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THE PRESENT STATUS OF AIRSHIP CONSTRUCTION, ESPECIALLY
OF AIRSHIP-FRAMING CONSTRUCTION

By Hans Ebner

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SUMMARY

This work purposes to sketch, in broad outline, the status of airship construction in the various countries, at a time when commerce over great distances might be finally opened up to the airship through the performances of the "Graf Zeppelin." After a short historical review, a survey of the most important rigid and semirigid airships built since 1925, their differences and special problems, is made. In more detailed treatment, the framing construction of the more recent rigid airships and some especially interesting structural questions are investigated. Since an exhaustive treatment is not possible in the limits of a magazine article, a list of the pertinent literature is appended.

I. HISTORICAL REVIEW**

In order to estimate correctly the present status of airship construction, it is necessary to review briefly the past. The dirigible airship today has a development of more than a generation behind it. The first serious attempts to make a balloon dirigible, in fact, to build an air "ship," go back to the year 1852. At that time Franzose Giffard sought to give to a spindle-shaped balloon the speed necessary for steering by installing a steam engine. Because of the unimportant results, these first experiments

* "Der heutige Stand des Luftschiffbaus, insbesondere des Luftschiffgerippebaus." Zeitschrift für Flugtechnik und Motorluftschiffahrt, vol. 24, no. 11, June 6, 1933, and no. 12, June 28, 1933. (Lecture before the Berlin Section, Verein Deutscher Ingenieur, March 15, 1933. Report of the Deutsche Versuchsanstalt für Luftfahrt E. V., Berlin-Adlershof - Static Section)

**See references 1 to 5.

were soon forgotten. Not until 1872 did the German, Hänlein, make a new attempt. He built an airship with one engine, which was driven by the lifting gas of the balloon. However, also in this case there were few experimental flights. Renard and Krebs in the year 1884, with the "La France," made the first rather important airship flights. This airship, with its electric motor of 9 horsepower, attained a speed of 6 m/s. The further development occurred around the turn of the century and was connected with the names Schwarz, Santos Dumont, and Lebaudy. The airship built by Schwarz is particularly interesting in that aluminum sheet was used as hull material, an experiment which has been taken up again quite recently and which will be further discussed herein.

The invention of the rigid airship by Count Zeppelin revolutionized airship transportation. After Zeppelin had already, in the year 1894, submitted the design of a rigid airship to the War Ministry, he succeeded only after tough battles in realizing his ideas and completing his first airship in the year 1899 (fig. 1). This airship, which took off for the first time on July 2, 1900, already had the customary distinguishing features of present rigid airships: particularly the rigid framing with light metal rings and longitudinals; further, the carrying of the lifting gas in a series of independent cells, and finally the division of the machinery installation into several units. The symmetrical hull, which had a gas volume of 10,000 m³, was very slender and had a long, symmetrical middle body. Control of this airship was still very primitive. Lateral control was by means of an upper and a lower control surface at the bow and by means of two side surfaces at the stern. Vertical control was at first attained through shifting of trimming weights along the gangway. Later, an elevator was placed at the bow underneath the hull. The two Daimler engines of 15 hp. each were located in two cars suspended from the keel girder, and by means of bevel-gear transmission drove the propellers, placed at the height of the center of resistance.

The operation of the first Zeppelin airship soon had to be discontinued for economic reasons, and only after a five-year interruption was Count Zeppelin able to raise the necessary means for a second airship. This airship still resembled its predecessor in many respects, having, however, more powerful engines of a lesser unit weight. The succeeding Zeppelin products, beginning with the successful third airship of the year 1906, indicate a continuance along the

course already started. Figure 2 shows a typical pre-war example, the commercial airship "Schwaben" (LZ 10), of the year 1911, with a volume of 17,800 m³. The gangway is constructed as a stiffening girder, the hull has been given stabilizing surfaces at the stern, the rudders are arranged in the box form distinguishing the pre-war Zeppelin airships. At this time there already existed the Luftschiffbau Schütte-Lanz, founded in 1909, which brought out its first airship at the end of 1911 and its second early in 1914. The second airship, the SL 2 (fig. 3), particularly exhibited a number of substantial improvements and was of special significance in the further development of rigid airship construction. As in the case of the first Schütte-Lanz airship, it had a streamlined hull with a form less slender than previous airships had and rudders attached directly to the stabilizing surfaces. The gangway was located inside the ship, an arrangement which had previously been used in the Zeppelin airship LZ 18, known as "Naval Airship L 2" and built in 1913. The propellers acted - as was customary in pressure airship construction - directly behind the engines on elastically suspended side and bottom cars. Gas-valving was through special openings at the top of the airship. Wood was used as material in the SL-airships, while the pre-war structures of the Z-airships were of aluminum.

However, pressure airship construction was not dormant in these years before the war. Pressure airships are distinguished by the fact that for maintenance of form they continuously need an inner superpressure, which is accomplished with the aid of air-inflated balloonets. Pressure airships are classified as semirigid and nonrigid, according to whether or not they have a stiffening girder for suspension of the car. This girder can be suspended from the hull, as was the case in the military ship of the Prussian Airship Battalion, constructed by Basenach (reference 6), or secured directly to the hull, as the Lebaudy-built airships feature it. More recently the stiffening girder is placed inside the hull and the car directly attached thereto. The development of the nonrigid system is principally the contribution of v. Parseval (reference 7). The first Parseval airship, shown in figure 4, which was followed by a series of successive airships, came out in the years 1905-1906 and had a gas volume of 2500 m³. An especially noteworthy feature of this ship is that it had two separate balloonets fore and aft, which with differing inflation could be used for altitude control. A further

interesting nonrigid pressure airship of the pre-war period is the Siemens-Schuckert airship designed by Krell and Dietzius (fig. 5). It had three cars, which were suspended from the hull with fabric curtain suspensions (reference 8).

Interesting though it would be to go more into detail concerning the individual states of development of the rigid and pressure airships and to follow further their development as advanced by the war, only the most important pioneers of airship construction can be introduced here. With regard to the two German airship types, Zeppelin and Schütte-Lanz, there are two comprehensive papers, which admirably describe their development up to 1925 (references 3 and 4).

In the first-named paper (reference 3) the airship LZ 126, built for the United States, is also minutely described. This airship in 1924 crossed the Atlantic Ocean from the European mainland and since then, as the "Los Angeles," has been in the service of the American Navy. The two post-war ships "Bodensee" and "Nordstern," of the Luftschiffbau Zeppelin preceded the LZ 126. The "Bodensee" is particularly noteworthy in that she conducted a regular air service between Berlin and Friedrichshafen as early as 1919.

II. SURVEY OF THE MORE RECENT AIRSHIP CONSTRUCTION

AND SOME FUNDAMENTAL AIRSHIP QUESTIONS

1. The More Recent Rigid Airships

In May 1926, the fetters placed upon German commercial airship construction by the Versailles treaty were removed and the Luftschiffbau Zeppelin began the construction of LZ 127 (fig. 6). The ship was completed in the middle of 1928 and as the "Graf Zeppelin" is known to all through its successful flights (references 9 and 10). Because of the insufficient dimensions of the old Friedrichshafen hangar, its gas volume had to be limited to 105,000 m³. Also, quite largely for the same reason, the slenderness ratio, i.e., the ratio of the length to the maximum diameter, was selected. The machinery installation consists of five reversible Maybach engines of 530 hp. each, which can be

driven with gasoline or gaseous fuel. The engines are installed in five cars, staggered longitudinally with respect to each other, outside the hull. The LZ 129, just now under construction in the new Friedrichshafen hangar of the Luftschiffbau Zeppelin has a gas volume* of 190,000 m³ and a distinctly "fatter" airship's form. Further substantial departures of the new ship will be discussed later.

In England in the year 1926, construction of the two rigid airships R 100 and R 101 was begun (references 11, 12, 13, and 14). R 101 was built by the Government itself in the Royal Airship Works in Cardington; R 100 was awarded to a private company, the Airship Guarantee Company, in Howden. For both ships the same gas volume and approximately the same slenderness ratio were originally contemplated. R 100 (fig. 7) was completed first and, at the end of July 1930, undertook its flight to Canada. The machinery installation of the R 100 consists of six reversible Rolls-Royce Condor engines of 670 hp. each, which are installed in tandem in three cars. In the R-101 (fig. 8) attempt was made for the first time to equip an airship with heavy-oil engines. Five Beardmore Tornado heavy-oil engines of 585 hp. each were installed in five cars. The heavy-oil engines, as far as they were concerned, were disappointing, as they gave a lower power, and turned out to be heavier, than was anticipated, and, besides, the reversibility of the light-metal propellers presented difficulties. After its first trial flights R 101, in order to attain more useful lift, was enlarged by inserting an additional bay amidships. Figure 8 shows the R 101 before rebuilding. The tragic fate of R 101 is still fresh in our memory. The airship met with its accident early in October 1930, in northern France, after starting its flight to India. Although, indeed, the two English airships no longer exist - R 100 was broken up after the destruction of the R 101 - they can, nevertheless, not be overlooked in a complete representation of the present status of airship construction, since they present a great number of very noteworthy structural innovations which will continue to be topics of discussion.

The largest rigid airships thus far completed are the "Akron" (fig. 9), with a nominal gas volume of 184,000 m³

*In airships, it is customary to give the nominal gas volume as the basic size. By this is meant the content of the gas cells with a fullness of 95 percent.

and her recently completed sister ship, "Macon"*. They were built in the years 1929 to 1932 in the United States by the Goodyear-Zeppelin Corporation in Akron (references 14 to 16). A principal feature of these airships is that the eight Maybach engines of 560 hp. each are placed inside the airship. They transmit their power through long shafts and bevel-gear drives to swiveling propellers arranged one behind another, as seen in profile.

2. Airship Volume and Airship Form**

In the above-mentioned, newer, rigid airships, one recognizes distinctly that the present development tends toward building larger and "fatter" airships. In figure 10 the more recent rigid airships are again shown in profile to the same scale and an older Zeppelin airship - it is the last wartime naval airship LZ 113 - added for contrast. According to this, since the end of the war nominal gas volume has increased three-fold, the slenderness ratio L/D has decreased from 8.8 to around 6.0 in the LZ 129 and "Akron," and to around 5.5 in the English airships. In the "Graf Zeppelin" the tendency toward a small slenderness ratio has not yet become so evident. This lies partly in the limited proportions of the old Friedrichshafen construction hangar. It must still be mentioned that earlier Schütte-Lanz airships had a slenderness ratio which corresponded to that in the "Graf Zeppelin." R 100 is omitted from the assembly shown, since, with respect to nominal gas volume and airship's form, it is approximately the same as the R 101 as shown before rebuilding.

The great advantage, which an increase of the gas volume contributes to the economics of airships is indisputable. Contrary to the case of the airplane, an increase in the useful-load ratio, i.e., that of the pay load and that of the fuel load to the total lift, occurs with enlargement of an airship, assuming constant speed. This is explained by the fact that the weight of the hull, exclusive of machinery installation, increases with a power of the volume which lies between 1 and 2/3, and that of the machinery installation, corresponding to the air resistance, with a power which lies below 2/3.

*The "Akron" in the meantime has been the victim of an accident. She encountered a severe storm on April 4, 1933, and was destroyed.

**See references 17 to 20.

Such definite judgment of the most favorable slenderness ratio is not possible. The air resistance of the hull is divided into form and friction resistances. With constant volume, the first increases with a fatter airship's form, the latter decreases correspondingly with decrease of outer surface. Since in an aerodynamically well designed hull the frictional resistance comes more into the foreground, in this respect the fatter form is the more favorable. However, a fatter airship's form, because of its tendency toward instability, requires greater stabilizing surfaces. Thus the advantage of the fatter airship's form is limited. Considered from the structural standpoint, the fatter airship is, because of its greater resistance to bending, the more advantageous, although here, also, transverse framing is associated with increase of airship's diameter. After consideration of all of these circumstances, it appears that one can choose, at will, between slenderness ratios from 5 to 7.5 without appreciable disadvantage.

