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TECHNICAL NOTES.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

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THE EMPLOYMENT OF AIRSHIPS FOR THE TRANSPORT OF PASSENGERS.

Indications on the Maximum Limits of Their Useful Load, Distance Covered, Altitude and Speed.

By

Umberto Nobile,
Director of Italian Aeronautical Construction.

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1. As an indispensable premise to this study it should be stated frankly that it is rather risky to judge of the approximate weight of an airship of large cubic capacity, ** say, 300,000 cubic meters, by taking as a basis the anticipated weight of a similar airship of small cubic capacity, say, 30,000 cubic meters.

Even were it possible, by applying the principles of mechanical similitude, to establish exact laws of variation for the weights of the various constituent parts of the airship, the previsions would still be far from the reality, especially for very large airships. It may, in fact, happen that with increase of dimensions we find ourselves, at a certain point under the necessity of radically modifying this or that part of the airship, or we shall have to adopt materials having characteristics different from those used in the model, or insurmountable and unforeseen difficulties in workmanship and assembling may constrain us to abandon that type of airship or completely change the cubic capacity.

It is, however, undeniably useful to try to establish, even by a very rough approximation, the laws governing the weight of similar airships which may give a sufficiently clear idea of the greater or lesser advantages to be obtained by a given cubic capacity. But when, having established these laws, we find, as in fact, we do find, that the unit weight first decreases to a minimum value in relation to the cubic capacity X and then increases until, in the cubic capacity Y (limit cubic capacity)

* From the "Giornale dei Genio Civile," Anno LIX, 1921.
** For the sake of simplicity and clearness we shall use no unusual or out of the way terms, but only such as are in current use, as cubic capacity, empennage, ballonet, etc.

the weight absorbs the whole of the lifting force, we must consider the values of X and Y as being acceptable only as indications of THEIR ORDER OF MAGNITUDE, since it may well happen that, for instance, for one of the reasons above indicated, the limit Y may be reached more rapidly, or even exceeded.

2. In applying, whenever possible, the laws of similitude to airship structures, we will keep in mind:

a) That the principal static efforts produced, either by weight or by the pressure of the gas, may, with sufficient approximation, be considered as proportional to the cubic capacity V. Consequently, the stresses in the various parts are proportional to V, and therefore the weight is proportional to $V^{4/3}$.

b) That the main dynamical efforts due to air pressure, are proportional to $V^{2/3}$ and consequently the weight of the various structures varies proportionally to V.

3. We will limit our investigations to the semi-rigid Italian T type, but it is obvious that, by generalization, the law of variation that we shall establish is applicable to any other type of airship and, in particular, to the rigid Zeppelin type, with some slight modifications in the numerical coefficients introduced in the general formula expressing the weight of the airship in function of the volume and maximum velocity.

By the maximum velocity of the airship we mean that velocity which it can safely develop at a low altitude, say, at 300 m. above sea level. This velocity, expressed in km/h., we indicate by w.

In speaking of the weight of the airship we will consider the following parts:

The external envelope and accessory organs;
The stiffening part of the bow of the envelope;
The stabilizing and control planes (keel and rudders);
The frame structure and accessories;
The maneuvering devices (landing, mooring, etc.);
Electric light plant, wireless plant, fans, etc.;
The pilot's cabin;
The passenger cabin;
Reservoirs for benzine, oil, and water.

Besides this, in order to complete the evaluation of the weights which, unlike those of the fuel and the useful load, remain constant, and cannot be dispensed with, we will also consider the following weights:

The crew;
Engine spare parts and various necessary tools;
The reserve ballast and the ballast corresponding to the first 300 meters.
The reserve stock of benzine and oil.

4. - THE ENVELOPE - The envelope comprises:

The external envelope of the gas bag;
The separating diaphragm between the gas and the air, commonly called the internal ballonet;
The ballonet on the beam;
The transversal diaphragms;
The connection between the frame with the keels and rudders;
The gas and air valves with their corresponding controls.

In the rubber-covered and varnished envelope employed in the various parts of airships, we must always distinguish the weight of the canvas part from the weight of the rubber and varnish applied to it. The function of the rubber is essentially to render the bag gas-proof and, consequently, in theory, by fixing the tolerance limit of the daily penetration of air in a cubic meter of hydrogen, the weight of rubber for every square meter of the gas bag surface may decrease with the increase of cubic capacity. In practice, however, for various considerations we may assume the unit weight to be about constant, and therefore the total weight of the rubber may be taken as proportional to $V^{2/3}$. The same proportion holds for the weight of the varnish.

EXTERNAL ENVELOPE. - The weight of the external part of the gas bag minus the weight of the rubber obtained as specified above, may be taken as proportional to $V^{4/3}$. In fact, while from one side the surface increases as $V^{2/3}$, on the other hand, the tension (and consequently, for the same specific resistance, the thickness also) increases in proportion to the pressure and to the radius of curvature, that is, in proportion to $V^{1/3} \times V^{1/3}$.

DIAPHRAGM SEPARATING THE GAS FROM THE AIR. - This gas tight diaphragm, interposed between the hydrogen and the air, must never come under tension. It must serve only as a means of holding the rubber and therefore its total weight may be taken as proportional to $V^{2/3}$.

TRANSVERSAL DIAPHRAGMS. - These must be capable of withstanding a given difference of pressure between two adjacent gas compartments. It is, however, rational to consider such difference as being proportional to the mean pressure of the gas and, therefore, proportional to $V^{1/3}$. Consequently, we may assume that the total weight of the diaphragms varies in proportion to $V^{4/3}$.

Implicitly we have also assumed that the number of diaphragms is always the same.

CONNECTING LINKS. - The tensions in the links connecting the external gas envelope and the longitudinal beam (catenaries) are proportional to V. The weight of such elements is therefore proportional to $V^{4/3}$.

Regarding the elements or links connecting the envelope with the keels and rudders, it should be remarked that, as we shall see later on, the total forces acting on them are proportional to $V^{2/3}$. Also, the stresses to which are subjected these connecting links (except the stresses produced by inertia) fall under the same relation of proportionality, and therefore the weight of these connecting links will vary in proportion to V, considering that their length increases in proportion to $V^{1/3}$.

GAS VALVES. - For simplicity's sake we will assume that the dimensions of these valves remain always the same

In this case, increasing the pressure of the gas in the proportion of $V^{1/3}$, the holding power of each valve increases in the ratio of $V^{1/6}$. It follows that the number of valves, and consequently, their total weight, varies in proportion to $\frac{V}{V^{1/6}} = V^{5/6}$.

In order to avoid introducing this new exponent, considering also the relative smallness of this weight, we will assume that the weight of the gas valves is proportional to $V^{2/3}$. On the other hand, this difference in the law of variation may be realized by suitably increasing the dimensions of the lifting part of the valve only, up to the limit allowed by the strength of the other parts.

CONTROL CABLES. - According to the hypotheses given above, the weight of the cables controlling the valves is numerically proportional to $V^{2/3}$, while their length is proportional to $V^{1/3}$. We may therefore take their total weight as proportional to V.

It should be remarked here that, in practice, constructors will probably avoid having an excessive number of valves and valve controls which would entail a more rapid variation of weight, unless the structure of the valve could be altered for the purpose of making it less heavy.

AIR VALVES. - In this case, considering the less favorable conditions of functioning, we must assume the pressure to be constant. We may therefore assume the number of valves, and consequently their total weight to be proportional to V.

Consequently, the weight of the control cables increases in proportion to $V \times V^{1/3} = V^{4/3}$.

TOTAL WEIGHT OF ENVELOPE. - We have now analyzed the weights of the various parts of the en velope of our model airship, and thereby obtain the following expression for computing the total weight of the envelope:

$$2.410\ V^{2/3} + 0.008\ V + 0.00374\ V^{4/3}.$$

5. - STIFFENING OF THE BOW.

The unit pressure exerted by the air on the surface of the stiffened part of the bow is proportional to the square of the velocity. Since, however, the linear dimensions are proportional to $V^{1/3}$, the bending moments, and consequently also the resulting stresses, are proportional to $V^{1/3}v^2$. On the other hand, the total surface varies in proportion to $V^{2/3}$. It therefore follows that the total weight is proportional to $V\,v^2$.

In order to be exact, we should also consider the secondary stresses due to the weight itself, stresses which, of course, increase more rapidly than the preceding ones. These, however, are negligible especially in the upper part which rests on the envelope.

In the case of our model, the total weight of the stiffened bow (including its covering) is given by:

$$10^{-6} \cdot 1.3\ V\,v^2$$

where, as always, V is expressed in cubic meters, and v in km/h.

6. - STABILIZING AND CONTROL PLANES.

It is extremely difficult to establish a law governing the variation of the weight of the stabilizing and controlling organs, and would first of all require a close examination of the various points connected with these functions, an examination which we cannot enter into here.

We will therefore make only a rough approximation by the aid of simplifying hypotheses. For instance, we shall not distinguish between the fixed and mobile planes, assuming that, according to the requirements of steering, a greater or smaller part of the total surface area may be rendered mobile without greatly affecting the mean unit weight.

VERTICAL PLANES. - Considering only the stabilizing function, it is evident that the total area of these planes must be proportional to the surface area of the envelope, if the righting moment due to the action of the air on the former is to be proportional to the upsetting moment caused by the action of the air on the latter.

On the other hand, the unit pressure may be assumed to be constant, and it then follows that the total weight of these planes varies in proportiom to V.

If we now consider the variation of speed, it is evident that, for increased speed these planes should be suitably strengthened, though it is difficult to establish a priori in what measure this should be done. But on the other hand, with increased velocity the deviations due to the disturbing cause diminish, and therefore if we wish to keep the stability constant we may reduce as required the area of the planes. So that, for the sake of simplicity and as a rough approximation we may say that the total weight of these planes is independent of v.

HORIZONTAL PLANES. - For these planes we might employ the same general considerations as for the vertical planes, were it not that the case is rendered more complex by the static righting moments which increase in proportion to $V^{4/3}$. However, considering only the stabilizing function, the total area of the planes in question may increase less rapidly than $V^{2/3}$, and therefore the total weight may vary less rapidly than V.

When, instead, we comsider the regime of movement along inclined trajectories, we easily come to the conclusion that if we wish, for instance, to maintaim the maximum climbing speed unchanged (that is equal to horizontal velocity, the maximum tangent of the angle of climb), it is necessary to increase the angle of attack, thus bringing about an increase in the unit pressure and therefore in the unit weight.

It is also useful to consider that by increasing V the mobile part of the horizontal planes must increase more rapidly than the fixed part. This may lead to notable modifications in the design which, in turn, will produce new uncertainties in the evaluation of the weight itself.

From the various considerations so far made, we may conclude that, as a rough approximation, the weight of the horizontal planes varies in proportion to V.

For our model we find that the total weight of the empennages may be expressed by 0.043 V.

