TECHNICAL NOTES.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 87.

HYDROSTATIC TEST OF AN AIRSHIP MODEL

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Washington, D. C.

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An airship model made by the Goodyear Rubber Company, was filled with water and suspended from a beam and the deformations of the envelope studied under the following conditions:

    (a) Both ballonets empty;
    (b) Forward ballonet filled with air;
    (c) Rear ballonet filled with air;
    (d) Both ballonets filled with air.

Photographs were taken to record the deflections under each of these conditions, and a study was made to determine the minimum head of water necessary to maintain the longitudinal axis of the envelope under these conditions. Additional photographs were taken of the model filled with air and after filling with water before any adjustment of the suspension was made. The form of the cross section when filled with water was obtained by bending a heavy piece of fuse wire to conform with the surface and then by laying the wire on paper and tracing the shape. The effect of filling with water on the length of the model was also noted.

    Apparatus used. - As may be seen, from the following photographs, the model was suspended from a framework in front of a vertical screen of cross section paper having lines one inch apart. The tension in the cords was adjusted by screwing up the nuts on

the 1/8-inch brass rods which ran through the beam, as shown in the photographs. The lower ends of these rods were bent to form hooks into which the cords were tied.

Conditions of Test.- Six cords on the end, both forward and rear were run to a single ring and fastened. In this test they were run through the ring in order to provide for adjustment of each cord. The rings were held in place by a wire, which may be seen in the photograph, and which was fastened to the Vee, at the end of the third cord from the end on each side. When filled with water an upward force was exerted near the stern at the position occupied by the rudders and fins on the airship. The weight of the fins and rudders on the full-size airship is 480 pounds. The forces acting on the model are $\frac{1}{30.18}$ times those on the full-size airship; hence this upward force was made $\frac{480}{30.18}$, or 15.9 pounds. This force was measured by supporting a stick at its middle on a knife edge and hanging a weight of 15.9 pounds on one end; while from the other end, as is shown in the photographs, the stern of the model was suspended. It will be noted that the moment exerted by this force, tending to tip the stern up, is $\frac{1}{30.18^2}$ times the moment of the rudders and fins on the full-size airship, and as the cords were adjusted to a length equal to approximately $\frac{1}{30.18}$ times that of the full-size airship, the moment of the weight of the model about the ends of the cords near the beam is $\frac{1}{30.18^2}$ times the moment in the full-size airship; hence the moment exerted by 15.9 pounds is correct in this report. It may also be shown

that the stress in the fabric caused by this moment is the same as in the full-size airship. The flat sticks under the band were simply to distribute the force of the band in a way similar to that in which the force of the fins and rudders is distributed in the full-size airship, and to prevent the band making a deep indentation in the model.

The entire apparatus was mounted on platform scales in order to determine the change in weight under the various conditions.

The pressures used were measured by manometer tubes, as shown in the photographs, and were as follows:

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Pressure of air (air filled)          19 1/2 in. water
   "     "  water (water filled)        1/4  "     "    (approx.)
   "     "  air in forward ballonet   20    "     "
   "     "  air in rear ballonet      20    "     "
   "     "  air in both ballonets
             (used together)          15    "     "
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The pressure of the air when air-filled was made 19 1/2 inches because about this pressure was necessary to straighten out the wrinkles and give the model a fairly smooth appearance. It was assumed that the same pressure would hold the ballonets in shape, and hence it was used. Due to a leak in the connections when both ballonets were filled the pressure had dropped to 15 inches when the picture was taken. This was considerably in excess of the water pressure on the outside of the ballonets, hence they must have been completely filled in all cases. One-quarter of an inch of water was used as this was the smallest amount that would indicate with certainty that the model was filled. A slight change in the air pressure, occurred constantly, due to the cooling of the

air after compression and also as a result of leaks, caused the water level to change slightly, requiring that a slight head be used to make sure that the head did not become less than zero.

Considering that the fabric in the model might take the form of that in the full-size airship, a quarter-inch head, equal to a probable increase of a 1/4" in the vertical distance from top to bottom of the envelope, was taken as zero head.

Correction for Readings on Cross-Section Paper.- The lens of the camera was kept at a constant distance of 200 inches from the screen, measured in the path of the light. As the distance from the axis of the model to either screen was 9 inches, the actual dimensions of the model may be determined for any point on it by reading the dimension on the cross-section paper and reducing it by the ratio $\frac{200-9}{200} = .955$. If a greater accuracy is desired, a correction for the inaccuracy of the paper should be made; the actual width being $19\frac{15}{16}$ inches instead of 20 inches. The correction lengthwise will be by the same ratio, of course.

DISCUSSION OF PHOTOGRAPHS.

