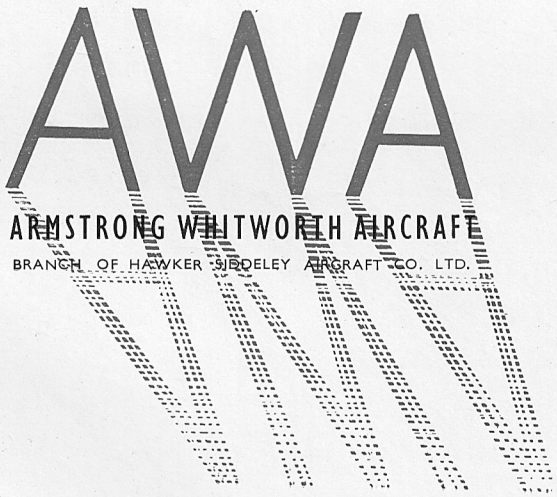
# *Pacemakers of Progress*

*A brief description of some of those outstanding technical developments of the last 25 years which have been pioneered by A.W.A. engineers and have become accepted landmarks in the progress of aircraft design*




SIR W. G. ARMSTRONG WHITWORTH AIRCRAFT LTD., COVENTRY, ENGLAND

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# FOREWORD

THROUGHOUT the Company's long experience in the aircraft industry, the resources of Sir W. G. Armstrong Whitworth Aircraft Limited have always been made available for research and development. During this time a Design team of outstanding ability has been built up to pursue the many and varied problems associated with aircraft design.

These technicians are provided with facilities and test equipment to assist them in keeping abreast of modern aeronautics so that new design features can be put into service with every confidence.

The fruits of this policy will be apparent when it is realized that many features which have become accepted practice of modern design were pioneered a long time ago by the Company, and this Brochure is intended to give a brief outline of some of the fundamental advances initiated and developed by the Company during the past 25 years.

