IGOR I. SIKORSKY (1889-1972)

THE DEVELOPMENT AND CHARACTERISTICS OF A LONG-RANGE FLYING BOAT (THE S-42)

BY

IGOR I. SIKORSKY

Almost a decade ago, with the rapid world-wide development of air transportation, came the demand for new types of aircraft. It became evident that a plane capable of operating from land or water was the logical step needed to open up larger areas for air transportation. The proximity of water compared with the remoteness of available landing fields to the centres of population was the deciding factor in amphibian development.

While the advantages of the amphibian are obvious, the limitations and difficulties of creating an efficient plane of this type are also evident. Compared to the seaplane or landplane, the amphibian must take care of the extra weight and parasitic resistance, as well as solve various other problems connected with combining the characteristics of the land and seaplane in one aeroplane.

In order to overcome these difficulties and produce an amphibian that would compare favourably in performance with the best land or seaplane, it was necessary to make the utmost effort to refine all basic elements. In other words, it was necessary to create highly efficient power plant, wing and control surface units so that a wide margin of increased performance would be obtained that would compensate for the extra weight and resistance of the amphibian.

Evolved from painstaking study and research came the S-38. Its history is the conception of the Pan-American Airways, the air yacht of the private owner, and the pioneering craft of exploration into hitherto inaccessible regions of Central and South America and Africa. Over a five-year period more than 100 of these aircraft were delivered and the majority of them are still in service.

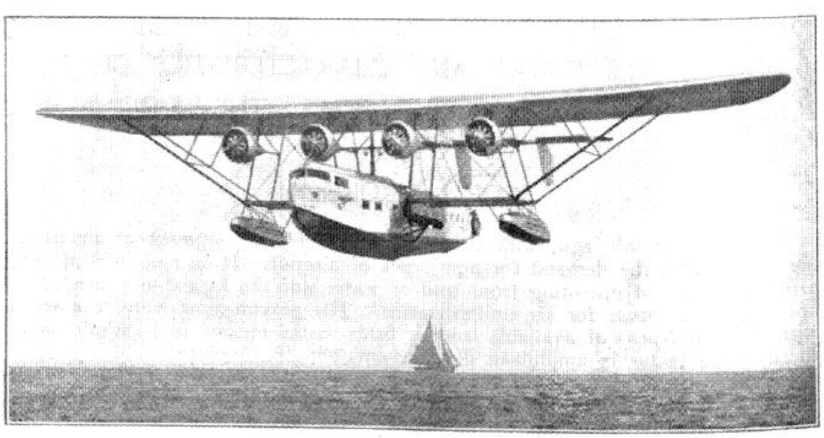
As the characteristics of this aircraft became more and more evident, the hazy dream of large aeroplanes materialised into a definite plan. With the increasing business of the Pan-American Airways, their fleet of S-38's became inadequate. Upon their request, the big flying boat idea became a reality.

The three Clipper flying boats that now fly over the Southern Americas are the results. In our minds, at the time of designing, was a flying boat diverting in outline from the usual Sikorsky outrigger design, but it was felt that radical changes were not advisable, particularly because the large plane was to be an amphibian. Knowing what the S-38 could do, it was felt that a large size edition of this type would be the logical jump from an eight to a forty-passenger ship.

A considerable amount of work, research study and experimentation was spent in the development of the S-40. The theoretical work, design, stress analysis and research required the full time of the Sikorsky organisation for more than two years. The Sikorsky Company realised that upon the experience that this model would give, an even more efficient amphibian would be based. Even then this new amphibian was gathering shape in the minds of the Sikorsky designers.

From its first flight, the S-40 was a success. Capable of carrying forty passengers over a considerable range, the S-40's dove-tailed with the need of larger equipment to meet an ever-increasing passenger list.

The engineers who built the S-40 watched the performance very closely. In November, 1931, when the first "Flying Clipper" made its cruise from Miami to Colombia and the Panama Canal Zone and return, the designer was



American Clipper S-40.

on board and had several conferences with Colonel Charles A. Lindbergh, technical adviser to the Pan-American Airways and chief pilot in charge of this flight, wherein the basic ideas and main requirements for a new type large flying boat were set down.

Immediately afterwards the engineers of the Sikorsky Company started actual research and development of a seaplane along these lines. The endeavour was to obtain a much higher all-round efficiency that would permit a much greater flying range and higher cruising speed, as well as to introduce various other improvements and refinements.

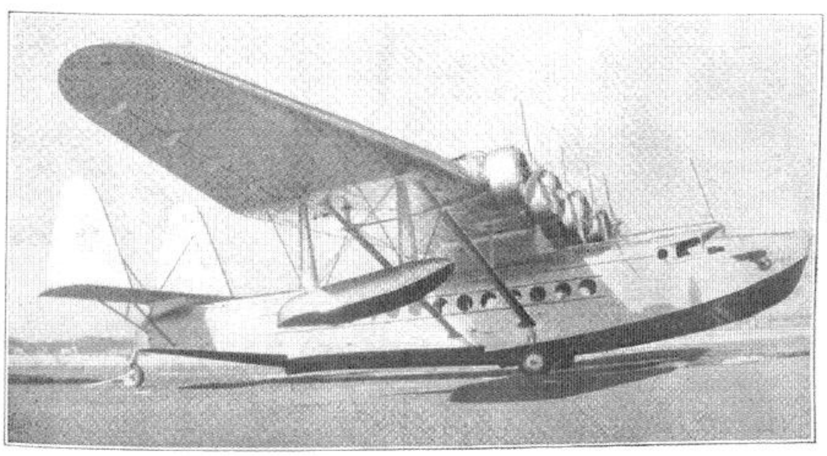
In the meantime, Pan-American Airways had placed in extensive service the second and third Clipper aircraft. The experience obtained from millions of miles of commercial flying gave Pan-American Airways excellent data for the development of a very complete set of detailed specifications for a plane that would cover the needs of further expansion and the possibilities of a commercial line across the Atlantic. Written into the specifications were requirements that were seemingly far in advance of the progress of aviation.

Gathering impetus from the reality of the S-42, power plant development advanced with great rapidity, so that when the question of engines and propellers became imminent, the Pratt and Whitney Aircraft Corporation was ready with its greatly improved Hornet model, and Hamilton Standard Propeller Company had to offer, what was considered by the Collier Trophy Committee an outstanding advance in the aviation world, a practical controllable pitch propeller.