Filled with Air.- Fig. 3 shows the model filled with air and was the first one taken. The model had stood for several days filled with water, and it presents a much smoother appearance than when first filled with air before standing filled with water. It was found necessary in order to bring the model to a horizontal position to support nearly the entire weight by the cords furthest to the right of those which appear vertical in the side view. The

other cords were drawn up as far as possible without causing any appreciable tension.

Filled with Water (not adjusted).- Fig. 4 shows the model filled with water, no adjustment of the cords having been made after taking photograph, Fig. 3. It will be noted that the stern had sagged more than the prow and there was an off-set in the axis under the rear end of the belly band. The vertical cords toward the rear were too tight, causing a narrow section to show from a top view. It is not only the cords which took the weight when air-filled, however, that were too tight as those just ahead of them appear equally stressed. The foremost of the cords passing through the rear ring caused an indentation and for this reason they were removed from the ring before the next picture was taken. The indentations around the ballonet valves were due to the fact that the cords attaching the ballonets to the envelope were too short. The wavy appearance of the sides was due to the seam and most of these waves did not extend much beyond the seam. The waves in the belly band took the form shown accidentally, and did not indicate that the cords would cause a similar form on the full-size airship.

Filled with Water (adjusted).- The following adjustments were made before taking photograph, Fig. 5. Numbering from the stern No. 3 cords were taken out of ring and adjusted, which caused the position of the ring to change; Nos. 1 and 2 were taken up about 1 inch; No. 5 was let out about 1/4 inch. The rear cords were not tightened more because of the wrinkle which began to appear just under their upper ends and because tightening them threw the cords,

which appeared in a vertical plane in the plan, more and more out of the vertical. The axis of the model was, however, straightened considerably in this way as may be noted.

Forward Ballonet Filled with Air.- The principal effect of filling the forward ballonet with air, as shown in photograph, Fig. 6, was to tip the forward end up and to broaden it, the broadening being chiefly due to the increased tension in the cords holding the ballonet. The model at the same time moved forward as is shown by the increased inclination of the cords. Due to some peculiarity in the lighting, the liquid in the tube did not register clearly, but the pressure was about 20 inches of water. The tension in the rear vertical cords was increased, as is shown by the tendency to wrinkle on the sides under them.

Rear Ballonet Filled with Air.- Filling the rear ballonet with air, as shown in photograph, Fig. 7, had the same effect as that in photograph, Fig. 6, except that it was at the other end while the dent under the beam toward the rear end which disappeared in photograph, Fig. 6, reappeared here. The cords in the middle section swung to a vertical plane, those farthest forward taking the greater tension.

Both Ballonets Filled with Air.- In this condition, shown in photograph, Fig. 8, the axis was in nearly the same position as with both ballonets empty, except that the stern was higher by about 1 1/2 inches. The cross-section at each end when the ballonet at that end was filled was of this form.

It was noted from a plan view that the filling of either of the ballonets with air distorted the stream line form considerably.

Force Exerted by Ballonets is of Proper Magnitude.- That the buoyancy of the air in the ballonets is of the proper magnitude, i.e., $\frac{1}{30.18}$ times the negative buoyancy of the ballonets in the full-size airship, is evident from the following reasoning. A ballonet from the full-size airship immersed in water would have 909 times the buoyancy in the opposite direction, but the ballonet in the model has $\frac{1}{909 \times 30.18}$ times the volume of the full-size airship ballonet; hence the force which it exerts is

$$909 \times \frac{1}{909 \times 30.18} = \frac{1}{30.18}$$

times the force exerted by the full-size airship ballonet; hence the ratio is the same as for the other forces.

Relation of Stresses in Model to Those in Full-size Airship.- The reason for making the model $\frac{1}{30.18}$ scale was that under this condition the stress in the fabric when filled with water is equal to that in the full-size airship when filled with hydrogen. A proof of this is given in the note following the data. The weights of the hulls, however, act in opposite directions in the two cases. In the full-size airship it causes no tension on the cords and increases the tension in the fabric on the top. In the model the weight is taken by cords and the stress in the fabric just outside of the belly band is increased. This difference may be eliminated by placing a rubber tube filled with air inside the model. It was impossible to place this tube inside this model, however, without

making an aperture in the envelope, which was not thought desirable nor necessary as the weight of the hull was very small compared with the weight of the water, whereas in the full-size airship it is much greater compared with the buoyancy.

