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SOME ASPECTS OF HYBRID-ZEPPELINS

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ABSTRACT: To increase an airship's maneuverability and payload capacity as well as to save bouyant gas it is proposed to outfit it with a slender delta-wing, which carries about one half of the total take-off weight of the vehicle. An optimization calculation based on the data of LZ 129 (the last airship, which saw passenger-service) leads to an Hybrid-Zeppelin with a wing of aspect-ratio 1.5 and 105 m span. The vehicle carries a payload of 40 % of it's total take-off weight and consumes 0.8 t fuel per ton payload over a distance of 10 000 km.

INTRODUCTION

For the economical transportation of large payloads aerostats must have huge dimensions. The last german Zeppelin used for transatlantic passenger service LZ 129 "Hindenburg" from 1936 for example, had a length of 247 m (820 ft) and 41 m (135 ft) diameter and could carry 19 t of payload. Airships of such dimensions are in the air difficult to maneuvre and would therefore heavily impede the air traffic in the crowded air-space of industrial countries. They require sophisticated and expensive take-off and landing procedures (ground crews!) and are on the ground difficult to handle because of their extreme wind sensitivity. Most of these disadvantages can be avoided if a wing is added to the airship, which compensates a considerable part of the unbalanced weignt of the vehicle by aerodynamic lift. So

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can not only be avoided the necessity of carrying a water ballast as maneuvring aid of more than twice the payload - 38.5 t in the case of LZ 129 - but also the let off of buoyant gas (usually helium) to compensate the loss of weight by consumption of fuel or in landing maneuvers.

Because such a vehicle is thinkable only as a rigid airship, I call it Hybrid-Zeppelin (abbreviated HZ in the following).

GENERAL CONSIDERATIONS

In order to keep the HZ easy to handle on the ground, the wing span should be small; for example 1/2 the length or less. Furthermore the structural weight of the wing should be low, in order to generate substantial more lift than it's own weight at the relatively low speed and therefore low wing loading of an airship. These two conditions are easily to meet with a slender wing, especially with a slender delta-wing. The poor lift to drag ratio of the delta-wing is slightly increased in the case of the HZ, because the thick body covers a large part of the whole wing area and only the relatively small exposed surfaces of the wings contribute to the frictional drag. The glide path angle ϵ of the vehicle is given by:

$$\epsilon = \frac{C_{Do} + C_{Di}}{C_L} \tag{1}$$

(Here are C_{Do} and C_{Di} the coefficients of friction drag and induced drag, respectively, C_L is the lift-coefficient). With the following three well known relations:

$$C_{Di} = \frac{C_L^2}{\pi A} \tag{2}$$

(A is the aspect ratio of the wing)

$$C_{Do} = C_F \cdot \frac{S_{WW}}{S} \tag{3}$$

(C_F is the friction coefficient, S the total wing area, S_{WW} the wetted wing surface):

$$S_{WW} = 2\,\frac{(b-d)^2}{A} \tag{4}$$

(b is the span, d the main-spar diameter) and with the constant:

$$K = \frac{L_D}{q\,\pi\,\frac{d^2}{4}} \tag{5}$$

(L_D is the dynamic lift, q the dynamic pressure) one obtains

$$\epsilon = \frac{C_L}{\pi A} + 2\frac{C_F}{C_L}\left(1 - \sqrt{\frac{C_L}{\pi A K}}\right)^2 \quad . \tag{6}$$

The second term in equation (6) decreases with decreasing A, which is important especially at low C_L.

To calculate the performance of a possible HZ one has to start with the simple and well known conditions

$$L_D = C_L \cdot q \cdot S \tag{7}$$

$$\frac{N_C \cdot \eta}{V_C} = \left(\frac{C_L^2}{\pi A} + C_F \frac{S_W}{S}\right) q \; S \tag{8}$$

(N_C is the continuous power output of the engines, η the propeller efficiency, V_C the cruising speed, S the total wing area and S_W the wetted surface of the whole vehicle). Though the friction coefficient C_F is well known (see e.g. Ref. 1):

$$C_F = \frac{0.455}{(\log Re_l)^{2.58}} \tag{9}$$

(Re_l is the Reynoldsnumber based on body-length l) we have still only two equations and four unknowns. A third equation is obtained from the optimization condition, which requires ϵ to be a minimum with respect to the geometry of the vehicle. The connection with the geometric arrangement is given by Spreiter (Ref. 2):

$$C_L = \frac{\pi}{2} A \alpha \left[1 - \left(\frac{d}{b}\right)^2 + \left(\frac{d}{b}\right)^4\right]^{*)} \tag{10}$$

