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METAL CONSTRUCTION DEVELOPMENT

By H. J. Pollard

PART I

General

Strip Metal Construction - Fuselage

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(Metal construction of aircraft has now come to be accepted as the ultimate form, at any rate for service airplanes, and every aircraft firm in the country is turning its attention to forms of construction possessing some particular merit, such as efficiency, simplicity, cheapness, and so forth. It is, therefore, with considerable pleasure that we are able to publish in the present issue the first of a series of articles on metal construction by H. J. Pollard, who is now engineer in charge of metal construction at the Filton Works of the Bristol Aeroplane Company, Ltd.- Ed.)

In reviewing the progress of the construction of airplanes entirely of metal, it must be noted this comparatively new art has developed slowly. A few aircraft manufacturers have tackled the problem systematically, and those few have made much headway; of the two British airplane and building firms who first made a systematic attack on the problem, one firm has had one type of airplane in production for a considerable time and the other is about to build one airplane in series. The difficulties of the art probably explain the apathy shown by the majority of aircraft constructors to metal construction; it is hoped that the knowledge that the pioneer experimenters are now reaping some of the reward of their endeavors, will act

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as an incentive and cause others to give the subject serious thought.

Consideration of some of the possible reasons for this attitude of indifference will throw light on some of the problems of light metal construction.

First, the manufacturer has had no outside incentive until recently to depart from the older methods of construction, since the materials employed have not been considered as of any particular importance by the purchaser; the main conditions have been that the airplanes should be airworthy, have a certain performance, and be able to do certain useful work. Indeed, in type competitions for which both composite and metal airplanes were designed, the metal airplanes were at a distinct disadvantage, since practically untried methods of construction had to compete with well-tried methods. Manufacturers were naturally chary of submitting airplanes which might periodically be unserviceable because of structural failures - even failures of quite minor importance. With an increase of general knowledge of the behavior of metal structures under vibration, this phase is passing, but the causes mentioned had considerable influence in delaying progress.

A reasonable certainty that production orders, though small, would follow successful metal constructions would have encouraged firms to install at least the fundamental equipment necessary to the production of metal aircraft. It could scarecely be expected that every firm would be in a position to install expensive special tools for the purpose of building single airplanes, and where the essential plant was installed, the very expensive hand work that was inevitable before further special tools were evolved, made the first airplane so costly that the whole matter was put in a very bad light when a comparison was made with the cost of timber aircraft.

Another reason of delay has been, and even now is, the absence from the machine tool market of machinery suitable for most of the processes associated with metal construction. Either machinery originally designed for totally different kinds of work has been employed or equipment (draw benches, rolling mills, etc.) have had to be specially designed and built for the work required. When there is a serious demand for metal aircraft, machine tool manufacturers will doubtless exercise their ingenuity in designing and producing machines suitable, for instance, for automatic assembly of spars. Even in these early days of development such a tool as indicated might be a commercial success; this particular problem has been partly solved by people other than machine tool designers, and the problem should present no difficulty to expert mechanicians.

Again, one expects that a number of firms have held back because the types and methods of construction are many and diverse; they have seen no clear indication as to which is the best construction to follow; and by waiting and gradually collecting information concerning the results of other people's work they have hoped to have the way made perfectly clear for them. Those who adopt that attitude lose heavily in missing the experience that the overcoming of difficulties imparts.

On the other hand, the shortage and cost of suitable timber has done much to assist the advancement of the art, for if timber had been cheap and plentiful it would have been practically impossible to develop metal construction because the clear advantages such as weight saving would be counteracted by all the disadvantages previously enumerated. Even the weight saving is difficult to realize in the early experimental stages; a case illustrating this point will be given later in this series of articles.

It is not necessary to put forward all the many arguments in favor of metal against wood; this has been done many times, and the arguments must be familiar to every one interested in aircraft.

Wide differences of opinion exist as to the relative merits of steel and duralumin. A comparison of the physical properties of the two metals points to steel as being the more suitable of the two. This comparison has been drawn before, but it is of such fundamental importance that a re-statement will not be out of place in this paper.

Taking 65 and 18 tons per square-inch as the compressive stresses that can be developed in steel and duralumin structural members, respectively, then dividing these figures by the densities of the materials, we obtain a ratio of 1.27 : 1 in favor of steel; in other words, for two similar short struts developing the stresses shown, then for the same external loads the steel member should be lighter by approximately 20 per cent.

