SOME PROBLEMS IN CONNECTION WITH THE STRUCTURE OF RIGID AIRSHIPS.

Paper read by Lieut.-Colonel V. C. Richmond, O.B.E., B.Sc., A.R.C.S., A.F.R.Ae.S., before the Institution at The Engineers' Club, Coventry Street, W.1 , on Friday, 25th January, 1924, Mr. W. O. Manning in the Chair.

(1) INTRODUCTION.

COLONEL RICHMOND said :—

Fortunately, cases of structural failure of rigid airships under normal flying conditions have been extremely few. Nevertheless the pressure under which these airships had to be produced during the war in this country prevented a sufficiently comprehensive study being made of all the conditions of loading to which they may be subjected and of the stresses set up in the structure as a consequence of these loads. Our own comparative ignorance led to a somewhat slavish copying of German design. Recent study goes to show that radical departures from the characteristic Zeppelin structure might be made with advantage certainly for large airships.

With regard to modifications of existing design, it is necessary, however, to issue a word of warning. In this connection reference may be made to a recent paper read before the International Air Congress* from which the following extract is quoted ;—

> " The structure, both as regards its arrangement and the dimensions of its parts is the outcome of much practical experience. New schemes of construction cannot be considered in preference to the tried schemes without, at least as a preliminary, the assurance that they are based on a knowledge both of the external loads which will act on the airship and also of the stresses which will be set up by these loads in the various members. Knowledge on these two branches of design is still very incomplete, more especially with regard to the aerodynamic forces which act on the hull in all types of manœuvres, and on the validity of a possible basis of stress determination in such a complicated structure."

* Vide—" The Hulls of Rigid Airships." V. C. Richmond, Proc. Int. Air Congress 1923.

A considerable amount of light has been thrown on the question of aerodynamic loading by the researches of the National Physical Laboratory. The results have now been made available for general use in the reports recently issued by the Aeronautical Research Committee and more particularly in one of the R.38 Memorial Prize papers by Mr. R. Jones. The problem of stress calculation has been very ably dealt with in the report of the Airship Stressing Panel.* This work of recent years has lifted the question of airship design out of the atmosphere of close secrecy in which it has been held in Germany and even by a limited circle in this country into the light of broad and healthy discussion.

It is clear to those who have studied the problem carefully that a rigid airship is a perfectly feasible, sound engineering proposition. Rigid airship construction has, in fact, already reached a stage where ample structural strength is not incompatible with a very useful performance for commercial or naval purposes. Such loose statements as appear in the non-technical press and elsewhere from time to time to the effect that "the airship is extremely fragile" and "a rigid airship is extremely weak in proportion to its gigantic size" are neither scientific nor accurate. It is true that such airships as R.38 and L.71 were left as a legacy from the war period and that in these cases structure weight was sacrificed in order to obtain a very high ceiling. It would manifestly be dangerous to drive such airships at full speed at low altitudes as they were not intended for this purpose. It would be possible to double the longitudinal strength of these ships at the sacrifice of less than four tons in a disposable lift of 45 tons.

(2) CHOICE OF SHAPE.

On a wise choice of shape practically everything else depends, in fact the diversity of factors which govern this choice are probably not fully realised. They may be roughly classified under three headings:—

(a) Aerodynamic forces.
(b) Resultant stresses and their effect on the structure weight.
(c) Constructional and housing considerations.

(a) Aerodynamic Forces.

A good deal of experimental work has been carried out to determine the best stream-line form for the hull of an airship. This work is probably ahead of practical construction, because the choice of shape has been chiefly governed by many other factors referred to later. By testing bare hull shapes some very good results have been obtained in the wind tunnel. These forms, however, when built into actual airships, give somewhat disappointing results, which indicate the difficulties in this work. It is misleading to test bare shapes, because the more perfect the shape the more sensitive it

---

* R. and M. 800.

is to any obstructions placed close to it, which, quite apart from their own resistance, may considerably increase the resistance of the bare hull itself by mutual interference.

TABLE I.

FORM CHARACTERISTICS OF VARIOUS SHIPS AND MODELS.