3. Lifting Gas and Fuel

A further important problem of present-day airship construction is the question of the lifting gas and the fuel for the engines. As lifting gas for an airship only hydrogen and helium are considered today. Helium has the great advantage of noninflammability; on the other hand, however, hydrogen has the lesser weight. For design purposes, a lift of 1.13 kg/m^3 is used for hydrogen in contrast to only about 1 kg/m^3 for helium. There is then, with helium inflation in comparison with hydrogen inflation, a loss in lift of around 11.5 percent. Furthermore, the helium is more costly, since 1 m^3 of helium costs today around RM 1.50, while 1 m^3 of hydrogen, on the other hand, costs only RM 0.20. The use of helium means, then, from the economic standpoint, a greater burden. This can, however, be substantially reduced if lightening of the airship due to the use of liquid fuel and the accompanying valving of lifting gas are avoided. This can be accomplished, as it is in the case of the "Akron," by means of a water recovery apparatus, in which the water vapor contained in the engine exhaust is precipitated. The present status is, that in this manner one can recover ballast water exceeding in quantity the fuel burned.

Another means, which was introduced in the "Graf

"Zeppelin," is the use of gaseous fuel having the specific weight of air. Then the total weight of the airship remains approximately constant. Besides this, the use of fuel gas is distinctly economical, since the space occupied by the fuel gas, if considered filled with hydrogen, can lift, in comparison with the fuel-gas weight, only a smaller quantity of gasoline and, in addition, the fuel consumption with gaseous fuel is less than with liquid, viz., 170 g/hp./hour against about 220 g/hp./hour.

The introduction of heavy-oil engines brings a further advance in the development of the airship. These are distinctly preferable to gasoline engines in many respects. First and foremost, in conjunction with the use of helium they bring about a considerable decrease in fire hazard. A further advantage is, that heavy-oil engines have a lower fuel consumption than gasoline engines have, which, with the nature of airships as long-distance carriers, works out particularly favorably. And finally, the use of the cheaper heavy oil instead of the more costly gasoline indicates a great financial saving. The installation of heavy-oil engines was carried out in the English airship R 101, even though, as is already mentioned, with little result. Also, for the new German airship LZ 129 heavy-oil engines are contemplated. Of course, the use of helium and heavy-oil engines are contemplated. Of course, the use of helium and heavy-oil engines necessitates, for the economic reasons mentioned, the installation of a water-recovery apparatus, unless the solution worked out in the construction of the LZ 129 is adopted. In this airship, inside the helium cells, and surrounded and protected against fire by them, smaller hydrogen cells are provided, for the accommodation of the gas to be valved in maintaining equilibrium.

A solution, which up to now has not been carried out in practice, is the joint use of helium and fuel gas. With this, to increase the safety against fire, the fuel gas can be placed entirely inside the helium cells. Experiments in this direction with a pressure airship are at the moment in progress in the American Navy. The Luftschiffbau Zeppelin has not gone further into this last solution, since from the standpoint of safety a helium airship with heavy-oil engines is preferred.

4. The More Recent Pressure Airships and Their Problems*

In connection with some of the more recent pressure airships, some of the problems of pressure airship construction should now be briefly discussed. The most important task here is, to build pressure airships with the smoothest possible nondistorting envelopes, with the greatest possible avoidance of appendages. In the new pressure airships of the semirigid type, this problem is solved, as already mentioned, by building a stiffening keel truss into the hull, suspending it from the upper part of the envelope. The car can then be attached directly to this truss. The three Parseval-Naatz pressure airships of the Wasser- und Luftfahrzeug-Gesellschaft built in recent years are constructed in this manner, which airships have become known to all as advertising airships (reference 22). Figure 11 shows the newest of these pressure airships, the PN-30. It is an airship of $2,650 \text{ m}^3$ and has a Siemens SH 14 engine of 115 hp. located behind the car. The keel truss built into the airship is shown in figure 12. Its ends are carried up high and serve forward for the attachment of the mooring apparatus and aft for the attachment of the stabilizing surfaces. The keel truss consists of articulatedly joined Lautal tubes; the panels formed by these are braced by wire diagonals. In some places, however, the counter diagonals are lacking, in order to attain an elastic giving of the keel truss.

In order to diminish the distortion of the fabric envelope in the larger pressure airships, a steel net may be inserted between the cells especially provided for holding the gas, and the outer cover, around the entire girth. This idea originates with Naatz and is to be tried out on a contemplated larger airship of the Wasser- und Luftfahrzeug-Gesellschaft. A similar development, in which, furthermore, the lower part is developed as a shell framing, comes from Wiesinger (reference 23).

A radical method for attaining a hull with little stretch is carried out by the Metalclad Airship Corporation in Detroit (U.S.A.). There the pressure airship of $5,700 \text{ m}^3$ provided with a metal envelope, as shown in figure 13, has been built (references 24 and 25). The eight stabilizing surfaces provided for increasing maneuverability are especially noteworthy. The metal skin consists of $1/4 \text{ mm}$ thick Alclad sheet strips, which are joined by means of a special rivet-sewing machine and have packing inserted at the seams.

*See reference 21, which gives a comprehensive discussion of pressure airship construction.

The Alclad is duralumin, which has a covering layer of pure aluminum as a protection against corrosion. Figure 14 gives an inside view of the ship and shows the ring girders and inverted channel longitudinals provided for stiffening the metal skin.

The idea of attaching the car directly to the hull in nonrigid pressure airships also has been carried out in the more recent pressure airships of the Goodyear Company in Akron. Figure 15 shows an example of this type, the pressure airship "Puritan," of $2,430 \text{ m}^3$, of the year 1928. The airship has two Siemens SH 10 engines of 60 hp. each attached at the sides of the light-metal car. The umbrella-like nose-stiffening of the hull is easily perceived. Besides the more recent pressure airships mentioned, a number of pressure airships, principally of the semirigid type, have originated in other countries in recent years, especially in France, where the "Vedettes" and "Escorteurs" are built for the Navy.

III. THE PRESENT STATUS OF AIRSHIP-FRAMING CONSTRUCTION

1. Structure

The framing construction of all present-day rigid airships has not changed in its fundamentals since the earliest Zeppelin airships. This construction is the following (fig. 16): A series of polygonal transverse rings is joined at the corners by longitudinal girders; the rectangular panels formed by the ring sides and longitudinal girders are stiffened by wire bracings, which are applied in a single or double panel arrangement. Besides this "external panel stiffening" another "inner net bracing" is usually present, which attaches to the inner faces of the longitudinals and serves for the transferring of the gas forces exerted by the cells. The thus constituted enveloping surface forms a stable space framework, which structurally is known as a basket frame. By stiffening of all or of only some transverse rings of this basket frame, a structure of high bending and torsional stiffness is obtained.*

The framing construction shown in figure 17, conceived by Unger, is fundamentally different. It consists mainly

*The suggestion of building the framing of a rigid airship in the form described originates with Müller-Breslau (reference 5).

of two plane trusses in the vertical and horizontal longitudinal planes, intersecting in the airship's axis. The rings are built around these plane trusses and attach to the two plane trusses at the edges of the latter. The obvious disadvantage of this construction is the practically unobtainable lateral stability of the deep plane trusses and, in addition, their deficient torsional stiffness. An advantage of this construction is, perhaps, that a natural attachment of the stabilizing surfaces results and that the vertical plane trusses can be used for supporting weights and the nose for mast mooring without anything additional.

In all of the more recent airships, however, the previously described basket-work framing has been used. In this construction the transverse rings are designated as main and intermediate rings, depending on whether or not they are stiffened in their own planes. The stiff main rings serve a double purpose. Firstly, they take care of a proportionate share of the external forces on the outer cover which affect the framing; secondly, they divide the total gas space into the individual compartments which serve for the accommodation of the gas cells. In the design of the framing the case of a deflated gas cell is considered. Then the adjacent cells which are still inflated are subjected to large side gas forces, for which either the main rings themselves must be carefully designed, or some other structural provision must be made.

In the main rings of the more recent rigid airships one may distinguish two different arrangements. In figure 18 they are shown in contrast, above and below. The "Graf Zeppelin," as well as the new airship LZ 129, now under construction, have wire-braced rings. The wire bracing is attached to alternate ring corners; the intermediate sides are constructed as trusses. Also, in the one English airship R 100 no departure from wire-braced rings has been made; the wire forces are here led to each ring corner. On the other hand, the "Akron" and the English airship R 101 have so-called inherently stiff rings. These are built up in such a manner that two external ring members lying in the outer surface of the airship are joined with an inner ring member by means of wall struts to form a stable triangular girder. The question, which of the two main ring types is the better for the present size and form defined by the framing, can not be definitely decided. This is due to the two opposing functions of the main ring, on

the one hand, to provide for a good weight distribution and stiffening of the framing, on the other hand, to form the necessary bulkheads for the gas cells. If only the first function existed, preference would undoubtedly be given to the wire-braced ring; for, as is well known, a cross-braced structure is superior to a trussed structure with respect to stiffness. However, a requirement for a good stiffening effect of the braced ring is as highly tensioned a wire net as is possible.

Now, however, for the second function, namely, for serving as a bulkhead, such a tensioned net is disadvantageous, for the side gas forces occurring with deflation of a cell produce in the wire bracing the greater forces, the less the bracing is able to bulge. These wire stresses become more appreciable with increasing ring diameter. They can be reduced, however, by supporting the wire bracing at the center by means of an axial girder, running through the entire ship. Such a solution is applied in the three newer rigid airships provided with wire-braced rings. However, the use of this axial support is accompanied by the structural disadvantage that either it must be passed through the cell, or must be encircled by the cell. The former method presents difficulties in making the cell gas tight where the girder passes through it; besides, the axial girder is inaccessible. For these reasons, in the two recent airships LZ 129 and R 100, the gas cells have been installed around the axial girder like millstones. In the LZ 127 the solution presented no such difficulty, since with the arrangement of lifting gas in the upper part and fuel gas in the lower part of the airship, a necessary separation of the cells resulted and the axial girder could be run between them.

In the two ships provided with inherently stiff rings, the "Akron" and the R 101, the problem of taking up the side gas forces is solved in different ways. In the "Akron" a netting bulkhead with a tensioning device is introduced inside the inner ring member (fig. 24). This is resiliently attached to the inner ring corners in the upper part. This resiliency yields only with large forces. The effect of this is that, in the normal condition of inflated cells, the netting bulkhead acts as a supplementary stiffening of the ring; on the other hand, in the unusual loading condition of a deflated cell, which is accompanied by large wire forces, the bulkhead net can bulge out, and thereby the wire forces are reduced. In the R 101, the placing of a

wire net inside the inherently stiff ring has been avoided. Instead, the whole cell is surrounded by a parachute-like wire net, which leads the side gas forces into the joints of the longitudinal girders (fig. 31).

The fact that the inherently stiff ring occupies some of the available gas space and thereby reduces the lift is always emphasized as an unfortunate disadvantage of such rings. To avoid this, it has been suggested that the ring be made as deep as possible and its inside filled with a special ring cell. However, this solution is accompanied by great structural difficulties and also results in an additional weight of cell material and valves, apart from the consideration that the increased surface of the whole cell installation involved in this solution causes increased gas loss.

Also, with respect to the spacing of the main rings, the newer airships differ very substantially. To minimize the ring and cell weights, it would be desirable to subdivide the gas space as little as possible. The size of the cells and therewith the main-ring spacing is, however, limited by the condition that the loss of lift in the event of the deflation of a cell, and the ensuing trim moment, may not exceed a definite maximum value. This maximum value depends upon what matter in the airship can be expended to offset the loss of lift and the trim of the ship with deflation of this cell. Besides this, a limitation of the cell size results from the requirement that the stressing of the framing with deflation of a cell may not be too unfavorable. The spacing of the main rings selected in the case of the "Graf Zeppelin" is 15 m. Between the main rings, two intermediate rings are placed (fig. 21). They serve to reduce the column length of the longitudinal girders to the most favorable figure of 5 m and also to provide a favorable angle of inclination for the shear wires. In the LZ 129, in spite of the large increase in the gas content, a cell length of 15.0 m, as well as the scheme of two intermediate rings, have been retained. Only amidships is the main ring spacing increased to 16.5 m. On the other hand, the wide main ring spacing in the "Akron" has been increased to 20 m amidships and to subdivide the column length of the longitudinals three intermediate rings have been used (fig. 23). In the English constructions, R 100 and R 101, the intermediate rings have been entirely omitted and, instead, the main rings have been put close together (fig. 26). This resulted in a relatively

large number of main rings and the rather large column lengths of about 11 to 13 m in the longitudinals. The close subdivision of the gas space may well have contributed to the fact that the structural weight in the two English airships has turned out to be relatively high.