Before dealing with the next phase of this subject, it is readily acknowledged that in the early stages of metal construction development, duralumin is a much simpler metal for the design and building of the structure than steel.

In reviewing the present position, the tendency of the steel constructions and the type of construction which should ultimately give the best results, will be described.

There are numerous ways in which steel may be employed in the structure of an airplane. Solid-drawn round tubes or square-sectioned tubes may be used, or again, lengths of corrugated strip may be riveted up into tubes having almost any section the designer chooses. Then, again, for any chosen form of the main members, the ways of joining may be legion. No attempt will be made to describe details of the numerous methods that have been devised from time to time for the purpose of joining solid-drawn tubes, except that one would say that they range from the simplest joint of all, considered as a manufacturing proposition, that is, the direct welded joint, to joints of extreme complexity in which many machined parts are used.

There are obvious reasons why round or other sectional solid-drawn tubes should make an appeal. The manufacture and supply of such tubes is no worry to the aircraft builder. A variety of specifications is available and a tube can be supplied for every purpose. If the joints are to be welded, mild steel tubes of eminent suitability are to hand, and at rather more risk of uncertainty in material and make-up, the designer may use higher grade alloy steel tubes. Again, if a 100 per cent reliability job is desired, the designer may choose any of the well-known socketed or pinned joints. With these, at an increased cost as compared with welded joints, something quite certain as regards strength can be realized.

In both the above cases, or a combination of them, it is a fact that no very special experience is needed, no equipment which cannot be easily obtained is required, and no extensive research is required.

It is fairly obvious, however, that in general these methods of construction have very well-defined limitations, both as regards weight and cost. Those who prefer welding are limited to a certain minimum thickness from the very nature of the welding operation. The socketed or wrapped fitting type of construction scores a decided point in the fact that tube may be used which is not of more than half the thickness of tube necessary for safe welding. Against this, a loss of weight is entailed in the case of pinned structures by reason of the weight of fittings, but certainty of strength, and a probable advantage in interchangeability must be credited to the pinned method. The relative importance of these factors must be considered in any particular case before a method of construction is decided upon, but it is certain that no substantial improvements, either as regards weight or cost, will be accomplished over recent practice in these sterotyped methods of construction.

It is to be shown generally, and in one simple case quantitatively, that strip construction can effect a substantial saving of weight over other methods of steel construction, and it will be further demonstrated along what lines detail design should run to make the construction inexpensive.

It will be well to point out at this stage that three essentials are necessary to an aircraft designer and builder before strip construction should be commenced; these points may appear trite and obvious, but lack of a full appreciation of them has, in some cases, led to considerable disappointment, and the great difficulties that have arisen through lack of adequate data and equipment may have been sufficient reason for the abandonment of attempted steel construction and the acceptance of a light alloy as the chief metal.

(1) Proper equipment should be installed, such as a rolling mill or mills, a drawbench, shearing machine, suitable presses, parting-off tools, and a variety of hand tools suitable for the complete assembly of components.

(2) The roll or die design section should have data to enable them to compute accurately and draw the final tool design in order to get the designed shape of section. This is easily obtainable only when fully-annealed steels are neing used. (The writer fails to see the need for the use of any metals other than fully-hardened and tempered ones, but this point will be amplified later.). Certain matters cannot easily be made the subject for formula, such as the correct "lead-in" for a die, or the amount of work that should be done on any one of a series of rolls, but a very little experience gives this knowledge; the subject of "spring-back" is essentially a matter for a semi-empirical formula.

(3) The design department should have some knowledge of the behavior of thin corrugated and flat strip under various external loads when assembled into various structural members. Suitable formulas are not to be found in textbooks dealing with metal structures at the present time, but a study of some of the works of Professors G. H. Bryan, A. E. H. Love, and Mr. R. V. Southwell will furnish information regarding the variables involved. With the help of a few tests on metal spars, the building up of empirical formulas should not be found a difficult matter, so that with but little experience, the fairly accurate prediction of spar performance should be possible. Although the fundamental variables such as thickness of strip, radii of gyration of sections, etc., are common to all formulas used in

metal spar or strut design, yet the "constants" in the expressions depend on the type of design of spar or strut selected. Where a radical change in spar design is made, it will be found that the "constants" need modifying accordingly.

