TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 277

RECENT RESEARCHES IN AIRSHIP CONSTRUCTION - III.

A New Type of Nonrigid Airship.

By H. Naatz.

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A New Type of Nonrigid Airship.

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In recent times the question has often arisen as to whether nonrigid airships, on further development, will be able to compete with rigid airships in size and performances. We know that a nonrigid often surpasses a rigid airship in its performances, especially with respect to non-sensitivity (e.g., in landing). We also know that nonrigid airships, especially large ones, present difficulties due to their flexibility. We know, furthermore, that nonrigid airships, in contrast with rigid airships, permit so many structural types, that it is not safe to conclude that the limit of its development has been reached. Consequently, in spite of the fact that nonrigid airships have not yet exceeded a gas capacity of 36000 cubic meters (1,271,300 cubic feet), it would still be premature to pronounce judgment.

In principle, nothing stands in the way of increasing the size of nonrigid airships. Thus, for example, it is almost as easy to attain rigidity during flight, in large airships as in small ones, as I explained in my last lecture before the W.G.L.

* From "Berichte und Abhandlungen der Wissenschaftlichen Gesellschaft für Luftfahrt," (a supplement to "Zeitschrift für Flugtechnik und Motorluftschiffahrt,") March, 1924, pp. 59-63.

Since this fact is not yet known to all of you, I will take the liberty to speak briefly regarding it. A nonrigid airship of 32,000 cubic meters, the PL 27 (Fig. 27) with a speed of 24 m (78.7 ft.) per second, withstood all stresses with 20 kg/m² (4.1 lb./sq.ft.) hull pressure during its life of two years. The moment of resistance is known, as also the stresses in the envelope for the given hull pressure. Consequently, we can tell how great the maximum bending moment must have been. I found the value of 56,850 m-kg (411,195 ft.-lb.) and utilized it to obtain a general formula

$$M_{max} = 0.01\ V^{2/3}\ L\ q, \quad \ldots\ldots\ldots \quad (1)$$

which applies, however, only to airships of similar shape. Here V = air displacement, L = length and q = dynamic pressure at maximum speed.

We also investigated the mean internal pressure necessary give the airship the requisite rigidity and to prevent buckling. This was calculated from formula (1), for airships having no strengthening frame

$$p_m = 0.0217\ \frac{n^{5/3}\ \delta^{2/3}}{\frac{e}{r}}\ q \quad \ldots\ldots\ldots\ldots \quad (2)$$

in which n = elongation ratio of airship = L/D,

δ = volumetric efficiency of displacement.

Hence,

$$\delta = \frac{V}{L\ \frac{D^2}{4}}$$

The quantities e and r are given in Figs. 28-29. In the bending of a nonrigid airship, the longitudinal tensions are distributed approximately as shown in Fig. 3 (Part I), and, indeed, so that their resultant is situated at the distance e from the axis of the cross-section passing through the center of gravity. The larger it is permissible to make e, the more bending the airship can stand. The buckling limit for fabric envelopes is reached when $e/r = 0.5$, but we will see later that it is possible for the number e/r to be larger.

Formula (2) indicates that the mean internal pressure remains the same for any geometrical enlargement of the airship. It changes only in direct proportion to the dynamic pressure at the maximum velocity. If, for example, we find a hull pressure of 20 kg/m^2 (4.1 lb./sq.ft.) sufficient for one airship, it will also suffice for a larger airship of the same speed and may even be diminished, since the mean internal pressure is composed of the hull pressure plus the mean gas pressure, which is greater in large airships, on account of the greater vertical diameter of the gas cells. Security against buckling is not the same as the elimination of distortions, which is hard to accomplish in nonrigid airships. All nonrigid airships are made of woven fabric. If we compare the elongation of a strip of fabric with that of a steel band of the same tensile strength, we will find the former is about 150 times as great as the latter. This explains the considerable flexibility of nonrigid airships, which is resisted by the addition of stiffening frames of various kinds. The fabrics have the further disadvantage of stretching unequally, which makes it difficult to adapt them to the stiffening frames.

