TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 274

STRUCTURAL AND ECONOMIC LIMITS TO THE DIMENSIONS OF AIRSHIPS

By G. A. Crocco.

From "Note di Tecnica Aeronavale," 1923.

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For airships as well as sea-ships it is advantageous to increase the dimensions, since the power required to obtain a certain speed increases less rapidly than the buoyancy. For both airships and sea-ships the power varies approximately as the square of the dimensions, while the buoyancy varies as the cube. Hence the unitary power (i.e. the ratio of the total power to the buoyancy) varies inversely as the dimensions. The weight of the machinery, therefore, with respect to the total lifting force follows the same law.

In opposition to this advantage of larger dimensions, there is one disadvantage, namely, the weight of the structure increases more rapidly than the buoyancy. It is not possible, however, to determine a general law. In order to formulate one having the merit of simplicity, we will divide the structure into two parts: one subject to tensile and compressive stresses, varying directly as the ascensional or lifting forces; the other subject to varying stresses of the surface areas, not accurately determinable.

The weight of the first part varies as the products of the volumes by the lengths, while that of the second part varies as

* From "Note di Tecnica Aeronavale," 1923.

the products of the surface areas by the distances, i.e. as the cubes of the dimensions.

Thus, by taking the ratio between these weights and the total lifting force, we obtain a term increasing directly as the dimensions and also a constant term. Consequently, the percentage (or fraction) of the buoyant force absorbed by the dead load of the airship, can be expressed by the following formula, which employs the diameter D of the largest cross-section.

Percentage dead load $= k + \frac{D}{s} + \frac{m}{D}$. The first two terms concern what we call "structure," for short, and the third term what we call "machinery" (engine).

The above considerations indicate the existence of "minima" which we will now take up. First of all, there is a minimum dead load for the dimensions giving the expression

$$D_1 = \sqrt{s\ m}$$

The airship, "unitarily" the lightest, corresponds to this minimum and hence is the one which can raise the greatest full load or rise to the highest altitude. It is also the best airship for short trips, for which the weight of the fuel is but a negligible fraction of the full load.

If, however, the weight of the fuel is large, i.e. if the airship is designed for long voyages, a second minimum must be found, which takes account of the weight of fuel required for a given trip, or for a voyage of a given duration. Since this weight is proportional to the power of the engine and to the duration of the voyage T, it will have the form cT/D. The useful residual load will, however, be given by the formula:

$$\text{Useful load} = 1 - k - \frac{D}{s} - \frac{m + c\,T}{D}$$

in which the maximum diameter is

$$D_2 = \sqrt{s(m + c\,T)}$$

If, in the above expression, the useful load is called zero, the maximum duration of the voyage will be

$$T = \frac{1}{c}\left((1 - k)\,D - \frac{D^2}{s} - m\right)$$

which is best for

$$D_3 = \frac{1}{2}\,(1 - k)\,s,$$

diameter limit corresponding to the maximum obtainable cruising radius. This limit coincides with that of the best economic efficiency, i.e. with that obtained by finding the maximum value of the ratio between the useful load and the weight of the fuel. This ratio takes the form

$$\text{Efficiency} = \frac{(1 - k)\,D - \frac{D^2}{s} - m - c\,T}{c\,T}$$

and attains its exact maximum for

$$D_4 = D_3 = \frac{1}{2}\,(1 - k)s.$$

For exemplifying the above expressions, we have taken the numerical values obtained by ourselves from one of the most recent semirigid airships. We give the diameter D in meters and assume a cruising speed of 100 km (62 miles) per hour:

$k = 0.125$; $s = 325$; $m = 2.77$; $c = 0.0861$. From these we obtain the following limits:

(for the dead weight) $D = 30$

(for the useful load) $D_2 = 48$ for $T = 50$ hours

$D_2 = 61$ " $T = 100$ "

$D_2 = 71$ " $T = 150$ "

$D_2 = 86$ " $T = 200$ "

(for duration of flight) $D_3 = 128$

(for efficiency) $D_4 = 128$

These limits correspond to the volumes obtained and indicate considerable room for improvement in the technics of airships. It only needs to be observed that the gain in useful load, range, and efficiency continually becomes less rapid as the dimensions increase, so that, from a practical viewpoint, it is not best to go too far. We have, therefore, added a diagram of the dead loads, useful loads and efficiencies. It has been plotted for 200 hours of functioning, with reference to the total lifting force, expressed in metric tons. The utility of increasing the dimensions is evident, up to units of about 1000 tons, corresponding to a diameter of 60 meters (197 feet).