In this article only a partial general survey of matters affecting the metal construction of airplanes has been made, and the articles to follow will deal in detail with matters of actual construction. This, it is hoped, will be of actual assistance to constructors. General surveys, while possibly making interesting reading, do not help the draftsman very much, and it is not proposed, therefore, to deal at any great length with the subject of metal-covered surfaces; that these are eminently desirable if the material of the skin can be made not only to take the various loads, but also to develop its full strength, no one can dispute; so also it is desirable that an engine should be built giving 1000 hp, and weighing 500 pounds. The mentality of a person who asks for the latter is on a par with that of the individual who asks for metal-covered wings, with metals now available, as light and inexpensive as the best that steel and fabric can give. Metal-covered wings are needed, but the future in this direction lies with the metallurgist.

To make this point perfectly clear a simple examination of the necessary thicknesses of both steel and duralumin as coverings in competition on a weight basis with wings as at present constructed will be helpful. These figures will be quite familiar to those who have given the question of metal coverings serious thought, but judging from what is occasionally written and spoken, there are many employed in the aircraft industry who cannot have worked out these simple cases for themselves.

Looking on the metal in the first case purely as a covering for equal weight with doped fabric, the average thickness of duralumin would have to be four and a half to five thousandths of an inch, and for steel one and a half to two thousandths. If the skin is to take the load, then an additional weight of metal equal to the weight of the spars and internal bracing may be added to the skin. Take a single outer wing of a biplane: Let the dimensions of this wing be 18 ft. by 6 ft., then for an average size two-seated airplane, the weight of the spars can be taken as 45 lb. This weight being distributed in the skin of the duralumin-covered wings might bring the average thickness up to from 18 to 20 thousandths of an inch, and the average thickness of a steel covering would be $6\frac{1}{2}$ to 7 thousandths of an inch. If such a distribution of metal were made with either duralumin or steel, it would be found that the wings would not support their own weight. With an addition of at least 50 per cent of metal for corrugation, some stiffness would be obtained; it is quite impossible, however, to say how much stiffer such a structure would be, nor is it likely that it will ever be known since the very obvious difficulties of securing the external bracing and the substantial reduction of the lift/

drag ratio are sufficient in themselves to prohibit any such construction being attempted on a competitive basis weight for weight with a two-spar wing fabric covered.

With a certain increase in size, and especially with heavy wing loading, such a construction is possible, and indeed has been made, but such information as is available shows this construction to be very heavy, as is to be expected.

It is the writer's firm opinion that the biplane or multiplane structure having metal-covered wings will never seriously challenge similar structures fabric-covered, but that for successful complete metal-covered wings we must look to the deep cantilever structures. Such structures will be arrived at step by step as more knowledge is gained on metal construction.

The difficulties involved in the designing and building of large cantilever monoplanes are well known, and there appears to be a regrettable tendency to exaggerate these difficulties. The inevitable increase in wing weight and loss in torsional rigidity compared with a biplane are always emphasized, but the saving in parasite drag which should be the ultimate end of all airplane design is often treated as quite a minor matter. Consideration of a simple comparative case between a biplane and a monoplane may be of some assistance in putting this question in true perspective.

Let us assume the weight of a complete biplane structure to be 1.4 lb. per sq.ft., and the weight of a monoplane wing

2 lb. per sq.ft. Take a biplane of 10,000 lb. all-up weight, having a wing area of 1000 sq.ft.; then, for the same capacity, the monoplane would weigh 10,600 lb. To make the comparison as simple as possible, the same basic airfoil may be assumed in each case. Apart from lifting surface the airplanes are in every way similar, each with a top speed of say, 120 m.p.h. If reasonable assumptions are made regarding the sizes of the members of the external bracing of the biplane and allowances made for aspect ratio, it can readily be shown that the effective horsepower required to propel the monoplane at top speed is some 6 to 10 per cent less than for the biplane, and that at lower speeds there is little difference in the performance of the two airplanes.

There is need for a full investigation into the relative merits of biplanes and monoplanes, even though such an investigation would be founded largely on conjecture, in so far as large monoplanes are concerned, due to lack of experience of such airplanes in this country. A report on such an investigation would be of a very voluminous nature, and it would be found that many of the factors introduced would operate in favor of the monoplane. For instance, the dimensions of the biplane structure might easily be such that the K_L would be equal to only 0.925 K_L of the monoplane. In the case given above, for the same landing speed, the loading could be 10.8 lb. per sq.ft., giving a wing area of 975 sq.ft. For a gap-chord ratio unity and aspect ratio of 8, the K_L would be the same in both cases. This point is introduced merely as an example of one of the large number of factors that would have to be included in the investigation. It may be said that, taking an isolated case such as the above is misleading, but a consideration of several such cases from various standpoints should convince the unprejudiced that there is a very real case for the moderately large monoplane.

