Biplanes are unfit for Atlantic air travel

In the early era of flight most practical airplanes were biplanes, i.e. airplanes with double wings. The double wing arrangement was a good way to obtain a large lifting area within a relatively short span. With a short span the construction could be kept light\(^1\). Also, fighters with short wings were highly maneuverable in dogfights. Some designers even went to tri-planes.

The large wing area was needed because the available engines could only deliver a modest amount of power and an airplane should be able to take to the air without too great an effort. However, there were also intrinsic problems: large wings, giving more lift, were also heavy. Was it worth using more than one engine? What was the weight of an additional engine and its fuel? As with all the principal parameters of flying machines, the designer had to find an optimum. The biplane offered a weight savings: its shorter span limited the bending moment of the wing caused by the lifting force during flight (upward) and by the landing shock (downward). The total construction could be kept lighter. The biplane was a brilliant way to get high lift at relatively low weight. The only adverse factor was the extra air resistance (“parasitic drag”) of the rigging between the wings.

The double wing arrangement had the additional advantage of providing an excellent (lightweight) way to absorb the bending moments on the wings during flight. If one looks at a biplane from the side, the double wings together form an I beam. The upper and lower wings are the flanges of the I beam and the web between them is in fact formed by the interconnecting rigging (wires for tension and struts for compression). In flight this rigging causes the top wing to be compressed, while the bottom wing is in tension. At the fuselage, where the wings are fastened, the two opposed forces balance the bending moment in the total wing assembly.

Looking from the front, the wing assembly gives the impression of an old fashioned box girder railroad bridge.\(^2\) The tension and compression forces in the wing halves are in fact rather small because there is a considerable “gap” between them. Because of this the wings can be thin, although here is one more trade-off to consider: greater distance between wings implies the need for longer struts. These may have to be quite robust to prevent buckling, thereby increasing weight and parasitic drag.

\(^1\) All qualifications like ‘light’, ‘short’, ‘heavy’, ‘weak’, should be considered in a relative sense, that is in relation to the overall machine and its constituent parts.

\(^2\) This is not a coincidence: the engineering of aviation was a natural continuation of nineteenth century railroaD construction, shipbuilding and carriage building.
There was much to be said for bi-plane construction. As more powerful engines became available they could be made bigger and bigger. After 1918, airliners were also built this way. Especially the English for a long time persisted in maintaining the formula. Land-planes and flying boats in bi-plane form, built by Handley Page and Short Brothers, were used well into the thirties on medium length commercial routes. In pioneering flights biplanes even conquered the Atlantic: the first non-stop crossing by Alcott and Brown; the first crossing via the Azores by the US Navy Curtiss flying boats; the Round the World flights by Douglas Cruisers in 1924. Except for the latter, all oceanic flights were from west to east. But to fly a regular air service two thousand miles over water from east to west against predominantly westerly winds with thirty passengers aboard would require something more substantial: a streamlined, low-drag, fast monoplane airliner, built of metal as it turned out.

Monoplanes

Air resistance or ‘drag’ is really the factor that rules out biplanes. The drag of wing struts and rigging wires is substantial and disqualifies the biplane. It slows it down to such an extent that the battle against hard blowing ocean winds is lost. On occasion the biplane Atlantic airliner would not arrive because it had run out of fuel.

The objection to external bracing holds of course for monoplanes as well. Ideally monoplanes should have clean wings without any external struts or wires. This rules out larger versions of beautiful airplanes as the Levavasseur Antoinette or the Blériot XI. The wing should carry all the supporting structure within itself. Such a wing construction is called a cantilever construction. Can such wings be built? The biplanes had wings which were generally very thin. The major strength bearing capacity came from the widely separated and firmly interconnected wing halves. Some way had to be found to squeeze this whole box girder concept INSIDE the sole wing. THICK wings were in order.