RUDDER CONTROLS. - The forces acting on the rudder control cables may be taken as proportional to $V^{2/3}$ and likewise their sections. Their weight is therefore proportional to V.

In our case, comprising also the control devices in the pilot's cabin, we have, for the total weight, 0.004 V.

7. LONGITUDINAL BEAM.

The complexity of the forces acting on the framework (longitudinal beam) makes it extremely difficult to establish a formula giving the variation in weight with sufficient approximation. We will again refer to the exceptions made at the beginning of this paper and here also, for the considerable item of the weight of the airship, we must be satisfied with a rough approximation.

The longitudinal beam is simultaneously acted upon:

a) By the static forces due to the loads it has to sustain, namely, the keels, rudders, power plant, fuel, and useful load.

The total weight of all these loads is represented by the difference between the total lifting force f V and the sum of the weights of the envelope, the larger part of the keels, and part of the stiffened framework. This weight can, therefore, only be expressed by a rather complex function of the volume.

However, on analyzing the above mentioned expression, we find that this total weight may be taken, with an approximation of 5%, asproportional to V.

On the other hand, for obvious reasons it would be difficult to vary the volume without altering the distribution of load in the model. Since it is evidently impossible to provide beforehand for such variations and even more impossible to account for them, we must inevitably accept the simplifying hypothesis that the distribution of load remains the same.

Admitting this hypothesis, we are justified in saying that the forces due to static loads are proportional to V and consequently, that the weight of the longitudinal beam increases in proportion to $V^{2/3}$.

b) By the dynamic forces brought about by the action of the empennages. These forces, according to the considerations made above, must be taken as proportional to $V^{2/3}$ and therefore the increase of weight in the armature due to them is proportional to V.

c) The dynamic forces due to the thrust of the propellers, or, which is the same thing, the reaction exercised by the air on the various parts of the airship when its axis is parallel to the line of flight. This reaction is proportional to

$V^{2/3}$ v^2 and consequently the resulting efforts in the armature vary according to the same law of variation.

We must however distinguish between v constant and v variable when evaluating the increase in weight due to these forces.

In the first case, combining the dynamic forces in question with the maximum least favorable forces enumerated in (a) and (b) (calculating these by means of various hypotheses on the distribution and value of the useful load and of the load of fuel, oil, and ballast) the result is that the increase in weight in the armature due to such forces, remains always proportional to V.

Things are much more complicated when the velocity is taken as being variable, because in that case, for a sufficiently high value of that velocity it may happen that, at a given moment, the reacting force of the thrust of the propellers in a given element of the armature will prevail over the forces a + b, thus giving rise to an increase in the weight of that element, which does not happen in the model due to the fact that the sign of the maximum resulting effort is reversed. It is easily understood that, under these conditions, it is not possible to find the means of accounting for such an eventuality.

However, considering that the dynamic forces of this category are small when compared with those of the two preceding categories, and considering also that the velocity limits attainable are relatively low, we shall be able to say, with a degree of approximation sufficient for the nature of our study, that the increase in weight due to the thrust of the propeller is proportional to $V\ v^2$.

In the case of our model, summarily analyzing the effects due to the three kinds of forces mentioned above, we will consider that a sufficiently clear statement of the total weight of the longitudinal beam is given by the following formula:

$$(10^{-6} \cdot 0.5\ v^2 + 0.022)\ V + 0.00236\ V^{4/3}.$$

8. ACCESSORIES OF THE LONGITUDINAL BEAM.

We shall consider as accessories the covering of the beam, the internal gangway, and the pneumatic shock absorbers.

The prevailing forces are those due to the action of the air. In consequence of these forces the weight of the covering of the beam varies in proportion to $V\ v^2$ and, for our model we have : $10^{-6} \cdot 1.3\ V\ v^2$.

THE GANGWAY. - We should remember that live loads, though remaining invariable in absolute value, increase numerically at least in the proportion of $V^{1/3}$. Therefore, assuming that the width of the gangway remains the same and that the number of supports remains also the same, the bending moments increase proportionally to $V^{2/3}$ and likewise the weight itself.

It is probable, however, that the constructor gains in weight by increasing, if possible, the number of suspensions of the envelope; but, on the other hand, it is probable that this will involve increasing the width of the gangway. In conclusion, therefore, it seems that we are justified in assuming the weight to vary in the proportion of $V^{2/3}$ as stated above.

For our model we have: $0.374 \cdot V^{2/3}$.

SHOCK ABSORBERS. - The forces to which the shock absorbers are subjected are about proportional to the cubic capacity of the airship. We may therefore assume that their number or length must be increased with increased cubic capacity, leaving the width unchanged. In that case the total weight will increase in proportion to V. For our model the value is $0.003\ V$.

9. ENGINE SETS AND SUPPORTS.

After determining the maximum velocity which the airship must be capable of attaining, the power required may be taken as proportional to $V^{2/3} v^3$ and in inverse proportion to the propeller efficiency:

$$N = \frac{k}{\eta} V^{2/3} v^3$$

For our type of airship, expressing v in km/h, we may assume:

$$k = 10^{-6} \times 1.05$$

and therefore for $\eta = 0.7$.

(1) $$N = 10^{-6} \cdot 1.5 \cdot V^{2/3} v^3 \ *$$

We may admit that the weight per horsepower, which we will call π remains constant, and we may also admit that the weight of all the accessories (radiators for water and oil, taken as full; piping system; starting devices; controls; instruments; propellers) is proportional to the power and averages 0.65 kg. per

* For the various types of airships constructed by us so far, we have found coefficients varying from 1.45 to 2.10. In our future constructions we shall presumably reach somewhere below 1.4. For Zeppelins the coefficient is smaller.

h.p. For engines weighing 1.20 per h.p. we may therefore consider the total weight of the engine set to be about 1.85 kg. per h.p.

As regards the supports, the forces to which these are subjected are partly static, proportional to the weight of the engine set and therefore to $V^{2/3}v^3$, and partly dynamic proportional to the thrust of the propellers. If we assume, therefore, that their number remains unchanged, their weight must increase in proportion to V.

Such an hypothesis is, however, hardly probable, since it is certain that, in order to obtain a better distribution of load, the number of supports must be increased. Such being the case, we will simply assume that their total weight is also proportional to the power developed by the engine set which, in our case, is given by 0.25 kg. per h.p.

Summarizing the total weight of the engine set we have:

$$(\pi + 0.65 + 0.25)\ N = (\pi + 0.90)\ 10^{-6}\ .\ 1.5\ .\ V^{2/3}v^3$$

and for $\pi = 1.20$:

$$10^{-6}\ 3.15\ V^{2/3}v^3$$

10. MANEUVERING DEVICES.

The total weight of these devices, and especially of the cables, evidently varies in proportion to $V^{4/3}$.

In point of fact, while the forces are proportional to V, the length of the cables is proportional to $V^{1/3}$.

In our case we have:

$$0.00060\ .\ V^{4/3}$$

11. LIGHTING PLANT, WIRELESS PLANT, ETC.

The equipment of the airship is completed by the lighting plant, wireless installation, ventilators, safety appliances, signals, and other minor accessories.

Of these weights some, such as that of the wireless installation, may be assumed to increase slightly with the cubature of the airship (in fact, it is probable that a wider range of wireless will be required for larger airships). Other accessories, such as the lighting plant, increase in proportion to $V^{2/3}$; others, as the ventilators and safety appliances, increase in the same ratio as the cubature.

In the case of our model we have:

$$4.5\,V^{1/3} + 0.19\,V^{2/3} + 0.007\,V$$

12. PILOT'S CABIN.

The Pilot's cabin is provided with all the instruments required for navigation and with other necessary equipment.

It is difficult to give a definite ratio of the variation of the weight with the cubature.

To simplify matters we will assume that the area of the cabin is proportional to $V^{1/3}$ and that the total load also increases in proportion to $V^{1/3}$. We then conclude that the total weight varies in proportion to $V^{2/3}$. In our case: $0.300\,V^{2/3}$.

13. PASSENGER CABINS.

It is not possible to determine a priori the weight of the passenger cabins and their equipment, since this must evidently be proportional to the number of passengers carried. We can, however, include this weight in the useful load by adding 20 to 25 kg. per passenger.

14. BENZINE, OIL, AND WATER TANKS.

The weight of these tanks, comprising their supports, amounts to about 6% of the weight of the liquid contained therein.

The weight of the water tanks can be counted in with the weight of the ballast, and we will reckon the weight of the benzine and oil tanks by adding 6% to the weight of the benzine and oil needed per kilometer.

We have now evaluated the entire weight of the airship itself. In order to consider the airship in flying shape, we must add the weight of the crew, spare parts, reserve ballast, ballast needed for take off, and the weight of fuel and oil.

15. THE CREW.

The number of men forming the crew depends not only on the cubature of the airship, but also on other circumstances which are not possible to account for a priori, and we will therefore be satisfied with a rough approximation.

The minimum crew needed consists of:

1 Commander
1 Pilot
1 Mechanic
1 Wireless operator.

With increased cubature of the airship, we may, generally speaking, assume that the journeys undertaken will be longer and more fatiguing, and that, therefore, double shifts will have to be provided for.

We are therefore justified in assuming that the weight of a minimum personnel will be in proportion to $V^{1/3}$.

The total number of mechanics, less the one included in the minimum crew, may be roughly considered as proportional to the power, that is, to $V^{2/3}v^3$.

There are also the all-around men who, though not required on a small airship are certainly indispensable on a large one. The weight of these may be taken as proportional to the cubature of the airship.

In the case of our model, including also the weight of clothes and food reserves, we have:

$$20\ V^{1/3} + 10^{-6} \cdot 0.20 \cdot V^{2/3}v^3 + 0.003 \cdot V$$

16. SPARE PARTS FOR THE ENGINE SET AND TOOLS.

This weight may be taken as proportional to the engine power. In our case it is given by:

$$10^{-6} \cdot 0.16 \cdot V^{2/3}v^3$$

17. RESERVE BALLAST AND TAKE OFF BALLAST.

As we said at the beginning, we shall suppose that navigation is normally started at an altitude of about 300 m. above sea level. The corresponding lightening of the airship will be approximately given by 0.030 V.

The reserve ballast may also be taken as proportional to the cubature and we may say that its weight in kg. is numerically expressed by 4% of the volume expressed in cubic meters.

The total weight of the ballast is thus expressed by:

$$0.030\ V + 0.040\ V = 0.070\ V.$$

18. RESERVE STOCK OF FUEL AND OIL.

It is logical, we believe, that, in order to ensure safe navigation, the reserve stock of fuel and oil carried must be large enough to meet all eventualities. This reserve must be in proportion to the amount required for normal navigation. We will calculate this by increasing by 30% the usual consumption per kilometer, or, which amounts to the same thing, the specific consumption per h.p.