SHIP.	Fineness Ratio. $\left\{\frac{\text{Length}}{\text{Max. Diam.}}\right\}$	Block Coefficient. $\left\{\frac{\text{Hull Volume}}{\text{Vol. of Enclosing Cyl.}}\right\}$
R.26	10.1	.896
R.29	10.2	.892
R.32	9.36	.785
R.33	8.15	.693
R.80	7.61	.65
L.71	9.4	.7 approx.
"Bodensee"	6.5	.65 ,,
S.S. (60,000)............	5.2	.66
S.S. (70,000)............	4.75	.66
S.S.E.3. (Form U.721)..	4.62	.605
Parseval	5.68	.65 approx.
H.33b, TE3 Models	5.36	.628
H.33b, TE3a only	6.02	.617

As in all aerodynamical work, there is "scale-effect" to be considered. A certain number of full-scale experiments have been carried out on airships. As far as they have gone they indicate pretty close agreement with the models, but they are incomplete.

The fineness ratio and block co-efficient of certain airships are given in Table I. The progress made in the shape of German rigid airships is shown in Fig. 1. The improvement in outline will be clearly seen, also the reduction in fineness-ratio. Many attempts have been made to find a mathematical formula for a suitable curve for the contour of the hull; such a formula would simplify the work of calculating the ordinates.

Separate mathematical curves have been tried for the nose and tail, but such information as has been gained has been chiefly by empirical work and an immense amount of trial and error. A few guiding principles may, however, be laid down.

The shape of the head is generally more important than the shape of the tail, but the more perfect the form of the head the more sensitive it becomes to small changes or alterations in the shape of the tail. A good head is one which has a small average curvature, and emerges very gradually into the parallel position if such a portion exists. A very bluff nose is not a disadvantage so long as the curvature of the remainder of the head is well designed. A parallel body is always a disadvantage. Forms having a fineness ratio of about $4\frac{1}{2}$ are better than those having a fineness ratio greater than this. About the tail the information is less definite. For a given length of curved portion, a pointed tip, and greater average curvature in the forward part seems to be preferable to a blunt tip and less average curvature. The better the shape of the tail the greater is the sensitiveness to small changes in the head. Irregularities and discontinuities in outline are not serious in the transverse plane. The cross-section of the hull may conveniently be a polygon rather than a circle and the number of sides to the polygon will not materially affect the resistance, provided it is not made less than about 10 or 12. Irregularities in the longitudinal plane are more serious. A series of flats in the nose and tail is bad.

Another source of irregularity in the surface is due to the impossibility experienced so far of keeping the outer cover taut. It may be of advantage to provide some means of maintaining the pressure inside the hull greater than that outside to get over this defect.

The non-dimensional resistance co-efficients of certain ships and models are given in Table II.

TABLE II.

RESISTANCE COEFFICIENTS.

	Coefficient.			
	Full-Sized Ship.		Model.	
Ship.	By deceleration test.	From speed and power, etc.	Complete model.	Model of hull only.
R.26..........	.0247	...	.030	.019
R.29...	.0227	...	.023	.02
R.32..........	.0187	...	.019	.014
R.33..........	.0173	.017	.0198	.010
R.80..........	...	...	...	.011
R.38..........	...	...	.0188	.013
S.S. (70,000) ..	...	018	...	.014
S.S.E.3. (U.721)	.0246	.0265	...	.007
H33b, TE3 ..	...	...	...	.0075
H33b, TE3a ..	...	...	...	.008

A careful prediction of the resistance of R.33 from model results is shown in Table III. This compared very favourably with the full-scale determination, and it will be noted that account has been taken of mutual interference of the cars and hull.

TABLE III.

GROSS PREDICTED RESISTANCE OF R.33.

Item.		Resistance lbs.		Percentage of Total.
		30 f.p.s.	80 f.p.s.	
Hull and fins (controls at 0°)		468	3,332	66.0
Forward car	Without suspensions or radiators	29	205	4.1
2 Wing cars		44	317	5.3
After car		26	183	3.6
Interference of cars on hull		20	147	2.9
Interference of hull on cars		...	...	...
Fin bracing wires		21	152	3.2
Control bracing wires		5	37	0.8
Sectors (8)		6	45	0.9
Suspension wires (forward car)		4	31	0.7
,, ,, (2 wing cars)		10	74	1.6
,, ,, (after car)		4	33	0.7
Struts to cars		11	85	1.7
Ladders, access tubes, and pipes		10	72	1.4
Radiators with tanks and supports		43	309	6.1
Total		701	5,022	100 0

It will be noted as a matter of interest that at the higher speed, the fin bracing wires have a resistance of 152 lbs., which is 3.2 per cent. of the total. This is high, and in the later airships such as R.36, a cantilever type of fin construction has been adopted in order to reduce it.

(b) Resultant Stresses and their Effect on Structure Weight.