Knowing the difficulties that are encountered in the endeavour to coincide the desired with the practical, close co-operation between the Pan-American Airways and the Sikorsky Company was necessary. Every detail from design to final fabrication was an approval based on careful criticism and study; every phase that forms a part of the commercial airline was considered, including cost of operation, maintenance, durability, and passenger comfort.

Design work again required over two years. Reports, records and tests, in seemingly endless procession, were culled of their best ideas and these were incorporated as far as was practical.

Stress men spent tireless hours figuring structural strength that would meet high self-imposed safety factors and still allow for simplified construction and



Side view—the S-42.

low weight. Their complete analysis covers almost a thousand pages of closely typed matter with no consideration to the countless pages that contributed to the final figures.

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 calling 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.

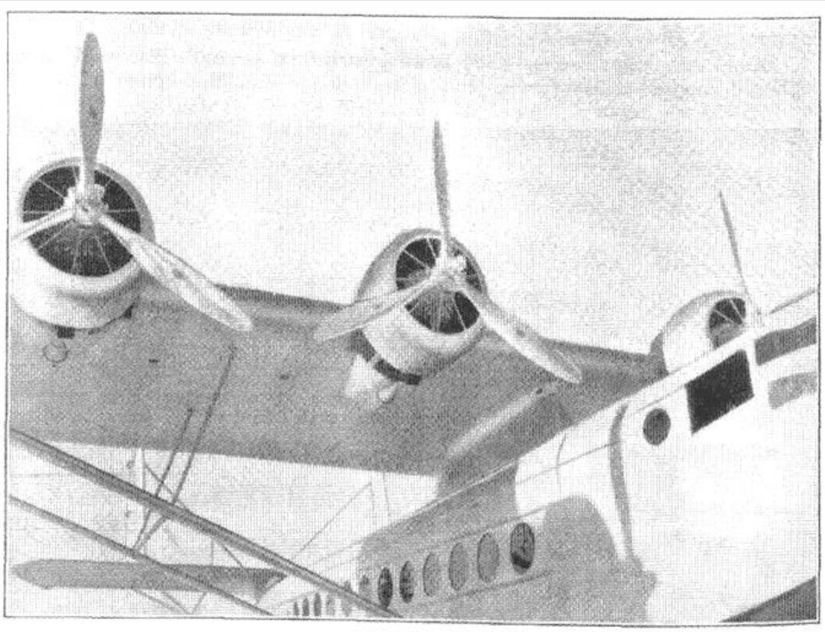
No drawing was approved until it passed through the manufacturing department for a check against complicated design that would involve expensive fabrication or that would require undue maintenance when put into operation.

The S-42

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, is 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.

With a span of 114ft. 2in., the wing has an area of 1,330 square ft. Spars and compression members, of modified Warren Truss design, are constructed of extruded duralumin shapes. Stressed metal skin covers the major portion of the wing surface. Flush type rivets are used throughout the external surface.



Power—the S-42.

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 electrical 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.

Ailerons of conventional design, tapering in conformity with the wing plan, are hinged to the rear spar outboard of the flaps.

The power plant units, consisting of four Pratt and Whitney 700 h.p. geared Hornet engines, together with the necessary accessories, are attached to the front spar by means of welded steel tubular nacelles. Completing these units are the three-bladed variable pitch propellers, the largest of this type ever produced by the Hamilton Standard Propeller Company.

The full anti-drag rings and nacelle cowls merge into the wing at the front spar.

Recessed into the leading edge are powerful landing lights. The lenses of these lights follow the curvature and form part of the leading edge.

Eight sections of the leading edge, one on either side of each engine, fold down and form engine servicing platforms.

Along the interior of the leading edge run the control cables, electrical conduits and other control and fuel units. All installations are made suitable for easy inspection and maintenance.

Cradled between the spars and compression members are eight elliptical fuel tanks of a total capacity of 1,240 gallons and four similar shaped oil tanks of 74 gallons capacity. Holding these in place are metal straps which are covered with thick padding to insure vibration insulation.

Removable panels, above the fuel and oil tanks, and on the entire centre of the lower surface afford access for inspection and servicing.

The re-fuelling system in the centre portion of the wing is an interesting time-saving device. A single intake pipe directs fuel under pressure to any one or all tanks by means of a series of control valves.

Equal in importance with the wing are the parts that make up the body group.

The two-step, long stern type hull measures 67ft. 8in. 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.

Take-off—the S-42.

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.

Nine watertight doors separate the various compartments.

Marine equipment is located in the bow compartment. This compartment has been designed especially large to afford easy handling of a convenient anchor winch and to facilitate rapid mooring operations.

The pilot's compartment following averages eight feet wide and seven feet from bulkhead to bulkhead.

An aisle 20 inches wide separates the pilot and co-pilot seats. These seats are extra roomy and are adjustable. They are designed to supply the maximum of comfort for long flights.

Both pilots have an unobstructed view of the complete flight instrument board. Special requirements as to making all instruments and parts readily removable for checking and servicing have been rigidly adhered to.

To the rear of the pilot's seat is located the flight mechanic's quarters. From his position the mechanic can readily attend to all the details under his control. Grouped on a separate panel directly in front of the mechanic's seat 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.

Engine control units are centred overhead, comfortably reached by either pilot and the mechanic. It affords either unit control for all engines, or selective control for each engine.

Next to this unit are the engine fire extinguisher controls. A twist of a dial directs extinguishing gas to one or all engines.

Reached from the outside by a hatch large enough to accommodate large packages as well as permitting for passenger exit, and located between the pilot's compartment and passenger cabins is the front baggage compartment. The allowable baggage space is 157 cubic feet. Here are also stored two life rafts and various tools. A strong box for valuables is located under the floor.

At the main passenger stairway in the rear are located additional baggage compartments with a total capacity of 95 cubic feet. Large packages find ready access through the main passenger entrance that measures 25 inches by 72 inches.

Between the front and rear baggage compartments are located the passenger cabins and the lavatories.

The four passenger cabins, measuring 76 inches by 110 inches 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 chair legs, thus permitting an unobstructed space beneath each seat for luggage.

Seats are adjustable to meet individual comfort. High head rests afford complete relaxation.

Accessories, including carpets, removable tables, magazine racks, and curtains, harmonise with the decorative scheme.

