AIRCRAFT ASSEMBLY

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PITMAN

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FOREWORD

The purpose of this book is to present some of the problems associated with assembly operations. As yet there does not appear to be any "best way" of constructing airplanes. Some manufacturers, particularly those in Europe, use wooden construction, others use steel and the majority use aluminum alloys to form the basic airplane structure. Nearly all airplanes incorporate all three of these materials to a certain extent, and now magnesium alloys and plastics are entering the field. With each material several types of construction may be employed: truss, geodetic, stressed-skin and monocoque—all of which have their own particular advantages and disadvantages. In addition to this, design theories and manufacturing methods are continually changing. It is obvious then that no hard and fast rules regarding aircraft assembly can be promulgated and it is doubtful if the aircraft industry will settle on one particular method of construction and one general manufacturing procedure for many years to come. This means that assembly methods will vary from plant to plant and from one type of airplane to another, depending upon its use and the service conditions imposed on it.

Men engaged in assembly work must be prepared to accept design changes as they occur. They should be alert to assembly short cuts and improved methods of doing their work. The information contained herein should be used merely as a guide. Every assembly operation presents its own particular problem. To solve any given assembly problem in the most efficient manner requires a general understanding which may be obtained from a book *plus actual working experience* for which there can be no substitute.

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CHAPTER 1

ASSEMBLY PROCEDURE

Aircraft assembly is the attaching and grouping together of the many detail parts which make up a complete airplane. For purposes of assembly the airplane is broken down into the following basic structural units: wing, fuselage or hull, stabilizer, fin, control surfaces, landing gear, power plant, control system, and the necessary aerodynamic fairing at the junctions of these parts. During the assembly of these units such items as flight equipment, passenger accommodations, and any necessary equipment required during the service life of the airplane are installed.

The assembly and installation of the power plant are, in themselves, a separate phase in aircraft assembly and therefore will not be covered here. The installation of equipment and passenger accommodations will be considered only in regards to their effect on the assembly of the basic airplane structure.

In order to simplify the assembly of the basic structural units, assembly operations are divided into two phases: primary and secondary. Final assembly is the third phase of the assembly operations and is the attaching together of the basic structural units. Thus, it may be seen that the assembly operations fall into three stages: primary, secondary and final. These terms should not be confused with primary and secondary structures as referred to in structural analysis.

Fig. 1 shows the scheduling of materials from the raw, uncut and unformed parts to the final assembly of the complete airplane. Standard stock—such as sheet, bar, tube, extrusions—and standard parts—such as screws, bolts, rivets, bushings, etc.—are carried in the raw-stores stock room. The standard parts are drawn out of stock as required during the assembly operations. The sheet, tube and bar stock are hand or machine formed into detail parts. The detail parts either are used immediately or are stored in the finish-parts stock room until they are required in some stage of the assembly operation. Special parts, designed to company specifications and built by outside manufacturers, are also carried in the finish-stores stock room. With standard, detail and special parts available, the primary-assembly operation may begin.

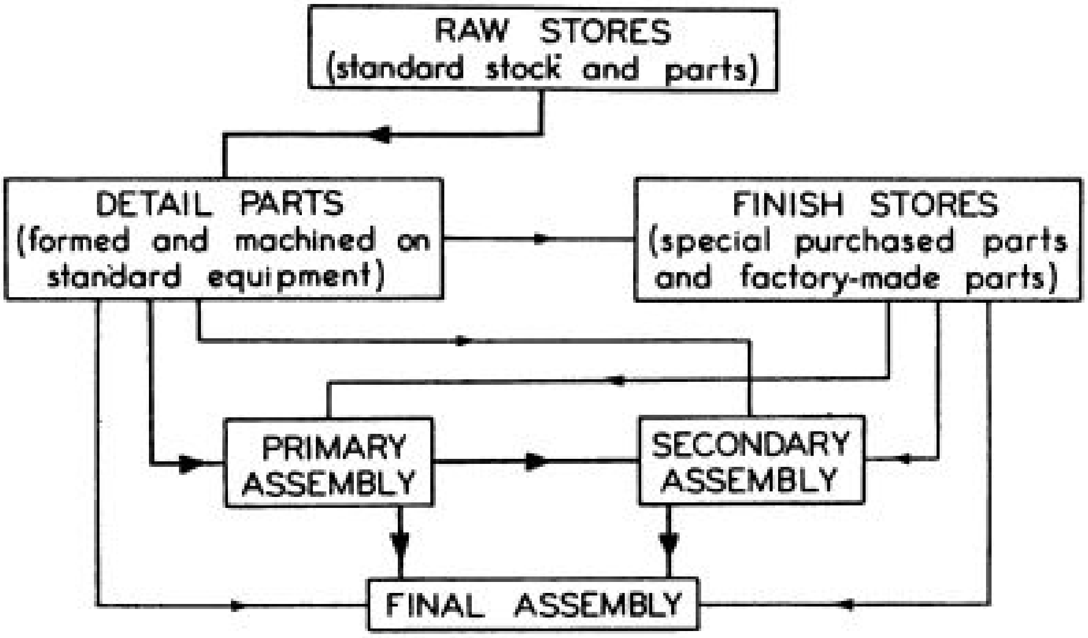


FIG. 1—ASSEMBLY SCHEDULE

In primary assembly, parts are attached together to form simple, relatively small subassemblies. Primary-assembly operations are carried out on simple jigs which serve to hold the individual parts in their proper relationship to one another while they are being put together. Typical examples of primary assemblies are: wing ribs, built-up bulkheads, fuselage panels, wing spars, etc. The parts fabricated in the primary-assembly operation also may be routed to finish stores or may be used immediately to form secondary assemblies. In some cases primary assemblies are used directly in final assembly instead of being used to form secondary assemblies. This is indicated in Fig. 1.

Primary assemblies are grouped together in larger and usually more complicated jigs to form the secondary assemblies. Very often several separate detail parts are added during secondary assembly to tie the primary units together. Detail parts may sometimes be assembled directly into secondary assemblies. However, primary assemblies are usually built up first in order to avoid undue complication of the assembly jigs and to permit a better distribution of labor. Typical examples of secondary assemblies are: fuselage sections, wing leading-edge assemblies, control-surface assemblies, and box-beam assemblies.

In both primary- and secondary-assembly operations, the individual parts are usually attached together permanently by means of rivets or welds, except in places where the design does not readily permit riveting or welding. In wooden airplanes, glued joints are used.

In the final-assembly operation, the secondary assemblies are grouped together along with any necessary detail and finish parts in the final-assembly jigs, and are attached together by means of bolts, screws, and hinge pins. These attaching elements are used to facilitate assembly, inspection, and maintenance. At this time, control and equipment installations are made and the fairings are put in place.

CHAPTER 2

ASSEMBLY DESIGN

The ease or difficulty of assembling any group of airplane parts depends almost entirely on the simplicity or complexity of the separate parts which make up the structure. Because of this it is absolutely essential that consideration be given to the assembly problems in the preliminary stages of the design.

Assembly methods will vary depending on whether wood, aluminum alloys, or steel is chosen as the principal structural material. Usually two, and sometimes all three, of these materials are combined to form the basic structural units. The choice of the material will be influenced by a number of considerations such as the cost of the raw material, the shop tools available for working it, the service for which the airplane is intended, the experience of the designers, and the specifications governing its construction as provided by the customer.

Assembly methods will also vary with the type of construction used. The structure may be a fabric-covered, welded-tubular type, as in the case of many of the fuselages of the present private airplanes; it may be riveted or welded sheet metal of the so-called stressed-skin type, as are most of the present large commercial and military aircraft; it may be a wooden-truss construction, as that commonly used in the wings of small and medium sized private aircraft; or it may be a full or semimonocoque construction in wood or aluminum, a type which is currently gaining favor because of its inherent simplicity and the weight reduction permitted by its use. It is obvious that the type of structural design chosen will influence the assembly methods used in the manufacture of the airplane. The same factors will govern the type of construction employed that influenced the choice of the material of construction.

From the above it is apparent that considerable thought must be given to the assembly problems even in the preliminary stages of the design. This is true not only because the material, the type of construction employed, and the assembly procedure will affect one another but also because the detail design of the separate parts, and consequently their cost of manufacture, will be influenced by all three of these items.

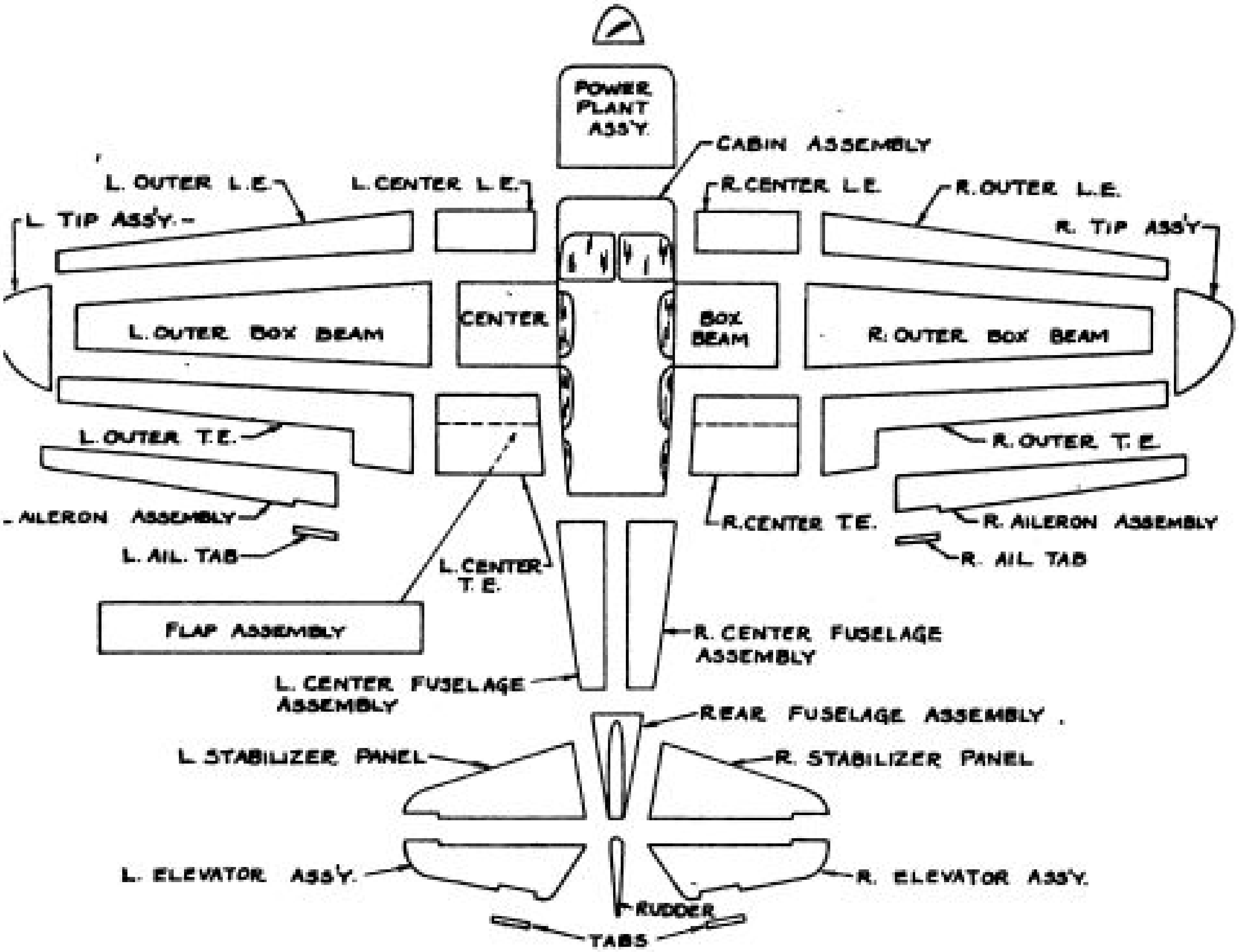


Fig. 2—Airplane Breakdown—Plan View

During the preliminary-design stages the airplane is tentatively broken down into its various secondary assemblies for production, through the joint efforts of the engineering, production and tool-design groups. Such a breakdown is shown in Figs. 2 and 3—a typical all-metal, single-engine, low-wing monoplane. This breakdown is made immediately after the major items of equipment have been located and the disposition of the useful load decided upon. At this time consideration is given to the structural and maintenance problems involved, as well as to the assembly problems. The methods of splicing together the secondary assemblies and the order in which they are to be assembled during the final assembly operation may then be decided.

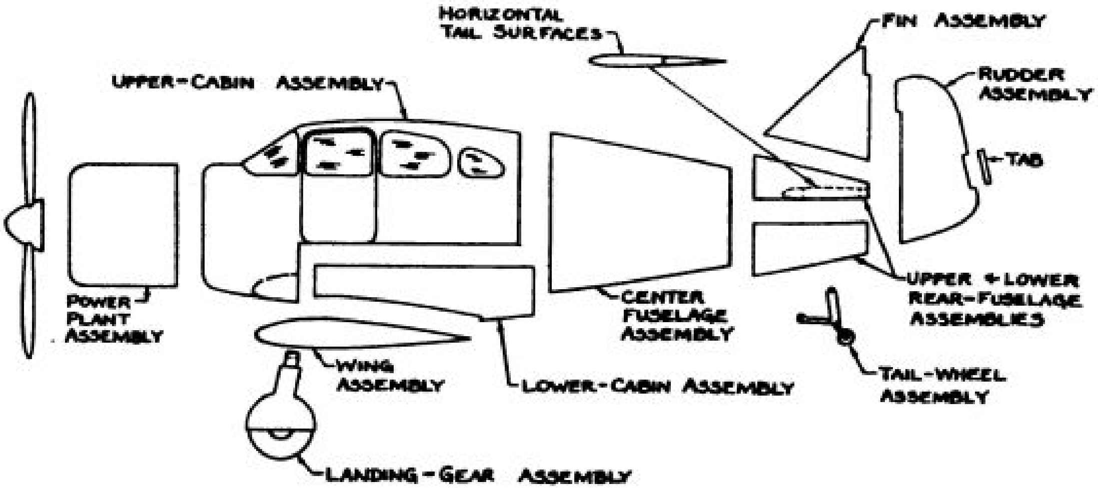


FIG. 3—AIRPLANE BREAKDOWN—SIDE ELEVATION

After the general size and shape of the secondary assemblies have been fixed, they are further broken down into primary assemblies. This is done during the detail-design stage when the size and shape of the individual parts are determined. Sometimes the detail design will show up faults in some step in the assembly process, requiring a new assembly procedure to be followed for the portion of the airplane affected. In general, the designer will follow through the assembly steps in the reverse order—that is, from final to primary assembly—to that actually used in manufacturing. This is done so that the detail design will fit the airplane rather than have the shape of the airplane and the placing of the useful load determined by design of the detail parts.

Because assembly costs are by far the largest single item in the total cost of the airplane, an increasing amount of attention is being given to designing in order to facilitate assembly operations. This is possible due to the increasing demand for airplanes and the larger number of each type which are being produced to supply this demand. In designing to simplify assembly operations, forgings, castings, and extruded parts are now being used to replace groups of assembled parts. New processes and materials are currently being developed to permit reductions in the number of parts to be assembled. This, in addition to recent advances in theories and methods of structural analysis and design, will provide less complicated structures and more simple assembly procedures in the future.

CHAPTER 3

ASSEMBLY EQUIPMENT

In aircraft assembly the following equipment is required:

1. Assembly jigs
2. Attachment elements
3. Drilling equipment
4. Hand-riveting equipment
5. Riveting machines—stationary type
6. Fusion-welding equipment
7. Resistance-welding machines

Assembly Jigs—Probably the most important of the assembly tools are the assembly jigs which hold the detail parts in their proper relationship to one another while they are being fitted and attached together. They are necessary for four reasons:

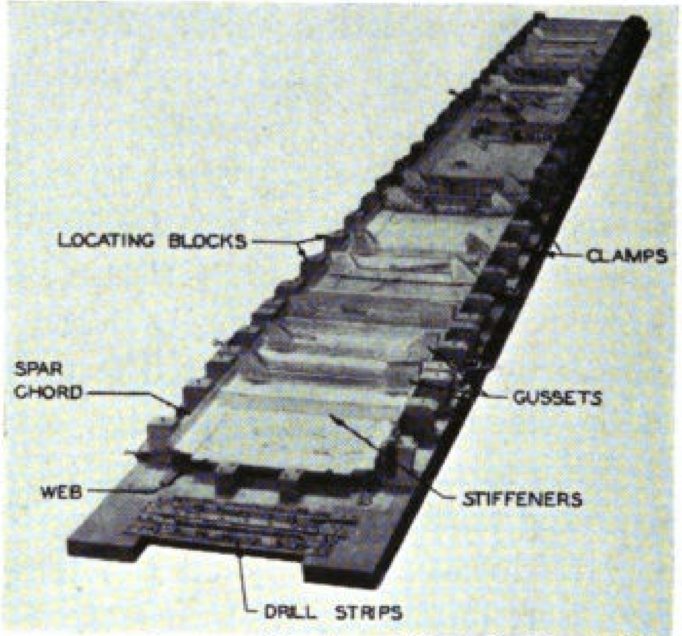
1. To maintain the proper contour of the airplane parts so that the finished product will be "fair" or streamlined.
2. To provide dimensional accuracy in the separate primary and secondary assemblies so that they will fit together properly.
3. To permit interchangeability of parts so that sections damaged in service may be replaced without any hand-fitting operations.
4. To locate *accurately* important connection points such as wing-hinge and landing-gear attachment points.

The assembly jigs are usually designed in the tool-design group by experienced engineers and production men working from the blueprints of parts and assemblies as provided by the engineering department. Because the jigs may be used only for the construction of one particular type of part, the complete cost of each jig must be written off over the number of units to be produced on it. As the number of airplanes to be built increases, it is economical to spend more time in the design and construction of each jig. This is true because minor refinements may then be made which will permit more rapid assembly of the detail parts. In the case of experimental work or in the construction of very simple structures, only the more important and larger assembly jigs may be designed by the tool-design group. In such cases the responsibility for the design and construction of the remaining jigs is left to the shop.

Assembly jigs are usually constructed of wood or structural steel or a combination of the two. Wooden jigs are employed where relatively few units are to be produced or where the assembly operations are not likely to cause wear and inaccuracy of the jig, even after many assemblies are constructed on it. Generally the use of wood is restricted to small or simple jigs such as those used in the assembly of built-up ribs, bulkheads, etc. Often such assemblies are drawn to full scale in the loft on sheet-metal templates so that the restraining clamps used to hold the parts in place in the jig may be located directly on the template which then becomes a part of the jig.

Fig. 4 shows a typical wooden jig used for the assembly of a web-type wing spar; this is a primary assembly. Because of the relative simplicity of the spar and because the wear on the jig during the assembly operations is slight, this jig was constructed of wood. The blocks which hold the restraining clamps for the spar flanges are screwed to the planks which form the base of the jig. Metal clamps are used. After the web and spar flanges have been assembled on the jig, the web stiffeners are set in place; these stiffeners are also located in their proper relationship to one another by means of the clamp blocks. The strips, shown in the foreground of Fig. 4, are steel with hardened bushings. They are used to locate and drill the rivet holes through the stiffener flanges and the spar web. Prior to setting the stiffeners in place and drilling them by means of these drill guides, larger steel strips (not shown in Fig. 4) are laid on the spar flanges for drilling the double row of rivet holes in the web and flanges. Note the power drill in the background.

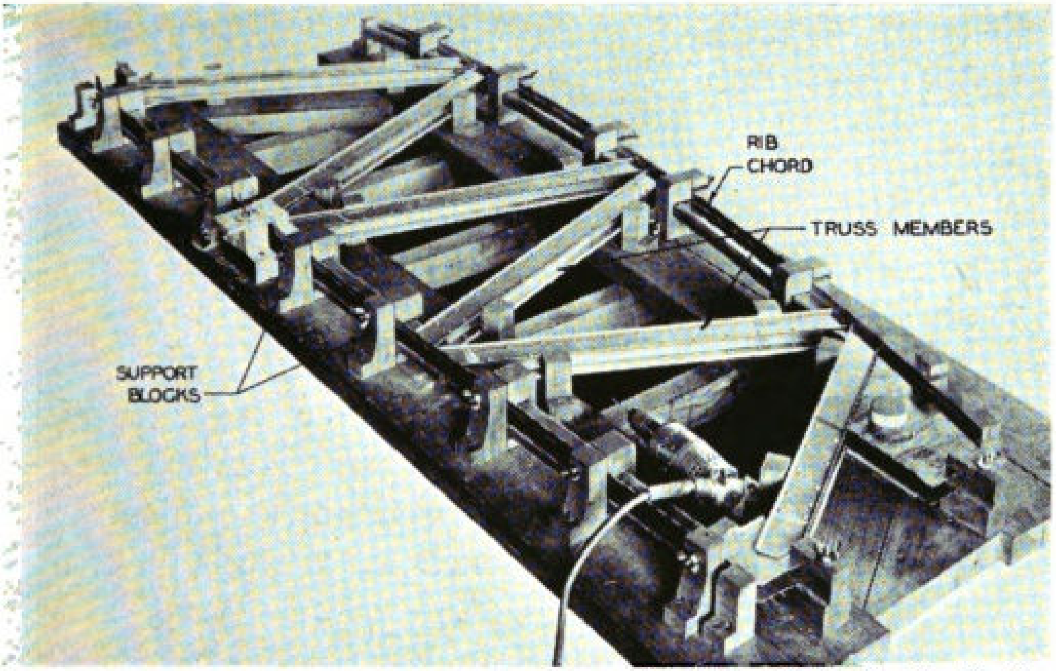
Fig. 5 shows a wooden jig used for the assembly of a truss-type interbeam rib; this is also a primary assembly. Note the use of wing nuts on the support blocks. The inner half of the support blocks may be removed by loosening these wing nuts so that the completely drilled and assembled rib may be removed from the jig. The truss members, which consist of four channels riveted together to form a tube, are assembled before being located in this jig.



Courtesy Glenn L. Martin Co.

FIG. 4—WING SPAR IN ASSEMBLY JIG

Steel jigs, although generally more expensive, are preferable to wooden jigs because of their greater durability and their ability to retain their original dimensions over a longer period of time and under varying atmospheric conditions. Steel is used when a large number of units are to be constructed and especially when duplicate jigs must be built to increase production schedules. Where great accuracy is required—as in the location of wing-hinge pins, landing-gear attachment fittings, etc.—steel jigs must be employed. In general, it may be said that from the standpoint of accuracy wood is satisfactory jig material for the assembly of sheet metal, tubular and extruded sections, but is unsatisfactory for the assembly of machined parts where tolerances are only several thousandths of an inch. Metal templates are also used in the construction of steel jigs.



Courtesy Glenn L. Martin Co.

FIG. 5—WING RIB IN ASSEMBLY JIG

Steel jigs are constructed from standard steel sections and are either bolted or arc-welded together. Bolts or removable pins are used where the jig must be partly disassembled to permit the removal of the finished part. Welding is used at all other points where permanent attachment of the jig parts is desired.

Fig. 14 shows a steel jig which is used for the assembly of a box beam of a typical two-spar stressed-skin wing; this is a secondary assembly. The spars and the ribs, one of each being shown in Figs. 4 and 5 respectively, are located in the assembly jig and lined up in proper relationship to one another. The hinge fittings are also located in this jig which is checked against the jig used in assembling the adjoining panel to insure that the assemblies will fit one another and be interchangeable. Note that the steel plate at the end of the jig has rectangular cut outs to provide ease of access to the parts being assembled.

The particular jig shown in Fig. 14 is a horizontal floor type and the box beam is assembled in the same relationship to the ground that it will be when it is installed in the completed airplane. Sometimes such jigs are set up with the spars horizontal and with the upper and lower wing skin vertical. They are then known as vertical jigs. The horizontally placed wing jigs make it easy to drill and attach such important elements as the flap-hinge brackets and engine fittings since they are located at chest height from the ground. On the other hand, riveting of the skin to the ribs is more difficult since the rivet guns and bucking bars must be held vertically, requiring the operator to crouch beneath the wing or climb upon it to work. Vertical jigs make riveting operations much easier but present more difficulties in the attachment of the hinge brackets, engine-mount fittings, etc.

