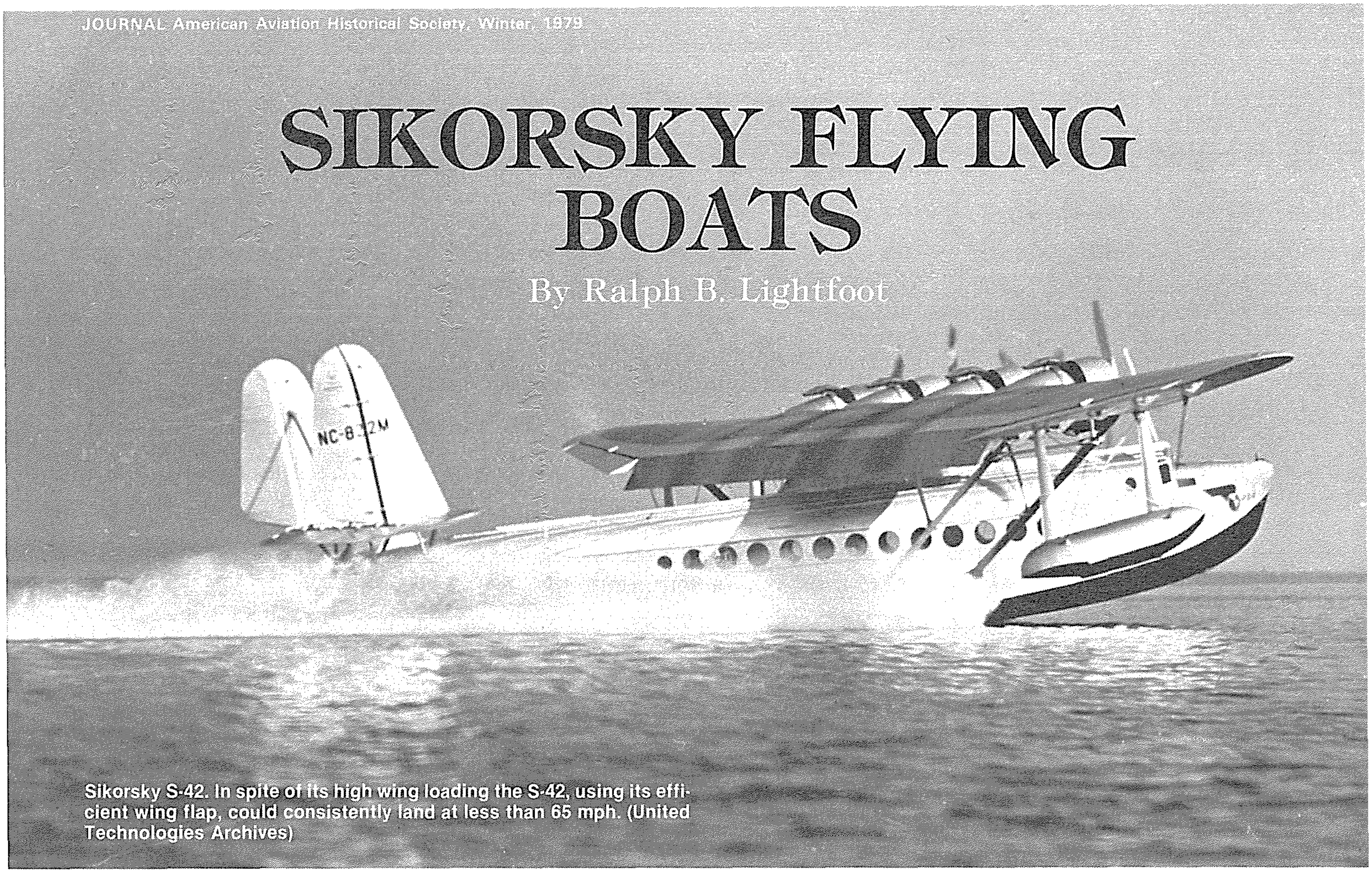
SIKORSKY FLYING BOATS

By Ralph B. Lightfoot



Sikorsky S-42. In spite of its high wing loading the S-42, using its efficient wing flap, could consistently land at less than 65 mph. (United Technologies Archives)

This article is based on a lecture given by the author to the Connecticut Aeronautical Historical Association at Stratford, Connecticut, on April 23, 1976. That data has been augmented by the author and put into a form suitable for presentation in the AAHS Journal.

There are two major aspects of flying boats that warrant consideration: first, the operational circumstances; and then, the technical development.

The need for airplane operation from water as well as land is as old as airplane development itself. Prepared takeoff surfaces, such as the tracks used by the Wright Brothers, were needed to reduce the drag of the earth's surface. Extensive area, extending in any direction, was needed to accommodate the changing wind directions. The free, available and expansive water surfaces of the world offered a ready solution to the takeoff and landing requirements. Flotation methods were well known. However, the designs of hulls were especially for sailing craft and for low drag displacement hulls of propeller-driven ships. Scientific research had been directed toward stability and reduced water resistance while still relying upon hydrostatic buoyancy.

Even this work was not concluded and justified for scientific ship design until the publication of C.O. Liljegren in 1943.[1] The aerodynamic success of wings prompted hydrodynamic research along similar lines.[2] The screw propeller made high-speed water surface vehicles possible, but it was soon apparent that the idealized displacement hull developed excessive drag with serious problems of stability.[3]

By applying lifting wing theory to the hull, hydrodynamically effective shapes were evolved. The sled type of hull, with rectangular cross-section, turned-up bow and turned-down stern, offered a distinct advantage by developing lift as a reaction to the downward displacement of a mass of water.[4]

Two floats of this type were applied to the Sikorsky S-5A in 1912.[5] This airplane was improved in 1914 by replacing the two sled floats with a single sled float.[6] A tail float was used in both configurations but wingtip floats provided the lateral stability of the single main float in the latter version.

The Sikorsky S-10 also used twin sled floats in 1915.[7] The sleds provided buoyancy, low resistance at high water speeds, and reasonably good takeoff and landing characteristics in relatively calm water. They did encounter problems under other circumstances. Takeoff in a dead calm was quite difficult. In a choppy or mildly rough sea, severe pounding impaired their structural integrity. Marked improvement was achieved in 1914 on the S-22 ILIA MOUROMETZ by pointing the bow, using a Vee bottom and a flared chine.[8] Efforts in this direction were hampered by the urgent requirements of World War I.

After the first World War, airplanes were more of a novelty than a means of transportation. Airplanes were appreciated for military purposes but since there were to be "no more wars," government support was lacking. Curtiss *Jennys,* deHavilland DH-4s and Martin bombers were converted for commercial transport airplanes and to carry mail. The public was concerned about the safety of air travel. In 1920 Raymond Orteig offered a $25,000 prize for a non-stop flight between New York and Paris. The Guggenheim Foundation provided financial support to several universities for aeronautical education and later offered a substantial prize to encourage the development of safer airplanes. The prize was won by the Curtiss TANAGER in January 1930.

Economically, airplanes were not attractive to investors because of their cost, the lack of a sufficient number of appropriate airports, as well as the absence of navigation and all-weather flying equipment. At the end of World War I in 1919 the U.S. Navy had on hand 1,172 flying boats and 695 seaplanes, attesting to the better appreciation of the flying boat. The value of the flying boat, in addition to the potential capability of the airplane, was demonstrated emphatically in May 1919 when the Navy-Curtiss NC-4 crossed the Atlantic from New York to England.[9]

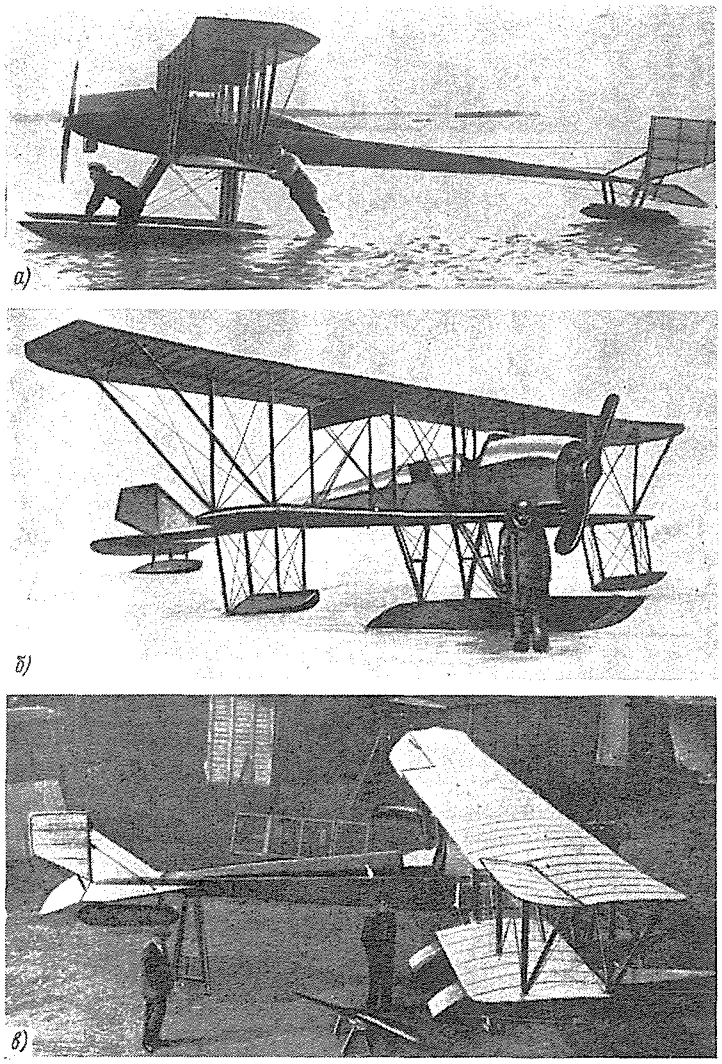
The next month saw a British landplane, the Vickers VIMY fly non-stop from Newfoundland to Ireland.[10] Subsequently, Aeromarine, Boeing, Curtiss, the Naval Aircraft Factory, Martin, Hall, Kirkham and others worked on the development of flying boats for long-range, over-water transportation. Correspondingly, there was similar development activity in Europe.[11] The dirigible was considered by many to be the ultimate solution. The German ocean liners BREMEN and EUROPA catapulted Heinkel He-58 seaplanes to hasten the delivery of mail within 300 miles of shore.[12]

The success of the numerous airplanes built by Igor Sikorsky in Russia was not well understood in America.[13] After his arrival in the United States in 1919, Mr. Sikorsky could not enlist sufficient support for an airplane project until the S-29 in 1923.[14] However, the S-29, S-35 and S-37 clearly demonstrated the practicality of large-size multi-engine airplanes.[15] [16] In the face of a quantity of surplus aircraft, the competition and the alternative approaches to aerial transportation,[17] Igor Sikorsky and his associates persisted in the advancement of aeronautical technology.

A superior airfoil, GS-1, with low drag, short travel of the center of pressure and especially high maximum lift with gradual stall characteristics, was built into wings on a subcontract basis for the Curtiss JN-4 *Jenny* and later on the S-37B Consolidated-Sikorsky *Guardian*. The sesqui-wing, structural integrity and tail configuration confirmed the aerodynamic efficiency and safety of the Sikorsky designs featured in the S-31, S-32, S-33, S-36 and S-37. All this, combined with the hydrodynamic experience with the S-34 and S-36 as a flying boat and an amphibian, pointed the way to economic success for Sikorsky Aircraft.

Only a few of each of these aircraft were built, but they all served to develop the design and manufacturing strength of the Sikorsky organization.[18] In various ways they each improved and expanded the Sikorsky reputation.[19] Financial success was illusive for all airplane manufacturers. The fatal accident at Roosevelt Field, Long Island, on attempted takeoff of the overloaded transatlantic S-35 on September 21, 1926[20] incurred a $100,000 loss to the struggling Sikorsky Manufacturing Corporation. The faith of the stockholders prevailed with their investment of $1,000,000 to design and build the Sikorsky S-38.[21]

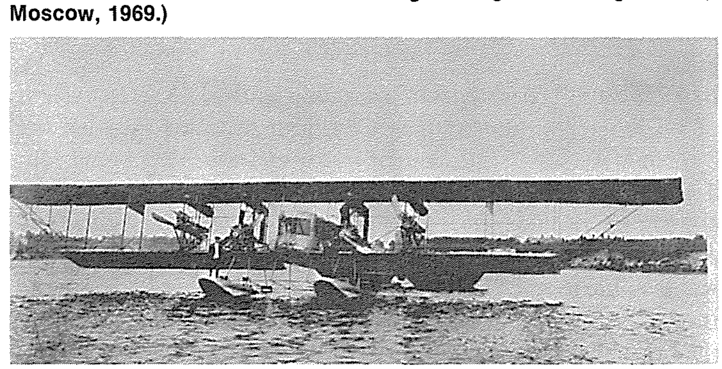
Available in 1928, the S-38 capitalized on the enthusiasm of the public and the airlines following the overwhelming success of Charles Lindbergh's non-stop flight from New York to Paris



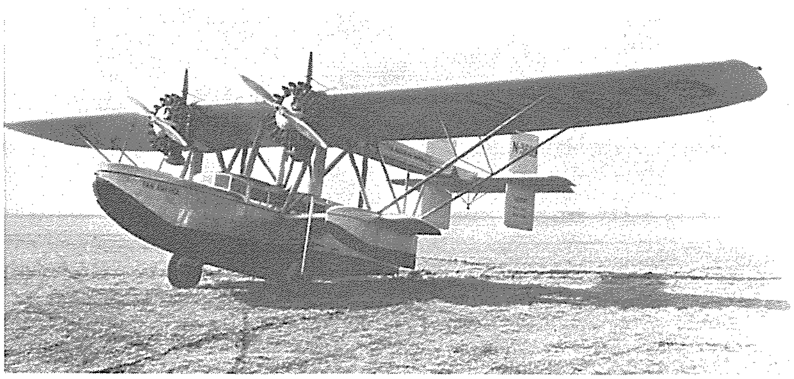
Sikorsky S-5A (top) built for the Russian Naval Institute in 1912. First Sikorsky seaplane was equipped with twin sled type floats and powered by a Gnome 60-hp rotary engine. Later it was rebuilt (center) employing single sled float and wing tip floats which provided better water handling characteristics. Improvements in fuselage and vertical tail surfaces, and use of an 80-hp Gnome engine gave improved airplane performance. Used by the Russian Navy as a reconnaissance airplane in 1914.

Sikorsky S-10 seaplane. Seven seaplane versions were built between 1913 and 1915 employing improved twin sled floats with pointed bows. Tail float swiveled to provide steering on the water. Most were powered by 100-hp Gnome engines though the S-10 illustrated was powered by a 100-hp Argus.