Sound and vibration have been the subjects of careful study. Thick pads of soundproofing material fill in the space behind the walls and ceiling. Because of their vibration, springs have been replaced in cushions by a special material that is proving more serviceable and comfortable. Windows are held in place by a clincher type rubber ring without the need of fasteners that would cause shattering. In any passenger cabin conversation may be carried on in a normal tone.

A concealed ventilating system supplies upwards of 30 cubic feet of air per passenger per minute. Auxiliary to this is an efficient exhaust system.

Installation fittings on walls, ceiling, floors, and seats are such that an entire passenger cabin can be stripped to its bare structure within 40 to 50 minutes and reinstalled in a similar period.

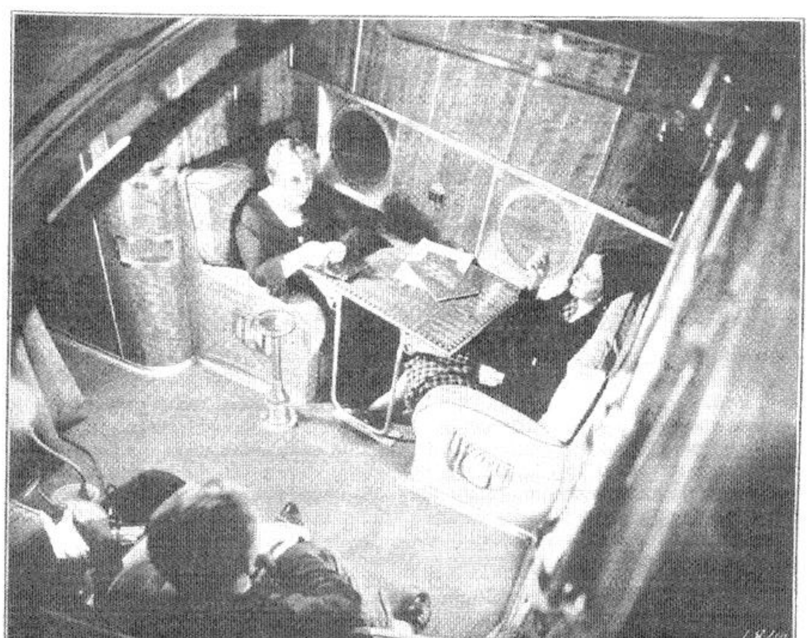
Each cabin is equipped with safety belts and lifebelts are distributed throughout the boat; in convenient locations are fire and emergency equipment. The two life rafts in the front baggage compartment and the two located rearward of the main stairway are suitable for carrying a full capacity crew and passenger list.

The superstructure, already mentioned, also serves as a passage-way for items of controls that pass from hull to wing. Entrance is afforded to this structure from the inside of the cabin as well as from the outside. The internal space of this structure is such as to allow a man to work with comfort.

Every external part of the hull may be reached by a centre ridge walk-way that extends from bow to stern. This walk-way, together with the wing walkways and the engine platforms, makes it possible to conduct almost any inspection or servicing operation without the need of outside scaffolding. The economic feature of this is obvious.

Pontoons, hinged from the wing on two streamline struts and braced by cross wires, follow similar construction design as the hull.

Easy handling from sea to land, or *vice versa*, is offered by the beaching gear. This is a three-part unit consisting of two twin-wheels-on-a-strut car-



Comfort—typical Sikorsky interior.

riages that attach to special fittings on the front of the hull and a single tail wheel that fits into a socket at the stern of the hull. All carriages may be turned on their axes so that motion is possible in any direction. Seven to ten minutes is required to attach or detach the entire gear.

Even more important than the structural characteristics of the S-42 is its performance.

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:—

Gross weight	38,000lbs.
Full speed at 5,000ft. altitude	188 m.p.h.
Full speed at sea level	180 m.p.h.
Speed at 75 per cent. b.h.p. at sea level	160 m.p.h.
Speed at 70 per cent. b.h.p. at 12,000ft. altitude...	170 m.p.h.
Climb, initial, four engines	1,000 f.p.m.
Climb, initial, three engines	400 f.p.m.
Ceiling, service, three engines	7,500ft.
Full speed at sea level, three engines	157 m.p.h.
Speed at 75 per cent. b.h.p., sea level, three engines	135 m.p.h.
Stalling speed	65 m.p.h.
Time of take-off, dead calm	25-30 sec.
Ceiling, service, four engines	16,000ft.
Range at cruising speed, sea level	1,200 miles
Range with pay load of 1,500lbs. (cruising speed 145 m.p.h. at 6,000ft. altitude)	3,000 miles

During the test flights the following world records for Class C-2 seaplanes were established:—

For a distance of 1,000 *km.* (621.4 *mi.*).

Speed	253.7 km./hr. (157.7 mi./hr.).
Speed with 500 kg. (1,102.3lbs.) ...	253.7 km./hr. (157.7 mi./hr.).
Speed with 1,000 kg. (2,204.6lbs.) ...	253.7 km./hr. (157.7 mi./hr.).
Speed with 2,000 kg. (4,409.2lbs.) ...	253.7 km./hr. (157.7 mi./hr.).

For a distance of 2,000 *km.* (1,248.8 *mi.*).

Speed	253.4 km./hr. (157.5 mi./hr.).
Speed with 500 kg. (1,102.3lbs.) ...	253.4 km./hr. (157.5 mi./hr.).
Speed with 1,000 kg. (2,204.6lbs.) ...	253.4 km./hr. (157.5 mi./hr.).
Speed with 2,000 kg. (4,409.2lbs.) ...	253.4 km./hr. (157.5 mi./hr.).
Greatest load to 2,000 m. (6,561.6ft.) ...	7,533 kg. (16,608lbs.).
Altitude with 5,000 kg. (11,023lbs.) ...	6,203.6 m. (20,406.7ft.).

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 19,764lbs. and a licensed gross weight of 38,000lbs., a useful load of 18,236lbs. 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 weight allocations for a gross weight of 38,000lbs. and a range of 1,200 miles fit commercial requirements. The fuel and oil for this range weigh 7,995lbs.; equipment weighs 2,181lbs., and pay load equals 7,060lbs. Should consideration be given to using the S-42 for fast freight only, practically all the 2,181lbs. of equipment, plus the chairs, wall and ceiling trim and sound-proofing, can be dispensed with, giving a pay load of approximately 10,000lbs. over a range of 1,200 miles. For a range of 3,000 miles, cruising at 145 miles per hour and at 6,000 feet altitude, the allowable pay load will be 1,500lbs. Thus the S-42, keeping well within the safe limitations of structural strength, capable of maintaining a high ceiling with only three motors, and at the same time carrying a reasonable pay load, is entirely suitable for the establishment of trans-oceanic routes.