In the particular case taken, the question that arises is: Can the monoplane wings be made strong and sufficiently rigid for an addition of 600 lb. or an average weight of 2 lb. per sq.ft. for an unsupported span of approximately 30 ft., loading of 10 lb. per sq.ft., and load factor of, say, 5? The answer is that a reliable structure can be so built, weighing probably less than 2 lb. per sq.ft., by adopting a steel multi-spar construction, the booms of the several spars lying along the contour of the airfoil, the whole being fabric-covered. With the advent of metal alloys lighter than any now commercially obtainable, fabric will have to give place to such material, but only if the covering can be made to operate as a primary structural member.

No sudden revolutionary developments need be expected. The desired end, that is, the airplane having lifting surfaces built to contain engines, useful load, etc., with the consequent elimination of parasite drag, will only be attained through the slow drudgery of scientific reserach, the foundations of which have been laid in the experiments found necessary for the construction of current types of steel airplanes.

F u s e l a g e

Before amplifying some of the foregoing statements, we will study a simple feature of strip metal construction and demonstrate its advantages. In doing this, one or two of the principles governing economic structural design will appear, and later some observations on the method of manufacture will be made.

In Figure 1 is shown a side view of a frame which might be a portion of a fuselage tail. Figure 2 is a view in perspective of the structure, and Figures 3 and 4 alternative nodal points. The bulkhead bracing has been omitted from Figure 2 for the sake of clearness.

From these illustrations the details of the construction are quite clear, and no elaborate description is necessary.

For such a structure to be light, safe, and rigid, two very important conditions must be fulfilled, and in certain special cases there is an equally important third condition. The first is that the built-up longitudinals must be continuous throughout their lengths. The best results cannot be obtained if the smaller of the two strips is cut away at intervals so that angular fittings may be secured to the flats of the larger section, because this would introduce a series of sections of discontinuity along the longerons with consequent substantial reduction of strength at these points. The second constructional feature to be observed is the method of securing the bracing members to the gusset plates.

These members consist of two similar sections riveted together along their edges, forming a circular or approximately circular sectioned member, having two diametrically opposite outwardly extending flanges. It might appear safe to cut off one of the component sections level with the outer edge of each of the gusset plates, forming a junction, as shown in Figure 5. The only object in doing so would be to save a little weight, but here, again, the necessity for continuity makes it imperative that the strut ends be divided, a section passing either side the gusset. Two other advantages are derived from this, one being exact centroidal loading of the member, and the other that the securing components are put in double shear, thus making it possible to effect an appreciable saving in assembly time due to the use of fewer rivets. The third condition is only of importance when the struts are "short," that is, when they are subjected to considerable intensities of stress. The load is transferred to the main section of the struts through the narrow riveting edges, and these edges in consequence are subjected to a stress much in excess of the average P/A for the section; this stress round the end rivets may exceed the compressive yield stress of the material, causing crinkling of the flats and premature end buckling of the whole section.

It might be possible to calculate the load at which the strut ends would fail if the direct forces only had to be considered, but owing to flexing of the compression boom and the change in shape of the frame bays due to the displacement of the panel points under load, a very complex stress system is set up round the rivets common to the bracing struts and gusset plates. The computation of this stress is not possible mathematically, but tests of a rather simple nature can easily be devised from which data can be obtained as to the end reinforcements necessary, so that the end of the struts may carry their loads up to the point of central failure by buckling. The "fixing" couples at the strut ends are probably of considerable magnitude; the end load effect on the compression boom is to produce a condition as shown in Figure 6 which, as stated, is resisted by the nature of the end connections of the bracing. It is seen, therefore, that a much greater radius of gyration is required in a strut about an axis at right angles to the line joining the riveting edges, than about the other axis of symmetry. Instead of the edges being "waste metal," as is sometimes alleged, they play a really large part in giving strength and rigidity to the frame, and apart from difficulties of riveting, if the edges are narrowed down excessively, it will be found on test that the struts will fail in the plane of the frame due to the abovementioned causes.

In Figure 7 is shown a simple method of counteracting the tendency to local end buckling. (Also in this figure is shown the socket attachment used for connecting one length of longeron to another length.)

