TECHNICAL NOTES.

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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 partsof 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:

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

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 consider the regime of movement along inclined trajectories, we easily come to the conclusion that if we wish, for instance, to maintain 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 personnël 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

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

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:

$$(2) \qquad P = 24.5\, V^{1/3} + (3.274 + 10^{-6}\, 3.51\, v^3)\, V^{2/3} + \\ + (0.160 + 10^{-6}\, 3.1\, v^2)\, V + 0.0067\, V^{4/3}$$

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

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* 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, ρf, 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:

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

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:

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

and substituting in the expression of ϵ:

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

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

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

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 cub atures 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:

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

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:

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

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 2δ = 0.0134, we find:

for 90 km/h	:	cubature of min. cons. = ~ 318000m³
" 120 "	:	" " " " = ~ 299000m³
" 150 "	:	" " " " = ~ 274000m³

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 m³	Velocity limit =	92.5 km/h
V = 5,000 m³	" " =	133 "
V = 10,000 m³	" " =	148 "
V = 50,000 m³	" " =	173 "
V = 100,000 m³	" " =	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:

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

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

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

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 is not 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:

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

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 m^3 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 m^3	n_o =	17
"	60,000 m^3	" =	55
"	80,000 m^3	" =	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 m^3	n_o =	59
"	60,000 m^3	" =	118
"	80,000 m^3	" =	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 <u>AN AERIAL SERVICE WITH AIRSHIPS IS ESPECIALLY AND PARTICULARLY SUITABLE FOR FLIGHTS OVER LARGE EXPANSES OF WATER.</u>

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* 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.

* 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	11.139	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 p	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.

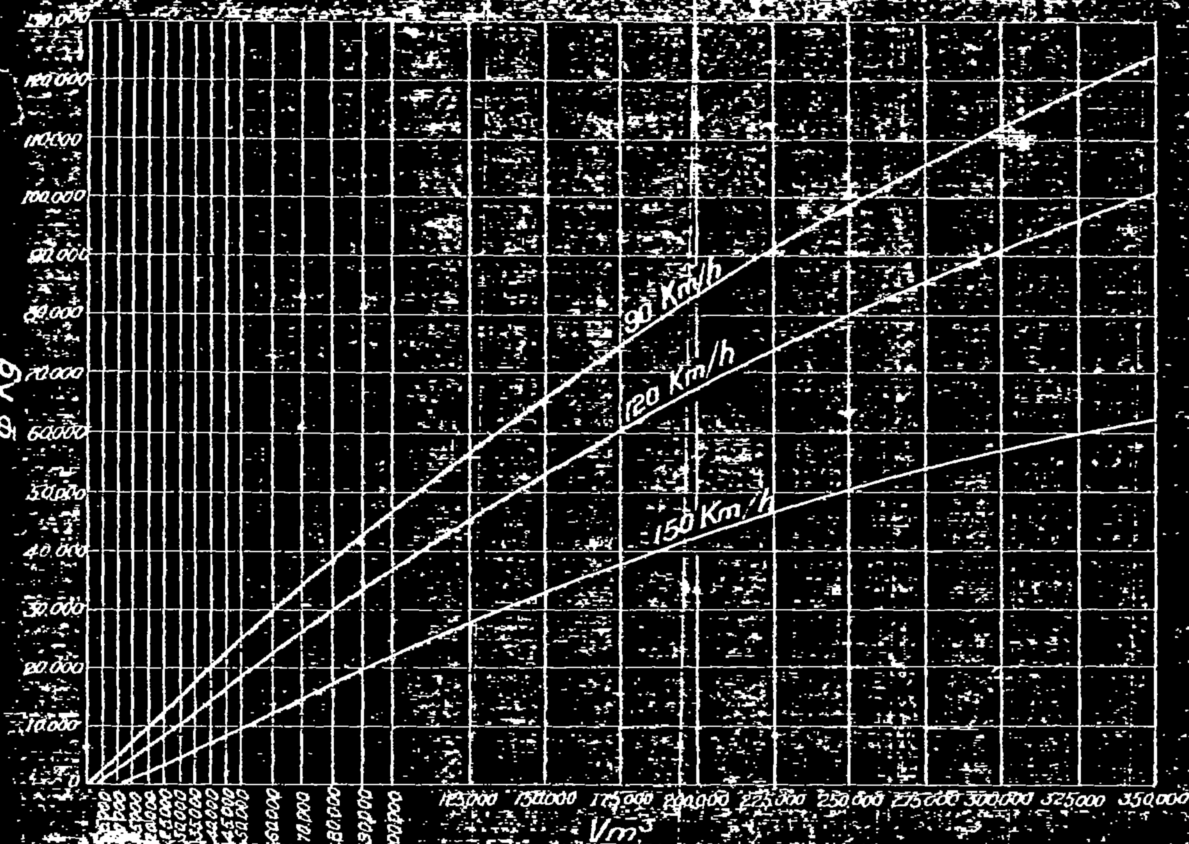
Maximum Velocity, 150 km/h.

Normal Velocity of Flight, about 119 km/h.

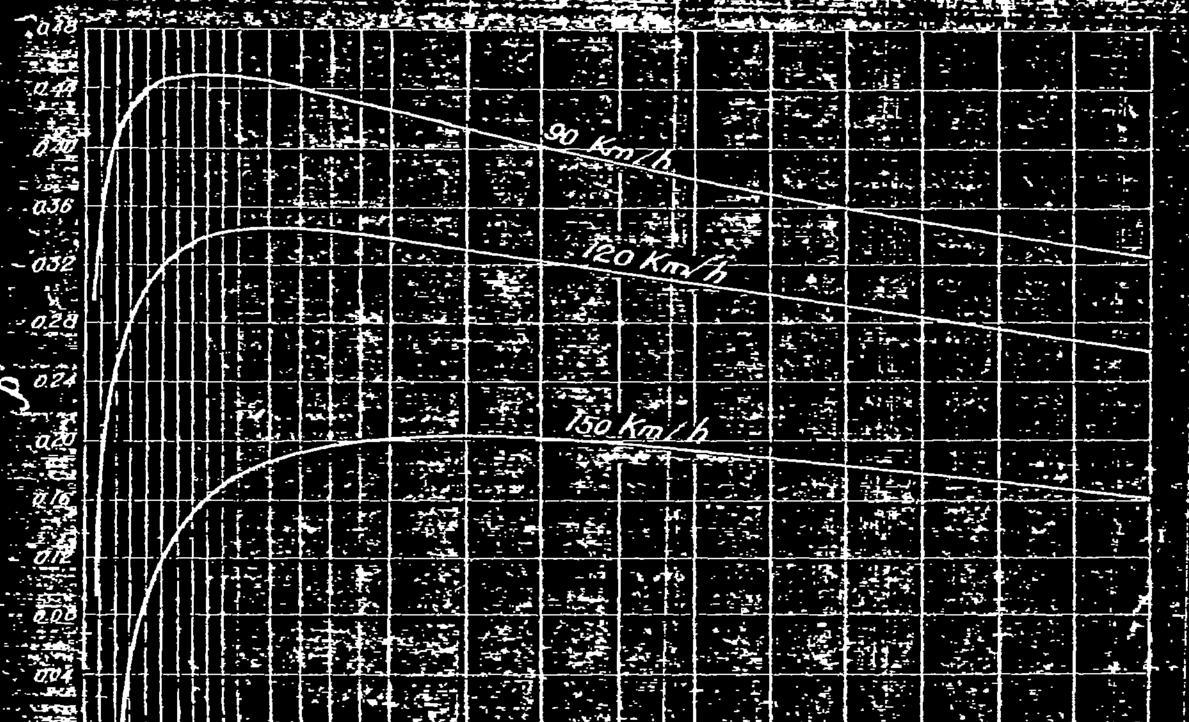
Cubature V m^3	Useful lifting force Φ kg.	Coefficient of utilization ρ	Fuel and oil per km. α kg.	Limit distance L km.	No. of passengers for 500 km.	No. of passengers for 1000 km.
5,000	-1,063	-0.296				
10,000	- 289	-0.026				
15,000	772	0.0468	4.461	173	0	0
20,000	1,957	0.0889	5.406	362	0	0
25,000	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	1,739	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

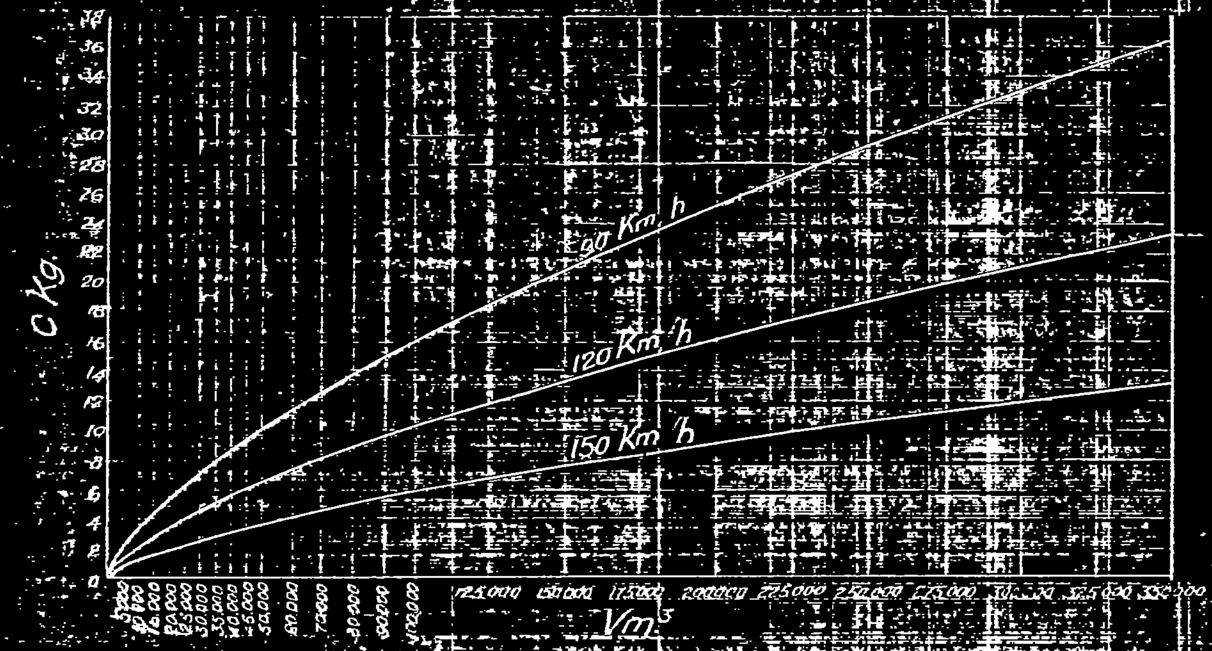
I USEFUL LIFTING FORCE. (Useful load + benzine and oil)