(The History of Aircraft Construction in the U.S.S.R. to 1938 by Vladimar B. Shavrov—Mechanical Engineering Publishing House, Moscow, 1969.)



Sikorsky S-22 on improved twin floats. The S-22 was the first "Ilia Mourometz" and was originally flown as a landplane. In April 1914 it was converted to a seaplane for the Russian Navy. It was the world's first four-engine seaplane ever flown. Powered by two 100-hp Argus and 200-hp Salmson engines. (United Technologies Archives)


Sikorsky S-36 built for Pan American Airways was completed in January 1928. The eight-place enclosed hull was considerably improved from earlier S-36 versions. (United Technologies Archives)

in May 1927. This one flight fired the enthusiasm and confidence of the great American public surpassing his own objectives.[22] No doubt this historic flight was the cornerstone of the aviation industry. The fact that the flight was made by an American in an airplane designed and built in America established the United States as a contender for world leadership in aviation. Before 1927 many commercial airplanes and engines were derived from European industry. After 1927 most commercial airplanes and propulsion systems throughout the world came from American industry.[23] By 1939 the backlog of orders in the United States industry was $300,000,000.[24]

The U.S. Navy and Pan American Airways were well pleased with the S-36 amphibians they had been using in 1927. Extensive discussions with Navy and Pan Am personnel indicated a similar airplane of about twice the capacity was warranted. The S-38 incorporated many of the design features suggested by the potential customers and benefited from five years of design and development experience.[25] A significant feature was the higher wing loading of 14.5 pounds per square foot in contrast to the previous practice of 10 pounds per square foot. Confidence in these factors of experience prompted the decision for the initial manufacture of 10 airplanes. Pan American Airways contemplated an expanded airline throughout the Caribbean, Central and South America as well as the rest of the world. Its officials, Trippe, Priester, Lindbergh, Franchimont and Borger, held extensive discussions with Sikorsky officials. It was emphasized that airports for landplanes were not and could not be made available. A flying boat with amphibious capability was required and yet it must compete with landplanes in many areas of operation.

After careful checking and inspection by the U.S. Department of Commerce, approved type Certificate #60 was awarded the S-38 in May 1928.[26] Subsequent certificates were numbered 126, 2-434, and 158. The first flight of the S-38 occurred in July 1928. This airplane, stated Mr. Sikorsky, "proved to be the real originator of the Sikorsky Aircraft Company. For the first time it was possible to sell a reasonably large number of these ships. The total sales amounted to several million dollars, which was stupendous at that time."[27] The S-38 was used extensively by Pan American Airways and established the foundation of that great airline.[28]

All together, 111 S-38 airplanes were built. They were used by the U.S. Navy; U.S. Army; Pan Am; Inter Island; Northwest; Colonial; Curtiss, SCADTA; Canadian; New York, Rio and Buenos Aires; China and numerous individuals and organizations. With a gross weight of 10,480 pounds, 10 passengers could be carried a distance of about 500 miles.

Many executives and sportsmen favored the S-38 because of its versatility and comfort, taking them from home to business or pleasure without regard for airports. One of the more exciting applications of the S-38 was its use by Martin and Osa Johnson for the exploration of Africa.

The success of the S-38 may also be measured by the International Air Records which it established in the summer of 1930. Classed as a C-2 Seaplane, the S-38 carried a 500-kilogram load to 26,929 feet; a 1000-kilogram load to 26,929 feet; and a 2000-kilogram load to 19,709 feet.

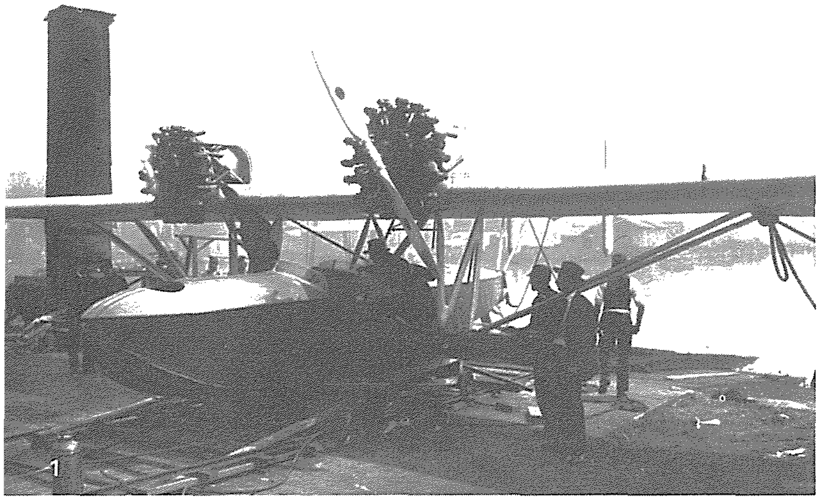
Another indication of the capability of the S-38 was manifest in the plan for a series of seadromes (huge Texas Towers) to be spaced in the ocean between New York and Bermuda. The seadromes, designed by Edward R. Armstrong, were to have been built by the Sun Shipbuilding Company and accommodate a fleet of Sikorsky S-38 amphibious flying boats. Pending satisfactory service, the plan would extend to Europe. High cost without government support discouraged the plan, but it prompted Sikorsky Aircraft to think ahead to transoceanic flights.[29]

The configuration of the S-38 did not match the streamlined designs of today for rather practical reasons. In fact, several clean-looking airplanes were in operation prior to the S-38, including of course THE SPIRIT OF ST. LOUIS built by Ryan for Capt. Lindbergh. It was realized that the hull must be of special design for flotation, stability, and low water drag. The two Pratt & Whitney Wasp engines and the Hamilton Standard propellers, tail and wing, must be well above the water. The supports must be as light and as strong as possible. The experience of the Navy with the NC-4 and similar configurations also had some bearing on the S-38 design.

Just as it was logical to build a large flying boat for commercial purposes, it was also appropriate to build a smaller version for the smaller airlines and sportsmen. The S-39 was similar to the S-38 in configuration and performance with one Pratt & Whitney Wasp Jr. engine with about one-half the capacity and gross weight.[30] The Department of Commerce issued approved type certificates #375; 2-391; and 2-436 to the S-39 starting in 1931.[31]

With 132 flying boats of the S-38 and S-39 types operating successfully throughout the world, it is no wonder that Pan American Airways asked for a 40-passenger ship. The prospects for future business were very bright and larger manufacturing facilities were needed. Governor John Trumbull of Connecticut, "The Flying Governor," encouraged Sikorsky Aircraft, which had recently become affiliated with United Aircraft Corporation, to move from Long Island to Stratford, Connecticut. There, on the banks of the Housatonic River and adjacent to Long Island Sound, ideal facilities were provided for the design and development of the S-40 and subsequent flying boats.[32]

The S-40 "amphibian"[33] astounded many by its sheer size, some people even doubting that flight would be possible.[34] Among Mr. Sikorsky's memorabilia is a check for five cents in payment of a bet that the S-40 amphibian could not fly.[35] However, in addition to the basic technical knowledge gained from the design and development of earlier airplanes, the Sikorsky engineers embarked upon a research program to assure that the



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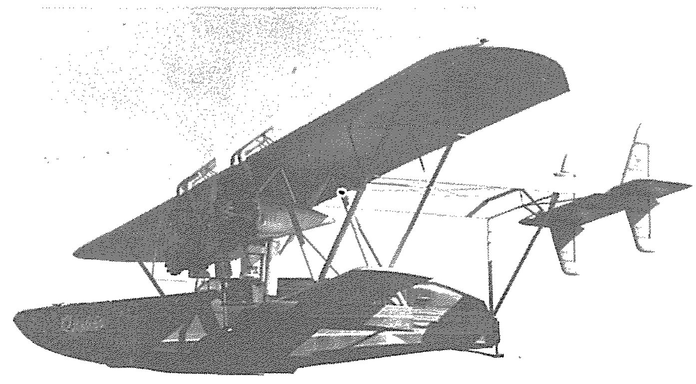

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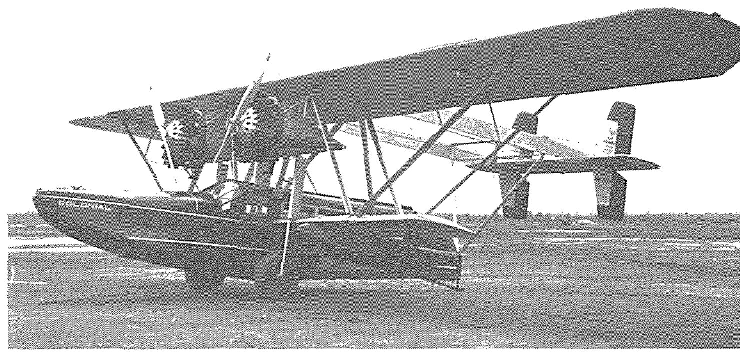

1 Sikorsky S-34. The first Sikorsky amphibian established in 1926 the basic configuration for subsequent Sikorsky amphibians. The short-lived S-34 continued the Sikorsky sesqui-plane tradition and carried six persons in open cockpits. Powered by two 220-hp Wright J-5 engines, it crashed on a forced down-wind landing as a result of engine trouble. One built. (United Technologies Archives)

2 Sikorsky S-38A. Affectionately called "A Collection of Spare Parts Flying in Formation," the 1928 ten-place S-38A was powered by two 420-hp P&WA Wasp C engines. One of the most successful amphibians of all time, it filled a great need for the time. A total of 111 of all models were built. (United Technologies Archives)

3 Sikorsky S-36. Based upon the S-34, the 1927 S-36 was the first practical and serviceable Sikorsky amphibian. Each of the five built had varying differences, open cockpits, cabins, different wing spans, nacelles, floats, vertical tails and the like. All were powered by two 220-hp Wright J-5 engines. The first Sikorsky airplane purchased by the U.S. Navy was a patrol version of the S-36, the XPS-1. (United Technologies Archives)

4 Sikorsky S-38B was an improved S-38 appearing in 1929. Among the many detailed improvements were 450-hp P&WA Wasp SC1 supercharged engines, relocation of engines forward and a sloping windshield. (United Technologies Archives)

5 Sikorsky S-39. A small edition of the S-38 was produced in 1931 carrying 4-5 persons and powered by one 300 or 420 hp P&WA Wasp, Jr. engine. The wood frame of previous hull designs was replaced by all-metal hull construction and the sesqui-wing was eliminated. Twenty built. (United Technologies Archives)

6 Sikorsky S-40. The 1931 S-40 of 17 tons gross weight and 40 passengers and 4 crew was a giant of the day powered by four 575 hp P&WA Hornet B1 engines, later replaced by 660 hp Hornet T2D1's. Though built as amphibians, Pan American normally operated them as flying boats between North and South America. Three built. (United Technologies Archives)

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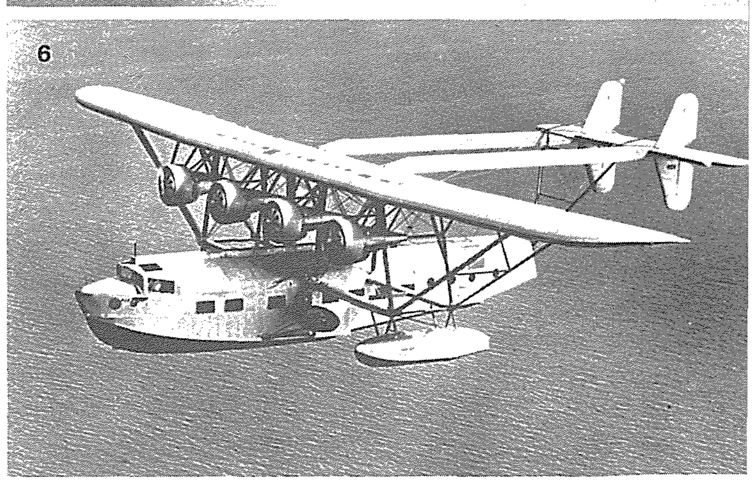
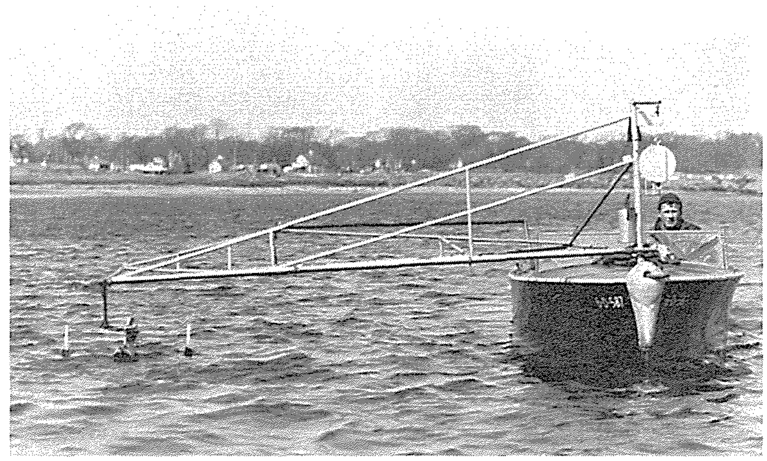




Sikorsky hull model tow test apparatus. A special planning motor boat equipped with a steel tube model supporting boom, instrumentation and photographic equipment was used to observe water characteristics of Sikorsky hull designs. (United Technologies Archives)

S-40 would have a longer range and four times the capacity of the S-38 and yet sell for $136,000.[36] Heretofore, hull dimensions had a length-to-beam ratio of about 4.5:1 to provide hydrodynamic lift with low water resistance. This broad beam was required to reduce water drag commensurate with the low wing loading of 14.6 pounds per square foot and the modest power installed in the early flying boats. The increased payload of the S-40 prompted a 27% increase in wing loading for a similar power loading. Tests on the proposed hull shape were first conducted at the Washington Navy Yard. Scheduling at the Navy Yard led to the development of test techniques in the Housatonic River.[37] [38]

The higher wing loading for the S-40 of 18.5 lbs./sq. ft. was simulated on the hull model which was towed from an outrigger boom on a speed boat. Various modifications led to a higher length/beam ratio of 5.6:1. Wind tunnel tests in the new Sikorsky five-foot open-throat vertical tunnel[39] were also more convenient[40] than those conducted at the Guggenheim Laboratory of New York University. The Sikorsky wind tunnel was designed to operate with the airflow down rather than horizontal and had an open-throat working section.[41] Models of the S-38 and S-39 hulls were tested in a similar fashion both in the wind tunnel and in the river (Footnote A). Attempts to correlate test data, as in the wind tunnel, by non-dimensional resistance coefficient were not satisfactory. Therefore, the Sikorsky engineers had the ideal opportunity to study models and full scale of the S-39, S-38, and then extrapolate to the S-40 with fair assurance, following the guidelines of Capt. Richardson.[43] Water tests with the models measured drag at various speeds, with appropriate amounts of wing lift introduced at each speed (Footnote B). The trim of the hull was noted under the influence of water drag and the propulsive effect of the simulated propellers. This was accomplished by towing the hull model from a point representing the thrust axis of the propellers. Probably more important was the visual and photographic study made of the wave action in various water conditions. While it was awkward to run tests at predetermined wave heights, the Housatonic River with its bays, coves, shelters, etc., usually provided almost any sea condition desired for testing. Correspondingly, similar observations were made during taxiing and takeoff of the actual S-39 and S-38 flying boats. The similarities, as well as the differences, were noted for supposedly identically scaled conditions.

