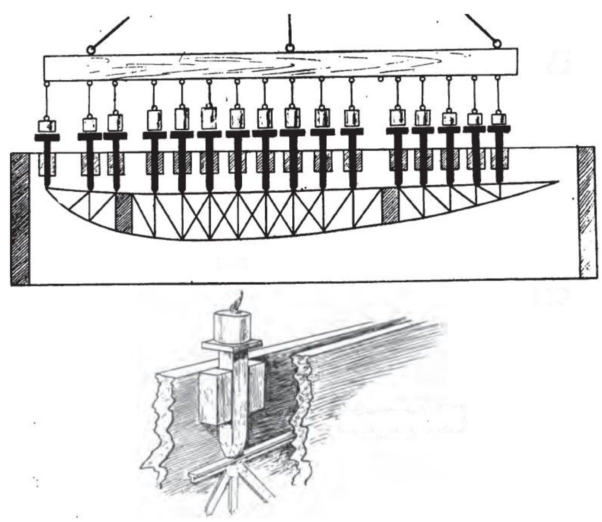

Figure 18. Westervelt's NC wing rib and rib testing device. *The structure and material construction of the ribs were developed and tested to failure to ensure that they could carry the requisite loads.*

F. Construction

Significant advances in construction were necessary in order to build the unprecedented *Nancy* flying boats. The aircraft was simply too large and complex to be built by a single manufacturer, especially given that the original intent was to produce the aircraft in quantity for combat use. It was decided to break the construction up into components and sub-contract the build to manufacturers who could fabricate the specialized pieces. Curtiss would be responsible for the overall construction and integration of all the parts, and the Navy, with Westervelt as its representative, would retain overall authority over the build. This method of construction, while standard today, and common for ships of the day, was new for aircraft and required significant coordination and precision in design in order for all the pieces to fit together and work as required. The following major components of the NC flying boats were built by the different companies shown in Table 1.[24]

Table 1: Manufacturers of NC Flying Boat Components

Hulls:	Curtiss Engineering Corporation, Garden City, NY (NC-1)
	Lawley & Sons Boat Co, Boston, MA (NC-2, NC-3)
	Herreschoff Co., Briston, RI (NC-4)
Tail Booms:	Pigeon-Fraser Hollow Spar Co., Boston, MA
Gas Tanks:	Aluminum Co. of America, Pittsburg, PA
Wings, Control Surfaces, and Struts:	Locke Body Co., New York City, NY
	Unger Bros., Newark, NJ
Metal Fittings:	Brewster Body Co., New York City, NY
	Beaver Machine Co., Newark, NJ
Wing Tip Floats:	Albany Boat Co., Albany, NY
Liberty Engines:	Packard Motor Company, Detroit, MI

These companies had significant expertise, but in areas not necessarily related to aircraft manufacturing. For example, Unger Brothers was a maker of fine silverware and jewelry, Locke Body Company was a high-end automobile coach-builder, and Pigeon Fraser Hollow Spar Company built masts and spars for racing yachts.[11] There was concern early in the process that the components would not fit or be serviceable, but those fears were quickly allayed during the first build of the NC-1. These companies were able to quickly adapt their specialties to the unique requirements of aircraft manufacturing and the assemblies all fit together very well (Fig. 19).

The Curtiss Company needed new manufacturing and assembly facilities to support the number and size of these aircraft. A factory was built for the purpose in Garden City, and in the course of one evening, the entire staff moved from Buffalo picking up immediately where they had left off the previous night. The variety of subcontractors and their geographic diversity, relative to the transportation options of the day, required logistical solutions to uncommon problems. The completed wings panels had to be moved from downtown Manhattan through Long Island to Garden City for assembly. These 12-foot by 45-foot structures were delicate and could not be moved quickly, or easily, through the narrow and rough roads. The only trailers available to move the large sections were built for moving theatrical sets, and there were only a couple in the entire city. It was decided that they would be moved in the middle of the night when there was minimal traffic, or witnesses, and this strange caravan would slowly make its way out of the city whenever wing sections were completed and ready for installation.