Shape bears a two-fold relation to the stresses caused in individual members of the hull, since it not only governs the loading, but also the geometrical arrangement of the structure.

In every airship there is a greater difference of pressure at the top between the interior and the exterior of the envelope than there is at the bottom. This gives rise to a bending moment, the magnitude of which is $\frac{\pi}{4} kr^4$ at a point where the radius of cross-section is r, the lift of the gas per unit volume being k. Let the diameter of the ship be D, and the bending moment Mg; then the gas pressure bending moment $Mg - \sim D^4$. But if the force in the longitudinals is represented by f obviously $f - \sim \frac{Mg}{D}$

Combining these two relationships it will be seen that $f - \sim D^3$. This means that the loading in the longitudinals due to gas pressure rises rapidly with increase in diameter, and from this point of view a low fineness ratio is bad. Secondly, there is the bending moment (Ma), due to transverse aerodynamic forces to be considered. It is generally assumed that $M - \sim \rho v^2 L^2 D$ so that $f - \sim \rho v^2 L^2$ (ρ=the density of air) (v=the speed of the airship). Here the advantage of the low fineness ratio will be apparent. Load in longitudinals due to the tension of the outer cover, will bear no particular relation to the shape of the hull. In certain systems of construction the longitudinals will also be loaded laterally by the pressure of the gas bags on the girders and on the netting which is attached to these girders. The distribution of load due to this cause will depend on the spacing of the girders and the amount of slackness permitted in the netting. The magnitude of the lateral load will depend on the head of gas and hence on the diameter of the hull. The actual stress in a longitudinal will also depend on its unsupported length and this length will be relatively greater in shapes with smaller diameters. It follows that the influence of shape on gas pressure lateral load may be neglected as a first consideration.

The calculation of the actual primary stresses which will arise in any geometrical arrangement of girders from a given system of lateral loads is a matter which it is beyond the scope of this paper to discuss. Those sufficiently interested will find this subject dealt with very fully in the papers referred to earlier.* Let a single bay of the hull be considered acted upon by a given bending moment and shearing force, other types of loading such as torsion and axial load being relatively negligible. The possible geometrical variables for any bay may be, the volume, the length, and the number of sides to the polygonal cross-section. It is possible to obtain a rough estimate of the effect on any structure weight by multiplying the load in any member by the total length of all the members of that class. The results may be summarised as follows :—

---

* See p. 7.

TABLE IV.

LOADS

Type of Loading	Variation in geometrical form.		Longitudinals.	Shear Wires.
Bending	Volume	Increase length	Load increases	Load increases
	Constant	Increase number of sides	Load decreases	Load increases
Shear	Volume	Increase length	...	Load increases
	Constant	Increase number of sides	...	Load decreases
Bending	Length	Increase volume	Load decreases	Load decreases
	Constant	Increase number of sides	Load decreases	Load increases
Shear	Length	Increase volume	...	Load decreases
	Constant	Increase number of sides	...	Load decreases

It will be seen that the balance is in favour of having a small number of longitudinals. This is specially the case for the shear wires, as it keeps their effective angle with the horizontal as large as possible. It will also be seen that for a fixed volume of bag it is most economical to keep the length as short as possible and further for a fixed length of bay it is generally economical to keep the volume as high as possible. These considerations point to the shape of small fineness ratio as being the most economical in structure weight.

It may be noted here in passing, that a shearing action will produce a certain tension in one of the diagonal shear wires which span any panel, and an equal compression in the other wire. When the compression exceeds any initial tension which there may be, the wire becomes slack. If now a sudden change occurs in the external loading, a serious racking action will be imposed on the joints. The advantage from this point of view of having the shear wires initially tensioned so that they function in compression as struts will be clear. This initial tensioning is rather difficult to carry out in practice, and it causes there to be an initial load always present in the other members of the structure. It may be necessary in future large airships to consider replacing these wires with struts and to alter the distribution of material as between longitudinal and diagonal members.

The problem of stress determination is somewhat involved, owing to the large amount of redundancy, but a definite theory has been worked out, based

TABLE V.

EFFECT ON STRUCTURAL WEIGHT.