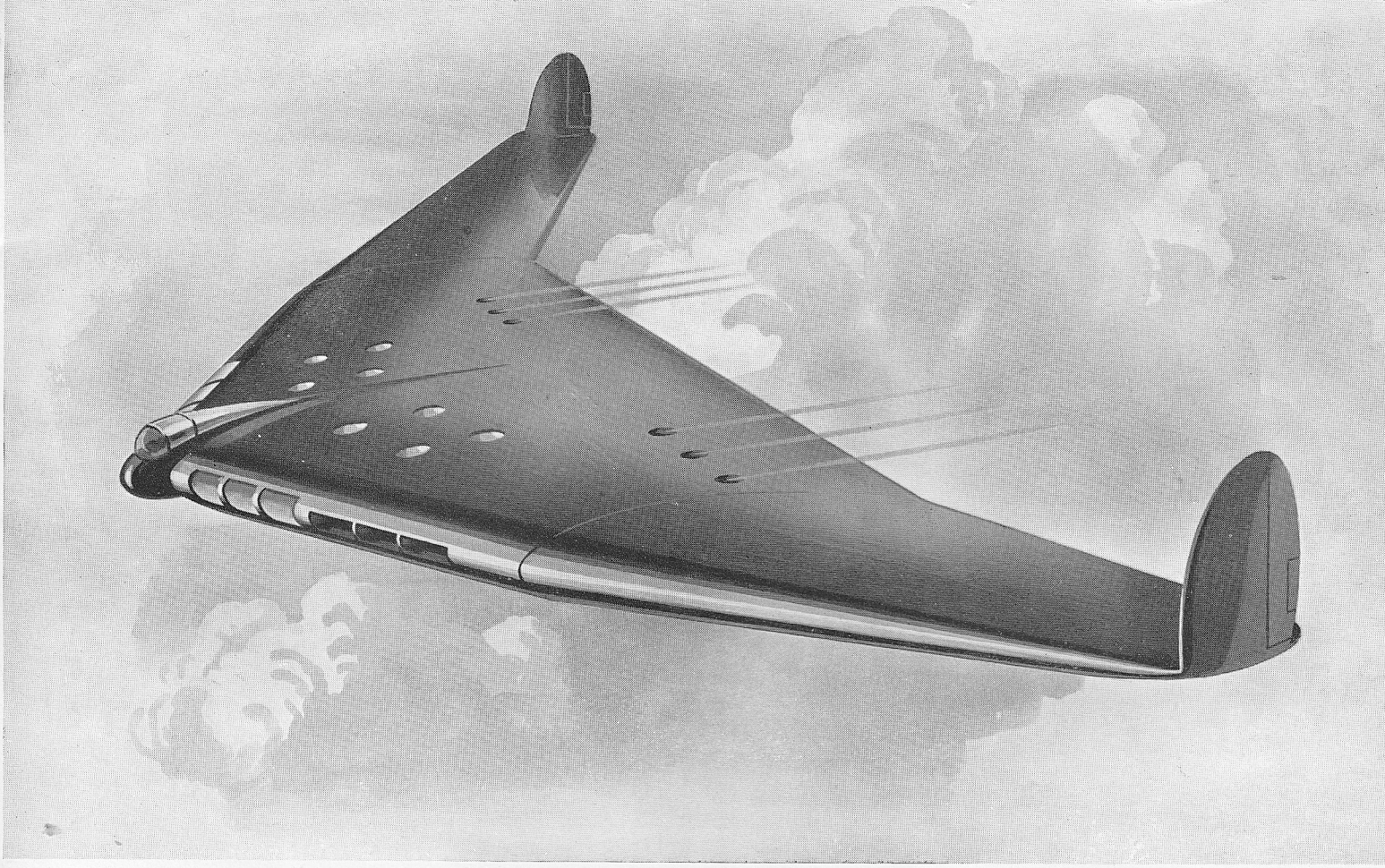


*Plate* 1. *The A.W.A. "Flying Wing" Air Liner*



*Plate* 2. *The A.W.*55, *"Apollo" Gas Turbine Air Liner*

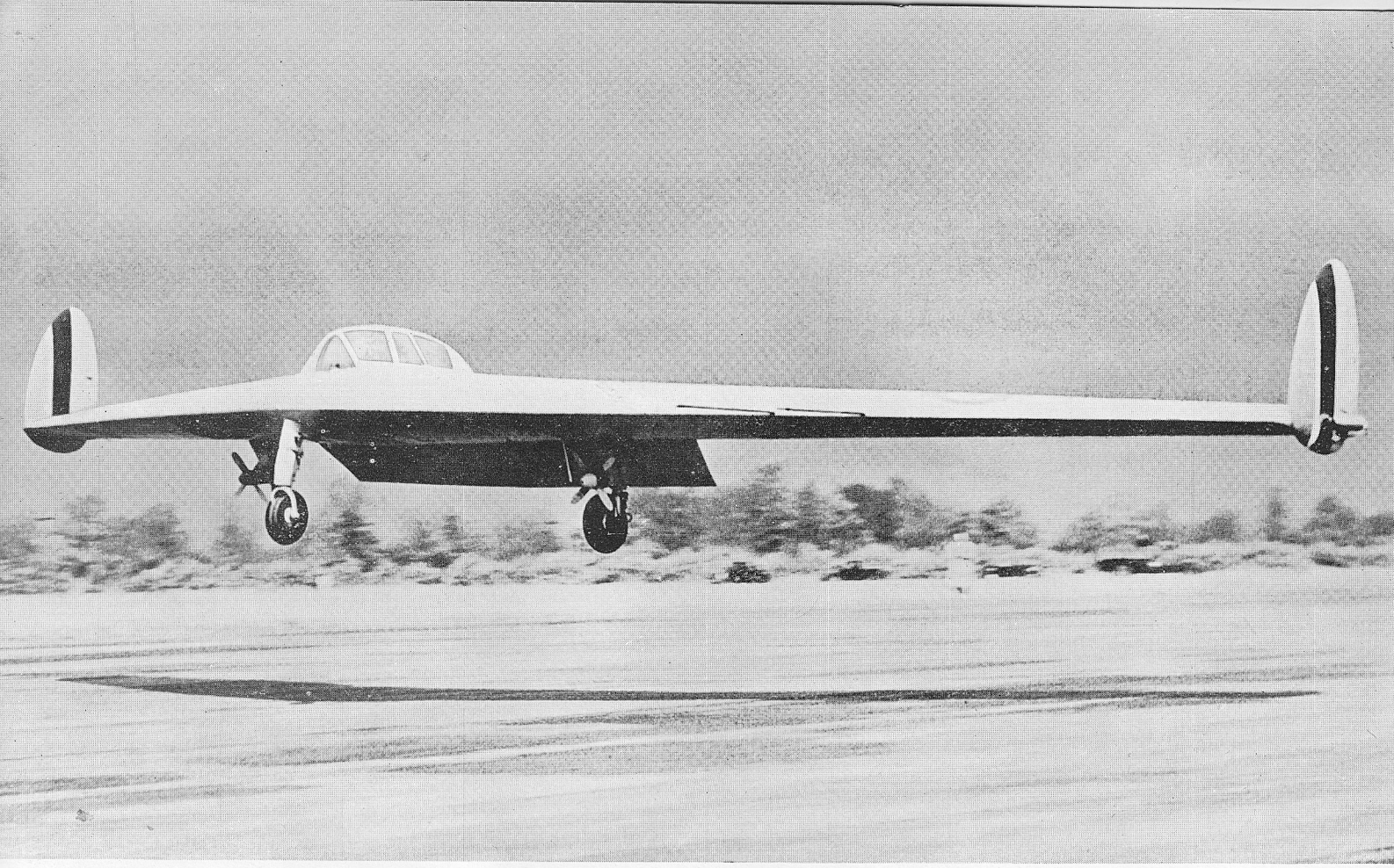


*Plate* 3. *The A.W.52g., Tailless Glider*

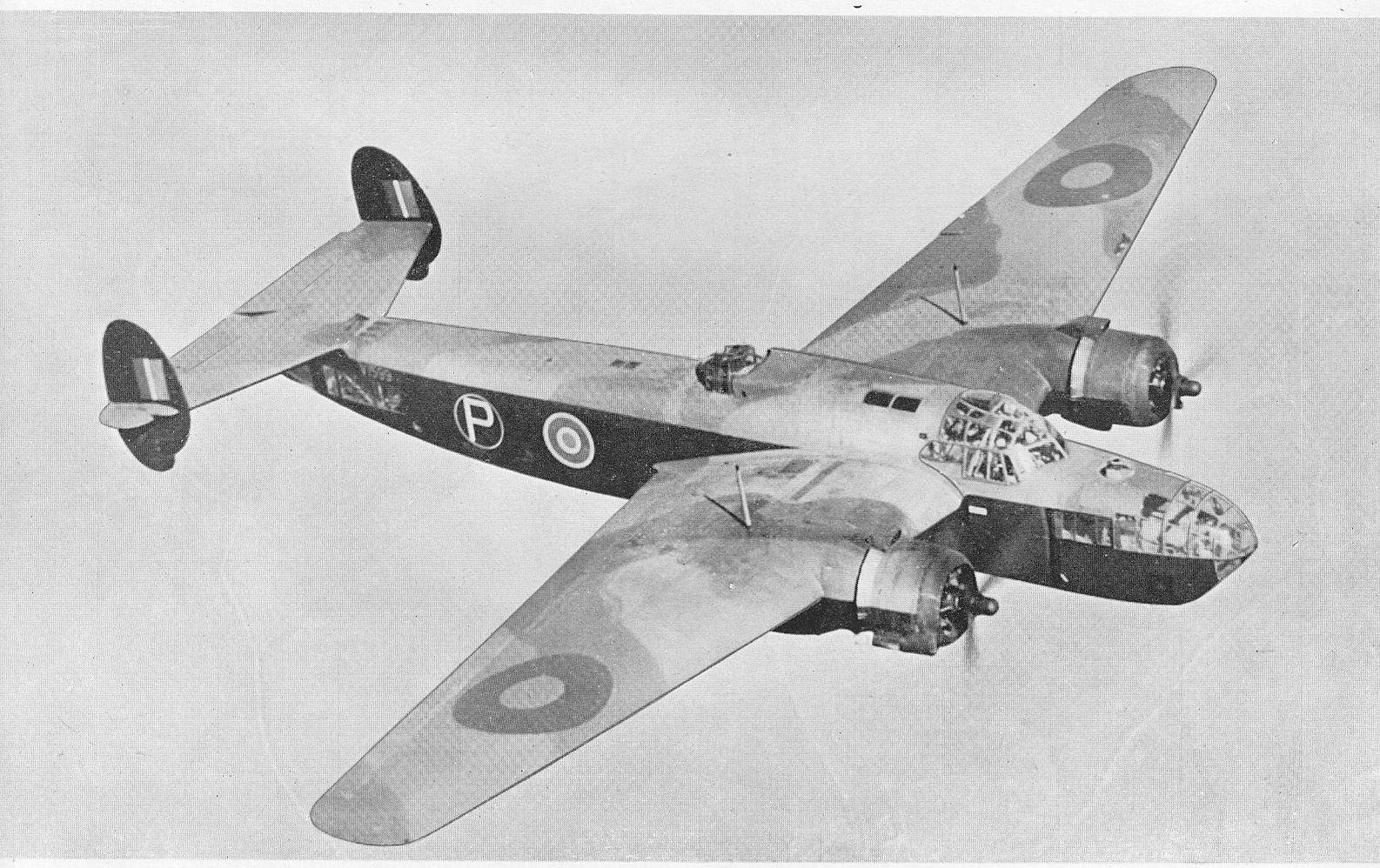




*Plate* 4. *The A.W.41 "Albemarle"*




*Plate* 5. *The A.W.27 "Ensign"*

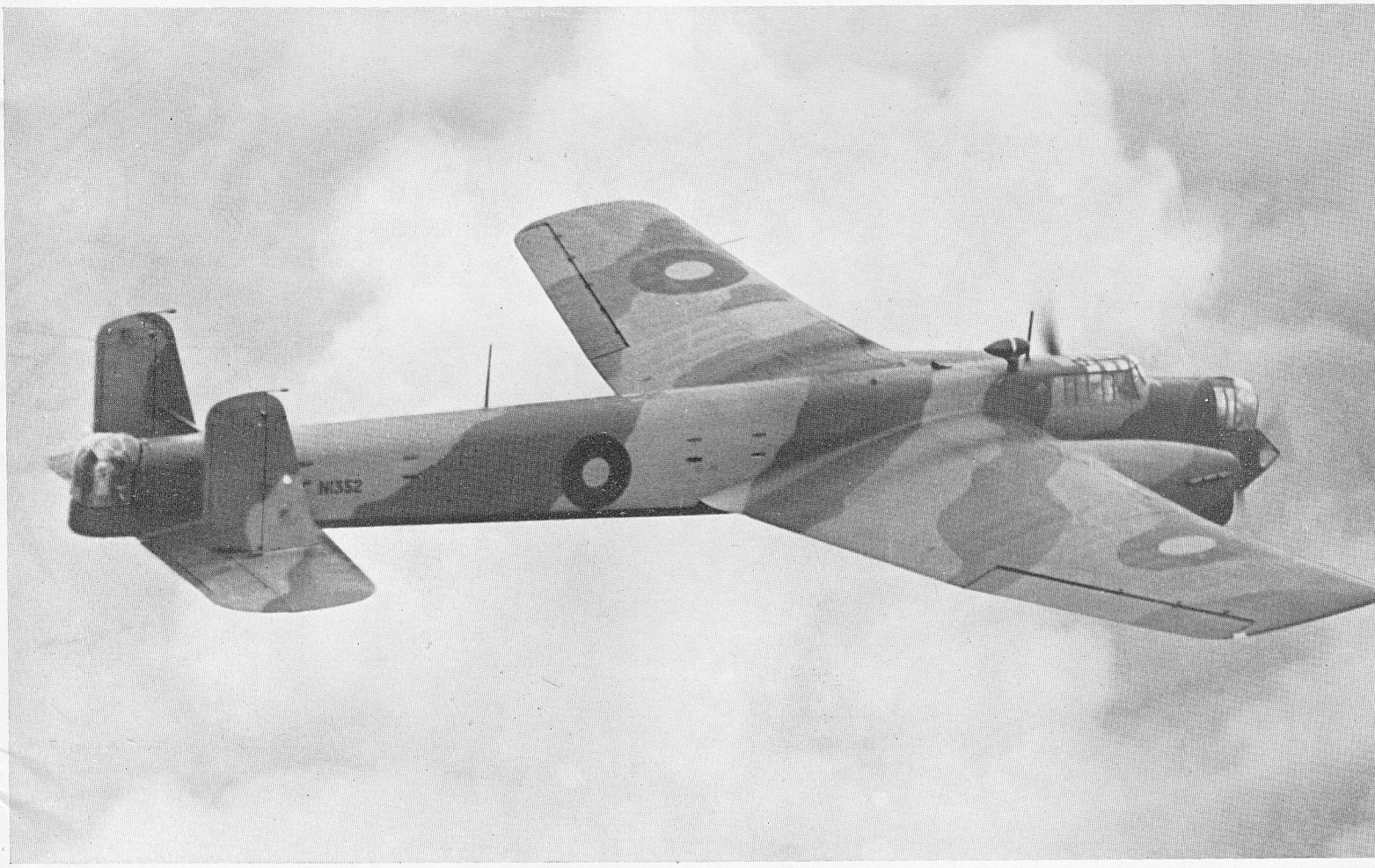



*Plate* 6. *The A.W.38 "Whitley"*

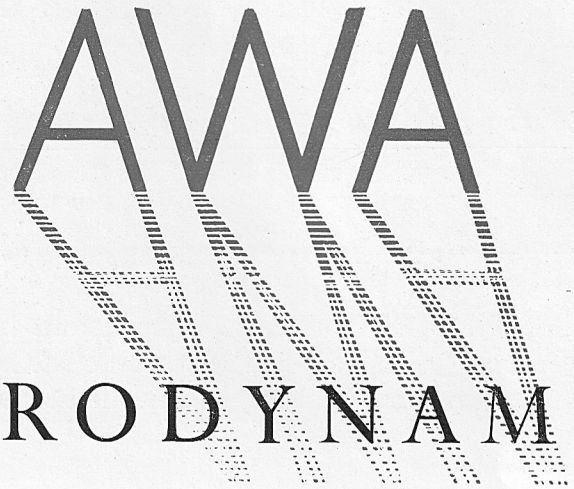



*Plate* 7. *The A.W.*15 "*Atalanta*"






*Plate* 8. *The A.W.A.* "*Siskin*" *IIIa.*




AERODYNAMIC

DESIGN

SINCE the Company's inception A.W.A. have pursued a policy of thorough investigation to ensure sound aerodynamic design, and from the earliest times full scale research has been carried out on the various aircraft produced.

After the installation of the Wind Tunnel in 1927 this full scale research was supplemented by a large amount of preliminary work on scale models at all stages of the design.

## THE BIPLANE PERIOD 1917—1932

The first aircraft which the Company designed and built was a small single seat fighter called the " Siskin," with an A.B.C. aircooled engine of 200 H.P. It was a private venture, constructed in wood, and proved to be a complete success with control and stability characteristics far in advance of contemporary types. Following intensive development, including conversion to steel construction, the " Siskin " was finally put into production for the British Government as the standard fighter type, and in addition numbers of these aircraft were supplied to Dominion and Foreign governments, giving excellent service under severe climatic conditions.

Illustrated in Fig. 1 is one of the most advanced features in the development of the " Siskin," a form of cowling for the air-cooled engine, which reduced the body drag by 30%. The King's Cup race was won twice with these machines; in 1923 Frank Courtney piloted a " Siskin II " and Captain Barnard won the race again in 1925 flying a " Siskin V."

During the period in which the " Siskin " was being developed in its various forms several other aircraft were designed and built. Amongst these were the " Sinaia " and the " Awana," both twin engined biplanes, the most significant feature about the " Awana " being the wing span, which was 117 feet—only six feet shorter than the span of the " Ensign." Then followed the " Wolf " used for training purposes in the firm's flying school.