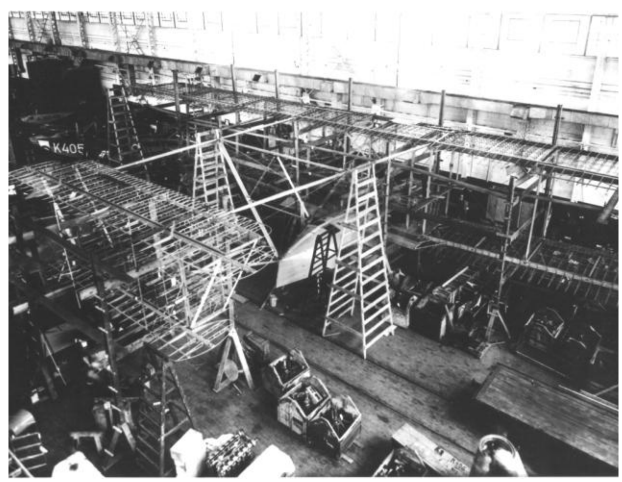

Figure 19. NC flying boat under construction at Curtiss' plant in Garden City, NY.

G. Engines and Power

Prior to 1917, very large aircraft were impractical due in large part to the lack of suitable engines. None of the available powerplants had the combination of power and lightness required for practical use in a large airplane. The first engine that offered this performance was the Rolls Royce V-12 Eagle, which was being used to power the large British bombers. Curtiss was also developing the K-12, an advanced, powerful engine made from lightweight materials and incorporating a gear reduction system to improve power and efficiency. While promising, the K-12 was ahead of its time and would not become a viable engine. Even though Taylor explicitly directed the use of the United States Motor, consideration was given to these alternatives if the preferred engines were not developed in time.[18] As the NC design progressed, so did the Liberty engine, as the motor was to be known. It was a serviceable powerplant by the time the NC-1 was ready for engine installation. Multiple versions of the Liberty were under development, each with progressively better performance, but all were based on the same 27 liter, 45° V-12 block. The first version of the Liberty was known as the low compression Liberty but these were quickly superseded by the high compression, or "Navy Liberties".[25] These engines produced 400 horsepower and weighed 850 pounds. A geared version was being developed that promised much greater efficiency, but it was too far from completion to be considered for use in 1918 or 1919. Through the course of the war, Liberty engines were built by many manufacturers, including Buick, Cadillac, Ford, and Lincoln, though the *Nancies* used engines built by Packard.

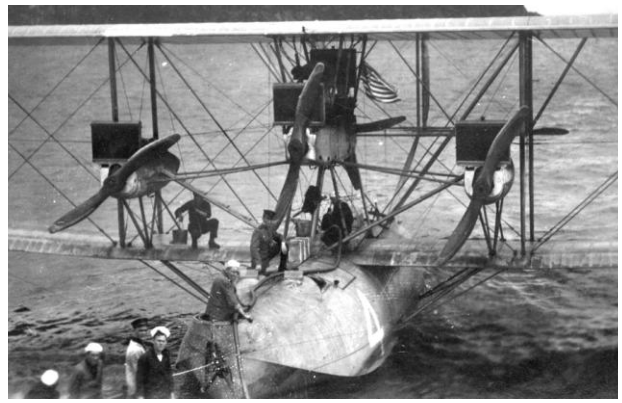

Figure 20. Liberty L-12 engines installed in the NC-4. *The final engine configuration of the Nancies had one engine on each wing and a pusher-tractor pair on the centerline.*

The initial design of the *Nancy* used three low compression Liberty engines in a tractor configuration, with the engines installed in nacelles between the wings. When it was determined through testing that engine performance was a limiting factor, it was decided that adding a fourth engine would be beneficial for performance and safety in the event of the all-to-common engine failures. The NC-2, originally built with three engines similar to the NC-1 (the centerline engine on the NC-2 was a pusher though), was modified to operate with four high compression Liberty engines, installed in tractor-pusher "twin-tandem" pairs between the wings. This "NC-2T" retained the center nacelle for the pilots, as shown in Fig. 16. When the NC-3 and NC-4 (Fig. 20) were built, a compromise arrangement was tried where a tandem pair was mounted along the centerline and single tractors were mounted in nacelles on the wings, as with the NC-1. The pilots were then moved to a cockpit in the hull. This configuration increased the efficiency of the propellers as only one would be operating as a pusher in the wash of another, and provided a further measure of safety by decreasing the likelihood of dangerous unintended yaw from differential thrust in the event of engine loss. This would be the final configuration and the NC-1 would eventually be converted to it as well.