Wings of this type had been investigated and indeed used before the Twenties. Professor Hugo Junkers proved that relatively small airplanes could be built with single wings with a deep section. His J-1 fighter from 1915 performed well. Other designers in Germany followed, notably Dornier, Fokker and Rohrbach. Anthony Fokker built beautiful thick wings out of wood.
The Fokker E.V or D.VIII of 1918

This aircraft builder had learned of the 'thick wing' principle during his short association with Prof. Junkers during the First World War. Using this concept and the results of experiments by the Swedish engineer Forssmann, he produced by the end of 1916 an experimental sesqui-plane, the V.I, with fully cantilevered wooden wings, lacking any bracing or struts between the wings. The new wing construction became from then on Fokker's trademark and enabled him to keep his position among the leading German aircraft builders. Fokker's well-known designer Reinhold Platz adapted the wing for every conceivable configuration: for a monoplane, (the E.V/D.VIII of 1918, see picture), for a biplane (the D.VII of 1917) and even for a triplane (the Dr.I of 1917, used by Manfred von Richthofen). At first structural failures occurred, caused by hasty assembly, omission of varnish (which caused the glue to dissolve in rain-water) and poor materials, but in the end it was clear that Fokker had worked out a unique way of constructing extremely strong, light-weight wings.

Thereafter he applied his new construction method to a remarkable series of high-wing airliners, which commenced with the model F.II in 1919, using a scaled-up version of the D.VIII wing. In fact Fokker dominated the continental airliner market with models derived from this type, until Lockheed, Douglas and Boeing arrived in the mid-thirties with their all-metal airplanes.

Note the true cantilever wing: complete absence of wing struts

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3 Forssmann worked with plywood wing coverings diagonally glued onto the spars, thereby making a skin that carried part of the wing load. The resulting wing proved extremely strong.

4 The US Army T-2 (a modified Fokker F-IV airliner) is on permanent display at The Smithsonian Institute in Washington.
The Fokker F-series airliners were extremely light and strong. Because of their lightness they could carry a large store of fuel and they were extremely well suited for record setting long distance flights. Apparently its mixed construction (wooden wing, welded tube fuselage with plywood covering) was very well suited for aircraft up to 20,000 lbs (9000 kg). Kingsford Smith made a series of highly publicized Ocean crossings with his Fokker F 7-3m “Southern Cross” in the years 1928 to 1934.

Fokker never attempted to construct a true Atlantic airliner. His major market challenge in Europe was to satisfy customers like KLM Royal Dutch Airlines that operated extended networks, some of them reaching into the Far East, with equipment suited for medium length stages over land. The biggest airliner Fokker produced in this formula was the F.36 for 32 passengers, with a take-off weight of 16,500 kg (36,000 lbs) a cruise speed of 280 km/h (175 mph) and a maximum range of 1500 km (960 miles). It had fixed undercarriage, steel tube fuselage and an impressive wooden wing (see picture).
The Fokker F.36 illustrates the closest the builders of “wooden” airplanes would come to a true long distance passenger plane. It is true that other equally remarkable constructions saw the light, such as the 1937 de Havilland DH.91 Albatross, meant as an Atlantic mail carrier, and during WWII the huge Hughes HK-1 flying boat for trans-Atlantic troop transport. But neither one came to any practical use.

The question wood versus metal in airplane building provoked intense principal discussions and in hindsight various books were written on the subject. It is certainly not impossible to build splendid high performing practical wooden aircraft, such as for instance the de Havilland Mosquito two-engine attack bomber of WWII. But for the intensive, heavy duty air service across the Atlantic, large vehicles were needed based on a construction material that combined light weight not only with strength but also with durability. Moreover, as it turned out, light sheet-metal offered the designer the freedom to find new ways to build load-bearing structures out of flat plates or sections with simple extruded or rolled shapes. This flexibility made it possible to build airframes with a very favorable strength/weight ratio, specifically suited for the large and the heavy machines that would be crossing the Atlantic by the end of the thirties.

The Large Metal Monoplane
During the First World War Germany had taken the lead in the construction of metal aircraft. As stated before, an early example was given by Professor Hugo Junkers’ “all-metal” J-1 monoplane fighter. Junkers also advocated the building of large flying wings for passenger transport. An indication of things that he meant to realize was the giant G-38 thirty-passenger airplane that first flew in 1929. Independent of Junkers’ line of development, the use of light metal in aeronautics had started even earlier with the activities of Ferdinand Graf von Zeppelin.