19. GENERAL FORMULA FOR THE USEFUL LIFTING FORCE.

Establishing, as we did at the beginning, the approximate laws governing the variation in the weights of the airship, the armament, and the crew, we find that the total weight, P, of the airship ready for navigation (except the passenger cabins, the benzine and oil tanks, and the reserve stock of benzine and oil) is expressed in function of the cubature and of the velocity by six terms respectively proportional to

$$V^{1/3},\ V^{2/3},\ v^3V^{2/3},\ V,\ v^2V,\ V^{4/3}.$$

In Table I (see at the end of this paper) the numerical coefficients of these terms are summarized, and from that table we derive the following expression for P:

$$(2)\quad P = 24.5\ V^{1/3} + (3.274 + 10^{-6}\ 3.51\ v^3)\ V^{2/3} + $$

$$+ (0.160 + 10^{-6}\ 3.1\ v^2)\ V + 0.0067\ V^{4/3}$$

in which V is expressed in cubic meters, v in km/h and P in kg.

V is the maximum effective volume of the gas bag after inflation.

If we subtract the weight P from the total lifting force at the sea level, f V*, we shall obtain the lifting force of which we can dispose for the useful load and for the provision of benzine and oil needed for navigation. We will call this the USEFUL lifting force and will represent it by Φ.

We should recall once more:

1st. That the useful load comprises not only the weight

* In our calculations for f we shall assume the mean value of 1100 kg. per cubic meter of gas.

of the passengers, their baggage and food supplies, but also the weight of the cabins suitably fitted up for the number of passengers that can be carried.

2nd. That in the provision of benzine and oil is included not only that required for normal navigation, but also a proper quantity of reserve stock together with the tanks required for holding the entire provision.

Putting formula (2) in the general form:

$$(2') \qquad P = \alpha V^{1/3} + \beta V^{2/3} + \gamma V + \delta V^{4/3}$$

we obtain for Φ

$$(3) \qquad \Phi = f V - (\alpha V^{1/3} + \beta V^{2/3} + \gamma V + \delta V^{4/3})$$

This formula shows that there are two values of V for which $\Phi = 0$, one very small, the other very large. Passing from the first to the second value, the useful lifting force first increases, then, after reaching a maximum value, decreases until it again equals zero.

The value of V which corresponds to Φ maximum, is obtained by extracting the value of V from formula (3) and making it equal to zero:

$$(4) \qquad f V = \frac{1}{3} \alpha V^{1/3} + \frac{2}{3} \beta V^{2/3} + \gamma V + \frac{4}{3} \delta V^{4/3}$$

20. VARIATIONS OF THE COEFFICIENT OF UTILIZATION IN FUNCTION OF THE CUBATURE AND VELOCITY. LIMIT REGIMES OF FLIGHT.

We will call "Coefficient of Utilization" the ratio ρ between the useful lifting force and the total lifting force:

$$(5) \qquad \rho = \frac{\Phi}{f V} = 1 - \frac{1}{f} (\alpha V^{-2/3} + \beta V^{-1/3} + \gamma + \delta V^{1/3})$$

Here also, starting from a minimum value of V for which $\rho = 0$, the value of ρ increases rapidly with the increase of cubature until it reaches a maximum. After reaching this maximum, the value of ρ decreases slowly down to zero again for a rather large value of V.

The values of V for which $\rho = 0$ (lower and upper limits of cubature) are obtained from the following equation:

(6) $$f V = \alpha V^{1/3} + \beta V^{2/3} + \gamma V + \delta V^{4/3}$$

and, of course, the lower limit is higher as the velocity is lower. In fact, in this case the coefficients β and γ are small also, and we have:

$$\beta = \beta' + \beta'' v^3$$

$$\gamma = \gamma' + \gamma'' v^2$$

In the case of our model we find for these lower limits of V the following values*

at 90 km/h $V = \sim 1000$

at 120 " $V = \sim 2300$

at 150 " $V = \sim 13000$

The maximum value of ρ is found by the following equation:

$$\delta V^{4/3} = 2 \alpha V^{1/3} + \beta V^{2/3}$$

from which, neglecting the first term of the second member, we obtain as a rough approximation:

$$V^{2/3} = \sim \frac{\beta}{\delta} = \frac{\beta' + \beta'' v^3}{\delta}$$

We may therefore conclude that WITH INCREASE OF VELOCITY MAXIMUM DIMINISHES AND TENDS TOWARDS LARGER CUBATURE.

As a matter of fact, in our case we find the following values (see Tables II, III, IV and diagrams):

at 90 km/h max. = 0.450 for V = 35,000 m.^{3}

" 120 " " = 0.345 " V = 60,000 m.^{3}

" 150 " " = 0.202 " V = 125,000 m.^{3}

We would remark here that, contrary to the current opinion, the maximum values of the coefficient of utilization are to be found for relatively small cubatures.

The upper limit regime of flight to which the airship can steadily lift itself (assuming that there is no change in equilibrium between the internal and external temperature) is that for which the corresponding value of the air density is in the

*Regarding the possibility of practically realizing these minimum values of cubature, the reservations and observations made at the beginning of this study apply here also.

same ratio to the density of the air at sea level as P to f V. This limit thus depends essentially on the value of ρ.

Considering the mean conditions of temperature and atmospheric pressure, and assuming a constant difference of temperature of 0.0055 centigrades per meter, we find the following values which have been computed taking into account also the first 300 meters elevation.

for ρ =	0.20	H max. =	2430	m. above sea level.
"	0.25	"	3050	" " "
"	0.30	"	3700	" " "
"	0.35	"	4380	" " "
"	0.40	"	5120	" " "
"	0.45	"	5870	" " "
"	0.55	"	6700	" " "

and in the case of our model, corresponding to the values of ρ max. given above, we find:

at 90 km/h	V = 35,000	H max.	= 5870 m.
" 120 "	V = 60,000	"	= 4260 m.
" 150 "	V = 125,000	"	= 2450 m.

21. OPTIMUM CUBATURE. CONSUMPTION PER KILOMETER.

For the balloon the optimum cubature is evidently given by the maximum value of the coefficient of utilization.

As a matter of fact, for ρ max. the useful load is raised to a given height which is maximum, and the altitude to which a given useful load can be raised is also maximum.

But in the case of an airship it is evident that we must take into account the maximum distance over which a given useful load can be carried.

If we call p_u the lifting force per cubic meter required for the useful load, and c the supply of benzine and oil required per kilometer, we shall be able to measure the UNIT VELOCITY of the airship by:

$$\epsilon = \frac{f\rho - p_u}{c}$$

which represents the maximum distance L over which the load p_u can be carried.

As we must first establish a value of p, we will take that which gives the maximum value of $L \times p_u$. This maximum is evidently obtained when the useful lifting force, ρ f, is equally distributed between the useful load and the supply of fuel and oil. We will therefore assume as the ratio of the unit efficiency of the airship, the value:

(7) $$\epsilon = 0.55 \frac{\rho}{c}$$

We will now determine the value of c in the hypothesis that THE NORMAL VELOCITY OF NAVIGATION, v_o, IS OBTAINED BY UTILIZING HALF OF THE AVAILABLE POWER, that is:

$$N_o = \frac{1}{2} \frac{k}{\eta} V^{2/3} v^3$$

We shall then have:

$$v_o = 0.794 \, v$$

and therefore:

$$\frac{N_o}{v_o} = \frac{k}{\eta} \frac{V^{2/3} v^2}{1.588}$$

We will assume that the engine plant consumes about 250 grs. of benzine and oil per hp/h. In order to calculate the total supply of benzine and oil needed, we will add 30% to the normal consumption, and in order to calculate the total weight we must also take into account the weights of the containers which we have evaluated at 6% of the total weight of fuel and oil. We shall then have per h.p./h. a weight of

$$(0.250 + 0.075) \times 1.06 = 0.345 \text{ kg.}$$

and therefore the total weight per kilometer will be given by:

$$c = 0.345 \frac{N_o}{v_o}$$

and assuming for $\frac{k}{\eta}$ the value 10^{-6} 1.5 we obtain:

(8) $$c = 10^{-9} \times 326 \times V^{2/3} v^2$$

and substituting in the expression of ϵ:

(9) $$\epsilon = \frac{10^9}{593} \cdot \frac{\rho}{V^{2/3} v^2} = a \frac{\rho}{V^{2/3} v^2}$$

The OPTIMUM CUBATURE is that for which ϵ assumes its maximum value. It is obtained by solving the following equation:

$$2\,(f - \gamma)\,V = 4\,\alpha\,V^{1/3} + 3\,\beta\,V^{2/3} + \delta\,V^{4/3} \tag{10}$$

We should not be surprised that we find some very low values. In fact it is evident that the optimum cubature must always be less than the one corresponding to the maximum value of ρ, because for larger cubatures the denominator of ϵ increases, while the numerator decreases.

In our case we find:

for 90 km/h. : optimum cubature = ~ 5,000

" 120 " : " " = ~10,000

" 150 " : " " = ~30,000

If we now consider the velocity only as variable, it is obvious that efficiency diminishes with the increase of velocity, that is, there does not exist an OPTIMUM VALUE OF VELOCITY outside of zero for which efficiency becomes maximum. And in fact, if in $\frac{\rho}{V^{2/3}v^3}$ we express the coefficients β and γ in function of the velocity:

$$\beta = \beta' + \beta'' v^3 = 3.274 + 10^{-6}\,3.51\,v^3$$

$$\gamma = \gamma' + \gamma'' v^2 = 0.160 + 10^{-6}\,3.10\,v^2$$

and then make:

$$\frac{d}{dv}\left(\frac{\rho}{V^{2/3}v^3}\right) = 0$$

we find:

$$v^3 = -\frac{(f - \gamma')\,V^{1/3} - \alpha\,V^{-1/3} - \delta\,V^{2/3} - \beta'}{2\,\beta''}$$

which, for greater clearness, we may write:

$$v^3 = -\frac{f\,V - (\alpha\,V^{1/3} + \beta' V^{2/3} + \gamma' V + \delta\,V^{4/3})}{2 \cdot \beta'' V^{2/3}}$$

from which we see that the existence of an optimum value of the velocity different from zero is contingent on the condition:

$$f\,V < \alpha\,V^{1/3} + \beta' V^{2/3} + \gamma' V + \delta\,V^{4/3}$$

which can never be attained because we should also have:

$$f\,V < P$$

22. CUBATURE OF MINIMUM CONSUMPTION. DISTANCE LIMITS.

When we come to consider the efficiency of the airship solely from a mechanical point of view, we find that for each velocity there is a certain cubature which permits of carrying the unit of useful weight to the unit of distance with a minimum expenditure of energy, that is, with a minimum consumption of fuel.

Let P_u be the maximum useful load which an airship can carry to a distance L. The consumption of fuel per kilogrammeter will be given by:

$$\frac{c\,L}{P_u L} = \frac{c}{P_u}$$

We will assume, as before, that the useful lifting force is equally distributed between the useful load and the supply of fuel and oil in such a way as to give $P_u L$ its maximum value.