Type of Loading	Variation in geometrical form		Longitudinals	Shear Wires
Bending	Volume	Increase length	Weight increases	Weight increases
	Constant	Increase number of sides	For large volumes weight decreases; for small volumes weight increases on long lengths and decreases on short ones.	Weight increases
Shear	Volume	Increase length	...	Weight increases
	Constant	Increase number of sides	...	Weight increases for large lengths; weight decreases for small lengths
Bending	Length	Increase volume	Weight decreases	Weight decreases
	Constant	Increase number of sides	For short lengths weight decreases; for long lengths weight increases on small volumes and decreases on large ones.	Weight increases
Shear	Length	Increase volume	...	Weight decreases for large lengths; weight increases for small lengths
	Constant	Increase number of sides	...	Weight increases for large lengths; weight decreases for small lengths

on certain assumptions. These assumptions require further testing, either by experiments on models of the framework or on an actual airship under a known system of external loads. A certain amount of information can be derived from water models. Some elaborate and beautiful tests of this nature have, however, been made at the Massachusetts Institute of Technology in America*. The members of the model were constructed of transparent celluloid material. If the members are stressed and an image of them projected on a screen with the aid of polarised light, bands of colour will appear owing to the birefracting power of the stressed material. It is claimed that the stresses can be estimated to within 5 per cent. by the analysis of the colours. There are obvious difficulties in the method, but at the time of writing sufficient information has not come to hand to show how these are met.

(c) CONSTRUCTIONAL AND HOUSING CONSIDERATIONS.

Unfortunately, owing to the lack of foresight or ready money in the past, existing sheds are of such a size that if any progress is to be made they must be enlarged or entirely new sheds must be built at heavy cost, or as a third alternative, airships must be built of the most unsatisfactory shape dictated by these housing conditions. As far as the question of enlarging existing sheds is concerned, it appears quite feasible to raise the roof, but at considerable cost. If this was done, increase in capacity of the airship could be obtained by reducing the fineness ratio and leaving the length unaltered. This would appear to be better than the other alternative of increasing the fineness ratio by increasing the length of the shed. This latter alternative would entail moving the doors at one end.

With limited shed room it is desirable that the dimensions across the stabilising surfaces should not exceed the maximum diameter of the hull. This is a difficult condition to fulfil with some shapes, since the tail must not be too long and thin or it will not have sufficient volume to lift these heavy fins. In hulls having a small fineness ratio it appears best to have the maximum diameter nearer the nose than the tail, in order to get the stabilising fins within the necessary compass. For small fineness ratios the block co-efficient is lower than for large ones (as will be seen from Table I) and hence the circumscribing shed space is not most economically filled. On the other hand, the forms with the least fineness ratio have the least ratio of surface to volume, which is important in its effect on structural weight.

Small fineness ratios entail large diameters and hence large transverse rings which are difficult to manipulate when lifted from the ground. Future design will tend towards the construction of very stiff transverse frames and this stiffness should minimise the difficulty of lifting these frames into a vertical position.

The disadvantage from the aerodynamic point of view of a long

---

* Vide Jour. Soc. Automotive Engineers, Dec., 1923, p. 497.

parallel portion or of flats in the contour has already been referred to. This is unfortunate, since it would simplify the construction of the longitudinal girders.

It will be seen that the balance of all the above considerations is in favour of having a low fineness ratio, and the trend of future design will undoubtedly be in this direction.

(3) CONDITIONS OF LOADING.

The conditions of loading to which an airship's structure may be subjected are very varied. The designer has not only to make a careful estimate of the loading to be expected from each cause, but he must also make a wise estimate of the conditions which may be combined to give the worst resultant loading in the girders. The designer has been obliged in the past to impose a limit on the commander to the extent of warning him that certain combinations of loading must definitely not be allowed to occur. The varied conditions of aerodynamic loading have only been appreciated and estimated in the last two or three years, in fact knowledge on this subject is still very incomplete. Enough is known, however, to make it safe to repeat that ample structural strength to withstand the various possible combinations of loading is not incompatible with a very useful performance for commercial or military purposes. With improvement in knowledge, size, design and construction, it should not be necessary to impose the past restrictions on airship commanders. The relative magnitude of the various bending moments are indicated by the ordinates of Figs. 2 to 5 which are all to the same scale.

STATIC LOADING.

It is not possible to ensure that the lift of the gas shall be exactly balanced by gravity loads at every point along the hull, and in consequence there is always a static bending moment. The bending moment for R.37 fully loaded and in trim and with the best possible distribution of weight, is illustrated by curve 1, in Fig. 2. The balance is seriously disturbed if it be imagined that all dischargeable weights are jettisoned, the airship then being taken up to its maximum ceiling so that the gas-bags shall be full and trimmed by means of non-dischargeable weights. This is illustrated by curve 2 in Fig 2. These curves represent the best distribution of weight, but it must be realised that in the course of the routine operation of the airship it would be quite possible for the commander to obtain trim by some other distribution of the moveable weights (e.g., petrol and water), which was less favourable from the point of view of the resulting bending moment, in fact it is quite possible to double the maximum bending moment in the fully-loaded condition by a distribution of fuel or water which would not strike the casual observer as unsafe.