In 1899, Von Zeppelin bought the exclusive rights to the use of this miraculous metal of the Victorian era: ‘aluminium’. He obtained the rights from Carl Berg of Ludenscheid, Westfalen, who was one of the first manufacturers of rolled aluminium profiles and sheet. Three years before the Wright brothers were flying their first motorized airplane (1903), Von Zeppelin had already flown his first airships constructed with the new material. The ‘zeppelin’ airship had an aluminium skeleton, in effect a huge, riveted three-dimensional space framework, determining the outline of the large cigar-like form, which was covered with rubber-soaked fabric. By the start of the First World War he had built one dozen more of these giants for civilian use alone and had started DELAG, a regular airline flying to Berlin using zeppelins. With these exploits he had not only achieved an enormous popularity with the German people, but he had also managed to build an important aviation manufacturing concern diversifying into flying boats and large bombers during WWI. The leading designers of these offspring activities were Claudio Dornier (flying boats at Lindau on the Bodensee) and Prof. Alexander Baumann (giant land-bombers at Berlin-Staaken), succeeded by Adolf Rohrbach.

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During the war Claude Dornier taught himself (and Adolf Rohrbach) how to build large metal flying boats. After the armistice he channeled his experience into a very viable design for a medium-sized all purpose metal flying boat, the Do J-Wal. He had this boat and its derivatives built outside Germany and found for it numerous military and civil users.

In 1928 Dornier received sufficient funds from the German government to build a large Atlantic flying boat. After much study, he chose a configuration of a metal monoplane with deep hull in which passenger accommodation, steering hut and baggage holds were distributed over multiple decks. The total starting weight of the first version came in at 48,000 kg (107,000 lbs). Its empty-over-gross weight ratio was 59 per cent. No less than twelve engines, mounted atop the wings, were needed for propulsion. As we have shown in the previous chapter, the resulting flying machine was a triumph in certain aspects: the Dornier Do-X showed once and for all that large airplanes could be constructed out of metal and that sheer size did not automatically lead to a construction that was too heavy to fly...

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8 Although its range was stated as more than 3000 kilometer, the two airplanes that were built of this remarkable type, were used by Lufthansa on its European routes only, between 1931 and 1940.
From an operational standpoint, however, the machine was a disaster. Although it did manage to make a return flight across the Atlantic, it was incapable of carrying any payload. The ship was too slow and underpowered. Inadequate propulsion (caused by weak engines and primitive air screws) was married to poor aerodynamic form. The design originated in a period where the reduction of parasitic drag was not considered of major importance. The L/D factor can not have been more than 8 or 9 and some maintain that the ship could only cross the ocean by flying low, at a height of not more than 15 meters (50 ft), making use of the ground effect of its stubby wings.

Being in a generous mood, the German government simultaneously subsidized Adolf Rohrbach to build his version of an Atlantic airliner for Luft Hansa, the German national airlines. In contrast to Dornier, who practiced a conventional style of engineering, Rohrbach had proved himself a designer with rather advanced ideas. He advocated large metal airplanes with an airframe that was precisely calculated to carry the anticipated working stresses. He had become renowned by presenting the aviation world with the first modern metal airliner as early as 1919. It was the Zeppelin-Staaken E-4/20, a four-engine all-metal monoplane with high mounted wing that astounded the professionals by being relatively small, resulting in a high wing load.⁹ As Rohrbach pronounced, this was the only way to tackle the problem of growth in airplane size. Being educated as a shipbuilding engineer, he also did not hesitate to exchange the traditional wing spars, such as used by Dornier, for a more capable type of box spar in which the skin of the wing was integrated as a load carrying element.

⁹ see http://ritstaalman.files.wordpress.com/2014/05/rohrbach-chronicles-5e-versiona4.pdf
The Ro-X Romar, Rohrbach’s entry into the Atlantic race, with a starting weight of 18,500 kg (41,000 lbs), was less than half the size of Dornier’s. It featured advanced aerodynamic and hydrodynamic developments in wing and hull shape, which was the work of Kurt Tank, Head of Research of the Rohrbach Metallflugzeugwerke. The wing load was at 110 kg/m², about equal to the Do-X. Head of Structural Design, Herbert Wagner, had developed new concepts in sheet metal construction which were also applied in the Ro-X. The machine was intended to carry a payload of 1100 kg (2425 lbs) over a range of 4000 km (2500 mi). Although the initial tests were very promising, it turned out that the desired range could not be reached. Like its competitor, the Dornier Do-X, this machine too failed because of inadequate propulsion and too high parasitic drag. Its empty-over-gross weight ratio was close to 60 per cent.