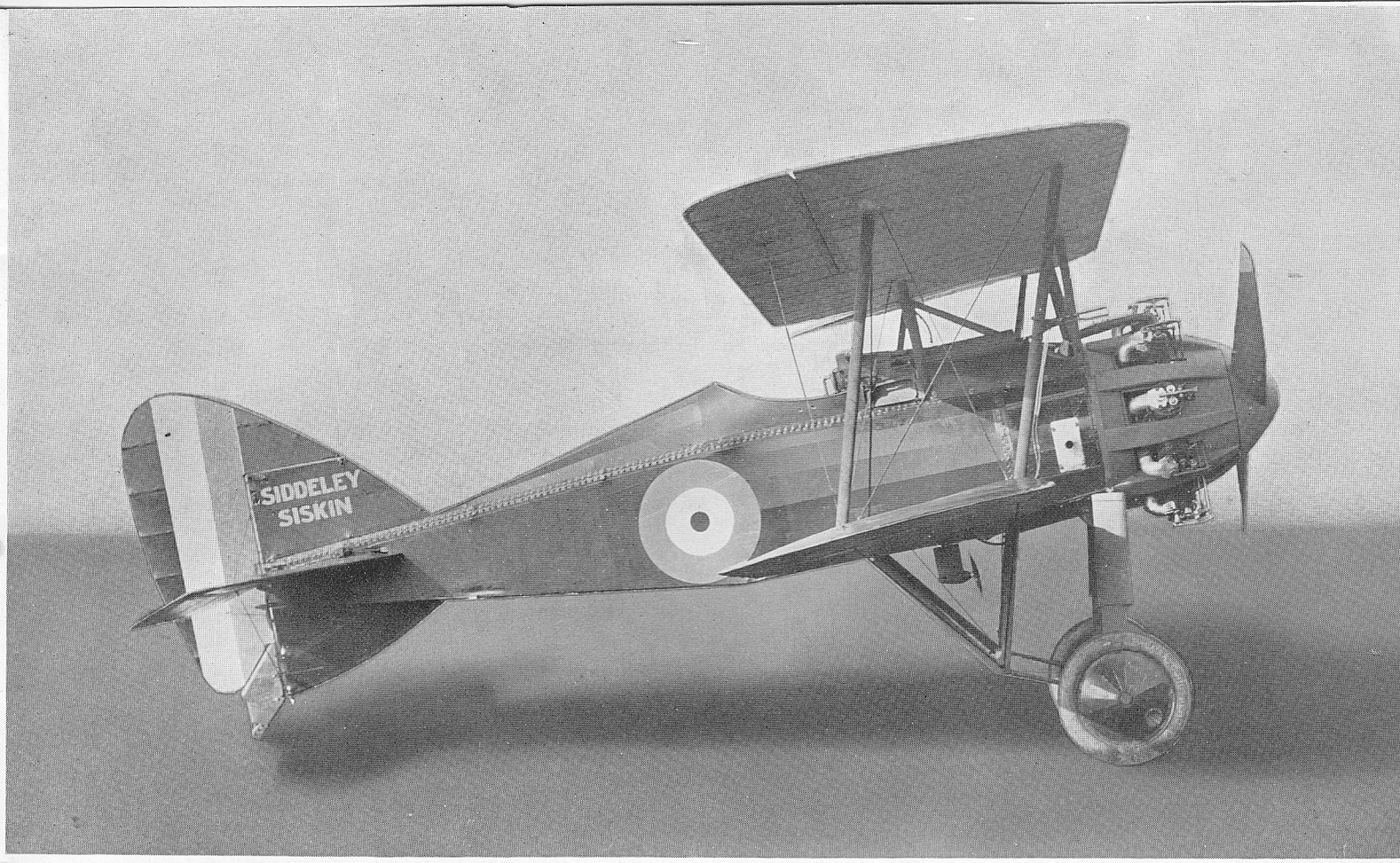



*Fig. 1. "Siskin" Aircraft showing Engine Cowling*

The next type to be produced in quantity was the "Atlas," a single-engined two seat army co-operation aircraft, large numbers of which were supplied to the British and Foreign Governments. The most outstanding development work on this aircraft was in connection with the Townend ring form of engine cowling, the significance of which invention was first appreciated by the Company, who also carried out the original full scale test flights.

An interesting aircraft known as the "Ape" followed the "Atlas," and was built specifically for full scale Aerodynamic investigations, being designed so that adjustments could be made to the settings of the various components.

The Company first entered the passenger carrying air liner field in 1926, with the design and construction of the "Argosy," a biplane fitted with three geared Jaguar engines and having an all-up weight of 19,200 lbs. Aircraft of this type operated on the London-Paris Service until 1933.

## THE MONOPLANE PERIOD—1930 ONWARDS

About 1930 the old controversy, biplane versus monoplane, began to resolve itself when it was realized that increase in speed and payload could only be economically attained by taking advantage of the superior aerodynamic cleanness of the monoplane design. Therefore when an order was received from Imperial Airways for an aircraft for Empire communications it was decided that, on paper, the monoplane was the obvious type for the job.

To obtain the cleanest possible design it was decided to make the wings fully cantilevered from the centre section. This meant mounting the four engines specified directly on to the wings, a feature which had never been attempted before and about which gloomy predictions as to the bad effect of the nacelles on lift, drag, and pitching moment were rampant in some quarters. Intensive aerodynamic investigations were carried out in the design stage, covering the effect of variations in taper and plan form of the wings, and particularly to find out the effect of the engine nacelles on lift, drag and pitching moment. Tests on stability and control of the complete aircraft received very careful attention, cabin ventilation was investigated, and everything done to make sure that the design was practicable.

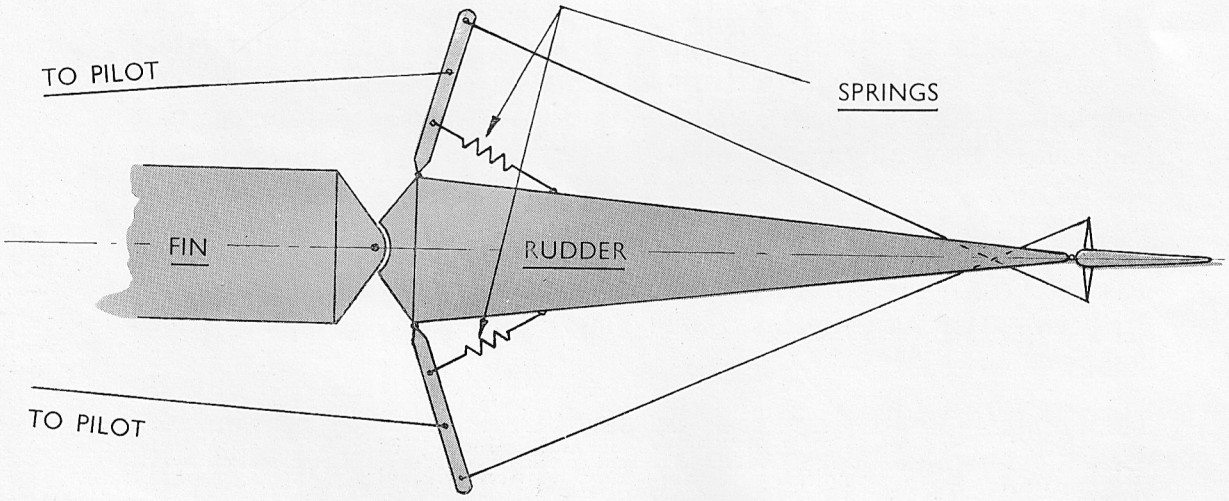



*Fig. 2. "Atalanta" Rudder Servo*

As is now well known, the result of this intensive study was the "Atalanta," the first four-engined cantilever monoplane, which proved to be an outstanding success. A fleet of twelve of these aircraft operated on Empire routes and did a great deal to enhance the prestige of British Aviation.

Apart from the general revolutionary design of this aircraft one or two features are of special interest. For instance, a better alternative to the sharp nose Frise aileron was found by thickening up the nose in order to cure snatch at small angles, whilst perhaps the most amazing device was that illustrated in Fig. 2 which was described as a Servo rudder. Unfavourable reports from the test pilot caused this to be dropped, only for it to be re-discovered many years later under the title of the " Spring tab."

During the period 1932-1936 several types of aircraft were produced to Air Ministry specifications, mostly biplanes, such as the " Scimitar," but the most outstanding type from the point of view of the firm's history was the A.W.23, a bomber transport aircraft. Only one prototype was built but it is noteworthy in that with slight modifications it formed the basis of design of the Company's first heavy bomber, the " Whitley."

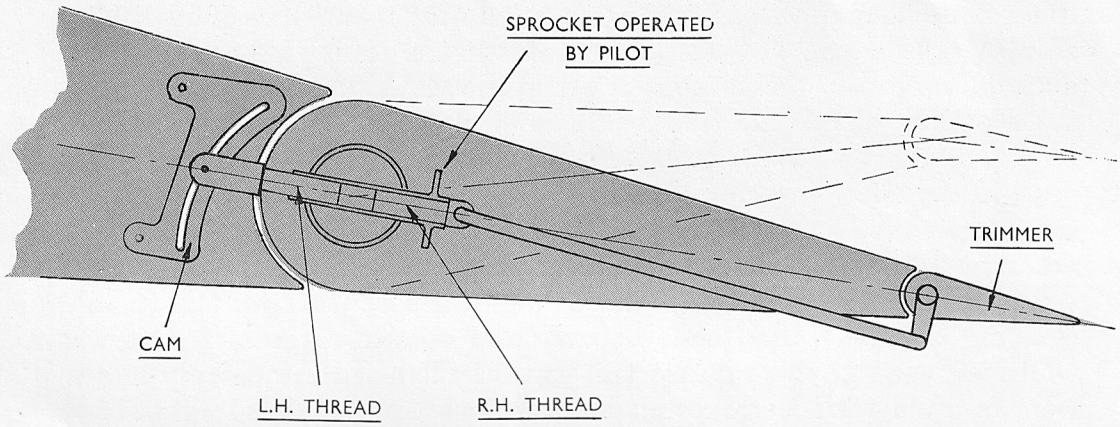



*Fig. 3. " Whitley " combined balance and trimming tab*

**WHITLEY 1936**

The " Whitley " was a twin-engined, mid-wing monoplane heavy bomber with a monocoque fuselage, the first of approximately 2,000 aircraft delivered, being produced in 1936. Several squadrons were equipped with

" Whitleys " at the outbreak of the war in September, 1939, and the machine was for some time the standard heavy night bomber of the Royal Air Force, whilst in 1942 many " Whitleys " were converted for use in Coastal Command and rendered valuable service in the detection and destruction of U-boats. Although operational requirements often meant an increase in all-up weight, practically no structural alterations were necessary to make the aircraft originally designed for 23,500 lbs. to carry a maximum all-up weight of 33,500 lbs., and a special aerodynamic feature of this aircraft was the use of combined balance and trimmer tabs as illustrated in Fig. 3. The tab angle to give balance was obtained by a cam, the shape of which was varied to give the required control characteristics. The " Whitley " also incorporated a retractable undercarriage, completely designed and built by the company, a feature of which was the complete avoidance of intricately machined components and special finishes resulting in an easily and cheaply produced unit.