Temporary jigs are usually used in the construction of experimental models and in some instances for the construction of the first set of parts for a production contract. Such temporary jigs are very simply constructed and are made from either wood or metal. Because jigs of this type usually do not locate all parts of the assembly, many are located by means of measurements made from a set of arbitrary reference plans. It is much more economical to do most of the experimental assembly work by hand than to build expensive assembly tools for the construction of one or two sets of parts.

When the first units of a contract are to be made on a temporary jig, the finished set is very carefully checked for accuracy and fitted to other parts to which it is to be assembled. When all dimensions are found to be satisfactory, permanent jigs are constructed around the first parts. Other units built on these jigs will naturally be exactly like the first ones. This method of constructing jigs is satisfactory when time limitations prevent the tool department from designing any but the most important jigs.

Attachment Elements—Attachment elements such as rivets, welds, bolts, screws, dope and various patented fastening devices are used to hold the separate parts together once they have been properly located in the assembly jigs. These attachment elements may be listed as aircraft parts—which they are—as well as assembly equipment.

In aluminum-alloy structures, rivets are the most common attachment elements, being used where the attachment between parts is more or less permanent. Bolts and machine screws are usually employed wherever parts are likely to be disassembled for repair or maintenance, in places where loads are too high to be taken by the small size rivets normally employed, and in places where it is difficult to head up rivets. Resistance welding, in the form of spot welds (sometimes also referred to as "shot" welds), is also coming into favor for both aluminum and steel structures. Rivets are very seldom used on steel structures because steel is difficult to drill and rivet and because it is so easily welded by resistance, arc, or fusion methods.

In the construction of wooden airplanes, animal glues and, more recently, synthetic glues of either the cold-setting or heat-setting varieties are used in the attachment of parts in primary and secondary assemblies. Steel fittings, bolted to the wood members, are used to connect the major structural units. Dope and screws are employed in the assembly of most fabric coverings to wood or metal structures.

Patented devices such as Dzus fasteners, elastic stop nuts, "blind" rivets, etc., are used when only one side of the assembly is accessible. An example of this is in the installation of wing-fuselage fairing where the inner face of the fairing is inaccessible for bucking up rivets or drawing up nuts because of the restricted space inside the wing and the interference of equipment in the fuselage. Removable cowling and access doors are attached to the main structure by means of easily removed fastening devices.

The attachment elements and their relative importance in various types of aircraft structures may be listed as follows:

A. Aluminum alloy
    1. Rivets
    2. Bolts and machine screws
    3. Welds
        a. Torch (fusion)
        b. Resistance (spot)
    4. Patented devices
B. Steel tubular
    1. Welds
        a. Torch
        b. Arc
    2. Bolts and machine screws
    3. Patented devices
C. Steel sheet
    1. Welds
        a. Resistance
        b. Torch
        c. Arc
    2. Bolts and machine screws
    3. Patented devices
D. Wood
    1. Glue
        a. Synthetic
        b. Animal or vegetable
    2. Bolts and screws

Drilling Equipment—Drilling equipment is naturally required for the drilling of bolt or rivet holes. This includes such items as power drills, bits, reamers, taps, drill extensions, countersinking tools, drill jigs, etc.

Both the light hand drills and the more powerful drill presses are used. The hand drills are used primarily for the drilling of rivet holes, etc., in sheet-metal parts. Due to the machineability of the aluminum alloys a certain amount of experience is required to prevent the drilling of elongated holes and tool marks caused by the drill "wandering," before it is properly centered. Drill presses are used where greater accuracy is desired, when large numbers of small formed parts are to be bench drilled, or where relatively large holes must be cut. Machined fittings and forgings which must be drilled are worked on drill presses with special drill jigs which are provided to center the holes. In the assembly of wing spars for large airplanes, drill presses mounted on tracks which straddle the spars are sometimes used to drill the bolt and rivet holes in the spar flanges and stiffeners.

Reamers are used whenever very accurate fits are required. Usually this means all bolt holes and particularly the hinge-pin holes for wing, landing gear, and similar places where high loads are concentrated. Standard aircraft bolts are made to close tolerances and are fabricated from high quality steels. Bolts must be properly seated in their holes in order to carry their full load. If oversize, rough, misaligned holes are provided the full permissible design load cannot be carried by the bolts, and structural failure may result.

Taps are sometimes used because the special nature of some part requires that bolts be threaded directly into it. The fine-thread series is normally employed.

During secondary- and final-assembly stages, rivets must sometimes be set in difficult positions where there is no room to line up and hold the power drill. In such cases flexible extension shafts (sometimes called "snake" drills) are used on the drills to hold the bits. Angle extensions are also used where there is insufficient clearance for a drill in a position perpendicular to the place to be drilled. Assemblies should be designed to avoid the use of such pieces of special equipment. However, the special nature of some parts of the structure makes it virtually impossible to eliminate such equipment entirely.

Countersinks and counterbores are required to recess the heads of countersunk-type rivets, screws and bolts. Countersunk rivets are being used more extensively to eliminate the rough surfaces caused by the protruding heads of round- and brazier-head rivets. They are also used when the heads of other types of rivets would interfere in a lap joint or where moving parts slide across the riveted surface. Counterbores are used to seat bolt heads properly on the surfaces of forged fittings where a draft angle exists or in any other place where the bolt head cannot otherwise be seated on a plane perpendicular to the bolt shank.

Drill jigs are the only piece of equipment used in drilling which are not standard. They usually consist of steel plates or strips with the proper size guide holes correctly located and are cut to fit the assembly. The jigs are hardened locally in the vicinity of the holes in order to prevent wear. When the size of the guide holes exceeds 1/4 in., hardened steel bushings are used instead of merely hardening the strip stock. Pins and stops are usually employed to locate the drill jig on the assembly jig. At important attachment points the assembly jig itself becomes the drill jig.

Hand-riveting Equipment—Hand-riveting equipment includes such items as pneumatic rivet guns, bucking bars, hand squeezers, rivet sets, etc. All such equipment is standard with the exception of bucking bars, which usually consist of blocks or rods of steel cut and bent to shape to fit the particular assembly being riveted. Recently the larger manufacturing plants both in the United States and abroad have made efforts to standardize their bucking tools in order to eliminate a large number of oddly shaped, unlisted, hand-made tools which are usually made to satisfy one particular riveting condition and no other.

Pneumatic rivet guns are used almost universally for heading up rivets. They may be either the "one shot" or repeating type. The one-shot guns are usually larger than the repeating guns since all the work in upsetting the rivet must be accomplished by one blow. This requires a larger chamber and longer stroke to produce the necessary energy. The advantage of the one-shot gun lies in the fact that the rivets are not progressively cold worked during upsetting, and hence the tendency to crack rivets is reduced. The repeating guns are usually preferred because energy, and hence the degree of "upset" applied to the rivet, may be regulated by the number of blows rather than by presetting the length of stroke as in the case of one-shot guns. Their somewhat smaller size also makes them more flexible.

Hand squeezers are used to upset rivets in places where there is insufficient room for a rivet gun in a direction parallel to the rivet shank but plenty of space perpendicular to a shank. Such a condition would exist where two flanges are riveted together, as shown in Fig. 6.

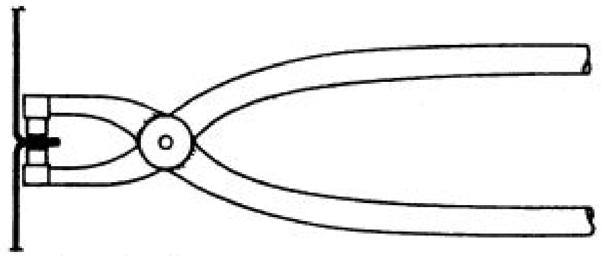
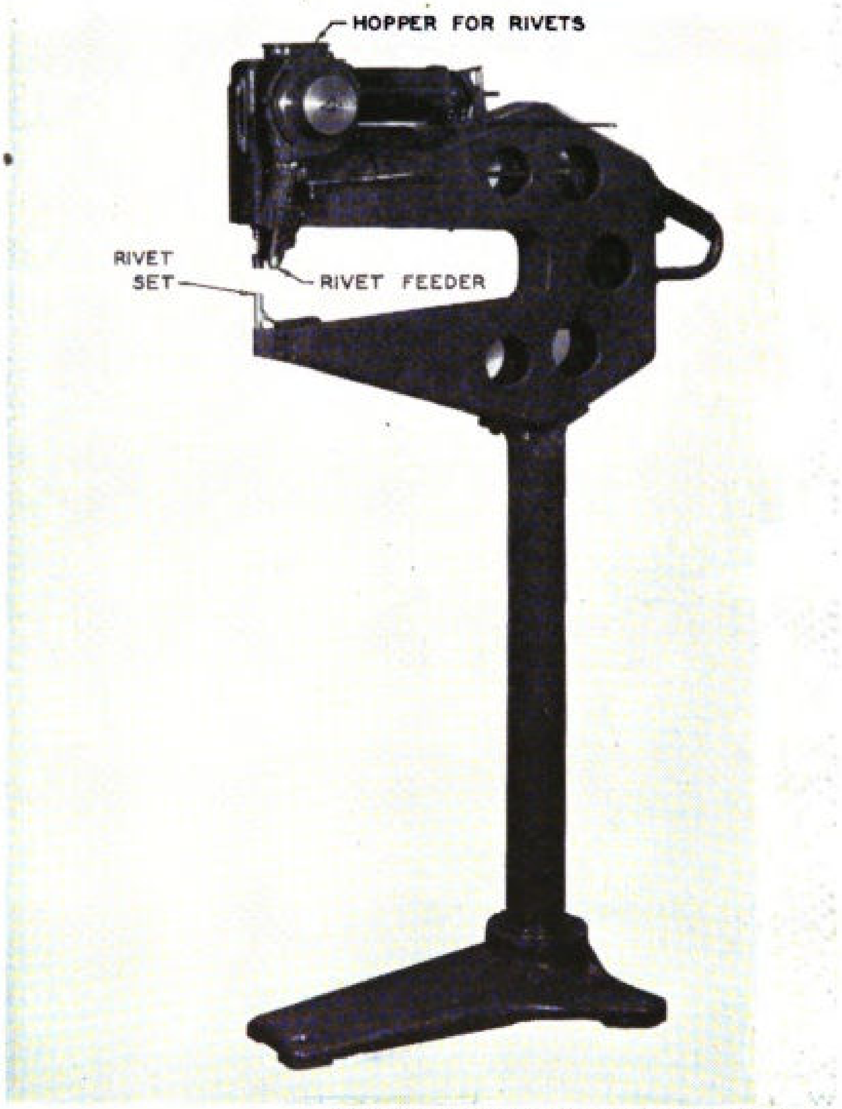


FIG. 6—HAND-SQUEEZE RIVETER

Rivet sets must be provided to fit each of the various shapes and sizes of rivet heads employed. These are fitted in the rivet gun as required for the riveting operation.

The small size of most of the hand-riveting tools renders them very flexible and permits the riveting operations to be carried out while the parts are in the jigs and immediately after the rivet holes have been drilled. This is an advantage on rather complicated assemblies where it is desirable to use rivets instead of screws or bolts but where riveting machines cannot be employed due to the shape or size of the assembly.

Riveting Machines—Stationary Type—Riveting machines of the automatic or semiautomatic types are now coming into general use, particularly for the less complicated assemblies such as beams, built-up bulkheads, and panels consisting of skin and stiffener combinations. Their use permits rivets to be set more uniformly and economically. Where the design adapts itself to riveting machines, the parts are assembled and drilled in the assembly jig and are attached together at a few critical places with machine screws. They may then be removed from the assembly jig



Courtesy Engineering Research Corp.

FIG. 7—ERCO RIVETER

and riveted on the machine. Since the time-consuming riveting operations do not then have to be accomplished in the jig, this procedure has the advantage of clearing more quickly the expensive assembly jig for the next unit, as well as permitting the use of a faster, cheaper riveting method.

Some riveting machines, such as that shown in Fig. 7, not only upset the rivet but also punch the rivet hole and feed the rivet into it. When this type of equipment is used it is usually desirable to make a frame-work type of jig which will hold the parts and which is light enough to be transported to the riveting machine. Machines of this type are now being used to rivet sheet-metal flap, aileron and spar assemblies on light airplanes. The "flat" nature of the parts and the relative simplicity of the jigs for such parts render the use of automatic riveting machinery very practical.

It is desirable to design to permit the use of riveting machines whenever possible because they speed up production, and also the reduced flexibility of the machines themselves sometimes force upon designers the use of more simple structures and a more careful breakdown of the airplane into less complex and more easily handled subassemblies.

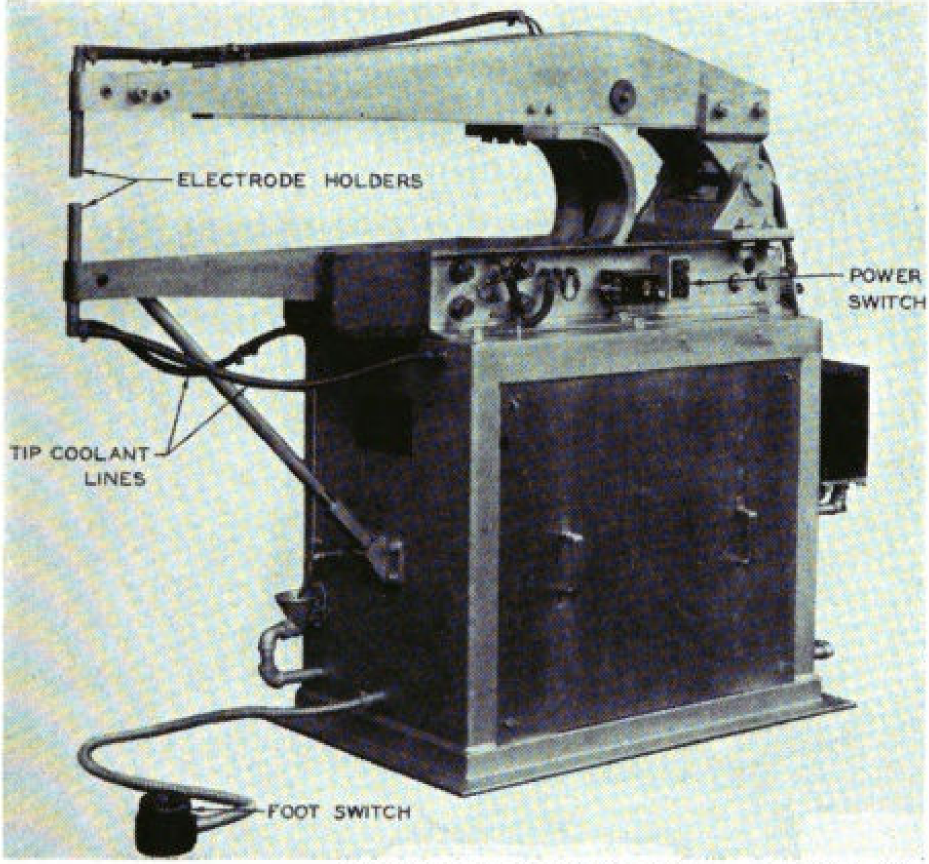
Fusion-welding Equipment—Fusion-welding equipment (consisting of welding torches, air and gas in tanks under pressure, welding rod and flux) is used in the assembly of tubular-steel structures, built-up fittings, exhaust manifolds and in the assembly of aluminum and steel fuel and oil tanks. Where this type of welding is used, parts must be very carefully located and rigidly held in the jig to prevent misalignment due to shrinkage and the uneven distribution of heat caused by welding. Since the present tendency is toward stressed-skin, sheet-metal airplanes, fusion welding now represents but a small portion of the labor required in assembly operations. The notable exception to this is the light airplane field where steel-tube fuselages are still generally used. Engine mounts, exhaust-collector rings, fuel tanks and built-up fittings are the only fusion-welded parts normally found in transport and military airplanes. Fusion welding does not readily lend itself to quantity production because the unit cost of a welded structure cannot be reduced appreciably as the number of units being produced increases. This is due to the high degree of skill required to produce a dependable torch-welded joint in the thin-walled sections usually welded and also due to the fact that a built-up, torch-welded structure cannot be further simplified for production.

Resistance-welding Machines—Resistance welding is now finding its way into the aircraft industry both in the forms of arc and spot welding.

Arc welding is, in some cases, being used to replace fusion welding in the typical parts listed above. Recent improvements in arc-welding technique has made possible the welding of thin-walled sections. Arc welding is widely used in the construction of steel assembly jigs because the very local heating of the steel does not cause appreciable shrinkage or warping of the steel, as in the case of fusion welding. This is one of the main advantages of arc welding. Where the jig parts are to be bolted together rather than arc-welded there is always more danger of misalignment of the jig parts caused by vibration of the drill during the drilling of the bolt holes.

Arc welding is accomplished by striking an arc between a flux-coated steel welding rod and the pieces being welded together at the point where they are being joined. The flux prevents the rapid oxidation of the metal while it is in the molten state and hence prevents the inclusion of iron oxides which would weaken the weld. Metals other than steel may also be arc-welded, but steel is by far the easiest to weld because of its high resistance. Steel is the only metal which is arc-welded for use in aircraft structures. Fig. 32 shows an arc welder being used in assembling an engine mount. The welder is a portable type and may be wheeled from place to place to suit the factory needs.

Spot, or "shot," welding is used in the attachment of sheet-metal parts in aluminum-alloy and stainless-steel structures. In the case of stainless steel, spot welding is the only economical method of joining the sheets because of the comparative difficulty of drilling the material and heading up steel rivets. Spot welding is generally much cheaper and faster than riveting for aluminum and steel structures. Portable welders may be used for welding steel because the amperages seldom exceed 10,000, whereas aluminum welding machines, such as that shown in Fig. 8, are stationary because the amperages are seldom less than 15,000. Because of this difference in the properties of the two metals and subsequently the difference in size of the equipment used to



Courtesy Federal Machine and Welder Co.

FIG. 8.—SPOT-WELDING MACHINE

weld them, steel may usually be spot-welded less expensively than aluminum. This production advantage is largely offset by the fact that when steel is used more parts are usually needed and the forming operations are more intricate than for aluminum when the same weight of structure and load-carrying ability are required.

Resistance-welding equipment is in general more flexible than riveting machines but not as flexible as hand-riveting equipment. Its use must be considered in the preliminary design stages, just as in the case of machine riveting, since the very design of the equipment itself influences the design and assembly of the parts to be welded.

In addition to the above equipment (which is furnished by the shop), screwdrivers, wrenches, pliers, micrometers, levels, squares, scales, plumbs and similar small tools which are normally found in the toolbox of a first-class mechanic are used in assembling airplanes.

CHAPTER 4

RIVETING AND BOLTING

While considerable information is available concerning welding, glueing and other methods of holding parts together, relatively little data on riveting and bolting is available—although rivets and bolts are the two commonest methods of forming joints in the aircraft industry. Neither riveting nor bolting may be considered difficult operations, but a great deal of attention should be given to the quality of this type of work because the integrity of the whole assembled structure depends upon the ability of these structural "links" to hold the load-carrying members together. The lives of the passengers and crew depend upon the ability of the assembly man and the watchfulness of the inspectors. Because of this the following information on rivets and bolts is presented.

Bolts are used in the assembly of all types of structures (see section on Attachment Elements in Chapter 3), while rivets are employed primarily in aluminum-alloy structures.

Table 1 lists the driving procedure and the physical properties of various rivet materials when used in aluminum-alloy structures. The hot-driven aluminum and steel rivets are practically never used in aircraft work; their use is restricted to the manufacture of heavy items such as cranes, pressure tanks, etc.

It will be noted that the 17ST and 24ST types must be driven cold after quenching. These rivets age-harden and must be driven shortly after heat treatment, which temporarily softens them. Unless stored in dry ice or at least at zero temperature (F.) (which retards age hardening), the 17ST rivets must be driven within 2 hours of heat treatment and the 24ST rivets within 20 minutes. If this is not done they are much harder to drive properly. Because of this restriction A17ST rivets are usually used instead, unless design conditions make it absolutely necessary to use the slightly stronger 17ST and 24ST types. The 2S and 3S rivets are generally used for fuel and oil tanks where it is desired to "puddle" the rivet head with a welding torch in order to prevent leakage from under the head.

TABLE 1. AVERAGE ULTIMATE SHEAR STRENGTH AND BEARING STRENGTH FOR DRIVEN RIVETS

Rivet	*Driving Procedure*	*Shear Strength, Lb. per Sq. In.*	*Bearing Strength,*[1] *Lb. per Sq. In.*
2S	Cold, as-received	11,000	33,000
3S	Cold, as-received	14,000	42,000
A17ST	Cold, as-received	30,000	90,000
17ST	Cold, immediately after quenching	34,000[2]	102,000
24ST	Cold, immediately after quenching	37,000[2]	102,000
53SW	Cold, as-received	24,000	72,000
53ST	Cold, as-received	26,000	78,000
17ST	Hot, 930° to 950° F.	33,000[2]	99,000
53SW	Hot, 960° to 980° F.	18,000[2]	54,000
Steel	Hot, 1700° to 1900° F.	45,000	135,000

[1] These bearing strengths are to be used only if they are less than the corresponding bearing ultimate strength for the plates or shapes in which the rivet is used.

[2] Immediately after driving the shear strengths of these rivets are about 75% of the values shown. On standing at ordinary temperatures they age-harden to develop their full strengths, this action being completed in about four days.

Courtesy Aluminum Company of America

To insure that the improper grade of rivet will not be used in shops where more than one rivet material is employed, the Aluminum Company has adopted standard identification marks for the most used grades. These are: a small raised teat in the center of the rivet head for the 17ST type, a small depression in the center of the rivet head for the A17ST rivets, and for the 24ST grade two raised ridges extending radially from a point near the center of the head to the rim and spaced 180 deg. apart. An examination of the wing and fuselage of any present transport airplane will disclose that A17ST rivets, distinguished by the small depression, have been used in its construction.

In aircraft riveting it is seldom that rivet diameters exceed $\frac{1}{4}$ in., and the majority of rivets used are of $\frac{1}{8}$-in. and $\frac{5}{32}$-in. diameter. The diameters vary by thirty-secondths of an inch from $\frac{1}{16}$ in. to $\frac{3}{16}$ in. Lengths vary by sixteenths for lengths from $\frac{1}{16}$ to 1 in. and by eighths from 1 in. to 2 in.

In setting rivets, a number of the fundamentals of good riveting practice must be followed. These and the reasons for their being may be listed as follows:

Always use the rivet material specified by the drawing. If too soft a rivet is used, the joint will not be strong enough, and if too hard a rivet is used, more energy and time is required to drive the rivet. Furthermore, if the plates being riveted are substantially softer than the rivet, they may be damaged by the heading of the hard rivet. The identification marks provide an easy method of getting the correct rivet.

Use the correct drill size in drilling rivet holes. These are:

Drill Size for	*Rivet Diameter*
#50	$\frac{1}{16}''$
#40	$\frac{3}{32}''$
#30	$\frac{1}{8}''$
#20	$\frac{5}{32}''$
#10	$\frac{3}{16}''$
$\frac{17}{64}''$	$\frac{1}{4}''$

Use the correct edge distance which is two rivet diameters from the center of the rivet to the nearest edge of the sheet. For example, the centers of $\frac{1}{8}$-in. diameter rivets should not be nearer than $\frac{1}{4}$ in. to the nearest sheet edge. If the edge distance is less than this amount, the full strength of the rivet will not be developed in this direction. If edge distances become excessively small, adjacent sheet edges may even be bulged by the expansion of the driven rivet.

If the rivet holes are drilled too large the rivet will not properly fill the hole, and hence may become loose and not develop full strength. If driven hard enough to fill the oversize hole properly, internal cracks may be developed due to excessive cold working, which will also cause rivet failure. If a rivet hole is drilled oversize by mistake, the next larger size rivet should be used—*but only through the authorization of the inspector responsible for passing on the workmanship.* An oversize rivet will not necessarily increase the strength of the joint; in fact it may weaken it due to the removal of the additional metal by the larger drill or by decreasing the edge distance below the minimum.