Two short lengths of section wrapped round the strut ends and continued above the gusset a short distance are sufficient to distribute the load evenly across the section of the strut; these reinforcements need securing only at the riveting edges, and not separately by rivets to the main body of the section. In cases of very high stress intensities, additional reinforcing may be made by means of a narrow strip, the width of each riveting edge running the length of the strut, the thickness of which is equal to the thickness of the gusset plate. This not only lends stiffness to the free edge, but also obviates the necessity for "joggling" the edges where the strut leaves the gusset. None of these precautions is necessary in ordinary fuselage construction, except where landing and other large localized loads are applied to the structure. A method of securing bulkhead bracing is shown in Figure 3; hitherto, wires have been used, but from the experience gained to date, there appears to be no reason why wires should not be totally eliminated from the frames, and struts only used in their place. There are several things that could be argued in favor of such a structure, probably the most important point being the freedom of the rigid members from initial stresses; apart from military aircraft, where members are liable to damage in action, there is no need for bulkhead bracing at all, since it is found experimentally, and by calculation, that such bracing does not affect the strength or rigidity of the structure. A panel point having no bulkhead bracing is shown in Figure 4.

A simple comparative weight and strength estimate will be made of a structure as described, and a similar frame built from T.5 tube and wires.

The dimensions of the uniplanar structure are given in Figure 1. It is assumed that a load of 800 lb. is suspended from O. Figures 8, 9 and 10 are sections of longerons, ties and struts made from steel strip to specification S.40. These have been designed to support the loads given in column 8.

The sizes of the struts have been derived from the appropriate curve, as shown in Figure 11.

In Tables I and II the full particulars of the "strip" and "tubular" fuselages are given.

For the section of Table I marked "Diagonals," the load has been reversed; these members have to act both as ties and compression members, and obviously the case to consider is when these diagonal bracings act as struts. A moment's thought will show that this procedure does not alter the numerical value of the load in the members, but merely the signs.

In Table II it is assumed that these struts are replaced by two swaged wires, complete with fork ends and pins. In each case, column 1 denotes the member; column 2 its length, L; column 3 its area, A; column 4 the radius of gyration, K;

column 5 the ratio, L/K; column 6 the corresponding value of stress, P/A, obtained from the graph; column 7 the loads from columns 6 and 3; in column 8 the forces induced by the applied load; and in column 9 a description of the member is given.

A comparison of the figures in column 7 in the tables gives the relative strengths of the two frames, which, in the worst cases, are approximately equal. A simple computation of the relative rigidities of these frames is not possible, but tests which have been made show this to be decidedly in favor of the strip construction. From the lengths and areas of members given, the weight of each is quickly derived; allowance must be made for tube sockets, pins, fork ends, rivets, etc., exclusive of longeron fittings, the percentage increase in weight of the wired over the strip frame is found to be 18 per cent. There is also the weight of fittings to consider. The gussets would be 24 G., with suitably shaped lightening holes. These would certainly be lighter than some forms of joint used in tubular construction, but as recently several very light, if costly joints for solid-drawn tube work have been designed, it may be assumed that the weight of fittings is equal in each type of structure.

The above is a fairly complete weight comparison of two methods of steel construction. A welded frame would show up very badly indeed, beside these two cases if U.S. tube, the strut curve of which is shown on the chart, was the material used. Molybdenum or manganese steels would show up better, but it has been admitted that where tubes have been used, notably in America, finished structures are on the heavy side. This is probably due to the fact that it is not considered safe to join tubes by welding where the wall thickness is less than 22 G. It should be noted that if the material of the gussets is distributed over all the corrugated members, the thickness of the material would only be raised one and a half thousandth of an inch. This fact should give the welding enthusiast food for thought.

To further this comparison, it should be stated that the sections shown in Figures 8 to 10 are practical propositions, although it would be wrong to give the impression that, without some experience on the part of the producer, such sections could be readily made. The question of the assembly of these members will be dealt with in a later article. A more favorable case could have been made out for the tubular structure if a larger diameter and thinner gauge of T.5 had been taken, but comparison with a tube outside the practical commercial range is useless. Tubes are now being offered to the aircraft industry of quality superior to T.5, and these are said to be quite suitable for structural work: the above comparison therefore, may need revising as experience with these higher tensile tubes is obtained. Advances are, however, to be expected in the design and methods of manufacture of components made from steel strip.

It is not suggested that the whole weight of 800 pounds could be taken locally on the strip longeron section, but the same remark applies to the solid-drawn tube. Provision for resting on trestles, lifting, etc., is easily made, and a fitting and method of attachment suitable for this is shown in Figure 12.

