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Further Studies in the Concept of Delta-Winged Hybrid Airships

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Recently, several concepts have arisen for hybrid airships. One of these concepts, a hybrid Zeppelin, combines a slender delta wing with a rigid airship. Before starting intensive (and expensive!) design work for such a vehicle, an approximate calculation should show that performances are at least comparable with those of existing airplanes and fully buoyant airships. Therefore, the aerodynamic performance of the hybrid Zeppelin has been calculated, starting from the technical state of the art of the prewar LZ 129 and based on the slender-body theory. The results show that the optimum hybrid Zeppelin lifts roughly one half of its takeoff weight by aerodynamic lift at a cruise speed in the range 125 km/h $\leq u \leq$ 225 km/h. If fueled with liquid hydrogen or Blaugas, payload and fuel consumption figures are much superior to those of existing aircraft.

Nomenclature

b = wingspan
b_{st} = span of horizontal stabilizer
C_D = drag coefficient
C_{Di} = induced drag coefficient
C_{D0} = drag coefficient at $C_L = 0$
C_f = friction coefficient (Ref. 1)
C_L = lift coefficient
C_{L0} = $L_D / S \cdot q$
$C_{2,3,4}$ = constants; see Eqs. (15-17)
d = wing thickness
D = body mean diameter
g = acceleration due to gravity
H = cruising altitude
K_s = equivalent sand roughness (Ref. 1)
l = wing chord length
L = body length
L_D = maximum aerodynamic lift
L_S = static lift (buoyancy)
m,n = shape parameters, Eq. (35)
N = engine power output
q = $\rho u^2/2$, dynamic pressure
R = range at zero wind
Re = $u \cdot L/\nu$, Reynolds number
S = wing area
S_B = wetted body surface
S_{em} = wetted area of whole empennage
S_W = wetted wing area
t = time (coordinate)
t_0 = comparable flight time, see Eq. (14)
T = R/u, travel time
u = cruising speed
V = body gross volume
V_G = gas volume
W_B = $\gamma_B \cdot V_G$, body weight (empty, without engines, but fully equipped)
W_E = $\gamma_E \cdot N$, engine weight
W_F = fuel weight
W_M = $L_D + L_S$, takeoff weight
W_P = payload
W_W = $\gamma_W \cdot S_W/2$, wing weight
x = coordinate in the body axis, $x = 0$ at the bow
y = local body radius
α = angle of attack
γ_B = W_B/V_G, relative body weight
γ_E = power-weight ratio of engines
γ_W = $2 \cdot W_W/S_W$, relative wing weight
δ = d/l, relative wing thickness
ϵ = C_D/C_L, glide path angle
ζ = L_D/L_S, lift ratio
η = propeller efficiency
λ = heat of combustion
Λ = b^2/S, aspect ratio
μ = kinematic viscosity
ν = μ/ρ, dynamic viscosity
ξ = D/b
ρ = density
σ = L/D, fineness ratio
φ = specific energy consumption, see Eq. (45)
ω = specific fuel consumption rate
Ω = $N \cdot \omega$, fuel consumption rate

I. Introduction

ONE of the most severe handicaps preventing airships from participating in today's air transportation systems are their poor handling qualities compared with those of existing airplanes.

The balance variations due to fuel consumption or alterations in atmospheric conditions, make sophisticated ballast systems necessary. Because the release of buoyant helium is prohibited for economical reasons, the ballast systems must allow for the recovery of water from the engine exhaust gases. Such installations are heavy and reduce engine efficiency.[2]

Takeoff and landing of large airships pose other problems. Even with the aid of horizontal and vertical thrust deflection, special ground equipment and special airfields are required.[3] Furthermore, large airships would heavily impede traffic in the crowded airspace over industrial countries, since their poor maneuverability, especially their low speed, make their integration into the controlled air traffic nearly impossible.