As by 1930 the German economy had once more collapsed, there was no more money available for endeavours of this kind and the lead in the development of this class of aircraft was taken over by the United States. Both the U.S. Army and the Navy stimulated new design for metal bombers and patrol flying boats, while subsidies for mail carriers also favoured new, efficient equipment. In this regard, it was particularly Pan American Airways that made a remarkable effort in the development of long range airliners. The consensus was that an ocean airliner of substantial size should definitely have the form of a flying boat. There were good arguments to support this choice: heavy airplanes would need long runways, and where could they better be found than on the water? Also there was the argument of safety. If an accident forced an airliner down over open water, what would be safer than a flying boat? Only a few experts, among whom Prof. Hugo Junkers, were of a different opinion. They argued that the demands of seaworthiness would place unwanted extra requirements on the design of a machine that was supposed to fly. In the future, land planes, they argued, would be built to such a degree of reliability that no ‘wet’ landings would ever be necessary. The collective effort should therefore be directed towards the development of large, reliable airplanes operating from land.
For the time, however, Pan American intended to stick to the principle of employing flying boats for the crossing of large bodies of ocean. At their request, the Sikorsky Company had scaled up its successful small S-38 to the S-40, which had a maximum seating for 40 passengers and which entered service in 1931. The all metal S-40 was in fact a blown-up version of the smaller boat and Sikorsky prided himself on the fact that he had taken the proven path and not entered into any new construction method which might have unsuspected pitfalls. The conservative design however retained all the ungainly, performance destroying, bracing structure from the past. Pan American called the airplane a 'Clipper' and, when flying, it indeed called up associations with a fully rigged large sailing vessel. Maybe 'windjammer' would have been a better name, because its rigging really slowed it down.

**S-40 (1931)**

Span: 35m, gross weight: 15400 kg; (34000 lbs); empty weight: 11000 kg (24300 lbs) .......... .....ca. 70 per cent
4 Hornet radial engines, 2300 hp total; cruising speed 185 km/h, wingload: 97 kg/m²; aspect ratio 6.9

fuelload... ...................... ca 15 per cent

range ca 1250 km, (8 á 900 mi) with a load of 2400 kg or 24 passengers ... ..........................ca. 15 per cent

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10 data partly based on: [http://www.clipperflyingboats.com/pan-am/sikorsky-s-40](http://www.clipperflyingboats.com/pan-am/sikorsky-s-40) Beautiful site!
The S-40 having been introduced successfully on the South American routes, the engineering director of Pan American, André Priester, and the company’s adviser for operational matters, Charles Lindbergh, were convinced that the time had come to take a quantum step forward with a really new design concept. It was time to construct the true Atlantic flying boat. An invitation to tender was issued to the industry for an aircraft which could carry a crew of four and at least twelve passengers over a range of 3200 km (2000 mi) on a northerly Atlantic route and 32 passengers on the South American network of Pan Am, with 1000-mile hops between Miami and Buenos Aires. In October 1932 both Sikorsky and Glenn Martin received production contracts for their proposed machines, ten Sikorsky S-42’s and three of the larger Martin flying boats. The Sikorsky company (by this time part of United Aircraft, to which also Boeing, Northrop and Vought belonged) and its design team headed by Michael Gluhareff, could count on the full support of Priester and Lindbergh. Test flight of the first S-42 started in March 1934 and caused a sensation among the experts. With a structural weight of approximately 80 percent that of its predecessor, the S-42’s performance figures were amazing:

The state-of-the-art Sikorsky S-42 (1934)

**S-42 (1934)**
Span: 35m, gross weight: 17240 kg (38000 lbs); empty weight: 8970 kg (19800)….. ..................52 per cent !
4 Hornet radial engines, 2800 hp total; cruising speed 185 km/h; wingload: 139 kg/m²; aspect ratio: 9.8
Extreme Range 4800 km (3000 miles) fuelload..........................................................37 per cent
with a load of 1880 kg, (no passengers).........ca.11 per cent
Carribean Range 1930 km (1200 miles) fuelload.........................................................19 per cent
with a load 5050 kg (32 passsengers) + mail+extra’s...29 per cent
per centages shown are with respect to gross weight
To fly (without passengers) the extreme range of 4800 km (3000 miles), a section of the passenger accommodation (the smoking lounge) would have to be emptied in order to make room for extra fuel tanks. Moreover, by reducing the fuel load to 28 per cent, the aircraft could be given a range sufficient for the Northern Atlantic (3200 km or 2000 miles), carrying twelve passengers plus extra’s (a total of 20 per cent of gross weight).