Action when Partly Filled.- In order to obtain additional data to aid in deciding as to the pressure to be recommended, additional tests were made as follows. Water was drawn from the water-filled model with ballonets empty until the tail collapsed, due to the rudder and fin weight. This occurred when the level of the water was about two inches below the inside edge of the belly band. To bring it to this level about 1/3 of the total weight of the water was drawn off. On the following day this part of the experiment was repeated at which time the level was brought 3 1/2 inches below the inside edge of the belly band before a collapse occurred. This difference in results is explained by the fact that when the model is only partly filled it is in an unstable condition. If for any reason the water starts to run toward one end, that end becoming heavy sinks while the other rises, and the water rushes to the lower end. The first day that this part of the experiment was made, when a level of two inches below the inner edge of the belly band was reached, the water began to run forward and a collapse occurred. The second day it started to run in the opposite direction, a crease developing under the rear filling valve which became 1 1/2 inches deep before the water began to run the other way and a collapse occurred.

Action of Rudder and Elevator Forces.- It was calculated that
at 45 miles per hour and with the rudder at 30°, the force on the
rudders for a model of this size would be about 3/4 of a pound,
and the force on the elevators would be approximately the same for
this condition. However, as the other forces are 30.18 times
those, correct to scale, for a model of this size, the rudder and
elevator forces must be increased in the same ratio; hence a weight
of 22 1/2 pounds was used to represent the total pressure on the
rudders, and the same weight was used to represent the total pres-
sure on the elevators. The effect of hanging this weight on when
with a head of 1/4-inch (ballonets empty) was to deflect the stern
about 8 1/2 inches. When exerted sidewise the deflection was about
one foot. Under a head of 10 inches the deflection was about 3 1/2
inches down and five inches sidewise.

Action with Rudder and Fin Weights Removed.- A head of 10
inches was then put on the model, and the rudder and fin weights
removed. The axis was not bent noticeably due to this removal, al-
though the inclination was of course changed. The head was then
decreased and the axis gradually bent until at one-inch head it
had bent so that the stern was about five inches lower than with
the 10-inch head, and it was also bent to the left about six inches
and there was a fold in the fabric on the left side and bottom about
1 1/4 inches deep under the rear filling valve.

Change in Volume with Pressure.- Under the 10-inch head the
weight was 483 pounds, an increase of about 4 per cent in net
weight over that for 1/4-inch head. However, there would be a much

greater percentage increase in buoyancy in the full-size airship due to this increase in head.

Cross sections of the water-filled model with 1/4-inch head are shown on Fig. 1. As previously stated these were obtained by bending a heavy fuse wire around the model. The tracing thus obtained was then reduced by the pantograph to the size shown in the figure. As noted above, the form when the ballonets were filled was with a valley on the under side. As this was due chiefly to the ballonet cords being short and would not occur to the same degree in the full-size airship, no reproduction of the cross section, when the ballonets were filled, was made.

Conclusion.- From the above it appears that any pressure sufficient to keep the airship full may be used. No data was obtained which could be used to determine to what extent the wind would affect the deformation. But it appears that a pressure of one inch of water would provide a suitable factor of safety, and therefore this is the pressure recommended. Due to the negative buoyancy of the ballonets, a pressure of about 0.4 of an inch of water in excess of the pressure used on the hydrogen is necessary to equalize the pressure inside and out at the top of the ballonet. This difference between air and hydrogen pressures should be increased to probably at least 3/4 of an inch to compensate for the weight of the ballonet and for the tension on the cords.

D A T A.

	Condition	Dimension in inches
DIMENSIONS OF MODEL		
Length	air filled	61.4
	water filled, not adjusted	61.1
	water filled, adjusted	61.0
	from specifications $\dfrac{1}{30.18} \times 160 \times 12$	63.6
Maximum diameter	air filled, actual,	13.4
	from specifications $\dfrac{1}{30.18} \times 31.5 \times 12$	12.5

Data continued.

WEIGHTS OF MODEL
(Including Apparatus)

How filled	Pressure in Model	Pressure in Ballonets	Weight in pounds
Air	19 1/2 in.	none	311
Water	1/4 "	"	476
"	1/4 "	Forward, 20 in.	461
"	1/4 "	Rear, 20 in.	455
"	1/4 "	Both 15 in.	439
"	10-in. head	none	433
"	-----	"	433*
"	-----	"	403**

*At point of collapse, first trial; level of water 2 inches below inside edge of belly band.

**At point of collapse, second trial; level of water 3 1/2 inches below inside edge of belly band.

Weight of water which model should hold, calculated from displacement given in specifications (77,000 cu.ft.) = $\dfrac{77,000 \times 62.4}{30.18^3}$ = 175 pounds.

Weight of water actually held by model at 10-inch head = 483 lbs. - 311 lbs. = 172 lbs.