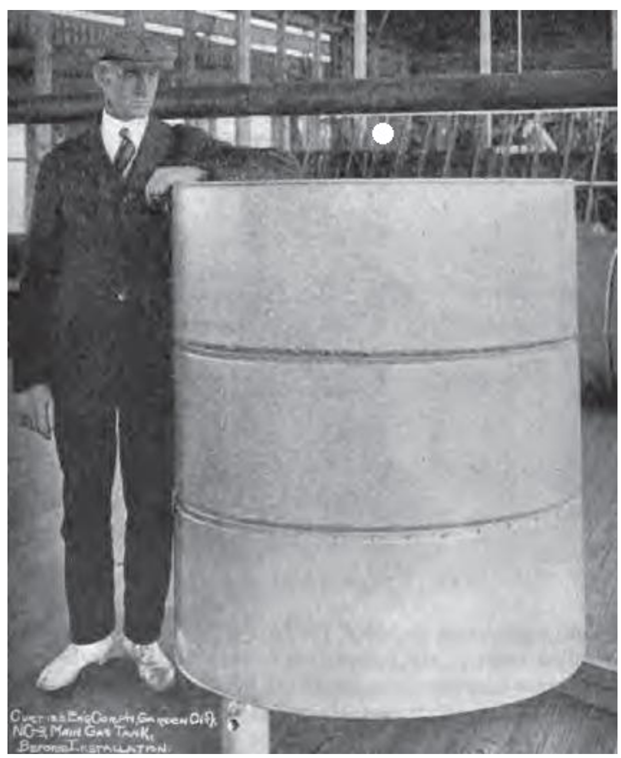

Figure 21. An NC's aluminum fuel tank. *The aluminum used in this 200 gallon tank was the first large scale application of aluminum in heavier-than-air aircraft. Its use saved 630 pounds over the equivalent tanks made from steel.*

In addition to the new engines, advances were made in the delivery of fuel and oil. The fueling system consisted of a set of nine interconnected 200 gallon aluminum fuel tanks in the hull (Fig. 21) and a single, 90 gallon gravity feed tank in the upper wing. Fuel was moved to the gravity tank by flow powered pumps

(Fig. 22) which then fed the engines. There were manual pumps in the event that they were needed. The use of aluminum in the fuel and oil tanks, and through their respective distributions systems, was the first large scale application of this material in heavier-than-air aviation. Each 200 gallon fuel tank weighed only 70 pounds, saving a total of 630 pounds compared to the equivalent steel tanks.

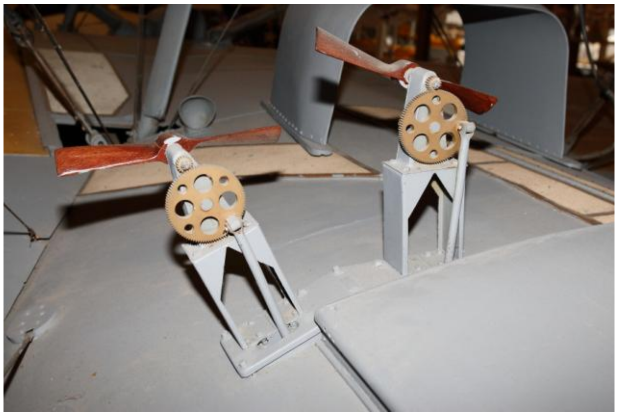

Figure 22. Wind driven fuel pumps. *The NC's were equipped with four wind driven pumps (two shown here) to move fuel from the 200 gallon storage tanks in the hull to the gravity tank in the upper wing.*