In such a case the consumption per kgm. will be proportional to:

$$\frac{c}{\Phi}$$

that is, in inverse proportion to the maximum distance which the airship can cover without any useful load. We will call this distance the "LIMIT DISTANCE".

It is evident that there exists a value of V for which the unit consumption is minimum and therefore the distance limit is maximum. In fact, we have only to consider that if the cubature increases indefinitely, the useful lifting force will finally reach zero, while c always has a positive value.

We will determine the value of this CUBATURE OF MINIMUM CONSUMPTION, which we may also call the CUBATURE OF MAXIMUM RANGE.

Keeping in mind formulas (3) and (8) we can put:

$$(11) \qquad L_{max.} = \frac{\Phi}{c} \; \frac{f\,V - (\alpha\,V^{1/3} + \beta\,V^{2/3} + \gamma\,V + \delta\,V^{4/3})}{10^{-9} \cdot 326 \cdot V^{2/3} v^2}$$

Solving this equation for the volume and taking it as equal to zero we find:

(12) $$f\,V + \alpha\,V^{1/3} - \gamma\,V - 2\,\delta\,V^{4/3} = 0$$

an equation which, solved for V, gives the value of the cubature of minimum consumption.

This value being very high, the terms $\alpha\,V^{1/3}$ may be considered as negligible, and then we have only:

(13) $$V = \sqrt[3]{\frac{f - \gamma}{2\,\delta}}$$

a result which may be enunciated thus: THE LINEAR DIMENSIONS OF THE AIRSHIP OF MINIMUM CONSUMPTION VARY LINEARLY WITH THE COEFFICIENT γ AND THEREFORE WITH THE SQUARE OF THE VELOCITY AND INCREASE AS THE VELOCITY DIMINISHES.

In point of fact, having, for our model:

for 90 km/h	$f - \gamma = 0.915$
" 120 "	" $= 0.896$
" 150 "	" $= 0.870$

and $2\,\delta = 0.0134$, we find:

for 90 km/h :	cubature of min. cons. = ~ 318000m^3
" 120 " :	" " " " = ~ 299000m^3
" 150 " :	" " " " = ~ 274000m^3

23. LIMIT VELOCITY.

For each cubature, the airship is designed for reaching a certain maximum velocity which cannot be exceeded. This limit value is at once obtained by solving for w the equation: $P = f\,V$.

Taking as a basis the expressions of P given by formula (2) we find, for our model, the following values:

V = 1,000 m^3	Velocity limit = 92.5 km/h
V = 5,000 m^3	" " = 133 "
V = 10,000 m^3	" " = 148 "
V = 50,000 m^3	" " = 173 "
V = 100,000 m^3	" " = 181 "

$V = 200{,}000\ m^3$ Velocity limit = 185 km/h

$V = 300{,}000\ m^3$ " " = 185 "

$V = 400{,}000\ m^3$ " " = 178 "

As we see, the limit velocity first increases rapidly with the increase of cubature, then, after reaching a maximum of 185 km/h. for a cubature of from 200,000 to 300,000 cubic meters, slowly decreases.

In practice, of course, these values of absolute maximum of velocity should not be reached; in fact, they should not even be approached.

24. INFLUENCE OF THE COEFFICIENT OF RESISTANCE AND OF PROPELLER EFFICIENCY.

In the general expression of P given in formula (2') the only term which depends on the power, and therefore on the coefficient of resistance k as well as on the propeller efficiency η, is

$$\beta V^{2/3} = (\beta' + \beta'' v^3) V^{2/3}$$

β being proportional to N and consequently also to $\frac{k}{\eta}$.

It is therefore easy to see the effects produced by a variation of the ratio $\frac{k}{\eta}$.

As regards the coefficient of utilization ρ, of course it increases as $\frac{k}{\eta}$ diminishes and vice versa. More exactly, we may say that, for a given cubature, the variation follows a linear law, as is shown by the general expression for ρ. We may add that the variation is more rapid for small cubatures, for which the term $\beta V^{2/3}$ acquires greater importance with respect to the other terms.

The approximate expression $V^{2/3} = \frac{\beta}{\delta}$ which givesthe cubature corresponding to ρ maximum, thus shows that with increase of $\frac{k}{\eta}$, ρ maximum is obtained for a larger cubature, and when $\frac{k}{\eta}$ decreases, ρ maximum tends towards a smaller cubature.

The CUBATURE OF MINIMUM CONSUMPTION OR MAXIMUM RANGE remains unchanged. This is clearly shown by formula (13) in which V is independent of β.

On the other hand, we have notable variations in the distance limit given by formula (11). Indicating by A a numerical coefficient, this may be put in the following form:

$$L_{max} = \frac{f V - (\alpha V^{1/3} + \beta V^{2/3} + \gamma V + \delta V^{4/3})}{A \frac{k}{\eta} V^{2/3} \cdot v^3}$$

and from this it clearly results that when $\frac{k}{\eta}$ increases, the numerator decreases and, at the same time, the denominator increases, and therefore L_{max} decreases. On the other hand, when $\frac{k}{\eta}$ decreases, the numerator increases and the denominator decreases, that is to say, L_{max} increases.

Finally, the limit velocity also varies with $\frac{k}{\eta}$, increasing as $\frac{k}{\eta}$ decreases.

25. VARIATIONS OF THE LIMITS OF DISTANCE AND VELOCITY FOR SMALL VARIATIONS OF VOLUME.

In order to show more clearly the influence of the increase of velocity and range on the cost of operation of aerial transport, we will consider a difference in volume sufficiently small to enable us to assume that for all intermediate cubatures the coefficient of utilization, ρ, remains just about constant. This we can always do, even for rather large differences in volume, when, for instance, we consider the region of the maximum value of ρ.

The distance limit, in the above hypothesis is given by:

$$L_{max} = \frac{\rho V}{A \frac{k}{\eta} V^{2/3} v^2} = \frac{\rho V^{1/3}}{A v^2} \frac{\eta}{k}$$

and therefore

$$V = \left(\frac{A k}{\rho \eta}\right)^3 v^6 L^3_{max} \qquad (14)$$

from which we may conclude that for small variations in volume, the volume is proportional to the cube of the ratio $\frac{k}{\eta}$, to the sixth power of the velocity and to the cube of the distance. This last result may also be enunciated in a suggestive form as follows: THE LENGTH OF THE AIRSHIP IS PROPORTIONAL TO THE MAXIMUM DISTANCE THAT IT CAN COVER.

Thus, for instance, in order to increase the distance limit by only 10%, we must increase the volume by 33%, and if we wish to increase the velocity by only 5%, the cubature must be increased by 35%.

Of course the results are even more unfavorable if, in the differences of volume considered, the value of ρ decreases, as is the case when this difference is on the right hand side of the cubature for which ρ is maximum.

26. DETERMINATION OF THE MINIMUM CUBATURE REQUIRED FOR A GIVEN TRIP.

The data of the problem are: the number of passengers n_o, and the distance L_o, to be covered without landing.

In round figures we may take 100 k for the weight of each passenger, comprising therein his part of the weight of the cabin and cabin fittings and also his part of the foodstuffs.

Then, taking V as the unknown cubature, we shall have:

$$\frac{1}{100}\left[f V - \alpha V^{1/3} - \beta V^{2/3} - \gamma V - \delta V^{4/3} - \frac{L_o}{B V^{2/3}} \right] = n_o$$

putting more briefly:

$$B = \frac{A}{100} \frac{k}{\eta} v^2$$

The preceding equation solved for V, gives the required cubature in function of L_o and n_o.

We may now ask what value of V renders n_o maximum, the value of L_o being established.

Solving the first member of the equation and taking it as equal to zero, we find:

$$f V = \frac{1}{3} \alpha V^{1/3} + \frac{2}{3} \beta V^{2/3} + \gamma V + \frac{4}{3} V^{4/3} - \frac{2}{3} \frac{L_o}{B V^{2/3}}$$

If we compare this equation with equation (4), we see, as we might have anticipated, that the volume V for which n_o is maximum, is always less than that for which Φ is maximum and that the difference of volume between n_o max. and Φ max. is less as the distance L_o is shorter. We may therefore deduce that for small values of L_o, the value of V corresponding to n_o maximum is greater than the cubature of minimum consumption. In other words, this cubature cannot, in general, be considered as a limit cubature, as might appear at a first glance.

The use of tables and diagrams gives a rapid solution of the problem, as we shall show by a few examples.

1st. Let us consider the transportation of 100 passengers (weight, 10,000 kg.) in a non-stop flight from Rome to New York, (distance about 7200 km.).

From the table we find that it isnot possible to use airships having a maximum velocity of 120 km/h., and still less those of 150 km/h. We will therefore suppose that we have $v = 90$ km/h., and consequently v_o, normal velocity of navigation, equal to about 71.5 km/h.

Glancing at the table, we may conclude that the required cubature (certainly greater than 60,000 cubic meters since for this value we have $L_{max} = 7231$ km.) is comprised between 100,000 and 150,000 cubic meters. In point of fact, we have:

for 100,000 $m.^3$	$\Phi - c\,L_o =$ 5,800 kg.
" 150,000 m^3	" = 12,380 kg.

Considering that we must have: $\Phi - c\,L_o = 10{,}000$, by a simple interpolation we at once obtain:

$$V = \sim 132{,}000\ m^3$$

The number of passengers which can be carried over the distance stated above by airships varying in cubature from 60,000 to 350,000 m^3, is as follows:

V = 60,000	n_o = ~ 1
" = 100,000	" = 58
" = 150,000	" = 124
" = 200,000	" = 182
" = 250,000	" = 230
" = 300,000	" = 270
" = 350,000	" = 300

2nd. In the previous case, suppose that we make a stop at the Azores for the purpose of taking in fuel. Under these conditions the maximum distance is reduced to about 3,700 km., and the cubature for $v = 90$ km/h., to 45,000 m^3, instead of 132,000 as in the first case.

3rd. Let us consider the line London-Paris-Marseilles-Rome-Naples-Taranto-Cairo, with stops at London, Rome, Taranto and Cairo.

There will be non-stop flights having the following lengths:

London-Rome	1625 km.
Rome-Taranto	460 km.
Taranto-Cairo	1700 km.

Adopting airships of 120 km/h., we find that with a cubature of 50,000 m³ we can carry 80 passengers, and with a cubature of 100,000 we can carry 200 passengers, covering the entire distance in about 40 hours' flight.

4th. Suppose we have a passenger service between Milan in Italy and Alexandria in Egypt (distance about 2,400 km.) operated by airships having a maximum velocity of 120 km/h. and a normal velocity of 95 km/h.

For a non-stop flight, we have at once from the table:

for 40,000 m³	n_o =	17
" 60,000 m³	" =	55
" 80,000 m³	" =	93

But suppose that we make a stop at Taranto (Milan-Taranto, 875 km.; Taranto-Alexandria, 1525 km.), the maximum distance to be covered in a non-stop flight is reduced from 2,400 to 1,525 km. and we have:

for 40,000 m³	n_o =	59
" 60,000 m³	" =	118
" 80,000 m³	" =	169

CONCLUSIONS.