Short Proof that Stress in Fabric in Model Equals that in Full-size Airship.- This proof is based on the fact that in a model made exactly to scale throughout, the stress per unit area, in any number, is the same as in a full-sized airship, if the pressure per unit area of the liquid remains unchanged at all points. This is the case, however, that if the head of the water is rightly chosen, both pressures are the same function of the height. This necessi-

tates in addition that the liquid used in the model have a greater buoyancy (positive or negative) than that used in the full-size airship, and if the thickness of the fabric in the model be reduced by the ratio $\frac{1}{n}$, which is the scale of the model, the buoyancy of the liquid used must be $\underline{n}$ times that of the hydrogen, but if it be not reduced, the cross sectional area of the fabric in any plane is $\underline{n}$ times as great as it should be to cause the desired stress with a fluid having a buoyancy $\underline{n}$ times that of hydrogen. Hence, in order to cause the stress in the fabric of the model to equal that in the full-size airship, it is necessary to make the buoyancy of the liquid $\underline{n}$ times as great as it would be if the thickness of the fabric were to scale. The ratio of the buoyancy of the liquid to be used, to the buoyancy of hydrogen, is therefore $\underline{n}^2$. The ratio of the buoyancies of water and hydrogen is 909. The scale to be used is then $\frac{1}{909} = \frac{1}{30.18}$. The negative sign is not introduced in connection with the buoyancy of water in air since the model was placed upside down, thus reversing the buoyancy.

APPENDIX

STRENGTH OF CROW'S FOOT.