### ENSIGN 1938

The company's experience on large monoplanes and the abundance of research information now in their possession enabled them to accept a contract for a long range passenger aircraft for Imperial Airways, and the resulting design was a four-engined high wing monoplane of 50,000 lbs. all-up weight capable of carrying 40 passengers. This aircraft was years ahead of its time, so much so that even today it is still a modern aircraft, and its wing span of 123 feet is still the largest wing span of any British land plane in service. The undercarriage of the " Ensign," which was designed by the company, was at the time the largest retractable undercarriage in the world, owing to the great height of the wings from the ground with the high wing arrangement. With the outbreak of war " Ensigns " were pressed into service for transport work for the R.A.F., carrying reserves of personnel, spares and outsize cargoes, and it was whilst engaged in these duties that two of them fell into enemy hands, were re-fitted with Mercedes engines and subsequently used extensively for senior officer transportation. A report of flight trials in Inter Avia gave a glowing account of their behaviour.

### ALBEMARLE 1939

Shortly before the war fears were felt as to the availability of sufficient quantities of light alloy, should hostilities break out, and the company

was asked to design a twin-engined bomber using wood and steel as the basic materials. The result was the "Albemarle," several hundred of which were made and successfully fulfilled many operational requirements such as parachute troop carrying and glider towing. It was the first R.A.F. aircraft to be fitted with a tricycle undercarriage, and led the way in removing some of the difficulties of landing.

## 3. MODERN DEVELOPMENTS

### TAILLESS AIRCRAFT

In early 1943 the company's activities extended into the realms of tailless aircraft. In many ways it was an even bigger step than the previous one from biplanes to monoplanes, and the new form involved big problems in control and stability. The most difficult problem was to provide sufficient longitudinal control, particularly at low speeds, and the solution finally arrived at after many wind tunnel experiments is shown diagrammatically in Fig. 4. After much theoretical study a

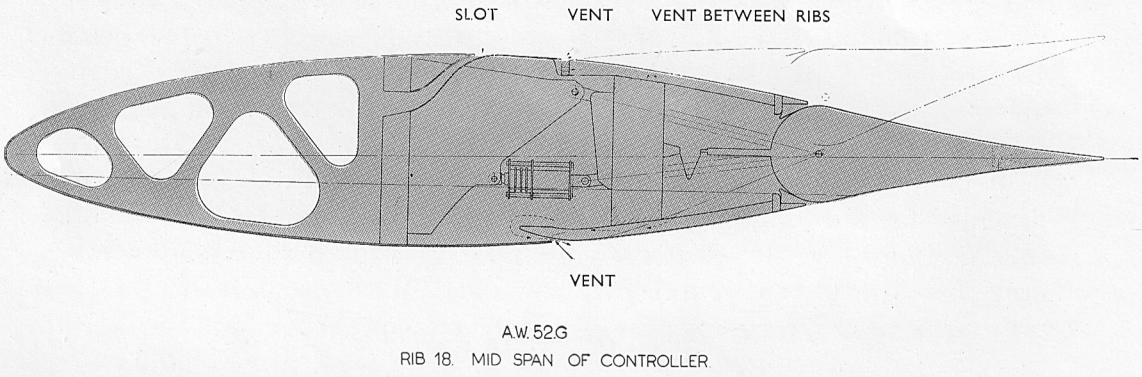



*Fig. 4. Longitudinal and Lateral control for tailless aircraft*

tailless glider for full scale flight investigations was designed and constructed, in which longitudinal and lateral control are achieved with one control surface, known as the controller, serving the functions of normal elevator and aileron. This has two forms of balance, by a shrouded forward surface, and a combined geared and spring tab. The controller is carried behind a power-operated surface known as the corrector, the main function of which is to provide a powerful trimming device without

impairing the lightness of the mechanically operated small chord control surface.

One of the major problems of tailless aircraft is the prevention of tip stall. The most promising method of doing this appears to be boundary layer suction, and on the glider this suction, supplied by a windmill driven blower, is applied to a slot in the upper surface at .4 chord from the leading edge. Flight tests with suction show a decided improvement in stalling characteristics and Fig. 5 shows some typical results of wind tunnel experiments in which its effect on correcting the outflow near the tip is clearly indicated. Landing flaps giving a large change of trim must be particularly avoided in tailless types, a slotted flap with a limited backward travel of 5% proving to be the most satisfactory. A laminar flow wing section is used on the glider with a theoretical transition point at 50% of the chord, and the aircraft has done a considerable amount of flying during the past twelve months, proving highly successful in every way and providing much useful information.

## FLIGHT INSTRUMENTATION

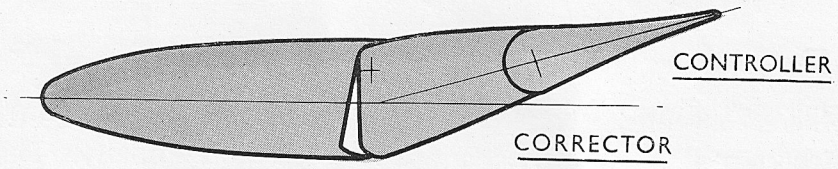
Due to the short period of glide after release from the tug, only a limited time is available for taking the numerous readings necessary to obtain the maximum amount of information from the tests. Full flight instrumentation has therefore been developed by the company's technical staff and is mainly centred around two automatic observers, one for flight instruments and the other for control surface forces and angles. Special manometers are also installed for measurements of local pressures on the wing surface and for measuring the drag by means of a total head comb.

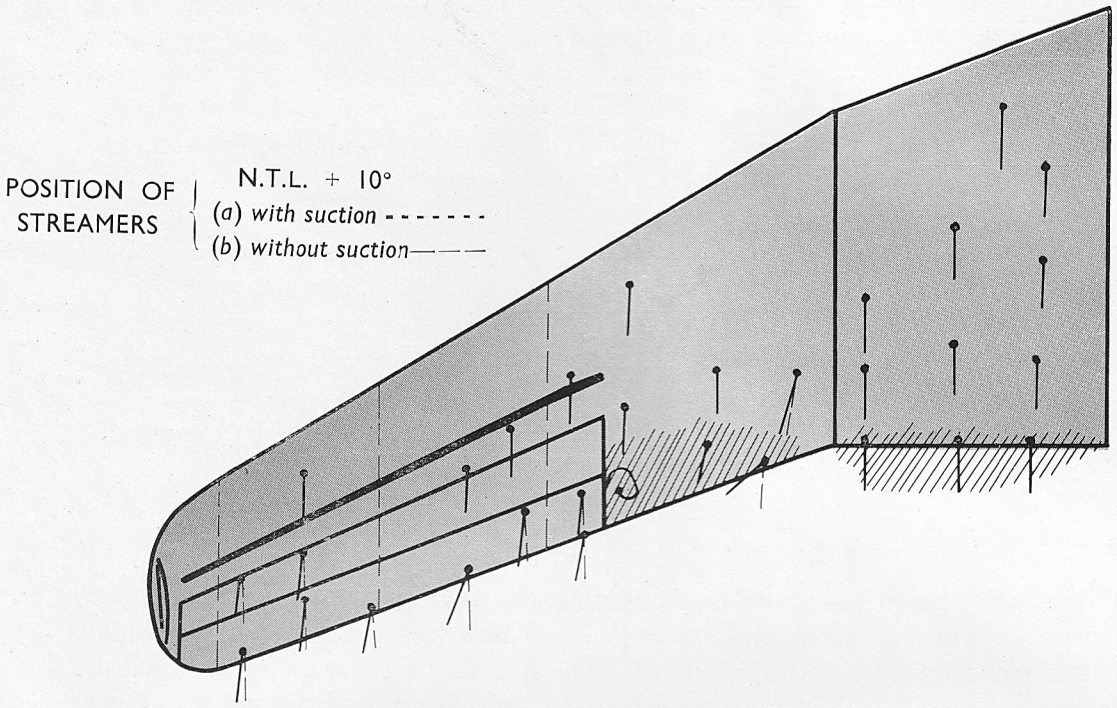
## EXPERIMENTAL TWIN JET TAILLESS AIRCRAFT

The next logical step in the development of large tailless aircraft is represented in the A.W.52 which weighs 30,000 lbs. and is fitted with two pure jet engines. All the features developed on the tailless glider have been incorporated in this aircraft, which is in an advanced stage of construction and is expected to fly before the end of 1946.

## TURBINE DRIVEN AIRSCREWS

This latest development in aircraft propulsion is incorporated in a



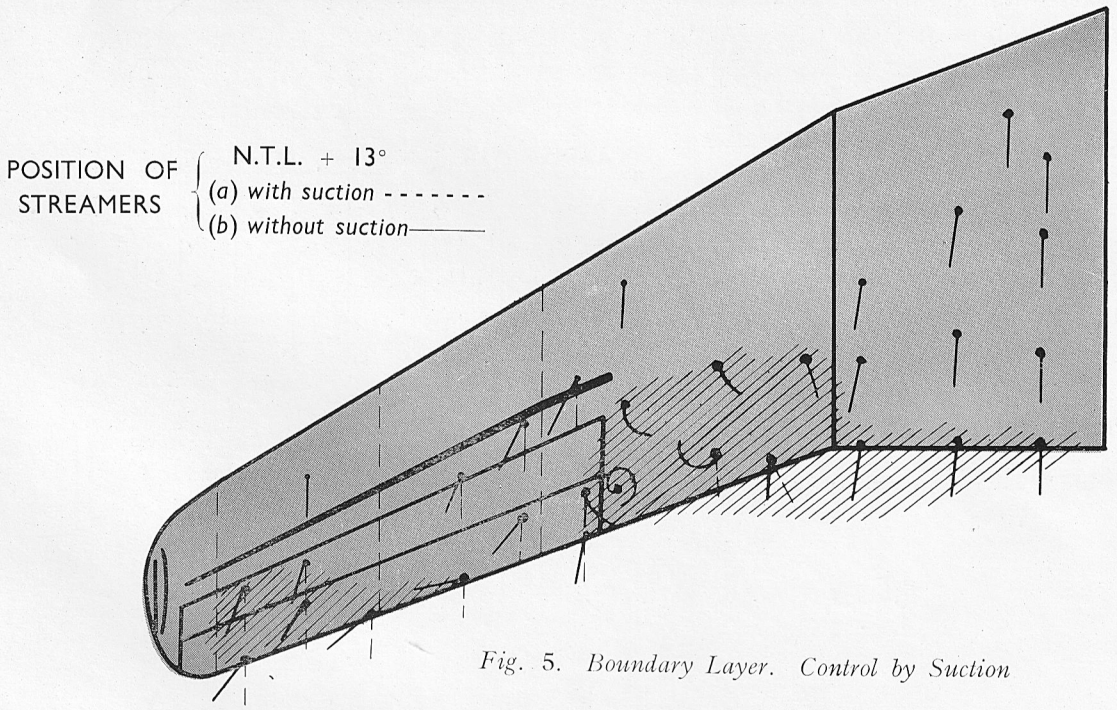




*Fig. 5. Boundary Layer. Control by Suction*

passenger carrying aircraft of 35,000 lbs. all-up weight, the design and construction of which has been entrusted to the Company. This aircraft will carry up to 31 passengers at a cruising speed of 240 knots at 20,000 ft. and will be fitted with a tricycle undercarriage. A new feature of the design is the special tab linkage for the elevator, illustrated in Fig. 6.