1. The results we have reached in this investigation fully confirm the essential points characterizing the airship: a flying machine relatively slow, but capable of carrying a large useful load over a long distance.

These characteristics are the contrary of those of the airplane, which, in the present state of aerial technical data, is a machine essentially fast, but which can only carry a relatively small useful load over a relatively short distance.

There is, therefore, no reason to talk about competition between these two means of aerial locomotion, since they are so essentially different from each other, each having its own definite field of activity, the one serving to complete the other, The co-existence of airships and airplanes forms a complete solution of the problem of aerial navigation.

The advantages of airships of large cubature are so evident as to justify the greatest hopes for their immediate future. It should be remarked that it is not too much to hope that the limits we have found, and which are already pretty large, will be exceeded in actual practice, since in our investigation we have abstained from considering the developments which may confidently be expected from the genius of inventors and the skill of constructors.

Even without taking these probable developments into account, though they are by no means negligible quantities, we see that there is a certain limit to the advantages of large cubature.

This limitation is due, essentially, to the gradual decrease of the coefficient of utilization and CONSEQUENTLY OF THE MAXIMUM ALTITUDE OF FLIGHT. By increasing the cubature beyomd the point corresponding to ρ maximum, (which our calculations show to be much smaller than is commonly believed), the maximum altitude of the airship goes on decreasing, in spite of the fact that the range of action in a horizontal plane and the useful load go on increasing.

Now, the possibility of rapid climb is undoubtedly an essential factor of security of aerial navigation in the case of storms.

The other factor of security is velocity. To run ahead of a storm is another way of avoiding it.

High altitude and high speed are, however, antithetical terms. It is possible to build airships capable of rising to high altitudes, but they will, necessarily, have low velocity, just as it is possible to build airships having high speed, but having a low ceiling.

Our investigation leads us to conclude that a maximum velocity of 120 km/h. is as far as we ought to go. This figure can only be exceeded by excessive reduction of altitude of ceiling, range of flight, and useful load.

Now, at 120 km/h., for a cubature of 200,000 cubic meters, we have a coefficient of utilization of 0.31, which, including the 300 m. of initial rise, corresponds to a ceiling of about 4,000 m. altitude, reached, however, with a zero useful load and at the end of the flight only, after having consumed the entire supply of benzine and oil. This ceiling is evidently of relatively low altitude, and we should therefore consider the advisability of exceeding the above given cubature for airships of this type.

Of course, with decreased velocity there would be an improvement. For instance, with the same cubature of 200,000 cubic meters and a speed of 90 km/h., the ceiling would be at about 5,000 m. The gain in altitude would not, however, altogether compensate for the pronounced decrease of maximum velocity.

2. We will now consider the use of the airship in a public passenger service.

The essential requisites of a public transport service are safety and regularity of service.

The first of these requirements can undoubtedly be met. We have only to adopt a cubature large enough for realizing the following three conditions: (a) the certainty of being able to rise rapidly to a height of 1500 or 2000 m. right at the beginning of navigation; (b) a fuel reserve sufficiently ample to enable the ship to sail for much longer than the anticipated time, should this be required by the atmospheric conditions; (c) the possibility of developing a relatively high maximum speed.

When these three conditions are satisfied we may say without fear of exaggeration that AERIAL NAVIGATION BY AIRSHIPS IS SAFER THAN MARITIME NAVIGATION. As a matter of fact, a ship on the water cannot rise above the gale as an airship can.

The necessity of satisfying all three conditions at the same time, leads us to conclude, on the basis of our calculations, that under the present conditions of aerotechnics it is not advisable with airships used for passenger service, to exceed a normal flying speed of 80 or 90 km/h. or a non-stop flight of more than 3000 to 4000 km. In other words, we are convinced that the best cubature to adopt is not that which aims at increasing the length of non-stop flights or of the speed of flight, but rather that which aims at safety in navigation by increasing the supply of benzine and the amount of ballast.

The requisite of regularity, meaning thereby starting and arriving at schedule time, is, for the airship, intimately connected with the question of safe navigation, since, when this is assured we may, in a large measure, count on the flight being accomplished within the stated time. It cannot, however, be denied that, aerial navigation being still largely dependent on atmospheric conditions, a strict adherence to schedule time can only be guaranteed if the service is limited to the most favorable season of the year, though it may be remarked that the regularity of the maritime service is also influenced by weather conditions in a certain measure.

We may hope that airships will be much less affected by weather conditions when, in the near future, the problem of mechanical mooring, housing, and getting the ship out of its hangar, has been satisfactorily solved.

3. It is thus possible to assure an airship service offering the most absolute guarantees for security of flight and also, within practical limits, regularity of service. We must now consider the question from the economical point of wiew.

We do not deem it necessary to enter hère into an analysis of the unit cost of aerial transportation, but we may certainly affirm that, in most cases, the cost of aerial transport will necessarily be greater* than transport by land or water, especially when, as in a public service, satisfactory regularity and absolute safety are required.

But in judging the economical aspect of transportation, we must consider not only cash outlay, but also another essential factor, namely, speed.

Considering the question from this point of view, we shall not be so foolish as to pretend that the airship competes with the railway or motor-car unless (and such cases are not rare) over difficult or mountainous country or where business is limited. In these cases the aerial service would show a considerable saving of time as compared with other means of transport, either on account of the airship being able to take the most direct route or on account of greater speed.

Also, we need not be surprised if in such characteristic cases the cost of aerial transport should prove to be less than the cost of transport by rail or motor-car. For instance, if the line is intended to link up two places difficult of access, far distant from each other, and having only sufficient business to warrant, say, a bi-weekly service. Under these conditions it is quite certain that the cost of establishing and running an aerial line would be much less than that of laying a railway or making routes for motor-cars.

Except for the exceptional cases just mentioned, we believe that AN AERIAL SERVICE WITH AIRSHIPS IS ESPECIALLY AND PARTICULARLY SUITABLE FOR FLIGHTS OVER LARGE EXPANSES OF WATER.

* And greater generally with airplanes than with airships. This statement may seem, at first sight, rather paradoxical, but it can easily be proved by even a summary analysis of the cost of transport.

We must here distinguish between short distance and long distance flights.

In the first case, it is evident that we can attain a high flying speed, thereby obtaining a considerable advantage over the usual maritime service, whether over seas or lakes. Such may be the case, for instance, for a line Rome-Cagliari, or Rome-Tripoli, or Rome-Palermo.

For a longer distance, we must, on account of the reasons given above, reduce our speed, but, in any case, we may take it that the journey will be completed in about half of the time required by the fastest ships.

The question now arises whether this gain in speed as compared with maritime navigation is such as to compensate for the greater cost and the inevitable decrease in comfort.

The answer to this query cannot be doubtful. When the safety of the journey is assured and there are regular departures (two conditions which, as we have seen, can be complied with) passengers will certainly not be lacking.

Concerning the question of departures at stated times, we may remark that for long journeys over the sea, punctuality in leaving according to a pre-arranged time-table is of less importance than for short journeys. That is to say, the departure of an airship need not be announced much ahead of the time, nor need the departures be arranged according to a fixed time-table. It will be sufficient if the time of departure is announced two or three days beforehand, so as to give intending passengers time to prepare, and to decide whether they will travel by air or by the usual maritime service. This consideration is of some importance, since it meets the objection raised that aerial transport being, as it is, dependent on the weather, cannot compete commercially with maritime navigation.

4. THE AIRSHIP FOR TOURISTS.

In this field the airship has a unique position, surpassing even the airplane. The airship tourist service cannot fail to develop and flourish since it requires only a small capital and combines large profits with absolute security of investment.

Such a service is especially important in countries like Italy, where there is always a great influx of visitors from abroad. We are convinced that a well organized system of touring airships, especially in tourist centers, would not only be successful from an investor's point of view, but would also react favorably on the general economic conditions of the country.

The following considerations justify the theory that a tourist service with airships is capable of being developed under the most favorable conditions.

1st. The sensation of absolute security given by an airship in comparison with that felt in other modes of flight, cannot fail to attract a large number of tourists.

2nd. For passenger transport the airship offers much greater convenience and comfort than the airplane; also, the airship can slow down during flight or even remain stationary in the air, thus allowing greater enjoyment of the panorama.

3rd. The risks of navigation are reduced to a minimum, or even altogether eliminated, since the tourist service will only operate in suitable weather.

4th. The cost of terminal stations, material and personnel are reduced to a minimum, especially for short distance flights such as Rome-Naples, Bay of Naples, the Italian Riviera, Sicily, etc. For longer flights, such as Rome-Constantinople, Rome-Cairo, Rome-Paris, etc., these items will amount to more.

5th. Considering the class of passengers who will be catered for, the rates charged may be fixed at a sufficiently remunerative figure.

5. RIGID AND SEMI-RIGID AIRSHIPS.

We will conclude this study by a rapid comparison between the two types of airships which are today contending for supremacy: the semi-rigid Italian type and the rigid German type.

Of the Italian semi-rigid type there are two classes, one having an articulated longitudinal beam, the other, a rigid longitudinal beam.

While for small cubatures, the absolute superiority of our articulated beam type is generally recognized (and proved by the numerous requests from foreign Governments for sample airships of this type and the appreciations of them expressed in the official organs of those Governments,*) many experts and especially many amateurs maintain that, even for large cubatures, the Italian semi-rigid type can successfully compete with the German rigid type.

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* Our Aeronautical Construction Works has just completed an M type airship for England, and two O types, one for the U.S.A., the other for the Argentine. Another of the same type is being built for Spain. The O type, derived from the P type, (Crocco-Riccaldoni) may be considered as the most successful of Italian small cubature airships. It was designed by Engineers Pesce and Nobile.

Though there may be a doubt in the matter as regards the articulated type, there can be none whatever as regards the rigid type, as shown by the brilliant success of our experience with our first T type airship. We are convinced that to whatever dimensions our T type may be increased (within the limits suggested in this study) we shall always find that the particular characteristics which constitute its fundamentally good qualities are not only preserved, but even accentuated.

Of course, we do not say that great increase of cubature can be made without giving rise to difficulties. When the cubature exceeds 100,000 cubic meters the problems of construction and assemblage take on a certain importance, but though these problems may be difficult of solution they are never such as to lead to unfavorable conditions.

We consider that the essential reason why our type is superior to the German, lies in the conception of the rigidity itself. In the German type, the whole of the external surface is made rigid, even where the natural pressure of the gas is sufficient to preserve the shape. The Italians only make rigid those parts which really require such treatment, thus greatly simplifying construction and assembling which more than compensates for the slight disadvantage of a less penetrating form. Moreover, as regards the preservation of the form, the rigid type does not appear to have much advantage over the Italian semi-rigid, since, with the rigid bow of the T type the excess pressure of the gas in the envelope can be maintained relatively low, without fear of any inconvenience arising either during navigation or during mooring operations.