A test was made to determine the strength of a crow's foot such as is used to fasten the ropes on airships and furnished by the Goodyear Rubber Company. The arrangement of the apparatus was as shown on Fig. 2. The small ropes of the crow's foot were fastened to the floor by means of a rope, and the fabric pulled upward by means of a chain hoist. Suspension scales between the crow's foot and the hoist were used to determine the force exerted. The apparatus was tried without the wood framework about the iron pipe at first, and it was noticed that the middle fingers were taking by far the greater part of the load due to bending of the pipe. In order that all four fingers might be stressed to more nearly the same degree the wood frame was made so that it supported the pipe at all points, and with a piece about 1 3/4 inches by 2 1/2 inches across the back, as shown in the rear view to prevent the ends being bent toward each other. However, even with this arrangement, it was noted that the two middle fingers were under greater stress than the others.

Failure occurred at 1125 pounds which gives, when the weight of the frame is subtracted, practically 1100 pounds. The fibers of the rope held securely, and it was only the fabric at the ends of these fibers which gave way.

Tests to determine the strength of small crow's feet (about 3 inches x 3 1/2 inches) were also made. These were cemented to the

fabric of the large crow's foot, and weights applied until failure occurred.   Seven tests were made and failure occurred at the following loads:

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No. of Test      1   2   3   4   5   6   7
Load (in lbs.)  190, 190, 185, 185, 200, 180, 180
Average Load = 187 pounds.
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The time taken on each test, except No. 7, was about 10 minutes. In No. 7, a load of 160 pounds was put on and left for about 20 minutes, in order to ascertain roughly if time was an important factor.   In this test practically all the strands of the cords pulled out, whereas in all of the other tests, except No.6, only part of them pulled out while the others broke, the number which broke varying from 1 to 3.
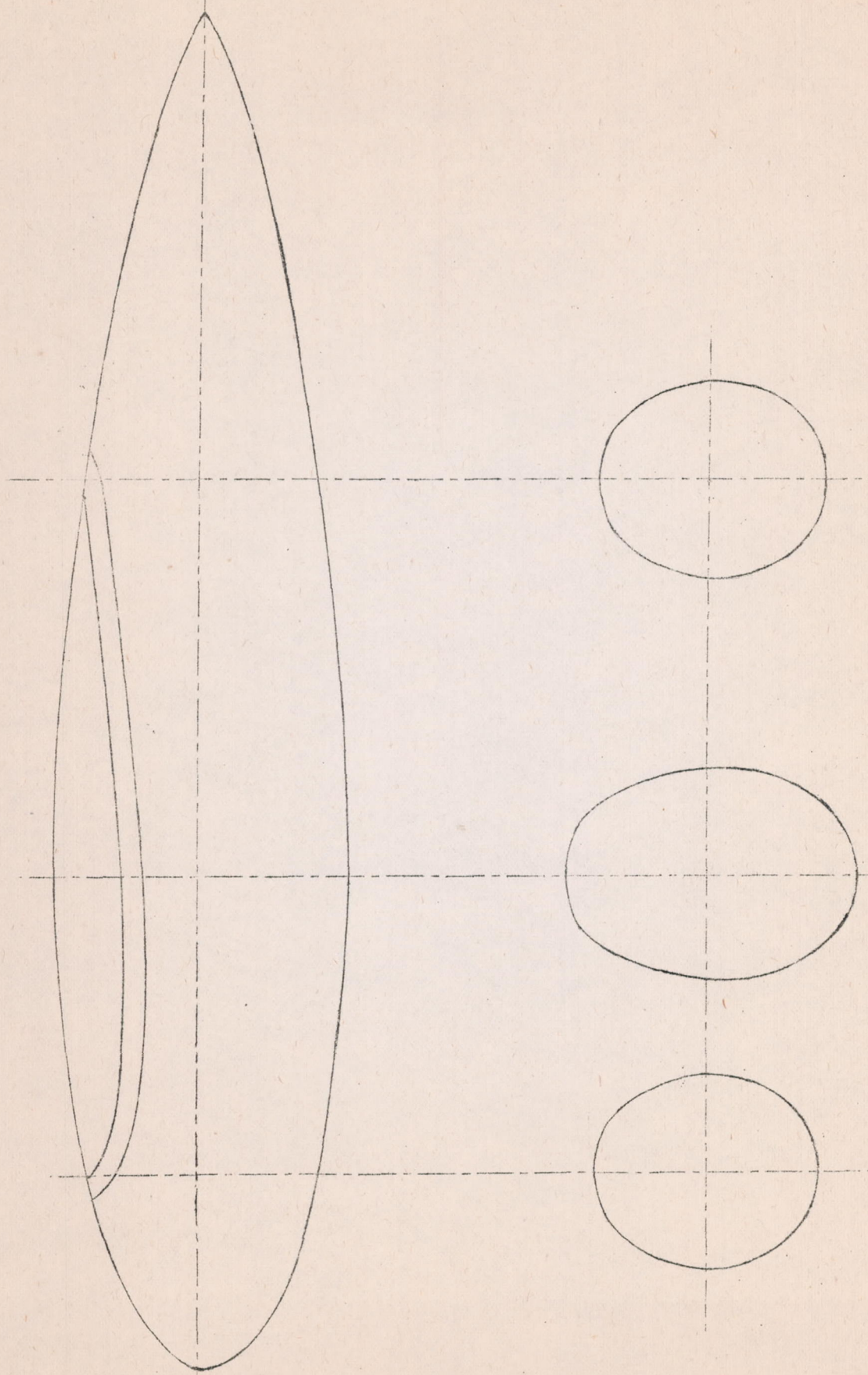
Fig. 1. Outlines of airship model filled with water.