To avoid most of these difficulties, the author has proposed an airship combined with a slender delta wing which compensates for a considerable part of the total weight of the vehicle with aerodynamic lift.[4-6] Such a "hybrid Zeppelin" would be able to use existing airports without special equipment because it is "heavy" on the ground by that

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amount of the landing weight, which is compensated by aerodynamic lift in flight. The necessity of carrying water ballast, the installation of water recycling systems, and the release of buoyant gas is no longer necessary, because all weight alterations can be balanced by adjusting the aerodynamic lift via the angle of attack.

Placing a hybrid airship in the controlled air traffic would be facilitated by the ability to maneuver nearly as well as a modern jet airplane.

In this paper the performance of a hybrid Zeppelin is predicted based upon slender-body theory and realistic assumptions about weights, fuels, and engines.

II. Calculation of Aerodynamic Performance

A. Fundamental Considerations

The idea of combining aerodynamic and aerostatic lift is not a very new one. The first patent for a "semibuoyant aircraft" arose in 1931.[7] Later, hybrids with high aspect ratio wings,[8,9] lifting bodies,[9-11] or those operating in ground effect[12] were proposed. In addition, a completely new concept has appeared in the combination of helicopter and blimp.[13,14] The main idea of the author's proposal is to outfit a rigid airship with a slender delta wing ($1 \leq \Lambda \leq 3$), which offers specific advantages compared with other types of wings:

1) Weight can be kept low, because for a given area the structural weight of a wing decreases with decreasing aspect ratio.

2) Introduction of the aerodynamic forces and moments into the girder structure of the body is much easier than in the case of a high aspect-ratio wing because of the delta wing's large root chord length.

3) Relative small span of slender wings facilitates the handling of hybrid airships on the ground.

The poor lift-to-drag ratio of the slender delta wing is slightly improved by the comparable thick body, which covers a large part of the wing area so that only the relatively small exposed surfaces contribute to the frictional drag. The glide path angle is given by (pressure drag and body drag neglected):

$$\epsilon = \frac{1}{C_L}\left(C_{Di} + C_f \frac{S_w}{S}\right) \tag{1}$$

With the slender-body approximation[15]:

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

and the wetted wing area expressed as $2\cdot(b-D)^2/\Lambda$, one obtains ($b>D$)

$$\epsilon = \frac{C_L}{\pi\Lambda} + 2\frac{C_f}{C_L}(1-D/b)^2 \tag{3}$$

which, for the wing of the hybrid Zeppelin ($D/b \approx 0.5$), is lower than for that of conventional airplanes ($D/b \approx 0.1$).

B. Characteristic Equations

As an air transport vehicle the hybrid airship must be designed for minimum glide path angle:

$$\epsilon = \frac{C_{D0}}{C_L} + \frac{C_L}{\pi\Lambda} \tag{4}$$

First, angle of attack, speed, and altitude must be selected so that ϵ becomes a minimum with respect to the lift coefficient C_L, which leads to the well-known condition

$$C_{D0} = C_{Di} \tag{5}$$

Besides Eq. (5), further conditions have to be fulfilled in order to minimize ϵ with respect to configuration parameters.

With the assumption that at $\alpha = 0$ the wing and empennages have the same drag coefficient C_{D0W} and the body C_{D0B}, by combining Eqs. (2) and (5) with

$$C_{D0} = \frac{C_{D0W}}{S}\left[S_{em} + 2\cdot\frac{(b-D)^2}{\Lambda}\right] + \frac{C_{D0B}}{S}\cdot S_B \tag{6}$$

one obtains for the wing span the fourth-order equation:

$$b^4 + 2Db^3 + b^2[D^2 + (\Lambda/2)S_{em} + (\Lambda/2)(C_{D0B}/C_{D0W})S_B] - [(\Lambda\cdot L_D^2)/(2C_{D0W}\cdot\pi\cdot q^2)] = 0 \tag{7}$$