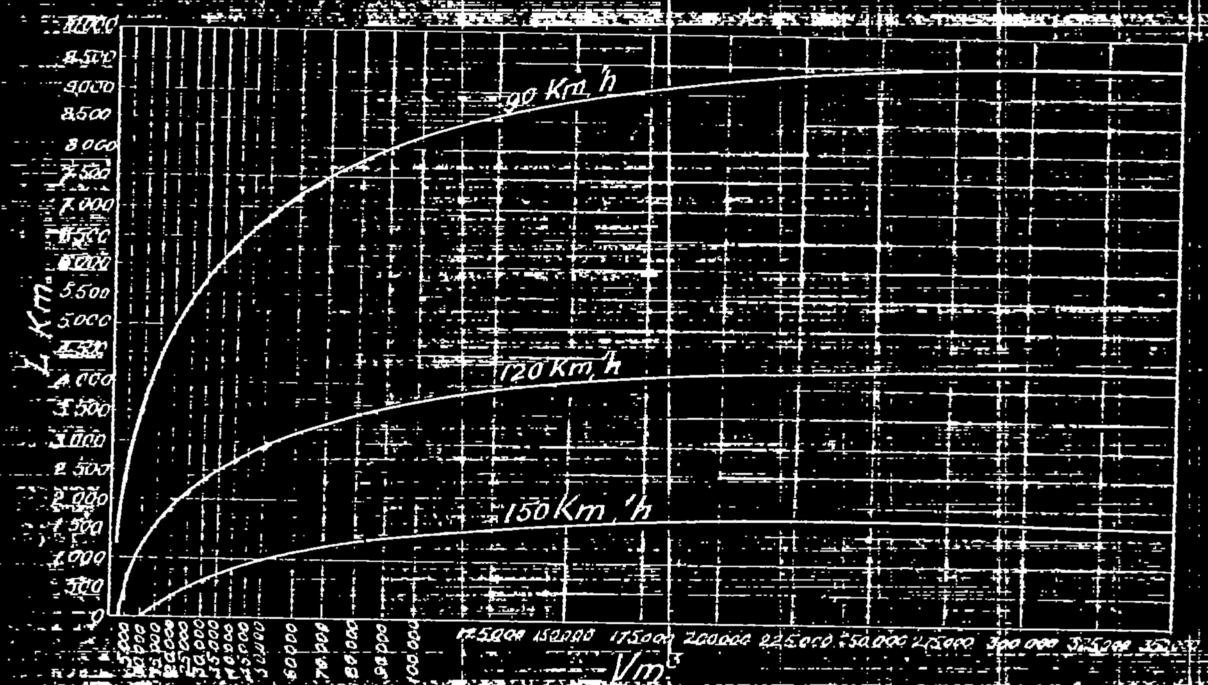
II COEFFICIENT OF UTILIZATION AND MAXIMUM ALTITUDES.



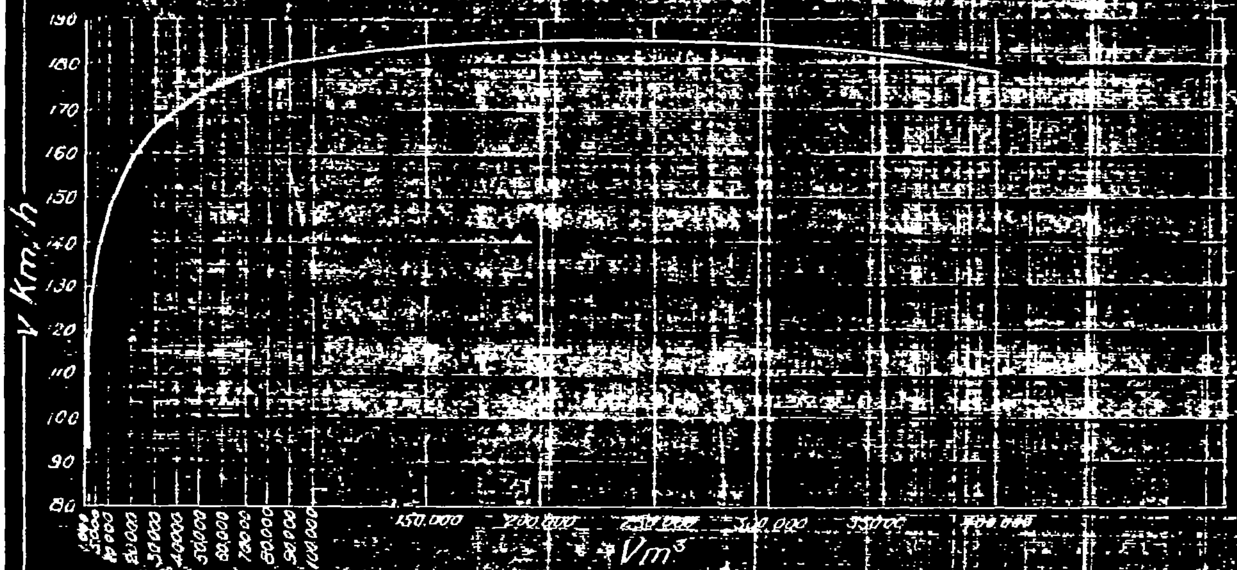
III SUPPLY OF BENZINE AND OIL PER KILOMETER.



IV LIMIT DISTANCES

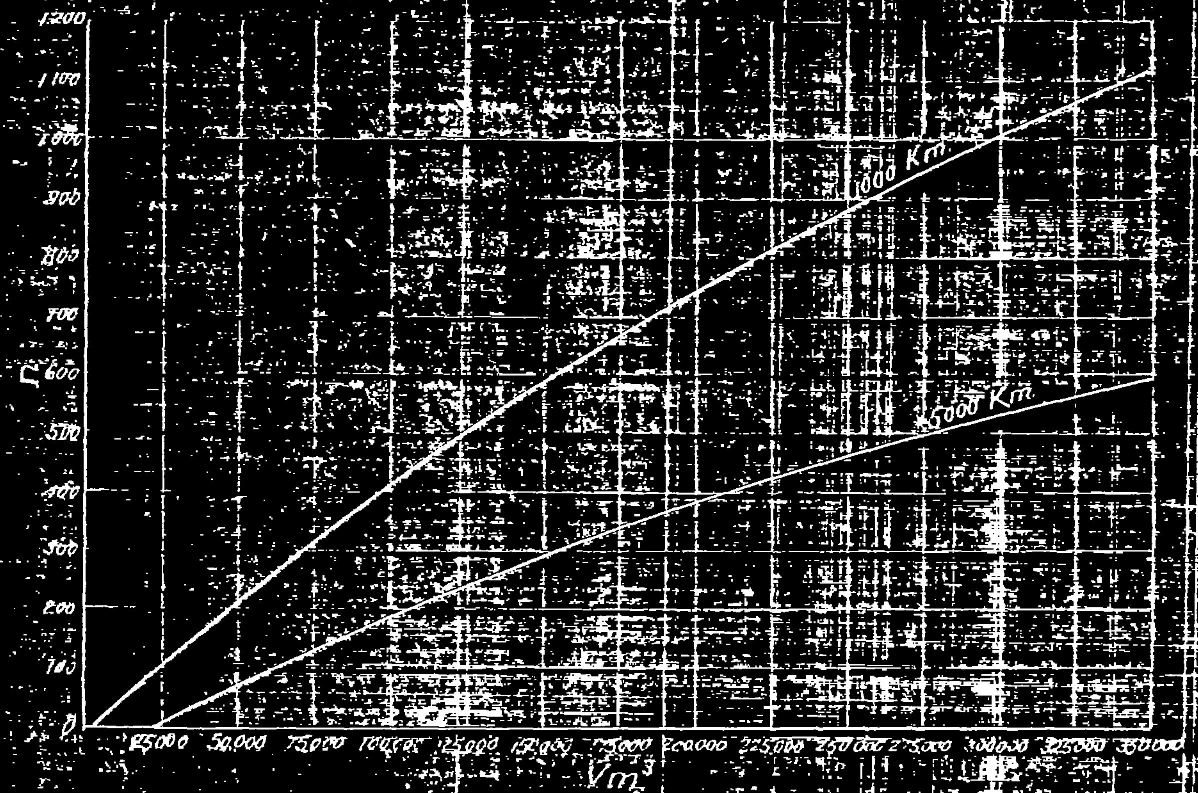


V - EFFECT OF VELOCITY

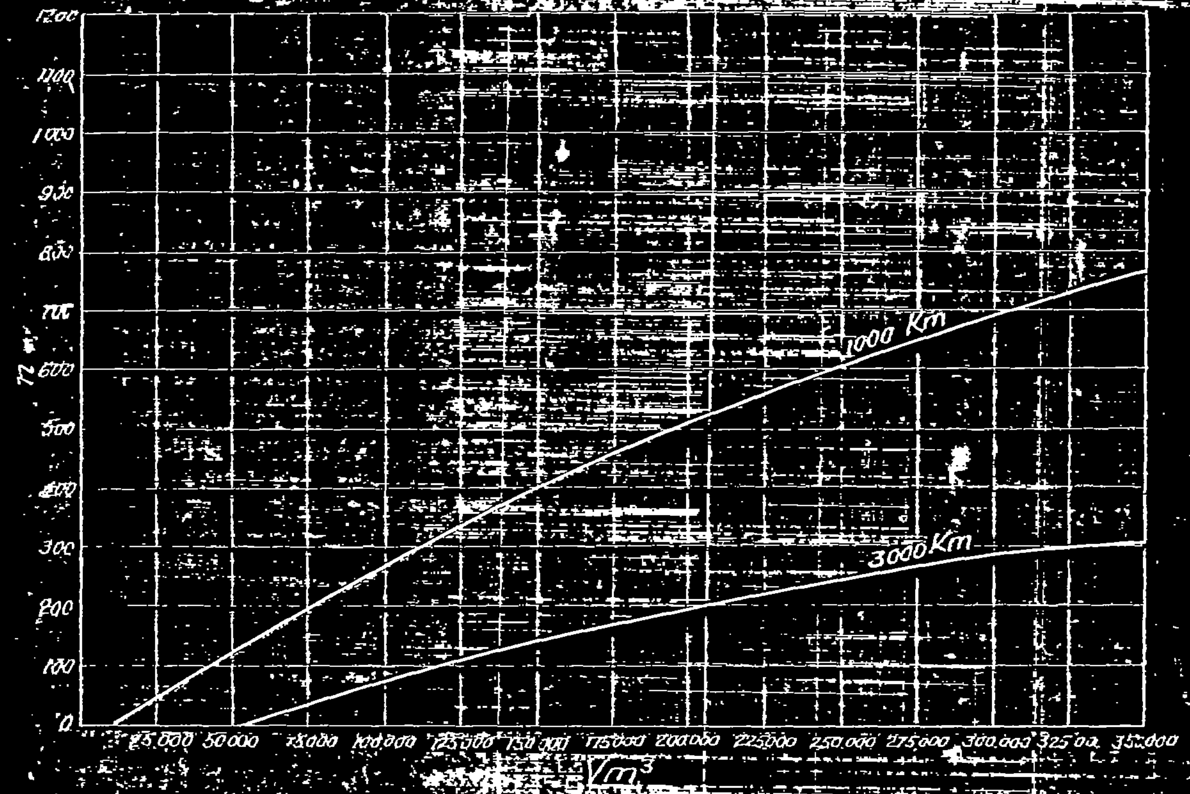


VI - VII - VIII - INFLUENCE OF LENGTH OF FLIGHT ON NUMBER OF PASSENGERS.

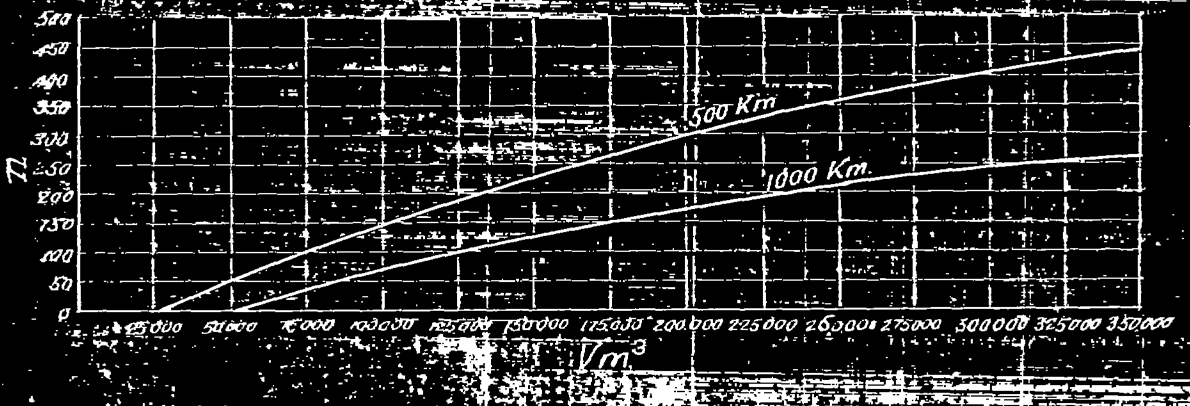
VI. v = 90 Km/h



VII. v = 120 Km / h



VIII. v = 150 Km / h



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

THE FUTURE OF AERIAL TRANSPORTATION IN PUBLIC SERVICES.