The following table indicates the benefits of the S-42 as compared to the S-40:—

	S-40.	S-42.
Weight empty	21,000lbs.	19,764lbs.
Gross weight	34,000lbs.	38,000lbs.
Equipment	1,000lbs.	2,181lbs.
Crew	1,000lbs.	1,000lbs.
Gas and oil (1,000 miles)	7,800lbs.	6,692lbs.
Pay load	3,200lbs.	8,363lbs.
Cruising speed (1,000ft.), m.p.h.	115	157
High speed, m.p.h.	137	182
Horse-power	2,300	2,800
Fuel consumption (cruising, per hr.) ...	140 gals.	162 gals.
Landing speed, m.p.h.	65	65
Range, miles	1,000	1,000
Time	8.7 hrs.	6.37 hrs.
Wing loading	19.5	28.58

Here is an indicated increase in the S-42 of 5,163lbs. pay load over the S-40.

If equal pay loads are considered, that is, 7,500lbs., the range for the S-40 is 479 miles and in the S-42 is 1,130 miles, an increase of 651 miles.

The extensive test made with the S-42 made it possible to make some interesting comparative measurements. With the engines of the S-42 throttled down to 575 b.h.p. to conform with the b.h.p. of the S-40's Hornet "B" engines, the speed obtained was 163 m.p.h. as against 137 m.p.h. obtained from the S-40.

The improvement in efficiency of the S-42 is better exemplified if a study is made of the cruising speed of the S-42 against the S-40, using equal horse-power in each case. Using 432 b.h.p. per motor, the S-40 cruises at 115 m.p.h., while with the same power and an increased gross weight of 4,000lbs. the S-42 cruises at 145 m.p.h., an increase of 30 m.p.h.

From an economic viewpoint, that is, comparing load carried against fuel consumed, an important deviation is found. Each plane using the same horse-power and the fuel consumption per hour of the S-42 being 144 gallons, and that of the S-40 140 gallons, the following ton-mile gallon is given:—

	Miles per gallon.	Payload in tons (1000 miles).	Ton mile per gallon.
S-40	0.82	3300/2000=1.65	1.35
S-42	1.0	8505/2000=4.25	4.25

In view of the fact that operating and maintenance costs are based on flying hours, consideration is here given to that item. Equal in size, the S-40 is again taken for our analysis. The unit of maintenance and operating costs per hour being considered equal, we find that for each flying hour the S-40 is credited with (1.65 tons × 115 mi.) 169.75 ton-miles, and the S-42 (4.25 tons × 145 mi.) 616.25 ton-miles.

It is quite clear that in this consideration of pay load ton-miles that operation and maintenance cost vis-a-vis load carried would be decreased in the same proportion. In reality, the decrease will be substantially greater because of the refinement for fast and simplified inspection, servicing, and maintenance incorporated by the Sikorsky engineers in conjunction with the staff of the Pan-American Airways.

General Considerations

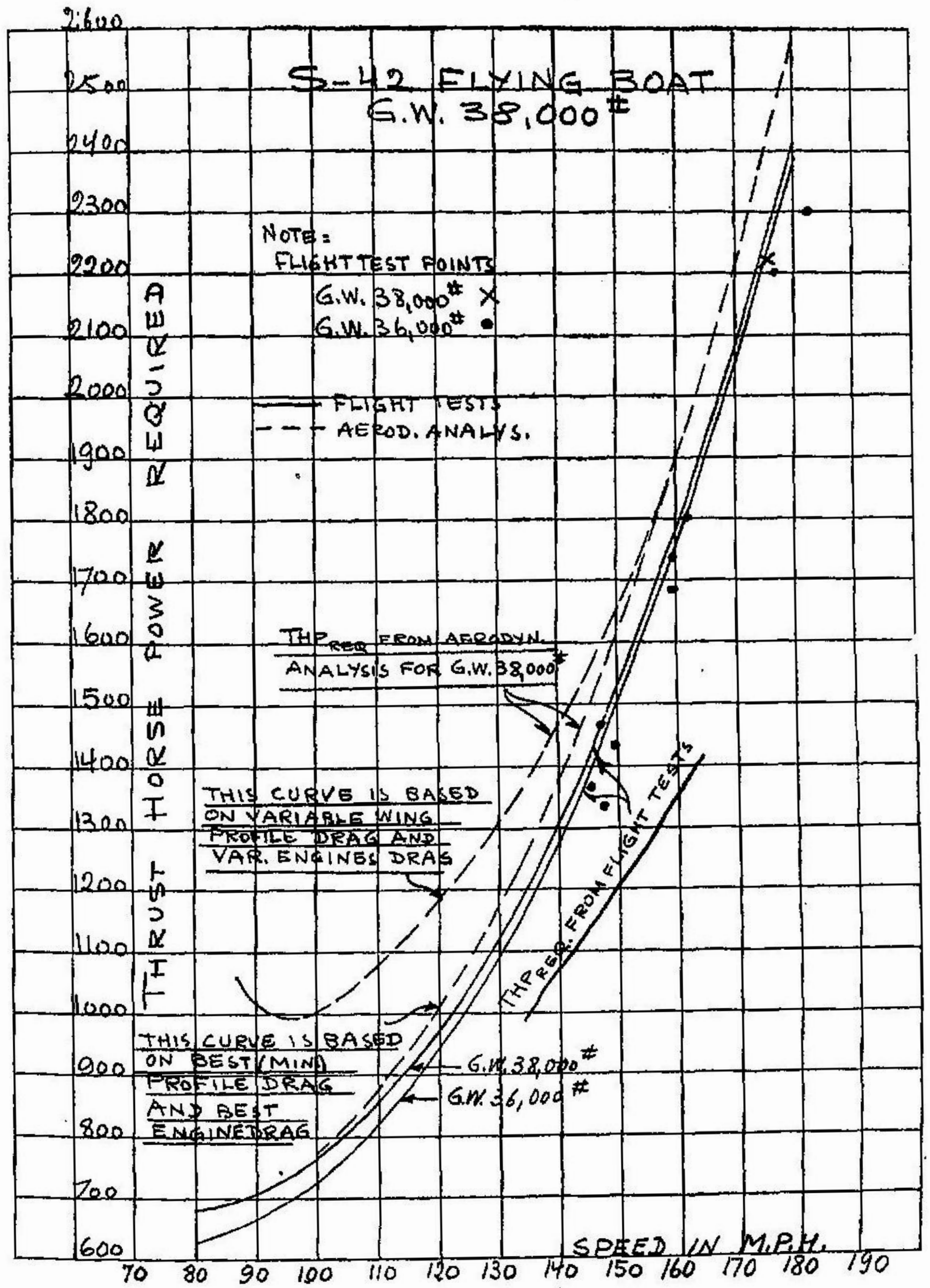
Because of the general cleanliness of the S-42, due to the careful study of the aerodynamic interference of parts, the total parasite resistance at cruising speed of 160 m.p.h. is only 3,620lbs. At the time of designing, careful consideration was given to the cantilever wing, but it was felt that the increase in profile resistance, due to the greater thickness of the centre 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 and struts.