The spacing of longitudinals is limited by the condition that a certain figure should not be exceeded for the free span width of the outer cover, which is laced to the outer booms of the longitudinals. In the German constructions LZ 127 and LZ 129, as well as in the "Akron," it amounts to around 3.50 m. Also with respect to these figures, those previously customary have been exceeded in the English airships. In order to reduce the distortion and fluttering of the outer cover resulting from the great span width, a special supporting structure has been provided in the R 100, which pulls the cover inward. On the other hand, in the R 101 portable intermediate longitudinals are placed between adjacent main longitudinals (figure 30), which serve to tension the cover radially. However, since these intermediate longitudinals are not adapted to taking tension, they represent a useless excess weight; a further reason for the high structural weight in the R 101.

All previous German rigid airships have a frame-stiffening keel girder, which serves to transfer to the main rings the weights located in the lower part of the airship (fig. 19). In contrast to this, in the R 101 such a keel girder has been entirely avoided, since for the greater part it was possible to place the weights in the spacious main rings. The corridors provided are made up of relatively weak framing (fig. 34). In the "Akron" three corridors in all are provided, one at the top and one on each side in the lower part of the airship at 45° to the longitudinal plane. In the forward part of the airship a corridor runs from the control car to the extreme bow. The engines are inside the airship in properly fitted rooms at the intersections of the side corridors with four midship main rings.

For the attachment of the stabilizing surfaces it has been heretofore customary to construct a stiff cruciform frame in one or more of the main rings in the longitudinal location of the surfaces, to which the surfaces can then be attached without bracing (fig. 33). In the German and English airships, this manner of construction has been retained. In the "Akron," on the other hand, the surfaces

have been attached directly to the outer framing, relying upon the inherently stiff main rings for rigidity. In the English airships the passenger and crew spaces are located in the interior of the airship in the forward half of the airship, likewise the living spaces for the complement of the "Akron." The latter are located adjacent to the side corridors; between them a free space is bridged over, which serves for the accommodation of five airplanes. Figures 19 to 24 can serve further to clarify the frame structures of the various rigid airships. Further figures are found in references 10 to 16.

2. Structural Elements

Just as the five newer airships differ in general arrangement of framing, they also differ from one another in girder design. The LZ 127 has girders similar to those which were usual in earlier Zeppelin airships. The longitudinal and ring girders are of triangular form, their channel-shaped corner members being joined by means of corrugated lattices (fig. 35). For the LZ 129, entirely new kinds of girders have been developed, which likewise are shown in figure 35. The corner members are joined by means of oppositely set U-shaped struts, extensively provided with lightening holes. The pot-shaped corner members used for the new girders are especially shown in figure 35. The upper sections are used in the more lightly stressed, the lower in the more heavily stressed girders. Figure 36 shows a truss member of a main ring of LZ 127. The kind of latticing for the various girders is clearly recognized in this. Figure 37 shows the girders newly developed by the Luftschiffbau Zeppelin and having the oppositely set strut bracing, and shows also the attachment of the latter to the outer and inner legs of the corner members.

In the "Akron" a departure has been made from the triangular type of girder and rectangular box girders (fig. 35) have been developed for the ring members. These girders have no real corner members. Rather, the wall plates of the girders grip over one another at the corners and have stiffening grooves there. Merely by the setting-in of a corner piece the corners are transformed into closed sections. The wall plates have extensive lightening holes. In like manner this construction is also applicable to triangular box girders. The ring girders used in the R 101 have an appearance similar to that of the ring girders in

the "Akron." In contrast to the "Akron," however, lipped tubes are used in the corners, into which the wall plates grip. In the three boom girders of the spacious rings these tubes are made of high-strength steel, while the wall plates are of duralumin.

Through the so-called efficiency factor one has a comparison of the values of the girders developed. By this is meant the relationship of the buckling load attained, in tons, to the running girder weight in kg/m. This has the dimension km. In figure 38 the efficiency factors of the triangular girders for LZ 127 and LZ 129 are plotted on the girder cross-sections. It is seen that the efficiency factors of the new girders, in comparison with the earlier ones, have increased significantly. It is especially significant in connection with the girders used, that the efficiency factors increase with increasing cross-section. From this it follows, that the structural improvement of lighter girders is particularly difficult. In figure 39 the efficiency factors for the girders developed by the Goodyear-Zeppelin Corporation are shown. In the case of the girders used in the "Akron," made of the American aluminum alloy 17SRT, they lie between 5 and 8. Moreover, they may be brought higher with the use of the high strength alloy 24SRT and with improved forming.

Those developed for the framing of the R 100 are triangular girders, the tubular booms of which show an especially noteworthy development. Figure 40 shows such a tube in formation. The tubes are rolled in spiral form from strips of plate and riveted along the contacting edges. As is evident from figure 41, the boom tubes are joined by means of box-type struts, which are arranged opposed to one another in a manner similar to that used in the previously described development of the girders of the LZ 129, and which have been provided with lightening holes.

The longitudinal girders in the R 101 are constructed in yet another manner (fig. 42). These longitudinal girders, which likewise are triangular girders, have booms of steel tubing and struts of duralumin tubing. The rectangular panels are cross-braced by means of wire diagonals. The girders have a considerable depth (up to 70 cm). The steel tubes of the booms are not drawn, but are of sheeting bent together.

In joint design one can distinguish fundamentally two

different types. In the first type the intersecting booms are riveted directly together. With this type one recognizes that, as a result of the eccentric attachments of the individual members and of the stiff construction of the joint, stress concentrations occur, which, however, are in general of no great disadvantage, since they occur only locally. The other type seeks to reduce these secondary stresses, since as much as possible it brings the members together at one point in special junction members. This type has the advantage in assembling, that all members can be completed in their correct lengths and then screwed up. The structural design is, however, more difficult and also involves more weight.

Because of these considerations German airship building has thus far not departed from the stiff riveting of the joints. Figure 43 shows a typical joint, as it occurs in the construction of the LZ 127. The longitudinal girder with the downward pointing apex passes through the ring girder. Underneath the attachment plate for field assembly is visible. Also the girders of the "Akron" are riveted at the joints. Figure 44 shows an inner joint of the main ring. Here especially simple attachments result from the rectangular design of the girders.

In the construction of the R 100, special joint members (fig. 46) have been riveted together, on to which the boom tubes of the longitudinal and ring girders are screwed by means of sleeve nuts. Such a joint completed is seen in figure 45, which again shows the continuity of a longitudinal girder at the ring corner.

A ring joint of the R 101 looks entirely different (fig. 47). The boom tubes of the ring struts are brought together in pyramid form and end in a light metal casting (fig. 48), which is held by the fork-like ends of the tubes of the inner ring booms. Also the wire attachments in the R 101 are worked out in an unusual manner. The wires are poured into sleeves, which are screwed into casings. The casings are swivel-fastened to a steel plate, which can turn around a bolt set in the joint casting.

In the "Graf Zeppelin" as well as in the "Akron" the ends of wires are looped, served with small wire and then soldered. The new structure of the LZ 129 has departed from this type of wire terminal for the bracing of the main rings. The wires, which here in places go to wire diameters up to 8 mm, end in so-called "Heddernheimer" casings,

which are turned up over the wire ends on the wire-drawing frame. According to tests which were conducted at the DVL, these casings represent an exceptional terminal joint (26). In the rings of the LZ 129, now under construction, an especially interesting attachment of the wire bracing to the ring corners has been developed (fig. 49). It has for its object the leading of the wire forces as centrally as possible into the ring joints, in order to reduce torsion and lateral bending stresses in the ring girders. The wires coming into the joint are brought together on a steel member, the so-called "spreader." Around this is laid an endless cable strop, which is led over a formed part, the so-called "whip." This formed part swings on a bolt, which is placed at the junction point of the ring and longitudinal girders.

3. Materials.

In the structures of LZ 127, LZ 129, "Akron," and R 100, duralumin is used as structural material. In the R 101 a mixed construction has been adopted, in which the boom tubes of the longitudinal girders are worked out in steel. The question, which of the two materials mentioned is more suitable for the airship frame is difficult to decide theoretically. If one compares the pure efficiency factors for columns, then, to be sure, duralumin shows up the better; one should not forget, however, that in view of the compact design and the possibility of welding in the case of steel construction the joints turn out lighter. With the size of present-day airship structures we have undoubtedly come into a range where steel, especially in the form of weldable tubes, comes into the picture as a serious competitor of duralumin, which is preferably used in open sections on account of riveted attachments.

In table 1* are assembled the duralumin alloys heretofore used in airship structures. Hardness 1 signifies: cold rolled after refining. The corresponding values can also be applied to drawn sections, since approximately the same strengthening results from drawing. The first series

*The table is taken from the paper by Dr. Ing. Brenner: "Die Auswirkung neuerer Erkenntnisse der Werkstoffforschung auf den Luftfahrzeugbau" ("The Development of New Conceptions of Material Research in Aircraft Construction"), appearing in the DVL-Jahrbuch 1933.

represents the ordinary duralumin, as it was used in the predecessor of the "Graf Zeppelin," the "Los Angeles," placed in service in the American Navy.

In the second series the substitute alloy 681ZB developed for the "Graf Zeppelin" is introduced, from which one perceives that the tensile strength as well as the elastic limit, for which in light metals the 0.2 limit is specified, have increased about 10 percent. In the last line the American 17SRT used in the "Akron" is entered. As may be seen, this alloy is not better than the normal alloy 681B, strengthened by cold rolling. Further, the table contains in the next to the last line a new alloy DM31, which was recently developed at the Dürener Metall-werke. With respect to its elastic limit and tensile strength, this alloy lies about 10 percent higher yet than the substitute alloy 681ZB used for the LZ 127. Since its other properties, especially its corrosion-resistance, are not worse than in those previously mentioned, this alloy might be especially suitable for airship construction. The corrosion resisting steel used for the longitudinal girders of the R 101 has a tensile strength of about 140 kg/mm². Still to be mentioned is, that in the construction of the gangway framing of the semirigid airship PN 30 (fig. 12) Lautal tubes have been used, which show a tensile strength of 38 to 42 kg/mm² and an elastic limit (0.2) of 22 to 27 kg/mm².

4. Loading Assumptions and Structural Design

After having gone into the construction and the structural elements of the framing in the foregoing paragraphs, the fundamentals on which the design of the framing rests should now be briefly treated: first something about the loading assumptions.

The forces which stress an airship are in the main of three kinds: the static, the aerodynamic, and the inertia forces. To the static forces belong the weights carried by the airship, which are divided into deadweight, operating, and useful load, as well as the lifting forces exerted by the lifting gas. One speaks of the weighed-off ship, when loads and lift are equal, of the heavy ship, when the loads exceed, and of the light ship when the lift exceeds.

The static forces are determined with the least error.

It is the task of the constructor to strive from the beginning for balanced distribution of the weights and lifting forces through suitable weight distribution plans. This, however, is possible only to a limited degree, so that especially after a rather large fuel consumption and in the very rare case of the deflation of a cell, the static loads can cause rather large shear forces and bending moments.

The forces of the second kind are the aerodynamic or air forces. They represent the most important group of external forces. Their determination is accomplished through pressure measurements in the wind tunnel (references 27 and 28) as well as through tests on the airship in flight (reference 29). Their theoretical determination is possible through the procedures worked out by Fuhrmann, Von Karman, and Munk (references 30, 31, and 32, respectively), the results of which in general show good agreement with the test results. The aerodynamic forces occur chiefly in trimmed flight, i.e., when the heavy or light airship flies with an upward or downward directed longitudinal axis for equalization of the static forces. Similar forces occur in curved flight. Further, the forces acting on the stern of the airship with rudder movement belong to the aerodynamic forces, and finally also the forces exerted by gusts.