(α is the angle of attack, b the wing span)

The derivative of equation (4) with respect to $\frac{d}{b}$ leads to the minimum condition

$$\frac{C_L^2}{\pi A} = C_F \cdot \frac{S_W}{S} \tag{11}$$

*) This relation is strictly valid only for a slender wing-body combination with cylindrical tail. The negative lift of the conical tail of the HZ is, however, compensated by the horizontal stabilizers.

Now we have the three conditions (7), (8) and (11) for the four unknowns C_L, S (or b), N_C and V_C, which means, that one of them can or must be chosen free.

CALCULATION OF AN EXAMPLE

The following calculation of a practical example is based on the data of LZ 129 (Table 1, left column, Ref. 3, 4).

	LZ - 129	HZ
length	247.2 m	247.2 m
diameter	41.2 m	41.2 m
span	—	105 m
aspect ratio	—	1.5
static lift	214 t	198 t
dynamic lift	—	250 t
cruise speed	125 km/h	230 km/h
range	14000 km	10000 km
cruise power	3600 PS	20500 PS
weights:		
body	86.5 t	74 t
engines	5.0 t	18 t
fuel	65.0 t	149 t
ballast	38.5 t	—
wing	—	27 t
payload	19.0 t	180 t
take off	214.0 t	448 t

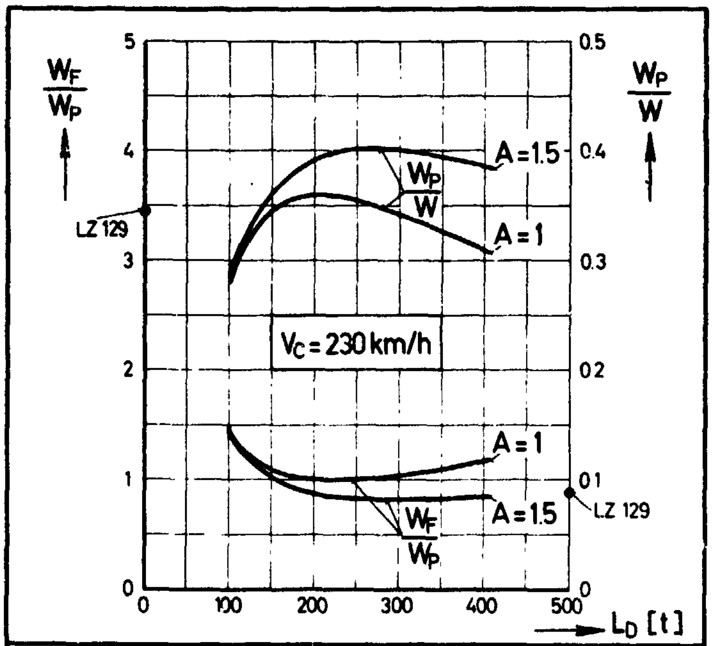
Table 1

Technical data of LZ 129 and HZ

To carry out the optimization, some of these figures are changed. Cruising speed was chosen according to a time-table that provides two weekly roundtrips Frankfurt - New-York - Frankfurt which yields V_C = 64 m/s = 230 km/h (= 124 kn) in 3000 m (= 10 000 ft) altitude. A range of R = 10 000 km (=5500 nm) is at this speed sufficient. It was also assumed that by use of modern materials and technologies the weight of the body in spite of the higher loads due to the higher speed can be reduced by 15 % to 74 t. The calculation of the weights of engines and fuel is based on the technical state at the end of World War II (Junkers "Jumo 205 D", Ref. 5). The weight per horsepower was assumed to be 0.9 kp/PS and the specific fuel consumption 0.168 kp/PSh. (Use of 75 % lighter gas-turbines is still prohibited because of their 35 - 40 % higher specific fuel consumption).

Furthermore it should be regarded that the aerostatic lift of the body is reduced by 7.5 % to $\underline{L_{St} = 198\ t}$ when helium rather then hydrogen is used. For the calculation of wing weight, it was supposed, that the expected low wing-loading permits a lightweight construction wing, the weight of which is not greater than 10 kp/m^2 (related to the exposed wing area). Finally should be regarded, that for the calculation of friction drag the surface of the body was approximated by that of a rotational ellipsoid.