It is usual to consider the possibility of any one of the gas cells becoming deflated, and the dischargeable weights being adjusted to give static equilibrium and trim. It is a tedious process to consider each bag in turn, but it is necessary to do this until the worst possible B.M. is found. How serious this may be will be seen from curve 3 in Fig. 2. The gas pressure bending moment has already been referred to, and this is illustrated in curve 4 in Fig. 2.

Aerodynamic Loading.

All the above static loads occur only in the vertical plane. It is possible to have combined with these certain aerodynamic loads also acting in the same plane. In the early airships it was not possible to obtain a very even distribution of weight or a high speed, and consequently the static bending moments were far more serious than the aerodynamic ones. But with large modern airships higher speeds are being obtained, and a more even distribution of weight. It follows that the aerodynamic forces which increase as the square of the speed, have attained prime importance. There are three conditions giving rise to aerodynamic bending moments in this vertical plane, viz:—

(a) The airship flying in a straight horizontal path, but pitched so that any difference between weight and buoyancy shall be balanced by dynamic up-thrust or down-thrust.

(b) The airship in straight flight meets a sudden change in the direction of the wind, i.e., a "gust."

(c) The elevators are suddenly thrown over to the maximum angle.

Figure 3 represents case (a) for R.37 flying "light," pitched 6° down by the nose. It should be noted that in a ship of this type, owing to the fact that the centre of gravity is close to the centre buoyancy, and that *the resultant aerodynamic force acts close to the nose and at a fairly large angle with the axis,* the elevators must be put *up* and not down, as might be supposed at first sight. If the speed of the ship is increased it will nose dive, owing to the relatively ineffective elevators, unless the elevator angle is increased upwards. The B.M. is shown in curve 1 for the airship flying at the angle of pitch stated above, at a speed of about 47 m.p.h.

Any calculations with regard to the air forces on the hull when the airship meets a gust are at present somewhat speculative, but assuming that gusts are so large that they can be treated as an extension of the case (a), the B.M. can be roughly estimated. The probable B.M. which results from the pitched airship flying into gusts as estimated on the above assumption is shown in curve 2.

Case (c) might equally occur if the rudders were suddenly thrown over in the horizontal plane and motion in the plane will now be discussed.

Any deflection of the rudders will of course cause the airship to turn and take up the condition of circling flight. There are two conditions of loading to be considered, i.e., (d) when the rudders are first thrown over, and (e) when the conditions of steady turning have been established.

Cases (c) and (d) are represented in Fig. 4. The deflection of the rudders causes a transverse force through their centre of pressure. If the airship continued on a straight path, this transverse force would produce a bending moment as shown in the figure, but this is a limiting condition. As soon as the rudders are moved the airship will start to turn, the only resistance to turning being provided by inertia. This turning will reduce the forces in the tail surfaces long before the rudders have attained their full throw; in fact it should be, and is, arranged that they cannot be thrown over too quickly.

Case (e) is illustrated in Fig. 5. It must be realised that as soon as circling flight is established centrifugal force comes into play. There is a resultant lateral aerodynamic force near the nose and another on the tail surfaces, both acting towards the centre of the turning circle and balanced by the centrifugal force acting outwards from the centre of the turning circle. This system produces the bending moment shown which is, in fact, in the opposite direction to that produced at the beginning of the motion by the sudden application of the rudders.

In estimating the total stress in any member, the local stresses arising from gas pressure, outer-cover tension and initial tension in the shear wires, must be added to the stresses arising from the selected loading combination.

(4) DESIGN OF GIRDERS.

In every rigid airship which has been constructed so far (with the exception of R.38) the longitudinal girders have been subject to both end loads due to the bending of the airship as a whole, and lateral loads due to gas pressure. The possibility of removing this lateral load has already been referred to and such a modification would, of course, materially affect the design of girders for large airships in the future. It will be clear that the lattice type of girder is the best to employ and fortunately there is no reason why deep struts should not be used. The type of design and of material which can be most economically employed depends on the magnitude of the load to be carried by individual members of the structure, and the possibility of uniformity in construction.