As a result of the accelerations occasioned by the air forces, the third kind of forces occurs: the so-called inertia forces. They are equated to the external air forces and moments in accordance with the d'Alembert principle and depend upon the mass and the moment of inertia of the airship.

In German airship construction it is customary to select a limited number of conditions of loading. Principally, there are the case of the airship flying in the vertical plane at a fixed limiting altitude, that flying in the horizontal plane with the smallest turning circle, as well as the case of the rudder hard-over at a fixed rudder angle. More recently there has been added the consideration of the stressing due to gusts, which attack the forward part of the airship with a velocity of more than 10 m/s, as well as the forces on the airship lying at the mooring mast. The loading conditions mentioned are investigated individually and in certain combinations together with the constant static loads. In the calculation of the "Akron" all aerodynamic loading conditions are combined in a single loading condition, the effect of which is assumed in all longitudinal

planes of the airship (references 17 and 33). In the construction of the English airships, on the other hand, combinations of loading conditions are considered in much greater number than was previously customary (reference 34).

Also in the matter of safety, distinct progress has been made in the newer airship structures. In German airship construction a uniform factor of safety (against breaking) of 2 for tension and compression is taken as a basis. With this the factor of safety for tension is applied to the tensile strength of the material and that for compression is applied to the experimentally established compression strength of the member concerned. In the American construction, on the other hand, the factor of safety 2 applies against exceeding the so-called "yield point," which in the alloy used, 17SRT, lies approximately around 30 kg/mm^2 (reference 33). Since this limit agrees approximately with the compressive stress attained in the compression members, this gives, even more severely than in airplane construction, a distinct security against the breaking of tension and compression members. A still more extensive graduation of factors of safety is followed out in the English constructions. The required factors of safety (against breaking) lie, depending on the kind of stress, between 2 and 4 (reference 35).

With the high degree of static indeterminateness, the exact calculation of an airship framework as a statically indeterminate space framework practically can not be accomplished. On this account one is compelled to adopt approximate methods (references 36 and 37). The simplest and, under certain hypotheses, also the most suitable approximate method consists in considering the entire airship frame to be a homogeneous beam, and to calculate according to the usual bending theory. In the determination of the moment of inertia of such a beam one must, however, consider not only the circular cross sections, but also the diagonal reinforcement of the tension zone by the outer panel and the inner net stressing, and under certain circumstances also that by the outer covering. In what magnitudes the individual portions are to be taken depends on the transverse force acting at the section considered.

Another approximate method consists in calculating the forces in the diagonals of the outer surface under the hypothesis that the transverse rings are rigid in and perpendicular to their planes and that only a parallel dis-

placement of these rings with respect to each other takes place. The circumferential forces are then determined from the components of the diagonal forces so determined. In contrast to the previously mentioned bending theory, this method is designated as the shear theory (references 4, 38, and 39).

Stress and bending measurements on the framing with definite conditions of loading can give an indication concerning the accuracy of the approximate methods discussed. A loading test of that kind was undertaken early in 1929 by the DVL with the framing of the LZ 127 in the hangar. The measurements were made on the weighed-off airship and the various loading conditions were obtained by shifting of the weights provided. The measurement of the stretch of longitudinal girders was mostly by the electro-acoustic method with Maihak strain gauges, tensions in wires were determined with the tensiometers developed by Luftschiffbau Zeppelin.

From the great number of measurements taken, there are selected in figure 50 the stress measurements in the longitudinal girders over an airship's cross section approximately amidships for two significant conditions of loading. In the first case a large bending moment acts in conjunction with a small transverse force; in the second case a small bending moment in conjunction with a large transverse force. The curves a show the variation of the stresses measured in the longitudinal girders under these conditions of loading. Superimposed on these are three calculated curves b, c, d, which were obtained in accordance with the above-mentioned beam theory b under the hypothesis that only the longitudinals alone, c, that the longitudinals and all diagonals, and d, that the longitudinals and only the diagonals lying in the tension zone contribute to the moment of inertia. In the case of the diagonals a cooperation of the net stressing and outer cover is considered. The course of the curves shows that the stress distribution measured lies in general between the two lines b and c, and, indeed, agrees well with b in the compression zone and well with c in the tension zone. The line d is in good agreement with whole course.

A somewhat expensive procedure for checking the stresses is the carrying out of static tests on models, which in their elastic properties duplicate the full size. Such model tests are in preparation at the DVL.

5. Weight Survey

In closing, a survey of the weights used for the framing and other parts of the dead weights of the airships mentioned should be given.

In figure 51 the weight ratios of framing, wiring, etc., to dead weight, as well as the ratio of the dead weight to static lift, are shown graphically to the same scale for the various airships. The square shown, representing 5 tons* serves as a measure of the actual weights. Primarily noteworthy in this drawing is the large ratio of the framing to dead weight in the two English airships R 100 and R 101. This probably lies, as is already mentioned, mainly in the close ring spacing as well as in the relatively high factors of safety chosen. The greater ratio of the wiring to dead weight in R 100 compared with R 101 is to be attributed to the greater ratio of the wiring area to the profile area of the hull in the case of R 100. The smaller weight ratio of outer cover and gas cells in the "Akron," R 100, and R 101 in comparison with LZ 127 is to be attributed to the greater volume and the smaller slenderness ratio. The large ratio of the machinery installation in the LZ 127 and "Akron" in comparison with the R 100 probably lies largely in the relatively high unit weight of the Maybach engines chargeable to operating safety, and in comparison with the R 101 in the relatively low total power of the machinery installation of the R 101. Finally, in addition there is the large ratio of the crew and passenger spaces in the two English airships. This results from the fact that in the two English airships a relatively high weight has been expended for the furnishing of these spaces. The dashed lines in the case of R 101 show the ratio if approximately the same expenditure is made as in the case of the "Graf Zeppelin."

In conclusion, it must be noted that in this comparison, in which all airships are assumed inflated with hydrogen, the "Akron" comes out somewhat too favorable, since with helium inflation the framing portion is more lightly stressed; however, offsetting this in the "Akron" is the additional weight of the water-recovery apparatus.

*Metric. 1 ton, metric = 2204.6 pounds.

IV. CONCLUSION

In covering the matters relating to the present position of airship construction it was possible only to a limited degree to go into them thoroughly. Particularly, only a part of the materials graciously made available by domestic and foreign airship authorities could be introduced. The foregoing discussion is intended primarily to give an idea as to what mental and material media have been used in airship construction up to the present time, and what guiding influence German airship construction has exerted on the previous development.

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TABLE I

Strength Data for the Newer Aluminum Alloys

Alloy and hardness	Yield point $\sigma_{0.2}$ kg/mm ²	Tensile strength σ_B kg/mm ²	Elongation δ (percent)	Remarks
681 B, untreated hardness 1	26-28 32-34	38-42 45-48	18-15 12-10	According to data of the Dürener Metallwerke A.-G., Düren
681 ZB, untreated hardness 1	28-30 36-38	42-44 46-48	18-15 12-10	
DM 31, untreated hardness 1	30-34 40-42	46-48 50-52	15-12 12-10	
17SRT, average	32	43	10-15*	According to American data

* Measured over 2 inches.

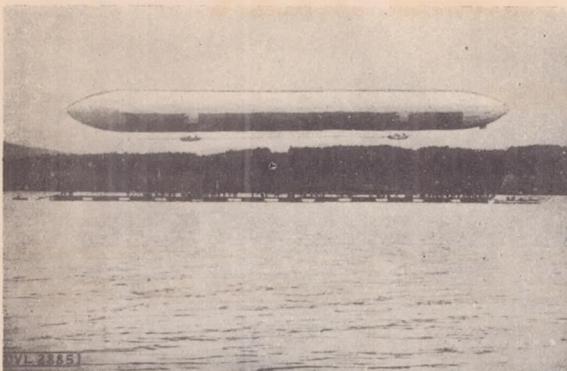


Figure 1.-First Zeppelin airship.

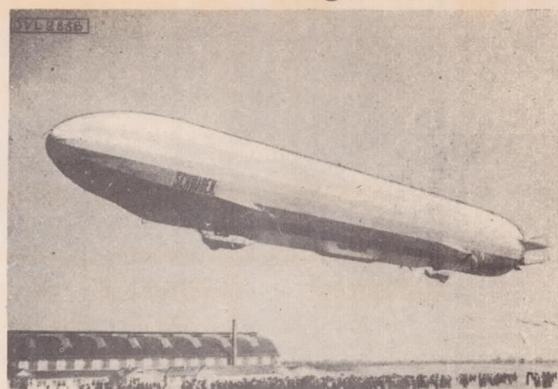


Figure 2.- Z-ship SCHWABEN.

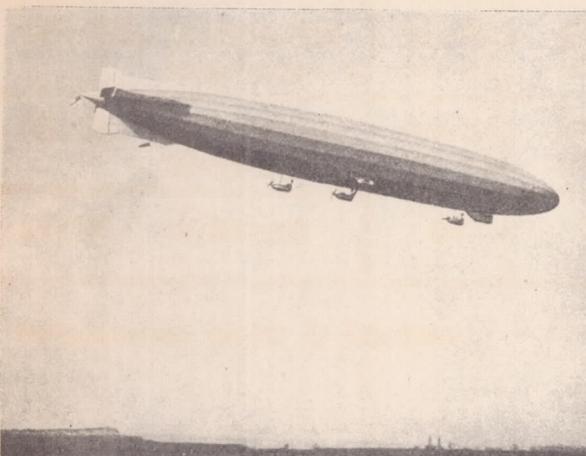


Figure 3.- Second Schuette-Lanz
airship, SL2.



Figure 4.- First Parseval
pressure ship.

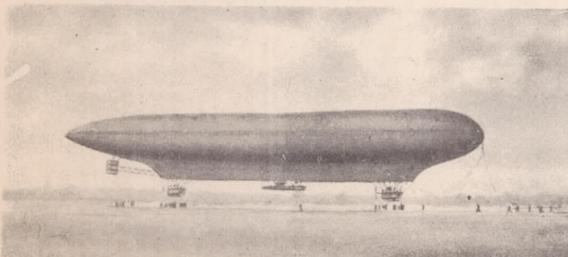


Figure 5.- Siemens-Schuckert
pressure ship.

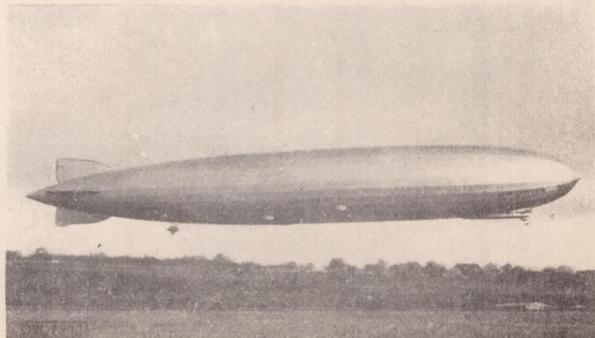


Figure 6.- GRAF ZEPPELIN (LZ-127).

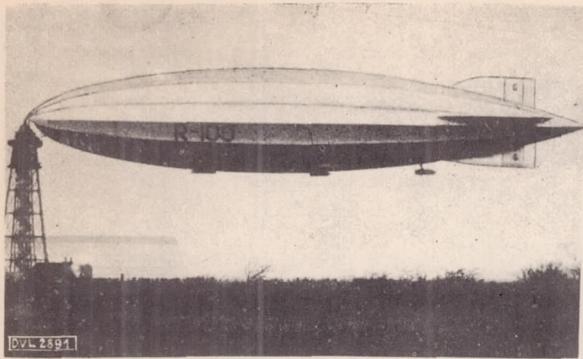


Figure 7.- The English rigid airship R-100.

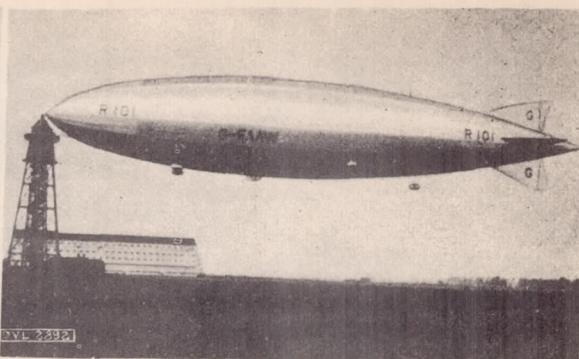


Figure 8.- The English rigid airship R-101.