The above comparison is presented in as simple a way as possible. At the same time, the over-all dimensions and externally applied loads are such as might apply to a portion of the structure of an airplane of 4500 pounds gross weight or thereabout. If the investigation is pursued further, it will still be found to favor the strip construction, particularly in the matter of fittings for the attachment of equipment, control surfaces, cable guides, etc.; the numerous "free edges" obviously lend themselves to this purpose. One such type of fixing is shown in Figure 13. This is a stabilizer spar attachment.

Space does not permit of further illustration or description of fittings, but in general, a simple bent or flat plate is all that is necessary; there is a sharp contrast between this and the machined fittings or clips with bolts that are common to tubular construction.

While the writer believes that aircraft frames as described have only been built by one company, yet descriptions and drawings of the various component sections have appeared from time to time; for instance, particulars of bracings made from two similar semicircular channels joined together along their edges were advocated for aircraft more than thirty years ago; similarly, drawings of longerons made from two parts shaped approximately as illustrated above have been published fairly recently, but such longerons have been shown discontinuous along their lengths, and it may be that this lack of continuity has been the reason for the abandonment of the method. Only one aspect of this construction has been dealt with; it may be possible in the future to describe further developments along these lines.

TABLE I. For Strip Frame

	1	2	3	4	5
-	Member	Length L	Area A	Radius of gyration K	L/K
Top longerons	BL	26	0.05	-	-
	BK	33	0.05	-	-
	BJ	31	0.05	-	-
	BH	29	0.05	-	-
Bottom longerons	AC	14.2	0.05	0.43	33
	AD	26.3	0.05	0.43	61.3
	AE	33.4	0.05	0.43	77.7
	AF	31.3	0.05	0.43	72.8
	AG	29.3	0.05	0.43	68.0
Vertical struts	CL	20.6	0.022	0.27	76.3
	DK	25.0	0.022	0.27	92.6
	EJ	30.8	0.0257	0.27	114
	FH	36.0	0.0257	0.27	133
Diagonals	BC	23.0	0.031	0.4	57.5
	LD	33.5	0.031	0.4	83.7
	KE	41.0	0.031	0.4	102.5
	JF	44.0	0.031	0.4	111
	HG	47.5	0.031	0.4	119

TABLE I. For Strip Frame (Cont.)

	1	6	7	8	9
–	Member	P/A = p	P	Actual load in member	Description of member
Top longerons	BL	–	8,300	550	Section as shown in Fig. 8 (0.009 in. thick, S.40)
	BK	–	8,300	1,280	
	BJ	–	8,300	1,875	
	BH	–	8,300	2,260	
Bottom longerons	AC	107,500	5,350	555	Section as shown in Fig. 8 (0.009 in. thick, S.40)
	AD	60,000	3,000	1,294	
	AE	42,000	2,100	1,900	
	AF	45,500	2,280	2,280	
	AG	51,000	2,550	2,560	
Vertical struts	CL	42,000	925	700	Section as shown in Fig. 9 (0.006 in. thick, S.40)
	DK	29,000	638	565	
	EJ	20,500	527	455	Section as shown in Fig. 9 (0.007 in. thick, S.40)
	FH	15,000	385	385	
Diagonals	BC	64,000	1,980	900	Section as shown in Fig.10 (0.006 in. thick, S.40)
	LD	35,500	1,100	930	
	KE	24,500	760	760	
	JF	21,000	650	530	
	HG	18,500	575	435	