Sikorsky and his team had been able to conquer the imagined Barrier of Size, which had, up to that time, made it inconceivable to construct aircraft which were at the same time large and light.

Igor Sikorsky lost no time to travel to Europe to promote his flying boat. In November 1934 he delivered a glowing lecture to the Royal Aeronautical Society in London, extolling the virtues of his design. One of the key factors in obtaining the remarkable performance had been in the wing design. The wing was really smaller proportioned than anything that had been in use up to now. A smaller wing implied a lighter structure and less air resistance. On the other side, it also implied higher takeoff speed and landing speed. Higher speed meant more required power, heavier engines. To keep landing speed down, full-width wing flaps were installed. A very daring aircraft was the result. A light construction weight for the wing was obtained by choosing a semi-cantilever arrangement with two struts per wing half. A great effort was made to save weight. (As an example: the adjustable passenger seats hung from the bulkheads, eliminating chair legs.11).

In fact a strict discipline was enforced during the whole design and production process. In Igor Sikorsky’s own words:

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Because of the stringent requirements of the contract calling for a useful load to gross weight ratio of 47-53, a rigid weight control was set up. A three-fold system was employed—one, an estimation from the design figures allocating to each unit a certain share of weight; another for calculation from the finished drawings and a comparison with the estimated; and the third, a programme of actual weighing of parts. The value of this triple control is shown in the 48-52 ratio obtained.

No drawing was approved until it passed through the manufacturing department for a check against complicated design that would involve expensive fabrication or that would require undue maintenance when put into operation.

During his lecture Igor Sikorsky exulted (rightly so) on the beautiful and excellent quantities of his creation:

"...In its very outline the S-42 represents simplicity. Diverting sharply from the past Sikorsky designs, external bracings have been reduced to a minimum. The tail, instead of being supported by outriggers [like on the model S-40], is now attached directly to the hull. The one-piece wing with tapering tips is attached to the hull by means of a superstructure. The necessary large external struts brace from the hull to the outer portion of the wing. These struts are the largest streamlined duralumin sections ever extruded..."

The S-42 was certainly more weight-efficient than any earlier large plane. Could the secret be in its wings? The all-metal Sikorsky wing (and also the Consolidated PBY-1 and the later-appearing Glenn Martin M-130 wings) seem to be a step midway between the old fashioned externally braced fabric-covered wing and the fully cantilevered semi-monocoque construction, where all torsional forces are absorbed by the top and bottom metal surfaces. In fact, in this particular construction, the external struts [of the S-42] will take care of the torsion load of the central part of the wing and its metal surfaces can be made lighter. The penalty paid lies in the additional drag forces caused by the struts.12

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12 see also: https://ritstaalman.files.wordpress.com/2014/09/laddon-catalina2.pdf  page 16
Furthermore: the sleek wing was built in one piece. The regular fuel tanks, eight in total, were located inside the wing, between the spars. Total capacity: 1240 US gallons. The engines were supported by welded steel-tube cradles from the main spar and were of proper streamlined design with adequate cowlings. It is to be noted that the design of the flying boat was conceived and executed in a period of time in which a whole new class of dependable engines had become available and that several major improvements of aerodynamic nature had been investigated and reported by NACA. Finally, the constant speed propeller had come of age, eliminating some principal difficulties of long range flight with fixed air screws. On each engine, the S-42 was proudly sporting a three-bladed variable pitch propeller, the largest type ever produced by the Hamilton Standard Propeller Company.

*Sikorsky* continues:13 “With a span of 114’2” (34.80 m) the wing has an area of 1330 sq. ft. (123.60 m²) The internal wing support structure of spars and compression members of modified Warren Truss design are constructed of extruded duraluminum shapes. Stressed skin covers the major portion of the wing surface. Flush type rivets are used throughout the external surface. The skin covering has the appearance of a smooth unbroken surface. This has been obtained by the use of a filler in the skin seams and the impressions of the slightly indented flush type rivets.