By Umberto Nobile,
Director, Aeronautical Constructing Establishment, Rome.

September, 1922.

THE FUTURE OF AERIAL TRANSPORTATION IN PUBLIC SERVICES.*

By Umberto Nobile.

Any one wishing to express synthetically the essential characteristics which differentiate the airship from the airplane, would not hesitate to ascribe to the former great potentiality of transportation with limited velocity, and to the latter great velocity with limited potentiality of transportation. (Note- In nomenclature peculiar to aerial transportation, it would perhaps be well to introduce this new term: potentiality of transportation, which is understood to mean the maximum quantity of passengers - kilometer or tons-kilometer - which the aircraft is capable of carrying, under the assumption that navigation is effected at a determined height of, say, 5000 meters above sea level. The opportunity of employing this new term comes on reflecting that the term "useful load," by which is meant the total weight of fuel with relative tanks and reserve containers, and the weight of the passengers with relative cabins, or, in other words, the term used in my previous article: useful lifting power, does not define completely the transportation characteristics of aircraft, and, consequently, one is obliged to give also the radius of action, which, however, varies according to the hypothesis made in regard to dividing up the useful load between the weight of the gasoline and oil, and the weight of the passengers or merchandise. Therefore, for the sake of uniformity and greater convenience in drawing comparisons, it is well to fix once and for all the criterion on which is based such distinction, and define, as stated above, the potentiality of transportation of aircraft. This also is proportional to the maximum distance over which aircraft can travel, without landing, or distance limit, as I termed it in my preceding study.)

These characteristics are deduced from a study of the progress made during the last years in both types of aircraft: in airships of recent construction the useful loads are calculated in tons, whereas the unit of measure as applied to airplanes is still the quintal.

Approximately, the same ratio is applicable to the radii of action, that is, a few thousand kilometers for airships, a few hundred kilometers for airplanes. As regards velocity, if airships have exceeded 100 kilometers per hour, airplanes have for some time now exceeded 200 kilometers per hour. In order to be convinced of the exactness of these statements, it is sufficient to glance at the characteristic data in the tables appended hereto of the airships and airplanes constructed in Germany during the war. These tables show that the maximum useful loads of the airships are quite twelve times greater than those of airplanes (Zeppelin L.71 compared to airplane Zeppelin R XIV) and the potentiality of transportation (and consequently also the distance-limit that can be flown without landing), is seven times greater

* Translated in Office of the Military Attache, Rome.

than that of airplanes (airship Zeppelin L.71 compared to airplane Friedrichshafen, G.IV a). Let us compare the data relative to the largest airship constructed by the Germans during the war, the L.71 to the greatest German bombardment airplane, the R.XIV, constructed in 1918 by the "Zeppelin-werke - Staaken," and with the fastest German pursuit airplane, the Siemens-Schuckert D.VI:

	Useful load kg.	Velocity km/hour	Useful load per HP kg.	Useful load per HP x velocity (proportional to potentiality of transportation)
Airship L.71	51,000	122	33.0	4,026
Airplane R.XIV	4,200	120 to 135	3.4	437
Airplane D.VI	2,300	220	1.4	317

Now, these different characteristics of the two systems of aerial locomotion are so closely connected with the very nature of the two systems, that a noteworthy variation of these characteristics is considered highly improbable in future constructions.

On the other hand, sufficient light has been thrown on this point by mathematical analysis through the application of the laws of mechanical similitude, analysis, which, while to some may perhaps be considered a tedious exercise, nevertheless develops previsions of indisputable value from the standpoint of order of greatness, and gives results which, in every case, constitute a valuable guide for the technician by pointing out the best way to improve the characteristics of the airplane, and surpass with his inventive genius the very roughly approximated previsions deduced in accordance with the law of mechanical similitude.

Quite distinct are the fields of practical application, both civil and military, accruing to totally different characteristics of the two means of transportation. It is a mistake to admit that the lighter-than-air and the heavier-than-air can compete with one another in the same sphere of activity; it is even a bigger mistake to suggest that one could actually beat out the other. Viewing in the same light the matter of land and sea transportation, no one can suggest that as a result of competition between the automobile and the train, the ship and the motor-boat, one or the other is doomed to disappear.

We will now take up the question as to whether the actuation of public services for transportation of passengers with either of the above means of aerial locomotion is possible and profitably expedient.

Such study must be made in relation to the four main points of the question: safety, regularity, comfort, and cost of the aerial journey.

I. THE SAFETY OF AERIAL TRANSPORTATION.

Theoretically speaking, in order to guarantee the safety of a public transportation service, everything must be tuned to a state of perfection, with a perfect functioning of the entire equipment: that is to say, fixed plants, the routes, the material, the personnel, the organization. Practically, absolute perfection is unattainable; consequently, it happens that defective material or mechanism, inattention or negligence on the part of the personnel the non-observance of a regulation, the influence of an extraneous action, can be the cause of a railway disaster or a shipwreck.

An accident obeys laws which, although not definable in themselves are none the less real: hence, transportation accidents occur with a certain frequency in every branch according to the type of plant, the grade of perfection of the material employed, the personnel, and the organization. Therefore it can be said that every branch of transportation has a degree of safety peculiar to it. In order to be convinced on this point, suffice it to note the great uniformity of the statistics of railway accidents. For example, on our State railways during the years from July, 1906, to June, 1914, the victimsof railway accidents, killed and injured, were for each year and for every 100,000 trains-kilometers: 1.36 - 1.22 - 1.33 - 1.49 - 1.36 - 1.55 - 2.11 - 1.60. The difference between the maximum and minimum values and the average value is only 40% and 30% respectively.

The question therefore is whether in the present state of aeronautical technique, an aerial service can offer a degree of safety comparable to that of the railway, automobile, or sea services, when run under normal conditions.

THE SAFETY OF AIRPLANES.

This is a question of such grave importance that it is more than ever a duty to be frank.

Although dynamic support, this brilliant conquest of human ingenuity, which, in its exterior forms and in its intimate mechanism is so much more genial and aesthetically suggestive than static support, has rendered a great service during the late war, it cannot be exploited to the same useful extent in civil activities unless the grave risks which seem to be inherent to it, are eliminated.

One of the chief causes retarding the civil progress of the airplane lies in not immediately acknowledging the really weak side of the technique of the heavier-than-air, and in attempting to launch prematurely into commercial aviation with airplanes which are not safe, because by failing to admit this weakness, energy and means which could be much more profitably used in solving this fundamental and essential problem of safety, are diverted into other channels.

The meager safety of dynamic flight with the airplane is unfortunately proven by the aviation disasters which occur with such alarming frequency. To conceal this painful truth will not eliminate the evil, for even now the public has rather an exaggerated notion that the safety of the passenger in an airplane practically depends on the good working of the engine and on the pilot's ability.

We give here some comparative statistical data. From an official report on the progress of British civil aviation, one gathers that during the period of May, 1919, to September, 1920, (17 months) about 2,000,000 kilometers were flown, carrying a total of 1,000,000 passengers. There were 45 accidents, of which 19 did no damage to persons, and 26 resulted as follows:

Passengers	(dead : 8	Pilots	(dead : 7	Casual	(dead : 1
	(injured : 15		(injured : 13		(injured : 1

That is to say, for every 100,000 kilometers flown (airplanes-kilometers) there were:

Passengers	(dead : 0.36	Pilots	(dead : 0.32	Casual	(dead:0.045
	(injured:0.68		(injured:0.59		(injured "

In order of greatness, these figures are fully confirmed by the statistics of accidents which occurred on the French routes. In fact, from a report of Monsieur Pierrot which appeared in the review "l'Aeronautique," one gathers that in 1919-1920, during which time 1,190,000 kilometers were flown, 7 persons were killed and 7 injured. That is to say, 0.59 dead, and the same percentage of injured for every 100,000 kilometers flown.

Let us compare the figures given above with those of the Italian State Railways. On the latter, during the period 1911-1915, the accidents for every 100,000 trains-kilometers with passengers, produced the following damage to persons:

Passengers	(dead : 0.01	Employees	(dead :0.008	Casual	(dead:0.004
	(injured:0.42		(injured:0.73		(inj. 0.37

In comparing these figures with those of the aviation service one must above all bear in mind the enormous difference existing between the average number of persons transported with each flight and in each railway train. Therefore, it is not surprising that the percentages of injured in both cases are the same notwithstanding the fact that the possibility of accidents in airplanes is unfortunately very much greater.

It should be noted that in the aerial service, of the total number of casualties (passengers and pilots) 35% were killed (English statistics), while on the railways the percentage of deaths is decidedly smaller, viz.: 2.4% for passengers and 1.1% for men on duty in the service. This does not confirm, even if confirmation were necessary, the heavier percentage of flying accidents over railway accidents. This remark, together with the other remark made above in regard to the number of persons transported on every journey, makes the comparison between the two statistics more alarming still. In fact, admitting that the relation between the number of persons transported by airplane and by train is only 1 : 100, the possibility that a passenger will lose his life in an airplane on account of an accident is 3600 times greater than if he were travelling on the railway.

Is it possible to solve the problem?

There is no denying that serious risks are, apparently, unavoidably and intimately connected with dynamic support. To remain in the air only in virtue of a working mechanism invariably implies the possibility of a fall or at least of an involuntary landing on perhaps some ill-adapted ground, when trouble or a breakdown occurs in the mechanism itself, or if the pilot makes an error in his maneuvers.

It is well to call to mind the example of nature, because in birds, the pilot and engine are just one harmoniously-working, organic whole, gifted with sensibility and reactive power, which is incomparably greater than that found in the mechanical bird

It must be stated that since the armistice was signed, only very small efforts have been made towards solving this problem, which is certainly not impossible to solve. The very psychology of war, which lowered the measure of consideration for human life, has influenced the direction of the efforts made and the means adopted, and an increase of velocity and endurance rather than safety has, so far, been the chief aim.

It is necessary, however, to convince oneself that whereas commercial aviation has not really made any serious progress by constructing airplanes similar to the present ones which may be capable of transporting 100 passengers or more, it would, on the other hand, make a gigantic stride if an airplane were constructed which would carry, maybe, only one person, but with that measure of safety which unfortunately is still a matter of conjecture.

A great step in the right direction has been made by the fractional distribution of the motive power, by the adoption of engines of greater reliability, and by greater strength in construction; but a really great progress will have been made only when the intrinsic stability of the airplane has been increased and when, under normal flying conditions, an important reserve power is available, as is already the case with airships.

This, in my opinion is the fundamental problem. Only when it has been solved, will the airplane make its triumphant entry into the field of public services, otherwise its activities will certainly be confined to those of a military and sporting nature.

SAFETY IN AIRSHIPS.

Happily, the same drawbacks are not found in the airship. Transportation by airship today can be made quite as safe as by sea.