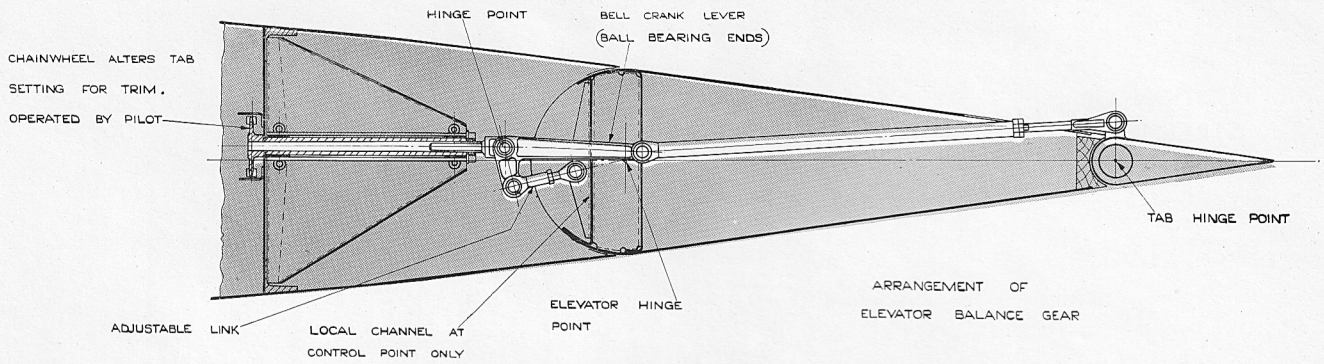
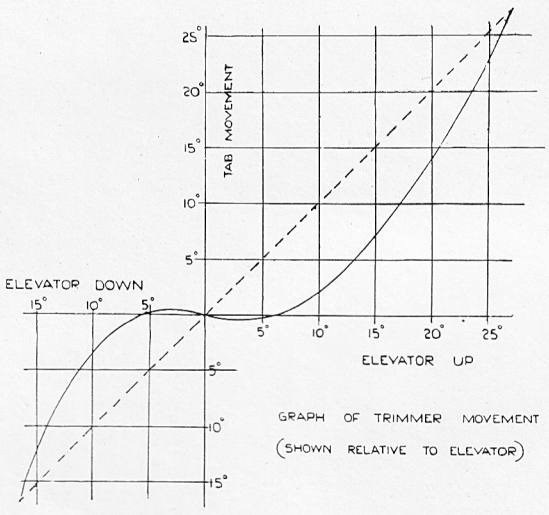
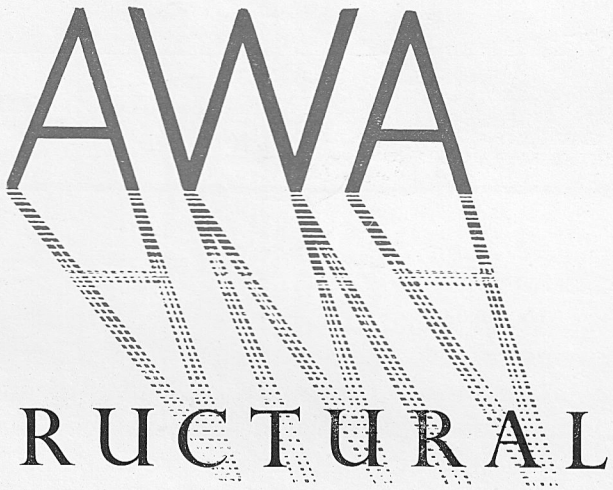



*Fig. 6. Elevator Tab Linkage*

The tab serves the combined purposes of trimmer and geared balance, but a special link mechanism provides a non linear gearing which makes the tab virtually inoperative for the first 5° of elevator movement on either side of its neutral position. The subsequent relationship between tab and elevator angles is shown approximately on the graph. It will be noted that when the elevator is trimmed upwards, as will be the case with the C.G. forward over the lower part of the speed range, the tab gearing is progressively increased and the stick free neutral point moves forward. There is thus a rough tendency for the neutral point with stick free, to follow the C.G. forward and so mitigate the excessive amount of trimming necessary on a very stable aircraft.






STRUCTURAL

DESIGN

# STRUCTURAL DESIGN

IN the field of structural design A.W.A. have always been in the forefront. Below are set out brief descriptions of the more outstanding developments in the history of the firm and in each case they represent a radical departure from the established customs of the times.

## 1. THE TRANSITION FROM WOOD TO METAL (1923 to 1926)

Shortly after World War I. it began to be realized that the basic material of aircraft construction then used i.e. wood, had grave disadvantages from the point of view of durability and maintenance. The best alternative material then available was steel, so the " Siskin," a single seat wooden biplane fighter aircraft, already produced by the firm as a private venture, was completely re-designed using high tensile steel for the main structural members. This aeroplane became the first all-metal aircraft in the world to be put into production, not only by the parent firm but by four other firms as well, and the methods employed were later developed for producing the " Atlas," a single engined two seat Army Co-operation aircraft.

### STEEL SPARS

One of the main structural problems arising from the decision to make all-metal aircraft was to design wing spars of sufficient strength but of reasonably light weight. The solution arrived at was to make the spar out of thin high tensile steel strip, corrugated to give it strength under compression stresses. The form of spar developed for the " Siskin " consisted of four separate corrugated strips riveted together, as illustrated in Fig. 7, the corrugations being formed by rolling flat strip in its hardened and tempered state, the maximum outside fibre stress which could be developed being 55 tons/sq. in. In order to increase the structural efficiency still further much stronger steel was used in subsequent designs such as " Atlas " and " Scimitar." The elements of a typical spar as