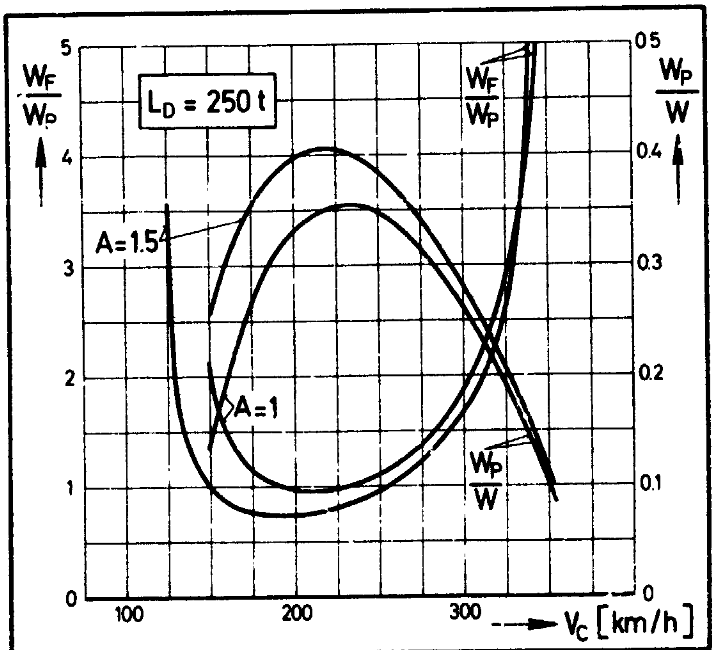
On the basis of these figures an optimizing computation was performed in the range $0.5\ L_{St} \leq L_D \leq 2\ L_{St}$.



Fuel consumption per ton payload and payload-factor of HZ versus dynamic lift

Figure 1

The computed results (Fig. 1) show, that the payload factor W_P/W (W_P is the weight of payload, W the total take-off weight) for A = 1 has a noticeable maximum of 36 % at L_D = 200 t and the fuel consumption per ton payload W_F/W_P has a flat minimum of 1 at about 225 t dynamic lift. For A = 1.5 the optimum values are even more favourable and both met at L_D = 275 t, but the extrema are much less distinct. Furthermore for the two intermediate values of dynamic lift L_D = 225 t and L_D = 250 t the payload factor and the fuel consumption per ton payload were calculated at $A = 1$ and $A = 1.5$ in dependence of the cruising speed V_C in the range $125 \text{ km/h} \leq V_C \leq 350 \text{ km/h}$.