Drive heat-treatable rivets—17ST and 24ST—within the prescribed periods. If this is not done cracks may develop around the edge of the driven head, which will greatly reduce the resistance of the rivet to vibration and may subsequently cause failure.

Use the proper length of rivet. This may be determined by taking the sum of the sheet thicknesses being riveted and adding to it 1½ diameters. Since rivets come in lengths by steps of $\frac{1}{16}$ in., the nearest standard-length rivet is used which is *greater* than the calculated sum. For example, if the sheet thicknesses .064 in., .045 in. and .040 in. are to be riveted by a ⅛-in. rivet, the length would be $(.064'' + .045'' + .040'') + (1.5 \times \frac{1}{8}'') = .337''$. Since this is over $\frac{5}{16}$ in. but less than ⅜ in., the ⅜-in. rivet length must be used.

The driven head should have a diameter approximately 1½ times the rivet-shank diameter when the proper length of rivet is used. This size for the driven head combines the best qualities of strength and appearance without excessively cold working the rivet.

Where there is any possibility that the sheets being riveted are not pulled tightly together before riveting, measures should be taken to pull them face to face. Otherwise the rivet shank will expand in the space between the sheets and make a poor joint, also the amount of shank extending will be insufficient to make a properly driven head.

Properly shaped rivet sets must be used on the side of the manufactured head. Undersized tools will cut into the head of crowned rivets—such as round, mushroom and brazier heads—while sets which are too large will cause a "flat" on the head and not force the edges down on to the sheet. For countersunk types, a polished, large diameter, flat set with well-rounded edges should be used to prevent marring the sheet. The bucking tools should be amply heavy. If they are too light the shank may be bent rather than upset during the initial blows, causing an off-center head.

Never set rivets in elongated holes or "double" holes (two holes drilled side by side but overlapping). In the first place, holes of this type weaken the structure, and in the second place, rivets set in such holes cannot possibly be properly headed. While this might appear to be needless caution, it is surprising how many times such conditions are found by inspection, and when they are not found, the result may spell disaster for the pilot and crew.

Bolts are used in place of rivets whenever:

1. Loads are too high to be taken by rivets.
2. The structure must be disassembled from time to time for inspection, repair or maintenance.
3. Accessibility restrictions make it impossible to head rivets.
4. Tension loads are to be taken by the attaching elements. Rivets are not considered satisfactory in tension.

Special high quality bolts on which diameters, thread fits, and thread lengths are held to exceptionally close tolerances have been developed for the exacting requirements of the aircraft industry. These bolts are always used. In certain instances where the heads of hex bolts would, if used, project into the air stream, countersunk screws are employed instead. Such screws are, of course, made to the same standards as bolts.

With bolts and screws two types of nuts are used: castellated or self-locking. Of the latter several types are used, the most popular of which is the elastic stop nut which has a fiber inset to lock it to the bolt. Other types have metal-locking devices incorporated in the nut.

Just as in the case of rivets, certain precautions must be taken in assembling parts with bolts and screws. These may be listed as follows:

Always meet the fit requirements for the bolt as specified, and to insure it the hole must usually be reamed. This is necessary because where bolts are used, the loads are generally high and no looseness which will permit relative motion of the assembled parts can be tolerated, because such motion might cause loads higher than those for which the bolt was designed.

Nuts should not be drawn up too tightly. It is almost as bad to have the bolt too tight as too loose. With a long handled wrench and the low pitch found on fine thread bolts a man can cause tension loads of thousands of pounds in a bolt. Sometimes overtightening causes the bolt or nut threads to be "stripped." In addition, overtightening can cause the bolt or nut head or the washers beneath them to be embedded in the parts being bolted together—as when steel bolts are used on aluminum parts.

When elastic stop nuts are used, bolts with cotter-pin holes should not be employed. The burr around the cotter-pin hole injures the fiber in the stop nut.

Stop-nut fiber must *never* be drilled or tapped; to do so defeats the purpose of the fiber (to grip the bolt so the nut will not become loose). This might seem like a needless precaution, but numerous cases are on record where stop nuts have been drilled and tapped.

Wherever possible and unless specified otherwise, bolts should be inserted so that the nut end is downward with the airplane in level-flight condition.

When taper pins are used (such as in the pull pins on folding-wing mechanisms), great care must be taken in reaming the hole for the pin so that smooth operation is attained.

Whether using screws or bolts, the bolt should be held and the nut tightened. The proper size wrench should always be used, never a pair of pliers which will mar the nut or bolt head.

Just as in the case of rivets, the size of bolt specified and the proper edge distance must *always* be used. Bolt-edge distances are usually about 2 bolt diameters. However, this is not as hard and as fast a rule with bolts as with rivets, because the loadings on the bolts sometimes permit smaller edge distances and sometimes require larger ones. This is caused by the difference between the physical properties of the steel bolts and the aluminum parts they join together, as well as the fact that bolts may be loaded either in shear or in tension, whereas rivets always are loaded in shear.

In some designs bolts are attached directly to structural members by tapping into the members. In such instances considerable care must be exercised in drilling and tapping properly. This condition seldom occurs except in fittings where jigs and fixtures may be used both for drilling and tapping the hole.

CHAPTER 5

WING BREAKDOWN

Inasmuch as the wing supports the airplane in the air and because of the present tendency to install power plants, fuel tanks, landing gear, and a considerable amount of equipment within it, the wing is probably the most important of the structural units.

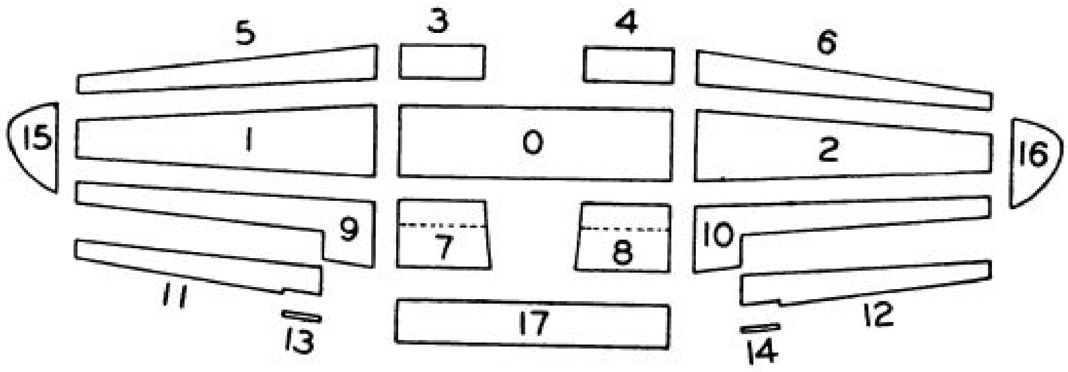


FIG. 9—WING BREAKDOWN

0. Center Box Beam
1. Left Outer Box Beam
2. Right Outer Box Beam
3. Left Center Leading Edge
4. Right Center Leading Edge
5. Left Outer Leading Edge
6. Right Outer Leading Edge
7. Left Center Trailing Edge
8. Right Center Trailing Edge
9. Left Outer Trailing Edge
10. Right Outer Trailing Edge
11. Left Aileron
12. Right Aileron
13. Left Aileron Tab
14. Right Aileron Tab
15. Left Wing Tip
16. Right Wing Tip
17. Flap

For purposes of assembly, the wing is usually broken down into a number of subassemblies, as shown in Fig. 9. This facilitates construction and also permits a greater number of men to work on the various wing parts at the same time.

The breakdown shown is fairly representative of normal wing construction; that is, it represents a two-spar wing, the front and rear spars of which form the vertical sides of the box beam, with the skin in between being stressed to take bending as well as twisting loads. The leading and trailing edge, as well as the tips, transmit their load to the box-beam portion which supports them.

Each of the separate subassemblies of Fig. 9 are made on a jig provided for their construction. After the subassemblies are finished they are assembled together into groups to form wing panels. The wing shown consists of three panels and the two tip assemblies. The left outer panel consists of items 1, 5, 9, 11, and 13; the right outer panel of items 2, 6, 10, 12, and 14; the center panel of items 0, 3, 4, 7, 8, and 17. These three panels and the tips are then assembled together to form the complete wing.

In the following chapters dealing with wing assemblies, the subassemblies which go to make up the complete wing will be taken up separately and discussed in detail.

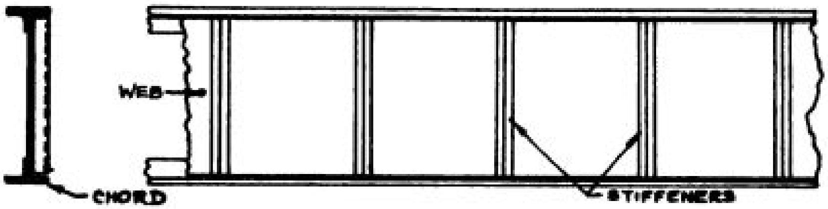
CHAPTER 6

WING-SPAR ASSEMBLY

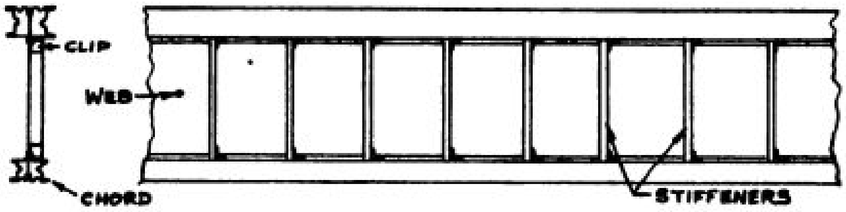
The main structural elements of the wings are the spars. These usually carry most of the load resulting from the lift of the airfoil section. Wings may be these types: monospar, two spar, or multi-spar, depending upon the number of beams used to carry the load. The most common type is the two-spar wing as described in Chapter 5. When corrugations or other stiffening members are added to the skin between the spars, the wing construction becomes what is known as a box-beam type.

The spars may be constructed of aluminum alloy, stainless or chrome-molybdenum steel or wood. Typical examples of spars made from these materials are diagrammed in Fig. 10. The choice of the material used for spar construction is generally dependent upon the material chosen for the construction of the remainder of the airplane, which in turn is determined by the factors mentioned in Chapter 2. Usually there will be relatively little difference in the weight and load-carrying ability of the spars for any particular design using any of these materials if the same degree of engineering and manufacturing skill is employed. The relative merit of each of the different materials as structural elements is too involved to be discussed here.

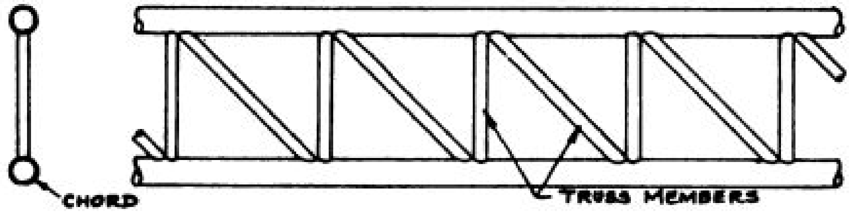
Owing to the fact that most airplane wings taper from root to tip, the spars must also taper. This fact plus the necessity of having to save every possible ounce of structural weight makes it necessary to build up the spars from a number of separate parts. On strut-braced airplanes whose wings do not taper, extruded aluminum-alloy sections or rectangular-section wood spars may be used in place of the more complicated but more efficient built-up spars. No taper is shown in any of the spars of Fig. 10 which merely represents basic differences in construction.



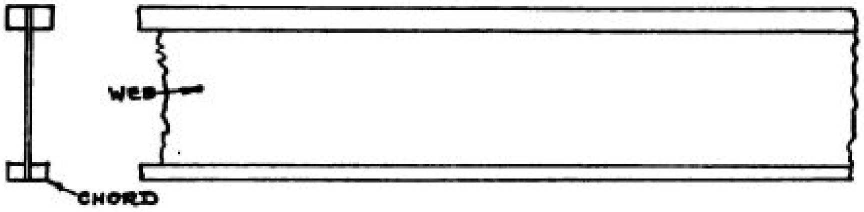
ALUMINUM ALLOY



STAINLESS STEEL



CHROME MOLYBDENUM



WOOD

Fig. 10—Typical Wing-spar Construction

Aluminum-alloy Spars—Aluminum-alloy spars will be discussed first since this class of material is the most widely used in aircraft construction.

Aluminum spars may be either web or truss type; the web type (shown in Fig. 10) is the most popular because it is generally somewhat lighter than an equivalent truss spar.

Technically, a web spar is referred to as a Wagner beam. It consists of the following:

1. Chords or flanges, upper and lower
2. A shear member, the web
3. Vertical stiffeners
4. Fittings
5. Attachment elements

The chords are the heavy upper and lower members. These are either heavy formed angles or, more popularly, extruded shapes such as angles, tees (shown) or channels. Normally they will taper in cross section from the wing root to the wing tip to save weight. This taper may be effected by machining off a portion of the extrusion or, when several sections are used to build up a spar chord, by dropping off sections one by one from root to tip. The cross-section area of the root chords may vary from ½ sq. in. in small lightly loaded airplanes to 6 or 7 sq. in. in large airplanes. Spar-chord material is nearly always 24ST. Extrusions are usually employed because of their somewhat higher allowable strength and because they may be made to fit the design better than bent-up sections.

The web is a piece of sheet—usually Alclad 24ST or 24SRT—which extends from the root to tip and from upper and lower spar chords. Web gauges will vary from .016 in. to as much as .064 in. and occasionally .125 in., depending on the shear load.

The stiffeners are vertical elements of bent-up sheet stock or extruded sections which run between the chords. They serve two purposes in the built-up spar. They space the spar chords at the proper distance from one another and they stiffen the web so that it will not easily wrinkle, thus permitting it to take higher loads. Web-type spars are known as Wagner tension field beams when they are of such a design that the thin web wrinkles under high loads. The stiffeners, like the web and chords, are usually 24ST. They may be channel, angle, hat, tee or zee sections. The zee section is one of the most popular because it is quite stiff for its weight and the riveting operations on the one flange and web are not interfered with by the opposite flange of the zee.

Certain fittings are usually attached to the spar during its assembly. These include the following:

1. Hinge fittings for attaching the inner and outer spars together.
2. Fittings for attaching the spar to the fuselage
3. Landing-gear fittings for the oleo shock absorber and braces or retracting-link mechanisms
4. Flap and aileron support brackets
5. Engine-support fittings
6. Small fittings for the control system, fuel tanks, pipe lines, etc.

The attachment elements, bolts and rivets, are used in assembling the chords, web, stiffeners and fittings. In a sense the clips, usually short angle or tee sections which hold the stiffeners and chords more firmly in place, may also be classed as attachment elements since they serve to locate the structural members but are not direct load-carrying parts.

The actual assembly of the spar usually proceeds in the following manner: The chords are first clamped into the jig and the web is laid in place on the outstanding flanges of the chords to which it is to be riveted. It is, at first, held down by C clamps or clamps which are integral with the jig. The rivet holes for the spars and web are then laid out using a soft pencil. A scribe is not used because it scratches the surface, increasing the chances of corrosion and the possibility of fatigue failure along the very shallow crack. Since the parts are usually anodized and given a coat of zinc-chromate primer before assembly, they are easy to mark for rivet holes. When the spars are made in production, a drill jig is provided to eliminate the tedious job of laying out the rivet holes. See Fig. 4, Chapter 3 and references to this jig. After the holes in spar chord and web have been drilled, a number of machine screws are usually used in the holes to clamp the members together until they are riveted. The stiffeners are located in place upon the web and chords, and the rivet holes drilled in accordance with the drawings. After this the fittings and clips are located and the holes for attaching them are drilled. The fittings are very often high strength alloy steel, even on an aluminum airplane. These are bolted in place after the holes have been reamed out to insure an accurate fit on the bolts.

Depending upon the production setup, the assembly may be riveted up in the jig or outside of it. Brazier- and round-head rivets are used. Riveting the assembly after removing it from the jig has the advantage of clearing the jig more quickly for the next assembly. When this is done the parts are joined together temporarily with machine screws, as noted above, and the fittings are usually assembled to the spar after riveting in a second jig provided only for the purpose of locating the fittings. Stationary squeeze riveters may be used and the spar passed through the riveters while it is suspended from the ceiling on a sling. When the assembly is to be riveted in the jig, the jig must be designed with this in mind so that clearances are provided for working with bucking bars, rivet guns, etc.

Every precaution must be taken to insure accuracy in the spar. Riveting normally should begin at the center and progress towards the ends. Spar warpage and very slight web wrinkles may then be worked out as the riveting progresses. Whenever there is likely to be any appreciable relative movement in chords and web, only pilot holes are drilled and these are opened up as the riveting is done so that the final rivet holes line up perfectly.

Aluminum-alloy wing spars are seldom spot-welded. In cases where spot welding is employed the web and stiffeners are usually welded together and this assembly is then attached to the spar chords. Since the spar chords are usually heavy, extruded sections and the web relatively light, the difference in thickness between web and spar flange is so great as to make it difficult to obtain satisfactory welds. In the future it may be expected that spot welding will be used more and will extend to the spot welding of spars, at least on small and medium size airplanes where the spar does not become too cumbersome to handle in the welder.

When fuel tanks of the built-in type are incorporated in the wing, the spar must be designed and built with this in mind. In such cases the fuel is carried between the spars in a two-spar or multi-spar wing or in the leading-edge portion forward of the spar in a monospar wing. In building a fuel-tight spar some means of sealing the lap joint between the chord flange and the web must be provided. The rivets which pass through the web and connect it to the spar must also be sealed. Several methods of accomplishing this are available. Neoprene tape and resin-impregnated cotton duck are commonly employed in lap joints. Synthetic rubber products of various types are now being developed for this purpose. Where rivets pass through the spar web into the tank, a washer of sealing material is placed beneath the rivet head or liquid neoprene or similar material is inserted in the hole just before the rivet is set. Where sealing materials are used between sheets or between a sheet and formed or extruded section, care must be taken to draw up rivets uniformly to prevent bulging between rivets and "tight" and "loose" areas.

The foregoing applies in general to magnesium-alloy spars as well as aluminum-alloy spars. Magnesium is coming into more general use in the aircraft industry principally because it weighs only two thirds as much as aluminum. Until recently magnesium alloys have been extremely subject to corrosion, especially in the presence of salt air. Diligent research on the part of the U. S. Navy has been largely responsible for overcoming these difficulties by providing more efficient protective coatings and making slight modifications in the amounts of alloying elements used. The principle difference between assembling aluminum and magnesium parts will be found in the use of somewhat thicker, bulkier sheet and extrusions.

Stainless-steel Spars—Stainless-steel spars, like aluminum-alloy spars, are built up by assembling spar chords, stiffeners and web. Although the design of steel and aluminum spars are somewhat similar, certain basic differences exist because of difference between the properties of the materials themselves. Steel, being approximately three times as heavy as aluminum, must be used in sheets having one third the thickness or in sections having one third the area of equivalent aluminum sheets or sections if the same structural weight is to be maintained. Because thin sections buckle much more easily * than thick ones they must be stiffened by the use of more closely spaced, and a larger number of, stiffeners. This is indicated by comparing the diagrams of the aluminum-alloy and stainless-steel spars shown in Fig. 10. It may be noted that the steel spar chords are built up from formed sheet rather than being extruded as in the case of aluminum. Steel cannot be extruded. The "fancy" shape of the sheets comprising the spar chords is to prevent the sheet from buckling locally under compression loads; it is a type of corrugation.

Stainless-steel assemblies are almost entirely joined by spot welding because of the ease with which stainless steel can be welded and because it is difficult to drill or punch for riveting. Portable spot welders are usually employed; the welding being done while the parts are in the jig. The sheets are pinched together at a predetermined pressure and then a definite electrical current is applied which melts the sheets locally where the pressure is applied so that they fuse together. For every combination of sheet thicknesses a

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* A complete understanding of this phenomenon and its relationship to the various physical properties of materials can only be obtained by a study of materials and stress analysis.

certain pressure, current and timing must be used. This is determined by experience.

In assembling the stainless parts, a definite welding routine usually must be followed. This is necessary in order to avoid inaccessible or "hard to weld" places. In the case of the particular spar section illustrated the following procedure would be used. The web and inner and outer spar flanges would first be located in the jig and welded together. The clips and web stiffeners would then be set in place and welded. Finally the channel sections which extend between the inner and outer flanges are placed and welded. If the channels and flanges were first welded together, it would then be impossible to weld the outer flanges to the web or to weld the clips to the inner flange. Because of the more complex nature of stainless-steel assemblies the assembly man must be careful to assemble and weld in the proper order. Fittings usually consist of relatively light formed-steel parts. These are also welded to the spar.

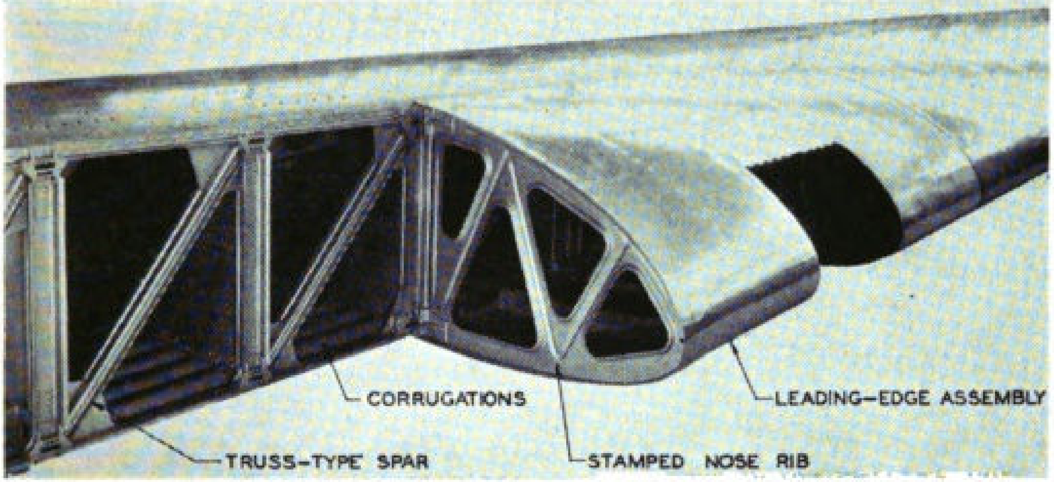
The greater number of parts usually required in stainless-steel assemblies as a result of the thin gauges which must be used to conserve weight, the relatively greater difficulty in forming the steel than aluminum, and the tendency of the thin sheet to wrinkle due to shrinkage caused by welding combine to prevent the more widespread use of this material in aircraft structures. It is very doubtful if it will ever replace aluminum to any appreciable extent even in small aircraft where its possibilities are greatest.

Truss-type Spars—Truss-type spars are sometimes used although designers favor the web-type construction described above. Truss spars are generally considered to be heavier than web spars although there is reason to believe that this weight difference may be very slight when the complete wing design is analyzed in minute detail. The main reason for using truss spars is for the added accessibility they afford to assembly operations. The large openings between the truss members do not restrict operations from one side of the spar to the other as do the webs which close off one section of the wing from another.

Fig. 10 shows a chrome-molybdenum truss spar, built up from tubular sections. This is not a common type of construction although it does indicate the general construction followed in assembling steel tubes such as might be found in steel-tube fuselages. The tubes may be assembled by torch welding or arc welding. Arc welding is coming into more general use in aircraft due to recently perfected methods of welding thin sections and light gauges of aircraft tubing.

In assembling the steel-tube spar the procedure would be somewhat as follows. One chord member is placed in the jig and clamped tightly in place. Heavy steel jigs are used. The truss members, which have been cut to fit the chord are next located and the other chord member is slid into place from the end. Welding is done working from one end to the other, care being taken to avoid excessive local heating and consequent shrinkage and warping. Shrinkage allowances must be made in the jig construction. Normally this will be $\frac{1}{16}$ in. per bay (from one vertical truss member to the next in Fig. 10) and $\frac{3}{32}$ in. between longitudinals (in this case between the upper and lower chords). Fittings are welded into place last and the holes drilled and reamed after all shrinkage has taken place.