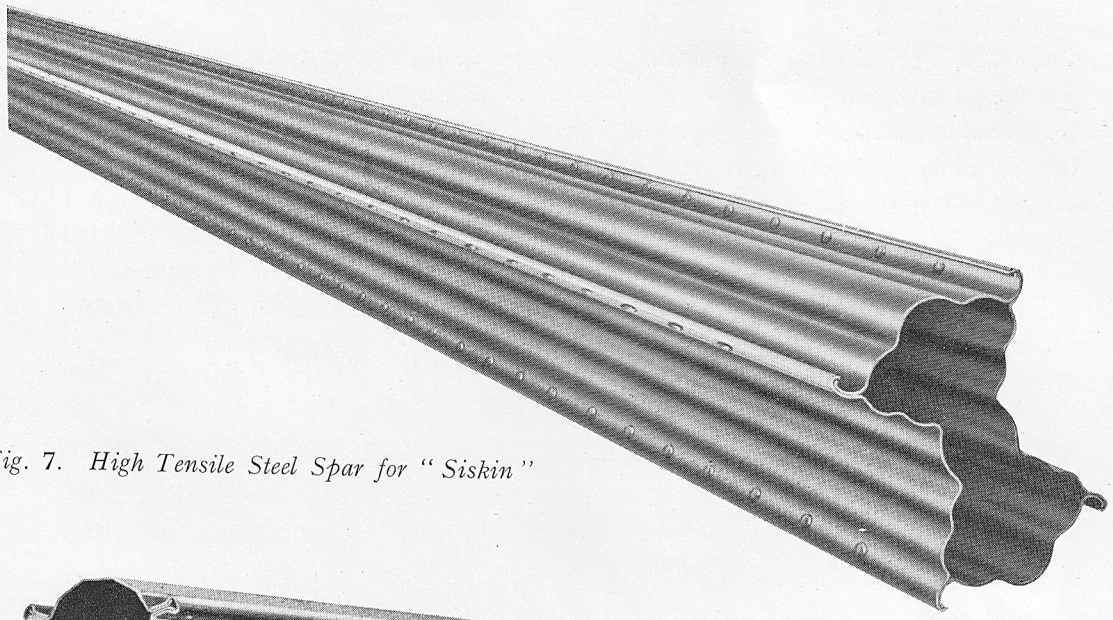


*Fig. 7. High Tensile Steel Spar for "Siskin"*

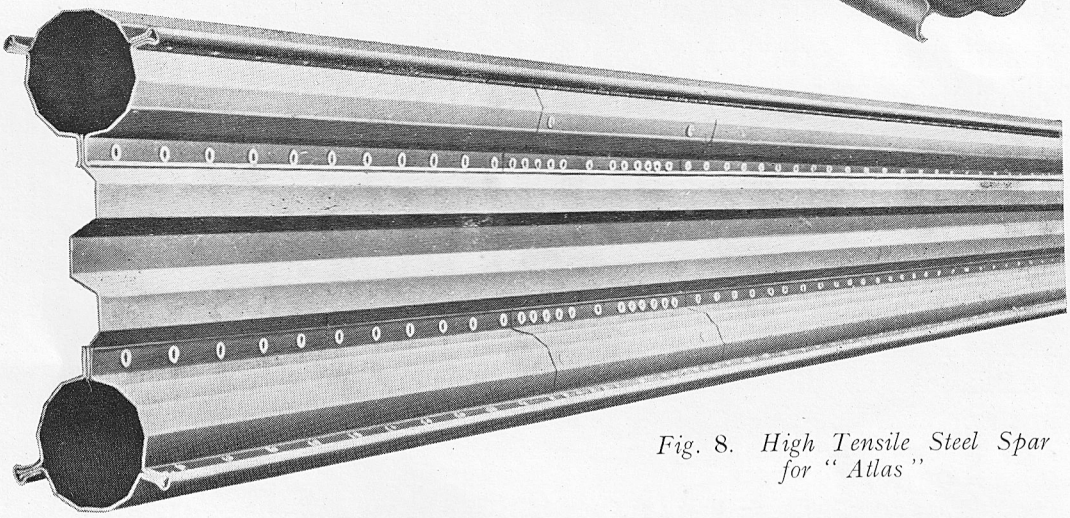


*Fig. 8. High Tensile Steel Spar for "Atlas"*

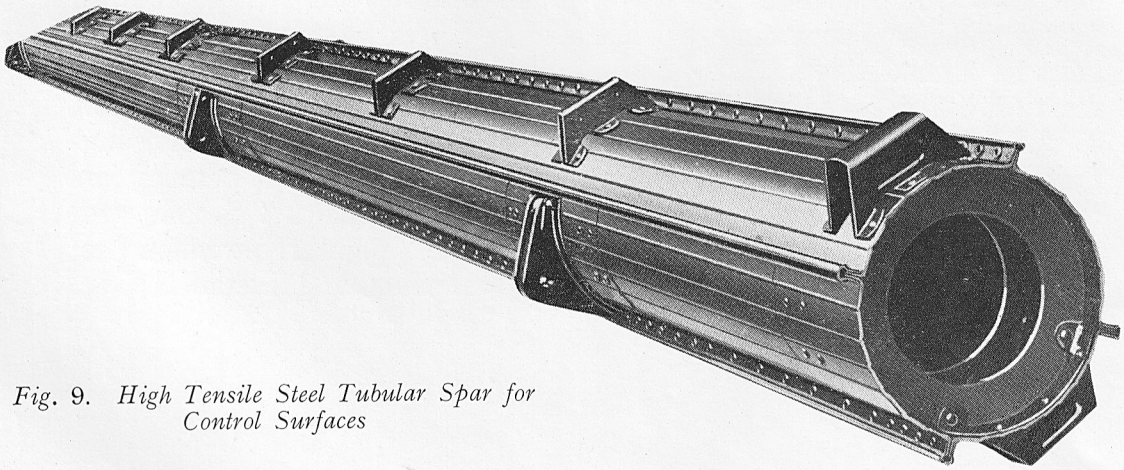


*Fig. 9. High Tensile Steel Tubular Spar for Control Surfaces*

shown in Fig. 8 were rolled in the softened condition and subsequently hardened and tempered by a tension-electric process ; the necessary heat treatment temperatures were obtained by passing an electric current through the strip through grips at each end and at the same time applying a small tension to it thus ensuring freedom from distortion after heat treatment. An air-hardening steel was mainly used in open horizontal benches with this method, but oil quenching was also used by a vertical arrangement in which the strip was heated by an electric current inside a muffle box after which it was drawn through a quenching box at the lower end of the muffle. By these means the allowable maximum fibre stress in the spar was increased to nearly 80 tons/sq. in.

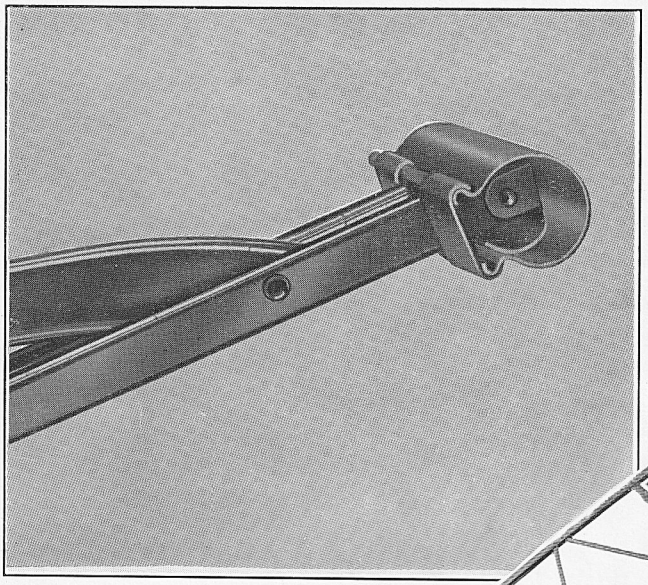
A further application of this type of construction is illustrated in Fig. 9 which shows a tubular spar made from corrugated steel for use as main structural members in control surfaces, where the main type of loading is torsion.

**SUBSIDIARY STRUCTURE AND DETAIL DESIGN**

Simplicity of design and ease of manufacture was the keynote of these early all-metal designs. Fig. 10 shows an " Atlas " rib as a typical example of detail design. This was made from rolled steel strip the thickness of some of the diagonal struts being as thin as .008". Other details shown such as rib fixings to spar and trailing edge attachments, avoided the use of bolts and provide maximum flexibility in assembly. Tube attachments in the fuselage structure took the form of a combined wrapper plate and lug made from a single bent up sheet of metal thus avoiding the use of complicated machined fittings and the general design was worthy of the title of a " production job " even by modern standards.

**BLIND RIVETING**

Very early on it was realized that some process by which a rivet could be expanded from one side only was a prime necessity for attachments to long tubular members and other inaccessible places where the use of long bolts or tubular rivets was heavy and cumbersome. After much experimentation and research the " pop " rivet was developed, which is now so well known and established as the pre-eminent form of blind riveting that it hardly needs description. A.W.A. held the original patents for this new form of riveting which was used on the " Atlas " as long ago as 1925, and Fig. 11 shows the principles of the " pop " rivet which has been used on the firm's products, with many variations and rivet materials, right up to the present day.



*Detail of Trailing Edge*



*Fig.* 10. *The "Atlas" Rib*



*Detail of attachment of rib to spar*

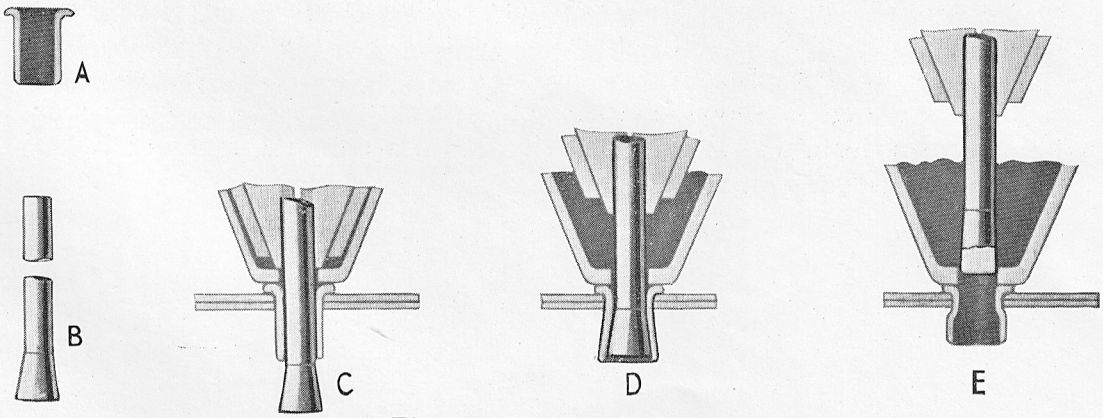



*Fig.* 11. *Pop Riveting*

## PASSENGER CARRYING AIR LINERS (1926—1932)

Whilst work was still proceeding on various types of military aircraft developed from the " Siskin " and " Atlas " the Company's first air liner, a three engined biplane civil transport aircraft known as the " Argosy," was designed and built with wooden wings and a tubular steel fuselage, on lines which had come to be recognised as orthodox construction.

The " Atalanta," a four engined monoplane, the next aircraft to be designed and built by the Company for Imperial Airways, represented a great step forward in both aerodynamic and structural design, the main advance in this connection being the mounting of the four engines on a cantilever wing, the first time that this had been attempted. Both the wing structure and the fuselage were built up in Warren girder form of high tensile steel strips of 65 tons/ins. proof stress formed into corrugated box sections, whilst the ordinary ribs, stringers, and skin covering were made of spruce and plywood. The durability of this construction is proved by the fact that machines built in 1932 are still flying in the trying conditions of the African climate.

## THE LIGHT ALLOY ERA (1933 ONWARDS)

With the increase in size and weight of aircraft and higher speeds, it became evident that problems of stability and durability could best be solved by the use of aluminium alloys which by now were greatly improved in strength and reliability. The first major component tackled was the wing of a bomber transport aircraft, the A.W.23, and led to the evolution of the box spar. This was later adopted, with a slight reduction in span, as the wing of the first heavy bomber produced by the Company, namely the " Whitley," which also carried the progress of structural design one step further in that the steel tubular structure of the A.W.23 fuselage was replaced by a monocoque body, and both box spar and monocoque body were later adopted for the much larger four engined Imperial Airways Liner, " Ensign."

## THE BOX SPAR

The main structural member of the wings produced in light alloy was the box spar. In section it consists of a hollow rectangular box, of which the top and bottom panels, of thin light alloy sheets, corrugated to take compression loads, provide adequate bending strength, and the front and rear panels form the main shear members, the whole comprising a large hollow box for resisting torsion. The great advantage of this type of spar is that the top and bottom panels as designed for bending stresses only are also capable of taking the shear stresses due to torsion with practically no additional material. This represents a large saving in weight over the two and multi spar type of construction with concentrated booms and a separate skin or bracing to take shear loads due to torsion. Furthermore the torsional stiffness of the spar is very great and the

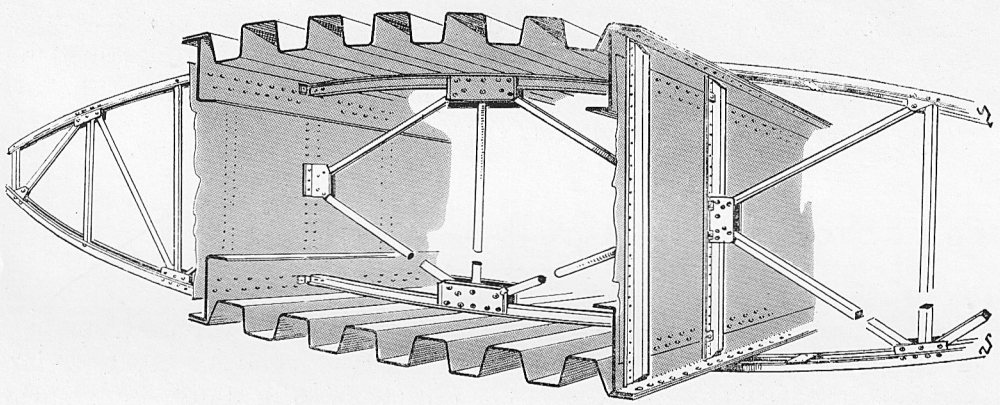


*Fig. 12a. "Ensign" Tailplane Box Spar*

requirements of flutter prevention and aileron reversal are easily met. Fig. 12a shows constructional details of the tailplane and Fig. 12b details of the spar used for wings of "Ensign" aircraft.