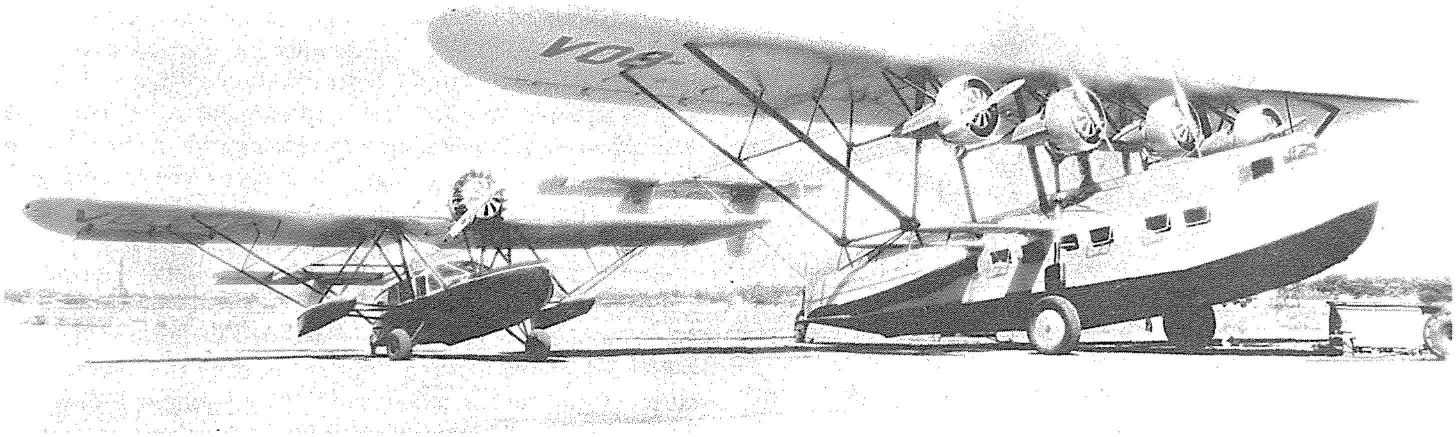
Some of the details of hull development involved the dead rise and flare at the chine. Deep vee hulls had been popular for soft rides in choppy seas with attendant structural integrity. The Sikorsky model tests showed that the water drag could be reduced if the dead rise at the keel were reduced to 26° and the flare at the chine would effectively reduce the dead rise angle to 22½°. The tests also indicated some added strength and weight of the structure were required to provide for the improved takeoff and landing performance.[44] Thus art was introduced to science and the S-40 was born.

The best part of the S-40 story is told in his own words by Igor Sikorsky:

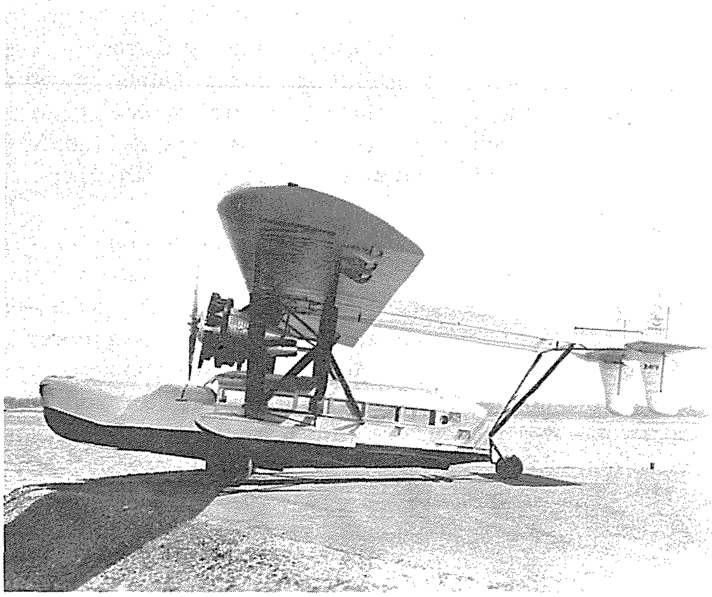
> "On the basis of our information and established reputation, we got from Pan American Airways an order for the first really large passenger airplane, the S-40. The largest ships up to that time were built by Fokker and Ford."

The Handley Page HP42 and the Short Brothers Kent were of similar size and the Junkers G38 and Dornier DO-X were much larger, but none of them met the economic requirements for cost, speed, range and payload set by Pan American Airways.[45]

> "Each of them carried less than 20 passengers and this new ship had to carry 40 passengers. It was built for Pan American Airways and proved to be a very successful aircraft. I had enough experience to realize that the large size of the ship would present several major difficulties. I thought that it would be better not to augment the difficulties by making a more modern-looking airplane, even though advanced design was known to us. For example, we could have placed the engines in a better streamlined way. Instead, I used the old-fashioned formula following the configuration of a ship that was successful—the S-38. The large S-40 was very controllable—very usable. Three ships were sold to Pan American Airways and were extensively used for a whole decade. Not a single one was cracked up and they were all retired for obsolescence at the beginning of World War II.
>
> "During the first flight of the S-40 with passengers from Miami to the Panama Canal, Charles Lindbergh was the chief pilot and the actual director of this flight. The rest besides the crew were passengers. The ship was full to capacity and I was among the passengers although I spent my time mostly in the pilot's cabin. Every evening I dined with the crew in some different spot. During these dinners, Lindbergh and I were usually together. On the backs of the menus of the restaurants we would write the specifications and make sketches for a ship capable of flying across the ocean. The flight to Panama was a great success. I became a good lifelong friend with Lindbergh whom I consider to be an outstandingly brilliant pilot and citizen of this great country. Following the return flight, we departed with the idea that he, Lindbergh, who was then the consultant of Pan American Airways, and I as Engineering Manager of this organization



Sikorsky S-39 and S-40. A comparison of the smallest Sikorsky amphibian with largest. (United Technologies Archives)



Sikorsky S-41. Based upon the S-38, the 1932 S-41 had a new all-metal hull of improved design that could accommodate 4 additional passengers. The sesqui-wing was eliminated and 575 hp P&WA Hornet B1 engines employed. Seven built. (United Technologies Archives)

Sikorsky XP2S-1. A U.S. Navy design, engineered and built by Sikorsky, underwent considerable development between 1930 when it appeared powered by two 300 hp P&WA Wasp, Jr. engines and 1932 when the airplane was rebuilt with two 420 hp P&WA Wasp C engines as shown. Only one was built and did not go into production. (United Technologies Archives)

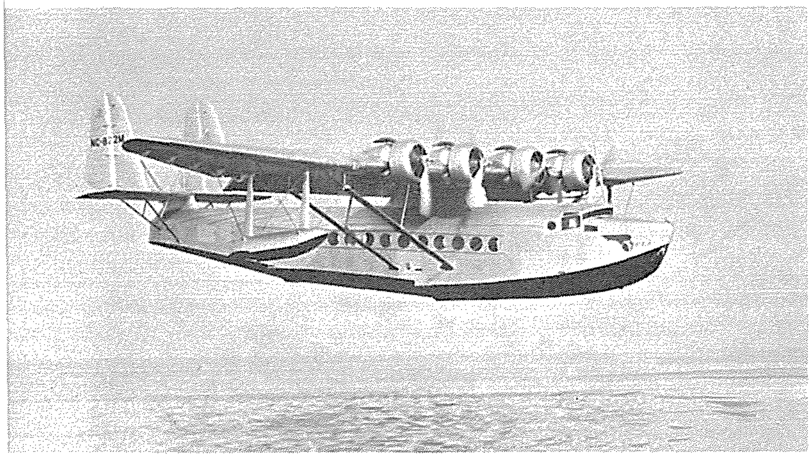
then, and in fact for a whole stretch of 34 years, were to promote the transoceanic airplane. I was going to sell the idea to United Aircraft to accept a contract and Lindbergh was to sell to Pan American the idea of giving United Aircraft a contract for the design and construction of a transoceanic flying boat.''[46]

The first flight of the S-40 was early 1931. The three ships built for Pan American were christened AMERICAN CLIPPER, CARIBBEAN CLIPPER and SOUTHERN CLIPPER. They were powered by four Pratt & Whitney Hornet engines of 660 horsepower, each driving two-bladed Hamilton Standard controllable pitch propellers. With 24 passengers, the range was 950 miles, and with 40 passengers, 500 miles. Cruising speed was 115 mph, high speed 130 mph, landing speed 65 mph. Wing span was 114 feet; overall length, 76 feet 8 inches. Gross weight was 34,600 pounds. Hull length was 23 feet 10 inches with a beam of 10 feet 3 inches.[47]

The Department of Commerce issued approved type certificate #562 in 1931 to the S-40A for a gross weight of 34,600 lbs. with 44 places.[48] The three S-40A flying boats were the mainstay of the Pan American fleet until they were requisitioned by the U.S. Navy following the Japanese attack on Pearl Harbor. They were used as military transports and training planes until their retirement in 1943, completing 12 years of magnificent service.[49]

The S-41 was a natural follower of the famous S-38. The Wasp engines were replaced with Pratt & Whitney Hornets. The lower sesqui-wing was eliminated to improve the water-handling characteristics. The monoplane wing was increased in span to 78 feet 9¼ inches, adding 9 more square feet of wing area for a total of 729 square feet.[50] The hull beam was broadened by four inches to a full 7 feet and the length increased by 3 feet 2 inches to 33 feet. The length beam ratio was thus increased to 4.7:1 commensurate with the higher wing loading of 17.6 LB/FT^2 and the lower power loading of 11.13 lbs. per horsepower. These improvements increased the range and performance over the S-38. Four more passengers for a total of 16 could be carried to improve the economy of operation significantly. Seven of these amphibious flying boats were built principally for the Navy and Pan American Airways.[51] The Department of Commerce awarded approved type certificate #2-286 to the S-41 in 1932.[52]

During the years 1930 to 1933 Sikorsky Aircraft assisted the U.S. Navy in the design and development of three special-purpose amphibious flying boats, the XSS-1, XSS-2, and XP2S-1.[53]



Sikorsky S-42 was the most advanced flying boat in the world when it appeared in 1934. Initial studies were of a twin-engine aircraft, later a three-engine configuration, before evolving into a four-engine type. Three S-42s were built (NC-822M the first) powered by 700 hp P&WA Hornet S5D1-G engines, with a gross weight of 38,000 pounds. (United Technologies Archives)

The plan of Charles Lindbergh and Igor Sikorsky to build a superior twin-engine flying boat, the S-42, was accepted favorably by both Pan American Airways and United Aircraft Corporation.[54] The GRAF ZEPPELIN was in regular transatlantic service at this time but the trip required three or four days—hardly better than a sea voyage. However, 17,591 passengers were carried on 139 flights across the Atlantic.[55] Obviously this aerial transportation and the success of the S-40 served as sufficient inducement to warrant the financial investment of both companies. As Igor Sikorsky has noted, the configuration of the S-40 was not in accord with the available knowledge for streamlined high-performance airplanes. Prime attention had been paid to the design of the hull so that the airplane could operate worldwide without the need for a huge airport. Large airports were still not available everywhere in the world. But it had now been shown by the S-40 that large airplanes could be built with higher wing loading, more power, and high payloads. Emphasis for long range was now placed upon the elements of the Breguet formula.[56] (See Footnote C.)

Each factor was studied diligently for improvement. Thus Hamilton Standard was urged to improve the propeller efficiency at the design cruising speed of 170 mph at 12,000 feet altitude and yet assure good propulsive thrust at the takeoff speed and hump speed on the water. The four 11-foot, 6-inch diameter three-blade constant speed propeller made this possible. Pratt & Whitney was responsible for producing an engine of 800 horsepower for takeoff and a normal rating of 750 horsepower. For cruising at low fuel consumption the engine developed 525 horsepower. These requirements, as well as good clearance of the propellers above the water, were satisfied by four engines versus the two in the original layout.[57] A wing loading of 31.3 pounds per square foot was selected. An improved airfoil GSM-3 was developed by Michael and Serge Gluhareff in the Sikorsky five-foot vertical wind tunnel[58] by reflexing the trailing edge of the original GSM airfoil by 3° to reduce its pitching moment. A trailing edge flap was also developed to improve takeoff performance[59] and to acquire a maximum lift coefficient of 2.39 with power on at landing gross weight to meet the Department of Commerce requirement for a landing speed not to exceed 65 miles per hour.[60]

This subject of landing speed coupled with maximum lift coefficient perplexed the certificating personnel for many years. For some reason, never explained, there was some magic related to safety associated with 65 miles per hour.[61] Accepting the 65-mph limit which was not defined for related conditions, Capt. Boris Sergievsky, chief test pilot for Sikorsky, a master of his art, demonstrated to the federal authorities that with the restraints imposed, the S-42 could be flown and landed repeatedly at less than 65 miles per hour commencing with the first flight of the S-42 in March 1934. The U.S. Department of Commerce awarded Approved Type Certificate Nos. 544 and 592 permitting gross weight up to 43,000 pounds.[62] [63]

Confident that the airfoil's maximum lift coefficient could be achieved, the wing was designed for long range by using a high aspect ratio of 10.4:1. While it was well understood that this would reduce the induced drag and increase the L/D for long range, it presented a serious problem of strength and weight. The availability of higher strength aluminum alloy extrusions for wing spars and the use of stressed aluminum alloy sheet for wing covering made the S-42 wing lighter and stronger than all previous Sikorsky designs.[64] The two wing struts of high strength extruded streamlined aluminum alloy tubing distributed the wing loads evenly between the main supporting pylon and the outer wing panels to the fuselage, thereby reducing the high bending moment which would have been developed on a full cantilever wing. There were 1240 gallons of fuel carried in tanks between the wing spars.[65]

The proportions of the hull on the S-40 indicated the internal space required for the passengers and crew. A similar hull was designed for the S-42 but it was narrower by 10 inches and longer by 8 feet 3 inches to accommodate a similar number of passengers with a larger crew under more comfortable circumstances including sleeping berths for overnight flights. The longer, narrower fuselage was particularly effective in reducing the air drag of the hull. The length/beam ratio became 6.9:1.[66]

One of the most significant drag reduction features, in contrast to the S-40, was the general configuration of monoplane wing, with engines in wing nacelles, and the tail fitted on the after portion of the hull. This eliminated the outriggers, inefficient lower wing, and the flying wires. The choice of wing to fuselage spacing was determined by wind tunnel tests for minimum drag and the most effectiveness of the tail surfaces in the wake of the wing pylon.[67]

The hull shape was tested extensively in the wind tunnel and on the Housatonic River, but this time in comparison with the full scale S-40 and S-40 models. Significant improvements in hull performance were obtained by relatively minor changes such as: bow shape, dead rise reduction by 3°, flare, upsweep angle of the stern and the height of the steps. A large reduction in overall drag and weight resulted from smaller wing floats being located further outboard.