Rear view

Sect.
A.A.

Sect.
B.B.

Fabric
cemented
to iron
pipe

A

B

Layer of fabric with rub-
ber on both sides. The
rope fibers were between
this and the wider piece
on top.

Rope fibers

Point of failure

Fabric spliced along
this line. Fabric on
other side at 45° to
this.

1/4" dia. rope
Fastened to
floor

Scale approx. 3/4" = 1'.
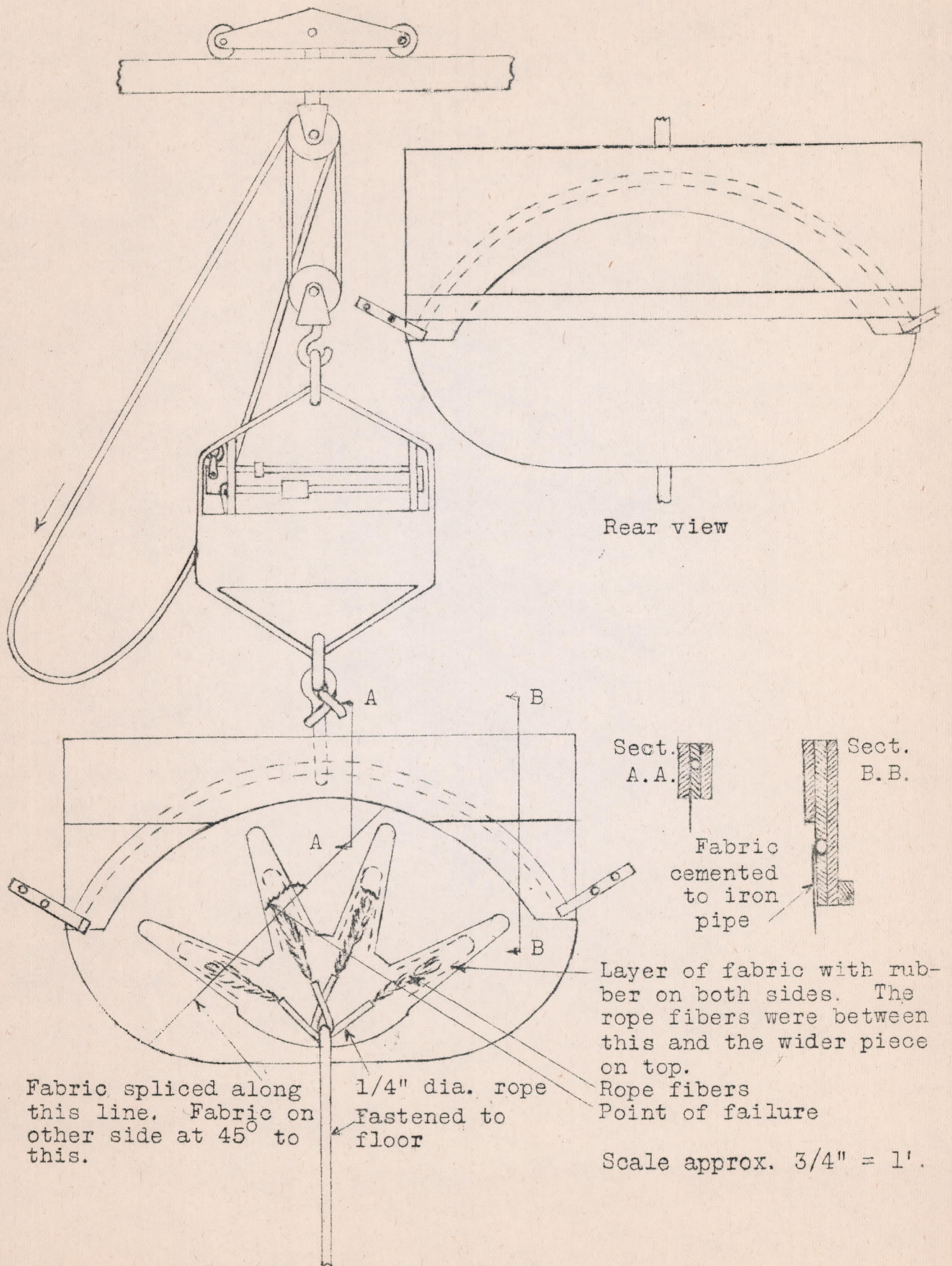
Fig. 2. Arrangement for test of crow's foot.
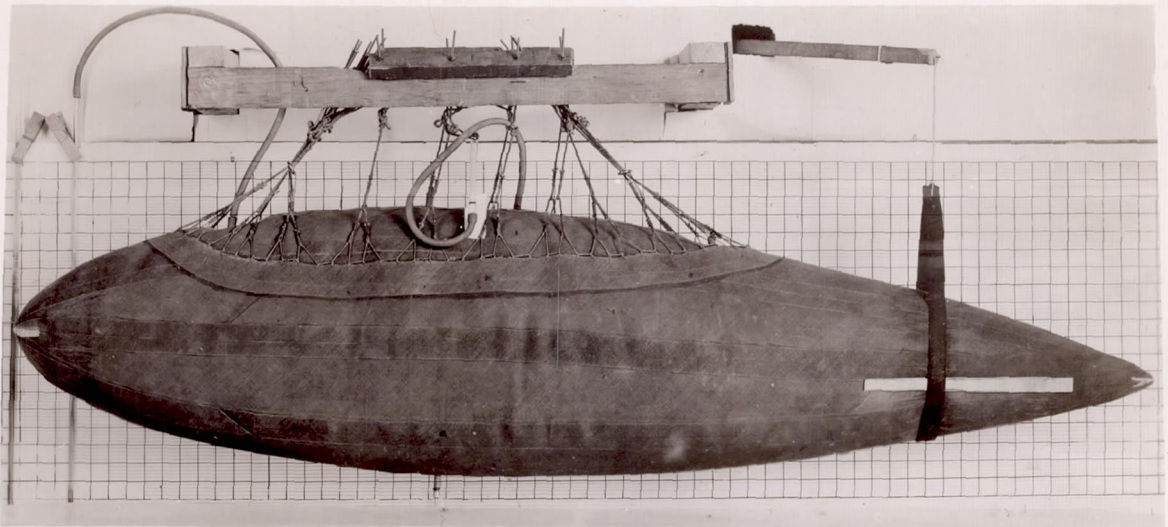
Fig. 6. Fore ballonet filled with air.
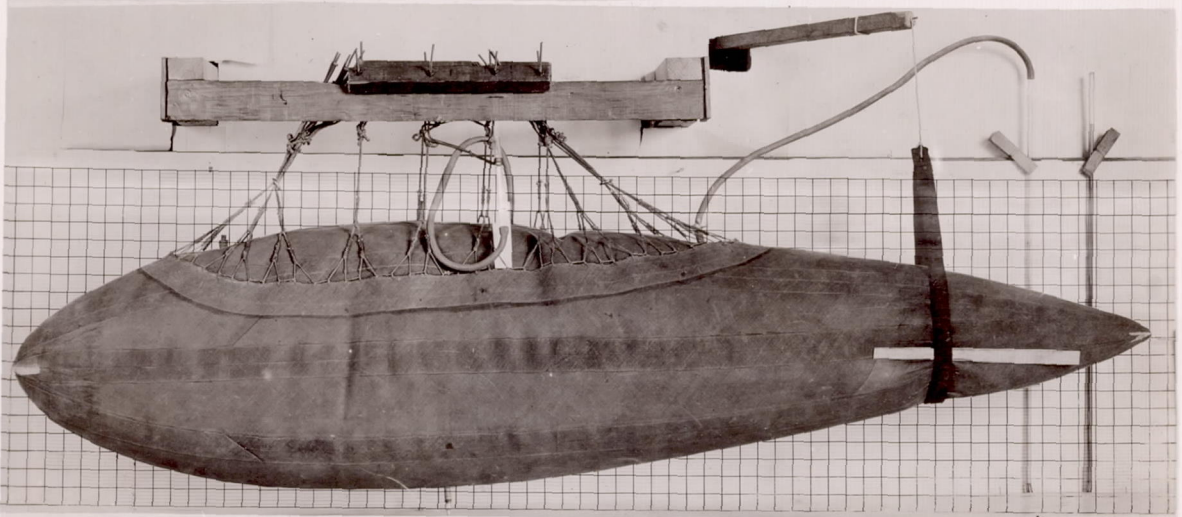
Fig. 7. Aft ballonet filled with air.
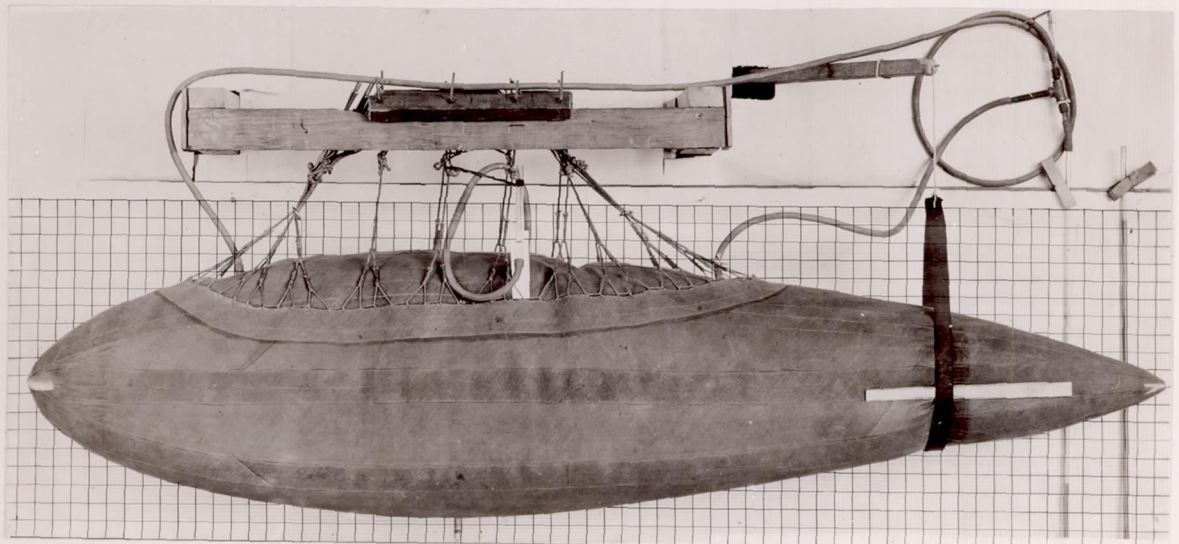
Fig. 8. Both ballonets filled with air.