In considering these facts, the idea occurs to make the envelope of some less deformable material, like metal, or, since this is almost impossible, to have two or three envelopes in place of one. One or two of these envelopes would serve for gas-tightness, while the third would take the stresses. The latter can be made of material not so easily deformable. This idea was the basis of the new type which will now be described. The envelope included a network a (Fig. 30) of steel tape, whose intersections, occurring at intervals of about one meter (3.28 feet), were immovably fastened. This network is secured to the bottom girder of the longitudinal keel containing the walkway and completely surrounds the hull. It is held down at the top by a network partition in the vertical plane of symmetry, this partition being attached to the top girder of the keel frame. This partition also serves: 1. To reduce the height of the hull and the drag of the airship, by giving it a more circular cross-section; 2. It affords a convenient means for attaching the control surfaces, by means of staywork extending inside the airship; 3. It enables the introduction of a walkway and the installation of valves on the top of the airship, as will be subsequently described. The increase in weight, due to this partition, is offset by decreasing the weight of the bulkheads and the keel frame, since otherwise the walkway would have to be made considerably wider, in order not to make the hall too narrow.

The spaces between the partition and the network, on both sides, are either partially or completely filled by the cells e according to the degree of inflation of the airship. The whole is inclosed in an outer envelope b, which begins underneath with the bottom cover f and is held at a distance of about 0.2 m (7.9 in.) and forms an arch over the top at a somewhat greater distance. This outer envelope is held in position by longitudinal stays fastened to the nodes of the network in such a manner as to be easily detachable. The intervening space between the network and the envelope is connected with the space under the gas cells and subjected to a pressure of 10 to 30 kg/m² (2 to 6.1 lb./sq.ft.). Thus the network is compelled to support not only the pressure from the gas cells, but also the above-mentioned pressure of 10 to 30 kg/m² and all accompanying stresses, excepting a small portion which is borne by the outer envelope and the gas cells. We have before us such a structure which reminds us of a rigid airship. The difference lies in the fact that, in the airship under consideration, the framework consists only of tension members and the inner space is subjected to increased pressure. The outer envelope is air-tight and waterproof, in order to enable the airship to remain a long time in the open air and dispense with hangars. The increased pressure in the airship is obtained from the relative wind during flight by means of special devices or, when the airship is at rest, by means of blowers. If the pressure gets too great, air is released through automatic valves on top. The inlet and outlet valves may be so adjusted as to ventilate the air space more or less, thus preventing the accumulation of inflammable gases and the overheating of the gas in the cells, which is very important on large airships.

The form of the network offers an interesting and extensive study, to which I may have the opportunity to return later. I will now show only a few pictures of experiments with a small body 6 m (19.7 ft.) long and 2 m (6.56 ft.) in diameter, which the newly founded "Lustuv" has undertaken. Fig. 31 shows the surface of this body with the network and a portion of the outer envelope. Fig. 32 shows the body with the network loaded to the contemplated limit of 100 kg (220 lb.) for a 6 m (19.7 ft.) span and 60 kg/m^2 (12.29 lb./sq.ft. inside pressure, and Fig. 33 shows the same body without the network and with a load of 80 kg (176 lb.). It was found that the loading of the body could unquestionably be carried so far that the previously mentioned quantity e/r would have a value of 0.75, while on the netless body it could not exceed 0.6 without danger of collapse. We may therefore assume an allowable bending load (for airships with the network, during flight) of 30-50% more than we have formerly done.