From the above point of view there is something to be said for keeping down the number of longitudinals. In the rigid airships constructed to date, the gas bags have pressed on the longitudinal girders and on a system of netting attached to these girders. With a small number of longitudinals (as for example 13 in the case of R.33) there will be large unsupported netted areas. These are usually assisted by a system of lighter, intermediate girder work which is considered to contribute nothing to the longitudinal strength of the hull, but which does take some of the lateral load off the main longitudinals. The intermediate longitudinals convert the figure of the cross-section from a 13-sided polygon into a 25-sided one. If the gas bags can be held so as to exert no lateral pressure on the main longitudinals, the need for the intermediates disappears. There is every indication that it will be possible to achieve this modification satisfactorily and therefore it is probable that future airships will have an external cross-section of about 13 sides or so, and that the longitudinal girders will only be subjected to very light lateral loads due to the outer cover. Further, the need for the immediate transverse frames whose function is to resist the bowing of the longitudinals under lateral load practically disappears also. It must be remembered that any considerable bowing of the longitudinal girders on the compression side of the hull will alter the position of the neutral axis of the complete hull in bending.

TABLE VI.

	Typical Longitudinal R.33	Longitudinal for 5 million c.f. airship with 25 sides and lateral loading.	Longitudinal for 5 million c.f. airship with 14 sides and very little lateral loading.
Length (unsupported)	33 ft.	48 ft.	55 ft.
Maximum depth	1 ft. 2 ins.	2 ft. 6 ins.	3 ft.
End load	.7 tons.	7 tons.	30 tons
Lateral load	14.4 lbs. per ft. run.	120 lbs. per ft. run.	20 lbs. per ft. run.

The figures in column 1 are from actual tests to destruction on a typical girder. The figures in columns 2 and 3 are estimated from alternative tentative designs for a 5-million cub. ft. airship, and the loads indicated are failing loads, a factor of safety of approximately 2.5 having been allowed on the worst possible conditions. It is hoped that these approximate figures will be sufficient to enable the expert in light metal construction to visualise the problem of future design of girders, and to ascertain in what manner he can improve on the existing type of Zeppelin girder as indicated in column 1. The weight of this girder is approximately .68 lb. per ft. run.

The type of failure which occurs in the longitudinal channels of this girder has suggested to many people the desirability of replacing them with tubes. The use of solid drawn tubes for the longitudinal members of future girders is hardly to be advocated, owing to the mechanical difficulties of assembly and the impossibility of developing the highest possible mechanical properties in such tubes. The typical Zeppelin girder was designed over ten years ago, and since that time considerable progress has been made in the production of the elements of light metal construction for aeroplanes. Examples of this may be seen in the development of thin metal strips, both in duralumin and steel, and the drawing of this strip into sections having the maximum stability against crumpling. Some of these modern sections might be used for the longitudinal members of the girders, and these would readily lend themselves to the easy mechanical attachment of the bracing pieces. It is probable that the fuselage type of construction with fewer bracing pieces more widely spaced would be more economical in weight than the existing type, and would be simpler to construct and repair.

These modifications in design, dimensions and loading will have an effect on the choice of material. It would appear that the case of column 2 represents the border-line between the choice of steel and duralumin, and that it should be possible to construct this girder for a weight of from 1 to 1.2 lbs. per ft. run in duralumin, and from 1.2 to 1.4 lbs. per ft. run in steel. Probably the case of column 3 would be best met in steel. The weight of this girder is likely to be about 2.3 lbs. per ft. run.

The main transverse frames, hitherto, have been constructed from a number of triangular or diamond-shaped trusses extensively braced with taut wires. When the airship is inclined or when one gas bag is more fully inflated than its neighbour, serious forces are set up in these taut wires and these in turn impose heavy loads on the trusses of the transverse frames. It would be advantageous if these wires could be slack, and hence if the frames could be sufficiently stiff to retain their shape without relying on bracing. The problem of designing a suitable frame of this character will be governed by the magnitude and direction of all the forces imposed on the frames, and beyond this brief reference is too extensive to be considered here.

The proper design of joints is very important. At present these usually consist of a complicated arrangement of gusset plates and angle plates, and it is by no means a cheap or speedy process to replace a faulty or damaged girder. " Pin " joints in the mathematical sense of the word would simplify stress calculation, but would be complicated and heavy to construct. It does appear desirable, however, for the quick and cheap replacement in commercial airships that the principal girders should have lug and socket joints at the ends of their longitudinal members.