The superiority of the Italian conception appears, however, not merely in simpler construction, but also, and more especially, in greater strength. This is evident when we compare the HUGE, DELICATE, FRAGILE ARRANGEMENT formed by the metallic framework of the Zeppelins with THE STRONG, ELASTIC BACKBONE formed by the longitudinal beam of the Italian type. This backbone is STRONG because its parts, being relatively small and exposed to great forces, have a resistance which we shall seek in vain in the framework of the Zeppelin. It is ELASTIC, because its articulated joints, the peculiar characteristic of our longitudinal beam, give it an elasticity which enables the airship to withstand shocks and bumps, while the Zeppelin, as experience has proved, cannot support such shocks without serious damage.

These are the two most important advantages of the Italian type over the German type. We may also mention the following:

1st. Rapidity and certainty in designing.

2nd. Rapidity of construction and utilization of materials of current use and constant characteristics.

3rd. Great rapidity and simplicity of mounting.

4th. Possibility of taking the airship to pieces rapidly either for purposes of storage or transport when it is not advisable to send it under its own power. We may note that the Zeppelin cannot be taken apart.

5th. Possibility in the future of assembling the airship outside the hangar. In fact, the assembling of our longitudinal beam complete with all its accessories, comprising the stiffening of the bow, the power plant, rudders, etc., can be done without inconvenience in the open air if it is protected from the weather by a temporary covering of limited dimensions. When the rigid part is assembled we can, given favorable conditions and fine weather, proceed rapidly to the inflation of the envelope and to its connection with the rigid part. After this, the airship may be ready in a few days, if not to fly, at least to be moored so that the final adjustments may be made without danger.

6th. Great facility of inspection and repairing of single metallic parts. This considerable advantage arises immediately from the fact that the rigid part occupies only a small space, and also that the various parts are articulated together, so that a damaged part can easily be changed.

7th. Lower cost of construction and assembling. We need not dwell on this point. Greater rapidity of construction and assembling together with the use of current materials must conduce to a lower cost of production.

This advantage, however, must be set off against the cost of operation. As a matter of fact, in the Italian type, when, from any cause, the gas bag becomes inefficient, it must be entirely renewed. It is certain that to change one of the gas compartments of the Zeppelin is a much less costly operation, but, on the other hand, when we consider that the cost of upkeep of the rigid part is much less in the Italian type, we come to the conclusion that, on the whole, the upkeep of a Zeppelin is more costly than the upkeep of an Italian airship.

In summing up all the advantages of an Italian airship over a Zeppelin, we must, however, admit that in one point the latter are superior, namely, in the coefficient of head resistance. But we are convinced that this inferiority will soon be eliminated by successive improvements in the Italian type of airships.

Rome, December, 1920.
Translated by Paris Office, N.A.C.A.

TABLE I.

WEIGHT OF THE VARIOUS PARTS OF THE AIRSHIP IN FUNCTION OF VOLUME AND SPEED.

$$P = V^{1/3} + (\beta' + \beta'' v^3) V^{2/3} + (\gamma' + \gamma'' v^2) V + \delta V^{4/3}$$

(P in kg.; V in m.³; v in km/h.)

PARTS	$\alpha V^{1/3}$	$\beta V^{2/3}$	
		β'	$\beta'' v^3$
Envelope with all accessory organs including valves and valve controls		2.410	
Stiffening of bow			
Stabilizers and rudders with controls.			
Longitudinal Beam			
Accessories of longitudinal beam (covering, gangway, shock absorbers		0.374	
Power plant with supports			10^{-6} 3.15 v^3
Maneuvering devices			
Plant for lighting, wireless, ventilators	4.5	0.190	
Pilot's cabin		0.300	
Crew	20.0		10^{-6} 0.20 v^3
Engine spare parts and tools			10^{-6} 0.16 v^3
Reserve ballast and ballast for initial climb of 300 m.			
	α = 24.5	β' = 3.274	β'' = 10^{-6} 3.51

TABLE I (Cont.)

WEIGHT OF THE VARIOUS PARTS OF THE AIRSHIP

IN FUNCTION OF VOLUME AND SPEED.

$$P = V^{1/3} + (\beta' + \beta'' v^3) V^{2/3} + (\gamma' + \gamma'' v^2) V + \delta V^{4/3}$$

(P in kg.; V in m.^{3}; v in km/h.)

PARTS	γV: γ'	γV: $\gamma'' v^2$	$\delta V^{4/3}$
Envelope with all accessory organs including valves and valve controls	0.008		0.00374
Stiffening of bow		10^{-6} 1.3 v^2	
Stabilizers and rudders with controls	0.047		
Longitudinal Beam	0.022	10^{-6} 0.5 v^2	0.00236
Accessories of longitudinal beam (covering gangway, shock absorbers)	0.003	10^{-6} 1.3 v^2	
Power plant with supports			
Maneuvering devices			0.00060
Plant for lighting, wireless, ventilators	0.007		
Pilot's cabin			
Crew	0.003		
Engine spare parts and tools			
Reserve ballast and ballast for initial climb of 300 m.	0.070		
	$\gamma' = 0.160$	$\gamma'' = 10^{-6}$ 3.1	$\delta = 0.0067$

TABLE II.

Maximum Velocity, 90 km/h.

Normal Velocity of Flight, about 72 km/h.

Cubature V m³	Useful lifting force (for f = 1100 kg/m.³ Φ kg.	Coefficient of utilization ρ	Fuel & oil per km. c kg.	Limit distance L km.	No. of passengers for 1000 km	No. of passengers for 5000 km.
5,000	1,877	0.3411	0.772	2,431	11	0
10,000	4,472	0.4005	1.226	3,647	32	0
15,000	7,095	0.4300	1.606	4,418	55	0
20,000	9,700	0.4409	1.946	4,985	77	0
25,000	12,275	0.4463	2.258	5,436	100	0
30,000	14,813	0.4489	2.550	5,809	123	21
35,000	17,312	0.4497	2.826	6,126	145	32
40,000	19,775	0.4494	3.089	6,402	167	43
45,000	22,202	0.4485	3.341	6,645	189	55
50,000	24,589	0.4471	3.584	6.861	210	67
60,000	29,264	0.4434	4.047	7,231	252	90
70,000	33,806	0.4390	4.485	7,538	293	114
80,000	38,226	0.4344	4.903	7,796	333	137
90,000	42,406	0.4283	5.304	7,995	371	159
100,000	46,699	0.4245	5.690	8,207	410	182
125,000	56,693	0.4123	6.602	8,587	501	237
150,000	66,083	0.4005	7.456	8,863	586	288
175,000	74,923	0.3892	8.263	9,067	667	336
200,000	83,258	0.3784	9.032	9,218	742	381
225,000	91,118	0.3681	9.770	9,326	813	423
250,000	98,541	0.3583	10.480	9,403	881	461
275,000	105,548	0.3489	11.169	9,450	944	497
300,000	112,164	0.3399	11.835	9,477	1,003	530
325,000	118,407	0.3312	12.484	9,485	1,059	560
350,000	124,299	0.3229	13,116	9,477	1,112	587

TABLE III

Maximum Velocity, 120 km/h.

Normal Velocity of Flight, about 95 km/h.

Cubature V m³	Useful lifting force Φ kg.	Coefficient of utilization ρ	Fuel and oil per km. c kg.	Limit distance L km.	No. of passengers for 1,000 km.	No. of passengers for 3,000 km.
5,000	758	0.1378	1.373	552	0	0
10,000	2,654	0.2412	2.179	1,218	5	0
15,000	4,678	0.2835	2.855	1,638	18	0
20,000	6,737	0.3062	3.459	1,948	33	0
25,000	8,802	0.3200	4.014	2,193	48	0
30,000	10,858	0.3290	4.532	2,396	63	0
35,000	12,895	0.3349	5.023	2,567	79	0
40,000	14,914	0.3389	5.491	2,716	94	0
45,000	16,911	0.3416	5.939	2,847	110	0
50,000	18,881	0.3433	6.371	2,963	125	0
60,000	22,751	0.3447	7.195	3,162	156	12
70,000	26,522	0.3444	7.973	3,326	185	26
80,000	30,197	0.3431	8.716	3,464	215	40
90,000	33,691	0.3403	9.428	3,574	243	54
100,000	37,246	0.3386	10.114	3,683	271	69
125,000	45,553	0.3313	11.736	3,881	338	103
150,000	53,335	0.3232	13.252	4,025	401	136
175,000	60,629	0.3149	14.687	4,128	459	166
200,000	67,468	0.3066	16.055	4,202	514	193
225,000	73,873	0.2985	17.365	4,254	565	218
250,000	79,877	0.2905	18.630	4,287	612	240
275,000	85,496	0.2826	19.852	4,307	656	259
300,000	90,752	0.2750	21.037	4,314	697	276
325,000	95,660	0.2676	22.190	4,311	735	291
350,000	100,237	0.2604	23.314	4,299	769	303

TABLE IV.

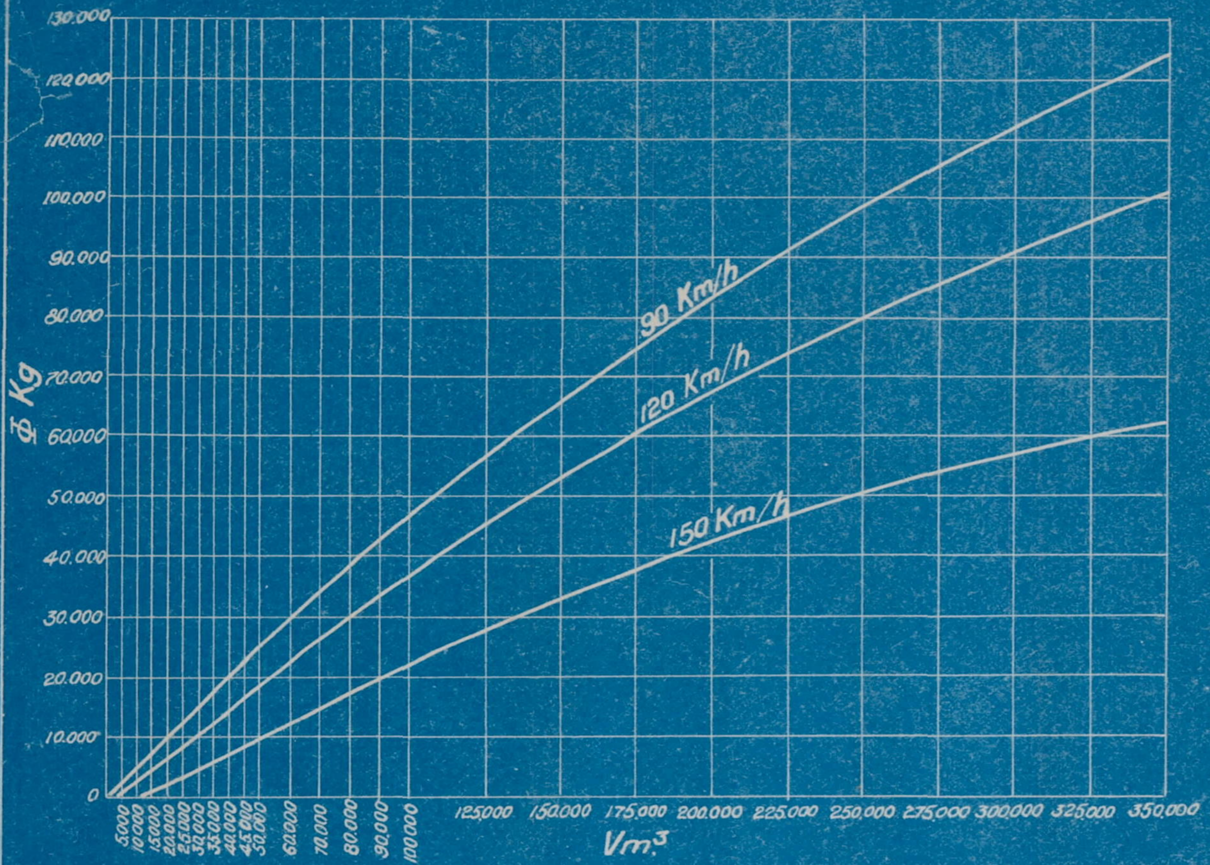
Maximum Velocity, 150 km/h.