H. Equipped for Success

The vehicle itself was not the only development in aviation technology. The equipment installed and used on the transatlantic flight was cutting edge, and some was being tested for the first time. The *Nancies* were equipped with a full assortment of avionics. The cockpit had airspeed gauges, altimeters, compasses, pitch attitude and angle of bank indicators, and engine performance and status gauges (Fig. 23). Up front in the navigator's compartment, the aircraft commander had a specially designed sextant that could be used without a horizon for sighting, a drift indicator, compass, and a table under the deck for all the necessary maps and charts. The real innovations were in the radio compartment, though. The radio operator had access to 75 mile short range and 300 mile long range radio sets, and there was an intercom system allowing the crew to speak with one another and even allowed the commander to speak over the radio. There were two sets of antennae for use depending on whether the boat was on the water or in the air; one fixed between the wing struts and one trailing unit that could be reeled in before landing (Fig. 24). These radios allowed the *Nancies* to communicate with each other and with the ships strung out across the Atlantic.

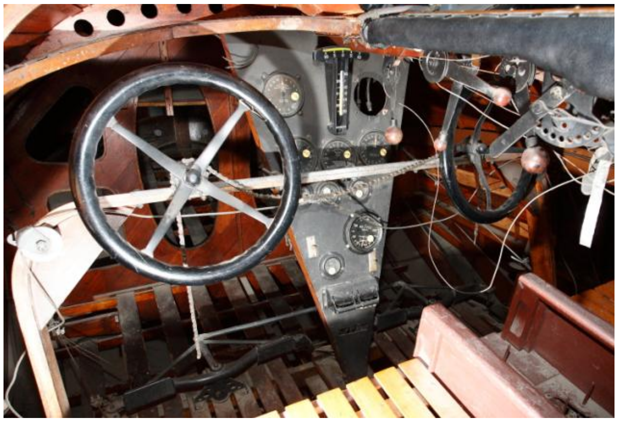

Figure 23. The cockpit of the NC-4 as it looks today. *While some gauges are missing, an assortment of avionics and controls can be seen. In addition, three Sperry compasses were installed, one in front of each pilot and one for the commander.*

Radio was not used for communication alone; for the first time it would be used over a long distance for navigation. The *Nancies* had radio compasses, or radio direction finders, that the radio operator would tune to a transmitter to determine the aircraft's relative bearing to the location of the transmitter. Ships strung out across the Atlantic were equipped with these transmitters to provide a beacon for the aircraft to follow. The radio compass worked well while installed on the NC-2 with its twin-tandem engine configuration, providing good bearings out to sixty miles. Unfortunately, there was insufficient time to fully test the installation with the final engine configuration and the interference created by the centerline engines significantly reducing the radio compass' effective range.[26,27] The compasses and gauges were self-illuminating for visibility at night, however these needed to be "recharged" regularly by flashlight. Powering all this equipment were batteries and a wind-powered generator located in the slipstream of the centerline propellers. The result was a better equipped aircraft than had ever before flown, and it needed to be, in order to find its way across the ocean.

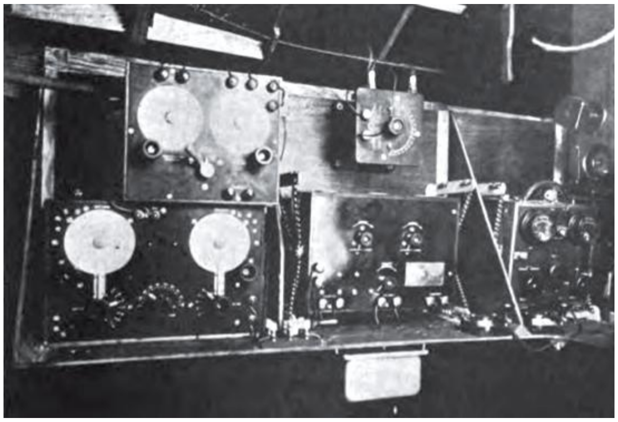

Figure 24. The radio compartment of the NC-4, as it looked in 1919. *The Nancies were equipped with two radios and a radio direction finder – the first long distance application of this technology.*