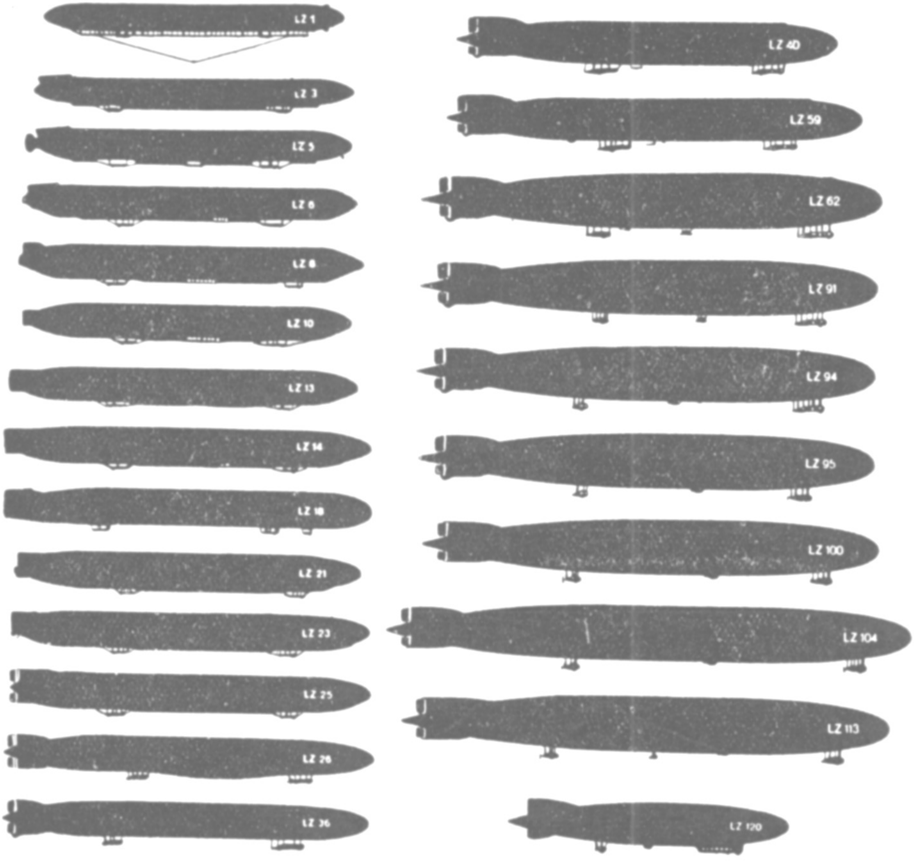

FIGURE 1.

SHAPES OF ZEPPELIN AIRSHIPS IN CHRONOLOGICAL ORDER FROM 1900—1919.

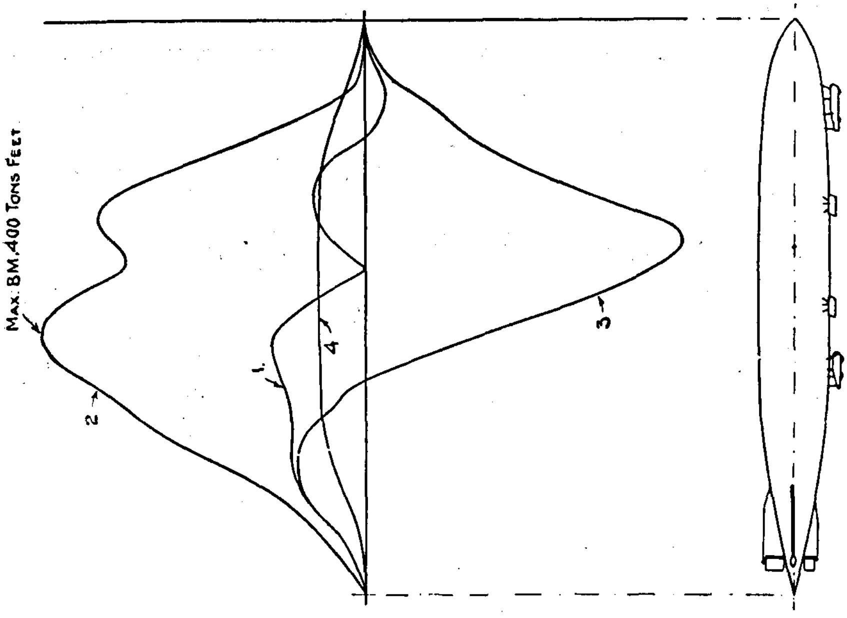

Figure. 2.