Translation by Dwight M. Miner,
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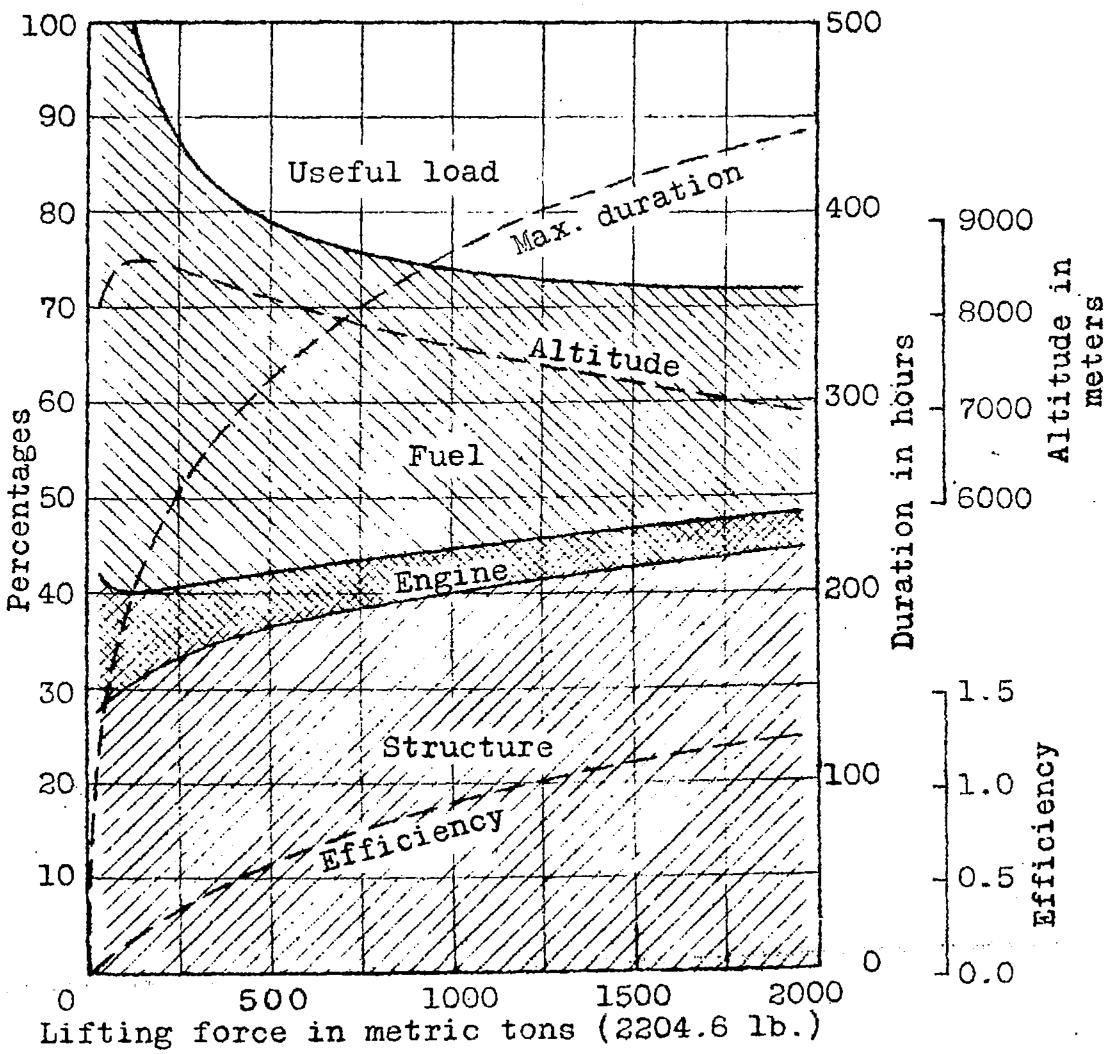
Useful load
Max. duration
Altitude
Fuel
Engine
Structure
Efficiency
Percentages
100
90
80
70
60
50
40
30
20
10
0
500
1000
1500
2000
Lifting force in metric tons (2204.6 lb.)
Duration in hours
500
400
300
200
100
0
Altitude in meters
9000
8000
7000
6000
Efficiency
1.5
1.0
0.5
0.0