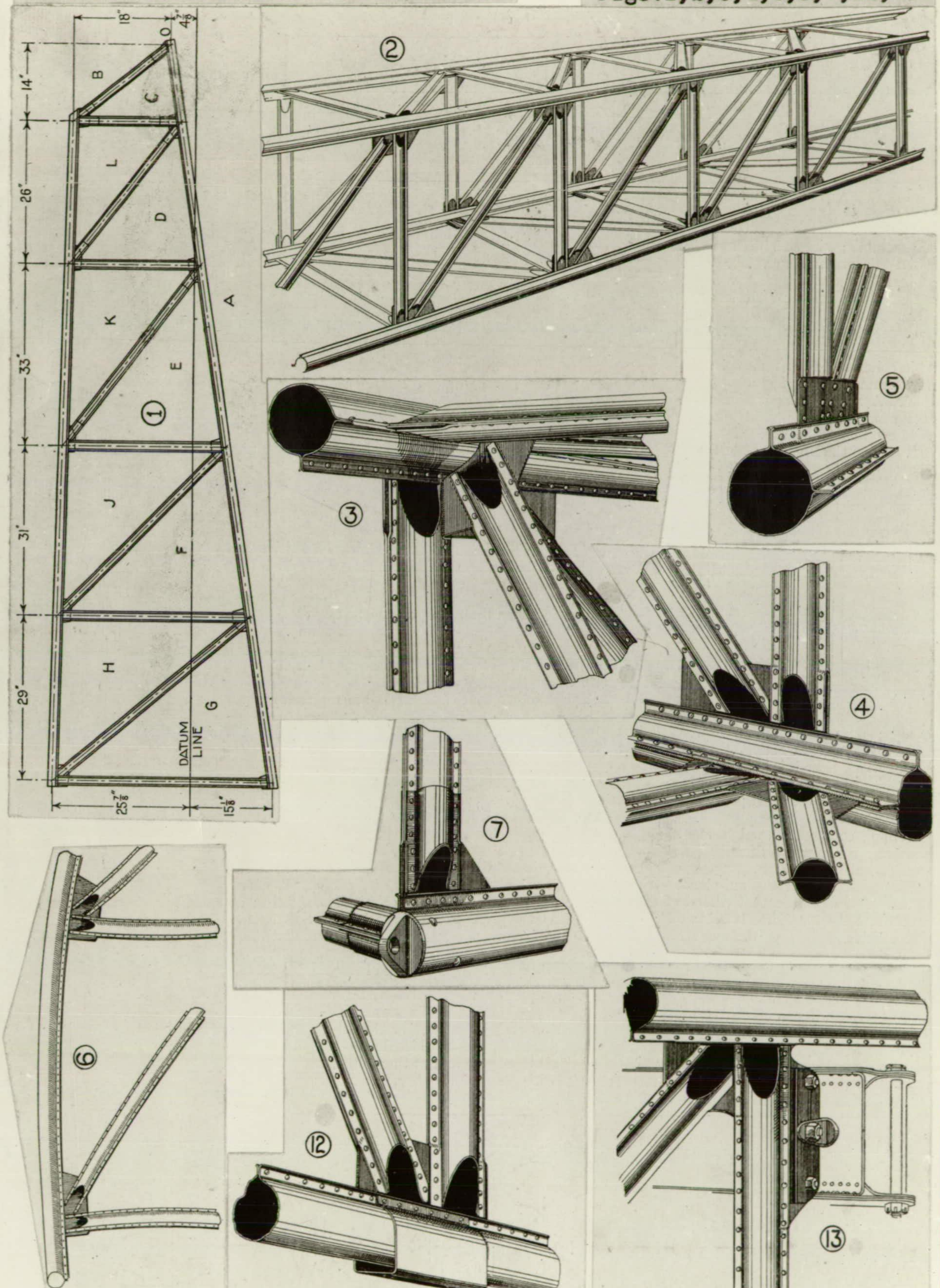
TABLE II. For Solid-Drawn Tubular Frame

	1	2	3	4	5
–	Member	Length L	Area A	Radius of gyration K	L/K
Top longerons	BL	26	0.057	–	–
	BK	33	0.057	–	–
	BJ	31	0.057	–	–
	BH	29	0.057	–	–
Bottom longerons	AC	14.2	0.057	0.425	33.3
	AD	26.3	0.057	0.425	62.0
	AE	33.4	0.057	0.425	78.5
	AF	31.3	0.057	0.425	73.5
	AG	29.3	0.057	0.425	69.0
Vertical struts	CL	20.6	0.029	0.21	98.0
	DK	25.0	0.035	0.260	96.5
	EJ	30.8	0.035	0.260	118.6
	FH	36.0	0.035	0.260	138.5
Diagonals	BC	23.0	–	–	–
	LD	33.5	–	–	–
	KE	42.0	–	–	–
	JF	44.0	–	–	–
	HG	47.5	–	–	–

TABLE II. For Solid-Drawn Tubular Frame (Cont.)

	1	6	7	8	9
-	Member	P/A = p	P	Actual load in member	Description of member
Top longerons	BL	-	7,000	550	1-1/4 in. O.D. x 28 S.W.G. (T.5)
	BK	-	7,000	1,280	
	BJ	-	7,000	1,875	
	BH	-	7,000	2,260	
Bottom longerons	AC	78,000	4,450	555	1-1/4 in. O.D. x 28 S.W.G. (T.5)
	AD	50,200	2,860	1,294	
	AE	36,000	2,050	1,900	
	AF	40,400	2,300	2,285	
	AG	44,000	2,500	2,560	
Vertical struts	CL	25,000	725	700	5/8 in. O.D. x 28 S.W.G. (T.5)
	DK	26,800	940	565	
	EJ	18,600	650	455	3/4 in. O.D. x 28 S.W.G. (T.5)
	FH	14,100	495	385	
Diagonals	BC	-	1,050	900	4 B.A. tie rods
	LD	-	1,050	930	
	KE	-	1,050	760	
	JF	-	1,050	530	
	HG	-	1,050	435	

For Part II, see N.A.C.A. Technical Memorandum No. 527, which follows.