Let us make a rapid survey of the more serious accidents that could occur and be a source of danger:

(a) Breaking of a part of the structure.
(b) Trouble with, or failure of an engine.
(c) False maneuver.
(d) Depletion of gasoline and oil supplies.
(e) Fog.
(f) Sudden storm.

(a) Breaking of a Part of the Structure.

The breaking of an element of the keel or of any other vital supporting part of the airship, or trouble with the controlling organs, very rarely happens with our airships on account of the great strength of every single part, which strength can easily be obtained without excessively reducing the coefficient of utilization. But even admitting that any breakdown of the kind should occur, the safety of the passengers would never on any account be jeopardized because the breakage could be repaired on board the airship itself. At the most, in the event of it not being possible to complete the repairs on board, a reduction of speed might become necessary.

The possibility of repairing a breakage goes naturally hand in hand with the possibility of having access to the seat of the trouble. From this standpoint, it is opportune to remark on the superiority of our T type (Roma type), in which all the supporting elements, all the organs of control, maneuvering safety, can easily be reached by the crew.

(b) Trouble with, or Failure of an Engine.

Considering that in the normal navigation of airships, only a part of the available engines is used, (in our T airship, one-half or one-third is used), the others being kept in reserve, one arrives at the conclusion that trouble with, or failure of a group of engines can never jeopardize the safety of the journey, all the more because in nearly every case it is quite possible to make repairs on board the airship without stopping the flight. Apropos of this, suffice it to mention that during the final testing and acceptance of our airship "Roma", a new cylinder was quickly put on without any difficulty, in addition to the usual changing of valves, springs, spark plugs, magnetos, etc. Changing the propeller became quite a matter-of-fact operation on every trip, substituting on one of the engines, a short time before landing, a reversing propeller for the normal air screw. The operation was carried out in about 15 minutes.

(c) False Maneuver.

Anybody who has travelled on our airships, and in particular on the "Roma", knows quite well that in the course of navigation the actual steering of the airship is a very easy matter. Even if the steersmen leave their wheels, the airship goes straight ahead just the same. In truth, under normal navigating conditions one cannot conceive how a false movement could jeopardize the safety of the airship. From this standpoint, safety is even greater than on the railway where the inattention on the part of the engineer or error by a switchman, is sufficient to cause a railway disaster.

The work and ability of the crew acquires the greatest importance only at the moment of landing. But even if a false maneuver in landing is made, the maneuver would merely have to be repeated, and in the worst of cases the airship would hit the ground and get damaged, but a disaster would never occur.

(d) Depletion of Gasoline and Oil Supplies.

This is the most serious thing that could happen to an airship. With depleted supplies of gasoline and oil, the airship lies at the mercy of the wind. Should this happen when the airship is travelling over the land, the passengers run no risk, because by maneuvering as if it were a free balloon, it would be possible to land, even though this is somewhat risky as far as the actual material is concerned. Should this shortage of supplies happen when on the high seas, it is a much more serious affair, even if life-belts are provided, or even small life-boats.

But such a contingency has merely been mentioned in order to exclude it, because it cannot, in fact, should not, ever happen. No matter what kind of journey is undertaken, one must, apart from the necessary quantities of gasoline and oil, also have an adequate reserve of fuel to face the possibility of the airship being dragged out of its course, or in case it is found necessary to lengthen the journey or increase the speed.

It is inconceivable that a flight should be made in an airship with an adequate supply of fuel, just as it is incomprehensible that a steamship should start on a voyage with insufficient supplies to carry it through the journey.

(e) Fog.

Whereas fog may constitute a real danger to the airplane in the event of it having to land, it is never so for the airship. (The accident which happened to the British airship R.34 on January 28, when it bumped against hilly ground at Scarborough, must be considered exceptional, and probably was due to a navigating error. Considerable damage was done to the cars containing the engines, but nobody was injured.) At the most, fog can cause a delay in landing, compromising the regularity but not the safety of the operation. The presence of thick fog, which is a prohibitive condition for the landing of airplanes, is not prohibitive in the same sense for airships. I will cite the case of two Italian military airships, the M II and M 14, which in February, 1918, during the same night, landed in a very thick fog, the one at P Piova di Sacco (Chioggia) and the other at Cavarzere (Padova), and on ground which was thickly covered with tall trees. The two airships remained anchored to the trees for about 11 hours, until the fog had lifted, whereupon they proceeded on their journey.

(f) Storm.

The possibility of a storm coming up, especially on long journeys, must also be taken into account, even if a good aerological information service is available. It may seem an exaggeration to assert that in such a case an airship is better off than a ship on the sea; nevertheless, it is an indisputable fact.

The airship (and much more so the airplane) has the advantage over the ship in that it has greater velocity (two or three times as much), and there is open to it the possibility of climbing up over and away from the storm. The ship has not this possibility and must face the storm.

The Danger of Fire in Airships, and Helium.

We have not included among the possible accidents, the danger of fire, because when airships are well designed and constructed, such as ours are, the danger is non-existent. However, it is well to dwell briefly on this point.

There has been much discussion about helium, and generally, great importance is attached to its industrial production under the consideration that by substituting it for hydrogen, all danger of fire in airships is eliminated.

Now, in principle, there is no denying that to substitute an inert gas for an inflammable gas is preferable. But apart from the fact that it is very improbable that helium can be produced in quantities sufficient to meet aerial navigation, and at a satisfactory price, I am of the opinion that the moral advantage gained by the substitution of helium for hydrogen, would not compensate sufficiently for the sacrifice of lifting power, with the exception naturally, of military airships, which are the only ones really exposed to the danger of fire during navigation when struck by hostile gunfire.

As regards civil airships, I spoke of the moral advantage because really, as the engines both on our and on the German airships are detached from the envelope, and work in the open air, there is no danger of fire during navigation. (An official report of the British Air Ministry states that on 4,000,000 kilometers flown by the British airships during the war, only one was lost by fire during navigation. This was during a trial flight of a new type of airship, and the cause of the fire was immediately located and eliminated.)

In order to avoid all possibility of fire in the hangar, it is necessary to take severe measures of precaution. Nowadays these measures are so very strict in airship hangars that undoubtedly a fire is more common in an airplane hangar than in an airship hangar.

It would not be surprising if, after substituting helium for hydrogen, and loosening somewhat the precautionary restrictions, the danger of an outbreak of fire will be increased rather than diminished.

2. REGULARITY IN AERIAL TRANSPORTATION.

When we speak of regularity in public transportation service, we mean essentially: punctuality in arrivals and departures.

From this point of view, we frankly recognize at once that regularity in an aerial service is seriously handicapped on account of the service being subject to atmospheric conditions, which means that navigation is possible only on a certain number of days of the year, a number which varies according to the characteristics of the aircraft, according to the region in which the service is developed, and according to the length of the voyage.

We hasten to add that such subjection is, in the case of airships really much greater than it is for airplanes, because the real difficulty is not that of keeping up in the air even against strong wings but in entering and leaving the hangar when strong cross-winds are blowing. (However, in the above-mentioned report of the British Air Ministry on this subject, it was stated that, "Worthy of note is the fact that for 11 months of the year 1918, there were only 9 days in which no flight was made by airships in the British Isles, where it is well known, the worst climatic conditions in the world prevail. The airship can fly on days of fog or low clouds when it would not be advisable for an airplane to do so.")

The Question of Hangars, and the Mechanical Maneuvering of Airships.

We are confronted here with a problem of fundamental importance for the civil future of airships, viz.: the possibility of leaving the ground and landing in strong winds without employing for the relative operations an excessive number of men, and without exposing to excessive risk the structures of the airships.

The problem may be met either by special forms and arrangements of the hangars, for example, with movable hangars such as are already in use in Germany, or by equipping the present hangars with two wind-screens, which, starting from the ends of the walls of the hangar, stretch out to the landing field in such a manner as to permit the airship to enter between the two projecting wings, keeping the axis of the airship normal to the axis of the hangar; or, again, by adopting special mechanical devices (a "Crocco" revolving platform, or rails). It is merely a question of expenditure for the relative plant and equipment.

This extra expenditure however would be largely compensated for not only by the attainment of greater regularity of service but also by a decrease in the expenses relative to labor, and above all by the increased transportation, so that even taking into account the major amortization and interest on the capital expended on the plant and equipment, a considerable diminution in the cost of the passenger-kilometer would be realized, as we shall show later by a few numerical data.

It is also thought that the question could be radically solved by abolishing hangars altogether, and substituting for them special anchoring devices either on the ground or on the water.

Without denying the importance of systems which serve quite well for short stops for fuel-replenishing purposes, and for loading and unloading passengers, we hold that there is no likelihood, at least for some considerable time to come, as far as large airships are concerned, that there will be any abandoning of that commodious, safe shelter offered by the hangar, which alone can effectively protect airships from the fury of storms, and assure them a long life. The hangar is no less indispensable for the actual execution of ordinary maintenance work.

The Necessity of Confining the Public Service to the Most Favorable Season.

No matter what improvements may be made in the technical construction of aircraft or in the fixed installation of airdromes, or in actual maneuvering, there is no denying the fact that an aerial service can never be run with the same regularity as railway or sea services, even though the service were maintained all the year round.

In a study which I made in 1918, on the cost of aerial transportation by airships, I pointed to the opportunity, or, I should say, to the necessity of confining the service to the most favorable season because it is only by guaranteeing punctuality of departures and arrivals, nine times out of ten, that it will be possible to win the confidence not only of pleasure-seekers, but also of business men. A minor punctuality could be tolerated only for the great transatlahtic services. By this we do not mean to convey that the plants, equipment, airships, and personnel could not be profitably utilized during the periods of fine weather of the off season. On the contrary, I consider it highly opportune also from the economical point of view, to take advantage of such periods of fine weather to run a service in places where there is a large circulation of the tourist element, there being no absolute necessity in this case of great punctuality and regularity as is the case with a public service. This applies particularly to Italy where, by a happy coincidence, the circulation of foreign tourists in the winter and spring months, which are the least suitable for a regular service of aerial transportation, is especially pronounced.

3. COMFORT IN AERIAL TRAVEL.

If safety and regularity are indispensable requisites for a public service, the actual travelling comfort is a matter of considerable importance. The superiority of the airship over the airplane, is also in this respect, very apparent.

The great space available on airships, and the great amount of useful load carried by them, afford the possibility of providing for the passengers' comfort, which is both desirable and necessary on a long journey, such as comfortable seats, sleeping accommodations, toilet rooms, reading room or sitting room, kitchen, etc In other words, with the airship it is possible to offer practically the comfort offered today on the railway and on transatlantic liners although in a reduced form. Naturally, obvious considerations of economy of weight and the exigiencies relative to the distribution of loads, will impose certain restrictions, but to compensate for these the traveller will not suffer from seasickness.

These statements require no illustrating inasmuch as any one who has travelled on our airships, and in particular, on the "Roma", will recognize the truth underlying same. The freedom to move in a space of over 300 feet, the smooth travelling, and perfect stability are matters which need not be elaborated upon.

The only thing which troubles the passenger, until he is accustomed to it, is the noise of the engines, which is quite as great a nuisance as the noises of the railway, but which, however, can be eliminated much more easily than those of the railway by simply placing the passenger cabins in front of the engines, or by adopting a special structure for the cabin walls.

As things stand, it should not be considered an exaggeration when we state that the airship will be one of the most comfortable and enjoyable means of travel, perhaps <u>the</u> most comfortable, in view of the advantages it offers over both steamships and railways in respect to seasickness, and the jolts, bumps, vibrations, and annoying sounds encountered on sea and land travel. Naturally, this statement cannot apply to the airplane in its present state. The limited space, and limited carrying capacity naturally reduce comfort to a minimum. Bumps, shocks, and vibrations are very difficult to eliminate. We must conclude therefore that the airplane today, although quite well adapted for sport and, generally speaking, for the transportation of passengers desirous of experiencing pleasant emotions, is not yet suitable for the transportation of <u>normal</u> passengers.