Although the empty weight of the S-42 was about the same as the S-40, with stronger material and improved structural design, the hull weight was 30% lighter, permitting the heavier, more powerful engines and extra equipment to be installed.[68] For the longer range survey flights, extra fuel tanks of 1563-gallon capacity were placed in the hull to provide a total of 2803 gallons of fuel. This extended the cruising range to 3200 miles. In 1935 Pan American Airways conducted Pacific surveys of 2400 miles from San Francisco to Hawaii, and beyond to New Zealand. In 1937 Atlantic surveys of 2000 miles between Newfoundland and Ireland, starting from London and New York, were conducted by

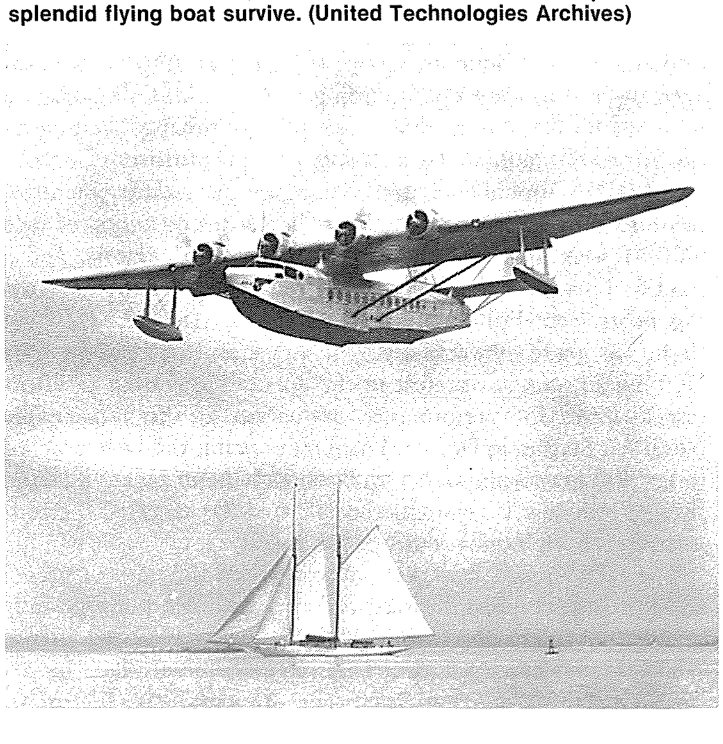
Sikorsky S-42's superior hull design enabled a 35-second takeoff with full load in a dead calm. (United Technologies Archives)

Pan Am in cooperation with Imperial Airways of Great Britain.

While the Sikorsky S-42 was operating on regular schedule in the Caribbean and South America, and blazing trails across both oceans, there was keen competition from other aircraft. In addition to the dirigibles GRAF ZEPPELIN and HINDENBURG, Martin in U.S.A., Latecoere in France, Dornier with the DO-X in Germany, Piaggio in Italy and, of course, Shorts in England, all contended for the Grand Atlantic prize. Each entrant suffered from various ailments, not the least of which could be classed as of an international political nature.[69] Again, we might note the words of Igor Sikorsky:

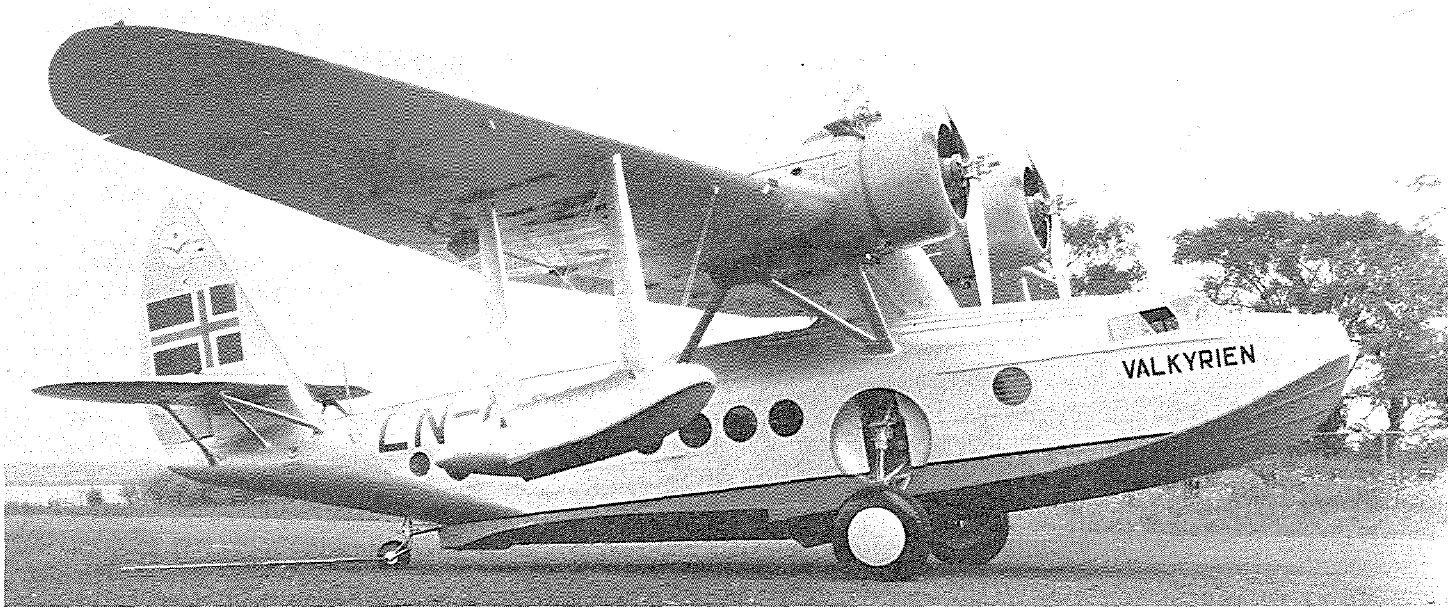
> "The S-42 proved to be a very advanced design flying boat. At one time this single aircraft held 10 world records, while the other 10 records were divided among all other flying boats or hydro airplanes of all other nations. The S-42 pioneered commercial flying over the Pacific Ocean in 1935 and over the Atlantic in 1937. This schedule calls for an explanation. The flight over the Atlantic had to be in accord with the British schedule of what was then called Imperial Airways. They were not ready to send their boat from England across the ocean to the United States until 1937. Consequently, Pan American out of courtesy and agreement would not send an American boat to England. In 1937 the S-42 starting from America, and the Short Brothers' S-23 flying boat starting from England, crossed the Atlantic at the same time. This was the beginning of regular transoceanic passenger-carrying flights. Between 1935 and 1937 the opportunity was utilized to develop the flying and navigational techniques with pioneering flights over the Pacific Ocean to the Hawaiian Islands, Asia, Australia and New Zealand."[70]

Sikorsky S-42A and S-42B had larger span than S-42 and higher gross weight. Improved 800 hp P&WA Hornet S2E-G for S-42A and S13E-G for S-42B gave improved performance and longer range. Four S-42As and three S-42Bs built; one A rebuilt as a B. No examples of this splendid flying boat survive. (United Technologies Archives)



On July 3, 1937, 161 years after America proclaimed its independence, the Pan American S-42 flying boat CLIPPER III, with Capt. Harold Gray commanding, departed Port Washington, New York for Southampton, England, via Shediac, New Brunswick; Botwood, Newfoundland; and Foynes, Ireland. Flying westward was the Imperial Airways' Short S.23 flying boat CALEDONIA substituting Montreal for Shediac on its way to New York. A series of coordinated transatlantic flights followed leading to international conferences in 1938 and 1939.[71] This was the beginning of the International Civil Aviation Organization (ICAO)[72] presently guiding worldwide and celestial transportation. Among the items considered at these conferences were the political, economic, technical and navigational aspects of transoceanic international air travel. One unfortunate problem was a misunderstanding of the 40°F temperature reduction in the carburetor throat that could cause icing and engine failure. One Short S.23 flying boat CAVALIER was forced down in January 1939 due to carburetor icing leaving transatlantic service to Pan Am until well after the second World War broke out.[73]

The success of these operations prompted keen competition



Sikorsky S-43. The basic S-43 was powered by 875 hp P&WA Hornet S1E-G engines though five were equipped by Wright Cyclone R-1820 engines. Three were built as flying boats without landing gear. Shown is the sole S-43 purchased by Det Norske Luftfartselskap (Norway) LN-DAG. (United Technologies Archives)

from other manufacturers—Martin, Boeing, Douglas, Consolidated. There was no question about the potential of the Sikorsky designs but it was incumbent upon the United Aircraft Corporation (now United Technologies Corporation, UTC) to build the flying boats profitably. Government and commercial contracts were awarded to the competitors due primarily to their better prices. Among the more promising airline routes were those connecting the urban communities of the world. The faster airplanes with good payloads required fairly long takeoff runs to achieve flying speed. Airports were still very small and few municipal governments were willing to invest tax money for development. Many cities were conveniently located adjacent to estuaries usable by flying boats. The inland cities required landplanes. In 1935 the S-43, satisfying these requirements, was placed in competition with the Boeing 247 and Douglas DC-2 twin-engine transports. The performance payload, range and cost were similar enough that there appeared to be an operational advantage for the amphibious S-43. The S-43 had a modest wing loading of 25.6 lbs./sq. ft. and a reasonable aspect ratio of 9.5:1. Better streamlining of the fuselage, cockpit, engine nacelles and empennage were facilitated by the good length/beam ratio of 6.7:1.[74] Considering the amphibious characteristics with retractable landing gear, the empty weight was a remarkable 64% of gross weight.[75]

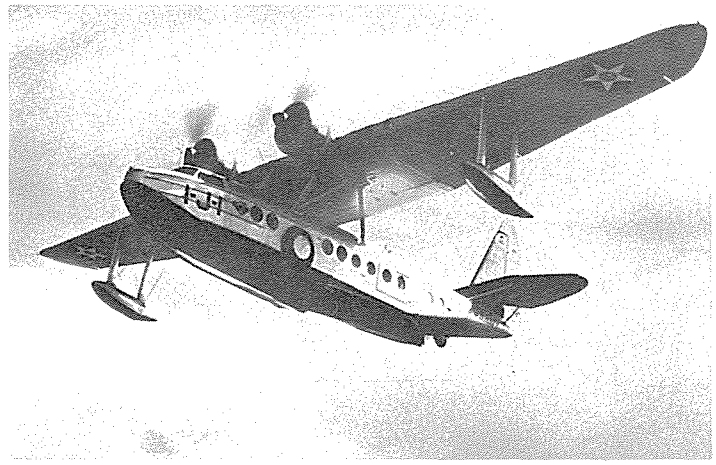
Fifty-three of these fine airplanes were placed in service around the whole world by eight airlines, three foreign governments, the U.S. Navy, U.S. Army and two private citizens, W.K. Vanderbilt and Howard Hughes. Hughes planned to fly around the world with the takeoff gross weight increased to 25,000 pounds. This was not done but he did use it extensively for research purposes on Lake Mead, Arizona, to assist the design studies of his huge flying boat HERCULES. Four world's records were established by the S-43, one of which has never been surpassed.[76] The Department of Commerce issued the S-43 Approved Type Certificate Nos. 593 and 623.[77]

Government support for airport development was provided by the Works Progress Administration (W.P.A.) during the later years of the Depression so that airline passengers exceeded the million mark in 1936.[78] The need for water-based operation subsided and the extra cost of amphibious characteristics was no longer warranted. The land-based Douglas DC-3, chief competitor of the S-43, became the standard airliner.[79] The need for transoceanic air travel increased and landplanes were not considered appropriate for over-water travel. Martin, Boeing and Consolidated continued to compete with Sikorsky for the flying boat business.