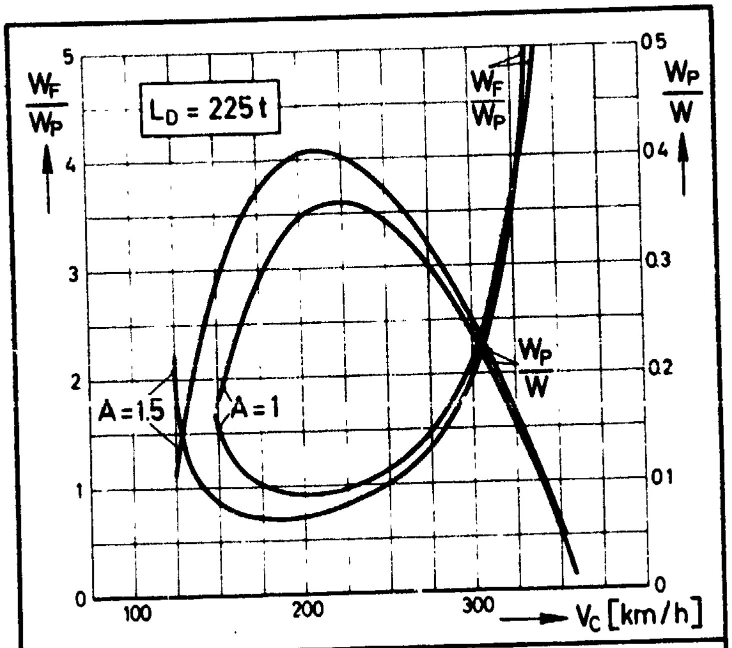


Fuel consumption per ton payload and payload-factor of HZ versus cruise speed

Figure 2

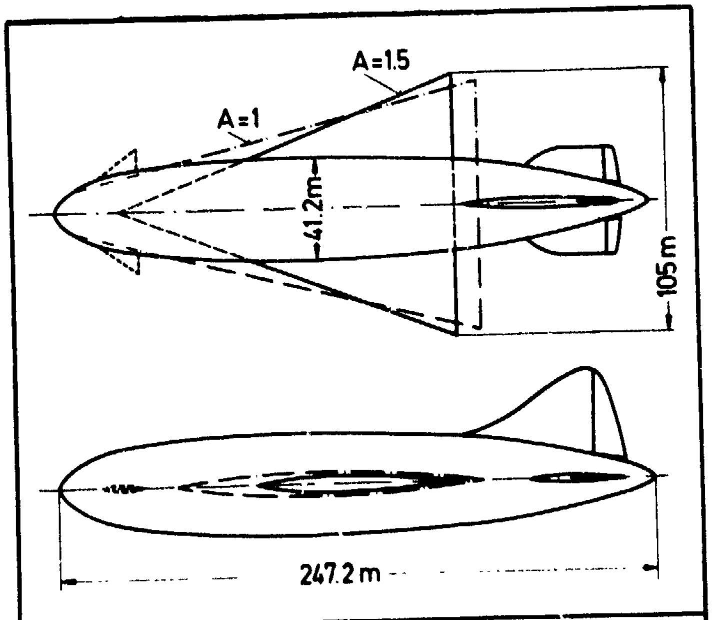
It can be seen clearly, that the heavier HZ (Fig 2) meets the optimum values at slightly higher speeds than the lighter one (Fig. 3), and that the payload factor of the HZ with $A = 1.5$ is at all speeds considerably higher (and the fuel consumption per ton payload lower) than the corresponding figures of the HZ with $A = 1$. The wing-loadings are $L_D/S = 25 \text{ kp/m}^2$ at $A = 1$ and 35 kp/m^2 at $A = 1.5$ and, therefore, confirm our expectations.

The general arrangement of a possible HZ with $L_D = 250$ t shows Fig. 4. The dorsal fin (and rudder) is considerably enlarged compared with that of LZ - 129 to gain lateral stability even if the ventral fin is deleted to provide ground clearance during take-off at high angles of attack. Possibly it can become necessary to apply small canard wings (eventually retractable) to improve take-off performance. The arrangement of propellers (engines will be hidden in the body) is not depicted, because the HZ is supposed to demonstrate only an aerodynamic concept and not a concrete project.



Fuel consumption per ton payload and payload-factor of HZ versus cruise speed

Figure 3



General arrangement of HZ (L_D = 250 t)

Figure 4

The technical data of the HZ are given in Table 1 , right column.

The figures show that a considerable progress in efficiency can be achieved compared to present aircraft. The payload factor of the described HZ on 10 000 km distance is 40 % whereas that of a modern jet-freighter on the same distance is about 11 % . Similar relations apply for the fuel consumption: the HZ consumes about 0.8 t fuel per ton payload for the given distance; a jet-freighter at the same conditions nearly 4.5 t ! Moreover, the fuel consumption of the HZ is rather an upper limit since it was not considered,that the weight of the HZ is continuously reduced while the fuel is being consumed. Finally, considering the acceptability with regard to the environment (less pollution and noise) and the high passenger-comfort, which the HZ offers, it's rentability is likely to be very good. Whether passengers and air-freight expeditors are willing to pay for these advantages with a four times longer travel time (33 h) must be investigated by marked analysis.

REFERENCES:

1. Schlichting, H., Boundary layer theory , 6. Edition, Verlag G. Braun, Karlsruhe, Mc Graw Hill, New York, (1968)

2. Spreiter, J. R., The aerodynamic forces on slender plane- and cruciform-wing and body combinations, NASA Rep. 962 (1950)

3. Das Zeppelin-Luftschiff LZ - 129 "Hindenburg" , Deutsche Luftwacht-Luftwissen 3 (1936), S. 66

4. Jane's All the World's Aircraft , (1936), S. 5 c, S 63 d

5. Jane's All the World's Aircraft , (1945), S. 54 d

6. Jane's All the World's Aircraft , (1973/74), S. 364/365