4. THE COST OF AERIAL TRANSPORTATION.

We come finally to the last but very important question of the cost of aerial transportation.

First of all, it is a curious thing that the general opinion is that the cost of aerial transportation by airship is greater than that by airplane. It is just the contrary, when of course the airship is used for transportation adapted to its peculiar characteristics.

The arguments brought forward in support of this opinion, without backing them by numerical data, are well known, namely: expenses incidental to the hangar, to the maneuvering personnel, and to hydrogen. Later on we will illustrate by a concrete example how unfounded this opinion is, and how the expenses for the hangar, maneuvering personnel, and gas, do not really figure excessively in the cost per unit of transportation.

Meantime, it is necessary to bear in mind that with airships the consumption for navigation (consumption of gasoline and oil, and wear and tear of the engines) is, with respect to the units of weight carried, considerably less than in airplanes. This difference, which is already considerable in small airplanes, becomes greater as the dimensions of the airplane increase. Taking as an example, the German constructions (see tables) we find that whereas in the airplanes we have a maximum fuel load of 4.17 kilograms per HP, with airships this maximum is eight times greater, 33 kilograms per horsepower.

There is no denying that the equipping of an airship service requires a much greater outlay of capital than the equipping of an airplane service; but it is a mistake to deduce therefrom that transportation is also more expensive, just as it is a mistake to argue that railway transportation costs, unit for unit, more than automobile transportation, because of the very much greater outlay for the former.

The great carrying capacity, coupled with the undeniable fact that the regular running of any service requires a heavy outlay for plants and organization, clearly shows that the airship is particularly adapted for transportation on a large scale and for an intense traffic. On the other hand, the characteristics of the airplane: small, useful load, limited endurance, comparatively small outlay for plant, equipment, and organization indicate that it is only suitable for a service of very limited traffic.

To adopt airplanes for transportation on a large scale, or airships for transportation on a small scale is, generally speaking, tantamount to increasing the cost of transportation.

Concluding, even from the economical standpoint, the fields of action of these two different means of aerial locomotion, appear to be well defined. A still closer analogy between the two means leads us to compare the airship with the train or steamship, and the airplane with the automobile or motor-boat. The airship clearly shows its suitability for a public service, and the airplane would appear best suited, generally, for services of a private nature.

We believe therefore that it is very probable that while in the future, the major public services will be run essentially with airships, the airplane will be housed at public airdromes and used principally for private transportation purposes, not excluding however the possibility that the grand aerial routes covered by airships would have branch routes run by airplanes, and thus complete the service, especially the postal service, just as public automobile services complete the railway network in Italy today.

The Cost of Aerial Transportation in Comparison with the Cost of Other Traction Systems.

A first attempt to establish, at least in order of importance, the cost per unit of transportation (cost of the passenger-kilometer or of the ton-kilometer) was made by me before the cessation of hostilities in 1918, (see Journal of Civil Engineering, Rome, 1918, p. 493). The study was confined to airships, but I also pointed out that the cost of transportation by airplane would in general be very much greater.

Basing naturally my conclusions on a roughly approximated assumption, I endeavored to point out how not only the characteristics of the airship itself (carrying capacity, maximum velocity, normal velocity) but also other characteristics of the service (length of route, number of flights, number of days navigation) influenced the question of cost.

I assumed the aggregate number of kilometers flown in one year to be constant, and implicitly reckoned that the airship was always to be utilized to its utmost capacity. With this hypothesis, it was clear that one would arrive at the conclusion that, in regard to transportation by airship, the greater the airship the smaller the cost per unit, but that the cost increased when a greater velocity was attained, and the journey lengthened. In view of the hypothesis made, this is tantamount to saying that the cost decreases as traffic increases.

As a result of the study one gathered, for example, that with an airship of the capacity of 30,000 cm. capable of developing a maximum velocity of 108 kilometers per hour, and which was worked at a normal velocity of about 86 kilometers per hour (one-half of the available power) with a supply of gasoline and oil equal to double the required amount for a normal flight, the cost of the passenger-kilometer (= quintal-kilometer) was L.0.49 over a distance of 600 kilometers, and L.0.69 over a distance of 1000 kilometers.

Furthermore, one foresaw the possibility of reaching minimum prices of 25 or 30 centesimi per passenger-kilometer with an increased traffic, adopting cubatures sufficiently large in relation to the velocity and to the length of the journey.

We must however point out that these forecasts were based on the assumption that the prices of raw materials had already gone back to their normal level, which I held to be only a little higher than pre-war prices. Thus, for example, the cost of an airship was calculated at 70 lire per kilogram of dead weight (today our types come up to about 120 or 130 lire). A workman was assumed to earn on an average L. 3,600 a year (today, double this amount is barely sufficient). Hydrogen was assumed to cost one lire per cm. (today it still costs about L.1.60), and, finally, the cost of gasoline was then held to be L. 1 per kilogram, but costs today five times as much.

It is therefore most probable that if we made up these calculations in accordance with present market prices, and without taking into account the general tendency of prices to decrease, the cost per unit of transportation would be just about three times the amount mentioned above.

Such being the case, it is easy to assert that today aerial transportation by airship or by airplane costs much more than by any other mechanical means of transportation.

On the Italian normal gage railways, the running expenses before the war, excluding those of amortization and interest on capital, was on an average L. 0.0525 per passenger-kilometer and L.0.046 per ton-kilometer. Multiplying these figures by the coefficient 6 in order to reach present costs,, the price per passenger-kilometer comes to about L.0.32 and the ton-kilometer L. 0.28. By including amortization of, and interest on, capital, we should not be very far from the truth in stating that today on a normal gage railway the cost per passenger-kilometer amounts to from L. 0.40 to L 0.45.

Now if we consider an automobile service, which of all the various transportation systems approaches more closely that of an aerial service in that the type of engine and the kind of fuel used are the same, and in both services there are no expenses incidental to road-making and upkeep of same, we find that today the total expenditure for each kilometer (assuming a journey of 50 kilometers with two one-way trips daily) is L. 4.62. In fact, we get:

Interest, amortization of fixed plants, renewal of rolling stock	L.	0.55
Personnel	"	0.60
Consumption (in general)	"	3.30
Insurance	"	0.07
Various expenses	"	0.09
Government control	"	0.01
Total, per vehicle-kilometer	L.	4.62

that is to say, about L. 0.57 per passenger-kilometer, assuming that the vehicle carries on an average eight passengers.

Finally, we must remember that the price of sea transportation is much the same as the other two means of transportation mentioned above.

We can therefore conclude by saying that transportation by airship costs two or three times as much as the other mechanical means of transportation, unless one wishes to sacrifice safety, and regularity of service by reducing the fixed plants or the personnel, the travelling speed or the reserves of gasoline, oil, and ballast.

Is the Cost of Aerial Transportation Prohibitive?

As already stated, a further reduction in the cost of transportation by airship can be made by increasing the capacity of the airship. One can foresee however in any case that the cost will be 50% higher than that of railway transportation or maritime transportation. The cost by airplane will be at least twice as high.

But even admitting that a sufficiently safe and regular aerial transportation service costs more than the other mechanical means of transportation, it would be quite as unreasonable to conclude that, from the economical standpoint it is not a profitable undertaking, as it would be to state that the automobile was superfluous because more costly to run than the horse-drawn vehicle. The possibility of shortening the time occupied for a journey both by travelling at a higher speed and by following a straight route between points of destination, even when these centers of contact are not situated on the same level, or are separated by rough, undulating ground, the fact of not having to make any outlay for plants and maintenance of roads puts the air service in a favorable position to compete with the railway, steamship, or automobile.

Furthermore, the airship is the only mechanical overland means capable of transporting on a single journey as many passengers as a train, without need of a heavy outlay for the road. Suffice it to say on this point that in Italy today the cost of laying a railroad of normal gage, with 36 kilogram rails is not less than L. 400,000 per kilometer. Adding to this figure the outlay for constructing the actual road, which if made over flat country, more or less, amounts to half a million lire, we reach an aggregate expenditure of approximately one million lire: half a billion lire for a railway five hundred kilometers long!

In face of these figures one can but feel persuaded that in actual practice it may happen at times that also from the economical standpoint, the air service can become the only possible or suitable means of communication, as for example, where the question concerns the linking-up of localities comparatively far apart across desert zones, or rough, rocky ground, or at points where the traffic is not sufficiently intense to justify the enormous expenditure for constructing an ordinary roadway or railroad. However, on one thing we must insist, and that is, where air, land, and sea services exist contemporaneously there can be no talk of real competition between them. Such essentially different means of transportation assuredly would satisfy diverse commercial and industrial requirements.

Government and Private Enterprise in Public Aerial Transportation Service.

In the present state of aeronautics, it would be harmful to nurse illusions concerning the immediate contribution that private enterprise will give towards installing and running public aerial transportation lines.

The huge capital required, the complex, delicate, and costly organization, the technical difficulties to be overcome in order to assure a certain regularity of service, the heavy risks connected with the managing of such a new kind of organization, the high tariffs, and, finally, the diffidence and skepticism of the public, (which today are justifiable in part, in view of the fact that the airplane offers limited security and the airship limited navigability) are considerations which lead one to foresee that some considerable time must elapse before serious private enterprise will definitively take up the question of running public aerial transportation services.

If the State does not step in and stimulate, support, and coordinate private enterprise, or even develop its own air service, civil aeronautics must remain confined to the field of sport and tourist services, which are the only services void of risk, at least if run with airships, and are highly remunerative in countries visited by great numbers of foreigners. The most that private enterprise could do, would be to extend its activity to particular tasks of limited importance, such as aerophotographic relief work, exploring of uncultivated regions, etc.

Everybody recognizes today the great political and military importance of aviation, and the State must, in face of a languishing private enterprise, necessarily increase its own military aeronautical organization. The latter, however, will occupy itself only within the sphere of its own peculiar requirements, and will therefore contribute little or nothing to the solving of the essentially different problems bound up in the civil use of aerial transportation.

To favor the development of civil aeronautics, and to stimulate private enterprise towards attaining a well-organized transportation service is equivalent to constituting in the most economical way a solid base for the possible future aerial defense of the country.

Such interest of the State in the creation of commercial aviation should, at the outset, manifest itself essentially not only by contributing, with its own means, to the solution of the most important technical problems relative to the civil employment of the airplane and airship, but also by managing directly, by way of experiment, a public transportation service, confining it to a passenger line with airships and to a postal line with airplanes.

It is, naturally, far from our idea to suggest that the State, notoriously a bad manager of industrial services, should assume the monopoly of aerial services. On the other hand, one cannot deny that in the present state of things, the State stands alone as regards means and capacity to try, with a strong probability of success, an experiment of the kind, and the results of which, if successful, would create a basis for, and encourage, private enterprise, as well as furnish important data on which to determine the quota of contribution which the State could give in the matter of supporting private industry and enterprise.

The State contribution to private undertakings would probably have to embrace not only the question of actual working expenses, but also that of the initial outlay for installations. On the other hand, by supporting the firms given concessions, in the matter of the heavy expenditure incidental to fixed plants, will perhaps be not only necessary for stimulating private enterprise but advantageous from a political-military point of view because in all probability, this would lead to the State becoming the absolute owner of air stations and landing fields, and to conceding them only temporarily to private enterprise.