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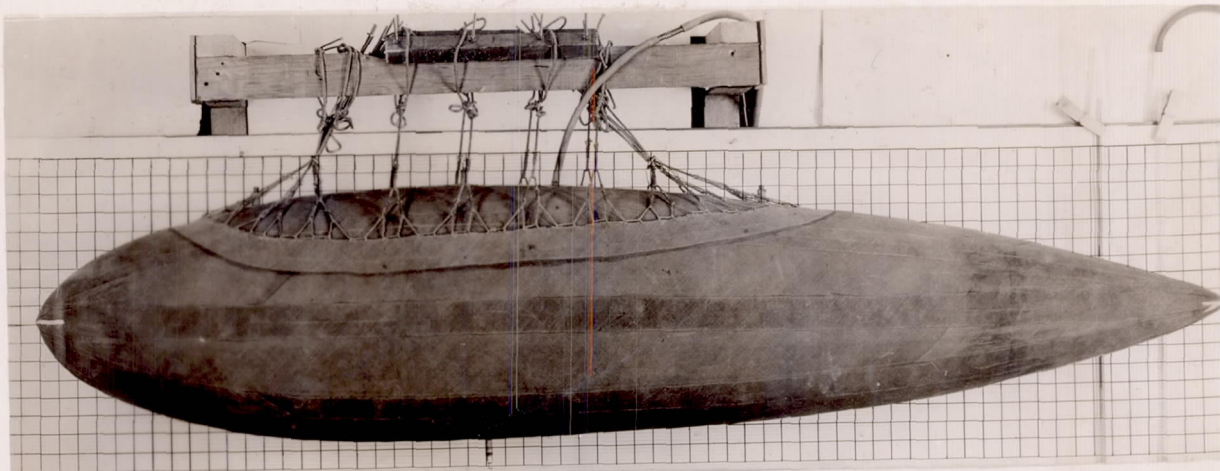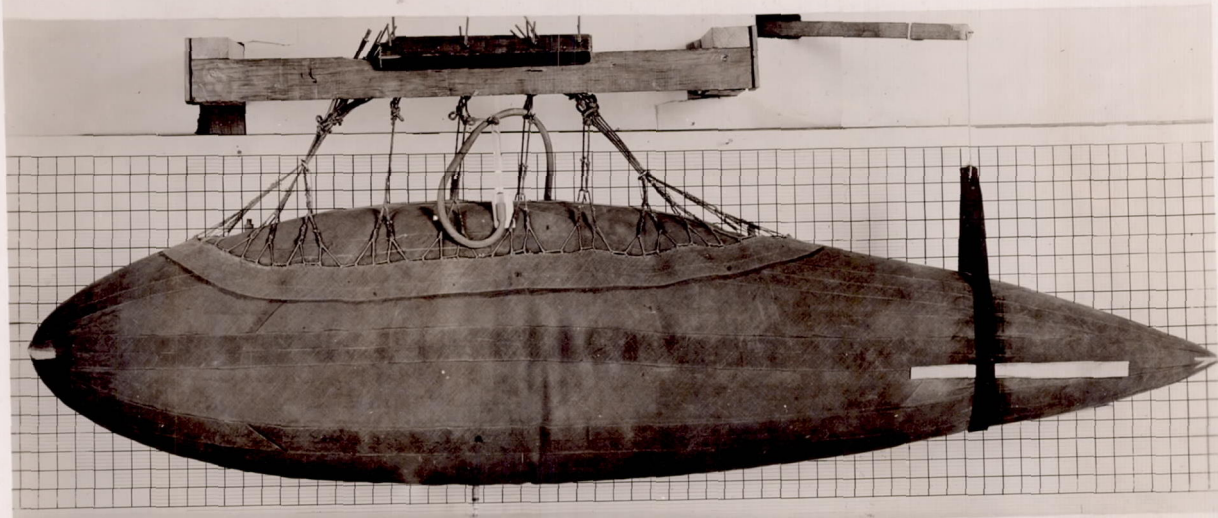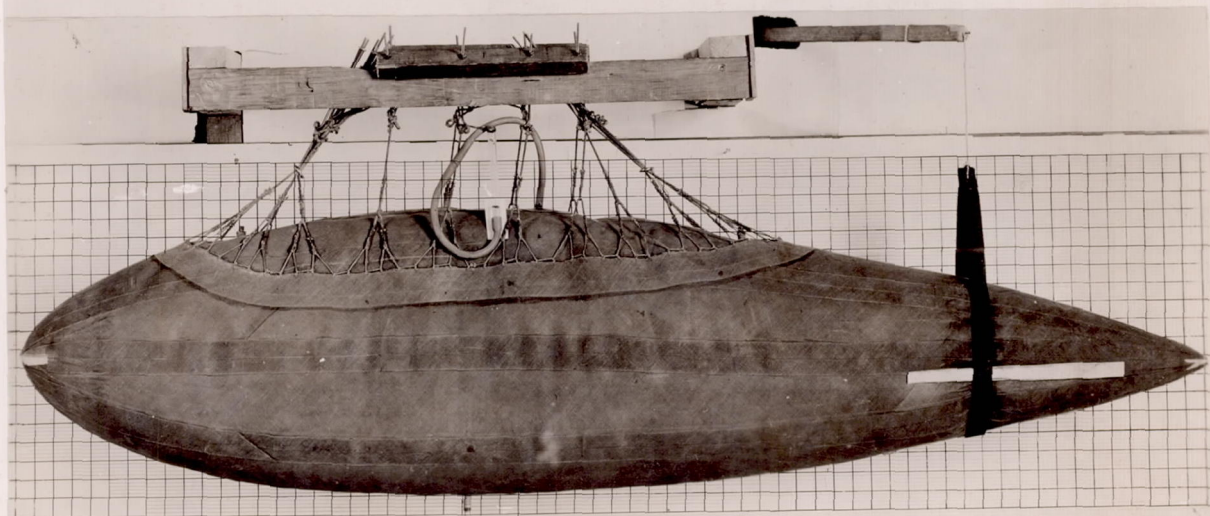
Fig. 3.   Filled with air.

Fig. 4.   Filled with water (not adjusted).

Fig. 5.   Filled with water (adjusted).

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