The transverse bulkheads constitute a question of vital importance for airships, since on them depend the static longitudinal stability, safety against increase of gas pressure at the ends and against the sinking of the airship from leakage of the gas cells. Though so necessary for an airship, it is extremely difficult to solve satisfactorily. Smooth walls can not be employed for nonrigid airships, on account of the troublesome wrinkles produced on the surface. They would then need to be stiffened by ropes and belts, as, e.g., on the PL 27. The stiffening cables, however, pass through the gas space and render it impossible to employ removable gas cells. The spherical bulkheads of the 1912 S.S.W. airship are more practical. They require no bracing and therefore allow the use of gas cells, but necessitate greater pressure in the spherical spaces. Cylindrical bulkheads (Fig. 34) are still lighter and more convenient. If we cause the horizontal cylinder a to be vertically penetrated by a half-cylinder b of the same thickness, there is formed the penetration angle ABC, which serves as an attachment edge in the new bulkhead structure. The bulkhead itself is the severed portion of the perpendicular cylinder-jacket. This wall is so introduced by auxiliary devices, only the horizontal circumferential threads take up the stress, when the pressure p, as shown in Fig. 34, is exerted on the wall. The threads run into the envelope a at various acute angles, which become zero at A, B and C and do not exceed 30° at other points. Consequently, the envelope is wrinkled only at points between A and B (e.g., at D). The constricting load at this point is small, however, constituting only about one-fourth of the tension of the bulkhead and is applied to edges directed obliquely to the axis of the airship. Hence the load will be taken up chiefly by the peripheral tensions in the envelope and occasion hardly noticeable wrinkles. As we shall see later, these conclusions have been confirmed by experiments with a water-filled model. The cylindrical bulkhead naturally supports only the pressure from within outward, but yields before the load from the opposite direction. The whole arrangement must be made in pairs as shown in Fig. 35. Here the intervening space is not left empty, but is filled with gas, just the same as the other spaces, or fitted out with gas cells. If both bulkhead walls are brought close together, the intervening space then becomes so small that its gas level begins to rise rapidly, as soon as one of the bulkhead walls is pressed only a little in the opposite direction. This characteristic can be successfully employed, in oblique positions of the airship, for causing the gas level of the intervening space to go with that of the neighboring, higher located, space, without danger of producing any useless stress in the inclosed bulkhead. Fig. 37 shows this condition in an experimental body partially filled with water and inclined 20°, in which the gas is replaced by water and the "lift" is consequently directed downward. Here the equalization of the water level has taken place in the lower section. Previously the same body was in the horizontal position with the same water level or air level, as seen in Fig. 35. Thus, while one bulkhead is being put into place, the other comes into action and accomplishes the desired pressure obstruction or air-level gradation (and, indeed, immediately), because no change in shape has to be made for receiving the stresses. No wrinkles were observed on the surface of the body, even in the third case, in which, according to Fig. 36, both bulkheads were loaded, one to the maximum limit. On the inside, only the regular course of events could be verified by means of windows.

For an airship which is provided with a middle partition wall, the bulkhead is best made in the form of an undivided cylinder surface, by taking (Fig. 30) two cylinders which intersect each other in the middle partition and are tangential or nearly tangential to the network on the sides of the airship. The saving in weight thus effected is considerable. While the ratio of the bulkhead surfaces to the surface of the undivided cylinder is 1.27, it is about 1.19 for the divided cylinder.

For further illustration, we will consider a small airship of 25000 m^3 (Fig. 38). The network rises above a jointed walkway 2 meters (6.56 feet) wide and inclosed on all sides by the outer envelope and walkway shelter. The bulkheads, to the number of 12, are made of porous fabric and attached to the network by cords. The gas cells (shown, for example, only 3.4 inflated in Fig. 38) occupy all the 13 compartments, so that each bulkhead is inclosed on both sides by gas cells. If the airship is subjected to pressure, it will retain its shape, even if some of the cells are not inflated. They can therefore be exchanged, even when their adjacent surfaces are convex, since the bulkheads allow, as shown by experiments, a sufficient filling out of the intervening spaces. The intervening space at the top, as already mentioned, is made into an inspection passage, in order to inspect the air vents and gas valves and, in case of need, to make adjustments on the spot. The gas valves open directly into the outside air and discharge the gas crosswise to the direction of the relative wind, which, on the one hand, effects a rapid mixing with the air outside the airship and, on the other hand, directs the outflow upward as much as possible. This upper air space increases the safety of the airship, by rendering it possible to search for and repair leaks during flight.

The middle partition in the airship allows a good and simple method for suspending the engines and propellers on laterally projecting arms. The propellers revolve about the same axes as the engine shafts, though with reduced speed, and are driven by either rotary or radial engines. They are started by compressed air, which is also employed for operating the valves. Reversal can be effected by swinging the arms, thereby dispensing with the reversing gear and utilizing the whole propeller thrust for backward flight. The propeller arms may be located anywhere on the airship. They may be drawn in for overhauling during flight. On small airships, where this arrangement would require too much space, the surety of flight can be increased by increasing the number of engines. Thus, for example, four 210 HP engines would suffice for the airship considered, but (since the weight permits it) two reserve engines are added. The engines are easily removed and replaced. It is advisable to keep engines in reserve at the airdromes, since in this way the reliability of the airships can be considerably increased.