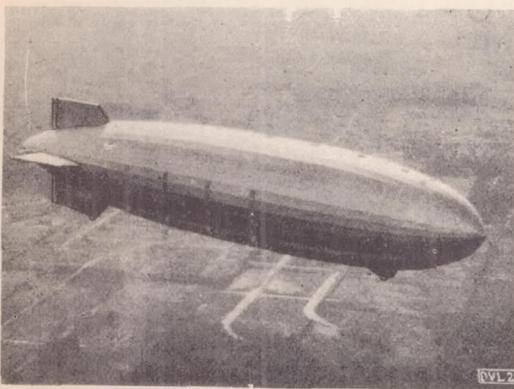


Figure 9.- The American rigid airship AKRON.

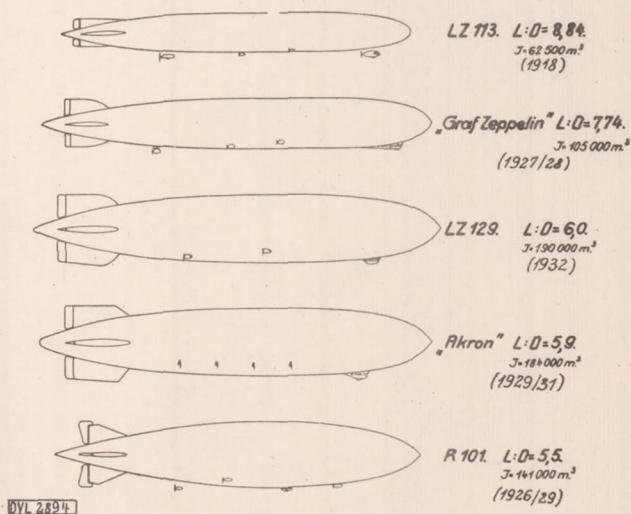


Figure 10.- Profiles of more recent rigid airships.

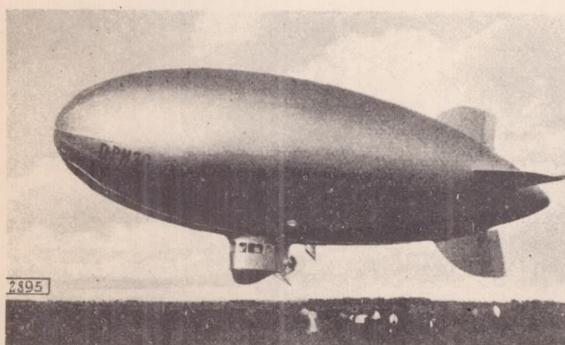


Figure 11.- Semi-rigid pressure airship PN30.

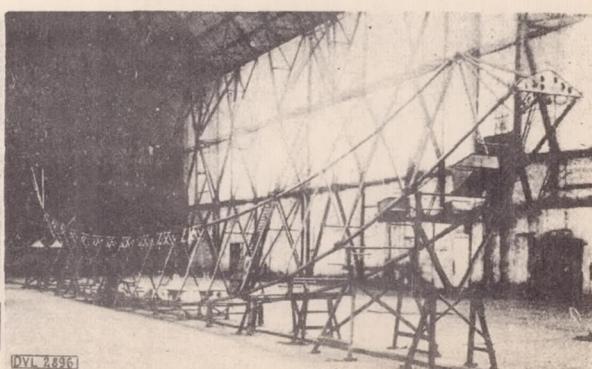


Figure 12.- PN30, gangway truss.



Figure 13.- Metalclad pressure airship ZMC-2.

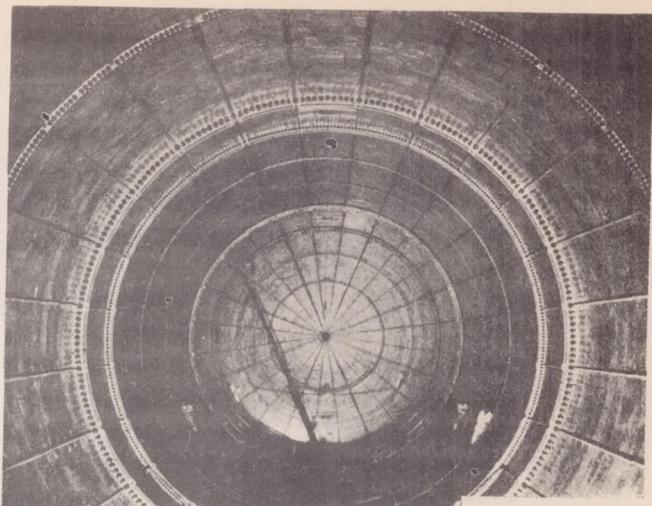


Figure 14.- ZMC-2, inside view.



Figure 15.- Goodyear pressure ship PURITAN.

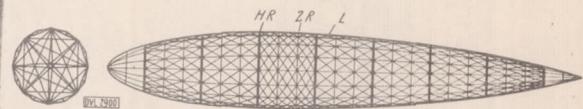


Figure 16.- Usual system of airship framing. HR = main ring.
ZR = intermediate ring. L = Longitudinal girder.

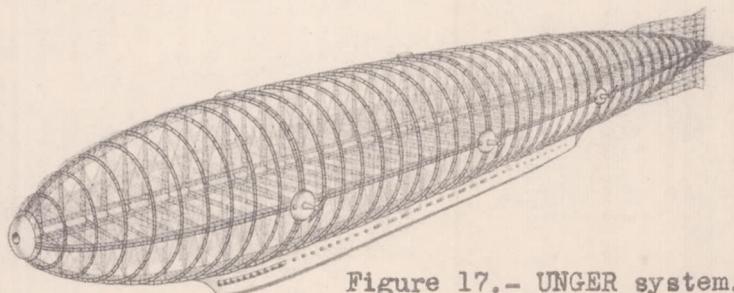


Figure 17.- UNGER system.

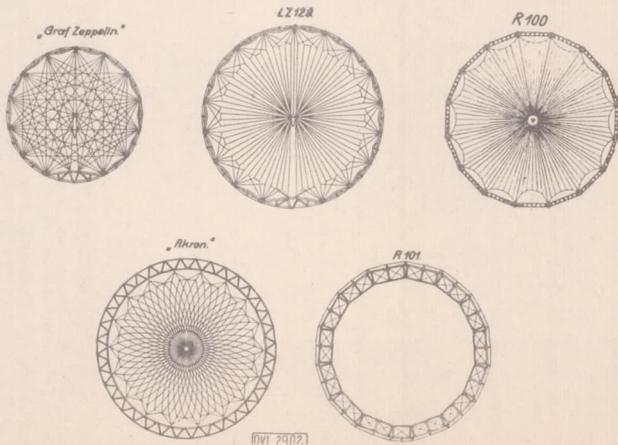


Figure 18.- Assembly of ring types.

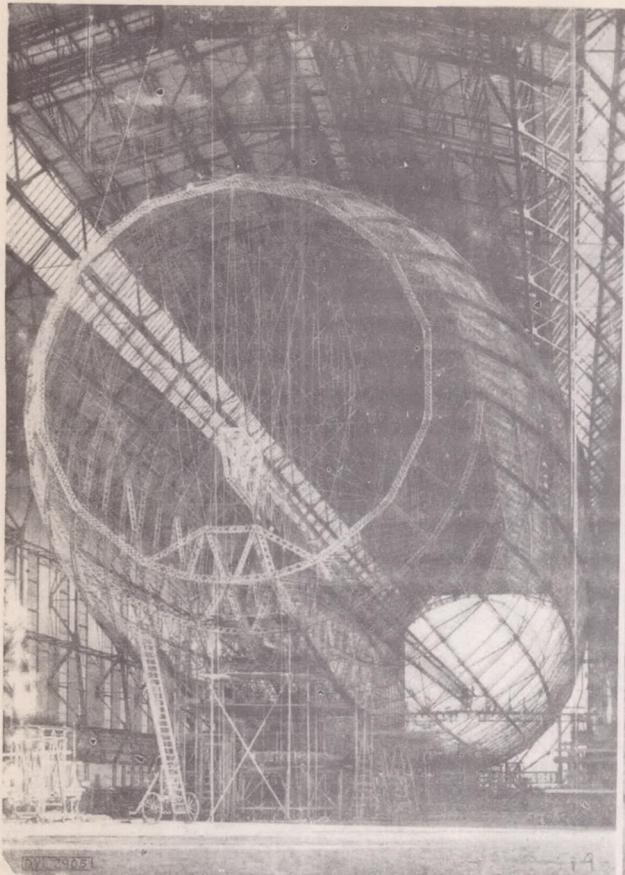


Figure 19.-LZ127-Framework during assembly, showing a view of rings. The rings are suspended from the roof trusses during assembly.

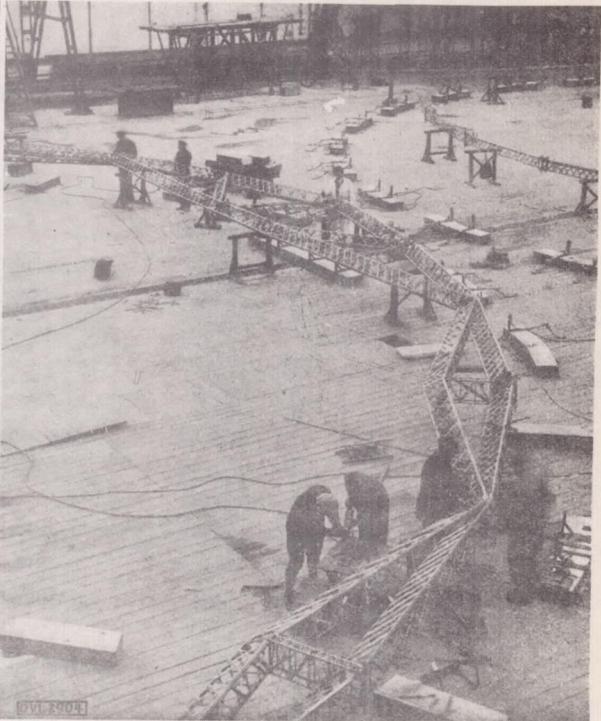


Figure 20.- LZ127-Main ring on the floor. The rings are completely finished on the floor and are erected by the aid of stiff assembly frames.

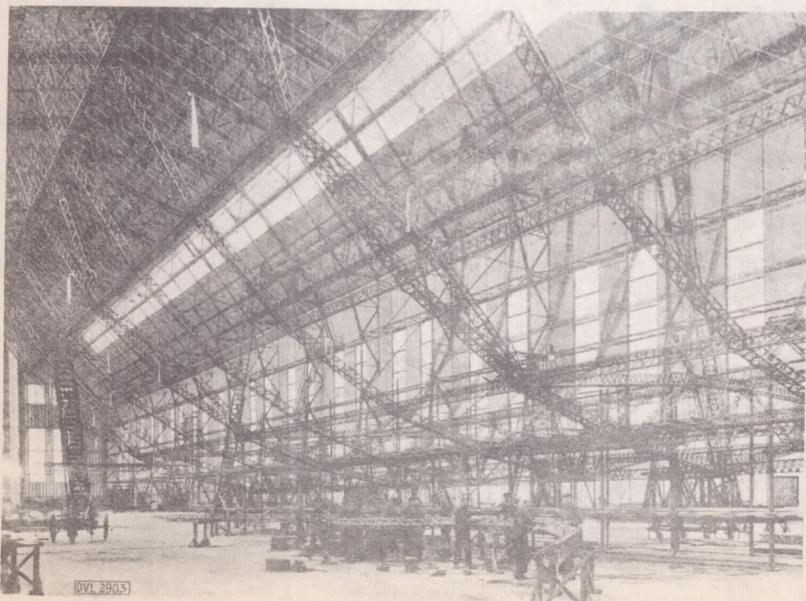


Figure 21.- LZ127 - Partial view of the framework showing the wire-braced main rings with the truss work, and the two unbraced intermediate auxiliary rings.