In running the service the State should have no hand in the actual determination of the fares or in establishing the status of the personnel (with the exception, naturally, of compulsory insurance against accidents during flight). The annual government subsidy should be given in such a form and measure as would effectually encourage the owners to attain not only the maximum of safety and regularity possible, but also at the same time an intense traffic. The subsidy could therefore consist of three distinct portions. The first should be proportional to the number of kilometers run, deducting heavy penalties for irregular or suspended service even if due to bad weather. The second should be proportionate to the number of passengers-kilometers actually transported in the course of a year. The third should be proportionate to the degree of safety which has been attained, or in other words, proportional to the number of accidents for every 100,000 kilometers flown.

COMPARISON BETWEEN COSTS OF TRANSPORTATION BY AIRSHIP AND BY AIRPLANE.

We will now proceed to give a concrete demonstration of the statements made above, that for a relatively intense traffic, the cost of transportation by airship is less than that by airplane.

1. GENERAL CHARACTERISTICS OF THE SERVICE.

We will consider an aerial service covering a route 500 kilometers long with a daily traffic of 75 passengers for the out journey and the same number for the return journey.

(a) Characteristics of the Service with Airships.

An airship of the capacity of 35,000 cubic meters is more than sufficient to transport 75 passengers over a route of 500 kilometers without a stop. However, the following conditions indispensable to a safe and regular service must be imposed:

A large reserve in motive power
A large reserve in fuel
A large reserve in ballast
Great strength in construction
High travelling velocity

Assuming the maximum velocity to be 120 kilometers per hour, and that normally, only one-third of the engine power is used, we obtain a flying speed of:

$$\frac{120}{\sqrt[3]{3}} = 83.1 \text{ km per hour.}$$

The total power installed on board the airship will be equal to:

$$N = 10^{6} - x\ 1.5\ x\ V\ 2/3\ v^{3} = 2775 \text{ HP}$$

therefore the power normally used will be 925 HP.

Let us calculate the average actual flying speed, assuming an average wind of 20 kilometers per hour:

$$w = 83.1 - \frac{20^{2}}{83.1} = 78 \text{ km per hour}$$

and therefore an average duration of the journey of:

$$\frac{500}{78} = 6.41 \text{ hours (6 h 25')}.$$

Therefore, for every journey we get an average <u>consumption</u> of:

0.25 kilograms/HP x 925 HP x 6.41 = 1480 kilograms and for each kilometer of the route:

$$\frac{1480}{500} = 2.96 \text{ kilograms}$$

equal to

$$\frac{2.96}{75} = 0.0395 \text{ kilograms for each passenger-kilometer.}$$

The useful lifting power of the airship, that is to say, lifting power available for passengers (including the weight of the cabins) and for the supplies of gasoline and oil (including the weight of the tanks) is: 12,895 kilograms.

If we impose the condition that the supply of gasoline and oil must be at least double the normal consumption of navigation, that is,

$$1.06 \times 1480 \times 2 = 3138 \text{ kilograms,}$$

and if for each passenger, taking the cabin into account, one estimated a weight of 100 kilograms, we should still have available

$$12,895 - (3138 + 7500) = 2257 \text{ kg.,}$$

which we should reserve for the safety ballast in addition to the 2450 kilograms which we have already taken into account in calculating the useful lifting power. We have, therefore, an aggregate of 4700 kilograms of ballast.

Owing to the short duration of the journey, the service could be run by only one airship. But we will estimate for the purchase of two airships, in order not to have excessive limits as regards time-tables, and because it is always better to have an airship in reserve.

We will assume that the service is run normally by both airships and only exceptionally by one, in the event of the other being out of commission.

In order to make a fairly accurate forecast we will assume that with the sheltering and maneuvering systems in use in Italy at present and taking into account the duration of the flight, we would have 150 flying days in one year. (The military airship M 1, employed for exploration work in the Tyrrhenian Sea from April 5, 1918, to March 10, 1919, made 120 flights without utilizing the full number of flying days.) Therefore, in one year, 300 trips would be accomplished, and 300 x 500 = 150,000 kilometers would be flown, transporting

$$150{,}000 \times 75 = 11{,}250{,}000 \text{ passengers-kilometer.}$$

(b) Characteristics of the Service with Airplanes.

In comparing the airplane with the airship, it is well to set forth the chief characteristics of the airplane. We will therefore select an airplane capable of travelling about 200 kilometers an hour. We will assume that the service is run with airplanes having the same characteristics as the "Savoia" seaplane S.12. It has:

Velocity : 214 km per hour
Power : 450 HP
Useful load : 725 kg (pilot excluded).

While taking into account the major number of flying days, it is well to assume for an airplane that the average wind is slightly greater than that for the airship; for example, 25 km per hour.

In this case we would have an actual average flying speed of:

$$w = 214 - \frac{25^2}{214} = \sim 211.1 \text{ km per hour,}$$

and consequently an average duration of journey of:

$$\frac{500}{211.1} = 2.37 \text{ hours } (2 \text{ h } 22').$$

For each trip we have a consumption of gasoline and oil of:

$$0.250 \text{ kg/HP} \times 450 \text{ HP} \times 2.37 = 267 \text{ kilograms.}$$

We will limit the reserve of gasoline and oil to only 50% of normal consumption. The supply will therefore have a weight of about 400 kg.

As there would be 325 kg of useful load still available, one can assume that the airplane is capable of transporting four persons on each journey.

The consumption of gasoline and oil for each kilometer will be on an average:

$$\frac{267}{500} = 0.534 \text{ kg.}$$

and for each passenger-kilometer:

$$\frac{0.534}{4} = 0.1335,$$

that is to say, 3.4 times more than when transportation is effected by airship.

In order to transport the daily number of 150 passengers, it is necessary to make $\frac{150}{4} = 37$ trips, and assuming that each airplane normally makes the round trip, we shall have 18 airplanes in service, to which number however we must add, in view of their short life, a reserve number of seven airplanes, thus making a total of 25 airplanes which it will be necessary to purchase for equipping the service.

The airplane has a greater number of flying days per year than the airship, that is to say, 200. Therefore, in one year 7,500 flights would be made, during which 3,750,000 km could be covered, transporting 15,000,000 passengers-kilometers.

2. CAPITAL FOR PLANT AND EQUIPMENT.

The unsettled state of the market as regards prices makes it a very difficult matter to estimate, even approximately, the expenses for the plant and equipment of an aerial service.

However, as our object here is merely to draw a comparison between the two types of transportation, the comparison itself will not be affected even if we are very far out in our estimation of the expenditure. Therefore attention is called to the fact that our figures have only a relative value.

(a) Service with Airships.

Fixed plants.

For each of the two terminus stations there must be provided a field and hangar with all its accessories (workshop, depot for fuel, gas generator, stores, offices, sleeping accommodation, etc.). Each hangar to be capable of housing two airships.

For each station one can determine, at prevailing prices, an estimated expenditure in round numbers:

Cost of ground	L. 2,000,000
Hangar, steel	" 8,000,000

Buildings for workshops, stores, and offices	L. 600,000
Small house for sleeping accommodation	" 600,000
Gas generator with relative roofing and water reservoirs	" 300,000
Water pipes for generator and for fire-extinguishing . .	" 300,000
Storehouse for gasoline and oil	" 50,000
Garage	" 100,000
Platform for maneuvering field	" 50,000
Equipment of airdrome (electric, telegraphic, telephonic, and radio plants, workshop machinery, 2 trucks, 2 automobiles, signalling apparatus, searchlights, hangar equipment, furniture, etc.)	"1,000,000
Total	13,000,000

The aggregate expenditure for the fixed plant is therefore:

L. 26,000,000

Flying Material.

The cost of the two airships of 35,000 cubic meters capacity equipped for transporting 75 passengers, can be roughly estimated at six million lire (L. 40,000 for each seat).

Working Capital.

We will fix the working capital at L. 1,000,000.

RECAPITULATION OF THE PLANT EXPENSES.

(Service with Airships)

Ground	L. 4,000,000
Fixed plants	" 20,000,000
Equipment of airdromes	" 2,000,000
Flying material	" 6,000,000
Working capital	" 1,000,000
Total	L. 33,000,000

(b) Service with Airplanes.

Fixed Plants.

For each airplane station we would have to provide hangars capable of housing at least 15 airplanes. The cost of these hangars for each station would be 2,500,000 lire.

For each station we have:

Cost of ground	L. 2,000,000
Hangar, steel	" 2,500,000
Buildings, for workshops, storehouses and offices	" 600,000
Small house, living quarters	" 600,000
Water pipes	" 150,000
Depot, gasoline and oil	" 50,000
Garage	" 100,000
Equipment	" 1,000,000
Total for each station	L. 7,000,000
Total for both stations	" 14,000,000

Flying material.

Cost of airplane equipped for four passengers: L.160,000 (L. 40,000 per seat).

Cost of 25 airplanes: L. 4,000,000. (Note: During the last years of the late war we paid the following prices per kilogram :

Airplanes (without engine) from 35 to 70 lire per kg.
Seaplanes (without engines) from 70 to 100 lire per kg.
Airships (engines included) from 120 to 130 lire per kg.
Engines from 80 to 90 lire per kg.
In airplanes the weight of the engine represents on an average 1/3 of the total dead weight. Roughly we can say that the average total prices are:

Airplane = L. 60 per kg. Seaplane = L. 90 per kg.; Airship = L. 120 per kg.

In the case of airplanes and seaplanes, one can assume, for computation purposes, that the useful weight (pilot, gasoline, oil, and passengers) is, in military aircraft, about one-half of the weight, empty.)

Working Capital.

We will allow, as for airships, one million lire.

RECAPITULATION OF THE PLANT EXPENSES.

(Service with Airplanes)

Ground	L. 4,000,000
Fixed plants	" 8,000,000
Equipment of airdromes	" 2,000,000
Flying material	" 4,000,000
Capital, working	" 1,000,000
Total	L. 19,000,000

Remarks.

The relation between the plant expenses of the two services with airplanes and airships, is equal to about 0.6.

Generally speaking, the cost of the plant is a function of the type of airplane employed, of the flying speed, of the length of the journey, and of the number of passengers transported, and naturally increases with the increase of the last three elements. It is however interesting to note that when the type and the dimensions of the airplane have been fixed, as well as the speed, and the actual length of the route is considered as variable, varying in inverse proportion to the number of passengers transported, the total cost of the plant can (within determined values of length of course and still maintaining the conditions imposed for the reserve supply of fuel) be held to be independent of the length of the course.

It does not follow therefore that the expense for interest and amortization relative to the passenger-kilometer, must necessarily increase as the distance increases (with a consequent decrease in the number of passengers) because in many cases the very opposite may happen.

To understand this one must remember that the number of passengers-kilometers transportable with a certain airplane at a given speed is proportional to the product of two quantities whose sum is a constant (useful load of the airplane). Consequently, one has a maximum when the useful load is divided into equal parts between the weight relative to the passengers and the weight of the supplies of gasoline and oil.

In the case of airships, for example, if the length of the route is extended from 500 to 1000 kilometers, the amount of capital required for the plant is practically the same, whereas the number of passengers is reduced from 75 to $\frac{7500-3138}{100} = 38.6$, and consequently, the passengers-kilometers increase from 37,500 to 38,600, that is to say, the per unit outlay for interest and amortization decreases.

The above remark holds, as already stated, as long as a route of a certain length is not exceeded, beyond which the number of the annual journeys made necessarily decreases, and along with it, the total of annual passengers-kilometers.

Finally, it must be noted that the cost of plant undoubtedly increases in proportion to the potentiality of the plant itself, that is to say, with the number of passengers-kilometer transportable in one year. It is therefore opportune to charge the outlay up to the passenger-kilometer. In our case we have:

L. 2.93 per passenger-kilometer: service with airships;
" 1.26 per passenger-kilometer: service with airplanes.

ANNUAL WORKING EXPENSES.