Fig. 11 shows an aluminum-alloy truss spar of the Vultee V-11 in place in a wing. Note that the ribs and the corrugations and skin forming the upper and lower wing surfaces are completely accessible when the leading edge is removed. This makes repair and maintenance easy and is probably worth any weight losses which may have been incurred. A web would close off the wing and make for very poor accessibility. Note also the use of channel-section truss members placed back to back and the gusset plates where they attach to the next truss member and the zee-section spar chords. Depending on production scheduling and procedures it may be that the spar chords are part of the skin-corrugation assembly and that the truss members are assembled to the spar chords after the upper and lower panel assemblies and the ribs have been assembled together.

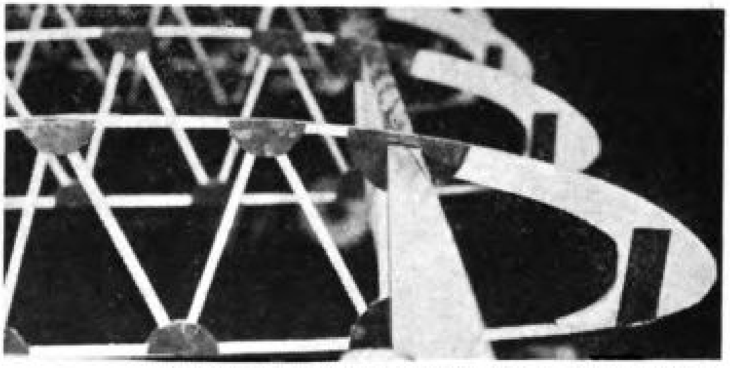


Courtesy Vultee Aircraft Corp.

FIG. 11—BOX-BEAM AND LEADING-EDGE ASSEMBLY

Wooden Spars—Wooden spars and wood construction in general have largely been replaced by metal, chiefly aluminum alloys. There is reason to believe that wood or some combination of wood and plastics will eventually replace metal in many aircraft parts due to its particular adaptability to the simple monocoque type of construction, the ease with which it may be fabricated, the smooth thick-skin structures which may be constructed from it, and its high damping capacity which renders it highly resistant to flutter. The last two advantages become more pronounced as speeds increase. New methods for treating and handling wood as well as means of eliminating defects are now being developed. For the present, however, the use of wood is confined mainly to small private airplanes.

The spar shown in Fig. 10 consists of a plywood web and rectangular cap strips (spar chords) which are glued to the web. No web stiffeners are indicated as the ribs which attach to the spar also serve to stiffen the web. Few stiffeners are required for the web in any case, as its thickness is such that it is quite stable in itself and hence resists buckling very well. In assembling a spar of the design shown in Fig. 10 very little jigging is necessary. The cap strips on one side are coated with glue, laid on a table and properly spaced from one another. The web is laid on the cap strips and the other set of cap strips is laid on the web. The whole is held together with wood clamps while the glue sets. If synthetic resin glues are used, the spar and table may be rolled into a heated chamber and left there until the glue cures. Brads are sometimes used to locate and attach temporarily parts being prepared for gluing.



Courtesy Aeronautical Corp. of America

FIG. 12—WOOD WING CONSTRUCTION

Fig. 12 shows the use of a plain rectangular spar on an Aeronca. This is the simplest possible type of spar.

Steel fittings are almost always used with wooden spars and are usually built up from plate stock and welded together. They are bolted to the spars with standard aircraft bolts.

CHAPTER 7

WING-RIB ASSEMBLY

Wing ribs, which run perpendicularly to the spars (*i.e.*, in a chordwise direction on the wing), are important to the wing structure for several reasons. Their primary purpose is to form and maintain the true airfoil contour of the wing. Besides this they locate and maintain the spars in their proper relationship to one another as well as serving as skin and stiffener support members. In stressed-skin construction their presence reduces the deflection caused by twisting because they prevent the skin from wrinkling at low loads. Ribs are primary assemblies.

Wing ribs are not continuous from the wing leading edge to the trailing edge except when the spars are not the full wing depth and the ribs pass over and under the spars. Ribs which are located in front of the forward spar are nose ribs, those which extend between spars are interbeam ribs, and those which are behind the rear spar are trailing-edge ribs. There are also aileron and flap ribs which will be discussed later in Chapter 10, Control-surface Assembly.

Like spars, ribs may be divided into two classes depending upon their design: web type and truss type. Both types may either be built up from a number of small parts or they may be stamped from a sheet of metal. Compare ribs shown in Figs. 5 and 11. They may be constructed of wood or metal depending upon the structural material employed.

Large ribs, such as are found on large airplanes and at the wing root of smaller airplanes, are usually of the built-up type. The small ribs are usually a single piece stamped out in sheet aluminum alloy.

Fig. 5 of Chapter 3 shows a truss-type interbeam rib being assembled. As previously noted, the truss members are assembled first and then they are assembled to the contour forming members which are known as the rib chords. In assembling ribs, and for that matter all internal structure, brazier-head and round-head rivets are used.

In stamped ribs the rivet holes may be marked by the use of small projections on the forming dies. The prick punch marks left by these projections then serve to center the drill. In the case of built-up ribs parts are drilled while they are in the jig and then temporarily fastened together with patented fasteners or screws. Riveting may then be done on a squeeze riveter after the assembly is removed from the jig. This permits one man to do the assembly work and another the riveting.

In Fig. 16 of Chapter 8, two web-type interbeam and two web-type nose ribs are shown in the assembly, as well as a number of truss-type interbeam ribs similar to the one in Fig. 5. Note the similarity of construction between the web ribs and the web spar in Fig. 4. The web ribs consist of the following:

1. Chords or flanges, upper and lower
2. A shear member, the web
3. Vertical stiffeners
4. Attachment elements

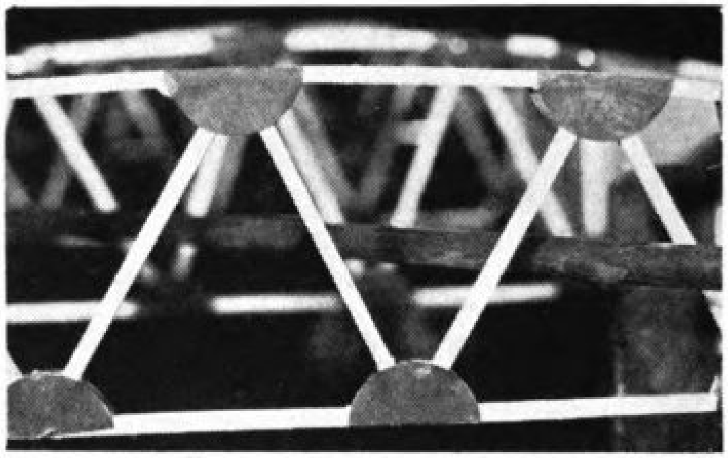
Ordinarily fittings are not attached to ribs although a few special ribs which incorporate a fitting to carry certain high concentrated loads are necessary in almost every design. The web ribs are built up in exactly the same manner as web spars, but unlike spars which are more often riveted in their jigs, ribs are usually removed for riveting.

In assembling built-up web ribs, spot welding is sometimes used. The ribs make "flat" assemblies which are ideal for welding. When assemblies are to be spot-welded they are not given any finish, such as paint or anodize, before welding because welding cannot be satisfactorily accomplished through dry paint, primer, or anodized surfaces. Parts to be welded should be thoroughly degreased and any paint marks which may be on the sheet stock for identification purposes carefully removed. Care should be taken not to allow dirt to get between the faying surfaces due to handling of the parts during assembly. Only a few rivets are used on spot-welded assemblies and they are just sufficient to hold the assembly together so that all parts are properly located. The rivets are placed at stiffener ends, corners of the assembly and wherever clips or lugs are attached to the assembly.

Fig. 11 shows a single-piece, stamped, truss-type rib. Such ribs require no assembly operations except of course their attachment to the main assembly. They are made either on a drop hammer or on the hydraulic press on metal or wood form dies. The lugs shown on upper and rear portions of the nose ribs serve to attach them to the spar. Web-type stamped ribs merely consist of a flat sheet flanged over at the edges to form the rib contour. Round, flanged lightening holes are usually provided to save weight. Actually the only difference between truss-type and web-type stamped ribs is in the shape of the lightening holes; in the former they are triangular, as shown in Fig. 11, and in the latter they are circular.

In the foregoing, only aluminum-alloy ribs have been described. Just as in the case of spars, ribs may also be constructed of stainless steel, chrome-molybdenum tubes or wood. Welded-steel tube ribs are practically never used and therefore will not be discussed here.

Stainless-steel ribs are almost always built-up truss or web type. Like stainless-steel spars, they are spot-welded rather than riveted and the assembly procedure is identical. Stainless-steel truss ribs are of course jig located and welded while they are in the jig. Web ribs are similar to the spars except that the rib chords are not as complicated in appearance as are the spar chords. The rib chord is generally merely an angle section formed to contour and welded to the web and stiffeners. On assembly to the remainder of the airplane, the outstanding flange of the chord is then welded to the wing skin or the stiffeners which support the skin.



Courtesy Aeronautical Corp. of America

Fig. 13—Wood Rib Detail

Wooden ribs are most often of the truss type. See Figs. 12 and 13. Fig. 12 shows a rib which is continuous across the spar, with the spar below the wing surface. Fiber gussets are used with a gusset on each side of the rib. The truss members are butted against the rib chords with the gussets holding them in place. Animal, vegetable or synthetic glues are used to attach the gussets to the rib members. Very often jigs for assembling this type of rib will consist of nothing more than a heavy plank with brads driven into it in such a way as to locate the rib members. Clamps are then used to press the joint to the flat surface of the board while the glue dries. Fig. 13 shows a view of the center portion of a wooden rib. Note the steel tube which passes diagonally through the rib. This is the internal drag strut.

Web-type wooden ribs are not generally used but, when they are they are constructed similarly to the web-type spar previously described. They consist of a plywood web with lightening holes and rectangular-sectioned flanges glued to the web at its contour.

CHAPTER 8

BOX-BEAM ASSEMBLY

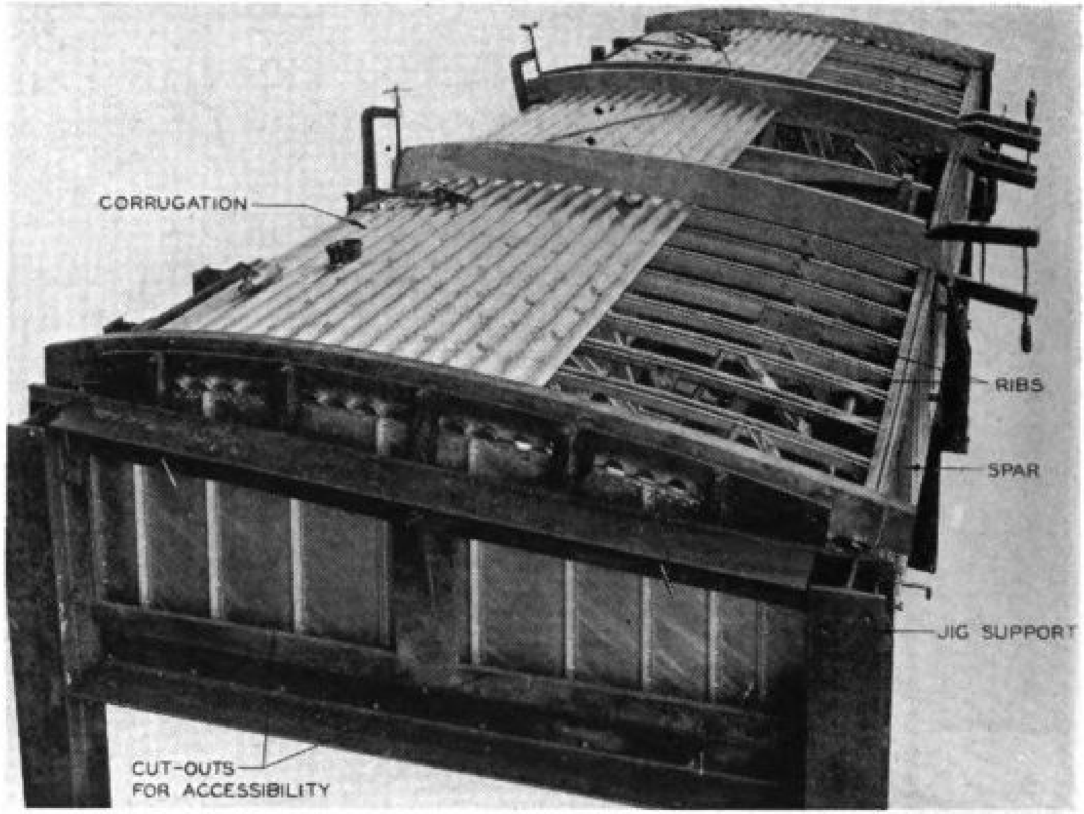
In Chapter 5 it was pointed out that normal wing construction usually consists of two spars with stressed skin connecting the upper and lower portions of the spars to form a box to take the bending and twisting loads.

After the spars and ribs have been built separately, these primary assemblies are assembled together to form a secondary assembly, the box beam. When the wing is a monospar type, the wing leading-edge assembly and the single spar are combined to form the box beam. On a multi-spar wing the front and rear spars as well as the spars between them are incorporated in the box beam. Since the two-spar type is the most common it is the one that will be discussed here as the other types are merely modifications of it.

After the spars are located in the jig the interbeam ribs are set in place and riveted, or in some instances bolted, to the spars. In Fig. 5, which shows one of the interbeam ribs, it may be seen that vertical members are omitted from the rib ends. The spar web stiffeners become this missing vertical member once the ribs are attached to the spar. The rib-attachment clips are riveted to the spar stiffeners during the spar construction. (See Fig. 4.)

Once the spars and ribs are completely assembled, the stress-carrying skin is set in place. The skin is reinforced with corrugations or spanwise stiffeners which are located above the ribs and under the skin. Fig. 14 shows corrugations being attached to the rib chords by rivets located at every node of the corrugations. Note the use of wooden "formers" to clamp the corrugations in place while the riveting is being done. Some of the assembly tools used lay on the corrugations; the cup in the foreground is used to hold the rivets until they are set in place and headed up.

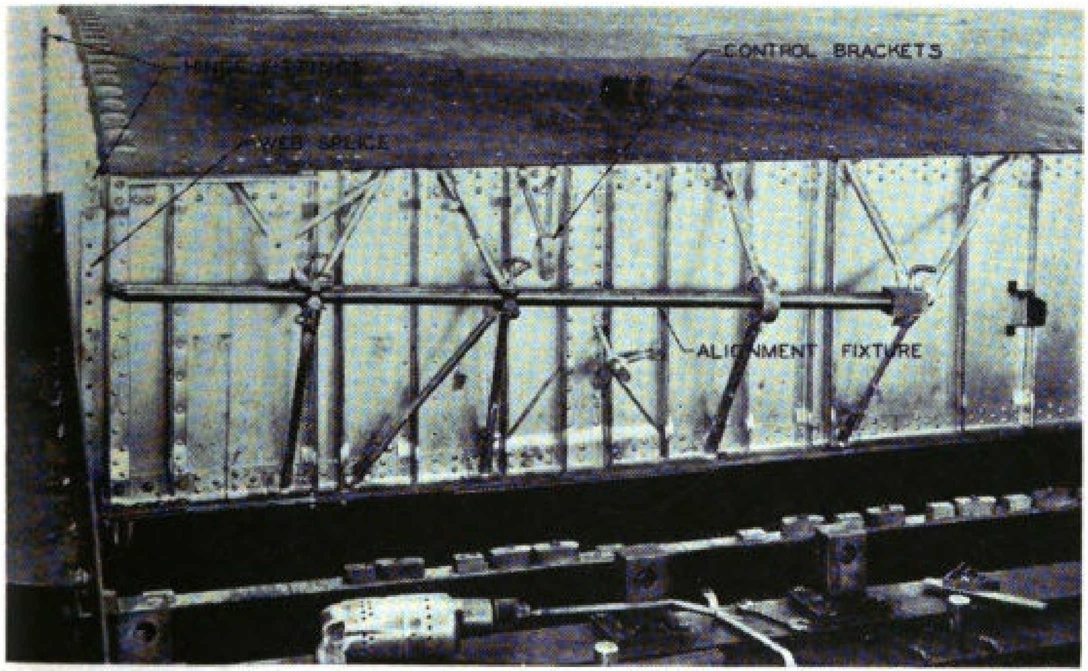
After the attachment of the corrugations to the ribs has been completed, the box beam is "skinned"; the skinning operation in this case being that of putting on the skin rather than removing it. Flush rivets are used for this purpose. The rivets may be spaced relatively far apart because when corrugations are used the skin is thin—in the neighborhood of .020 in. thick—and carries practically no load. Fig. 15 shows a rear view of a completed box-beam assembly after the skin has been placed.



Courtesy Glenn L. Martin Co.

FIG. 14—PARTIALLY COVERED BOX BEAM IN ASSEMBLY JIG

It is important that the skin be stretched slightly when it is placed on the corrugations because the thin aluminum-alloy sheet is inherently wavy as it comes from the supplier. The sheets are laid spanwise on the wing and the forward edge of the sheet (the edge nearest to the wing leading edge) is riveted in place. Clamps and turnbuckles are used to grip the rear edge of the sheet and stretch it tight over the corrugations. The second row of rivets is then set in place, then the third, etc., until the rear edge of the sheet is riveted down. When the covering sheets are not as wide as the wing (which is usually the case) a spanwise skin splice is made. The splice is lapped rearward; that is, the rear piece of skin is placed between the forward piece and the corrugation before the rear edge of the front skin is riveted.



Courtesy Glenn L. Martin Co.

FIG. 15—REAR VIEW OF ASSEMBLED BOX BEAM

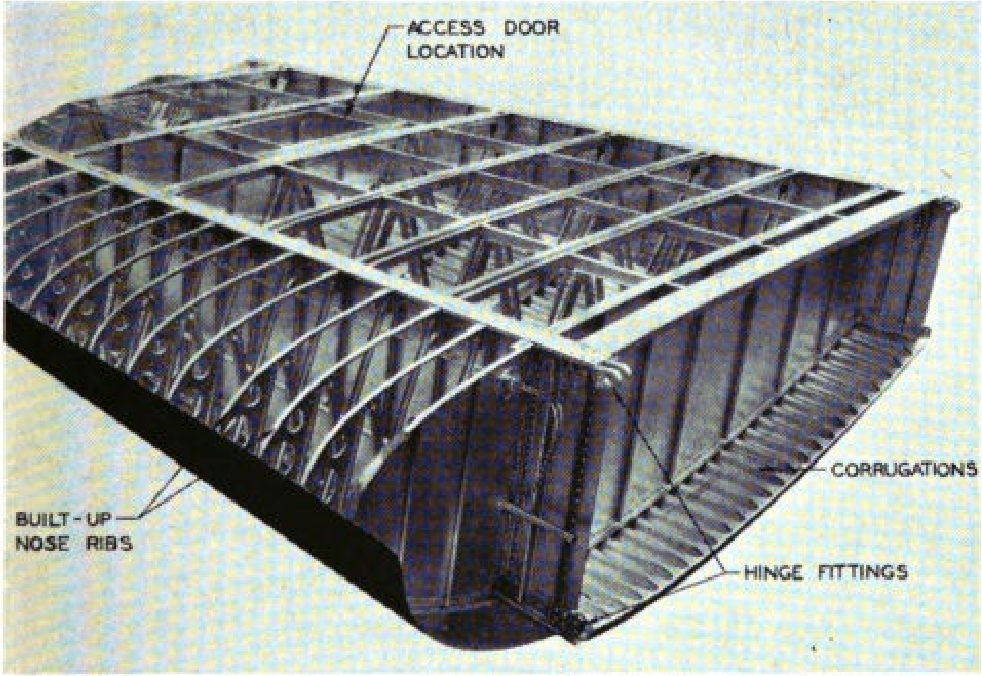
As the speed of airplanes increases, more attention is being paid to smooth surfaces. This requires the use of thick skin which eliminates the time consuming and costly skin stretching during assembly. Butt joints and splice strips will replace the lap joints described above. Skin splices may eventually be made in the chordwise direction only, rather than spanwise as at present. Even the crack caused by a butt joint placed spanwise may materially reduce the airplane speed.

In cases where stringers are used in place of corrugations, the skin is relatively thick—.040 in. or heavier—and carries an appreciable amount of the load. With stringers, two methods of assembling the skin-stringer combination to the ribs and spars are available. One is first assembling the stringers to the ribs and then applying the skin to the ribs and stringers in a manner similar to the assembly of the corrugations described above. The other is making a panel assembly of the skin-stringer combination and applying this complete assembly to the ribs and spars, clipping the stringers in place to the ribs from the inside. It should be observed here that a skin-corrugation assembly cannot be made first and then applied to the ribs as in the case of the skin-stringer assembly. If the skin were attached to the corrugations it would prevent the corrugations from being riveted to the ribs. This difficulty is not encountered where stringers are used, because the skin may be attached to both the ribs and stringers rather than to the corrugations only, as when corrugations are used.

Fig. 16 shows the box-beam assembly turned upside down after the corrugation has been covered by the upper skin. During the skinning operation rivets are driven which will attach the skin, corrugations and spar flanges together. In Fig. 14 it may be seen that the flattened portion of the corrugations which runs spanwise above the spar flanges has not been riveted at this stage of the assembly.

The bottom skin (Fig. 16) is riveted to the flanges of the lower rib chords and to the spanwise members placed between the ribs. The rivets must be bucked from the inside. This is possible because the particular wing section shown is large enough to admit a man through a hole between the ribs and spanwise members. In Fig. 16 the position of this hole is indicated by the frame in the background of the figure next to the web-type rib and midway between the spars. The flatness of the lower surface permits the skin to be "rolled on" and riveted progressively in a spanwise direction until the access hole is reached. It is then a comparatively simple matter to head the rivets surrounding the access hole and within several feet of it. The hole is finally closed up by a plate which is screwed to the frame by means of anchor nuts.

The reader should note that in Fig. 16 several web-type ribs are used. These form the end bulkheads of the built-in tanks. The space between the rib chords and corrugations is made leakproof by means of a stamped piece shaped to fit the corrugations. This is riveted to both the rib chord and the corrugations. A sealing material is used between the portions of the assembly where leaks could occur. The access door in the bottom of the tank also serves as the inspection door for the inside of the tank. Inspection must be made at periodic intervals to check for corrosion and possible leaks and to repair any leaks which might exist.



Courtesy Glenn L. Martin Co.

FIG. 16—UNDER SIDE OF BOX BEAM

In the assembly of the box beam shown, a horizontal jig is used. In many instances a vertical jig is employed instead. A vertical wing jig is one in which the spars are laid horizontally, one above the other with the ribs and skin placed vertically. This permits the riveting of the skin to be done most conveniently with the drills and riveting tools being held horizontally while the assembly men stand upright beside the work.

The wing box beam is usually broken into three parts for purposes of assembly, replacement, maintenance and crating. This has already been indicated by items 0, 1, and 2 of Fig. 9, which shows the beam broken into a center section and two outer panels.

CHAPTER 9

WING LEADING-EDGE, TRAILING-EDGE AND TIP ASSEMBLY

Leading-edge, trailing-edge and tip assemblies may be classed as secondary assemblies since the ribs and frames of these units are often built up to form primary assemblies such as the leading-edge ribs, shown in Fig. 16.

Except in cases where the leading edge forms a part of the basic structure, which it does when it becomes the box beam in monospar designs, this assembly may be considered a separate unit of the wing. Leading-edge assemblies are usually broken down into several sections in the spanwise direction of the wing. This is done to make handling easier and also because of leading-edge cutouts for lights, gun installations or landing gear. The leading edge consists of the nose ribs, skin and the rivets, clips, angles, etc., necessary for attaching these parts together and to the front spar.

Two general assembly methods are employed on leading edges: one is to separately assemble the leading edge on a separate jig and then attach it to the spar; the other is to assemble the nose ribs to the spar and then attach the leading-edge skin to the ribs.