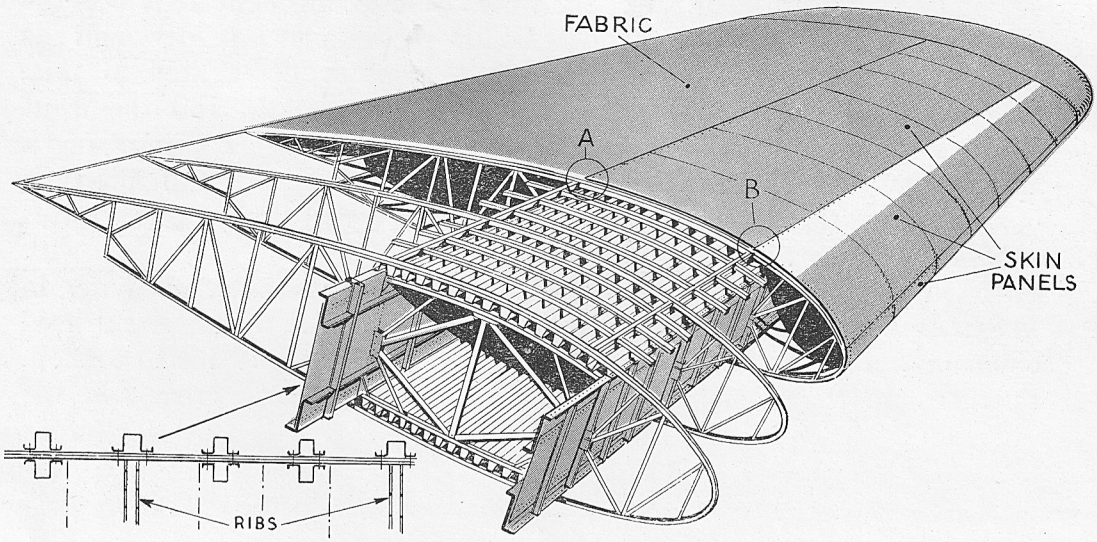



*Fig. 12b. "Ensign" Wing Box Spar*

## MONOCOQUE FUSELAGES

The decision to construct the "Whitley" fuselage in monocoque form again represented a big step forward at the time. Information as to the strength of skin-stringer combinations was very scanty and large numbers of detail tests were carried out to provide basic information. A full scale test at R.A.E. produced a failure at 98% of the design load. That the finished product was strong and reliable was amply proved by subsequent service mainly in the early stages of the recent war when numerous cases of severe damage to the fuselage structure occurred, in spite of which machines returned safely from raids in enemy territory. Fig. 13a shows the stringers and frames assembled in the jig prior to riveting and Fig. 13b the detailed design of the rear fuselage attachments to the centre section. The methods developed for the "Whitley" were later applied to the "Ensign" fuselage which was at the time of its construction one of the largest monocoque bodies then existing.

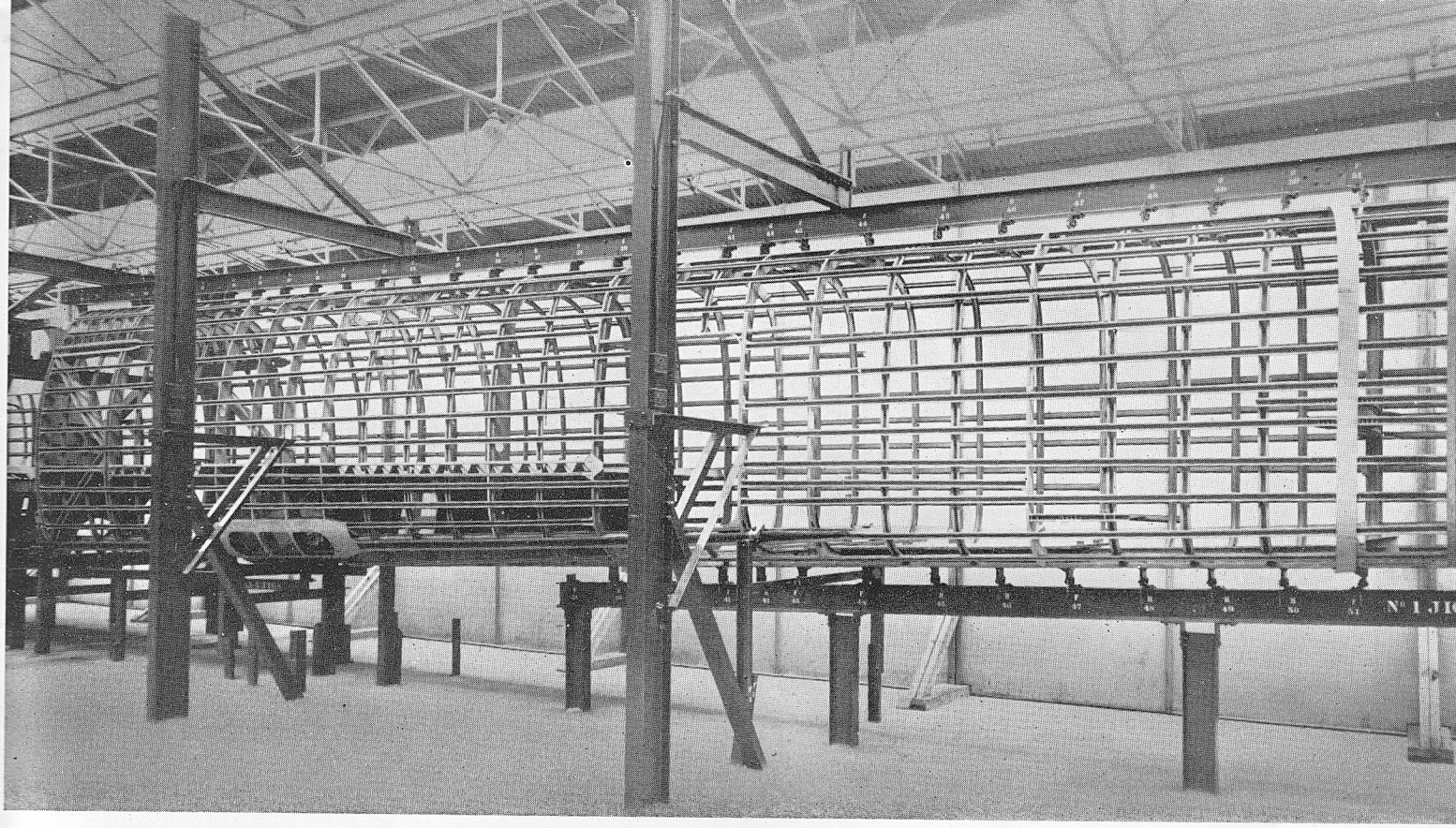


*Fig. 13a. "Whitley" Monocoque Fuselage. Stringers and frames in the jig prior to riveting*

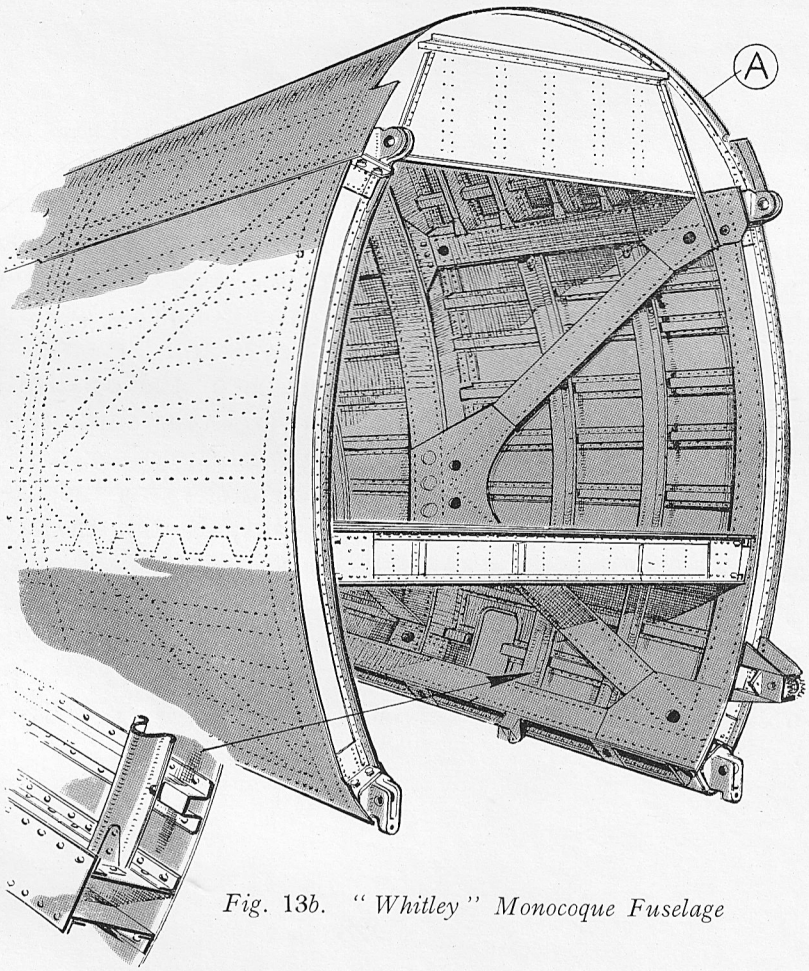



*Fig. 13b. "Whitley" Monocoque Fuselage*

### UNDERCARRIAGE DESIGN

Armstrong Whitworth Aircraft were the first firm in this country to realize the great advantage of the nose wheel arrangement and the " Albemarle " was the first production aircraft to be fitted with a tricycle undercarriage. Later developments included the design of a " long travel " undercarriage in which the permissible energy absorption was sufficiently high to allow the aircraft to be flown straight on to the ground without flattening out and a feature of this design is the use of a large backward wheel travel during the landing shock which reduces the final pitching velocity and hence reduces the maximum nose wheel load. All current and future A.W.A. designs will have " long travel " tricycle undercarriages.

## 4. CURRENT DEVELOPMENTS
## LAMINAR FLOW, JET PROPULSION AND FLYING WING

Early in 1942 a new type of aerofoil section was evolved with its maximum thickness much further back than usual—the laminar flow wing, capable of halving the parasite drag of existing conventional aerofoils. The snag to this highly desirable development was the super accuracy to which the skin surface had to be made. Recognizing the immense possibilities of this new type of section the Company made up a metal wing section on the lines of the " Whitley " and " Ensign " box spars with the thick skin riveted to the outside of the corrugations which was tested at the N.P.L. and found completely successful. It then became clear that the type of aircraft most likely to benefit from the low drag obtainable from the laminar flow aerofoils was the all-wing type, and that a further development, i.e. the introduction of jet propulsion, was also peculiarly suited to tailless aircraft in that the optimum range with jet engines is more sensitive to parasitic drag and less sensitive to induced drag than with the conventional engine and propeller. The tailless aircraft has an inherently low parasitic drag and preferably a moderate aspect ratio to obtain the greatest wing stowage, and is thus

ideally suited to jet engines, and Armstrong Whitworth Aircraft are developing this type of machine with laminar flow wings as the long range transport aircraft of the future.