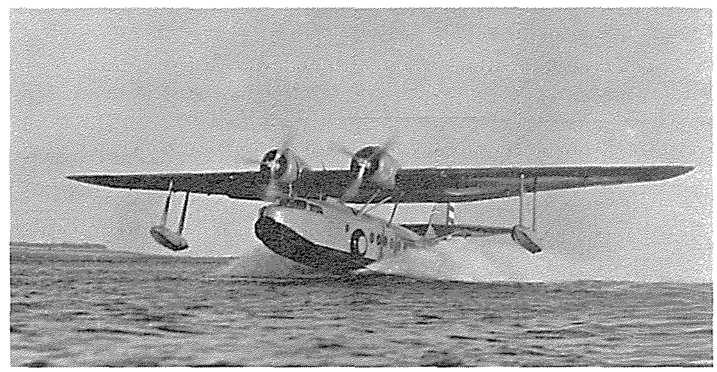
After intense competition, the U.S. Navy awarded a contract on June 25, 1936, to Sikorsky to build a huge flying boat, the XPBS-1 THE FLYING DREADNOUGHT patrol bomber. Later, a similar contract was awarded to Consolidated for the XPB2Y CORONADO. The first flight of the prototype S-44 (XPBS-1) was August 13, 1937, with delivery to the Navy on October 12, 1937. The XPBS-1 flew special missions all over the world accumulating 1365.7 hours of service until it was irreparably damaged by hitting a log upon landing at Alameda, California, on June 30, 1942.[80] Again, due to competitive pricing, production quantities of the PB2Y CORONADO were ordered from Consolidated.[81] The superior features of long-range, stability, control, comfort and excellent water-handling characteristics of the XPBS-1 were appreciated by the commercial operators, and a modified design was produced as the VS-44A. Three of these flying boats were built for American Export Airlines. The first flight was made six weeks after the attack on Pearl Harbor. The Navy again took an interest in the aircraft, providing excellent test facilities for performance evaluation at the Jacksonville Naval Air Station in Florida. Production quantities were ordered to be built in coordination with Nash-Kelvinator as the JR2S and JRK. World War II priorities for F4U Corsairs canceled the contracts before deliveries could be made.[82]

The XPBS-1 hull lines were developed on the basis of model and full-scale comparative tests on previous hulls, but especially in relation to the S-42. The XPBS-1 hull was tested in the Washington Navy Yard Model Basin[83] and the airplane model was tested at NACA and MIT. The original XPBS-1 airplane operated at a maximum gross weight of 49,059 pounds. The flight testing under the guidance of Eddie Allen, a skilled test pilot, indicated wing stall possibilities upon landing. The flaps and ailerons were developed by the same technology used on the F4U-1 Corsair and OS2U-1 Kingfisher airplanes that were under development at the same time. As consideration was being given to the commercial version, several modifications were suggested. The bomb bays in the wing could accommodate additional fuel tanks for a total of 3820 gallons of 100 octane fuel. The flying qualities for stability, wing stall, minimum control speed and water handling characteristics were reviewed, particularly with regard to the new federal airworthiness requirements which were being promulgated at the time.[84] It was realized that higher wing loading would be required to achieve the maximum ratio of takeoff gross weight to the light empty weight (W_O/W_1) for the long range determined by the Breguet formula. The highly efficient slotted flap developed for Corsair and Kingfisher was further developed in the Sikorsky wind tunnel.[85] [86] The slotted flap resulted in one which was almost as good as the flap of the F4U but was considerably lighter. The flap extended only 53½% of the span with the ailerons, also slotted, extending to the wing tip. The long span aileron was especially helpful for obtaining a low, 105-knot, minimum control speed with #1 engine inoperative, propeller windmilling and 100 lbs. of rudder pedal force.[87] The efficient flap developed a very high lift coefficient for landing and was very beneficial when partially deflected for takeoff. The development of the takeoff flap involved wind tunnel tests and full-scale tests of an S-43 under static thrust conditions which indicated the wing with small flap deflection could reduce the hull displacement by an amount approaching the thrust of the propellers.[88] As a result, a 10° flap setting reduced the takeoff speed approximately 10 knots with a corresponding reduction of takeoff distance. In reference to modern STOL objective, the S-44 was excellent. At a gross weight of 57,500 lbs. it could take off and clear a 50-ft. obstacle with critical propeller windmilling in 6,250 ft. With a 10,000-lb. useful load at 40,000 lbs. gross weight it could take off and clear a 50-ft. obstacle in 500 feet with all engines operating. Even at the 30-ton takeoff weight, the total distance required for rejected takeoff (i.e., takeoff and land) was 8,000 feet. In March 1942, during takeoff and landing tests at light and maximum gross weights in the St. Johns River in Florida with test pilots Blair for Sikorsky, and Fornasero and Swartz for the CAA, distances were measured by theodolite cameras operated by Ted Linnert and Ed Gaydos of the Civil Aeronautics Authority.[89]

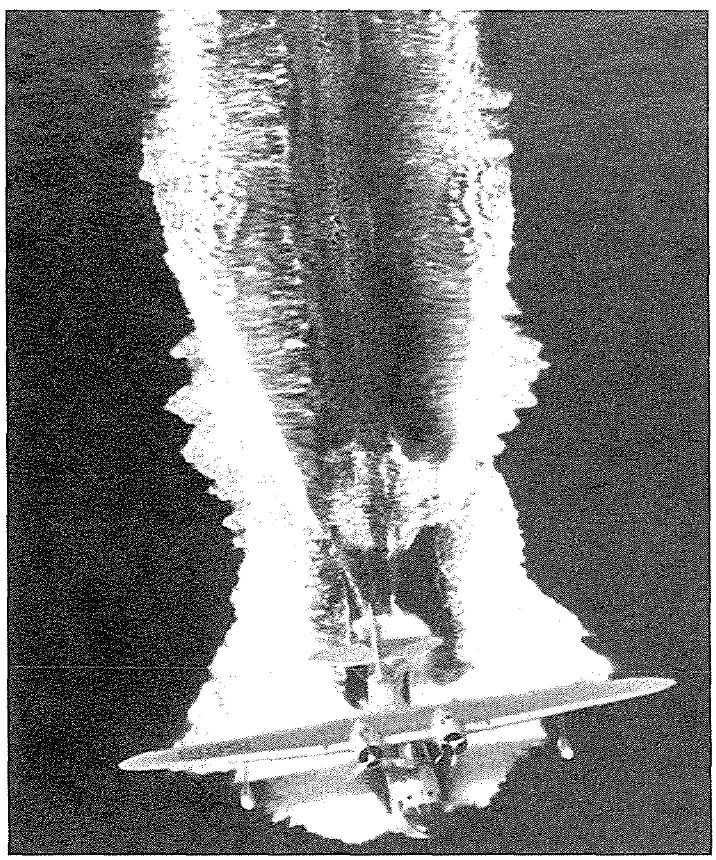
As noted earlier, the XPBS-1 prototype of the S-44 exhibited certain stall characteristics. The whole landing situation was improved by a series of investigations prior to the final design of the VS-44A. The hull tests of the XPBS in the Navy tank[90] and related observations on the XPBS-1 flying boat showed some spray or even green water impinging on the propellers, but particularly on the tail surfaces.[91] The XPBS-1 tests were conducted by the National Advisory Committee for Aeronautics (NACA) for the U.S. Navy at Norfolk, Virginia, and off the coast of Newport, Rhode Island, site of the famous "America's Cup" yacht races. The wind tunnel tests of basic wings with slotted flaps showed relatively smooth air, well deflected, commensurate with high lift coefficients. Published design data for tail surfaces were based upon wing loadings of 10 pounds per square foot with attendant low downwash angles.[92] The NACA and



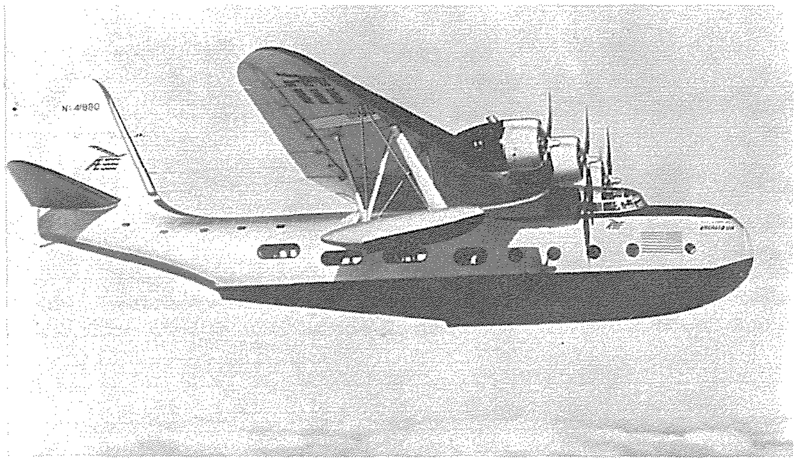
Sikorsky JRS-1. Seventeen U.S. Navy versions of the S-43 were built in 1937 and 1938 powered by R-1690-52 and -54 engines. One JRS is preserved at the National Air and Space Museum. (United Technologies Archives)



Sikorsky X10A-8. U.S. Army version of S-43 on takeoff showing low profile spray pattern. Powered by 800 hp P&WA R-1690-23 engines. Five built in 1937. (United Technologies Archives)



A dramatic view of the water wake of an S-43 on takeoff. (United Technologies Archives)



Sikorsky VS-44A "Excalibur." The three Vought-Sikorsky VS-44A flying boats were delivered to American Exports Airlines in 1942. "Excalibur" was soon crashed when the crew lost control on takeoff. Powered by four 1200 hp P&WA Twin Wasp engines, the VS-44As served well on North Atlantic operations throughout the war. (United Technologies Archives)

MIT wind tunnel tests made little reference to airflow at the tail, so flow studies were made in the Sikorsky wind tunnel. It was noted that in landing attitudes the flat XPBS horizontal tail was completely immersed in the downwash of the wing. Vee tail surfaces had been developed for other flying boat designs [93] and were suggested as a modification for the S-44A. The flying qualities of the XPBS were satisfactory but the Civil requirements and the large center of gravity travel at the desired higher gross weight for the VS-44A merited additional study. The XPBS-1 hull model was tested extensively in the Housatonic River.[94] More elaborate and accurate measurements were made. Careful attention was paid to trim. Wing lift due to forward speed and propeller thrust[95] at all flap settings was accurately introduced to render the displacement waves more realistic for each increment of water speed and surface condition. While free to trim or with slight download at the tail, similar to back stick, the hull operated beautifully with keel virtually level. However, solid water would occasionally strike the tail. Measurements indicated a 10° dihedral would raise the tips of the horizontal tail 3 feet. With those modifications, tests on October 14, 1940, were made in water from calm to scale size four-foot waves.[96] At no time did water go over the horizontal tail. The stability analysis indicated a small increase in vertical tail area was desirable in addition to that required to retain the horizontal projected area of the 10° Vee horizontal tail. The wind tunnel tests of the larger 10° horizontal tail indicated better stability and, more importantly, the downwash from the wing did not totally immerse the tail.[97] Flow studies showed as speed was reduced the lower inboard sections would encounter the downwash first with the tips in the clear. At stalling speed, the tips could be in the downwash, but the more effective center section of the tail surface was operating in undisturbed air.

Additional wind tunnel tests revealed an undesirable vortex action originating at the wing-hull intersection caused the fishtailing on the XPBS-1 and S-43 flying boats. A vortex generator 30'' long and 5'' wide above the chine forward from the rear step on the S-44A eliminated the periodic vortex system and corrected the fishtailing.[98]

A series of flight tests for the Civil Aeronautics Authority in March 1942 demonstrated a power off-lift coefficient of 1.8 with flap 0° and 2.3 with 35° flap. With 70% power, the maximum lift coefficient was 2.1, and an amazing value of 2.7 with 20° flap deflection.[99] Thus the required landing speed of 80 mph was readily achieved by the S-44 at 72.2 miles per hour.

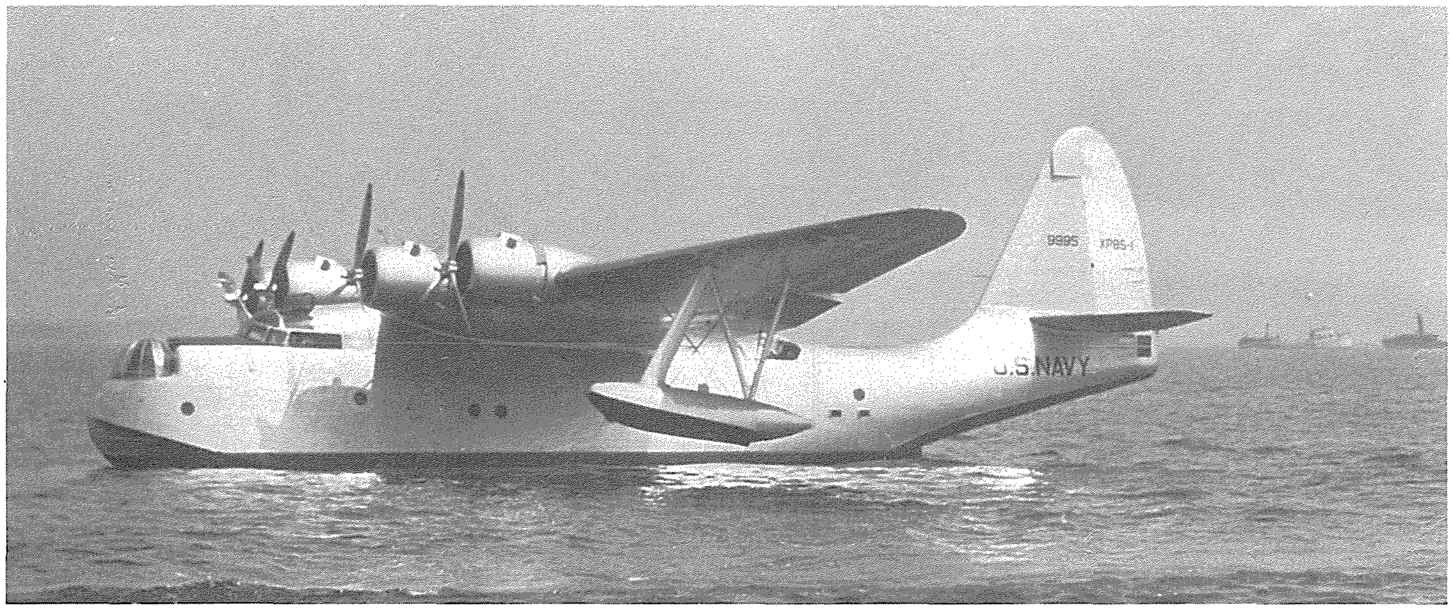
The actual water characteristics reflected the developments on the hull models. Takeoffs and landings were made in two-foot waves and landings were made in four-foot waves off the coast of Jacksonville, Florida, in March 1942 to the full satisfaction of the CAA, and the VS-44A test pilot, Capt. Charles Blair, including the structural integrity of the VS-44A hull. During takeoff Capt. Blair advised a speed of 55 kts. to taxi on the step with a slight back pressure on the control column to maintain a level keel. Using 2700 rpm at 48'' Hg manifold absolute pressure (MAP) the VS-44A accelerated to the takeoff speed of 90 knots in 40 seconds. The ship literally flew itself off the water with 59,225 lbs. gross weight, 5 tons more than the prototype, XPBS-1.

The modifications to the tail surface were substantiated by static and dynamic stability flight tests for a center of gravity variation of 6% along the Mean Aerodynamic Chord (M.A.C.)[100]

The range determination, of course, was the ultimate objective. Unlike a transcontinental flight, there are no alternate fields available on a transoceanic schedule. In the face of the keen competition promised by Boeing with the 314, the Martin 130 and the Consolidated Coronado boats, both American Export and United Aircraft were sincerely concerned for meeting the contractual obligation of non-stop transatlantic operation.