“Extending along the full straight portion of the rear spar is the hydraulically controlled flap. The flap is mechanically operated by means of a substantial hydraulic piston. The piston is actuated by an electric pump that is controlled from the pilot’s compartment. For emergency use a manually operated pump is provided. The angular position of the flap can be altered in accordance with the attitude of flight, thus changing the performance of the whole wing. The full anti-drage rings and nacelle cowls of the engines merge into the wing at the front spar. Eight sections of the leading edge, one on either side of each engine, fold down and form engine servicing platforms, a dearly needed feature considering that maintenance has to be performed while the boat is moored on the water. The two-step, long stern type hull measures 67’8” (= 20.60 m) from bow to stern. Deep keel, transverse frames which are widely spaced in order to facilitate maintenance, and heavy stringers form the hull skeleton. Keel and frames are of plate girder type. Duralumin shapes and sheeting are used throughout. Nine watertight doors separate the various compartments...

“Both pilots have an unobstructed view of the flight instrument panel. To the rear of the pilot’s seat is located the flight mechanic’s quarters. Grouped on a separate panel directly in front of him are all the instruments pertaining to power plant operation. Opposite the mechanic’s quarters and in an uncrowded space is the radio receiving and sending station. Surface controls are of the dual type featuring ease of operation. Controls are hooked up to the automatic pilot unit located beneath the floor. Dials and instruments for setting and regulating the automatic pilot are on the centre of the flight instrument board within easy reach of either pilot.

“Reached from the outside by a hatch large enough to accommodate large packages as well as permitting for passenger emergency exit, and located between the cockpit and passenger cabins is the front baggage compartment. The allowable baggage space is 157 cubic feet (4.4 m³). Here are also stored two life rafts and various tools. At the rear of the ship is additional baggage storage of 95 cu ft (2.7 m³) Here is also the main passenger entrance. The four passenger cabins, measuring 76” (1.95 m) by 119” (2.80 m), each seat eight passengers. More than sufficient space is allowed for wide aisles and comfortable leg room. The distance from the floor to the ceiling is well over six feet. Tubular racks suspended from the bulkheads support the seats. This construction eliminates chairlegs, thus permitting an unobstructed space beneath each seat for luggage. In any passenger cabin conversation may

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be carried on in a normal tone. Igor Sikorsky then discussed at some length the performance and the economics of the S-42:

Reports on performances were handed in by three of the outstanding pilots in the aviation world—Captain Boris Sergievsky, holder of numerous world records and chief test pilot for the Sikorsky Aviation Corporation; Mr. Edwin Musick, chief pilot for the Pan-American Airways, and an airman of outstanding experience and ability; and the final stamp of approval by Colonel Charles A. Lindbergh. Thirty-two flights on an average of over two hours each filled in the five months' period of performance testing.

The final accepted report shows the performance as:

<table>
<thead>
<tr>
<th>Gross weight</th>
<th>38,000 lbs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full speed at 5,000 ft. altitude</td>
<td>188 m.p.h.</td>
</tr>
<tr>
<td>Full speed at sea level</td>
<td>180 m.p.h.</td>
</tr>
<tr>
<td>Speed at 75 per cent. b.h.p. at sea level</td>
<td>160 m.p.h.</td>
</tr>
<tr>
<td>Speed at 70 per cent. b.h.p. at 12,000 ft. altitude</td>
<td>170 m.p.h.</td>
</tr>
<tr>
<td>Climb, initial, four engines</td>
<td>1,000 f.p.m.</td>
</tr>
<tr>
<td>Climb, initial, three engines</td>
<td>400 f.p.m.</td>
</tr>
<tr>
<td>Ceiling, service, three engines</td>
<td>7,500 ft.</td>
</tr>
<tr>
<td>Full speed at sea level, three engines</td>
<td>157 m.p.h.</td>
</tr>
<tr>
<td>Speed at 75 per cent. b.h.p., sea level, three engines</td>
<td>135 m.p.h.</td>
</tr>
<tr>
<td>Stalling speed</td>
<td>55 m.p.h.</td>
</tr>
<tr>
<td>Time of take-off, dead calm</td>
<td>25-30 sec.</td>
</tr>
<tr>
<td>Ceiling, service, four engines</td>
<td>16,000 ft.</td>
</tr>
<tr>
<td>Range at cruising speed, sea level</td>
<td>1,200 miles</td>
</tr>
<tr>
<td>Range with pay load of 1,500 lbs. (cruising speed 145 m.p.h. at 6,000 ft. altitude)</td>
<td>3,000 miles</td>
</tr>
</tbody>
</table>

Operating Efficiency

In no way, however, has high performance reduced the practical purposes of this boat. The weight ratio of useful load to gross weight is very satisfactory. With a weight empty of 19,764 lbs. and a licensed gross weight of 38,000 lbs., a useful load of 18,236 lbs. is obtained. This ratio is then in the nature of 48:52, or the useful load equals 48 per cent. of the gross weight.