3. <u>Interest on, and Amortization of Capital Expended for Plants</u>

We will calculate the interest at 7%, the amortization of the fixed plants at 3%, and the amortization of the cost of equipment at 10%. We get:

Cost		Service with Airships	Service with Airplanes
Interest on capital for plant, at 7%.	L.	2,310,000	1,330,000
Annual amount of amortization of fixed plants, at 3%	"	600,000	240,000
Amount relative to equipment expenses		200,000	200,000
Total	L.	3,110,000	1,770,000
Expenditure per passenger-kilometer . .	"	0.276	0.118

4. RENEWAL OF FLYING MATERIAL.

The actual life of the flying material depends essentially on the number of hours of flight. However, one must remember that some parts of the structure (and, in the case of airships, particularly the outside envelope) wear out, even though it is slowly, even when the airplane is idle. This is inevitable even when the greatest care is taken in maintenance. However, in the instance we are examining at present, the renewal of material on account of wear and tear is so frequently made that we can exclude all calculations referring to actual depreciation of the material while in the hangar.

Sufficient data are lacking in order to be able to determine the actual life of the various parts of aircraft, particularly for airplanes. The data which we set forth later on have therefore only a relative value.

<u>Airships</u>.

From the experience gathered with our airships, we can deduce that an envelope will remain in good condition for about two years and a half, approximately one thousand flights being made during that period. As regards the durability of the other parts of the structure, one can forecast at least double this period of time.

Due to the fact that the engines on airships are worked almost always at a reduced load, it is reasonable to suggest that they have a life of 500 hours' flight. Therefore, as we utilize normally 1/3 of the engines, they would all have to be renewed after 1500 hours' flight.

Supposing that on the total cost, the bag represents 43%, the engines 10%, and the remaining parts 47%, the annual expenditure for renewals for each hour's flight will be:

$\left(\frac{0.43}{1000} + \frac{0.47}{2000} + \frac{0.10}{1500}\right)$ x cost of the airship = L. 2196, (This amounts to saying that the average durability of the whole airship is about 1370 hours), and with 1923 hours' flight in one year, the aggregate outlay will be approximately:

L. 4,223,000.

The outlay for each kilometer covered (actual average velocity = 78 km per hour):

$$\frac{2196}{78} = \text{L. } 28.15$$

and for each passenger-kilometer:

$$\frac{28.15}{75} = \text{L. } 0.375$$

Airplanes.

Assuming that the life of an airplane, engines included, is 300 hours' flight, the outlay for each hour's flight would be:

$$\frac{160,000}{300} = 533.33$$

and for each kilometer flown (actual average velocity = 211.1 km per hour):

$$\frac{533.3}{211.1} = \text{L. } 2.53$$

and for each passenger-kilometer:

$$\frac{2.53}{4} = \text{L. } 0.633.$$

In one year 17,775 hours' flight are made. The total expenditure will therefore be: L. 9,480,000 approximately.

COMPARISON OF EXPENSES FOR RENEWAL OF FLYING MATERIAL.

Annual expenses for renewals:		Service with	
		airships	airplanes
Charged to each hour's flight	L.	2196	553.3
Charged to each kilometer flown	"	28.15	2.53
Charged to each passenger-kilometer	"	0.375	0.633
Total	L.	4223.000	9,480.000

5. EXPENSES FOR PERSONNEL.

Services with Airships.

(a) Airdrome Personnel.

For each airdrome one must provide the following personnel:

Office, HQ	3	persons.
" Administration	4	"
" Traffic	4	"
Chief Technician	1	"
Chief Workman	2	"
Mechanics and Tailors	10	"
Riggers	6	"
Service, gas	4	"
" gasoline and oil	2	"
" storehouses	2	"
" aerological	2	"
" radio, telegraphic and telephonic . . .	4	"
" electric	2	"
" garage	4	"
Laborers	8	"
Watchmen	2	"
Total number of personnel for each airdrome	60	"

that is to say, 120 for both airdromes. Calculating an average outlay for each person of L. 10,000, we get a total expenditure for the personnel, of L. 1,200,000.

(b) Auxiliary Maneuvering Personnel.

Part of the above personnel will assist in the actual handling of the airship. In addition, a maneuvering personnel of about

150 men are required. This body of men would not however be permanently attached to the organization, but would be drawn from some neighboring agricultural or industrial concern. They would perform duty on the field only for departures and arrivals of the airships, and would be compensated on an average of L. 5 per head for each maneuver. Consequently the outlay for this particular personnel would amount to L. 1500 for each flight, that is to say:

$$\frac{1500}{75 \times 500} = \text{L. } 0.040 \text{ per passenger-kilometer,}$$

a total of = L. 450,000 a year.

(c) Navigating Personnel.

Each crew would consist of the following:

1 Commander
1 Second Commander
2 Steersmen
1 Chief Motorist
3 Motorists
1 Radio Operator
1 Laborer
1 Rigger
1 Mechanic

Total : 12 persons

One would have two complete crews, apart from the reserve personnel which would be included in the airdrome personnel.

For each member of the crew, one would pay on an average:

An annual salary of	L.	10,000
Flying pay, for each flight	"	50
Life Insurance Policy of L. 500,000 corresponding to an annual premium of	"	2,000

As each airship would make 150 flights a year, the outlay for each flight would be:

$$12\left(\frac{12000}{150} + 50\right) = \text{L. } 1560,$$

equal to:

$$\frac{1560}{500} = \text{L. } 3.12 \text{ for each kilometer covered,}$$

and

$$\frac{3.12}{75} = \text{L. } 0.042 \text{ for each passenger-kilometer.}$$

The total annual expenses would be : L. 468,000.

Service with Airplanes.

Airdrome Personnel.

From the airship personnel list given above we will deduct the workmen of the gas service and the tailors, and reduce the number of riggers, substituting two or three fabric workers. On the other hand it is well to increase the number of motorists as well as the number of permanent laborers, in view of the increased number of engines employed for the service, there being no auxiliary laborers for the maneuvering operations. On the whole, one would have to provide for each airdrome a personnel of about 75 individuals.

Total annual expense: 75 x 2 x 10000 = L. 1,500,000.

Navigating Personnel.

For each airplane in active service there is only the pilot. The motorists are considered to belong to the airdrome personnel.

It is assumed that the pilot receives a fixed salary, plus a flying pay, and a Life Insurance Policy, but in order to simplify the computation of the expense, we suggest that it amounts to L. 100 for each flight, that is to say:

$$\text{L. } \frac{500}{100} = \text{L. } 0.20 \text{ for each kilometer covered}$$

equal to:

$$\frac{0.20}{4} = \text{L. } 0.05 \text{ for each passenger-kilometer.}$$

The total annual expenditure will be:

L. 750,000

EXPENSES FOR PERSONNEL.

Expenses.			Service with airships	Service with airplanes
Airdrome personnel	(Annual total	L.	1,200,000	1,500,000
	(Per passenger km.	"	0.106	0.100
Auxiliary maneuvering personnel	(For each flight "	"	1,500	-
	(Per passenger "	"	0.040	-
	(Annual total "	"	450,000	-
Navigating personnel	(For each flight "	"	1,560	100
	(Per km. flown "	"	3.12	0.20
	(Per passenger "	"	0.042	0.050
	(Annual total "	"	468,000	750,000
	Annual total expense	"	2,118,000	2,250,000
	Expense per passenger km.	"	0.1888	0.150

6. MAINTENANCE EXPENSES

We calculate the expenditures for maintenance as follows:

Fixed plants	at 3%
Equipment	" 5%
Flying material	" 10%

Maintenance Expenses.

		Service with airships	Service with airplanes
For fixed plants	L.	600,000	240,000
For equipment	"	100,000	100,000
For flying material	"	600,000	400,000
Total	L	1,300,000	740,000
Per passenger-kilometer	"	0.116	0.049

7. CONSUMPTION OF FUEL.

As regards the consumption of gasoline and oil we have found the following values:

Consumption		Service with	
		airships	airplanes
For each hour's flight	kg.	231	112.5
For each kilometer covered	"	2.96	0.534
For each passenger-kilometer	"	0.0395	0.1335
For the entire journey	"	1.480	267
	"	444,000	2,002,000
		airships	airplanes
Expenses per passenger-km.	L.	0.197	0.667
Total annual expenditure	L.	2,220,000	10,010,000

The relative expenditure was computed on the basis of an average price of 5 lire per kilogram.

Consumption of Gas for Airships.

Approximately, an equal number of cubic meters of hydrogen as kilograms of gasoline and oil, is consumed for each kilometer flown. The total annual consumption will be therefore about 444,000 cubic meters, that is to say, 222,000 for each airship; and 610 cubic meters for each airship each day.

Now, an average supply of 610 cubic meters per day is sufficient to maintain the airship with a good lifting power, provided the bag is well constructed. It is not necessary to provide for any other consumption of gas for the washing process.

Cost of Hydrogen.

Last year the cost of hydrogen compressed in cylinders, delivered at the Terni railway station was L. 0.30 per cubic meter. In this figure the expense of maintenance of the cylinders is included. It is necessary to add the expense for interest and amortization of the cylinders themselves, which are assumed to be the property of the air service company. Computing the total expenditure at L. 1,125,000 (4500 cylinders at L. 250 each) one can gage thee relative annual expense to be approximately 170,000 lire, that is, L.0.40 per cubic meter.

For an average distance of 150 kilometers, which we will assume separates the gas-producing center from the airdrome, the transportation expenses to and from the gas factory will come to about six lire per cylinder (weight of the cylinder is about one quintal), that is, L. 0.60 per cubic meter.

Taking finally into account the transportation expenses of the cylinders from the railway station to the airdrome, and back again from the station to the gas works, one can calculate that the aggregate expenditure today per cubic meter of gas would not be more than L. 1.60.

Therefore we have:

For every hour's flight	L.	370
For every kilometer covered	"	4.75
For each passenger-kilometer	"	0.063
For each journey	"	2375
Total per annum	L	712,000

COMPARISON BETWEEN THE TWO SERVICES AS REGARDS

AGGREGATE CONSUMPTION FOR NAVIGATION.

Expenses		Service with	
		airplanes	airships
For every hour's flight	L.	1525	562.5
For every kilometer covered	"	19.55	2.67
For each passenger-kilometer	"	0.261	0.667
Annual total	L	2,932,000	10,010,000

8. GENERAL EXPENSES, AND INSURANCE FOR PASSENGERS.

The general expenses include principally:

Consumption of electric power.
Consumption for automobile transportation.
Stationery.
Various taxes.
Compulsory insurance of working personnel of airdromes.
Insurance against fire for fixed plants.

We will estimate the amount to be 10% of all the preceding working expenses.

It is well to take into account also the expenses for the insurance of passengers, which we assume to be proportional to the price of the trip. We shall estimate it at 5% of the total amount of all the working expenses, excluding the preceding general expenses.

RECAPITULATION OF THE WORKING EXPENSES PER PASSENGER-KM.

Expenses			Service with airships		Service with airplanes		Relation between the expenses of the two services
Interest & amortization	(fixed plants	L.	0.238)	)0.276	0.099)	)0.118	2.34
	(flying material	"	0.038)		0.019)		
Renewal of flying material		"		0.375		0.633	0.59
Personnel	(of airdrome	"	0.106)		0.100)	0.150	1.25
	(navigating	"	0.042)	0.188	0.050)		
	(auxiliary for maneuvering	"	0.040)				
Maintenance	(fixed plants & equipment	"	0.062)		0.022)		
					[illegible])		
	(flying material	"	0.054)	0.116	0.027)	0.049	2.37
Consumption for navigation		"		0.261		0.667	0.39
		"		1.216		1.617	0.75
General expenses & insurance of passengers		L.		0.182		0.243	

		Service with airships	Service with airplanes	Relation between the expenses of the two services.
Total	L.	1.398	0.860	0.75
of which (relative to fixed plants.	L.	0.467	0.254	1.84
of which (relative to flying material.	"	0.931	1.606	0.58
Total expenditure for every kilometer covered.	"	105	7.4	14.2

Relation between the Single Items of Expenditure

and the Total Expense.