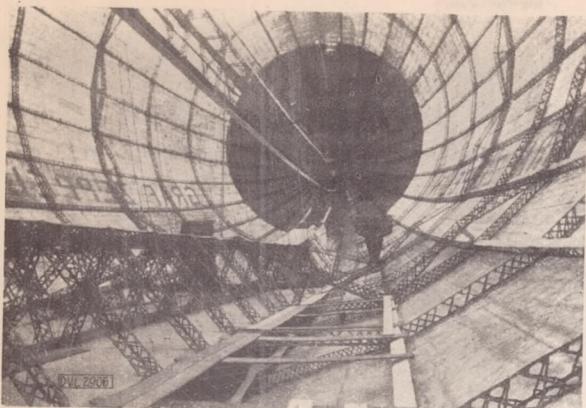


Figure 22.- LZ127 - Inside view of framework. The axial girder may be seen between the upper lift gas cells and the lower fuel gas cells. Below is seen the gangway girder.



Figure 23.- AKRON- Framing with tip of stern suspended beside it. The inherently stiff, three boom, main rings with their zig-zag strut bracing are easily visible. The framing of the AKRON was assembled on "framing towers". Two of these are placed under each main ring.

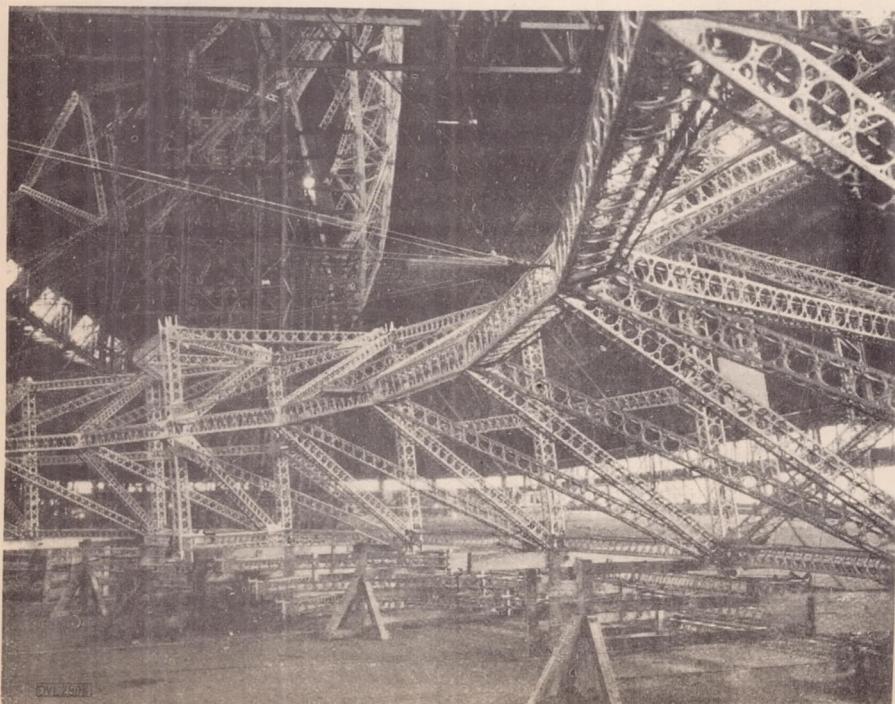


Figure 24.-AKRON- Main ring lying down with resilient bulkhead netting. The casings attached to the corners of the inner ring member in the upper part of the ring contain the resiliency devices. At the left is seen the junction of the side corridor with the main ring.

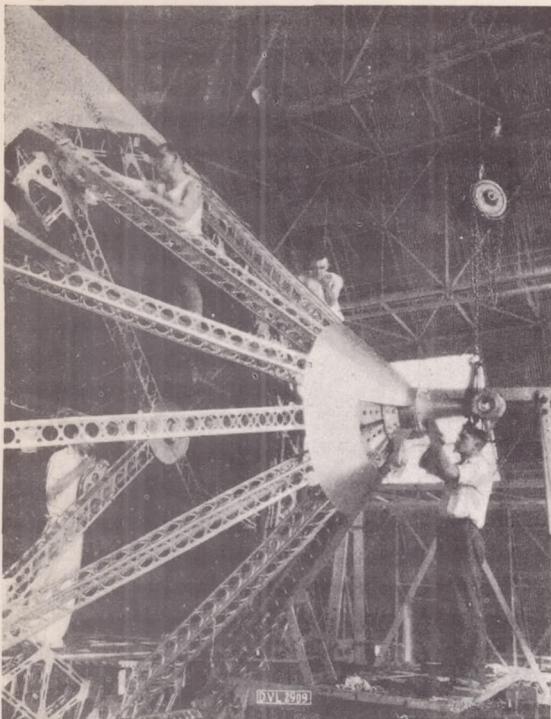


Figure 25.- AKRON - Tip of the bow with mooring spindle. The mooring spindle is at the tip of the bow and in the middle of the background a cruciform ring is seen. The mooring cone, here still lacking, hangs from the tip of the spindle.

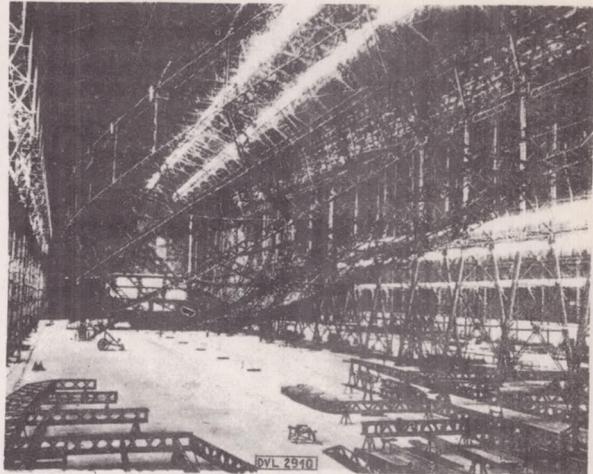


Figure 26.- R-100 - Assembly view of the framing. The great ring and longitudinal spacings, as well as the single-panel bracing, are noteworthy.

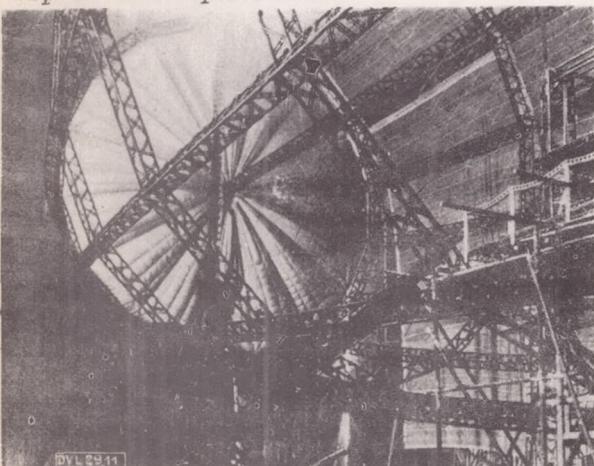


Figure 27.- R-100 - Partial view showing cell and ring bracing. The ring bracing is distinctly marked on the end of the cell. The axial girder seen above supports the wire netting at the center and is inclosed by the gas cell.

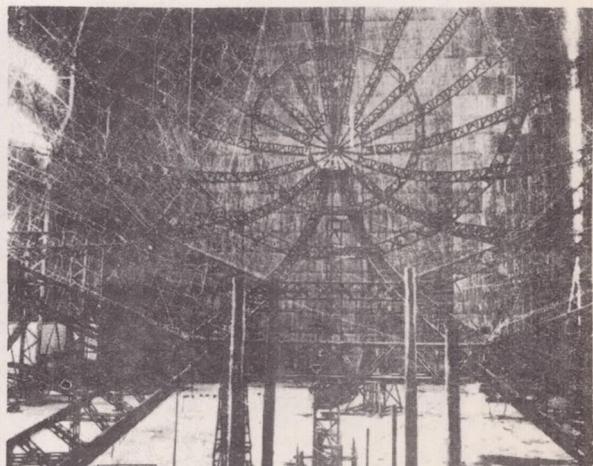


Figure 28.- R-100 - Inside view at the bow. In the foreground the ramie cord net is visible between the ring wires.

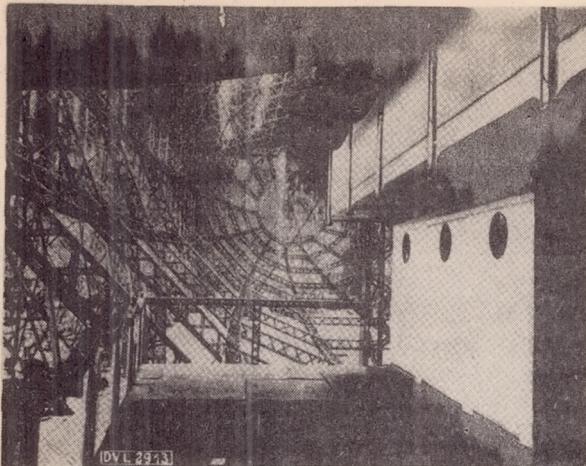


Figure 29.- R-100 - Inside view.

In the foreground the promenade deck of the passenger space located inside the ship. The walls are fabric covered.

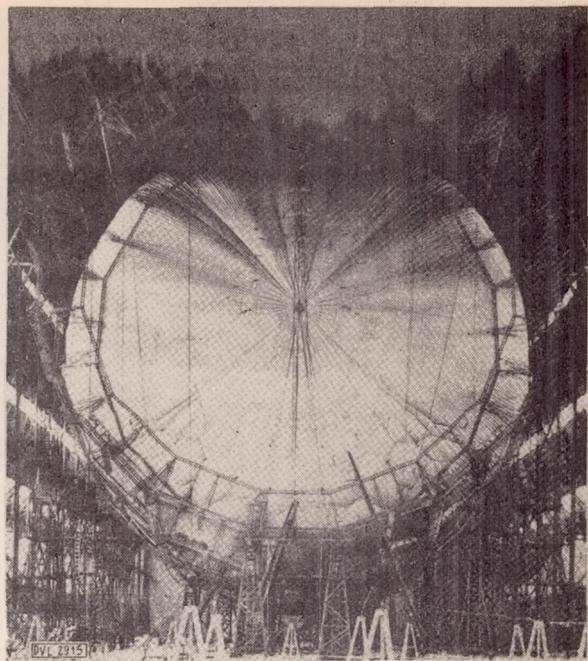


Figure 31.- R-101 - View of rings.

The three boom ring has rectangular panels, which are wire braced. The wire netting surrounding the cell and its attachment to the lower part of the ring are easily seen.

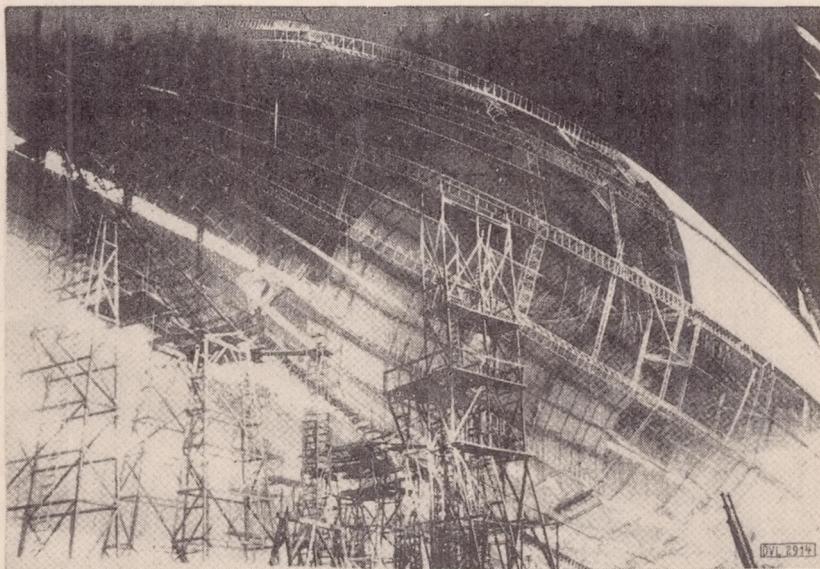


Figure 30.- R-101.- View of the bow framing. Between the widely spaced wire braced

longitudinal girders are located the numerous strut braced intermediate longitudinals. These can be used for final tensioning of the outer cover in the radial direction.