In the first method the ribs are first lined up on a jig which resembles a truss-type wing spar, except that it is made of angle iron and provided with stops which locate the ribs. The leading-edge skin, which is previously bent to contour and cut and trimmed as required, is then placed over the nose ribs. A series of steel straps provided with holes wherever rivets are to be located are then placed over the outside of the skin opposite from the rib flanges on the inside. The straps form the drill jigs which locate the rivet holes. The rivets are easily bucked from the inside of the assembly because the open truss work of the jig permits easy access from the rear. After the skin and ribs are attached together the assembly is ready for attachment to the spar in the final assembly of the panel. The clips which are used to attach the ribs to the spar are riveted to the ribs before the nose skin and these clips serve to attach the ribs to the assembly jig.

The leading-edge section shown in Fig. 11 is an example of a leading edge being separately assembled and then attached to the front spar or the box-beam assembly. The design is such as to permit assembly of the leading edge to the beam by working from the outside since it may be noted that the location of the wing-nose portion on the box beam renders the wing interior inaccessible for bucking rivets or tightening nuts. Whenever possible a separate leading-edge assembly is preferable because it permits a smoother skin-riveting job and has the production advantage of making the leading edge a complete and independent subassembly. The use of truss-type spars usually favor this. When separate assembly is impossible because of design limitations, the second method of assembly is employed.

The second method of assembling leading edges is to attach the separate nose ribs to the spar itself and then to wrap on the nose skin. This is practical where the nose skin is rather light—.025 in. thick—and will permit wrapping on. The sheet is first riveted or screwed to the upper spar chords. It is then pulled down around the nose. As this is done several rivets are set in place on each rib. This is carried on progressively until the nose section is almost completely closed and it becomes impossible to get between the skin and the lower spar chord to buck the rivets. Screws and anchor nuts in the ribs are then used to attach the skin to the lower spar chord and to the rib flanges for several inches forward of the spar chord. Fig. 16 shows this method of assembling a leading edge. In this instance the skin is in two sections, upper (which is shown on the ribs) and a lower section (not yet in place because the sheet stock is not wide enough to be wrapped from the upper rib chord around to the lower).

When leading-edge skins are spot-welded to the ribs, the wrapping method cannot be used and the leading edges are separately assembled, as described above, except that only 3 rivets hold the skin to the ribs prior to welding. One of these is located at the very nose of each rib with the other two rivets at the aft portion of the nose rib, one upper and one lower. When leading edges are separately assembled they are attached to the spar either by screws and anchor nuts or by long piano hinges into which the pins are inserted by spinning them with a drill.

In wood construction the leading-edge assembly presents little difficulty because the gluing of the plywood skin to the ribs does not require that the inside of the wing be accessible. In designs where the wooden wing is fabric covered, as in the case of light airplanes, the plywood skin merely covers the most forward portion of the rib and does not even extend back to the first spar, thus providing complete accessibility behind the nose skin.

Stressed-skin steel wings are usually of the monospar type and hence they have no separate leading-edge structures. However, if they do, the welding requirements peculiar to steel permit welding to be accomplished without an electrode within the wing. Inaccessibility is not such a problem then and the assembly may be constructed by either of the two previously discussed methods with equal ease.

Trailing-edge assemblies do not present as great assembly problems as do leading edges. There are several reasons why this is so. Leading edges are usually entirely "closed off" once they are assembled to the wing, whereas the trailing-edge assemblies are often open in the rear due to the location of the flaps and ailerons and because several access doors are usually provided along the wing span for control inspection. These features, inherent to trailing-edge wing design, provide accessibility to the wing interior so that riveting of the skin to the ribs may be relatively easily accomplished. The detail design of trailing edges is somewhat simpler also because the wing surface is practically flat. Further, lap joints (rather than butt joints) in the skin are often permissible because skin "roughness" is not as important in the rearward sections of the wing. Such factors tend to simplify the assembly operations.

The trailing edge consists of skin, ribs, clips, angles and rivets also. The forward part of the trailing-edge section is attached to the rear spar. Either the separate assembly method, described above, for leading edges may be used for trailing-edge assembly or else the ribs may be attached to the spar and the wrapping method employed. Because the trailing edge is a sharp radius and because there is usually an aileron or flap cut out in the rear ribs the trailing-edge skin is invariably put on in two pieces: upper and lower. The upper skin is usually assembled to the ribs first and the lower skin second because the upper is wider and may be assembled more efficiently with the lower skin out of the way.

Regarding wood and steel construction the same remarks apply for trailing-edge and tip assemblies that apply for leading edges.

Wing-tip assemblies tend to be rather complex and expensive when well-rounded tips are employed. Because of this several prominent manufacturers in this country have adopted blunt, "square" tips, which are very simple and less costly.

Wing tips consist of ribs, skin and clips and rivets. The ribs run both fore and aft and spanwise, the spanwise ribs continuous and with the fore and aft ribs located between them.

Tip assembly is difficult because the thinness of the wing section reduces accessibility to the inside of the tip and because the tip quite naturally becomes a box-like section with but one open end. Tips are almost invariably built on a separate jig and then assembled to the outer wing panel with screws. The spanwise ribs are first located and then the fore and aft ribs are riveted in place. The skin portions which have compound curvature are made on the drop hammer or press. On small airplanes the skin is stamped out in two pieces—upper and lower—while on large airplanes the upper and lower skin is broken up into two or more pieces.

The upper and lower skin is joined along the leading and trailing edge either by a lap joint or else by riveting both to a formed splice plate which runs around the tip contour. The upper skin is usually attached to the tip first. In cases where the top and bottom is divided into two or more portions, the skin nearest the tip is first attached. For example, in assembling a four-piece skin to ribs, the attachment is as follows: upper tip skin, lower tip skin, upper inboard tip skin, lower inboard tip skin. This procedure is followed so that riveting operations will be progressive from the thinnest, most inaccessible sections to the deeper inboard sections of the tip.

Material gauges now used in the construction of wing leading edges, trailing edges and tips are usually light—in the neighborhood of .025 in. with an upper limit of .040 in. Present tendencies toward monocoque designs, higher wing loadings and greater surface smoothness are resulting in the use of heavier skin gauges in these assemblies.

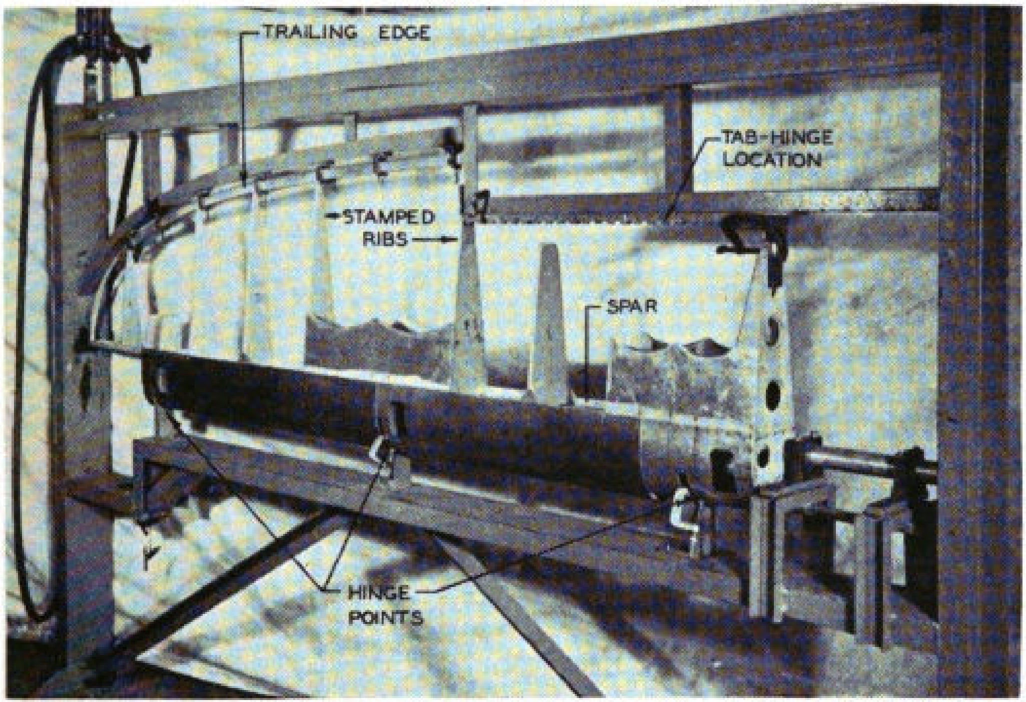
CHAPTER 10

CONTROL-SURFACE ASSEMBLY

The various airplane control surfaces are so similar that their assembly may be described under one heading. Specifically, the control surfaces are the ailerons, rudders, elevators, flaps, and trim and balance tabs. They may be classed as secondary assemblies.

Fabric covering is usually employed with control surfaces because it has been found that fabric covering somewhat dampens out flutter tendencies induced by buffeting of control surfaces due to their position in the turbulent air at the rear of the wing or fuselage. The control-surface frames to which the fabric is applied are usually constructed from the same material as the rest of the airplane. Tubular-steel control-surface frames were once popular on wood or steel-frame airplanes. They have largely been replaced by stainless-steel assemblies which have been especially developed for control surfaces by several manufacturers of stainless-steel aircraft parts and assemblies. Wood is relatively seldom used even on wooden airplanes.

Fig. 17 shows a Vultee V-11 elevator assembly in its jig. The pencil lines for laying out the rivet holes can be seen. This assembly is typical of many control surfaces in that it employs a single spar with the leading edge (the lower part of the assembly as shown) being a torque box which takes the twisting loads. There are two sets of ribs, nose ribs and trailing-edge ribs. Each rib is a single piece stamped from sheet stock. In fabricating such an assembly the leading-edge ribs and skin would first be made, riveting of skin to ribs being accomplished before the spar is set in place. This might be done in a separate jig which would locate the ribs. Note that in Fig. 17 the three hinge points are jig located (two of which are at the steel C clamps shown and the third is at the far end of the elevator). Flush rivets are used on skin and nose ribs because the fabric will be run around the leading edge.



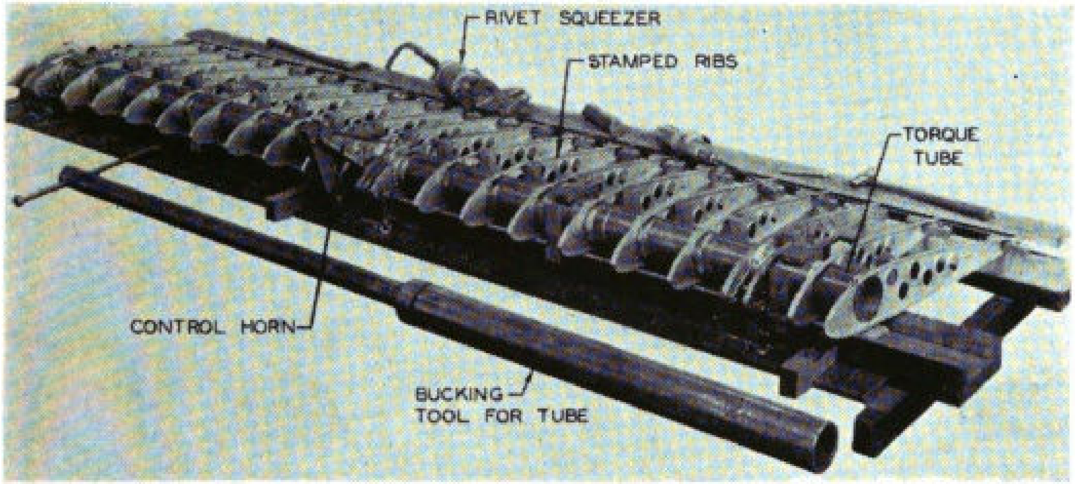
Courtesy Vultee Aircraft Corp.

FIG. 17—ELEVATOR IN ASSEMBLY JIG

After assembling the leading edge the torque box is closed up by the spar, which is merely a piece of sheet stock flanged over to form a channel section. The flanges face to the rear (upward as the elevator stands in the jig) so that the rivets joining the nose skin and flanges may be easily set. The nose ribs generally have a flange which butts against the spar. These flanges are equipped with anchor nuts or nut strips so that they may be screwed to the spar. They cannot be riveted because the spar web prevents the insertion of bucking bars to head up the rivets. The trailing-edge ribs are located before riveting takes place so that rivet holes for joining them to the spar flange also may be lined up. The purpose of the scalloped sheet metal, which also forms a part of the trailing-edge portion, is to carry the torsional stresses around the hinge point cutouts. The piano hinge in the jig locates the piano hinge on the elevator trailing edge, which will serve to attach the tab. The offset in the far end of the jig base is where the elevator balance is located. A trailing-edge piece consisting of a piece of sheet stock bent over 180 deg. and formed to contour is riveted on the rearmost portion of the trailing-edge ribs with "through" rivets to complete the assembly. As the assembly now stands in the jig, several trailing-edge ribs are lacking, as well as the piano hinge and the channel section which will support it. Ailerons and rudders of this type of design would be assembled in the same manner. The only difference would be in size and shape of the finished assembly.

Some manufacturers spot-weld aluminum-alloy, control-surface assemblies. When this is done the nose skin and ribs are first assembled with the ribs being temporarily attached to the skin with screws or some sort of patented fastening device at three places, the rib nose, and at the top and bottom of the rearmost portion of the rib. The assembly is then sent to the welders who weld the remainder of the rib flange to the skin. If the skin and spar flange are also to be welded this is done by nesting the spar in place after the ribs and skin are welded. Rivets may or may not be used in the holes drilled for temporarily attaching the ribs to the skin depending on whether or not they are believed to be necessary. The trailing-edge portion is usually riveted even when the torque box is welded.

Fig. 18 shows a somewhat different type of control-surface assembly, in this case a center-section flap for a Martin M-139. Note the air-operated squeeze riveter and the electric drill with angle attachment among the tools in the background. In this design, which is also used for elevators and rudders, the large tube serves both as spar and torque-resisting member. The advantage of this type of construction lies principally in the fact that the ribs are not split into two parts, nose and trailing-edge portion. The disadvantage is the difficulty of riveting the ribs to the closed tube. Collars must be provided to each rib also. A "mouse," the heavy steel tubes shown in front of the jig, is used to rivet the ribs to the tube. This is pulled through the torque tube of the assembly so that the ribs are riveted to the tube progressively from one end to the other. Note the three hinge points at the leading edge of the flap and the control horn in the center of the flap for actuating it.



Courtesy Glenn L. Martin Co.

FIG. 18—FLAP ASSEMBLY

The assembly is completed by a light gauge sheet of aluminum placed over the leading edge of the ribs and extending around from a point directly below the torque tube to a point just above it. This is riveted in place, the heading being accomplished by inserting the bucking tool in the space between the tube and the rib contour.

Stainless-steel control surfaces generally follow the type of design shown in Fig. 17. All parts are jig assembled with the spot welding being done with portable welders while the parts are still in the jig.

After the control-surface frames are built they are fabric covered and doped. Covering and doping requires a skill which can only be obtained by experience. Mercerized cotton cloth is the fabric used.

Two methods for fabric covering surfaces may be employed: the envelope method and the blanket method. In the envelope method, widths of fabric cut to specific dimensions are machine sewed to form an envelope which can be drawn over the frame. The blanket method is accomplished by sewing together proper widths to form a blanket covering all surfaces of the frame. The trailing and outer edges are joined together and sewn. The spanwise seam should always occur at the trailing edge unless the taper of the surface is such that a seam along the leading edge is also required. The cloth should always be cut in such a way that the warp threads will be parallel to the line of flight.

The frame is prepared for covering by protecting all parts which come in contact with the fabric with dope proof paint, cellulose tape or .0005 in. thick aluminum foil. After this is done the fabric is placed on the frame. The fabric is attached either by fabric strips screwed in place or by sewing around the rib chords. Fabric strips or some equivalent method for obtaining flush surfaces are usually employed because the rough surface caused by protruding threads and knots is undesirable from standpoints of appearance and aerodynamics. When the fabric is secured by cotton lacing cord, laced around the entire wing-rib depth or only around the rib cords, a reinforcing strip must be placed between the cords and the section of fabric held down by them. The reinforcing strip prevents the tightly drawn lacing cords from cutting through the fabric. Surface or finishing tape, applied after the first coat of dope has dried, is doped down over the lacings or over the flush joints of the mechanical fasteners to reinforce and further protect the joints.

When the fabric has been satisfactorily tied down and stretched to eliminate wrinkles and slack places, the dope is applied. The first three coats of nitrate dope are brushed on and the dope, which is of the semi-pigmented variety, should not be thinned for the brushing operations. The first coat usually is of a cream shade to prevent discoloration of the inside surface of the fabric from dark pigmented dopes. After the brush coats are applied, three spray coats are put on. Thinned dope may be used for spraying.

In order to produce a smooth finish the surface may be given a light sanding after the second brush coat and the last spray coat using 0000000 waterproof sandpaper. To avoid sparks from static friction the parts being sanded should be grounded during this operation. Pigmented nitrate dope or paint may be used to provide suitable color once the doping is complete.

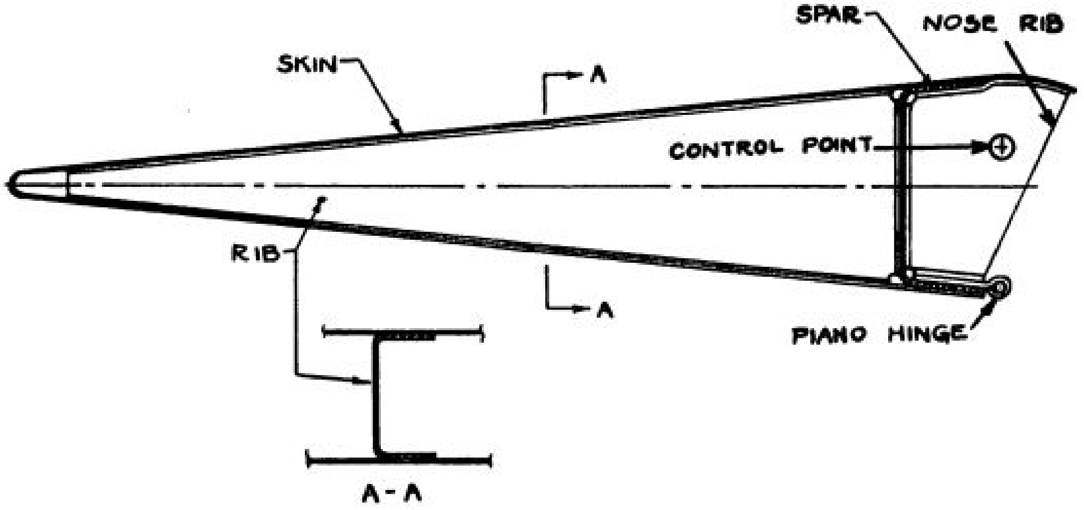


FIG. 19—SECTION THROUGH TAB

Once the surfaces are completely fabric covered, doped and painted they are ready for installation on the airplane during its final-assembly stages.

Trim and balance tabs are located in the trailing-edge portions of the control surfaces of most airplanes. The purpose of trim tabs is to trim the airplane by causing the control surfaces to ride off neutral and thus eliminate the effort of the pilot to hold the airplane off neutral. They are controlled by special levers or cranks in the cockpit. Balance tabs are necessary on large airplanes to assist the pilot in moving the control surfaces against the force of the air.

Tabs are nearly always metal frames, metal covered. Their relatively small size—most are seldom more than 18 in. in length—makes metal covering necessary from a practical standpoint. The tabs usually consist of a channel-section spar formed from sheet stock, flat sheet skin usually .020 in. in thickness, stamped ribs, the piano hinge for attaching the tab to the control surface and the clips necessary for attaching the tab actuator control to the tab. The actuator control permits the tab to be operated from the cockpit to trim the airplane while in flight. A typical section through a tab is shown in Fig. 19. The simplicity of tab construction makes their assembly relatively easy, if design is good. Tabs are primary assemblies; once built they have no secondary-assembly stage except that of attaching them to the finished control surfaces.

CHAPTER 11

WING ASSEMBLY

After the wing primary and secondary assemblies have been completed they are assembled and fastened together to form the complete wing. This work is facilitated by first assembling each wing panel separately. The wing is divided into panels for several reasons, and as explained previously in Chapter 5 there are usually three panels and two tip assemblies. This permits the wing to be broken down into several sections for crating and shipping, provides a natural break in the wing for the replacement of a damaged portion and divides the wing into sections for greater ease of assembly.

The first operation in wing final assembly is to attach together the subassemblies of each of the panels. The leading-edge, box-beam and trailing-edge assemblies of each panel are normally fastened together more or less permanently; that is, rivets are used wherever they may be conveniently headed up and where screws must be employed they are filled and painted over to provide a smooth finish which prevents their easy removal for disassembly.

In the conventional two-spar wing, the box beam forms the basis of the assembly and the other parts are fastened to it. This also holds true where monospar construction is employed except that there is no separate leading-edge assembly since the leading edge is itself a part of the box beam. After the box beam has been removed from its assembly jig the control system and plumbing is attached to it. Wiring, oil lines, fuel lines and engine controls (if the airplane has two or more engines) are fastened to the front face of the front spar before the leading edge is attached. Some of this may be seen in place in Fig. 16. Wiring is usually encased in conduit both as a protection and to prevent radio interference. The conduit is fastened to the spar with clamps which attach to the spar stiffeners. Oil and fuel lines are similarly attached. Engine controls are usually located last in order to facilitate the lining up of control pulleys or the bell cranks where push-pull rods are used.

Flap- and aileron-control brackets are usually an integral part of the trailing-edge assembly, though they are sometimes connected to the rear wing spar as a separate part. An example of this is shown in the flap brackets of Fig. 15. The flap-control brackets in this case are welded steel-tube assemblies. They are lined up, as shown, by means of a steel rod. One of the aileron-control brackets may be seen below the "line up" rod in Fig. 15. The aileron controls attach to this bracket on their way out to the outer panel where the aileron is located.

When the leading edge is a separate assembly it is usually attached to the front spar flanges by screws and anchor nuts or nut strips. The leading edge shown in Fig. 11 is attached to the ribs only by means of a pin which ties together the mating casting which may be seen on ribs and spars. In some cases the leading edge is attached by means of piano hinges located on both upper and lower cords of the front spar and which mate with piano hinges riveted or welded to the rear edge of the leading-edge skin. The hinge pins, sometimes 15 ft. long, are placed by greasing them and "spinning them in," using an electric drill to rotate the pin while it is held every 3 ft. to prevent it from coiling up. The leading edge can seldom be riveted to the spar when constructed as a separate assembly because of the inaccessibility of the rivet shanks.

Trailing-edge assemblies may be attached to the rear spar by means of nut strips, piano hinges or rivets. It is possible to rivet the trailing edge to the rear spar because the cutout for the flap or aileron usually leaves an opening in the rear portion of the trailing edge through which the rivets may be headed up. In this respect the leading edge and trailing edge differ since the latter is *not* a closed section when it is placed on the spar.

The wing tip is assembled to the wing after the leading and trailing edges. The tip attaches to a heavy rib flange, usually an extruded section, by means of screws turned into nut strips located on the inner face of the rib flange. Access holes are provided in the tip and have removable covers so that the tip light may be connected. These holes also provide access to the inside of the wing to facilitate repair or removal of a damaged tip.

Ailerons complete with aileron tabs are normally attached to the outer panel after the wing is completely assembled. Fig. 20 shows an outer wing-panel assembly in the foreground complete with aileron. The aileron connection is usually made by three bolts, one at each of three hinge brackets. Another bolted connection is required to fasten the aileron-control horn to the push-pull rod or the swaged connection on the cable end if cables are used. On very large airplanes, such as the B-19, the aileron is often broken up into two sections, inner and outer. This is done so that each section will have but three hinge points, the maximum which can be conveniently "lined up" for mating assemblies. Breaking the long aileron into two sections also prevents wing deflections from being transmitted to the ailerons. High deflections in the aileron would make its operation difficult or impossible.