Compressors are provided for generating compressed air and are driven by auxiliary engines, which also drive the ventilators. The airship can be moored from the forward part of the keel or directly from the large shock absorber. The latter has the shape of a float and can be filled with water or emptied, according to whether the airship is to be moored on the water or allowed to ascend. This method is contemplated for the operation of airships, especially large ones, on lakes or other bodies of water, without hangars.

As far as the weights of this new type are concerned, we can form an approximate judgment in comparison with rigid airships, since its construction is very similar. We must, however, imagine the new type without the constricting partition wall. The weights, as just stated, remain the same. In the new type, the bulkheads are about 27% larger than on a rigid airship, but, on the other hand, they require no heavy transverse frames, so that the comparison shows, in general, that in one airship most of the girders are made very strong and rigid, while, in the other airship, they only need to have tensile strength and can accordingly be made much lighter, especially when good materials are used. The difference in weight, which is thus in favor of the new type, is indeed, diminished somewhat, due to various devices, such as pressure regulators, auxiliary engines and a heavier envelope, but always remains considerable, as shown by the calculations.

In summing up the essential features of the new type, we may characterize it by the following advantages.

1. The new type is as rigid as a rigid airship.

2. It is just as strong as a nonrigid airship.

3. It is not nearly so sensitive to injuries as a nonrigid airship, due to the network under the envelope, and tears are not propagated so easily as in cloth envelopes.

4. The gas cells are arranged the same as in rigid airships.

5. It is only slightly affected by the heat of the sun and by the weather, on account of the wide ventilating space.

6. It is lighter than a rigid airship.

7. It can be made of all dimensions, up to the largest, since the stresses are taken up by a metal network, which can be made as strong as desired.

Translation by Dwight M. Miner,
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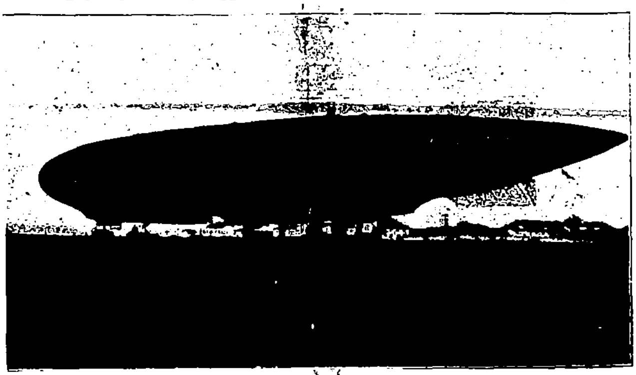


Fig.27 Parseval-Luftschiff PL27
32000 m^3 (1130064 cu.ft.) capacity.

Fig.31 Experimental hull with network and a portion of the envelope.