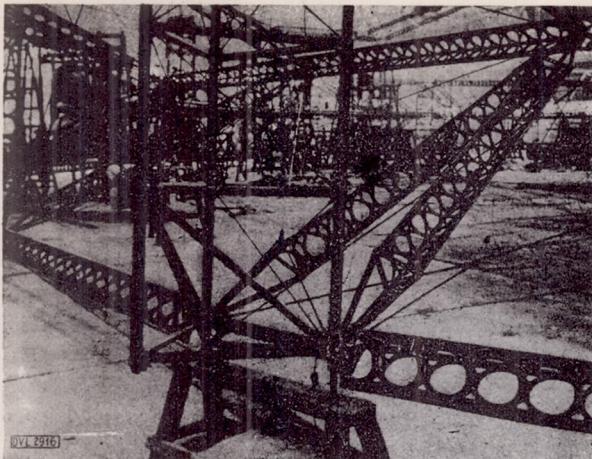


Figure 32.- R-101 - Ring lying on the floor. The columns in the outer ring plane consist of longitudinal girder sections.

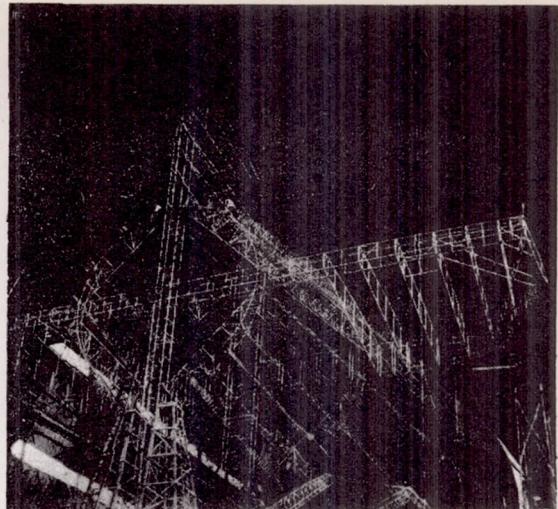


Figure 33.- R-101- Stabilizing surface structure. The two rings in way of the surfaces are of cruciform type, extensions of which form the spars for the surfaces.

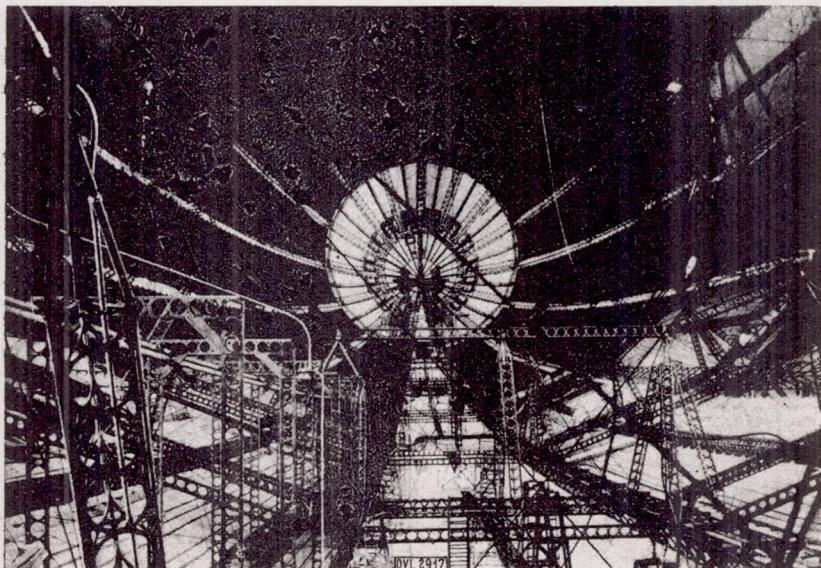


Figure 34.- R-101. Inside view. In the foreground at the left the corridor made up of weak framing, and at the right a portion of the three boom ring, are visible.

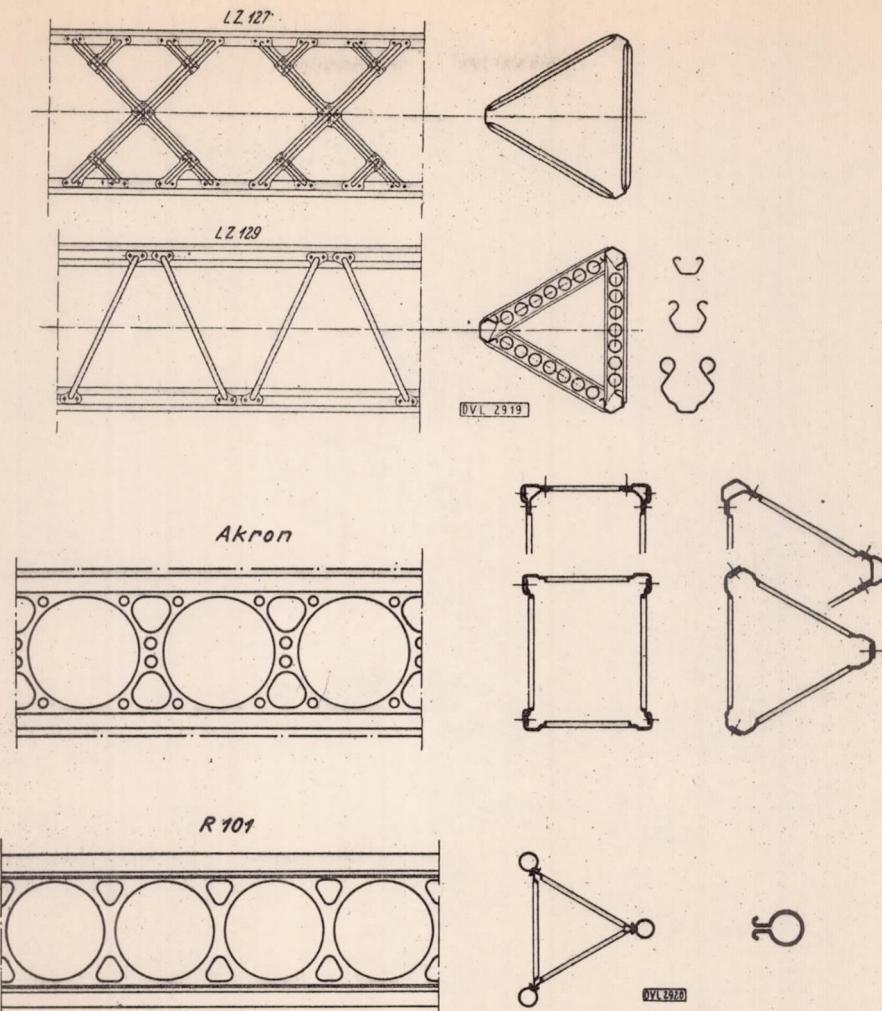


Figure 35.- Various girder types: Longitudinal and ring girders of the LZ-127 and 129, structural shapes of the LZ-129, Ring girders of the AKRON and the R-101.

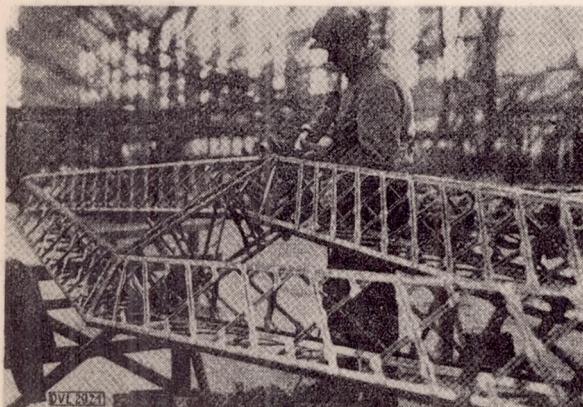


Figure 36.- LZ-127 - View of a main ring truss member.

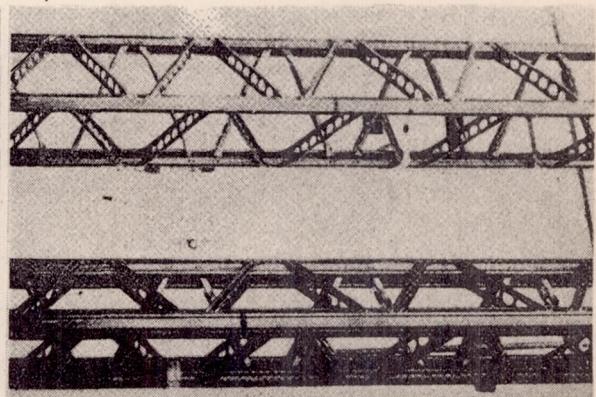


Figure 37.- LZ-129 - View of the new girders.

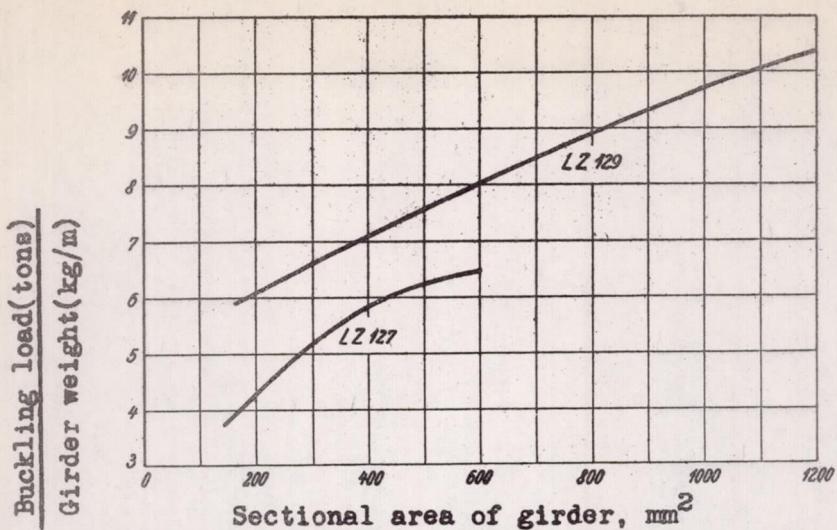


Figure 38.- LZ-127 and LZ-129 - Efficiency factors.

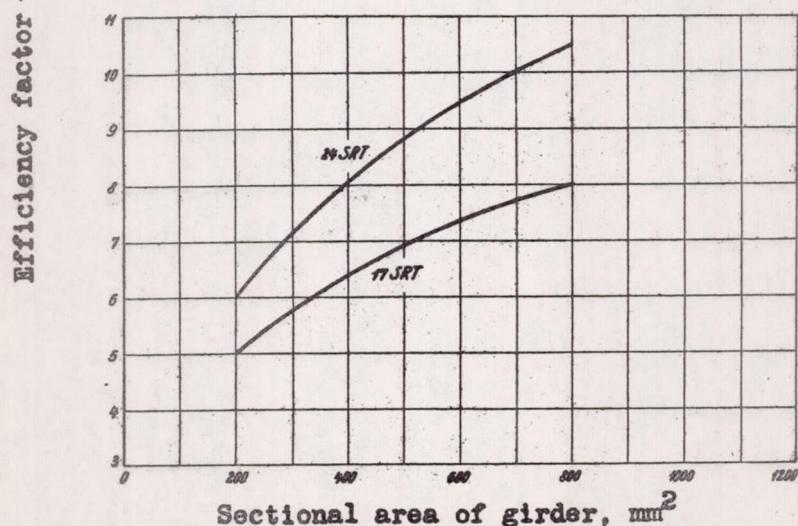


Figure 39.- AKRON-Efficiency factors.

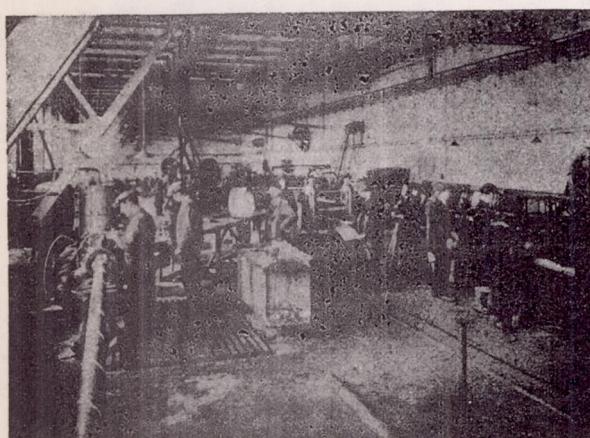


Figure 40.- R-100 - Spiral tubes in formation.