Other features enhanced the VS-44A design such as the high lift coefficient for landing and the takeoff flap, the high wing loading which allowed a narrow beam for low air drag with good water characteristics. The length/beam ratio was increased again in comparison with the 6.9:1 value of the S-42 to 7.6:1 for the VS-44A. The 19° 23' dead rise of the hull at the first step found to be satisfactory on the S-42 was retained for the VS-44A with good results. The wing loading was also increased to 35.5 pounds per square foot and the power loading was improved to 12.3 pounds per horsepower. The VS-44A wing was fully cantilevered with an aspect ratio of 9.22:1 and a taper ratio of 0.25, a ¼-chord sweepback angle of 6° 30', a span of 124 feet and an area of 1670 square feet. The airfoil was of the NACA 23000 series tapered in thickness from 18% at the root to 9% at the tip.[101] Higher strength aluminum alloys, better knowledge of airloads and waterloads, together with advanced techniques of structural analysis, produced a basic empty weight of only 50% of the gross weight.[102] The fuel consumption was of a natural concern to Pratt & Whitney Aircraft, while Hamilton Standard was alert to propeller efficiency and structural integrity. Little experience was available so that conservative approaches were appropriate. Independent flight tests were conducted by Sikorsky and Pratt & Whitney Aircraft; and careful records were kept by American Export Airlines during several transatlantic flights including the most valuable item of total fuel and oil consumed.[103] The propellers exhibited some resonance, so that operation was to be avoided between 1400 and 1600 rpm.[104] Pratt & Whitney tests on the Twin Wasp S1C3-G engine for fuel consumption showed a decrease at lower power and lower engine speed. Minimum specific fuel consumption (sfc) in pounds of fuel per brake horsepower per hour occurred at a brake mean effective pressure (BMEP) of 140 lbs. per square inch with Auto Lean Mixture on the carburetor. (See Footnote D.)

It became evident during the testing that highest propeller



Sikorsky XPBS-1 (S-44) of 1937 represented a major refinement in flying boat design. Powered by 1050 hp P&WA R-1830-68 engines, the XPBS-1 had great potential and better performance than the Consolidated PB2Y-1, but lost out on price. (United Technologies Archives)

efficiency, lowest fuel consumption and highest cruising speed occurred when the engine inlet manifold maintained substantially sea level atmospheric pressure plus the forward flight ram air pressure or approximately 31'' Hg MAP for a BMEP of 140 lbs. per square inch. Inexperienced pilots were tempted to maintain 1800 rpm and only 26'' Hg MAP at light weight which caused excessive fuel consumption.

The extensive testing showed the need for a tachometer schedule, reducing 100 rpm for approximately each two hours of flight after takeoff from 2200 to 1200 rpm to maintain this most efficient manifold pressure.[106] Engine speeds between 1400 rpm and 1600 rpm were avoided to preclude undesirable propeller vibration.[107] Even the climb after takeoff was scheduled at a low rate to conserve fuel. Many hours of flight testing were conducted at a full range of gross weights, altitudes, engine powers and speeds, and airspeeds with calibrated instruments especially for airspeed and fuel flow. The flight testing was centered around 140 BMEP for good engine efficiency but varying engine and, of course, propeller speed to achieve maximum propeller efficiency. The best combination assured optimum range for each gross weight and altitude up to 12,000 feet. Since the VS-44A did not have a pressurized cabin, range testing did not trespass upon the high altitude or full throttle power limits.

While several methods were available to determine range, they often involved approximations. The analysis of all flight data for the VS-44A taken by Sikorsky, Pratt & Whitney, and American Export was quite involved, ruling out any approximations. Virtually all flight test data taken under stabilized conditions was reduced to fundamental non-dimensional values of lift (C_L) and drag (C_D) coefficients throughout the cruising range. See Footnote E.) The engine power calibration and propeller efficiency procedures established by Pratt & Whitney Aircraft and by Hamilton Standard were used in the same manner that the actual transatlantic flights would be conducted. Fuel consumption as low as 0.39 lbs. per brake horsepower per hour and propeller efficiency as high as 89% were measured in cruising conditions. (See Footnote F.) Not only was level flight data used but also climb data, and operations with three, as well as two engines operating. Some concern was felt for flying at low engine speed toward the end of the journey. The first few flights were from Newfoundland to Ireland, with the engines turning 1800 rpm, and this resulted in little reserve fuel. Subsequent flights followed the reduced engine speed schedule with approximately 31'' Hg manifold absolute pressure to yield a uniform BMEP of 140 psi. Then there was elation because so much fuel remained that more cargo could have been carried.[109 110 111]

The cruise schedule was developed into two charts. One showed power required for several gross weights at all operating altitudes for the selected speed. The other showed the best airspeed and engine speed for the power. These were the main charts in the flight manual.[112] The range determination showed that all the independently obtained data were in agreement. From sea level to 12,000 feet, the range was 3700 statute miles for a takeoff weight of 57,500 pounds, a payload of 4528 pounds including 16 passengers, 10 crew, and baggage; fuel consumption was 17,200 pounds with 2400 pounds in reserve. The gross weight was increased to 59,224 pounds which permitted an increase of over 1500 pounds in payload.

Regular transatlantic service commenced June 22, 1942, with Capt. Charles Blair commanding. Frequently the trips were nonstop from New York to Foynes, Ireland, a distance of 2685 nautical miles, refueling stops were available at Botwood, Newfoundland, which offered a margin of confidence when headwinds prevailed.

Many records were established by the VS-44 which held for several years:[113]

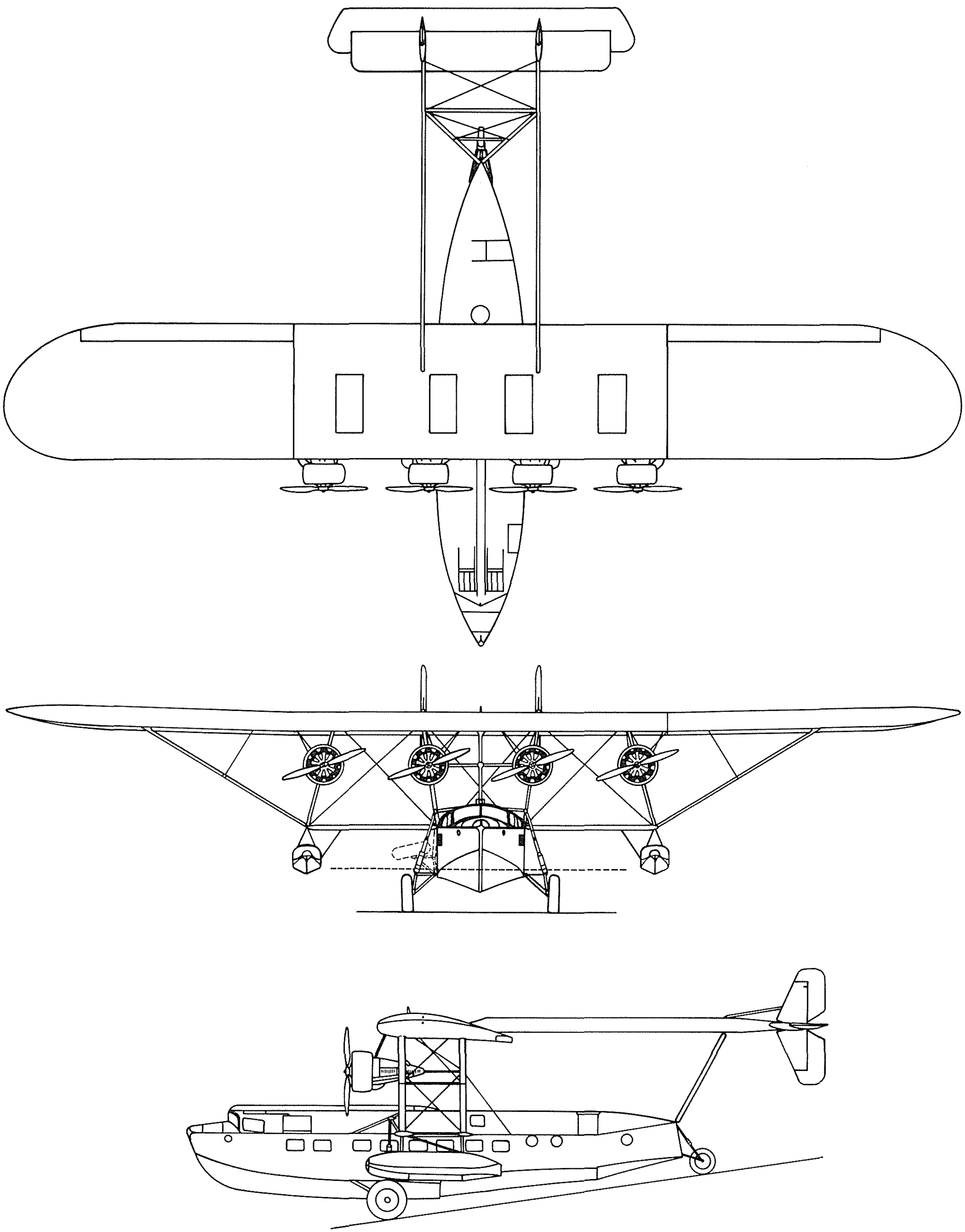
(1) A non-stop transatlantic record of 3329 miles in 14 hours 17 minutes, Oct. 25, 1944.

(2) Non-stop New York to Lisbon 3383 miles in 20 hours 14 minutes. (Date unknown, Airman's Almanac 1945.)

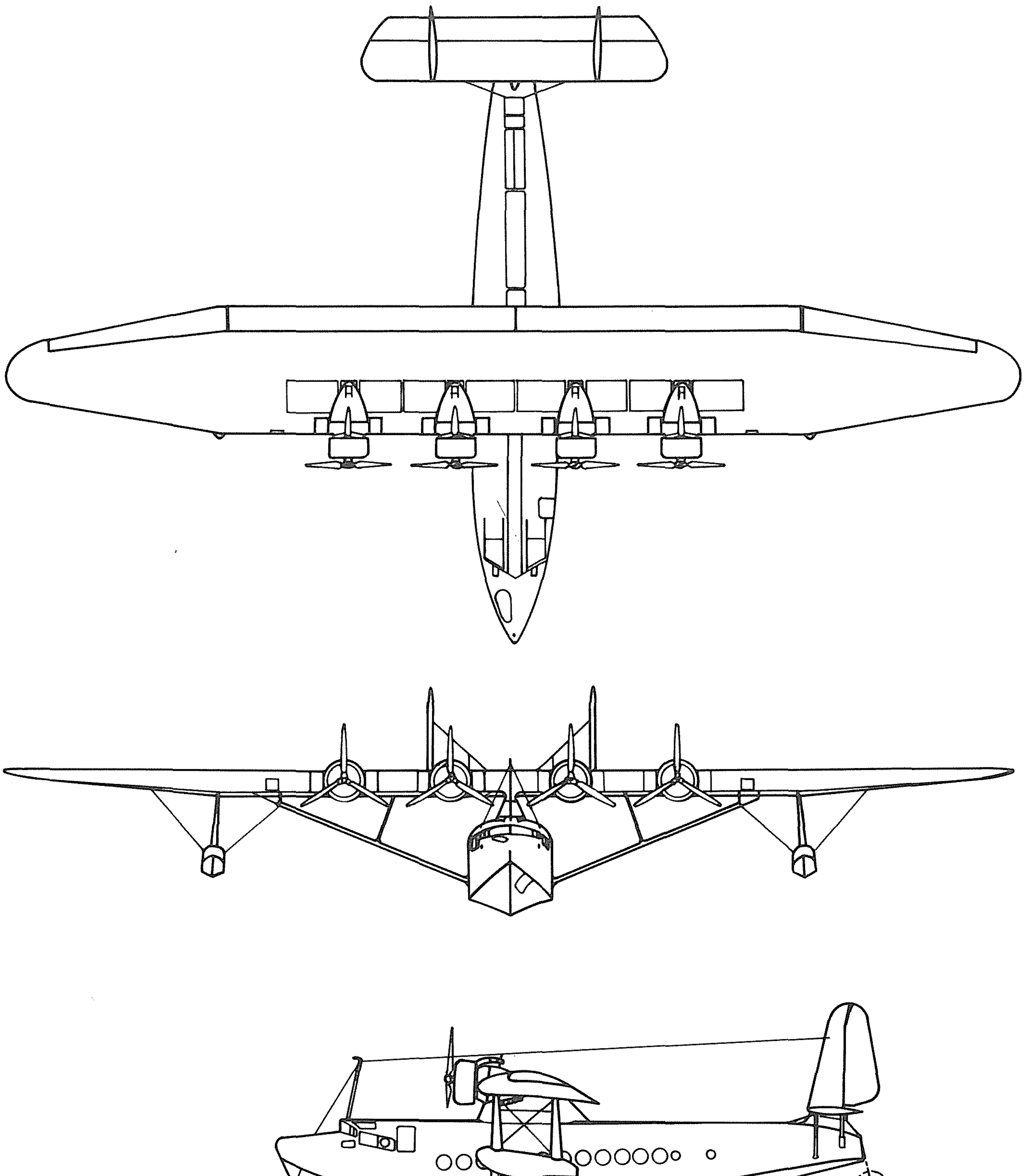
(3) Fastest westbound Atlantic flight Europe to USA 16 hours 57 minutes, July 1944.

(4) Fastest non-stop flight Europe to New York 18 hours 5 minutes. (Date unknown, Airman's Almanac 1945.)