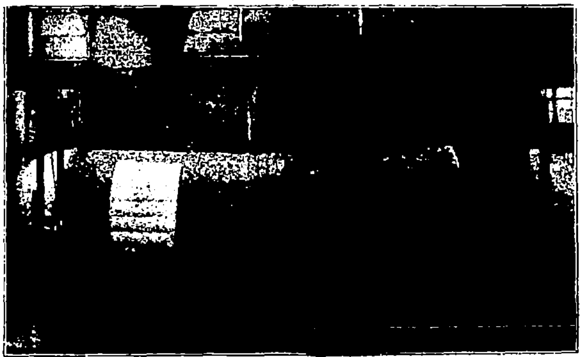


Fig.32 Bending of hull with network

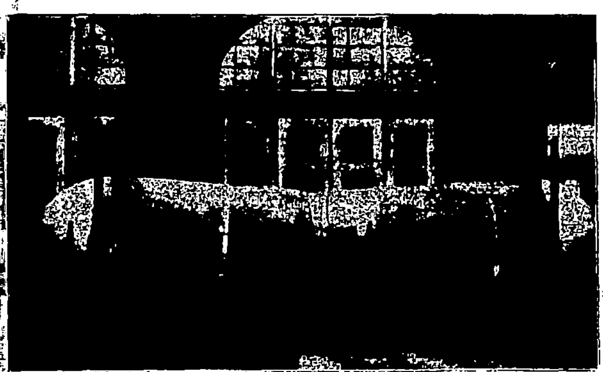


Fig.33 Bending of hull without network

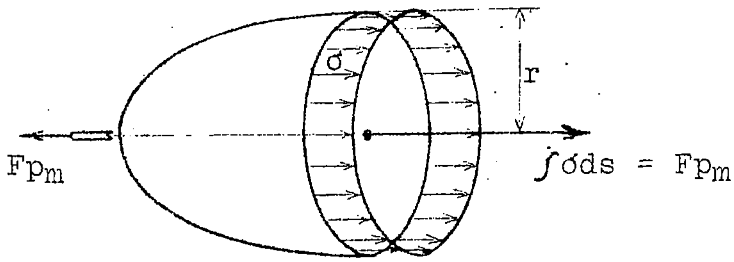


Fig.28

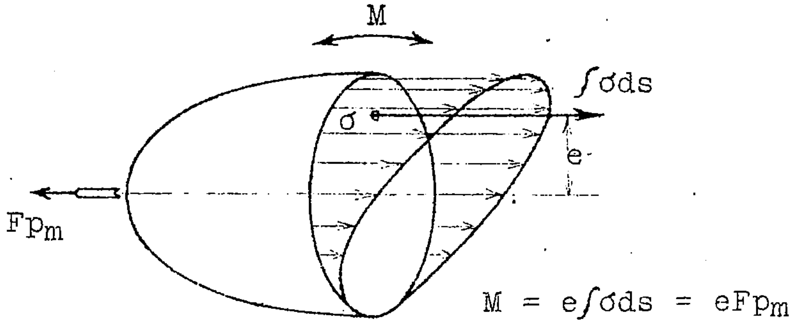


Fig.29

Distribution of longitudinal tensions on unloaded and bent airships.