The table attached gives the curves of the original estimated performance compared with data measured during test flights. It should be noted that actual performance is in general accord with the figures estimated by the more liberal simplified method in which the profile drag of the wing and the resistance of engines are taken as having a constant value subject to the square of speed. It is believed that the slight excess of actual performance over the original estimate is due partly to greater scale speed effect other than the one that was considered, and partly due to the smooth surface created by flush riveting. It is evident that the ship with full load is able to maintain flight easily, using much less than half the power available. It is shown further that the best L/D ratio of the whole aeroplane is above thirteen. The data on which the table is based were recorded during test flights with calibrated intake manifold pressure gauges mounted on all engines. The reading of these instruments, plus careful observation of the r.p.m., permitted the accurate establishment of the power used at various conditions of speed and load.

After a careful study of the conditions under which this ship would operate, it was decided to have a high wing loading. The ship was designed 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 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 action of a squall or of a vertical air gust becomes more violent as the wing loading decreases. Therefore, a heavy wing loading of 28.5lbs., combined with ample h.p. per square foot of 2.1 b.h.p., 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.



This flap produces an increase in lift of about 40 per cent. When placed at a 40 degree angle, the flap affords an actual stalling and landing speed of 65 m.p.h.

Test showed that the best position for take-off is with the flap set at $+10^\circ$ to $+12^\circ$. Carrying a definite test load, the ship with the flap in neutral position took 12 seconds for take-off. Landing immediately, the flap was set at $+10^\circ$ and the take-off time was reduced from 12 seconds to 7 seconds, indicating that the flap decreased take-off time by nearly 40 per cent.

Future Considerations

The results achieved with this new seaplane are encouraging for the future development of large planes. They prove that it is now possible to make accurate estimations of structural weights, performances and all general characteristics for planes of even more substantial size and advanced design. It is, therefore, permissible to make a forecast of the future development, design and operation of large aircraft.

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 power plant 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.

With respect to structural limitations, the hydro and aerodynamic advantages of large planes, particularly flying boats, may be pointed out. As the size of the boat hull increases, the displacement and therefore the normal loading grows as the cube of the linear dimensions, while the air resistance increases substantially less than the square. This is due to the scale effect and because many auxiliary parts, such as pilot windows, doors, handles and many other items, do not increase in proportion to the size. In line with this, the water characteristics improve as the size increases, and high aerodynamic efficiency, offering high cruising speed, becomes entirely possible for the large seaplane.

Passenger comforts would increase with the size of the ship. In a seaplane of 100,000lbs., or more, it would be possible to have individual cabins, dining-rooms, smoking lounges, etc., entirely comparable in comfort and luxury to those of the modern ocean liner.

There is no doubt that planes of great weight, capable of non-stop ocean flights, cruising between 150 to 200 miles per hour, can be designed at this time and be ready for service within two and a half to three years.

Greater cruising speeds are possible, but the size of the earth does not warrant greater speeds.

The progress of air transportation will benefit more if designers will give more attention to increased passenger comfort and ways and means to lower transportation costs rather than greater speed. It is expected that within the next five years great strides will be made in this direction.

How high will the luxury air liner of the future fly? A few years ago nearly everyone pointed to the stratosphere as the height. While this is possible, the writer believes that the contingent limitations and difficulties will permanently keep the major part of air traffic below the stratosphere.

The need of an airtight plane for stratosphere flying brings up a very serious consideration. Should a leak occur, allowing a momentary release of the oxygen in the ship, disaster would result. Possible safeguards against this condition would mean large increases in structural weight.

This consideration, together with the well-known basic complications of the stratosphere plane, will probably limit its use to a few exceptional services.

The flying altitude of the commercial air liner will be between 12,000 to 20,000 feet. At this altitude the plane will be clear of the majority of air disturbances and will be capable of cruising at considerable speed.

This discussion is based on the results of present-day achievements. Projected from them will be the future great air liner. Present aerodynamic experience predicts aircraft of long ranges, carrying many passengers with comfort, safety and dispatch over routes that will reach to the far corners of the world.

Discussion

Mr. H. O. Short (Fellow): They were indebted to Mr. Sikorsky for having made a long journey from America to give the Society his interesting account of his practical achievements in flying boat construction.

He did not think that any foreign designer of aircraft would wish to deny the share of credit which fell to British flying boat constructors in regard to flying boat development, especially where all-metal construction was concerned. It could not be denied also, however, that they in this country lagged behind where very high cruising speed was concerned.

He believed the cause of their having fallen behind in the matter of speed was that they had not made speed the first consideration to which other desirable features of air travel might be subordinated. When they had really endeavoured to achieve speed, as they had in connection with the contest for the Schneider Trophy, they had shown what they could do against the leading aircraft designers of the world; also, Messrs. De Havilland had shown what they could do when they had made up their minds to be first in Melbourne recently. They in this country designed their machines around a set specification which defined comfort, equipment, stalling speed, ease of maintenance, etc.; the speed was what it might be, but the specification was immutable. On the other hand, it would appear that the American designers had specifications which fixed the speed as the main consideration, and that other considerations were fitted inside that. Perhaps some of the more technically minded might care to say something about high wing loading; that was a matter in which they in this country had been afraid to make explorations. Risk in aircraft development involved expenditure and possible losses; success or failure involved the national prestige, and that was a matter which should concern the Government of a nation.