The S-42 flies one mile to a gallon and can transport 4.25 tonmiles per gallon. Mr. Sikorsky finished his presentation with additional noteworthy remarks:

— "The total parasite resistance at 160 mph is only 3620 lbs (1640 kg at 256 km/h). [If the gross weight at this time was 38,000 lbs, the ratio L/D would be 10.5, which is in line with expectations for an airplane of this configuration.] Sikorsky then states that the "best L/D ratio of the whole airplane is over 13."

— His next statement was noteworthy indeed: "At the time of designing, careful consideration was given to the [true] cantilever wing, but it was felt that the increase in profile resistance, due to the greater thickness of the center section of the wing, would be greater than the drag of external struts. Research also revealed that the structural weight of the cantilever wing would be greater than the present wing with struts." ¹⁴

— "After a careful study of the conditions under which this ship would operate, it was decided primarily for high cruising speed and operation over long trans-oceanic routes. A service of this character offers no intermediate landing possibilities, and in view of the distances and duration of the

¹⁴ This finding could indicate that the semi-cantilevered or so-called continuous beam type of wing such as employed here could be the optimum solution for wings of large dimension in general. see also: Tohoku University / MIT project: http://www.gizmag.com/boomless-biplane/21871/
flight, the ship must be able to withstand varying weather conditions. Good airworthiness in stormy weather was considered most essential. A simple aerodynamic study shows that the actions of a squall or of a vertical air gust becomes more violent as the wing loading decreases. Therefore, a heavy wing loading of 28.5 lbs/sq.ft. (139 kg/m²), combined with an ample 2.1 bhp per sq.ft. (22.7 hp/m²) was found desirable.

Flight tests confirmed this decision. The S-42 flies easily and smoothly in the roughest of weather. The comparatively small and rigid wing has the added advantage of safely weathering strong wind and heavy squalls while afloat, particularly with the flap in neutral position. Added approval of this consideration is given by nature. It is interesting to note that large birds that fly over the sea, having long distances to traverse before being able to alight in case of stormy weather, have a much heavier wing loading than birds of similar size that fly over land.

The disadvantages of heavy wing loading, namely, difficult take-off and fast landing, were avoided by the use of the specially designed flap. After a very careful wind tunnel study of several types of auxiliary surfaces, preference was given to the straight flap that now fills up the rear of the wing between the ailerons.

The S-42 was the first airplane that really met the specs for the Atlantic Airliner.

If it weren’t for the British, a regular trans-Atlantic air service along the northern route could have been started by the end of 1934, carrying mail and a small number of passengers.

In the last part of his lecture Igor Sikorsky touches on the so-called Barrier of Size: “In the past it has been intimated that efficient planes of large size would be impractical. It was argued that with increasing size the structural weight would increase beyond reasonable proportion to the gross weight, so that the ratio of useful load to gross weight would become progressively worse. It is claimed, however, that if careful study is made to distribute the powerplant weight and other units of weight along the wing, stresses decrease and an efficient structure becomes possible.”

“As previously mentioned, the structural weight of the S-42 is only 52 per cent of the gross weight; but, at the same time, the ship is built not only in strict conformity with the load factors as set down by the U.S. Government, but, in many cases, has even wider margins of safety. In view of these considerations, it is reasonable to conclude that efficient planes of still larger size and weighing hundreds of tons are not only possible, but practical.”

Dumbfounded

If the English audience were dumbfounded by Sikorsky’s exposé, not all were inclined to admit it. Some, like the flying boat builder H.O. Short emphasized that they were not after speed. Indeed, if they wanted speed they would build a craft to win the Schneider Trophee or the London Melbourne Race. He implied that it was safety they were after and safety was to be found in large double wings and slow touchdowns. They therefore had not pursued the merits of high wing loadings. There were others at the meeting however who showed great admiration for the achievement of Mr. Sikorsky. Indeed, Mr. Arthur Gouge, the well-known designer of the renowned double-winged Short flying boats was convinced by the presentation of Sikorsky’s figures. Shorts were the oldest airplane manufacturer in Great Britain and certainly not a newcomer in the field of metal aircraft. In 1920 the firm had already amazed British aviation with the little all-metal Silver Streak bi-plane and the firm was well known for its high-quality all-metal fuselages that were part of their Navy patrol boats and Imperial Airways airliners. After the demonstration of the Sikorsky plane, Shorts was now prepared to follow the lead and make the step from bi-plane to monoplane.
The following three photographs show the evolution in design of Short aircraft between 1920-1935.