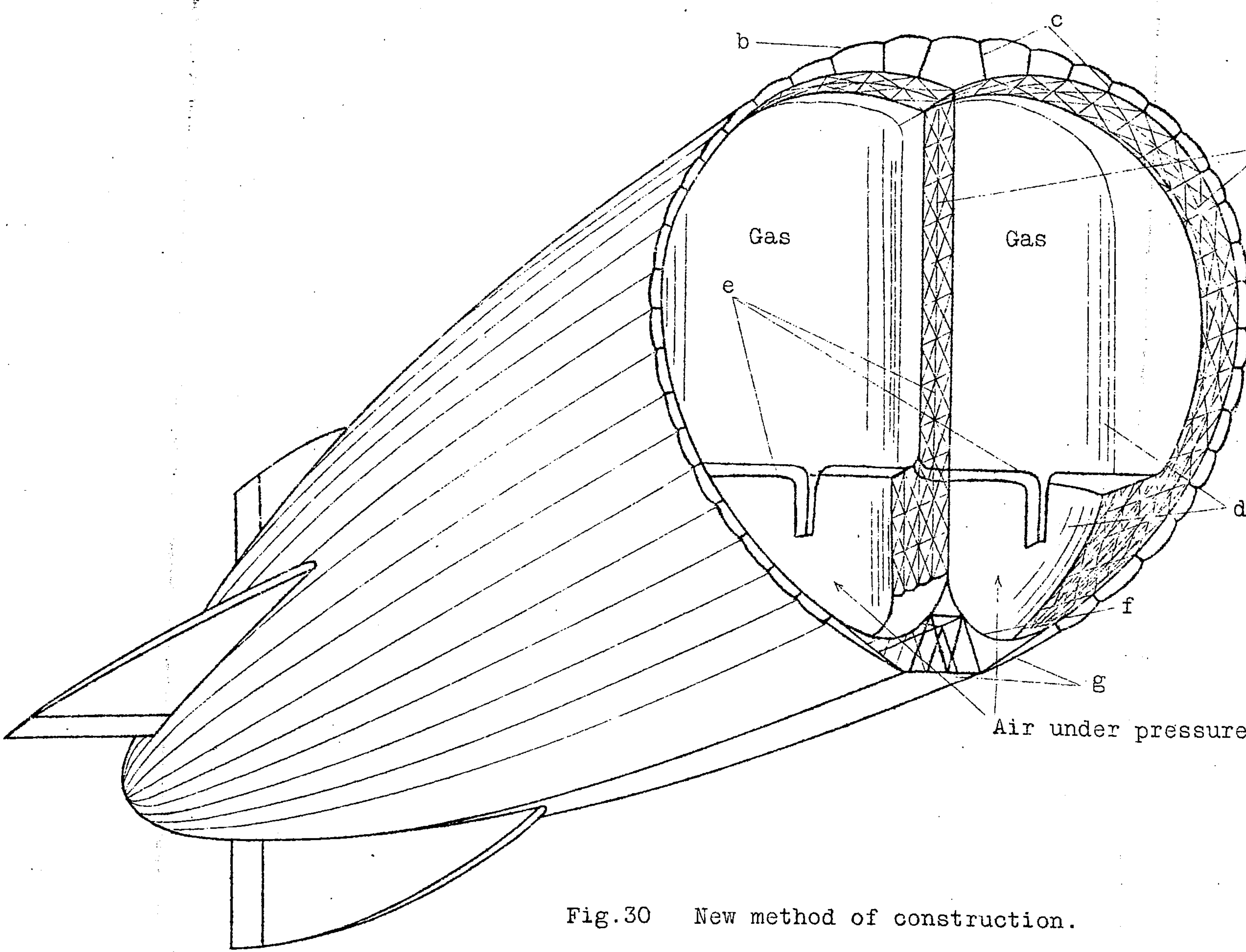


Fig.30 New method of construction.

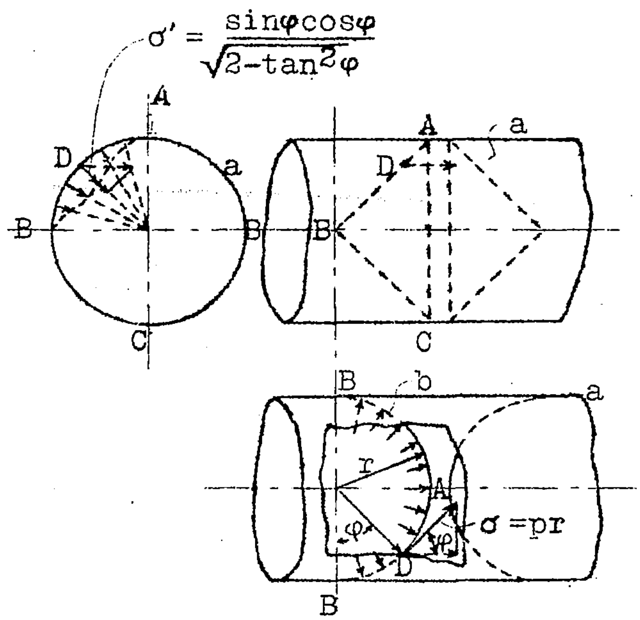
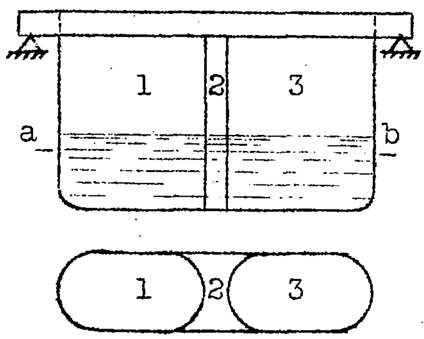
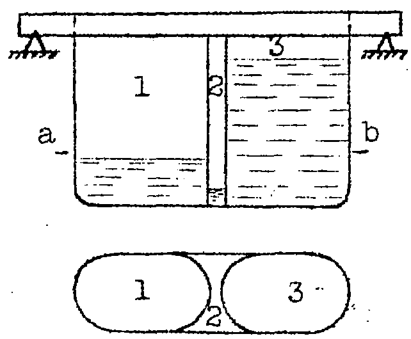


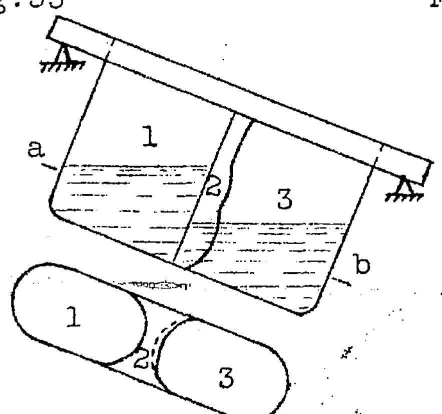
Fig.34 Cylindrical bulkhead.