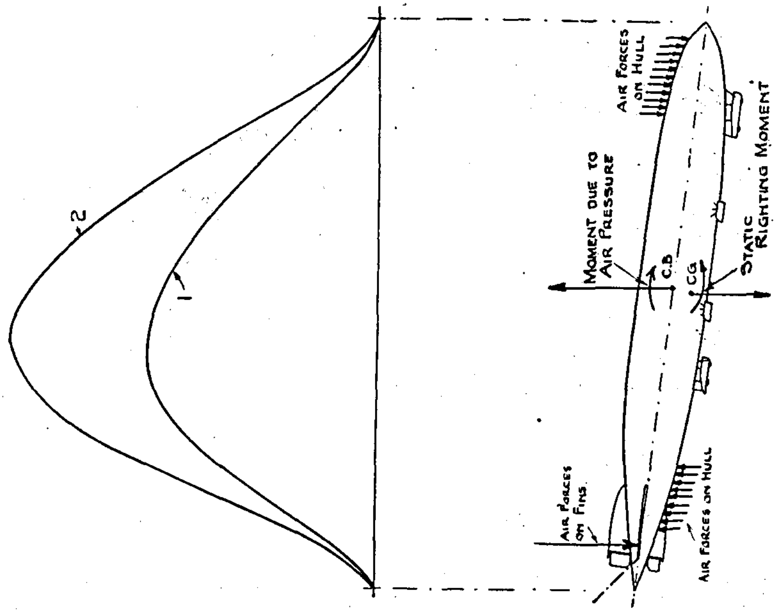

Figure 3.

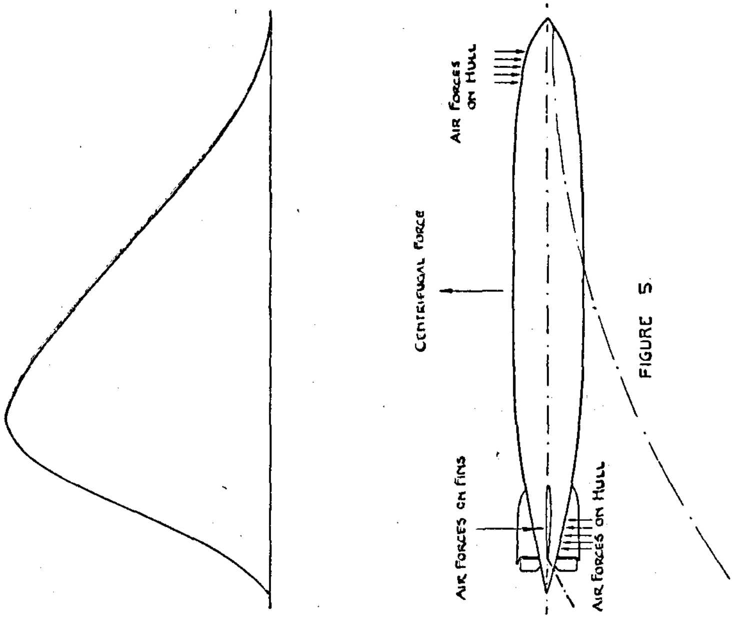

FIGURE 5

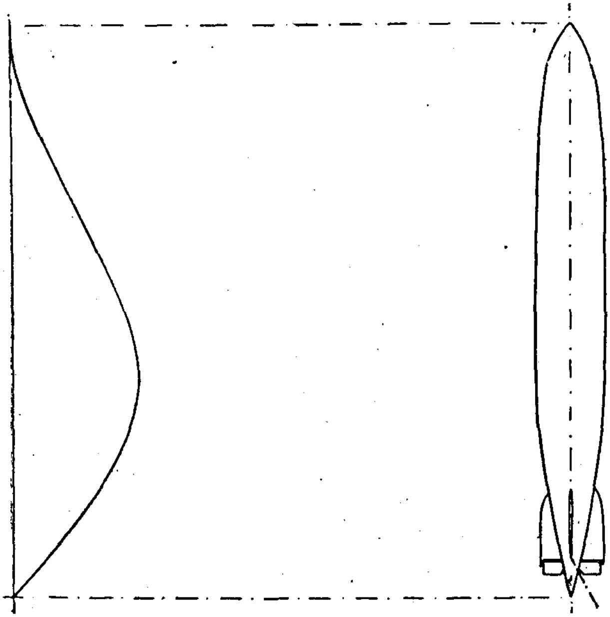

FIGURE. 4