Mr. W. O. Manning (Fellow): In order to illustrate the advance in design made by Mr. Sikorsky, he compared the performance of the S-42 with the flying boat used by Imperial Airways, Ltd., in the Mediterranean, though he pointed out that his remarks were not intended as a criticism of the latter. It was sufficient to say that when it was introduced its performance was certainly better than that of any other machine of its type in the world. But Mr. Sikorsky had put it completely out-of-date.

In spite of the fact that the S-42 had rather less horse-power in proportion to its weight, its cruising speed was 52 m.p.h. faster than that of the English boat; the speed of the S-42 with one of its engines stopped was 20 m.p.h. faster than that of the English boat with all engines operating at full power. The S-42 carried nearly 1,000lbs. more pay load in addition to fuel for 550 miles increased range. The climb of the S-42 was also better, the landing speed was 5 m.p.h. higher, and the time to leave the water was about the same. This improvement in performance could only be described as colossal. The new Atlantic liner, "Queen Mary," possessed hardly so great an advantage over the so-called Atlantic greyhounds of the last century as the S-42 possessed over the English flying boat referred to.

In order to illustrate the matter still further, Mr. Manning roughed out a specification for a new flying boat of the size and power of the Imperial Airways boat, based on what Mr. Sikorsky had proved to be possible. The figures for the proposed boat and the present Imperial Airways boat were as follows:—

	Proposed Boat.	Imperial Airways Boat.
Total weight ...	32,000lbs.	32,000lbs.
Horse-power ...	2,400	2,400
Range	450 miles	450 miles
Crew	660lbs.	660lbs.
Equipment	1,560lbs.	1,560lbs.
Weight empty ...	16,600lbs.	18,900lbs.
Fuel	2,120lbs.	3,420lbs.
Pay load	11,060lbs.	7,460lbs.
Top speed	200 m.p.h.	137 m.p.h.
Cruising speed ...	170 m.p.h.	105 m.p.h.
Landing speed ...	65 m.p.h.	60 m.p.h.
Initial climb ...	1,000 ft.p.m.	840 ft.p.m.
Time to take-off ...	25-30 secs.	25-30 secs.

Thus, said Mr. Manning, there would be a saving of 2,300lbs. in weight (empty) of the new boat as compared with the older one. There would be a reduction of about one-third in the weight of fuel for the range of 450 miles, owing to increased speed; the pay load would be increased by about 3,500lbs., partly owing to the reduction of the weight of the machine empty and partly owing to the saving of fuel. He had adopted the top speed of 200 m.p.h. for the proposed boat, because such a boat could not be produced until about two years hence, and by that time one would naturally expect an improved performance over that of Mr. Sikorsky's S-42, which was designed two or three years ago. The cruising speed of the proposed boat would be 65 m.p.h. faster than that of the Imperial Airways boat; the landing speeds would be much the same, and the initial climb, which was not a very important item, would be increased by about 160ft. per minute in the case of the proposed boat.

Major R. E. Penny (Associate Fellow): The secret of the success of Mr. Sikorsky's flying boat was to be found in the enormous amount of detail work, the fairing up of the details so that the combined resistances had been reduced to an absolute minimum.

He would like a little further information concerning a few of the figures, relating to stalling speed and times of take-off, because the facts were not quite clear to him.

Mr. Sikorsky had displayed wisdom and foresight in concentrating upon large flying boats, and one was grateful to him for having stressed the cumulative aerodynamic and hydrodynamic advantages of the flying boat in increasing sizes. The theory of this was well known, but it was dismissed by most people without a moment's thought or it passed out of mind for other considerations, which considerations were of minor importance if one took the long view as Mr. Sikorsky had. It must be the conviction of everyone with imagination that a trans-oceanic service by air could be practicable only if large flying boats were used. Not only did Mr. Sikorsky share this conviction, but he had acted upon it. That was why they would have the pleasure, about four years thence, of congratulating him upon the production of a flying boat suitable for a trans-Atlantic service affording efficiency and comfort far in advance of anything produced in Europe.

Mr. A. Gouge (Fellow): They in England had to take a lesson from the paper and re-cast their ideas, with particular reference to the wing loading. It would appear that practically the whole of the improvement in this boat over its predecessors was due to the increased wing loading and aerodynamic cleanliness. In England they had been very loath to work to such high wing loadings because of their effect upon the landing speed. Whilst he gathered that the landing speed of the S-42 was 65 m.p.h.—which, incidentally, required a lift coefficient of nearly 1.4—it seemed to him that the question of the landing speed on the water, if the water were reasonably calm, was of minor importance.

Would Mr. Sikorsky amplify his figures to show what would be the weight of the aircraft when the range was 3,000 miles, which range was referred to at the bottom of the table showing the performance of the S-42? From a rough addition, it appeared that the weight of the aircraft under this condition was 40,000lbs., instead of the 38,000 mentioned at the top of the table as being the gross weight. He also asked for the benefit of Mr. Sikorsky's experience of the long struts running to the hull—whether they got in the way when loading the aircraft and whether they were subject to much corrosion and damage. It had been the practice in England during the last year or so to delete struts of this nature, owing to the amount of trouble attributed to them in the direction of corrosion and damage.

With regard to possible future developments, he agreed that as the size of the boat hull increased the cross-sectional area was again up less than the square of the linear dimensions and, therefore, the air resistance was relatively improving for this reason, so that a larger boat should perform better than a small one.

Mr. M. Langley (Member): It was a little difficult to make comparisons between the S-42 and others, on economic grounds, which must include petrol consumption against pay load, or resistance. Would the tankage mentioned in the paper represent United States gallons or imperial gallons? The difference between the two was quite considerable.

One outstanding figure was that of the ratio of the gross weight to the tare weight, which was far above that for any machine produced in this country, within his knowledge, particularly in flying boats. Flying boats had always been regarded as inefficient in comparison with land planes, only to be used when land planes were not possible; indeed, land planes had been used frequently on services which were essentially flying boat routes. It appeared, however, that the S-42 was not only ahead of all other flying boats, but that economically, and from a profit-earning point of view, in spite of its speed, it was better than any commercial land plane in this country.

At every turn one heard the argument that speed was obtained only at the expense of greater horse-power; Mr. Sikorsky had shown, however, not only by his ideas but by his products, the existence of which could not be denied, that increased speed could be obtained by other means than by increasing the horse-power. They had known that in theory, but he had shown it to be possible in practice, and the great lesson to be learned from his paper was that more courage and more forethought was needed.