Two VS-44A flying boats were in the class of the transoceanic league throughout World War II. The competition between American Export Airlines with their VS-44As and Pan American



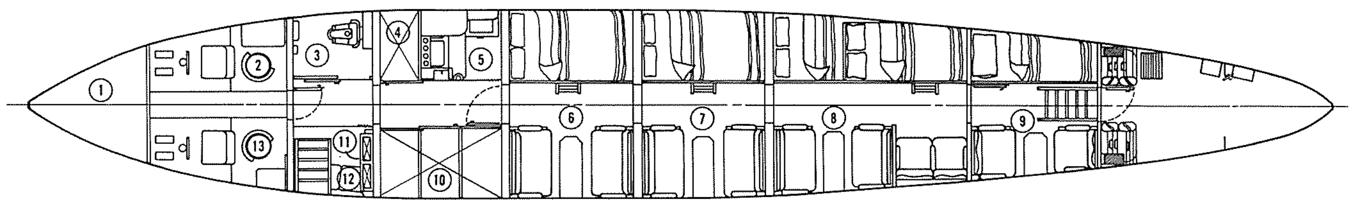
SIKORSKY S-40



SIKORSKY S-42

DON WILLIAMS

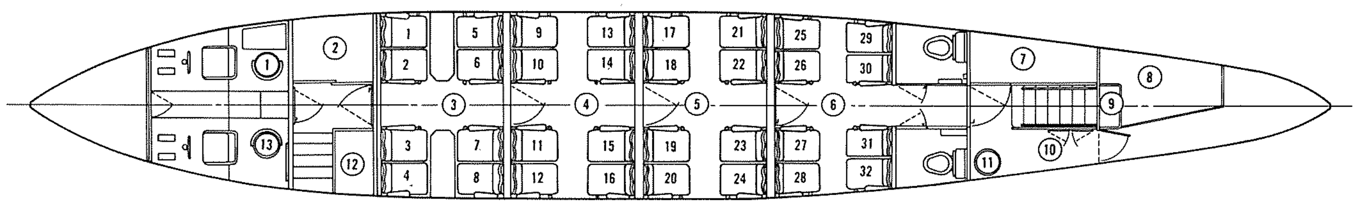
1. ANCHOR COMPT
2. RADIO OPERATOR
3. WASH ROOM
4. MAIL COMPT
5. GALLEY
6. COMPT – D
7. COMPT – C
8. COMPT – B
9. COMPT – A
10. CARGO COMPT
11. BATTERIES
12. STEWARD
13. MECHANIC



S-42A SERIES

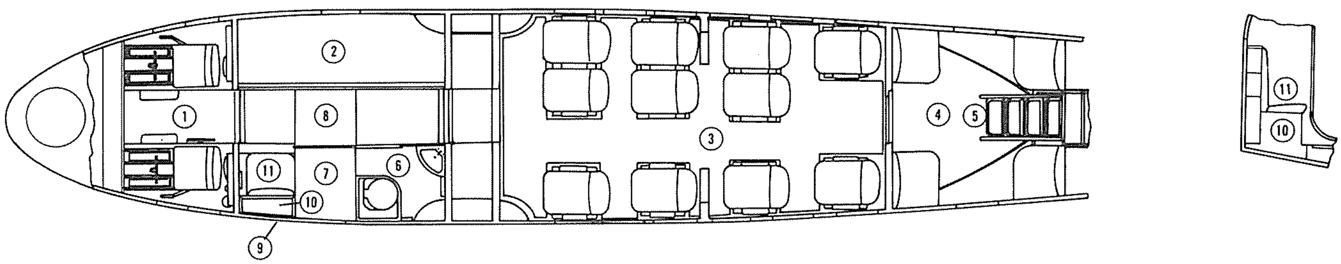
Convertible 32 Day to 14 Night Passenger Accomodation

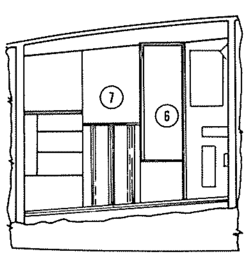
BOB AKERS



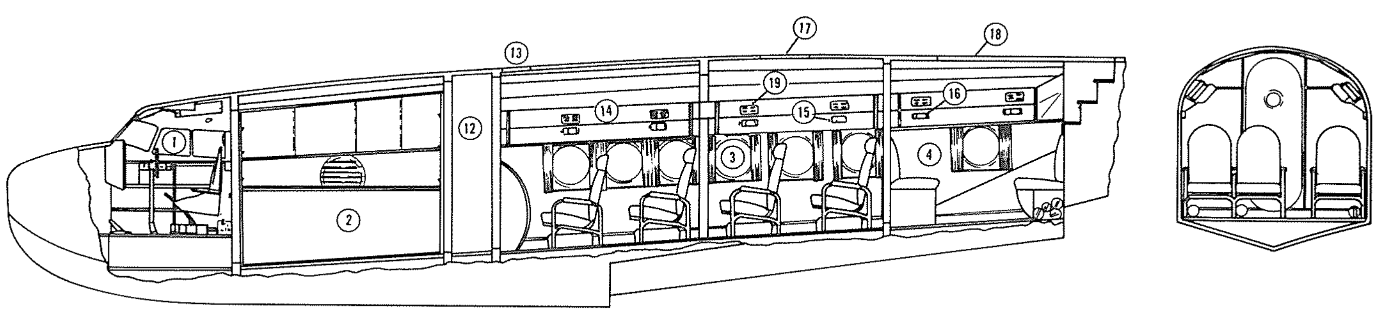
1. RADIO OPERATOR
2. 95 CU. FT. BAGGAGE (STRONG BOX UNDER FLOOR)
3. 1st COMPT
4. 2nd COMPT
5. 3rd COMPT
6. 4th COMPT
7. 60 CU. FT. BAGGAGE
8. 60 CU. FT. MAIL
9. 2 10-PASS. RAFTS
10. FOOD & ICE BOX
11. STEWARD
12. 45 CU. FT. EQUIP. LOCKER
13. MECHANIC

S-42 SERIES



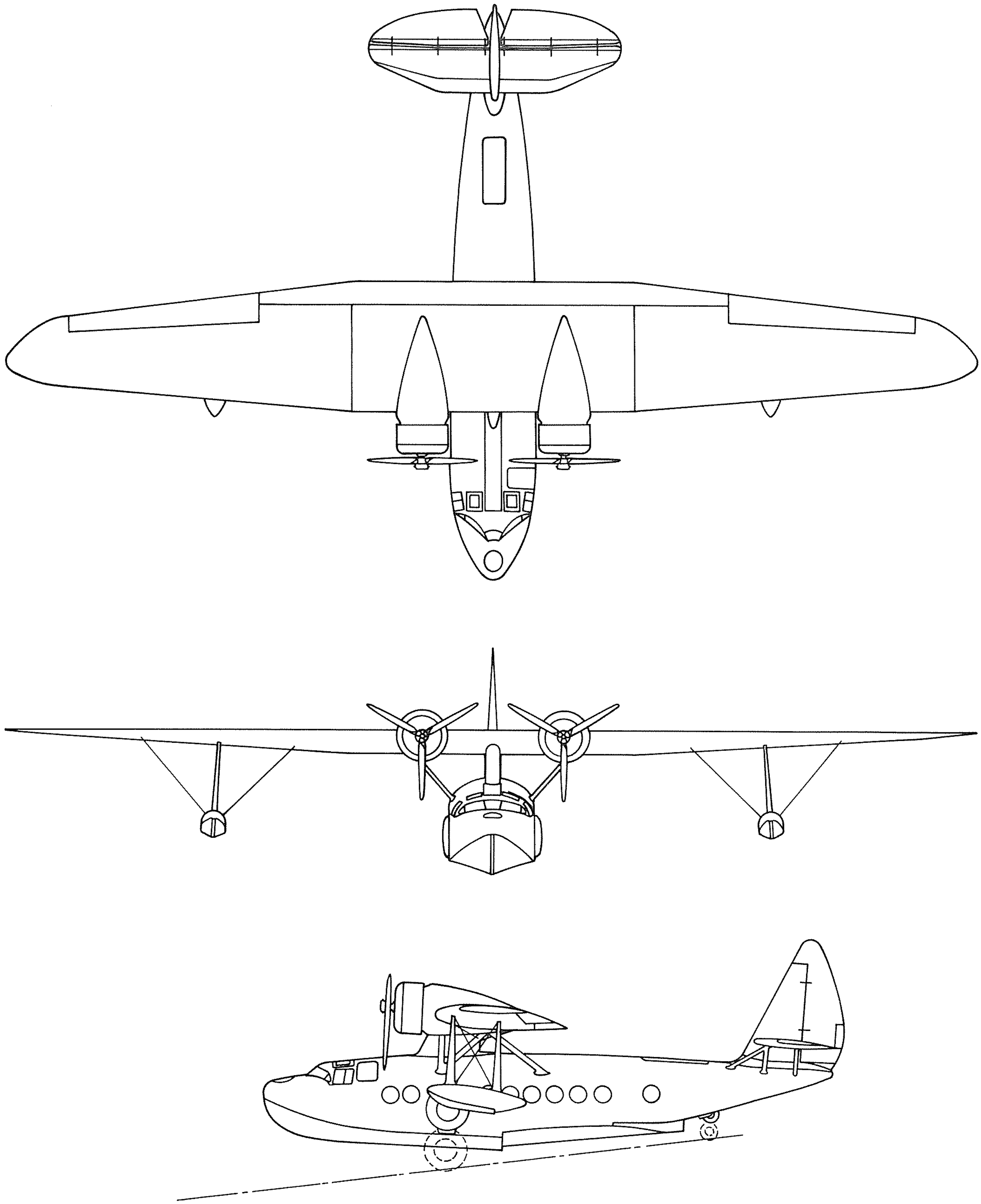


1. PILOT'S COMPT
2. BAGGAGE COMPT
3. MAIN CABIN - 11 PASSENGERS
4. SMOKING COMPT - 4 PASSENGERS
5. COLLAPSIBLE STAIRS
6. TOILET COMPT
7. MAIL COMPT
8. BATTERY COMPT
9. FRONT ENTRANCE HATCH
10. STEWARD'S LOCKER
11. STEWARD'S SEAT
12. SPACE FOR CARGO IF USED AS BOAT
13. CABIN AIR OUTLET
14. AIR DUCT AND SMALL BAGGAGE RACK
15. CALL BUTTON
16. READING LIGHT
17. EMERGENCY EXIT
18. MAIN ENTRANCE HATCH
19. AIR REGISTERS

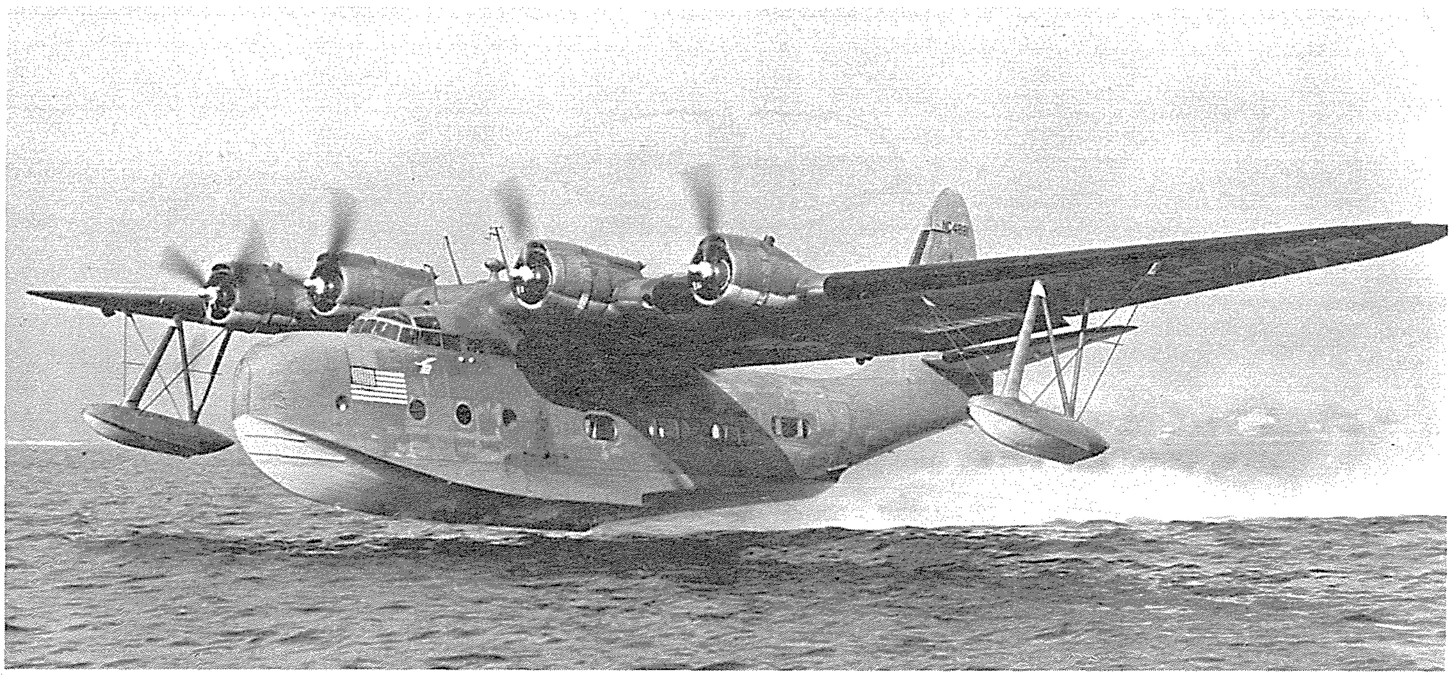


SIKORSKY S-43 INTERIOR

DON WILLIAMS



SIKORSKY S-43



Sikorsky VS-44A "Excambian" in wartime paint when owned by the U.S. Navy and operated under contract by American Export Airlines. Today the sole remaining American commercial four-engined flying boat, "Excambian," is now at the Naval Aviation Museum, Pensacola, Florida. (United Technologies Archives)

Airways with their Boeing 314 flying boats was quite spirited in spite of the common cause of wartime. During the war, ownership of the VS-44As and the B314s was taken over by the U.S. Navy (though for a while four B314s were owned by the Army); they were operated by their respective airlines under contract to the Naval Air Transport Service (NATS). In 1945 American Overseas Airlines, a division of American Airlines, acquired control of American Export. In 1950 Pan American took over the operations of American Overseas. Soon after World War II the two remaining S-44As were sold by the U.S. Government as war surplus property.

During the war many military planes were ferried across the oceans establishing a good safety record. Of more significance to the flying boat future, however, was that the military services of all nations had constructed a multitude of airports with very long runways for the numerous heavily loaded fighters, bombers, and transports. At the end of the war, these flying fields were available to commercial flying. American Overseas started Douglas DC-4 landplane operations across the Atlantic on the 24th of October 1945, while Pan Am followed with the pressurized cabin Lockheed Constellation on February 3, 1946.[114]

With airports more conveniently located, the flying boats were relegated to areas of the world without airports. The VS-44As saw much service in South America and coastal Pacific runs. For 10 years the last VS-44A was the pride of the fleet of Avalon Air Transport flying between Catalina Island and Los Angeles. On the twenty-fifth anniversary of the VS-44A the author had the thrill of flying in the VS-44A, NC-41881, with Capt. Dick Probert. It was a great pleasure to guide Capt. Probert through the intricacies and simplicity of power management to operate more economically at the (S.L.) atmospheric manifold pressure relationship with a brake mean effect pressure (BMEP) of 140 lbs./sq. in.[115] [116]

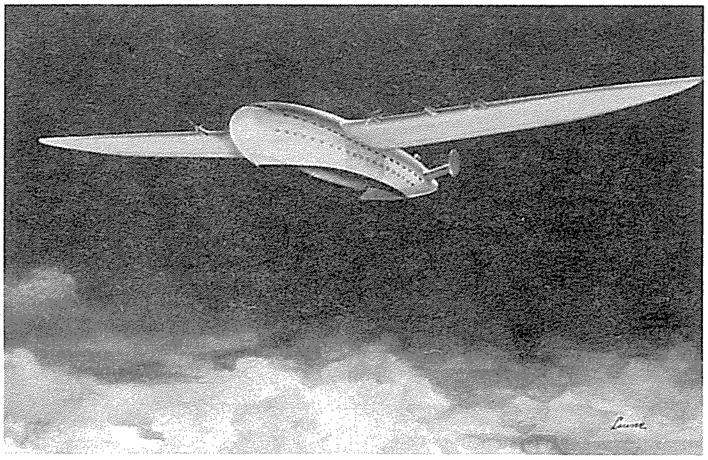
The final service of the VS-44A flying boat found Capt. Charles Blair, the original test pilot, operating NC-41881, "Excambian," in the Caribbean with Antilles Air Boats. Flight operations were terminated due to the need for extensive overhaul. This last Sikorsky flying boat was donated by Capt. Blair in 1977 to the U.S. Naval Aviation Museum at Pensacola, Florida, for permanent display. The aircraft is in an advanced state of corrosion but can be salvaged as a static exhibit.