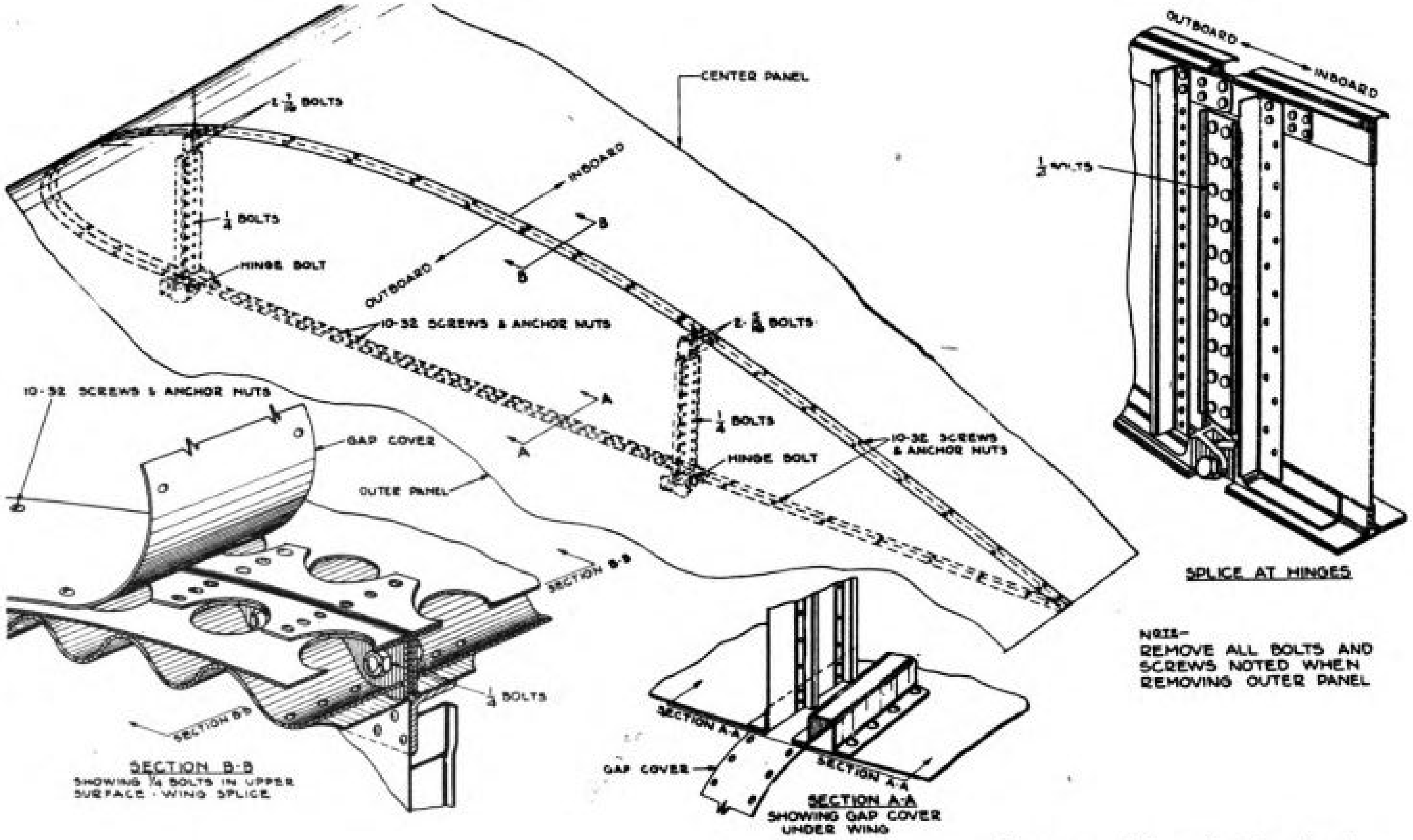
Flaps are usually connected to the trailing-edge section by means of a piano hinge which is spun in place to complete the assembly. In cases where slotted flaps are used, the flap connection is similar to that employed on ailerons.

Details for making the splice between outer and center panels on a typical stressed-skin wing are shown in Fig. 21. This splice is for the wing shown in Figs. 14 and 15. Note that the lower hinge pin is heavier than the upper one at the hinge splice detail of Fig. 21. This is due to the fact that all loads on the lower portion of the wing are carried by the spar flanges, while loads in the upper surface are carried by both the spar flanges and corrugations. Section B-B of Fig. 21 shows the ¼-in. bolts which are used at every depression in the corrugations in order to carry the bending loads across the splice. The holes in the skin directly above these bolts permit assembly and disassembly; the gap cover closes these holes and the crack where the panels join. In this particular wing splice the spar webs are joined by means of a splice plate and ¼-in. bolts. Very often all the shear load is taken out at the spar-chord hinges and the web splice is eliminated. Both methods are consistent with good design. From an inspection of the wing splice diagram it is readily apparent why considerable care must be exercised in drilling the bolt holes for the splice and in locating the hinge fittings perfectly. Unless this is done it would be impossible to match the holes and set the bolts in place.

Courtesy Glenn L. Martin Co.

Fig. 20—Assembly Floor

Usually the outer panels are not joined to the center panel until just before the airplane leaves the assembly floor. This is done to conserve floor space and to prevent the wing tips from becoming damaged due to bumping other airplanes or assembly equipment while it is being pushed around the

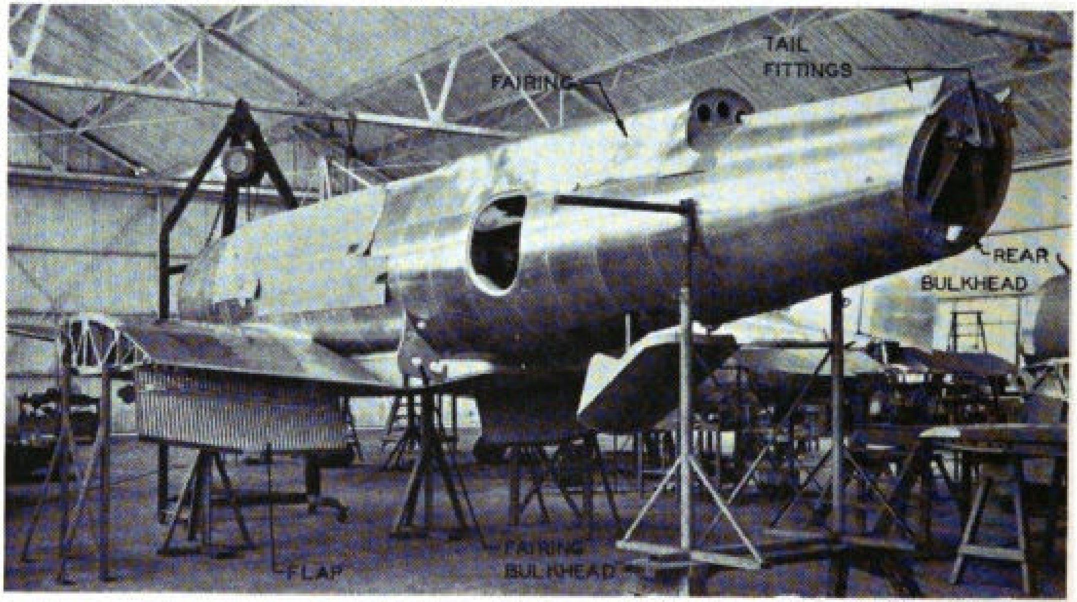


NOTE–
REMOVE ALL BOLTS AND
SCREWS NOTED WHEN
REMOVING OUTER PANEL

Courtesy Glenn L. Martin Co.

FIG. 21—WING-SPLICE DIAGRAM

assembly floor. Generally the center panel (to which the landing gear is attached) is fastened to the fuselage and this portion of the final assembly then moved about on its own wheels. Fig. 22 shows fuselage center-wing assemblies before the landing gear has been attached and Fig. 23 shows the landing gear of the airplane in Fig. 22 set in place. Fig. 22 shows the flaps in place and the two control links by which the flaps are operated. The flap, which is of the "split" type, is novel in that it employs corrugations as the stiffening elements.

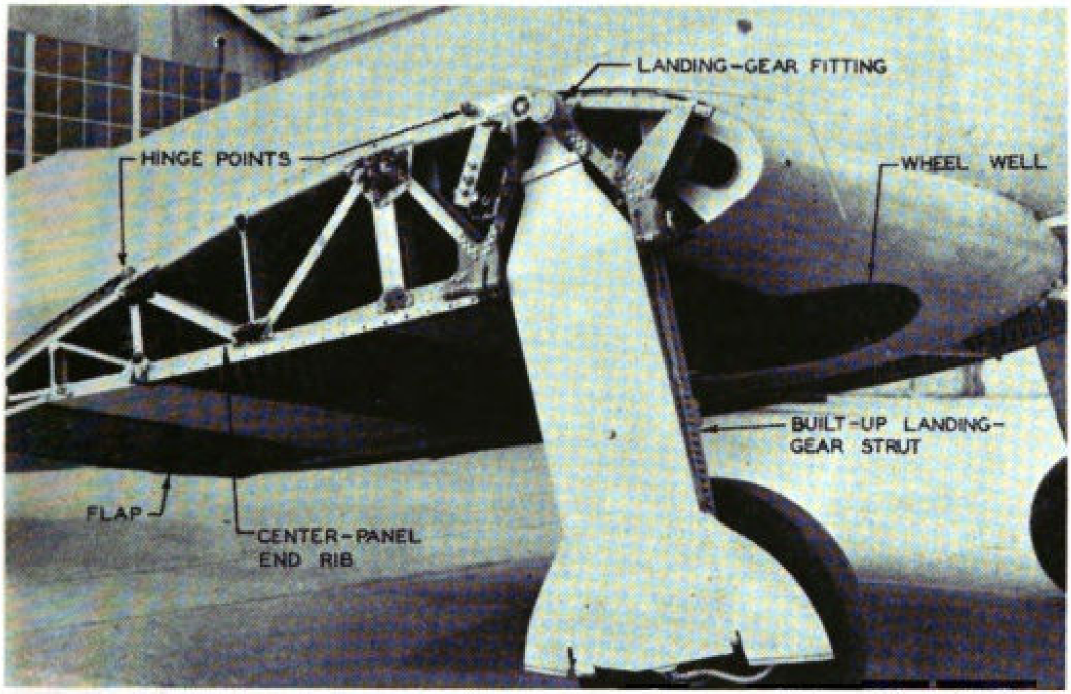


Courtesy Vultee Aircraft Corp.

FIG. 22—WING AND FUSELAGE ASSEMBLY

Thus far only aluminum-alloy structures have been dealt with. Magnesium structures are similar.

Wooden wings are most often used on light airplanes and their assembly merits some consideration. Usually these wings are fabric-covered and hence assembly procedure varies slightly. Fig. 12 shows the assembly of the spars to the ribs. Two assembly approaches may be followed in this case. One is to line up the two spars on a jig and then to assemble the ribs together on the spars. In this case the leading, interbeam and trailing-edge sections of the ribs are separately assembled and then located on the spars. The other method is to slide the complete rib over the spar and into place as in the case of Fig. 12. The internal drag struts, which are usually chrome-moly. tubes bolted to the spars, are placed and fixed and the spars and ribs are fabric covered in a manner previously described in Chapter 10. This latter method of assembling ribs to spars is used only where there is no taper on the wing and all ribs are of constant shape and size. The ribs are fastened to the spars with brads and glue.



Courtesy Vultee Aircraft Corp.

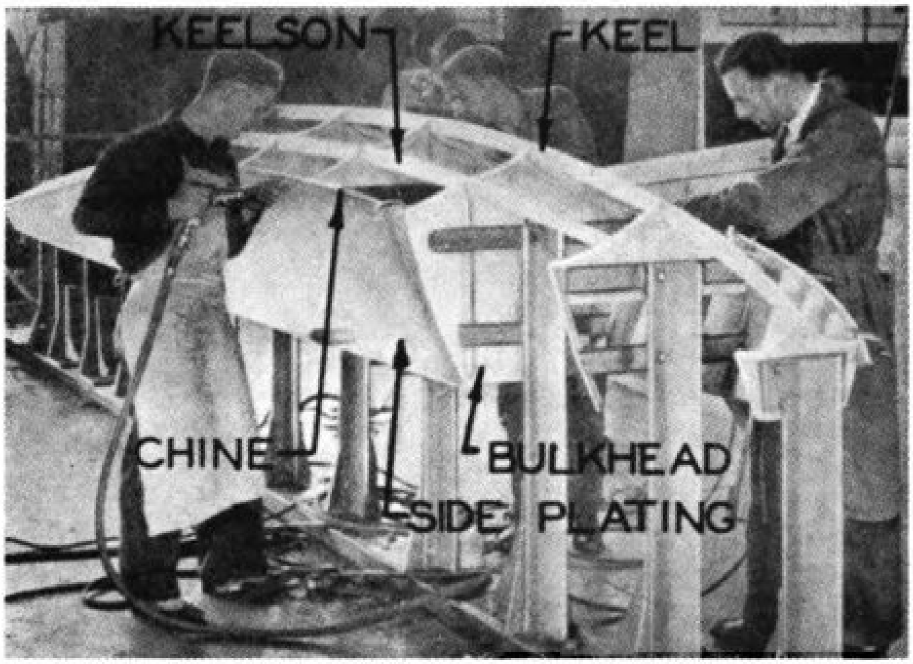
FIG. 23—WING CENTER PANEL AND LANDING GEAR

In a wood-covered wing the ribs and spars are first assembled and the plywood covering is put on last. The curved sections of plywood are bent to shape by being steamed and allowed to dry in the bent condition. Attachment of the plywood to the spars and ribs is by brads and glue. Normally the plywood covering takes only the twisting loads in the wing and the beams take the bending load. However, some wooden wings are now being constructed which use thick plywood sheathing to assist the spars in taking the bending. In any event, wood members are most satisfactory when bonded together with glue, particularly synthetic resin glues. Whereas bolted hinge connections suffice for connections between panels when two spar wood wings are used, the use of stress carrying plywood covering requires that some connection be made between the inner and outer skin at the break. A splice strip glued to one section and bolted to the other serves this purpose.

CHAPTER 12

FLOAT ASSEMBLY

Seaplane floats are now made almost exclusively from aluminum alloys. They are used as the main landing gear on small airplanes operating over water and on the wing tips of large flying boats. Except for the wing-tip floats, whose general dimensions are often determined by the wing sections into which they retract, float design has been more or less standardized. Unlike other structural elements of airplanes, no cutouts are permitted in the stressed skin of floats except those provided for manufacturing, inspection and repair. These are closed with watertight stressed doors. The necessary integrity of watertight float structures has probably done much toward making a standardization of

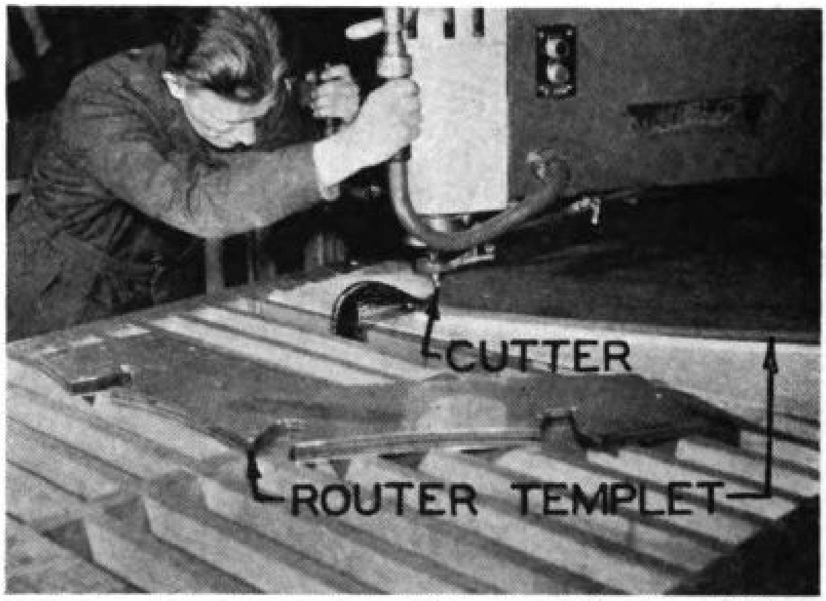


Courtesy Edo Aircraft Corp.

FIG. 24—RIVETING FLOAT SKIN TO FRAMES

float lines possible. Floats are probably the only aircraft structures to which standardization has even been applied with any degree of success.

For all practical purposes floats may be likened to the box beams of wings with the vertical sides of the floats forming the spars and the frames, and bulkheads the ribs or forming members. Some floats are constructed with a longitudinal vertical member running down the center, thus making a three-beam float. In this case the keel member, usually an extruded section, forms the bottom chord of the beam. On a two-beam float, such as that shown in Fig. 24, the vertical side members carry all the load. In either the two-beam or three-beam floats the side beams use the chine as the lower beam chord. The chine is the extruded section at the intersection of the bottom and side plates. The top and bottom plating corresponds to the upper and lower surface of the wing sections respectively. The bottom plating is usually fairly heavy, .051 in. thick and greater, because of the high impact loads due to landing. Very often stringers are run longitudinally along the bottom plating to fur-

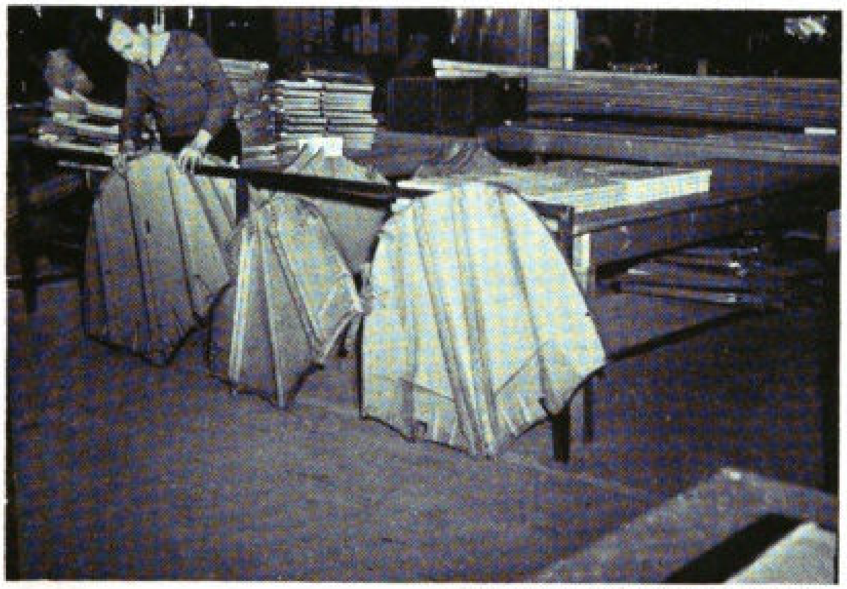


Courtesy Edo Aircraft Corp.

FIG. 25—ROUTING OUT BULKHEAD WEB

ther support the skin. Such a stringer may be seen in Fig. 24 midway between the keel and chine members. In this particular design the stringers are referred to as sister keelsons because they also form the bottom of a secondary keel caused by the fluted bottom design found on Edo floats.

Floats are usually riveted together and flush rivets are normally used to reduce aerodynamic and hydrodynamic drag. Just as with any other major assembly, subassemblies are first made and the individual parts are pre-drilled. Fig. 25 shows a number of bulkheads being routed out simultaneously. A top plate usually serves as a drill template for locating rivet holes in the face of the part being routed. Note the notches in the former shown in the foreground of Fig. 25. These are for the keel and two longitudinal bottom plating stiffeners.

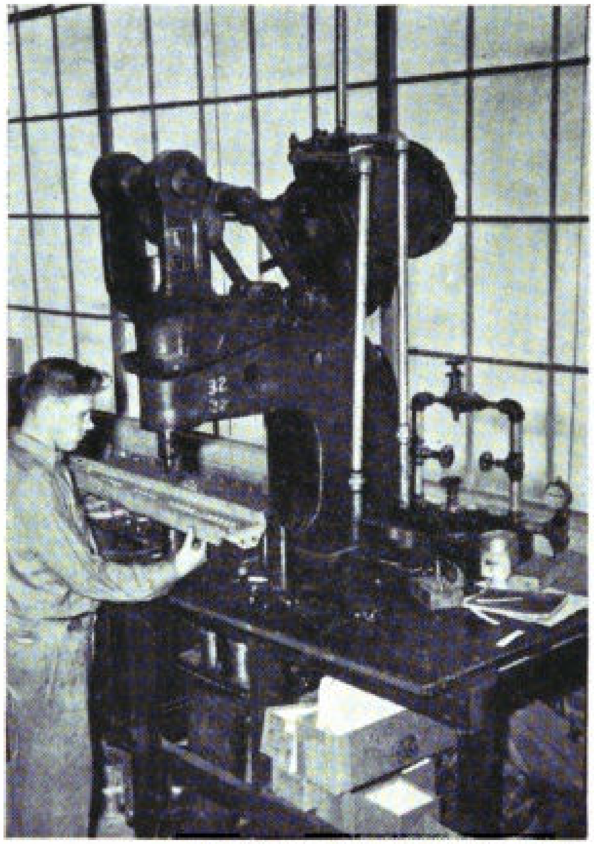


Courtesy Edo Aircraft Corp.

Fig. 26—Bulkhead Assemblies

Fig. 26 shows a number of bulkheads which have been first formed from the routed out blanks and then stiffened and strengthened by the addition of angles, channels and gussets which are attached by means of a machine riveter, shown in operation on another part in Fig. 27. Such assemblies are pre-drilled and then held together by screws or patented fastening devices until they are riveted.

The first step in assembling the float from the subassemblies is to lay the keel or, if a center-beam design is being built, to locate this beam in the assembly jig. In the case of the assembly in Fig. 24 the frames and bulkheads are set in the jig and the keel member then located in the notches provided for it in the bulkheads. Clips are used to attach the keel to the frames. The bulkheads are similar in construction to web-type interbeam ribs. Stiffeners consisting of either bent angles or extruded sections are provided to prevent the thin web from buckling. The bulkheads divide the float into several compartments, fore and aft, so as to prevent it from entirely losing its buoyancy even though one section may be damaged enough to fill with water.



Courtesy Edo Aircraft Corp.

FIG. 27—RIVETING FLOAT SUBASSEMBLY

Where a central beam is used it also divides the float into right and left compartments.

After the keel and bulkheads have been set in place, the side-skin and stiffener assembly (primary) is set in place and riveted to the frames. These side-skin assemblies include the chine angle. The bottom plating—which is preformed, heavy gauge sheet—is next assembled to the float. The top of the float remains open and permits easy access to buck the rivets which fasten the bottom skin to the stringers and frames. The bottom plating is broken at the step and along the keel so that it is assembled to the float in at least four separate pieces. Where two steps are employed the bottom plating is in at least six pieces. Due to the heavy gauges used in bottom plating the rivets are usually machine countersunk.

The top plating is put on last. It is usually broken up into a relatively large number of separate pieces, each of which has an access hole. The top plating is put on by working from one end (usually the forward end) to the other. The access holes permit the bucking of the rivets around the edges of the top plating and provide means of inspecting the float and easily repairing it when it is in service. The very usage of floats requires that they be quite frequently inspected and often repaired. Access holes are closed up by watertight plates which are screwed in place and which employ a gasket to maintain watertightness. Nut strips or "gang nuts," as they are sometimes called, are used extensively for the attachment of access hole covers.

Before the top plating is put on, the float is usually tested by filling each division with water and watching for seepage from the filled sections into the adjacent compartments. After this check is made the whole float is filled and checked for leaks from inside to outside. Leaking seams are marked with pencil and then made tight by drawing up the rivets in the vicinity of the leak or, if necessary, replacing them.

Very few fittings are necessary on floats. The main fittings are those which attach the float to the rest of the airplane. These are often made of steel and are attached to the float at a heavy bulkhead by means of bolts which pass through the fitting, the deck plating and the bulkhead flanges. Resin-impregnated tape insulates the fittings from the rest of the float. Mooring posts are also bolted to bulkheads while catapult fittings (if used) are attached to the keel and chine.