The main structural problem to be solved in this field is the method of designing laminar flow wings of economically light structure weight reasonably cheap to build so that the advantage gained by low drag shall not be nullified by a heavy structure. The all-wing type has a fundamental advantage in that the weights are distributed over a large portion of the span thus reducing the shear and bending moments on the centre section.

### THE PRODUCTION OF LAMINAR FLOW WINGS

The Company's objective in this field was to design a structure which was capable of being manufactured with the required degree of surface accuracy and which would preserve that accuracy under all conditions of flight and maintenance but would involve no weight penalty. These requirements lead directly to the conclusion that the skin should be as thick as possible. This means that, for economy, the skin must be made to take bending and shear stresses. In order to stiffen the skin adequately against strut failure some form of stringer is necessary, and furthermore, in order to obtain the greatest efficiency from the skin and to prevent its waving at low loads, the stiffeners must be placed at a very close pitch. These conditions have led to stiffening the outer skin by riveting to it a corrugated inner skin which provides the effect of stringers at close pitch and of high torsional stiffness. The inner skin is also able to take shear and so relieve the outer skin of a proportion of the shear stresses as well as providing a high measure of stability to the skin in shear. Against distortion of the profile shape this construction forms a strong beam for carrying the load between the ribs and the corrugations split the skin up into very narrow panels which limit the local distortion between the rivets, caused by air loads.

Fundamentally, the usual method of building the wing is to build up from the ribs, i.e. inside to outside, but this method adds up errors cumulatively until the skin becomes the most inaccurate part of the structure. In building smooth wings the method most likely to give the required

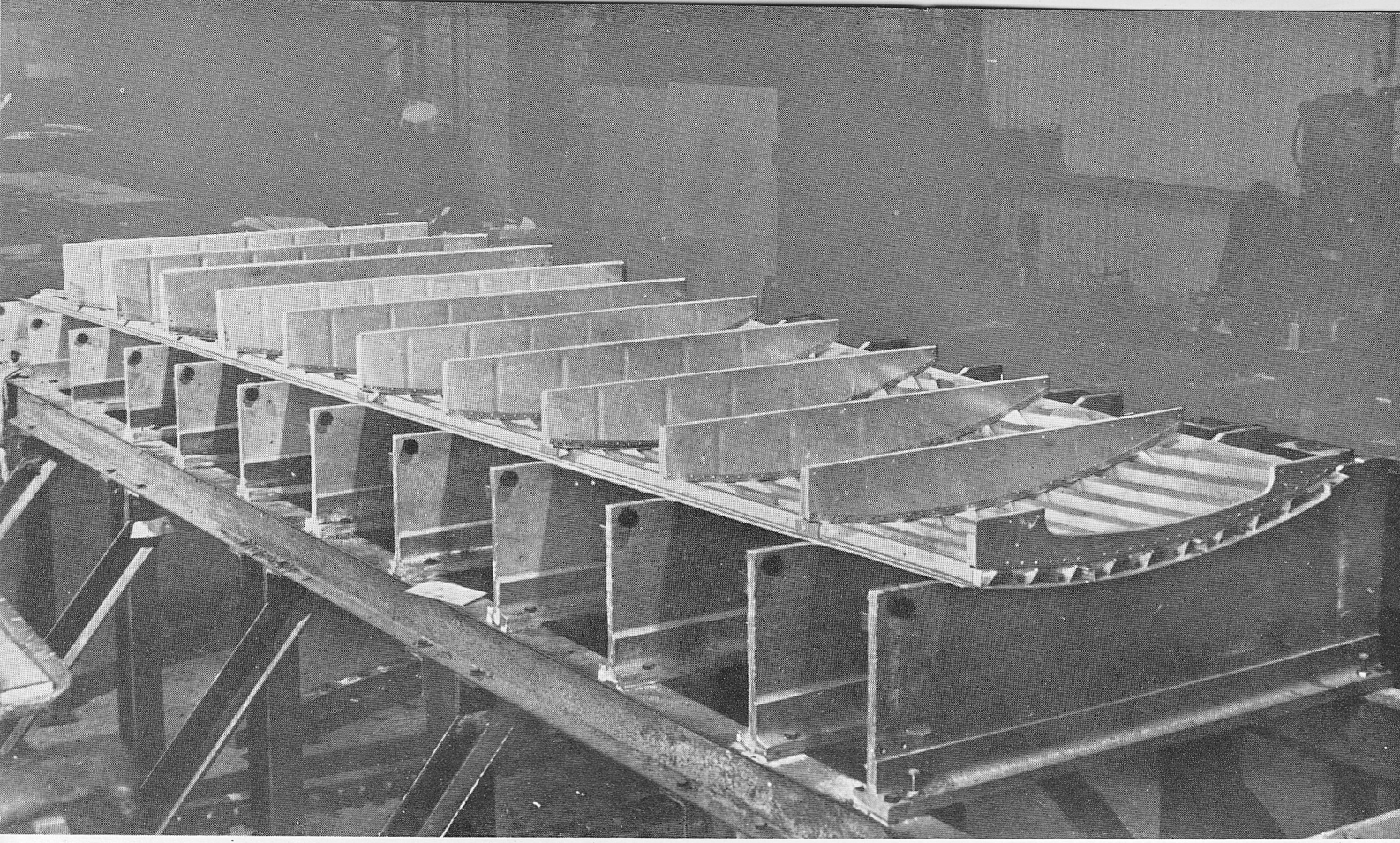


*Fig.* 14*a*. *Laminar Flow Wings.* *" Hurricane " wing after attachment of half ribs—jig clamps removed*

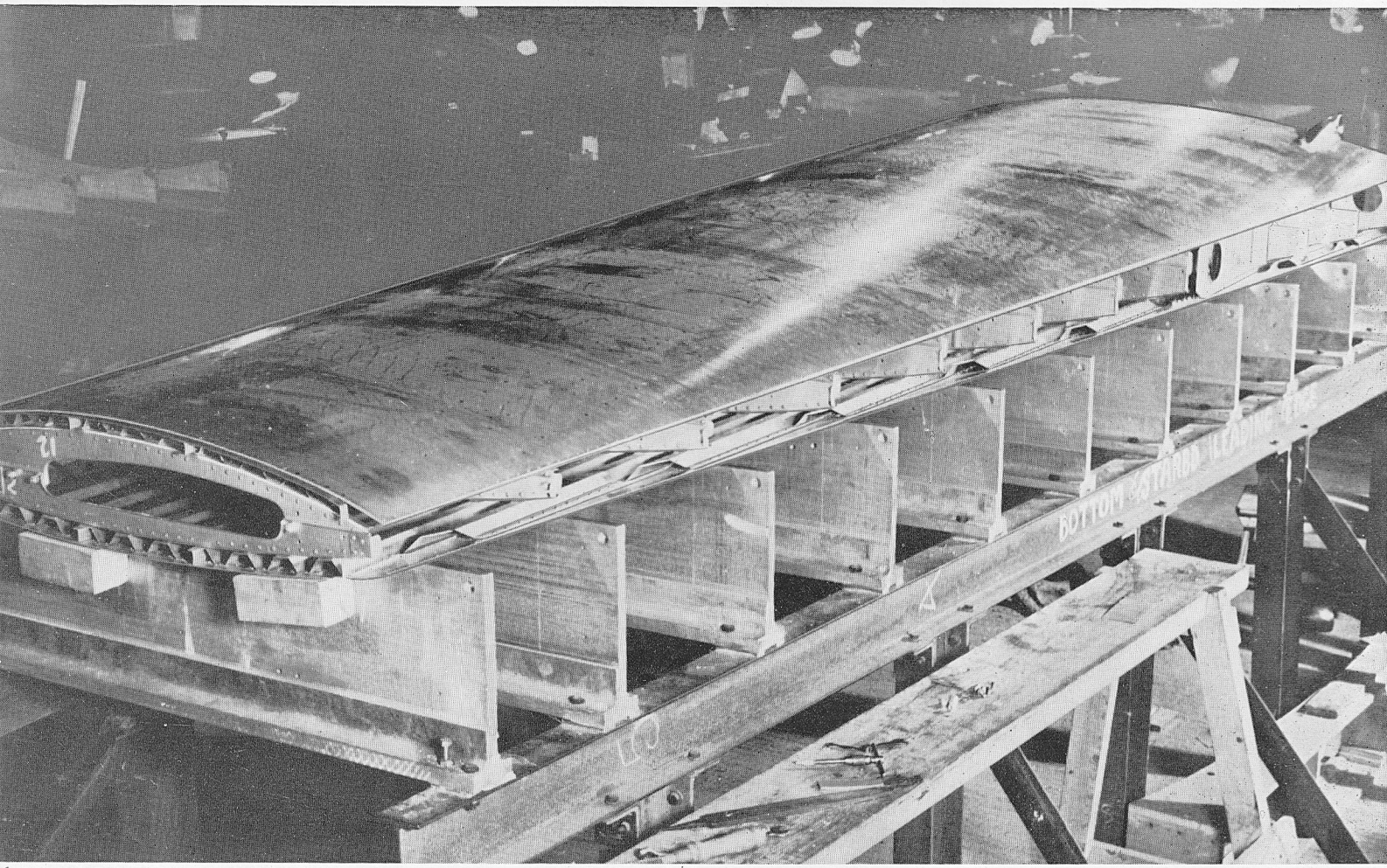




*Fig.* 14*b*. *Laminar Flow Wings.* *Two halves of " Hurricane " wing joined together before fitting webs*

results is to build from outside to inside, i.e. start with the skin accurately formed and held in position against an accurate jig and build up the ribs on to the skin and stringers. This is the procedure adopted in the Company's method of construction, and apart from the initial cost of the accurately formed jigs the method is perfectly adaptable for quick production.

A complete pair of wings for a " Hurricane " aircraft has been made on the above lines and has undergone tests at R.A.E. This aircraft is the first British aircraft to fly with laminar flow wings with the required accuracy of surface finish and the waviness after a special finishing process is now within $\pm 0.001''$ in $2''$ over the whole top and bottom surfaces of the two wings. The method of construction of these wings is shown in Figs. 14a and 14b, and is now being applied to the A.W.52, a twin-jet all-wing aircraft of 30,000 lbs. all-up weight.