Mr. S. Scott-Hall (Associate Fellow): Referring to the author's comparison between the S-40 and S-42, he gathered that the figures given for the S-40 were those for the aircraft as a flying boat, not an amphibian. The photographs had shown it with amphibian gear fitted.

Did Mr. Sikorsky consider any radical improvements in flying boat hull design could be expected—not merely minor improvements, such as cleaning up the surface of the hull by such expedients as flush riveting, but by radical changes in design?

He had examined some figures for the landing speed of British flying boats, and, indeed, had made exactly the same comparison that Mr. Manning had just given, but had decided that it was so pessimistic that he would not pursue it further. But it was interesting to note that Mr. Sikorsky's S-40 had a wing loading of 19½lb. per sq. ft. and yet its landing speed was given as 65 m.p.h. The lift coefficient, worked out on those figures, was in the neighbourhood of 0.9. What was the wing section used on that machine and were there flaps of any description? The above figure seemed extremely high. Moreover, the machine was a high wing monoplane and one would not expect much "ground effect."

On this question of landing speed, which was one of the main factors that had influenced British design, they had been rather inclined during the last few months to condemn themselves unnecessarily. In days gone by—as of course now—the main consideration was to produce a machine that was safe. Engine reliability was not then what it is to-day, and landing speed was a factor far more prominent in people's minds in connection with safety than it had been recently. They should not forget the low-speed research carried out in this country at a time when the question of safety had been translated in terms of landing speed. It had placed them in the forefront as regards safety in aviation. Low landing speed was one of the main factors influencing top speed and now that engine reliability had eliminated its necessity, they had been left so to speak in the lurch.

Commenting on Mr. Sikorsky's reference to the heavy wing loading of sea birds, he presumed that the lecturer had in mind the albatross. He pointed out that that bird had not got it all its own way, because under certain conditions its take-off was a matter of concern both to the bird itself and to anybody watching it; and from that fact they could learn a lesson which would perhaps modify Mr. Sikorsky's remarks in that connection. But in spite of this it seemed that they had reached a point at which they could no longer disregard the demands of top speed; the fetish of low landing speed was imposing a burden on British aviation which it could not support.

Mr. E. M. BUXTON: The two extreme conditions mentioned by Mr. Sikorsky when discussing landing speeds did not cover the whole of the variations, and one would like to know how his flying boat hull would behave under conditions in which there was not a great deal of wind but a long swell.

It was most entertaining to hear a lecture delivered from a severely practical point of view, leading to conclusions which people of less experience than the lecturer might consider to be visionary.

Mr. E. C. GORDON ENGLAND (Fellow): The conclusion at which Mr. Sikorsky had arrived, that neither he nor his engineers knew anything about aerodynamics, impressed him. They might learn a tremendous lot from a statement to that effect, made so charmingly and modestly, because it contained an enormous amount of truth. The trouble was that they *thought* they knew a great amount about aviation whereas they were virtually ignorant—and Mr. Gordon England emphasised that he made that statement in all seriousness. He felt sure that Mr. Sikorsky appreciated fully the truth underlying it. They imagined that they had established the main facts about aviation, whereas they knew extremely little of what the science contained still to be revealed.

A matter having a very great bearing on the future operation of large flying boats was, in Mr. England's opinion, that of re-fuelling in the air, and he asked what was Mr. Sikorsky's attitude towards that particular problem. He asked for Mr. Sikorsky's opinion as to the extent of the extra pay load that could be carried by a flying boat if it were fuelled immediately after it left the water, as compared with taking-off with a full load of fuel, and whether it would be practicable, in Mr. Sikorsky's opinion, to re-fuel large flying boats in mid-Atlantic. If that could be done, it seemed obvious that the pay load could be increased tremendously; it was, to say the least, an interesting speculation.

Major F. M. GREEN (Fellow): Could Mr. Sikorsky add some further information to his paper and so add still further to its value as a standard work of reference, as undoubtedly it would become? For instance, the horse-power of each of the engines was given as 700; one would like to know exactly what was the rating and at what height that horse-power was obtained. Also, one would like more details of weights of the engine units, wings, and so forth. Such information would be of very great value to English designers.

Finally, Mr. Sikorsky had given many good reasons for adopting high wing loading; but Major Green suggested that there was one more reason which would make them all favour high wing loadings, which was that a very considerable saving of weight was effected.

Lieutenant-Commander the Hon. J. M. SOUTHWELL (Associate Fellow) (*communicated*): Mr. Sikorsky had referred to the close co-operation between his firm and Pan-American Airways. He thought he would agree with him that there was a third partner whom he had omitted to mention—the public.

The public will pay for good service if it is offered to them, but the public will not pay for goods or services unless they are produced first, and it is only with the co-operation of the public that practical experience and development can be obtained. This was a simple economic problem, and he thought it could not be too strongly emphasised that it is not a matter for wet-nursing by ministries, but entirely a matter for the air industry itself.

Air transport has to offer high speed in comparison with surface transport. On overland routes speeds of 180-200 must be achieved, but he questioned whether the same speeds are necessary with oversea routes.

Since for a given speed the seaplane cannot carry as high a percentage of pay load, he suggested that some sacrifice of speed is permissible and desirable.

There are three questions he would like to ask Mr. Sikorsky:—

1. In the S-42 Mr. Sikorsky gives a pay load of 22 per cent. of the gross weight. What would be this figure if the cruising speed were reduced from 157 to 127?
2. Could Mr. Sikorsky give figures of the relative capital cost per ton (or per 1,000lbs.) of pay load capacity of the S-40 and S-42?
3. Mr. Sikorsky gives 65 m.p.h. as the landing speed with a maximum flap angle. Is this with or without the motors?

REPLY TO DISCUSSION

Dealing first with the high wing loading, which is one of the particular characteristics of the S-42, Mr. Sikorsky said he had already mentioned the main considerations in favour of it. Repeating briefly, he pointed out the smooth riding and the good control characteristics in rough air; the high efficiency and increased cruising speed, and the greater safety in stormy weather.

Referring to landing speed characteristics, he said the 65 miles per hour figure had been well established for the S-42 in the fully loaded condition with the engines rotating at zero thrust. This landing speed, which corresponds to a very high lift coefficient, is the result of the combined action of a high lift wing, together with a flap that influenced approximately 75 per cent. of its area.

The landing speed of the S-42 with its wing loading of 28.5lbs. per sq. ft. is identical to that of its predecessor, the S-40, which had a wing loading of only 19.5lbs. per sq. ft. The much higher lift of the S-42, he said, is due to the action of the flap. This was forecast by the results of wind tunnel tests.