A nose bumper for the float prow is essential. This is a separate piece, usually molded rubber, which is attached to the foremost bulkhead by means of screws. The prow bulkhead is the nearest one in the assembly shown in Fig. 24 and it may be seen that this is "flat" so that the bumper will be attached to this flat face.

On single-float seaplanes only one or two vertical struts are now used to fix the float to the fuselage. In such cases the strut is an integral part of the main load-carrying bulkhead. This strut is generally a built-up member which is covered by a streamlined fairing which also houses any controls which pass to the float. In cases where the float is used for a fuel tank the fuel lines will pass beneath the streamlined fairing, as do also the rudder-control cables. A rudder is provided to assist in water handling of the seaplane at speeds below those at which the air rudder is effective.

One important phase of float assembly which has not yet received our attention is the method of making floats watertight. The simplest seam to waterproof is the one where a flange of a stiffener or bulkhead is riveted to the inside of the covering. In such a seam leaks can only occur through an imperfectly set or sealed rivet. These seams may usually be satisfactorily sealed by the generous application of primer paint in the rivet hole immediately before it is set. The rivet is then drawn up tightly so the paint fills any minute spaces beneath the head and the skin or the shank and the hole. While this method is good in case of brazier-head rivets, it is not always satisfactory with flush dimple rivets.

Where this type of rivet is used an impregnated fabric strip is placed between the faying surfaces just prior to riveting. Synthetic rubber, in ½-in.-wide strips, is also often used for sealing "flange joints." The synthetic rubber is softened with a solvent just before riveting so that it will "flow" during riveting and seal the rivet shank between the sheets. The other seam is the "joint" or "lap" seam which is more common since it occurs along the keel, chines, step and intersection of side and deck plating. A sealing strip is almost invariably used in lap seams. Again the seal may be impregnated fabric or synthetic rubber. Wherever possible, and especially below the waterline, double rivet rows, staggered, are used at lap seams and exceptional care is exercised in riveting to make sure the rivets are not only tightly drawn up but that the heads and shanks are concentric. In spite of all precautions some leakage is inevitable, especially after the float has seen service. In order to insure against internal corrosion and to also prevent leakage, floats are sometimes sprayed inside with resin.

Because of the relative severity of corrosion of aluminum alloys in the presence of salt water, all float parts are anodized before any assembly work is done or else immediately after the primary assemblies are made. The anodic treatment provides an excellent surface for painting the parts to further protect them from corrosion. With the anodic processes and the extreme care used in painting floats, corrosion difficulties are considerably reduced.

CHAPTER 13

TAIL ASSEMBLY

Control-surface assembly, which includes rudder and elevator tail units, has been covered in Chapter 10, so only the assembly of the fin and stabilizer will be dealt with here.

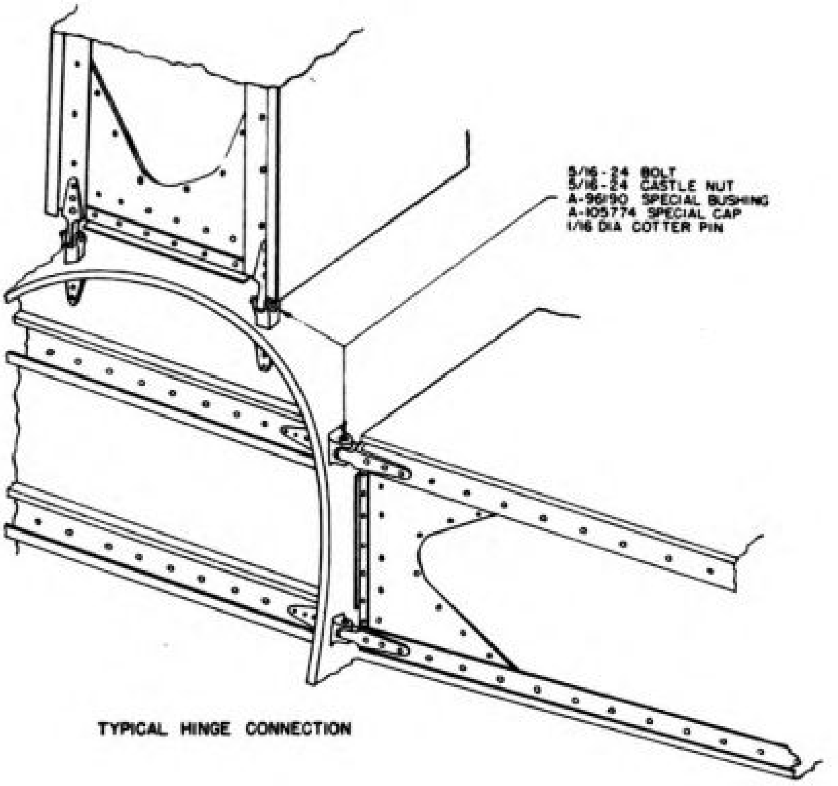
The majority of fins and stabilizers are either steel-tube or aluminum-alloy structures. The former are quite common and are usually found on light airplanes. Aluminum alloy is used almost exclusively on transport, military and on medium and heavy private airplanes. Unlike the wing which must provide the "lift" to keep the airplane in the air, the sole function of the tail surfaces is to stabilize the airplane and control the direction of flight. Any lift developed by the tail surfaces for control is the result of the rudder or elevators being deflected. Because a lifting surface is not required for level flight, the tail surfaces usually have a symmetrical airfoil section. Sometimes this symmetry permits interchangeability between the right and left stabilizer units.

Tubular-steel tail surfaces are always fabric covered. The individual sections of tubing are first cut to length and the ends are milled or filed to fit the other tubes to which they are to be welded. Normally the leading edge is made up of one steel tube, bent to contour at the tip. The rear portion is a straight steel tube which connects to the tip end of the leading-edge tube. The ribs which space the leading edge and rear tubes apart are usually $\frac{3}{8}$-in.-diameter tubes, so located as to form a triangle with its apex at the leading edge and its base at the rear tube, one of the $\frac{3}{8}$-in. tubes being welded to the upper side of the rear tube and the other $\frac{3}{8}$-in. tube to the bottom. Hinge brackets, consisting of steel (4130) sheet, bent to form, are welded to the rear tube. All the welding is done in a rigid steel jig. The tubes are very tightly clamped in place during welding to prevent warpage due to the unequal distribution of heat caused by welding. Some tubular structures of this type are arc-welded to prevent shrinkage and warpage. The application and use of arc welding is constantly being expanded for structural welding in airplane parts because of greater strength, lesser degree of shrinkage and warpage by this process. Attachment of the tail surfaces to the fuselage may be made by bolting or welding. When the attachment is by bolting, the surfaces are covered first and if welding is used the covering is done afterwards.

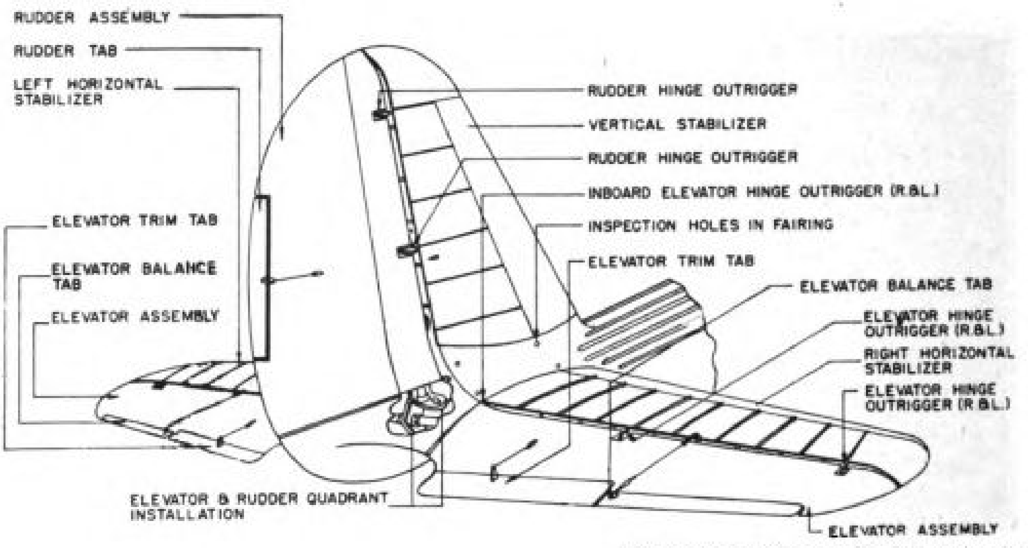
Aluminum-alloy fins and stabilizers may be either fabric covered or metal covered. The metal-covered surfaces are predominant. Aluminum-alloy tail construction is very similar to wing construction and the assembly procedure is virtually identical except that there is no trailing-edge portion unless the rudder and elevators, which are separate, may be considered as such.

Except on relatively large airplanes the spars may be stamped out in one or several pieces. When stamped out the spars are channel sections and are located with the flange facing aft. Built-up tail-surface spars are assembled in jigs in a manner identical to that employed on wing spars. Ribs are either stamped out in one piece or built up; usually they are stampings.

Tail construction is usually two-spar type with the spars carrying all the bending load and the skin the twisting load. With two-spar construction the assembly may be "progressive" or by assembling subassemblies. In progressive assembly the nose-skin-to-nose-rib assembly is made separately and located in the main assembly jig. The front spar is then located and attached to the leading edge by screws and rivets. The interbeam ribs are next located and fastened to the front spar. Following this the skin assem-



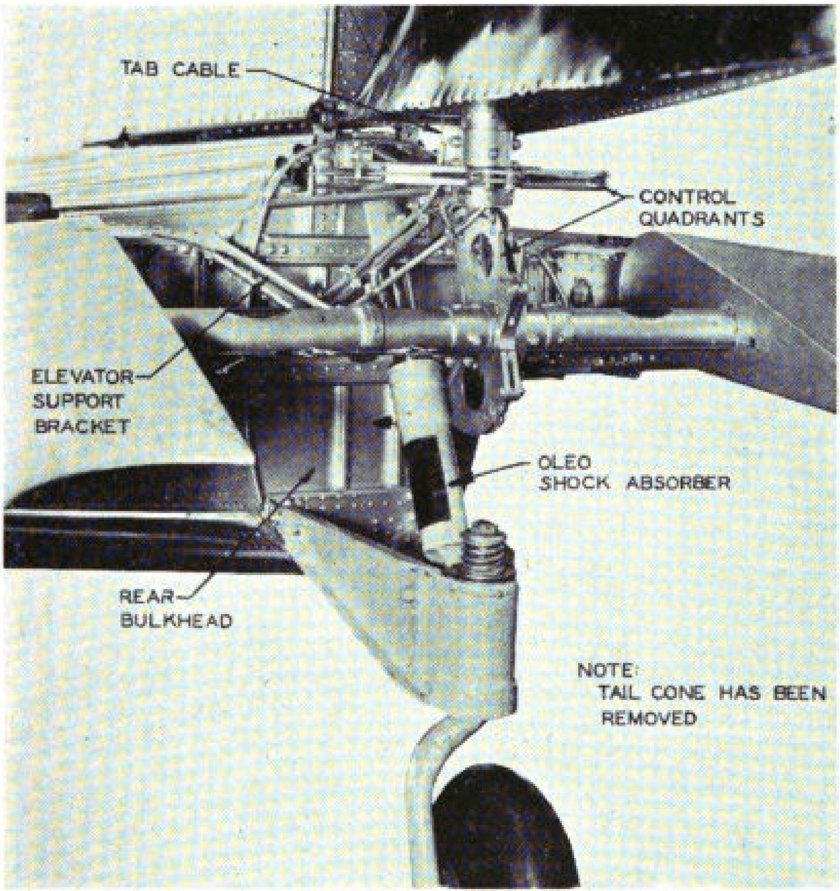
TYPICAL HINGE CONNECTION



Courtesy Glenn L. Martin Co.

FIG. 28—EMPENNAGE DIAGRAM

blies, which may be reinforced by light stringers, are riveted to the rearward-facing flange of the front spar and to the interbeam-rib flanges. The assembly is completed by the rear spar and the control-surface hinge brackets which are attached to it. When the subassembly procedure is followed the spars, interbeam ribs and skin panels are assembled into a box beam, just as in the case of a box-beam-type wing. The leading-edge assembly is attached afterwards. Monospar tails are by far the simplest to assemble since there are but half as many separate ribs and rib-to-spar connections. In assembling the monospar tail the ribs are jig located. The skin assemblies consisting of skin and stringers are riveted to the ribs. Accessibility for this riveting is from the open rear before the spar is located. The single spar is assembled to the load-carrying nose section last. Fin and stabilizer tips are constructed and assembled to the tail similarly to wing tips.



Courtesy Glenn L. Martin Co.

FIG. 29—TAIL-WHEEL AND CONTROL-SURFACE ASSEMBLY

Aluminum-alloy fins are usually made in one section, whereas the stabilizer is usually broken up into two and sometimes three panels. When the breakdown is to three panels the center panel normally runs only to the side of the fuselage. The empennage diagram (Fig. 28) shows a three-panel stabilizer with the outer panel-hinge connection occurring at the fuselage side. In a two-panel tail the panels join at the fuselage centerline and are attached to the fuselage by an angle which is located at the intersection and runs from front to rear spar on both upper and lower surfaces. Fig. 29 shows the actual connection diagrammed in Fig. 28. Note that the fairing between the vertical and horizontal tail is not in place and the tail cone is removed to show the control and tail-wheel details.

The hinge-connection detail of Fig. 28 shows that the spar is built up from bent angles which form the spar chords and a web to which these angles are riveted. The web is reinforced near the hinge point by a doubling plate which is located and assembled to the spar when it is built.

Because of the restricted space within the tail, the sequence of assembly operations must be carefully scheduled to avoid closing off portions which have not been riveted. This precaution is unnecessary where production procedure has been worked out down to the minutest operation, but on experimental work the assembly men must pay particular attention to this possibility.

CHAPTER 14

FUSELAGE AND HULL ASSEMBLY

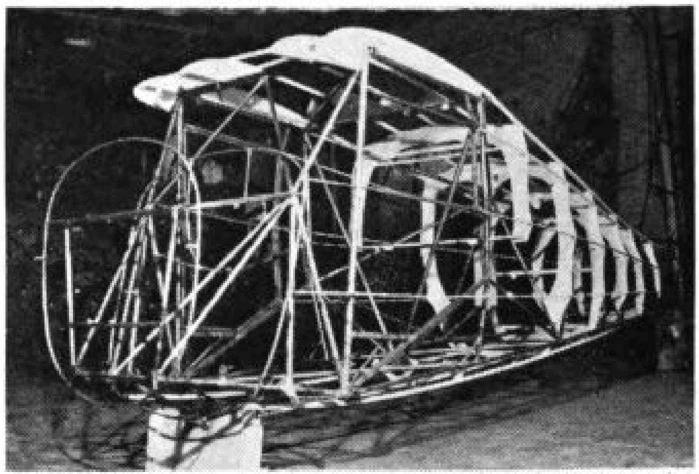
Airplane fuselage and hull assembly may be discussed together since fuselages and hulls are so very similar. Basically a hull is nothing more than a fuselage with a fluted bottom to provide proper hydrodynamic properties for landing and taking off. Fuselages and hulls are more easily assembled than the other portions of the airplane. This is because their very shape and size naturally provide accessibility to most parts. Further, the depth and proportioning of the fuselage are more satisfactory structurally and the structural members and skin gauges are generally lighter and easier to work with and assemble. However, controls, equipment and cutouts for windows and doors tend to make some portions of the fuselage assembly more complex.

Fuselages, like wings, are constructed from steel, wood or aluminum alloy, and each material requires its own assembly methods.

Steel-tube fuselages were once used on practicaly all airplanes, but now the use of steel in fuselages is principally on light airplanes and in some instances on military aircraft where accessibility to controls and armament is so necessary that the use of stressed skin is impossible. In such cases large, easily removed access doors are provided so that controls and armament may be readily serviced.

Fig. 30 shows an Aeronca fuselage before the fabric covering is applied. All steel members are cut to length and the ends milled to shape for fittings and intersections with other members. The first step is to locate the individual parts in the assembly jig. Usually there is one jig for the right-hand panel and one for the left, a panel being all the tubes located in the vertical side plane. Assembly is by torch or arc welding. During the panel assembly all lugs and fittings which belong to the panel are jig located and welded in place.

After the two side panels are welded they are placed in another assembly jig, which serves to locate them in the proper relationship to one another. This larger jig locates the upper and lower lateral members so their ends may be welded to the longitudinals which extend from front to rear along the top and bottom of each side panel. Sometimes other subassemblies, smaller than the side panels but more complex, are welded on separate jigs and assembled with the side panels in the main jig. Fig. 31 shows a welder working on a cluster at the forward end of the fuselage of Fig. 30. In this instance a repair job is being done since the fuselage is not located in its welding jig.

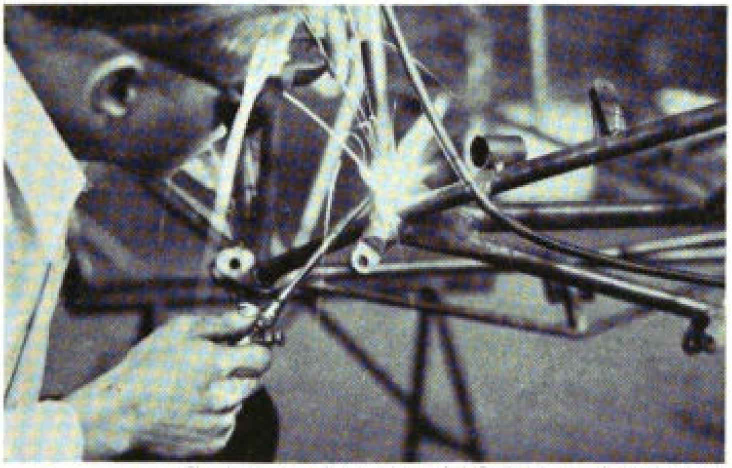


Courtesy Aeronautical Corp. of America

Fig. 30—Welded Steel-tube Fuselage

When welding is completed the fairing strips are set in place. These may be seen in Fig. 30. The frames are usually plywood, cut to shape on a band saw and dressed on a power-driven sander. They are attached to the welded framework by tape and screws which are tapped into lugs on the framework. Spruce strips running longitudinally attach to the plywood frames. The wood members are varnished either before or after assembly to the fuselage in order to reduce moisture absorption. The mercerized cotton cloth is attached to the wood members with brads and dope and to the steel tubes by doping to tape wrapped around the tubes. Usually the fin forms an integral part of a steel-tube fuselage and is covered at the same time as the fuselage. Flying-boat hulls are constructed from aluminum or plywood instead of steel tubing.

Engine mounts, except when located in the wing, may be properly considered a portion of the fuselage. Whether the basic airplane structure is steel, wood or aluminum alloy, the engine mounts are usually steel-tube structures. Some engines, particularly liquid-cooled types, are supported by forged engine bearers and in some designs air-cooled engines are supported within monocoque nacelles but the majority of mounts are still steel-tube structures. Fig. 32 shows a tubular mount being arc-welded. Note the heavy jig which rigidly supports the mount to insure accuracy.

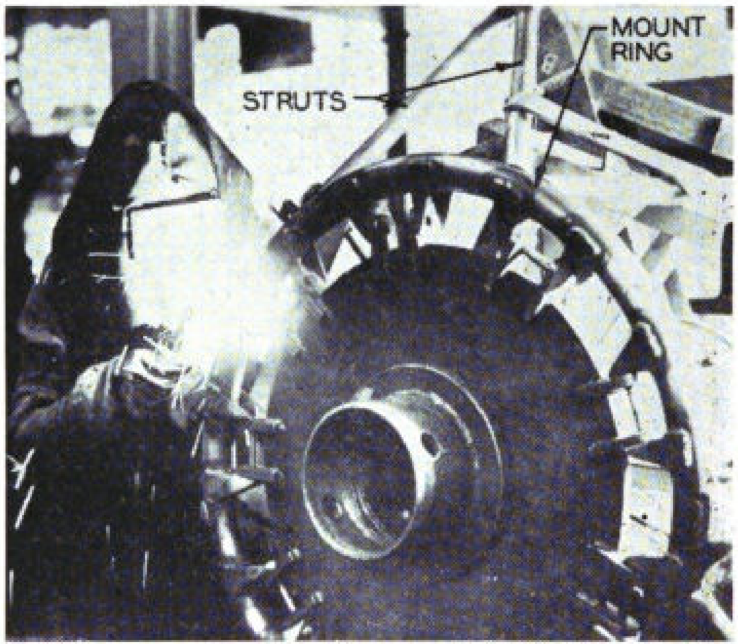


Courtesy Aeronautical Corp. of America

FIG. 31—WELDING STEEL-TUBE FUSELAGE

Wooden fuselage construction was once quite popular but metal displaced wood because the latter was subject to decay and warpage under damp conditions. Recent improvements in bonding plywood veneers with fungus-proof, stronger, more stable plastic glues—such as urea and phenol formaldehydes—eliminate these difficulties. More advanced concepts of structural analysis and improved shop methods of forming and processing wood combine to make it a satisfactory structural material from all standpoints.

Modern wood construction is the stressed-skin variety with plywood frames and bulkheads to hold the skin to contour. In assembly the frames are first jig located in proper relation to one another. Longitudinal members are next located on the frames which are usually notched out to receive them. The longitudinals are attached to the frames by screws and liquid resin glue. After the location of all stiffening elements—frames and longerons—the plywood skin is applied. Fig. 33 shows a plywood-covered fuselage during the process of assembly. Note the method of jig locating the frames. The heavy tubular member running down the center of the fuselage is supported at the fuselage tail and near the forward end. At each frame station four light tubular members extend and support the frame. Two of these four are collapsible, in this case the lower and near ones, so that the fuselage may be stripped from the jig over

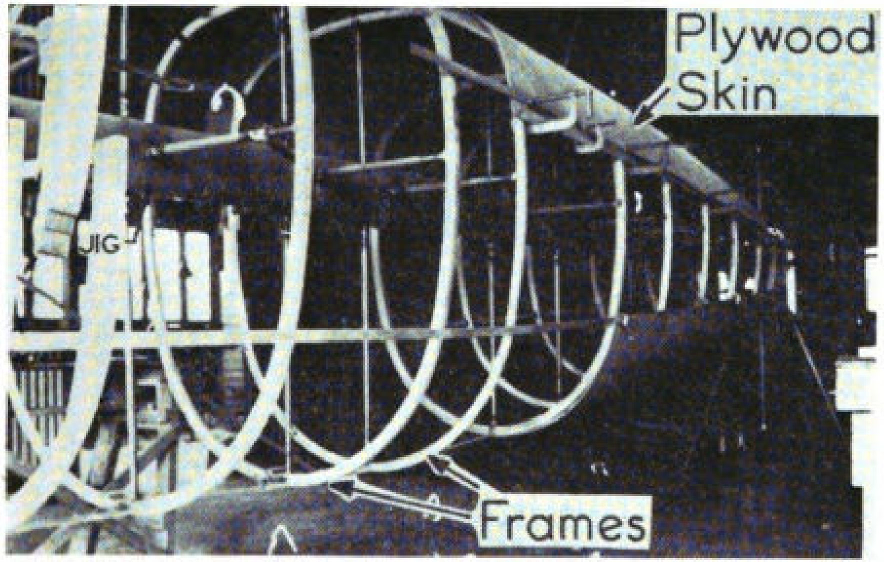


Courtesy Lincoln Electric Co.

FIG. 32—ARC WELDING AN ENGINE MOUNT

the tail end. If no collapsible members were used some of the forward frames might interfere with the jig during removal of the assembly.

In Fig. 33 the upper tail skin and part of the lower are already located. A longitudinal member occurs at the upper edge of the lower skin and so stabilizes the free edge during assembly. The absence of a similar member along the lower edge of the top skin requires that a light batten be temporarily clamped to the outside of the free edge, as shown.