	Expenses		Service with airships	Service with airplanes
1	Interest and amortization	L.	0.20	0.06
2	Renewal of flying material	"	0.27	0.34
3	Personnel expenses	"	0.13	0.08
4	Maintenance expenses	"	0.08	0.03
5	Consumption for navigation	"	0.19	0.36
6	General expenses	"	0.13	0.13
		L.	1.00	1.00

CONCLUSIONS.

1. From the above two tables, one gathers that the expenses for interest, amortization and maintenance, as well as those for the airdrome personnel, represent, in the case of airships, 33.4% of the total working expenses, and for airplanes 13.6%.

Now, it is clear that for obvious considerations, the above mentioned expenses (referred to the passenger-kilometer) rapidly decrease as traffic becomes more intense. This increase is met, when possible, either by increasing the number of journeys of the aircraft or by increasing their number, or by increasing their dimensions.

It follows therefore that with the increase of traffic the economical advantage which the airship has over the airplane, becomes still more accentuated. By increasing the number of journeys of aircraft, or by increasing their number, leaving their dimensions unchanged, the relation between the total working expenses per passenger-kilometer has a tendency to be confused with the relation between the aggregate amounts of the expenses, which can be considered to be approximately proportional to the number of journeys made, that is, the expenses relative to consumption for navigation, to renewal of rolling material and to the navigation personnel.

In our particular case, the total amount of the expenses mentioned above, increased by 15% for general expenses and insurance of passengers, is 0.931 for the airship, and L. 1.616 for the airplane. The relation is 0.58.

The increasing of the dimensions of aircraft would, generally, bring about a reduction in the working expenses, provided of course, the additional space is used to advantage. This is due to the fact that the expenses of the navigating personnel of consumption and of renewal per passenger-kilometer, decrease, although not indefinitively. (For airships the limit is that cubuture which we call economical.)

Considering this and also the fact that there is no doubt of the possibility of being able to greatly increase the dimensions of airships while the same possibility is problematical in the case of airplanes, one concludes that in the relation between the transportation costs of the passenger-kilometer, the economic advantage which the airship has over the airplane would probably exceed even the limit mentioned above.

Naturally, as traffic decreases, we get exactly an opposite result. The expenses relative to fixed plants and to the airdrome personnel, make their weight felt in the determining of the cost per unit of transportation, and the advantage of the airship over the airplane suffers first, then disappears and finally becomes a negative quantity.

2. We have already stated that the expenses for the hangar do not weigh very much on the cost of transportation by airships, provided of course that the traffic is sufficiently intense. Thus, in our example, the expense for their erection is eight million lire, and the relative annual expense is 13% of this amount, that is, L. 1,040,000 which is equal to L. 0.093 per passenger-kilometer, or barely 6.6% of the total expense.

This also justifies our remark that it is of no advantage to be sparing in the matter of this expense, and that it is profitable in the long run to sustain even a greater expenditure equipping, for example, the hangar with side wind-screens or with a mechanical device for the entrance and exit of the airship, when by such means it is possible to increase the yearly number of flying days.

Thus, for example, by assuming that such auxiliary appliances entail an extra expenditure of two million lire, and consequently a greater working expenditure of L. 260,000 per annum (making it possible, however, to have 200 flying days instead of 150) the aggregate amount of expenditure relative to the fixed plants (interest, amortization, maintenance) and to the airdrome personnel, increases from L. 5,090,000 to L. 5,376,000, but with reference to the passenger-kilometer, the expense decreases from L. 0.449 to L. 0.358, not to mention the indirect advantages accruing from a greater regularity of service.

Data Relative to Airplanes and Airships Constructed in Germany During the War.

The following tables give data relative to the characteristic types of airplanes and airships constructed by the Germans during the war. The useful loads include: the crew, armament, gasoline, oil, and, in the case of airships, ballast.

The values which I have computed in the last column (product of the unit useful load by velocity) represent proportionally the potentiality of transportation, and also the maximum distance attainable without a stop.

Taking as a basis the velocity values of the various types of airplanes, I have calculated the average values of the useful loads at the various speeds, and on such basis have drawn the relative curve shown after the tables.

CHARACTERISTIC TYPES OF GERMAN AIRSHIPS.

Type of airship	Volume cu.m.	Total ascensional force kg.	Useful load kg.	Useful load / Total ascensional force.	Max. Power HP	Useful load / Max. power kg. per HP	Velocity km. per hour	Useful load & velocity / Max. power
L. 3	22,500	25,900	8,700	0.33	630	13.8	75	1,035
L. 10	31,900	36,700	15,600	0.43	840	16.6	94	1,748
L. 20	35,800	41,000	17,800	0.43	960	18.5	92	1,702
L. 30	55,000	63,300	28,500	0.45	1,440	19.8	97	1,921
L. 60	55,850	64,200	39,600	0.62	1,200	33	110	3,630
L. 71	68,500	78,800	51,000	0.65	1,560	33	122	4,026
S L 3	32,400	37,300	13,200	0.35	840	15.7	81	1,272
S L 6	35,000	40,300	15,800	0.39	840	18.8	93	1,744
S L 8	38,700	44,500	19,500	0.44	960	20.3	93	1,888
S L 20	56,000	64,400	35,300	0.55	1,200	29.4	102	2,999
P L 19	10,000	11,500	3,300	0.29	360	9.2	78	718
P L 25	14,100	16,200	6,000	0.37	420	14.3	79	1,130
P L 27	31,150	35,800	18,000	0.50	960	18.7	90	1,683

CHARACTERISTIC TYPES OF GERMAN PURSUIT AIRPLANES.

Constructing firm	Type	Weight empty kg.	Useful load kg.	Useful Load / Total load	Max. power HP	Useful load / Max. power kg/HP	Velocity km. per hour	Useful load & velocity / Max. power
Albatross	D II	673	225	0.251	160	1.40	175	245
"	D V	680	235	0.257	160	1.47	165	241
Fokker	D VI	393	190	0.326	110	1.73	200	346
"	D VII	688	218	0.241	185	1.18	200	236
"	D VIII	405	200	0.331	140	1.43	200	286
Luftfarzeug-Ges.	D VI a	640	180	0.220	160	1.12	190	213
"	D VI b	640	180	0.220	185	0.97	200	194
Rumpler	D I	615	190	0.236	185	1.03	200	206
Siemens-Schuckert	D III	525	230	0.305	160	1.44	180	259
"	D IV	525	230	0.299	160	1.44	190	274
"	D VI	540	230	0.299	160	1.44	220	317
Fokker	Dr. I	375	196	0.343	110	1.78	200	356
"	E I	385	178	0.316	80	2.22	130	289
"	E IV	466	258	0.356	160	1.61	160	258

CHARACTERISTIC TYPES OF GERMAN RECONNAISSANCE AIRPLANES.

Constructing firm	Type	Weight empty kg.	Useful load kg.	Useful load / Total load	Max. power HP	Useful load / Max. power kg/HP	Velocity km/hour	Useful load & velocity / Max. power
Ago	C I	800	520	0.393	160	3.25	145	471
"	C IV	900	430	0.323	220	1.95	180-190	361
Albatros	C XV	890	430	0.326	200	2.15	165	355
A.E.G.	C IV	800	320	0.285	160	2.00	158	316
Aviatic	C III	980	360	0.269	160	2.25	160	360
Deutsche Flugzeug	C V	970	460	0.322	220	2.09	155	324
Halberstadt	CL II	701	370	0.345	160	2.31	175	404
"	CL IV	658	368	0.359	160	2.30	168	386
"	C V	900	460	0.338	200	2.30	180	414
"	C VIII	903	435	0.325	260	1.67	190	317
Hannover	CL V	720	360	0.333	185	1.95	185	361
Junkers-Fokker	CL.I	735	420	0.363	160	2.62	190	498
Luftfahrzeug Ges.	C II	764	520	0.405	160	3.25	165	536
Luftverkers Ges.	C VI	930	460	0.331	200	2.30	170	391
Rumpler	C IV	1,050	580	0.356	260	2.23	175	390
"	C VII	1,050	435	0.293	260	1.67	175	292
Sablatnig	C II	1,080	510	0.321	260	1.96	150	294
Zeppelinwerke	CL.I	718	340	0.321	160	2.12	168	356
Albatros	J I	1,399	410	0.227	200	2.05	140	287
"	J II	1,517	410	0.213	200	2.05	140	287
A.E.G.	J I	1,455	285	0.164	200	1.42	150	213
"	J II	1,480	285	0.161	200	1.42	150	213
Junkers-Fokker	J I	1,766	410	0.188	200	2.05	155	318
Gotha	G I	1,860	970	0.343	300	3.23	130	420
"	GL VII	2,420	720	0.229	520	1.38	180	248

CHARACTERISTIC TYPES OF GERMAN BOMBARDMENT AIRPLANES.

Constructing firm	Type	Weight empty kg.	Useful load kg.	Useful load / Total load	Max. power HP	Useful load / Max. power kg/HP	Velocity km/hr	Useful load & velocity / Max. power
A.E.G.	N I	880	520	0.371	150	3.46	143	495
Sablatnig	B I	1,100	700	0.389	200	3.50	125	437
Albatros	G III	2,064	1,086	0.345	400	2.71	150	406
A.E.G.	G IV	2,400	1,235	0.340	520	2.37	165	391
"	G V	2,700	1800-2100	0.419	520	3.75	145	544
Friedrichshafen	G IV a	2,800	2,100	0.422	520	4.03	142	572
Gotha	G V	2,570	1,325	0.340	520	2.54	140	356
Rumpler	G I	1,998	0,940	0.320	300	3.13	150	470
"	G III	2,385	1,235	0.341	520	2.37	165	391
Siemens-Schuck	L I	4,400	2,000	0.312	720	2.78	125	347
Deutsche Flugz.	R I	8,600	3,860	0.325	1,040	3.71	132	490
Linke-Hofmann	R II	8,000	4,000	0.333	1,040	3.84	130	499
Siemens-Schuck	R	4,000	1,000	0.200	660	1.52	120	182
" "	R I	4,200	1,200	0.122	450	2.67	130	347
" "	R VII	6,200	1,850	0.230	780	2.37	130	308
" "	R VIII	10,500	5500-7000	0344-0400	1,800	3.05-3.89	125	381-486
Zeppelinwerke Staaken	R II	6,500	3,000	0.316	720	4.17	120-135	532
"	R III	8,600	3,000	0.258	1,020-1,220	2.68	"	342
"	R IV	9,600	3,200	0.250	1,020-1,220	2.85	"	363
"	R V	9,600	3,400	0.261	1,225	2.78	"	354
"	R VI	8,200	3,200	0.280	1,040	3.08	"	393
"	R VI	8,200	3,200	0.280	980	3.27	"	417
"	R VI	9,000	2,600	0.164	1,040	2.50	"	319
"	R VI	9,300	3,575	0.278	1,040	3.44	"	439
"	R VII	9,700	3,300	0.254	1,020-1,220	2.94	"	375
"	R 43-48	10,200	4,200	0.292	1,225	3.43	"	437
"	R XIV	10,000	4,200	0.296	1,225	3.43	"	437

Average Variation of the Useful Loads

per H.P. in Relation to the Velocity of the Airplane.

(German Aircraft).