Normal Velocity of Flight, about 119 km/h.

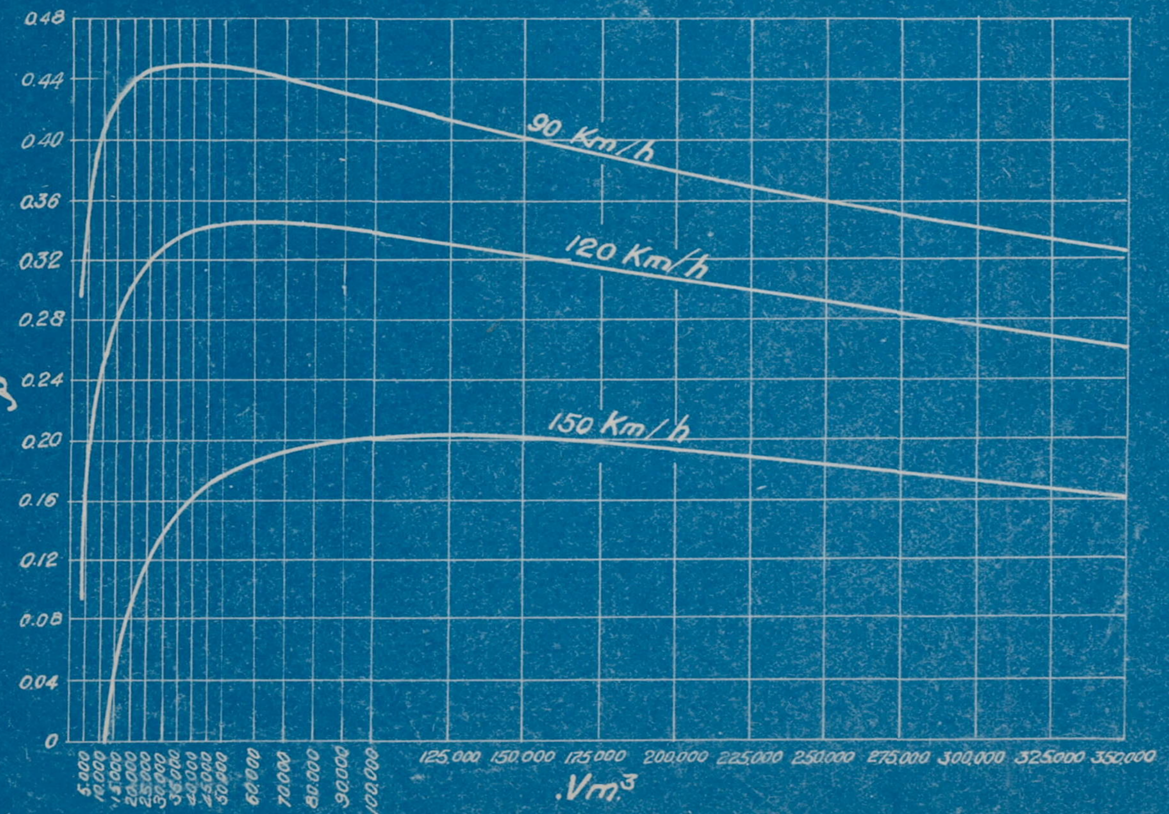
Cubature V m³	Useful lifting force Φ kg.	Coefficient of utilization ρ	Fuel and oil per km. c kg.	Limit distance L km.	No. of passengers for 500 km.	No. of passengers for 1000 km.
5,000	-1,063	-0.296				
10,000	- 289	-0.026				
15,000	772	0.0468	4.461	173	0	0
20,000	1,957	0.0889	5.406	362	0	0
25,000	3,210	0.1167	6.271	512	1	0
30,000	4,496	0.1362	7.083	635	10	0
35,000	5,800	0.1506	7.848	739	19	0
40,000	7,113	0.1617	8.579	829	28	0
45,000	8,428	0.1683	9.279	908	38	0
50,000	9,735	0.1770	9.955	978	53	0
60,000	12,331	0.1868	11.242	1,097	67	11
70,000	14,883	0.1932	12.458	1,195	87	24
80,000	17,384	0.1975	13.618	1,276	106	38
90,000	19,742	0.1994	14.730	1,340	124	50
100,000	22,192	0.2017	15.802	1,404	143	64
125,000	27,850	0.2025	18.337	1,519	187	95
150,000	33,115	0.2007	20.707	1,599	228	124
175,000	37,993	0.1974	22.948	1,656	265	150
200,000	42,497	0.1932	25.085	1,694	298	174
225,000	46,638	0.1884	27.134	1,719	331	195
250,000	50,335	0.1830	29.109	1,729	358	212
275,000	53,899	0.1782	31.019	1,786	384	229
300,000	57,045	0.1729	32.871	1,735	407	242
325,000	59,883	0.1675	34.673	1,727	425	252
350,000	62,426	0.1621	36.429	1,713	442	260

T

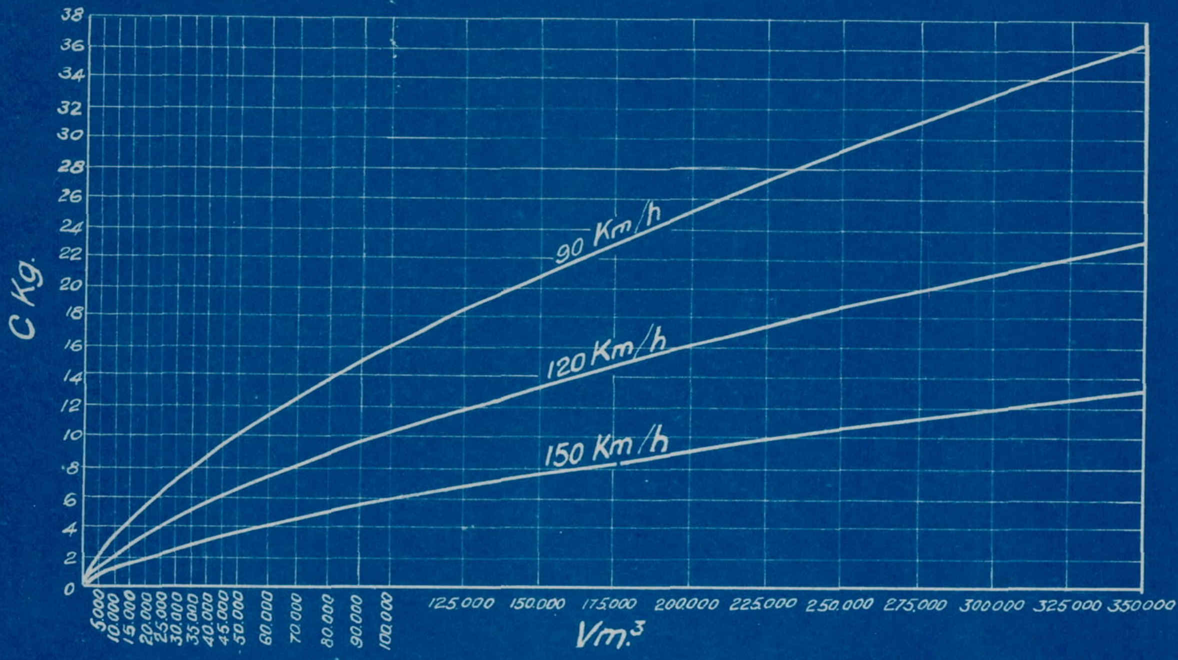
I USEFUL LIFTING FORCE. (Useful load + benzine and oil)



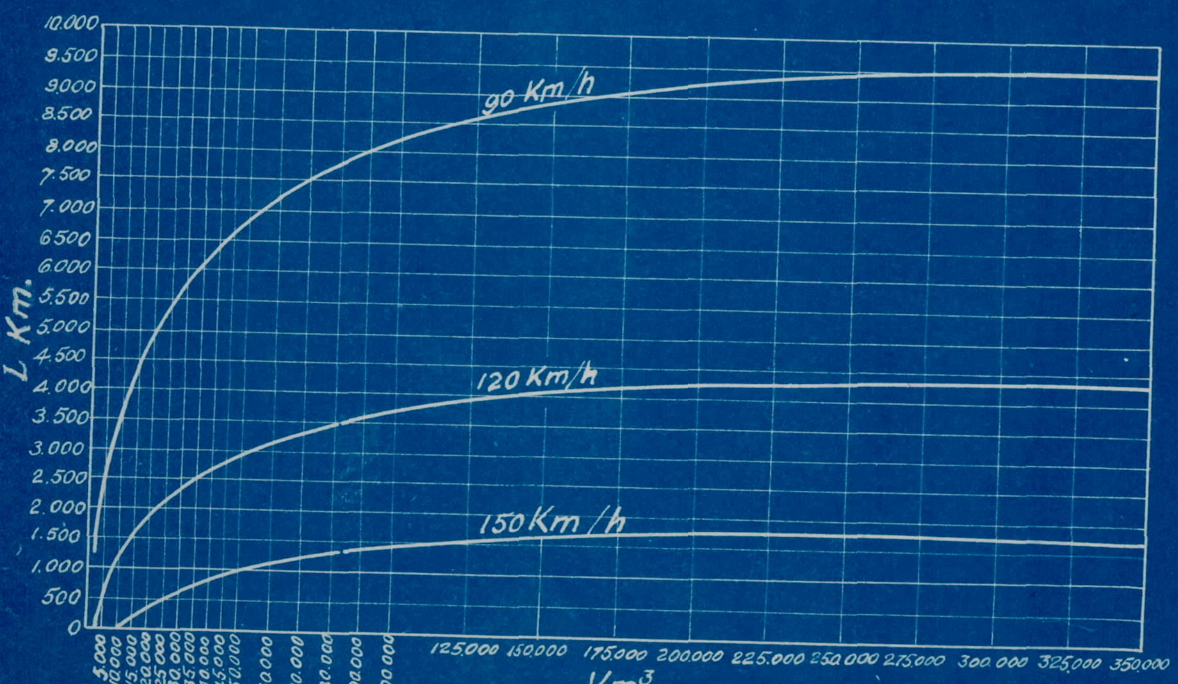
II COEFFICIENT OF UTILIZATION AND MAXIMUM ALTITUDES.