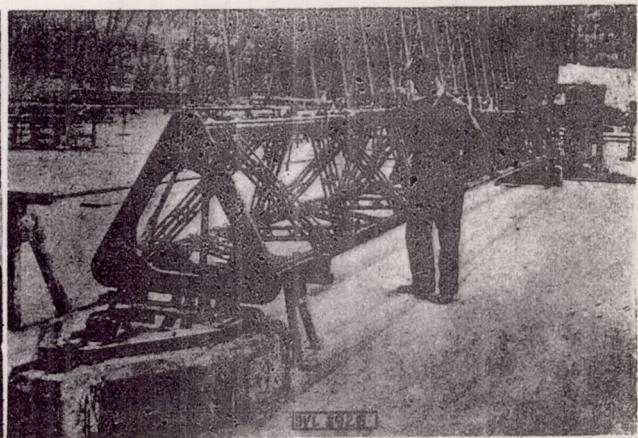


Figure 41.- R-100 - Girder.

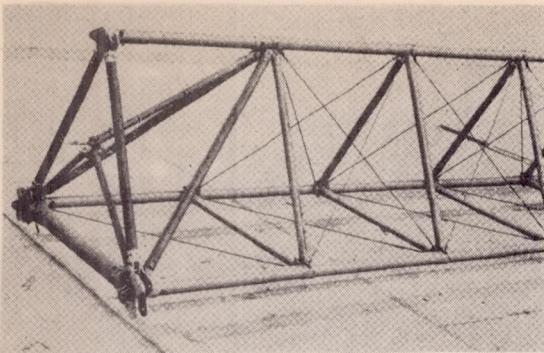


Figure 42.- R-101 - Longitudinal girder.

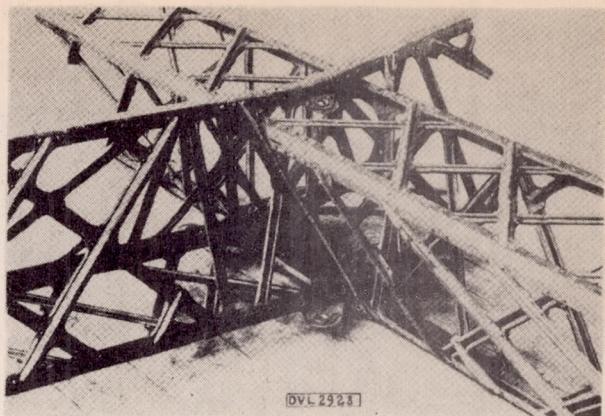


Figure 43.- LZ-127 - Joint.

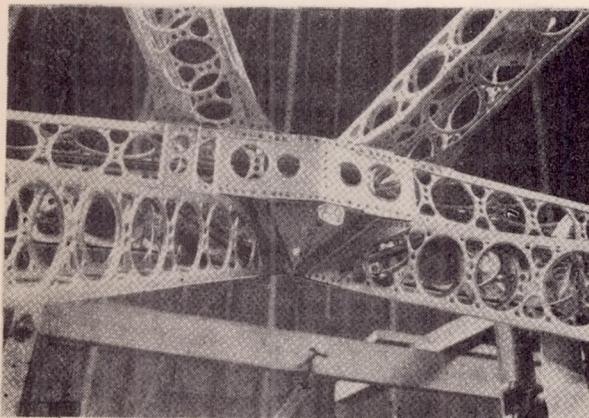


Figure 44.- AKRON - Joint.

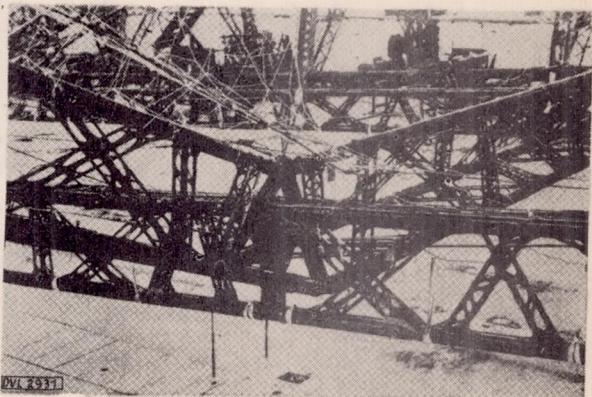


Figure 45.- R-100 - Joint.

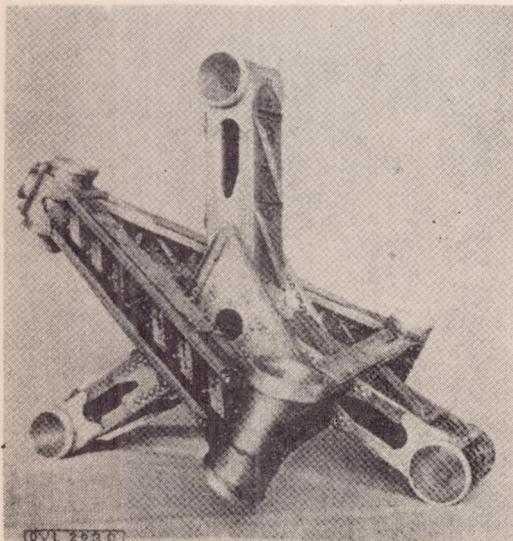


Figure 46.- Junction piece.

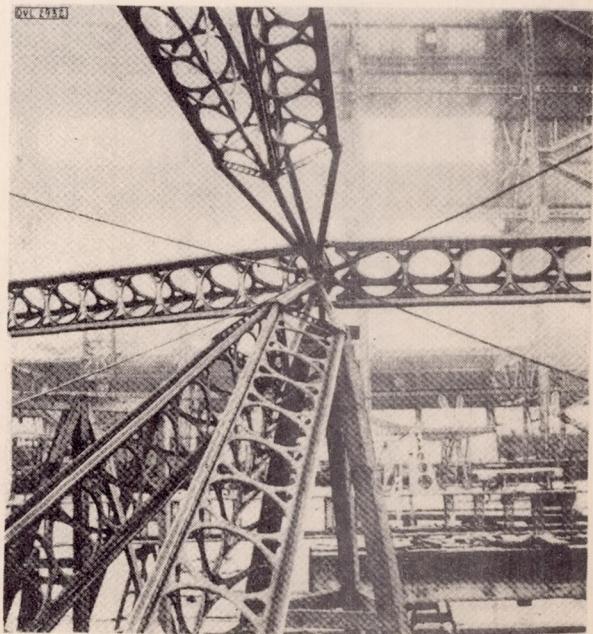


Figure 47.- R-101-Inner ring joint.

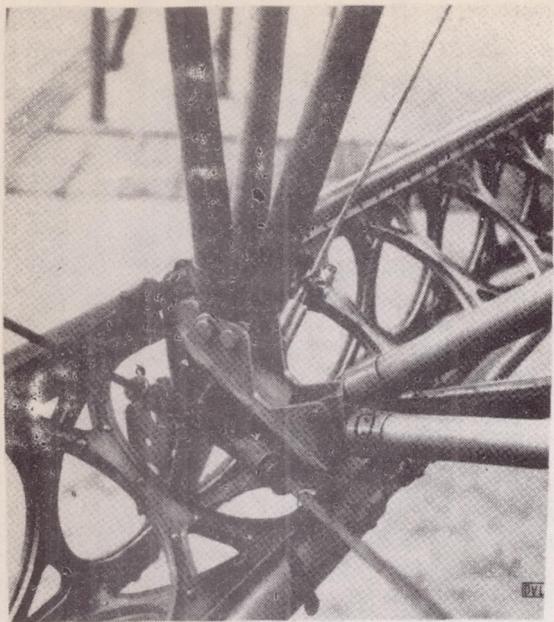
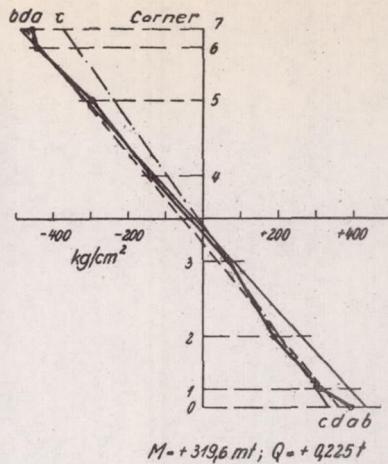
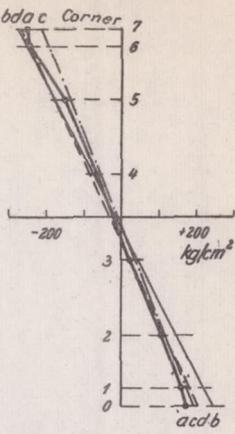


Figure 48.- R-101 - Junction piece and wire attachment.



$M = +319.6 \text{ mt}; Q = +4225 \text{ t}$



$M = +180 \text{ mt}; Q = +4531 \text{ t}$

- a) ——— Measured. According to the beam theory by the aid of moment of inertia.
- b) ——— Longitudinals alone.
- c) - - - " and diagonals.
- d) - - - " " " in the tension zone.

Figure 50.- Measured and calculated stresses in the longitudinal girders of LZ-127.

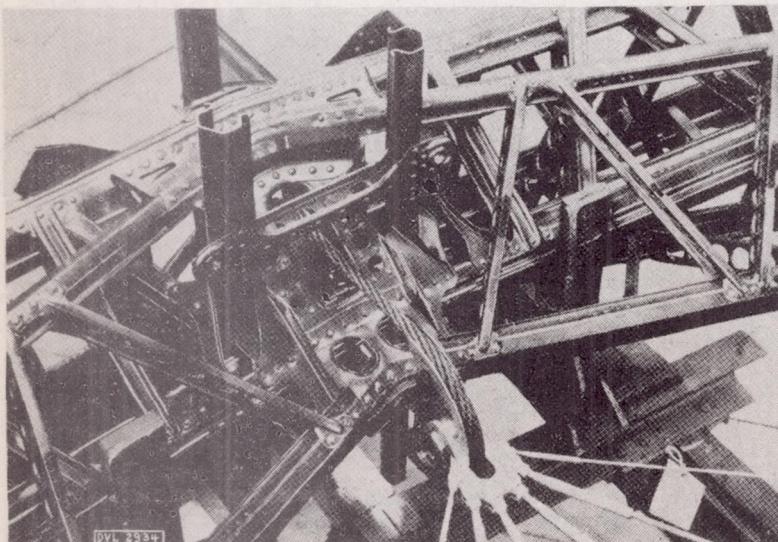


Figure 49.- LZ-129 - Wire attachment to the ring.

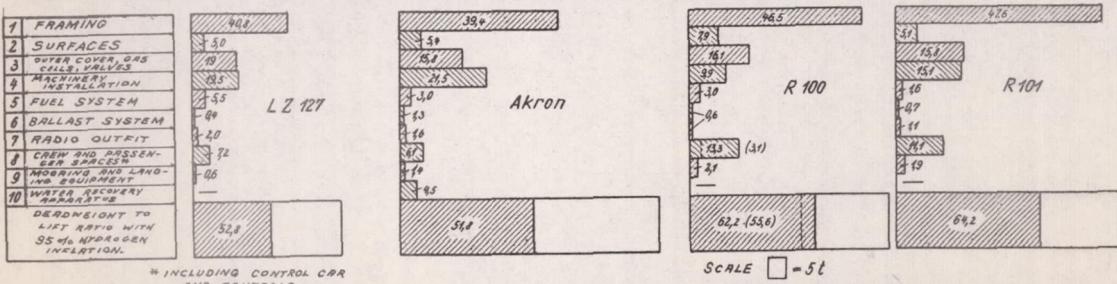


Figure 51.- Ratios of weight groups to deadweight and of deadweight to lift, in per cent.