A parametric review reveals several significant technical advances which made flying boats successful and good competition for landplanes. In some cases the pioneering work on high wing loading, vortex generators, long span ailerons, high aspect ratio, wing flaps, tail size and location, structural design and powerplant first developed for flying boats was later introduced to landplane designs.

PRACTICE COMMON

		S-38	S-40	S-42	S-44
	1927[117]	1928[118]	1931[118]	1935[118]	1937[118]
Wing Loading lbs./sq. ft.	10	14.5	18.5	31.3	35.5
Power Loading lbs./HP	15	11.6	13.1	13.1	12.3
Length/Beam Ratio	4.0	4.5	5.6	6.9	7.6
Empty Wgt./Gross Wgt. Ratio	.65	.65	.69	.57	.50
Passengers and Crew	20	10	24	32	39
Range Nautical Miles	500	500	950	1,120	4,319
Cruising Speed Kts.	86	96	115	139	168
Landing Speed Kts.	45	48	66	56	63
Aspect Ratio (Span²/Area)	6	9	7.5	10.4	9.2

There were three other flying boat projects which deserve attention, even though they were never built by Sikorsky. Although the U.S. Navy was basically pleased with the S-44, there was some feeling that four engines were too much for one pilot to control, even with the assistance of a co-pilot. With more powerful engines and improved propellers under development, a twin-engine version of the S-44 was requested. Obviously, the 12-ft. 7-in. propellers would have to be replaced by larger diameter propellers. To assure adequate water clearance, the hull height would have to be increased, or some other arrangement would be needed. Boeing was also invited to consider the proposed development. Considering the dilemma, the Sikorsky proposal seems to have been considered unresponsive and the



Sikorsky S-45. Designed in 1939-1941 to carry 100 passengers in comfort but never built. First-class passengers were to be accommodated in state rooms and large communal lounges with a dining room provided—an ocean liner of the air. Six 2300 hp P&WA X-3130 engines buried in the wing were planned. Wing tip floats retracted. Wing span 236 feet; gross weight 210,000 pounds. (United Technologies Archives)

contract was awarded to Boeing for the XPBB-1 Sea Ranger, of which only one example was built.

The Navy was also farseeing in sponsoring the development of the VPB, heavier than air, Patrol Bomber. This was a program of sophisticated technological infusion. Numerous companies were invited to submit ideas. Several funded iterations were devolved in a competition between Martin and Sikorsky. The technical suggestions of other companies were integrated by a "brains trust" in an attempt to secure the "best." The Sikorsky engineers like to think they contributed measurably to this project. And they did! But, again realizing the geo-financial politics of the era, the contract was awarded to Martin for the Mars JRM-1. It would be of historical benefit to identify the details of Sikorsky's contribution to final Mars long-range patrol bomber for the U.S. Navy. Some of the contributions appear to be reflected in U.S. Naval Air Test Center work of Dommasch, Sherby and Connolly.[119]

The other intriguing project was another one sponsored by Col. Lindbergh of Pan American Airways. This called for a long-range, high-speed, very comfortable airplane to carry 100 people across any ocean. On March 15, 1938, Sikorsky won the contract to design such an airplane, the S-45. It was to be a flying boat. The basic shape followed the lines of the latest dirigibles HINDENBURG and AKRON to assure minimum air drag for a given cross-sectional area. The hull lines were minor modifications of this shape to permit water operation. The wing was of high aspect ratio fitted with the best of high lift devices. The sophisticated powerplant installation provided cabin air conditioning and was accessible for in-flight maintenance.

Of course, reciprocating engines and propellers were a key function with financial commitment the determining factor. The decision still reflected the availability of airports. World War II had decisive impact on all these factors. Turboprop and turbojet engines developed during and after the war altered design concepts. Of great significance to the decision were the great number of military airports on both sides of the oceans which were made available to commercial operations.[120] The safety of military transoceanic ferry and transport flights were examined in great detail. It was finally determined that the reliability of airplanes was so good that concern for landing at sea was no longer warranted. The maintenance needed for flying boats was more than that required for landplanes. The airports were provided at little cost in comparison to the supposedly free waterways. The same equipment for transcontinental and transoceanic service attracted the support of the investors. The flying boats were fully competitive[121] with the landplanes in all aspects but one—they could not land on land, where the passengers lived.[122] When the people provided large public airports at the traffic-generating centers, the flying boat passed into history.

FOOTNOTES

A. Scale effects had been expressed by William Froude in his "Law of Comparison" in the latter part of the 19th century. He stated that "when the speeds of the ship and its model were proportional to the square roots of their lengths, the resistances would be proportional to their displacements" and that "specific skin resistance equals R_f/AV^2 where R_f is the frictional resistance in pounds, A is the wetted surface in square feet and V is the speed of the model or ship through the water in knots."[42] Subsequent experiments in England, Germany and the United States showed the relationships were not entirely valid.

B. The actual displacement, Δ, in proportion to resistance, R, (Δ/R), was noted at increments of getaway speed. The power requirement was determined with air drag included by DV/375 = THP where D = total drag in pounds, V = speed in miles per hour, and THP = thrust horsepower.

C. Breguet formula:

$$R = 863.5 \frac{\eta}{c} \frac{L}{D} \text{Log}_{10} \frac{W_0}{W_1}$$

R is range in statute miles
where
η is propeller efficiency
c is specific fuel consumption lbs/hp/hr
L is lift in pounds
D is drag in pounds
W_0 is takeoff gross weight in pounds
W_1 is landing gross weight in pounds.
The constant 863.5 is derived from the factors:
1 H.P. = 550 ft lb/sec
1 hr = 3600 sec
1 statute mile = 5280 ft

$$\frac{550 \text{ ft lb/sec} \times 3600 \text{ sec}}{5280 \text{ ft}} = 375 \text{ lb/mph}$$

$$R = 375 \frac{\eta}{c} \frac{L}{D} \text{Log}_{10} \frac{W_0}{W_1}$$

converting to Log_{10}

$$R = 863.5 \frac{\eta}{c} \frac{L}{D} \text{Log}_{10} \frac{W_0}{W_1}$$

D. Pratt & Whitney formula

$$\text{BMEP} = \frac{792{,}000 \times \text{BHP}}{\text{Displacement} \times \text{RPM}}$$

for the S1C3-G engine with a displacement of 1830 cubic inches the most efficient engine speed is:

$$\text{RPM} = \frac{792{,}000 \times \text{BHP}}{\text{Displacement} \times \text{BMEP}} = \frac{792{,}000 \times \text{BHP}}{1830 \times 140} = 3.09 \times \text{BHP}$$

where the factor 792,000 is the product of 33,000 (ft. lbs./min. for one horsepower); 12 (inches/foot) for engine piston stroke and 2 as the number of revolutions per power cycle to make consistent units of displacement, pressure, power and speed.[105]

E. Plotting $C_L{}^2$ against C_D established the relationship of

$$C_D = 0.03 + 0.0475\, C_L{}^2$$ [108]

This could be expressed as

$$C_D = C_{Dp_e} + C_L{}^2 / \pi Ae$$

where C_D = Total drag coefficient
C_{Dp_e} = Parasite (effective) drag coefficient – 0.03
C_L = Lift Coefficient
A = Aspect Ratio – 9.21 for the S-44
e = Oswald (airplane efficiency) factor = 0.729

F. The drag relation was expressed as brake horsepower required for cruise as:

$$BHP = \frac{0.0114}{\eta} V_i{}^3 \times C_D \sqrt{\rho_o/\rho_{ALT}}$$

which was derived from the fundamental relation

η BHP = THP = DV/375
with V in miles per hour
D is total drag in pounds

for consistent units the constant 375 = 550 x 3600/5280 =

$$\frac{(\text{ft.lbs./sec})\,(\text{sec/hour})}{(\text{feet/mile})}$$

and the constant:
$0.0114 = 1.467^2 \rho_o S/2 \times 375$
with ρ_o = air density at standard sea level = 0.002378 Slugs per cu.ft
S = Wing area - 1670 sq.ft. for the S-44
and the constant 1.467 converts ft/sec to miles per hour =

$$\frac{5280}{3600} = \frac{\text{ft. per statute miles}}{\text{seconds per hour}}$$

ρ_o/ρ_{ALT} = density ratio at altitude
η = propeller efficiency
C_D = total drag coefficient
V_i = Indicated Airspeed calibrated for installation error

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*33. I.A. Sikorsky, op. cit., p. 68 (the suffix "on" was used in contrast to "an" to distinguish the inanimate airplane from living amphibious creatures).
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*35. Col. Virginius E. Clark, famed aeronautical engineer, made a 5¢ bet with Igor I. Sikorsky that he could not design and build a successful large amphibian as the proposed S-40. He lost and sent a check for 5¢ drawn on the Chemical Bank & Trust Co., New York, dated Jan. 23, 1932, accompanied by a letter of same date acknowledging loss of the bet and congratulating Sikorsky on his achievement.
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*54. An aircraft design usually undergoes a progression of concept and design development to meet often changing requirements. The S-42 was no exception. Its conception studies began in the Fall of 1930 resulting initially in the S-42-X, a 100-foot shoulder wing amphibian of 21,000 pounds gross weight with four P&WA 420-hp Wasps mounted in two pusher-tractor nacelles above the wing. This design did not progress beyond the conceptual stage.

*Igor I. Sikorsky, *Design Notebook No. 4* (manuscript), dated December 4, 1930, pp. 8a, 9, 9a, 10.

The next design concept to progress to a proposal stage was the S-42-X-6, a flying boat similar to the S-42-X, but using two projected geared P&WA 800-hp Hornet engines driving large 14-foot-diameter propellers.

*Ibid., pp. 14a-16a dated June 11, 1931. Also internal memorandum from I.I. Sikorsky to E.E. Wilson on "Proposed Pan American Air Mail Plane" dated June 11, 1931.
55. Capt. J.C. Kelly-Rogers, op. cit., p. 21.
56. Clark B. Millikan, op. cit., p. 132.
*57. Before arriving at the final four-engine version, the S-42 design went through many design variations influenced by engine availability and customer requirements particularly in the area of gross weight and range. By 1931 Pan American was interested in a flying boat of around 24,000 pounds gross weight for carrying only air mail. As the availability of a P&WA 800-hp engine was not immediate, the next concept of the S-42-X-13 was for a tri-motor with three 575-hp P&WA Wasp engines.

*Igor I. Sikorsky's "Design Notebook No. 4" (manuscript), pp. 17a, 18, 18a dated July 9, June 28 and July 8, 1931, respectively.

Several versions of tri-motored S-42s evolved with varying dimensions, weights and range all on shoulder wings with the engine nacelles mounted on struts above the wing. Then a two-engine version appeared utilizing 720-hp Junkers Jumo 4 diesel liquid-cooled engines. The performance obtained was only slightly better than the three-engine version.

*Ibid., pp. 30a, 31, 31a dated November 8, 1931.

Then the gross weight was scaled up to 36,000 pounds and a trimotor version with either 800-hp P&WA or Junkers diesel engines was projected.

*Ibid, pp. 32a, 33, 33a, dated November 12, 1931.

Finally by May 1932 the four-engine S-42 was firm with four P&WA 550-hp Wasps SD mounted on struts above the shoulder wing.

*Notes on "The Fourth Technical Advisory Committee Meeting May 2-6, 1932," Research Division, United Aircraft & Transport Corporation, dated May 13, 1932, pp. 34 and 35.

During the summer of 1932, as a result of wind tunnel studies, the wing was raised on to a pylon and the nacelles incorporated into the leading edge of the wing. Also, four P&WA 675-hp Twin Wasp, Jr. engines were to be installed.

*Contract (for S-42), Pan American Airways, Inc., and Sikorsky Aviation Corporation, October 1, 1932.

Later the contract was modified to substitute 700-hp P&WA Hornet S5D1-G engines of lighter weight and known reliability. As the Twin Wasp Jr. engine had just appeared and had little operational use, apparently Pan American decided to stick with the use of the proven Hornet.

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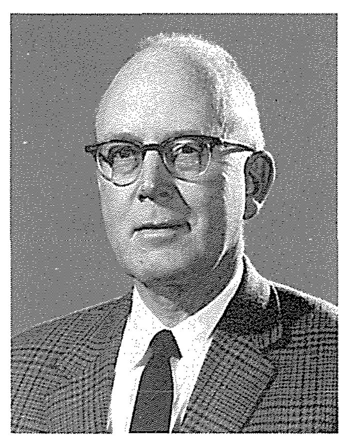
ABOUT THE AUTHOR



Ralph B. Lightfoot, a native of Massachusetts, graduated from the University of Rhode Island with a B.S. degree in Mechanical and Aeronautical Engineering whereafter he joined Sikorsky Aircraft Division of United Aircraft Corporation in 1935 to become a wind tunnel test engineer working on S-43, S-44, VPB and high lift devices. In 1940 he became Senior Flight Test Engineer and later Chief, Flight Test, Chief of Flight Research until 1957 when he became Chief Engineer. Meanwhile he had made the transition from airplanes to helicopters. In 1966 he was appointed Engineering Manager and retired in 1974 as Senior Staff Engineer to the Executive Vice President. Lightfoot is the holder of seven patents and many honors and has produced a prodigious quantity of papers, reports and publications in aeronautical engineering. He is an Honorary Fellow of the American Helicopter Society, a Fellow of the AIAA, Royal Aeronautical Society and the New York Academy of Sciences. Interested in the historical aspects of aeronautics, he was a Director of the Connecticut Aeronautical Historical Association for several years. In retirement at Stratford, Connecticut, he spends much of his time lecturing and consulting in the educational field.