Mr. Sikorsky said that the design of the S-42 was outlined with a view to obtaining a wing loading as high as practical and still remain within the 65 m.p.h. limit. He expressed the opinion that it is possible in future designs, still higher wing loadings may be expected.

With respect to the structural struts, he replied that they in no way interfered with the loading of the ship as the forward and aft hatches were far removed from the struts.

With respect to maintenance, he is informed that there has been no trouble, and that the maintenance engineers preferred the straight extruded thick aluminium tube to other types of construction.

All figures of gallonage given in the paper were in terms of United States gallons, based on six lbs., English, per gallon.

Replying to the question of the given weight of the plane with fuel for a 3,000-mile range, Mr. Sikorsky said the gross weight would remain at 38,000lbs. This is possible by reducing the weight empty by completely stripping three passenger cabins of all non-structural items, such as seats, panellings, carpets, etc.

In the future, however, he expected to increase the gross weight of the ship to 40,000lbs. by using slightly stronger material. The ship had been built of duralumin, 17 ST. There was a new material, known as 24 S, or 24 ST (according to its heat treatment), giving greater structural strength, and the use of this would permit the increase of the gross weight without structural changes. The take-off characteristics left no doubt that the ship would easily take-off with considerably greater load. In that event the landing speed would be increased—not substantially, but to something above the figure now permitted. Therefore, the Government would be asked to issue a double certificate, whereby the ship would be licensed to take-off at a certain weight, but would not be licensed to land at that weight. In that case, if the machine had to land soon after it had taken off, and before it had used much fuel, the pilot would have to drop fuel, and provision would have to be made to enable him to release it quickly in order that when the ship landed its total weight would be within the permitted maximum. He believed that this system was very much recommended for long-distance flying, where the weight of fuel to be carried at the start might amount to 25 or 30 per cent. of the gross weight of the machine—an enormous percentage.

In regard to flying boats, he did not foresee very radical changes in hull designs. He had heard of many attempts and had himself made several attempts to combine other shapes of boats with some kind of vanes or submerged wings, but until now had not obtained satisfactory results.

With reference to the behaviour of the ship in a long swell on the water, Mr. Sikorsky said that perhaps this represented the most severe condition for landing. In that circumstance, a low landing speed may be advantageous, but only if the air was relatively calm; in a stormy wind it would be to the contrary. With respect to the S-42, the plane proved to possess very satisfactory rough sea characteristics. During one of the tests the plane took off and landed 17 times with full load on a reasonably rough day with the waves being fully 6ft. high. It was found that the plane behaved excellently and would stand considerably greater sea if needed. The plane was tested in circling on the water, taking-off, landing, taxying, and so on, repeatedly.

He believed there were most interesting possibilities in the direction of re-fuelling in the air. Re-fuelling immediately after the take-off could certainly be done and would increase the flying range or the pay load. Another interesting possibility would be to re-fuel midway between stages, and by that means one could at least double, and possibly more than double, the useful load that could be carried across the ocean. Based on present aerodynamic information, it could be predicted that a ship of a range of 4,500 miles will allow a pay load of from 7 to 9 per cent. of the gross weight. Within the hull of a flying boat of a gross weight of about 100,000lbs., one could carry 8,000lbs. as pay load, which would be satisfactory to justify trans-oceanic transportation; and by re-fuelling in mid-ocean one could increase the pay load to 15,000 or 20,000lbs. But there was another problem to be faced, that for long journeys one could not keep the passengers in one place, but must provide further accommodation for them. Sleeping accommodations would become necessary, and there must also be a smoking-room and a dining cabin at least. So that while a machine might have the lifting capacity there might not be sufficient room for the passengers to travel in comfort, and one might not be able to use the lifting capacity, which results from re-fuelling, at any rate for passengers.

Replying to Major Green's question concerning the power of the engines, Mr. Sikorsky said that on the S-42 he used a new type of Hornet engine, rated at 700 h.p. at altitudes from zero to 3,000ft. The engines were not highly supercharged; therefore the maximum power was about 730 h.p.

Finally, he expressed again his sincere appreciation of the friendly reception accorded him, and said he would carry away with him most pleasant memories of the occasion and hoped to return to Great Britain in the future.

Vote of Thanks

The President: Mr. Sikorsky was indeed a very remarkable man and it was regrettable that he was not an Englishman. The quality of the applause which had followed the reading of the paper and the reply to the discussion was very much above the average—and that was a significant fact, because the Royal Aeronautical Society was a scientific body, not swayed by sentiment, but one which judged a paper purely on its merits. One could say absolutely without question that Mr. Sikorsky's paper was the sort of contribution the Society wanted more than anything else. (Hear, hear.) One hoped that Mr. Sikorsky would visit this country again even before he built the machine to operate across the Atlantic.

One was particularly delighted that Mr. Sikorsky had the great daring to consider the ordinary "man in the street," who paid for the commercial machine; Mr. Sikorsky had actually taken account of the fact that the passengers on long-distance routes would need sleeping accommodation and would want to walk about, and that if they could not do that they would not travel in the machines. And when all the scientific people had been afraid of loading the machines, for purely technical reasons, he had put forward an overwhelming case for high wing loading, namely, the importance of avoiding air-sickness. From the point of view of "the man in the street" there was very little attraction in air travel, except, of course, its speed; it was a rather dull method of locomotion, rather expensive, a little dangerous and very noisy. However, there was in fact a lot to recommend it, and if air-sickness, which was one of the distressing aspects of aerial travel, could be avoided it was all to the good.

There had been some very lugubrious speeches at that meeting, continued the President, concerning the position of English aviation, and most of them seemed to have been addressed to him, as though he were responsible! Whilst he supposed that he must accept a certain amount of responsibility, he pointed out that if they in this country were behind hand on the technical side of aviation, the people to blame were the members of the Royal Aeronautical Society; it was of no use pushing the blame on to somebody else. But Mr. Sikorsky, by visiting this country at the present time, had caught them, so to speak, "assuming the unperpendicular." However, the position might be represented by a waving curve, and it might well be that before Mr. Sikorsky visited this country again we should be sending some of the members of the Society to America to read papers in his presence.

Meanwhile, the President invited the meeting again to thank Mr. Sikorsky for his model lecture, which was so unassuming and so unboastful, and to show their admiration for Mr. Sikorsky himself.