Section a-b
Fig.35



Section a-b
Fig.36



Section a-b
Fig.37

Diagrams of bulkhead tests on the experimental body.

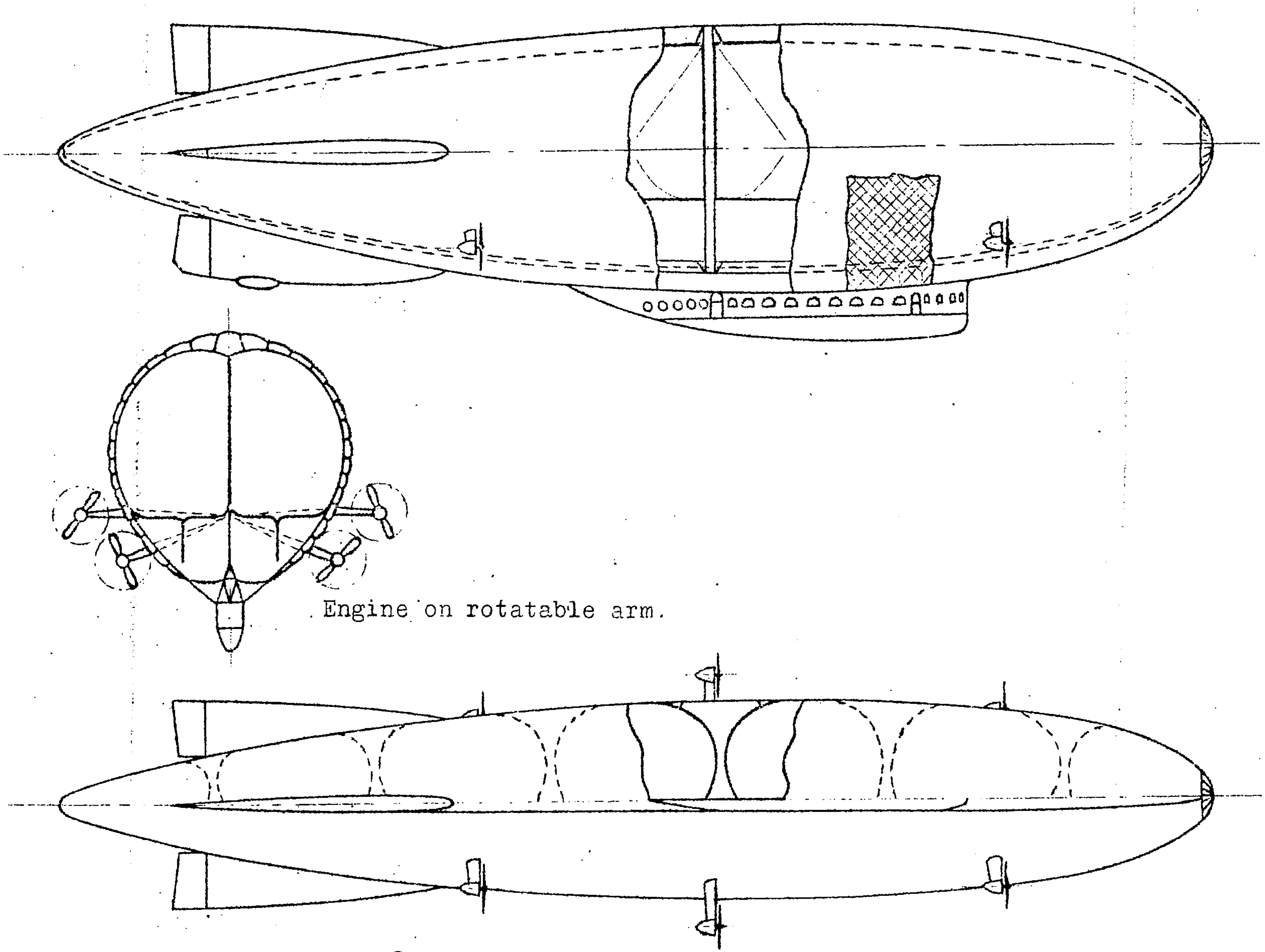


Fig.38 25000 m^3(882863 cu.ft.) commercial airship of the new type.