18"
4 7/8"
O
14"
26"
33"
31"
29"
B
C
L
D
K
E
A
J
F
H
G
DATUM LINE
25 7/8"
15 1/8"
1
2
3
4
5
6
7
12
13

13085 A.S.

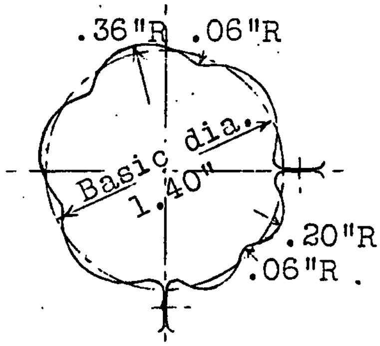


Fig.8

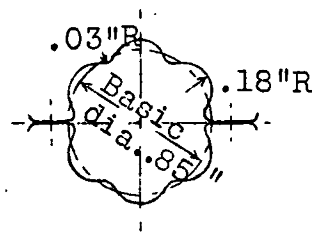


Fig.9

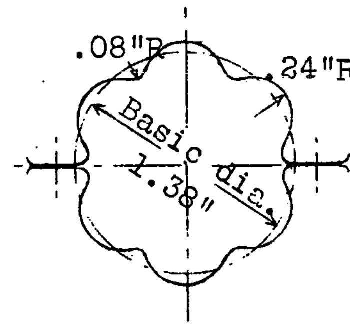


Fig.10

Theoretical strut curves for tubes made from steels having yield points

A, 65 tons /sq.in.
B, 40 " / " "
C, 18 " / " "

On tests from built up struts it has been found that the results when plotted lie slightly above curve A.

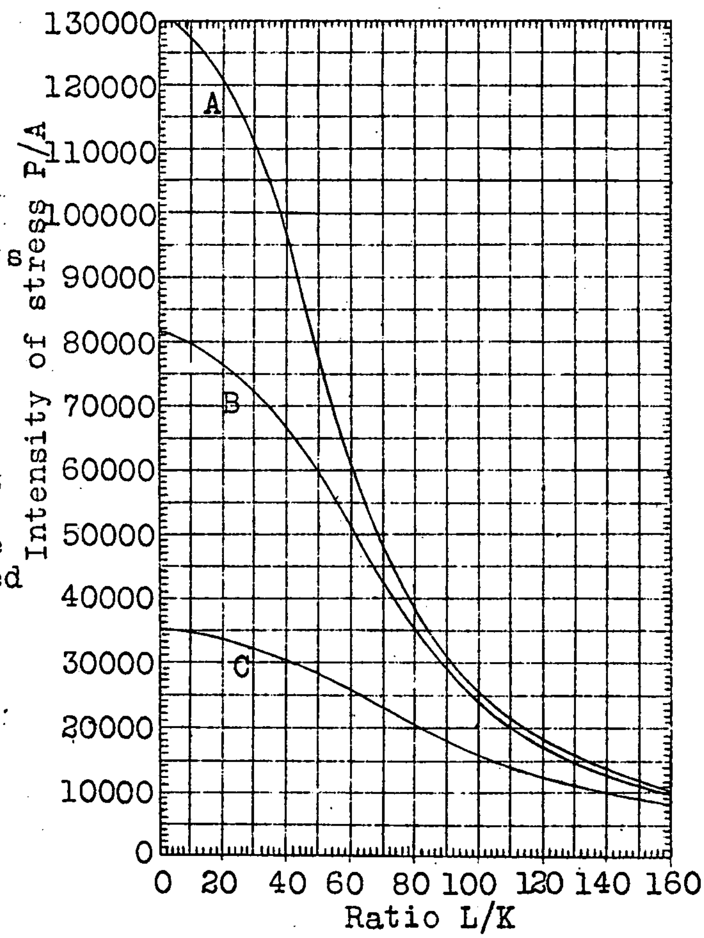


Fig.11