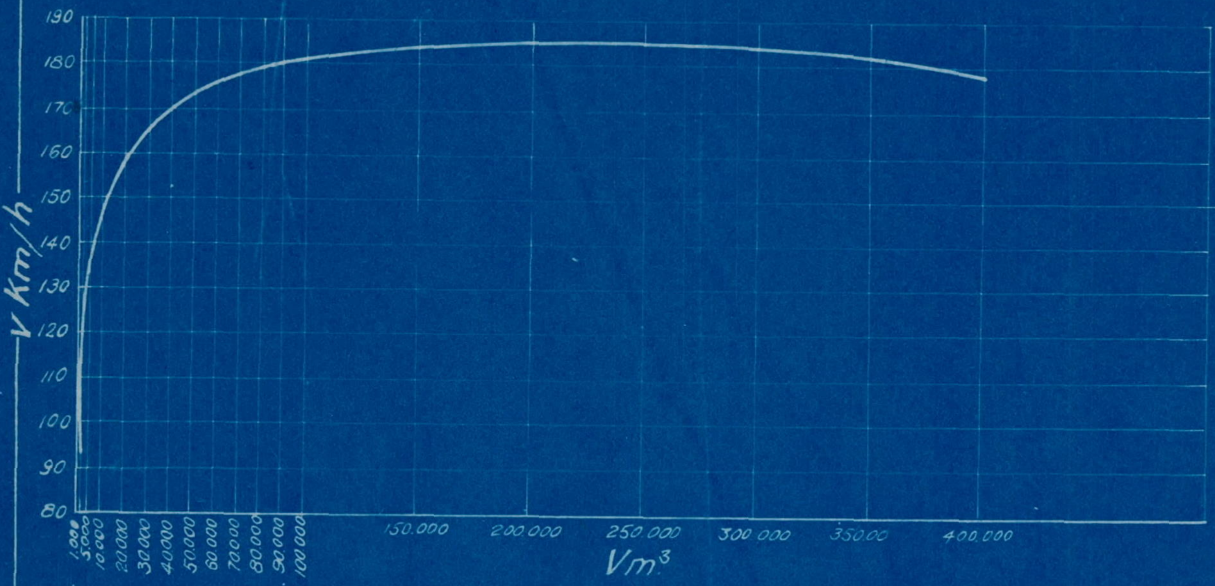
III SUPPLY OF BENZINE AND OIL PER KILOMETER.



IV LIMIT DISTANCES.

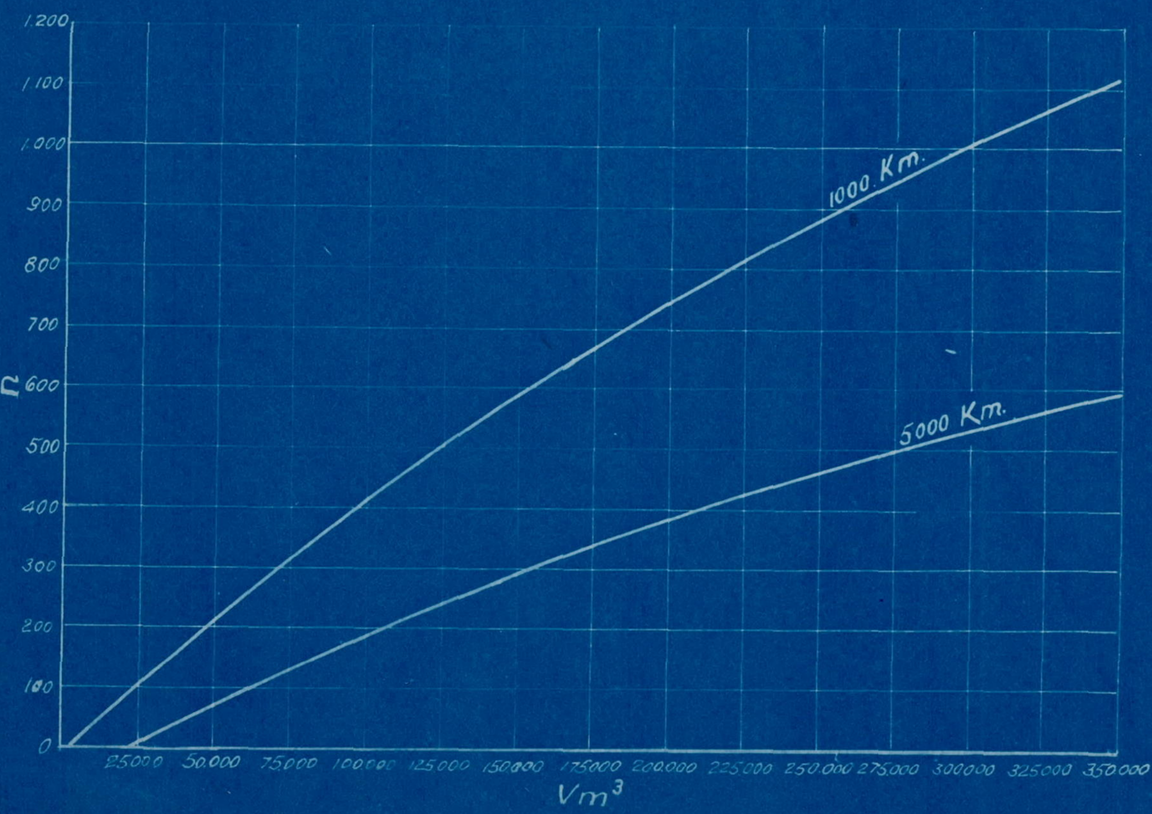


V LIMIT OF VELOCITY



VI - VII - VIII - INFLUENCE OF LENGTH OF FLIGHT ON NUMBER OF PASSENGERS.

VI. v = 90 Km/h



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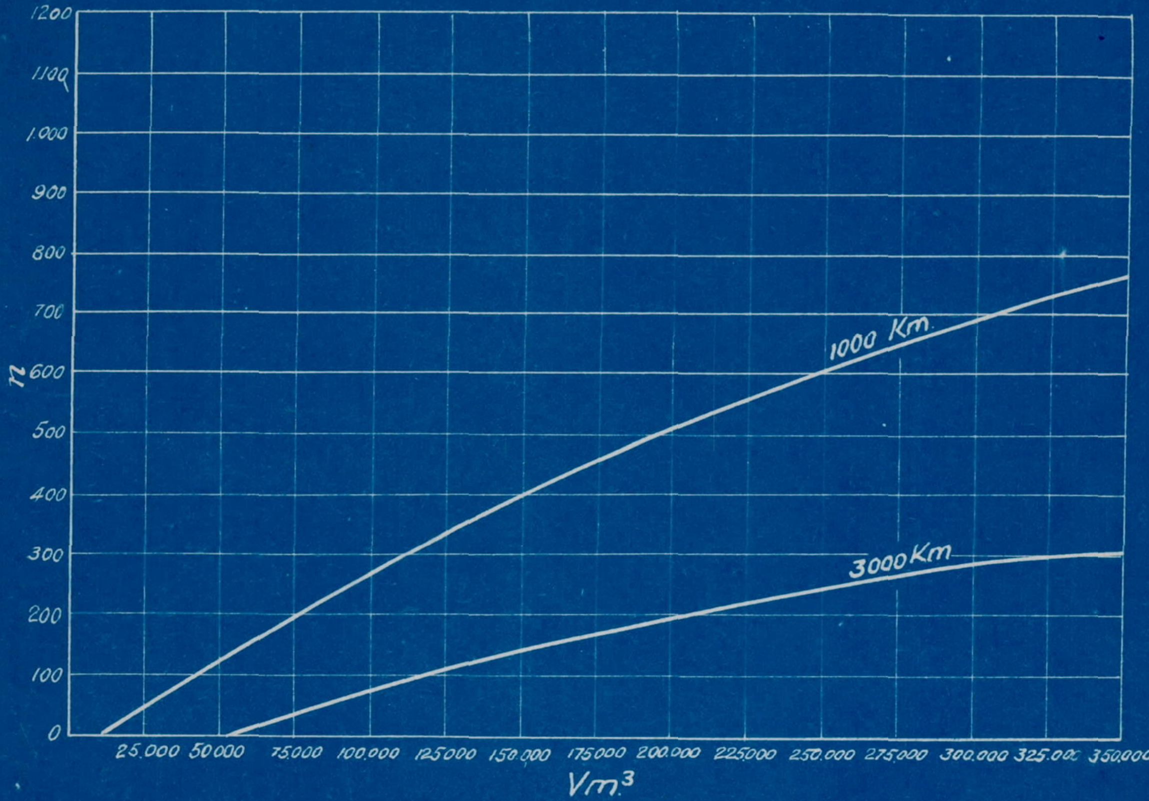
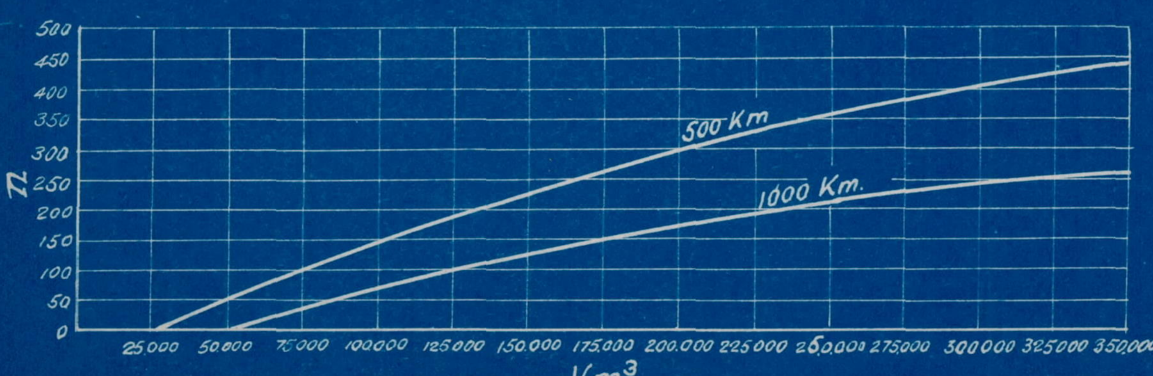
VII. v = 120 Km / h



VIII. v = 150 Km / h



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