V. Legacy of the NC Flying Boats

The men involved with the design of the NC flying boats and NC Seaplane Division One would go on to have a lasting impact on the Navy and aeronautical engineering. David Taylor, of course, had already made his mark on the Navy, but was also a founding member of NACA, the predecessor to NASA, and continued to be an innovative force in aircraft design. When the Experimental Model Basin moved to Carderock, Maryland, it was renamed the David Taylor Model Basin in his honor. Today, the basin is part of Naval Surface Warfare Center, Carderock Division, where the authors are employed. Jerome Hunsaker was one of the United States' most influential aeronautical pioneers. Among his many contributions and achievements, he was head of MIT's Departments of Mechanical Engineering and Aeronautical Engineering, chairman of NACA, awarded the prestigious Guggenheim Medal, and was honorary president of the AIAA. As chief engineer at the Naval Aircraft Factory, Holden Richardson developed a catapult system enabling aircraft operations from ships and pioneered the development of carrier based aircraft. After retiring from the Navy, he became the first Secretary of NACA. During World War II, Captain Richardson was recalled to serve as head of the Navy's Aerodynamics Laboratory after it moved with the Experimental Model Basin to the David Taylor Research Center at Carderock. After commanding NC-4, Albert Read continued serving in the Navy, eventually becoming Chief of Air Technical Training during World War II. He retired as a rear admiral. John Towers, commanding officer of NC Seaplane Division One also continued serving in the Navy where, among other things, he was instrumental in developing carrier aviation. He rose to the rank of admiral before retiring in 1947.

Just a few weeks after the triumphant flight of the NC-4, Britons Alcock and Brown completed the first non-stop transatlantic flight. Eight years later, Charles Lindbergh achieved a similar feat solo. Their flights, while certainly heroic, were following in the footsteps of NC Seaplane Division One. Lindbergh himself noted that the challenges faced by the crews of the *Nancies* were greater, in many respects, than those that he faced. The crew of the NC-4, supported by NC Seaplane Division One and the might of the U.S. Navy, proved it could be done, and their legacy can still be felt today. Juan Terry Trippe, the founder of the first commercial transatlantic service provider, Pan American Airways, was influenced in many ways by the flying boats of NC Seaplane Division One. As a young man, he saw the great flying boats at their hangar at Rockaway Naval Air Station just before leaving on their transatlantic voyage, and wrote that the flight would "demonstrate that a flight across the Atlantic Ocean is a perfectly safe and sane commercial proposition and not a gigantic gamble." Later, he took that same hangar as his first base of operations for the nascent PanAm, and twenty years after the NC-4's first historic crossing, their first commercial transatlantic flights followed the route of NC Seaplane Division One.[28,29] On the occasion of the 50th anniversary of the NC-4's historic flight, Vice Admiral Tom Connolly, Deputy to the Chief of Naval Operations (Air), remarked: "In its day the flight of the NC-4 was equal to the voyage of Columbus…or of last year's moon trip by the astronauts." The United States was less than two months away from landing men on the moon, and the accomplishment of the NC-4 and her crew fifty years earlier was considered an equivalent feat. After the flight, the victorious Albert Read said "as for the future, this is certain; anyone who today declares anything impossible is apt to bark his knuckles…anyone in the present age of new and startling inventions who says positively that we will never attain an altitude of 60,000 feet, will never fly at 500 miles an hour, or will never be able to cross to Europe in the forenoon and return in the afternoon is a most courageous person".[30] This may be the true legacy of the NC flying boats and the first transatlantic crossing by air. Engineering and ingenuity, not a daring act, had broken a barrier that many thought to be impenetrable. Today, the NC-4 is on display at the National Museum of Naval Aviation located at Pensacola Naval Air Station, Pensacola, Florida. It stands as a reminder of what can be achieved when the right people, tools, and ideas are brought to bear on a problem, no matter how daunting.

Acknowledgments

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