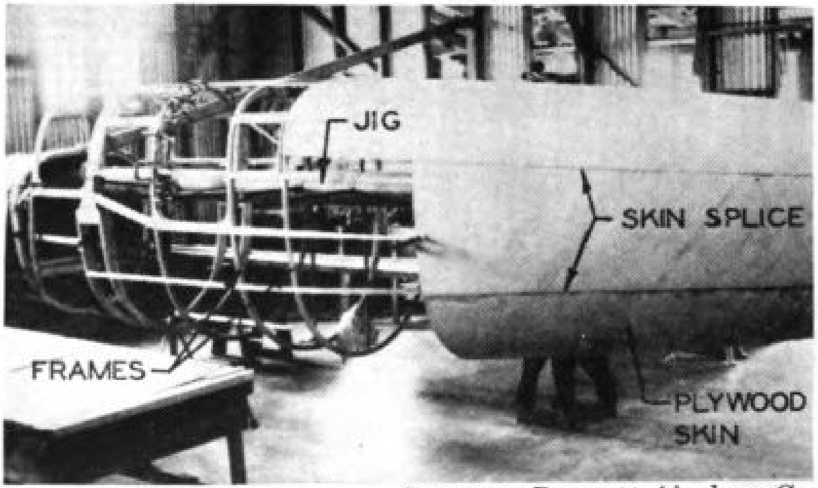


Courtesy Bennett Airplane Co.

FIG. 33—WOODEN FUSELAGE IN JIG

Attachment of the plywood covering may be by a cold-setting glue or a heat-setting resin. The outer frame edge is covered with the glue and the skin is tightly clamped in place, small copper brads sometimes being used every several inches to insure contact all along the joint. When heat-setting glues are used the whole fuselage assembly must be wheeled into an oven which maintains an elevated temperature of about 150° F. while the resin cures. Fig. 34 shows the fuselage with the rear side skin in place. Skin joints of this type are generally made by scarfing the edges and then glueing. This particular fuselage is assembled progressively; that is, part after part is added until the assembly is completed. Sometimes fuselages of this type are made in two halves, right and left, with each half being divided into several subassemblies. When this is done much of the equipment, controls and brackets are installed during the subassembly stage. The fuselage halves are fastened together along the top and bottom with a splice strip to finish the assembly.

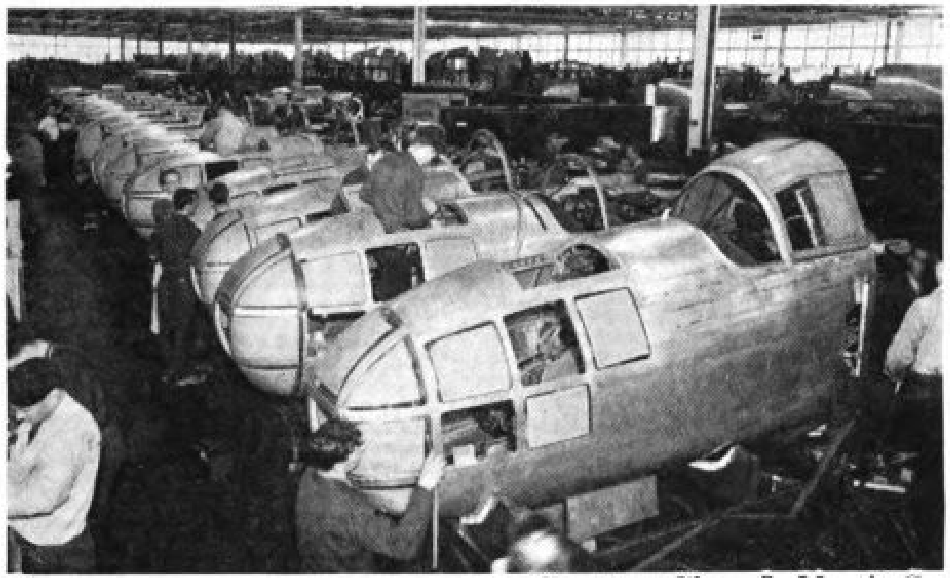
While there is a definite trend toward wood and impregnated wood construction the majority of the military and commercial airplane fuselages are of the stressed-skin aluminum-alloy type. Current practice is to divide the fuselage into a number of subassemblies, each subassembly being finished as nearly as possible, and then to bolt these subassemblies together to complete the fuselage assembly. The breakdowns shown in Figs. 2 and 3 indicate how the fuselage may be split up.



Courtesy Bennett Airplane Co.

FIG. 34—PARTIALLY COVERED WOODEN FUSELAGE

Basically, the fuselage structure of a metal airplane consists of frames or formers which correspond to the ribs of wings, longitudinal stringers which have their counterpart in the spanwise stringers in wings, and the skin which covers the frames and stringers to form the smooth load-carrying shell. The primary fuselage assemblies are the assembly of the skin, frames and stringers into panels. The secondary assembly is the attachment together of these primary assemblies to form finished portions of the fuselage. Fig. 35 which shows a series of Martin bomber nose sections being assembled represents secondary fuselage assemblies. The primary assemblies of this unit are (a) the nose section comprising the forward windows and frame including the bomber's window, (b) the right and left halves from the nose section to the rear of the pilot's cockpit, (c) the cockpit enclosure (which is in place on the nearest fuselage in Fig. 35), (d) the flooring, seats, control units, etc., which are installed within the fuselage, and (e) the entrance and emergency exit doors. The entrance door may be seen at the bottom of the near fuselage and the emergency door covers the opening in the top of the fuselage just forward of the windshield.



Courtesy Glenn L. Martin Co.

FIG. 35—FUSELAGE NOSE-SECTION ASSEMBLIES

By inspecting the line of fuselages of Fig. 35 it may be seen how the fuselages are built up. All the controls, brackets, etc., which belong distinctly to one side or the other are assembled to the structure while the right and left halves are separate from one another. These halves are then attached together by splicing along the top and bottom. The flooring, seat, rudder pedals, control column and similar units common to both sides of the fuselage are next assembled. In this particular case, access to the bomber's cockpit is obtained from the front and the pilot's cockpit from the rear. The nose section is added after the bomber's cockpit has been completely fitted and the pilot's enclosure is set in place after the pilot's controls have been installed. Doors are added last. The plastic windows are covered over with gummed paper or wrapping paper and masking tape to prevent them from being scratched during assembly. This remains on the windows through final assembly. Plastic windows will take considerable distortion and are attached by means of screws which bind them between metal frames, inner and outer. On the other hand considerable care must be exercised in placing plate-glass windows to prevent any tendency to twist the window and crack it. Normally a generous thickness of rubber is provided around the edge of plate-glass windows to separate them from their frames.

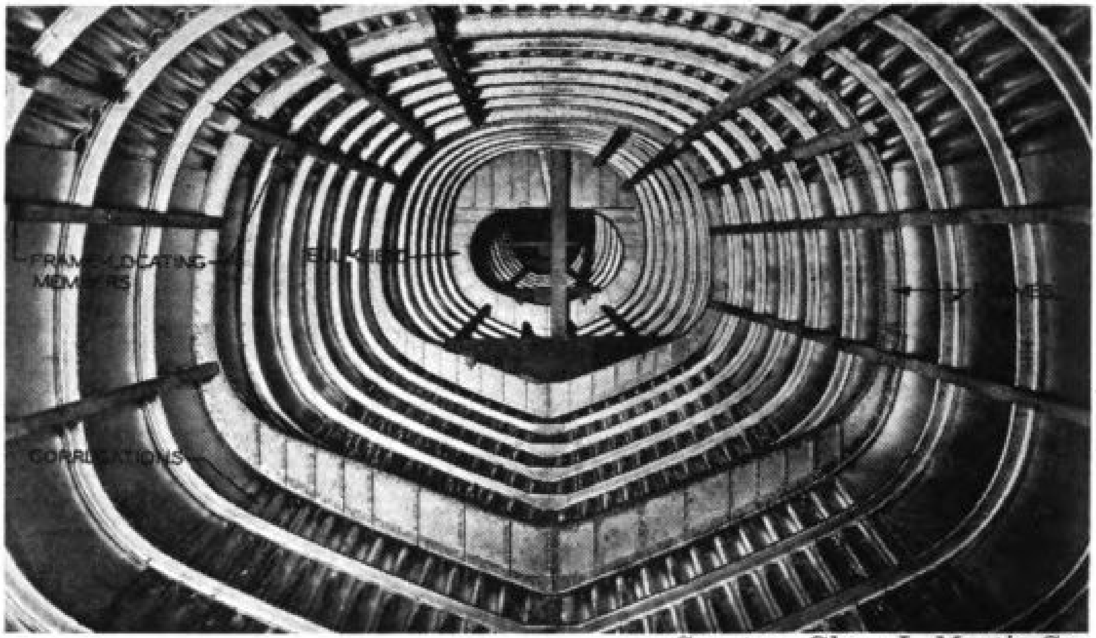
In the background of Fig. 20 may be seen the rear section of the same fuselage. Like the nose assembly this too is divided into two halves, right and left. The gunner's equipment, etc., is assembled to the individual halves insofar as possible before they are attached together. After they are joined the flooring, gun mounts, seats, etc., are assembled within the fuselage. All main locating points are jig drilled so that these separate parts will fit in place without additional hand fitting. The assembly operation is speeded up by building the fuselage in halves because the location of frames and stringers is simplified and the riveting of the skin to these elements is made much easier because the subassembly is completely open on both sides. By subassembly the individual jigs are made simpler and interfere less with the work of the assemblyman. Furthermore, any given jig is tied up only for the length of time required for a limited number of operations, after which it is cleared for the assembly of another set of parts. When the parts are assembled one upon the other until the complete fuselage is finished and when this work is done on one jig, no new fuselage can be begun until the previous one is completed. By the subassembly procedure a whole series of parts are being simultaneously constructed. The rear fuselage sections in Fig. 20 show the center stabilizer panel and the fairing in place. These units are attached after the two fuselage halves are riveted together and at the same time that the internal equipment is being located. When the individual fuselage sections are finished, they are ready for final assembly.

Contrasted with the subassembly method described above is the progressive assembly method usually employed in building flying-boat hulls. Flying boats are usually considerably larger than land planes and are usually less in demand and consequently are not built in large numbers. Because of this, it is more efficient to assemble them progressively, unless rather sizable quantities are ordered. The same holds true for very large commercial and military landplanes.

Fig. 36 shows an interior view of the tail portion of a flying-boat hull with the skin in place. The bulkheads and frames are separately assembled. The assembly jigs for these units may be either vertical or horizontal, the former being preferred. Rivets are almost always used to attach the bulkhead stiffeners to the web. Because of the relatively few parts normally made, rivet and bolt holes are located by hand since the quantities do not warrant the expense of a drill jig.

Hulls are very similar to floats except that they are much larger and the interior of the structure is completely accessible for work. The first step is to lay the keel which is a relatively heavy extruded section bent to contour. This is clamped onto a steel or wood structure built up from the floor. Upon the keel the frames and bulkheads are set up. Each is located from a reference point at the nose of the hull. They are held in place by notched planks supported from the floor. When a steel jig is used to locate the frames, it consists of a scaffolding built on either side of the hull and the vertical members of the scaffolding are equipped with lugs which line up the frames.

The first part of the skin to be placed is the bottom plating. It is first riveted to the keel member, usually being spliced there. (See Fig. 36.) Pilot holes are drilled in the frame flanges before the frames are located on the keel. These pilot holes are used to drill the skin rivet holes. In drilling through the flange hole it is enlarged to full size for the rivet. The rivets which attach the bottom plating are then headed up. Considerable care is taken in drawing up all rivets to insure watertightness. Skin splices below the waterline have two rows of rivets closely spaced. Seam compound, synthetic rubber tape, and impregnated fabric are used on splices to close the seams. All parts are anodized before assembly and very often are given a coat of



Courtesy Glenn L. Martin Co.

FIG. 36—INTERIOR OF FLYING-BOAT HULL

zinc-chromate primer for added protection against corrosion.

After the bottom plating has been riveted in place the top skin is added. The side skin is riveted on last. In some cases the flooring is added before the side skin so that the large sections of flooring may be gotten inside the hull through the open side. When corrugations are not used for top and bottom plating, longitudinal stringers are employed. These are set in notches in the frames or bulkheads or else directly on top of the frames. Sheet stock is flush riveted to the stringers. While the top and side skin is usually light, sometimes as thin as .020 in., the bottom plating is usually heavier than .064 in. with bottom stringers spaced as closely as 5 in. Heavy gauge skin and close stringer spacing are used because of the very high impact loads caused by landing.

The control system, pilot's compartment, furnishings, partitions and doors are installed within the hull after the outer structure is complete. The controls, partitions and doors are built especially for the airplane. The doors and partitions are relatively simple subassemblies consisting of flat sheet stiffened by formed or extruded sections or by corrugations. The controls are built up from forgings, tubes, pulleys and cables riveted or welded together. Controls must be lined up perfectly to prevent binding or looseness which may cause excessive wear on the moving parts and ultimate failure. Furnishings such as chairs are often purchased complete, ready to install, so that they need only be bolted in place on assembly. Control installations and furnishing assembly cannot be generalized because each airplane has its own special requirements for these items; their location, method of installation and detail design must fit the airplane. Hydraulic and electrical-control installation are separate subjects in themselves and require special skill and ability on the part of the assembly man handling these installations.

CHAPTER 15

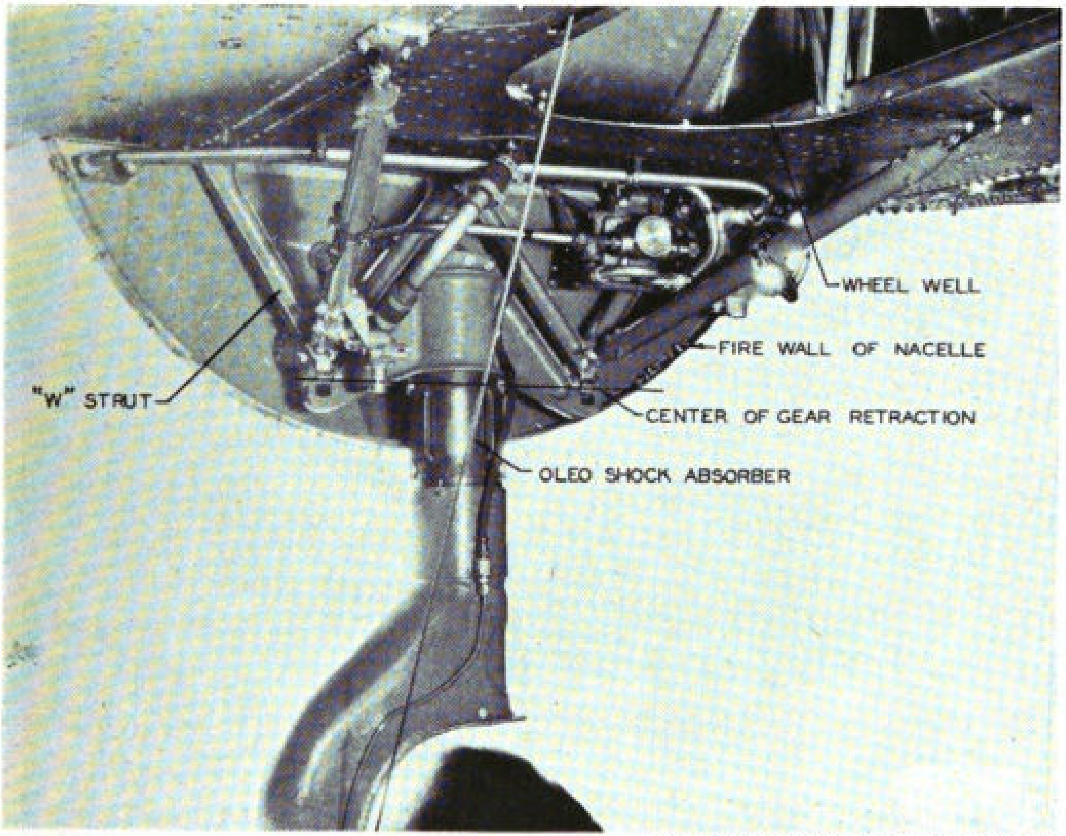
LANDING-GEAR ASSEMBLY

The assembly of the landing gear to the airplane is relatively simple. The shock-absorbing unit is the most complex part of the landing gear. This unit is manufactured by specialists in this type of mechanism and is purchased by the aircraft manufacturer ready to install. Consequently the assembly of the springs, metering pin, collars, etc., which make up the shock-absorbing unit need not be discussed here.

The landing gear may be of the fixed or retractable type. The fixed gear consists of the wheel, struts, oleo shock absorber, tire and brakes. The struts are usually chrome-moly. tubing with steel end fittings welded in place. The welding is done in a jig and the completed struts are machined on another jig to line up the bolt holes which attach the struts to the oleo. The separate struts and other parts are assembled in a special jig which lines up the individual units so that they may be bolted to one another. The assembly jig is built to mate with the portion of the fuselage or wing where the landing gear is to be attached finally. After removal from this jig the only work required to attach the fixed gear to the airplane is to slip the required bolts in place and connect the cables which run from the rudder pedals to the brakes.

The assembly of the retractable-type gear is not as simple as the fixed type. The number of parts on the retractable gear is largely a function of the method of stowing it within the airplane contour when it is retracted. Retractable main gear may be installed in the engine nacelle, wing or fuselage depending upon the requirements of the design. Fig. 37

shows a retractable gear which is housed in the engine nacelle aft of the firewall. The plumbing on the right of the gear is for the fuel system and has nothing to do with the wheel-retraction mechanism. Retraction is accomplished by a strut (not shown) which pulls the wheel backward and upward. The retracting strut is mechanically operated.



Courtesy Glenn L. Martin Co.

FIG 37—MAIN LANDING-GEAR INSTALLATION

The fork of the landing gear of Fig. 37 is welded construction; chrome-moly. steel is used. The oleo unit is located in the top of the fork as shown. The fork is machined to receive the oleo. The inverted Y-shaped forging at the top of the oleo attaches the oleo (fork) wheel assembly to the supporting struts. The hydraulic brake lines may be seen on the oleo and fork. The struts are jig assembled separately. The rear struts, which are built up from tubing and fittings bolted together, are assembled by themselves beforehand. The two forgings which make up the W strut are jig machined to insure accurate alignment and perfect fit with the yoke on the top of the oleo and the lower front-beam spar chord. The strut assembly together with the oleo and wheel assembly are located in an assembly jig which is also used to test the gear. The gear is retracted and extended by its own operating mechanism while it is on the jig. Alignment, retracting speed and clearances are all carefully checked during this stage. The completed gear is then assembled to the airplane structure by bolts, and the controls from the cockpit are installed. The airplane is jacked up on hydraulic jacks and the complete landing-gear installation is reinspected and given retraction tests. It is extremely important that considerable care be given to the proper assembly of retractable gear because its malfunctioning can completely wreck the airplane.

Courtesy Vultee Aircraft Corp.

FIG. 38—AIRPLANE DURING FINAL ASSEMBLY

Fig. 38 shows a retractable gear which is stowed in the wing when retracted. This is the same gear as shown in Fig. 23. It pivots about the front and rear hinge points on the lower surface of the wing. Retraction is accomplished by a hydraulic cylinder acting about the pivot point in such a way as to lift the wheel inward and upward. The shock strut is located within the built-up cantilever aluminum-alloy support strut. One of the jacks which support the airplane while the landing gear is checked may be seen between the wheels in Fig. 38.

Very often closure doors are employed to completely cover the landing gear when it is in the retracted position. These doors, which are built up from aluminum-alloy sheet, form an integral part of the landing-gear system since they must be operated from the gear-retraction mechanism so that they open and close with the operation of the gear. The doors are usually assembled to the airplane by a piano hinge and the door-retraction mechanism is linked to the landing gear and bolted in place.

A typical tail-wheel installation may be seen in Fig. 29. In this case the gear is assembled to the airplane by three bolts, one at the upper end of the shock strut and one at each side of the lower fuselage. The individual parts are assembled together by screws and bolts. Retractable tail wheels are not as common as retractable main wheels because the tail wheel contributes far less drag than the main wheels. Retraction is relatively easily accomplished, however, and, in the case of the tail wheel of Fig. 29, retraction would be accomplished by pulling the shock strut forward from the upper connection point. Like the main gear, the tail gear must be jig assembled and tested prior to installation on the airplane.

CHAPTER 16

FINAL ASSEMBLY

The finishing assembly operations are performed on the airplane on the final-assembly floor. Here the fuselage sections, wing panels, tail, landing gear and power-plant units are brought together to form the finished product. The wing center section and center fuselage (in some cases the complete fuselage) form the nucleus of the final assembly. (See Fig. 22.)

The main landing gear and tail section of the fuselage complete with the tail wheel are attached first. By doing this, wheels are provided to the assembly which permits it to be easily rolled around the assembly floor. The nose section of the fuselage is next bolted to the center section and the control connections completed to these units. The control cables or push rods are completely finished between the rudder and elevator quadrants and the control columns. The cables are checked for tautness by a meter provided for this purpose; the pulley alignment is checked, and quadrant joints are made tight to eliminate play. Fig. 29 shows the connection between the cables and elevator-rudder quadrants. There may be no deflections between the control column and the control surfaces themselves. Controls from the cockpit to the flap are also lined up and aileron controls are rigged as far as the outer end of the center panel.

The power-plant units are assembled on a separate assembly line where the engines are placed on the mount and the controls set in place. As the cowling panel comes from the subassembly group it is rechecked for fit on the engine-mount cowl supports. As the complete power units are finished they are assembled to the fuselage or nacelles as the case may be. Assembly consists of bolting the engine mount to the mating fittings on the firewall. The ends of fuel lines are covered over with a transparent cover until the connections are made. This is done to keep out dirt and moisture. All controls must be inspected immediately after installation and later reinspected before the first flight.

After the engine is installed the control gauges are usually placed in the instrument panel. Besides engine-control instruments there are the flight instruments, flap, landing gear and tab indicators, radio, etc., which are installed as they become essential for the checking of the equipment with which they are used.

The fin and stabilizer are bolted in place on the fuselage as described previously. Once they are in place the metal fillets which cover the junction of the fuselage and tail are screwed on. Mating holes and elastic stop nuts are provided in the fin, stabilizer and fuselage to take the screws which attach the fairing. The rudder and elevator are assembled to the fin and stabilizer respectively after the attachment of these units to the fuselage. Connection is made by a single bolt at each hinge point. These bolts connect the hinge brackets to the control-surface attachment fittings.

The outer panels are the last large units to be connected to the airplane. This assembly was previously described in Chapter 11. Aileron controls are connected through an opening near the junction of the panels.

From the foregoing it is apparent that final assembly is a progressive operation, and in modern quantity production it is the only place where progressive assembly may be said to be used. When production is low and on experimental projects, the airplane is often assembled piece by piece with each separate part being added when the assembly is brought up to a point where that part is needed. When production is relatively high the breakdown of the airplane into subassemblies is very carefully thought out by the production-planning group. With properly co-ordinated production and by breaking down the large airplane assemblies into conveniently sized subassemblies, line assembly is made possible. Plant layouts are now being designed with line production in mind so that the subassemblies may be brought to the assembly line where they are needed.

Automotive final-assembly methods are coming into general use in the aircraft industry. In the near future conveyer systems will doubtless be employed to carry the parts during final assembly and each man on the line will be assigned to but one or two jobs. It is doubtful, however, if airplane assembly will reach the stage of automobile line assembly for quite a few years to come. Probably the most important reason is that an airplane, even the smallest, is larger than the largest automobile. The requirements of floor space are naturally very large even for limited production on large airplanes; while in the quantity production of medium bombing planes and commercial transports the floor space requirements are staggering. This factor alone will doubtless be a determining one in both design and production considerations when truly large-scale production is undertaken.

Throughout assembly operations—from primary to secondary to final assembly—considerable care must be exercised by the assembly man. Upon him depends the quality and the safety of each unit. Each man must be critical of the parts which come to him for further assembly operations, not with the idea of finding fault with previous operations but with the idea of maintaining and improving the quality and uniformity of parts which pass through his hands. On the other hand an intelligent assembly man will seeks means to eliminate faulty workmanship and to improve quality. Also, he will make reasonable suggestions as to improvements in design and the sequence of assembly.

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