The Shorts S-23 Empire flying boat was originally intended for the passenger routes along the Mediterranean and in North Africa. It was the first design following the Sikorsky concept and it meant a revolution in British thinking. Still, certain modifications would be necessary for the Atlantic.
Short Mayo-Mercury piggyback combination

Short S-26 long range flying boat of 1939
As it turned out, Shorts S-23 Empire boat, even fully stripped of all passenger trimmings down to the bare framework and carrying mail only, was still unable to make it across the ocean. This boat, which had a most appealing, competent and streamlined look and heavier engines than the Sikorsky S-42, did not have the capacity to carry enough fuel for the flight. It was simply too heavy. The barnlike hull that carried the cantilever wing flat on top was of course built in the now generally accepted stressed-skin aluminium fashion, but it all came out too heavy. The structural weight was a high of 60 per cent of gross design weight.

The British, hurt in their national and professional pride, finally started to pay proper attention to the economic importance of the Atlantic run. They devised all manner of schemes to devise a quick mail service, including refuelling in the air and piggy-back configurations (the Short Mayo-Mercury, in which a flying boat would barrel over the waters of the Solent to take a four engine mail plane aloft that would then have just enough fuel to reach the North American shore). It was all very embarrassing. Even a specially designed version of the Empress, the Short S-26 with a re-engineered structure, using more extrusions rather than built-up aluminium shapes, fell short of expectations. It also flew at a late stage, i.e. in 1939. By that time Pan American had acquired even better equipment to connect the continents.

Meanwhile, the Sikorsky S-42 passed through several phases of re-engineering. Or as Captain Bill Masland put it: “The S-42 turned out to be a splendid ship - after we cracked up a few and modified the structure.”\(^\text{15}\) The S-42A (four built) was constructed with a stronger aluminium alloy; its wing was slightly larger and its starting weight went up slightly. The S-42B (four built) had further strength improvements and two of these were certified at a starting weight of 45,000 lbs or 20,400 kg. Between the first and the last of the series, maximum take-off weight had increased by 9.5 per cent and the disposable load by 10.8 percent.\(^\text{16}\)

Being unable to exploit the Atlantic routes because of political reasons, Pan American Airways put the S-42s to full use in the Caribbean. The first flight from Miami to Rio de Janeiro took place in 1934. Soon the airplane was used on all the major South American routes, slashing travelling time by 40%. Pan Am next turned its full attention to that other world ocean that borders the United States. With the aid of the Sikorsky’s extreme long range, the year 1935 was used to thoroughly explore the Pacific. Intermediate flying boat facilities, including hotels, were built on the islands of Wake and Guam. Finally, a regularly scheduled connection between San Francisco, via Honolulu, Wake and Manilla was opened in 1936.

In November 1937, all eyes were turned back to the Atlantic, when a Sikorsky S-42B commanded by Captain Harold E. Grey made the first mail run between Newfoundland and Southampton by way of Foynes, Ireland. The 2000 Atlantic miles were covered in 15 hours. The plane landed exactly as scheduled on the river Shannon. It had been navigated by Captain William M. Masland by dead reckoning and occasional observation of the heavens, and had landed dead on target despite some confusing radio bearings. It had a crew of eight and 1000 lbs freight and mail, no passengers. After that, a regular mail service was started with the British flying via Bermuda.

A regular passenger service had to wait till 1938, when Pan American had even bigger airplanes\(^\text{17}\) at their disposal. American dominance had only just begun.

\[\text{[all picture credits in this article: Wikimedia Commons]}\]

\(^{15}\) William B. Masland “Through the Back Doors of the World in a Boat that had Wings.” 1\textsuperscript{st} ed Vantage Press NY 1984 (caption on page 247)

\(^{16}\) Richard K. Smith “The Intercontinental Airliner and the Essence of Airplane Performance”; 1983; Society for the History of Technology

\(^{17}\) The Boeing B-314, which would also be sold to the British.