With the solution of Eq. (7), the geometry is completely defined and the empty weight of the vehicle can be computed. Together with the design values of Λ, L_D, and L_S, the required engine power rating N (dependent upon cruising speed u), is given by

$$N = (u/\eta)\cdot C_D\cdot S\cdot q \tag{8}$$

Once N is known, engine weight W_E can be calculated. Thus the main performance parameter of a transport vehicle, the payload W_P

$$W_P = W_M - (W_B + W_W + W_E + W_F) \tag{9}$$

can be calculated once the fuel weight W_F is known. To calculate total fuel weight or consumption of the hybrid airship with a given range R, and constant cruising speed u, one has to take into account the fact that the continuously decreasing overall weight of the aircraft, caused by fuel consumption, decreases the required aerodynamic lift and hence the induced drag. Consequently, the required engine power N and the fuel consumption rate Ω decrease. At any time t the fuel consumption rate Ω is given by

$$\Omega(t) = \omega\cdot N(t) \tag{10}$$

and the lift coefficient

$$C_L(t) = \frac{1}{Sq}\left(L_D - \int_0^t \Omega(t)\,\mathrm{d}t\right) \tag{11}$$

Combining Eqs. (2), (8), and (11) with Eq. (10) leads to:

$$\Omega(t) = \frac{u}{\eta}Sq\omega\left[\frac{1}{\pi\Lambda}\left(C_{L0} - \frac{1}{Sq}\int_0^t \Omega(t)\,\mathrm{d}t\right)^2 + C_{D0}\right] \tag{12}$$

From Eq. (12) one obtains the fuel consumption rate $\Omega(t)$ as

$$\Omega(t) = C_2\{1 + \tan^2[C_3(t-t_0)]\} \tag{13}$$

with the abbreviations

$$t_0 = (1/C_3)\arctan C_4 \tag{14}$$

$$C_2 = (u/\eta)Sq\omega C_{D0} \tag{15}$$

$$C_3 = (u/\eta)\omega\sqrt{C_{D0}/\pi\Lambda} \tag{16}$$

$$C_4 = C_{L0}/\sqrt{\pi\Lambda C_{D0}} \tag{17}$$

The total fuel weight is obtained by integrating $\Omega(t)$, yielding

$$W_F = L_D - (C_2/C_3)\tan[C_3(t_0 - T)] \tag{18}$$

Finally, the angle of attack must be calculated with the slender-body theory as formulated by Spreiter in Ref. 16:

$$C_{L0} = \alpha\cdot(\pi\Lambda/2)(1-\xi^2+\xi^4) \tag{19}$$

III. Design of Examples

A. Geometry, Lift, and Drag

To limit the computational effort, a first estimation under simplifying assumptions was done,[4,5] which leads to the optimum data:

$$\Lambda = 1.5 \tag{20}$$

$$\delta = 0.12 \tag{21}$$

$$\sigma = 4 \tag{22}$$

acceptable speeds in the regime

$$125\ \text{km/h} \leq u \leq 250\ \text{km/h} \tag{23}$$

and dynamic lift to buoyancy ratios

$$0.5 \leq \zeta \leq 2.0 \tag{24}$$

To cross the North Atlantic with modern navigational and meteorological aids, a range of

$$R = 10{,}000\ \text{km} \tag{25}$$

is sufficient.[5] The cruising altitude was varied as follows:

$$500\ \text{m} \leq H \leq 3500\ \text{m} \tag{26}$$

Computations started from the technical data of LZ 129 "Hindenburg."[17,18] With gas volume $V_G = 200{,}000\ \text{m}^3$, (Ref. 19) the buoyancy at altitude H is given by:

$$L_S = 0.95 \cdot V_G [\rho(H) - \rho_{He}(H)] \cdot g \tag{27}$$

where the densities $\rho(H)$, $\rho_{He}(H)$ are derived from the normal atmosphere.[20] (The factor 0.95 represents a 5% contamination of the buoyant gas by air.) The Reynolds number in the speed-altitude area under consideration is:

$$3 \cdot 10^8 \leq Re \leq 10^9 \tag{28}$$

In this range, a wing made from glass-fiber reinforced plastics (GRP) can be assumed to be hydraulically smooth. Thus the friction coefficient for the wing (and the similarly made empennage) is[1]:

$$C_{f,W} = \frac{0.455}{(\log Re)^{2.58}} \tag{29}$$

For the body, an equivalent sand roughness of

$$K_s = 0.1\ \text{mm} \tag{30}$$

is assumed, which agrees very well with measurements on painted wing surfaces.[1] The friction coefficient for the body is then[1]:

$$C_{f,B} = (1.89 + 1.62 \cdot \log L/K_s)^{-2.5} \tag{31}$$

The pressure drag at $\alpha = 0$ is taken into account by[21]:

$$C_{D0,W} = C_{f,W}(1 + 2.4\delta) \tag{32}$$

$$C_{D0,B} = C_{f,B}(1 + 0.6/\sigma) \tag{33}$$

Finally, the drag coefficients are related to the wing area S and 5% is added for interference effects (body-wing, fin-rudder, etc.).

The wetted wing surface S_W is given in Sec. III.A; the wetted area of the empennage is approximately

$$S_{em} = 10 \cdot \frac{(b_{st} - 0.5D)^2}{\Lambda} \tag{34}$$

The Factor 10 in Eq. (34) is taken to make allowance for the enlargement of the stabilizer, which is required to compensate for the moments caused by the wing.

The body surfaces S_B and the body volume V is obtained by integration of the function[22]:

$$y(x) = \frac{(n+m)^{n+m}}{2\sigma n^n m^m} \cdot \frac{x^n}{L^{n+m-1}} (L-x)^m \tag{35}$$

As shown in Refs. 22 and 5 with $m = 0.65$, $n = 0.48$, and $\sigma = 6$, this function agrees very well with the contour curve of LZ 129.

B. Weight Considerations

In the frame of the presented calculation, the weight of the wings can be estimated from the weight of GRP-wings of high-performance gliders. The relative weight γ_W of this type of wing with aspect ratio Λ between 20 and 30 and wing loadings of about 35 daN/m^2 amounts between 8 daN/m^2 and 13 daN/m^2.[23] For the hybrid Zeppelin's wings with $\Lambda = 1.5$ and $\delta = 0.12$ (see Sec. IV.A)

$$\gamma_W = 10\ \text{daN/m}^2 \tag{36}$$

is assumed. This assumption (probably too pessimistic) is, at any rate, on the safe side.

To estimate the empty weight of the body (without engines, but otherwise fully equipped), the relative weights γ_B of various rigid airships which have been built or designed[24-26] are plotted against the gas volume in Fig. 1. Figure 2 is an attempt to estimate weight variation with speed. The maximum speed of LZ 129 was 130 km/h and the fineness ratio $\sigma = 6$. Changing the fineness ratio to 4 would reduce the weight by about 10%. According to DGLR investigations,[27-30] a further reduction of roughly 5% can be credited to the use of modern materials, especially for gas cells.

The NASA proposal[25] has an envisioned speed of 160 km/h and a fineness ratio of 5. Relative weight can be reduced by about 5% by reducing the fineness ratio to 4. The line in Fig. 2 shows the assumed approximation for weight increase with speed in the presented calculations.

C. Engines and Fuels

Because of the lack of certified airplane diesel engines (which would be optimal for a long-range, long-duration vehicle as the hybrid Zeppelin), an available engine representative of current technology—the General Electric T 700—is selected. The power-weight ratio, according to Ref. 23, is:

$$\gamma_E = 0.197\ \text{daN/kW} \tag{37}$$

and specific fuel consumption (for kerosene):

$$\omega = 0.284\ \text{daN/kWh} \tag{38}$$

This engine will be assumed to be fueled with kerosene, liquid hydrogen (LH_2), and combinations of kerosene with 40,000 m^3, 60,000 m^3, and 80,000 m^3 of Blaugas. (Blaugas is a mixture of gaseous hydrocarbons, whose density is exactly that of air and whose heat of combustion is approximately 60,000 kJ/m^3.)

To take into account the somewhat higher weight of the tank installations for LH_2, heat of combustion is assumed to be 2.5 times that of kerosene (instead of the actual 2.8 times[31]).

The use of Blaugas requires space for the sea-level volume V_{Blg} and additional space for the expansion when the hybrid is climbing to an altitude of 3000 m,

$$V_{Blg,H} = 1.3 V_{Blg} \tag{39}$$

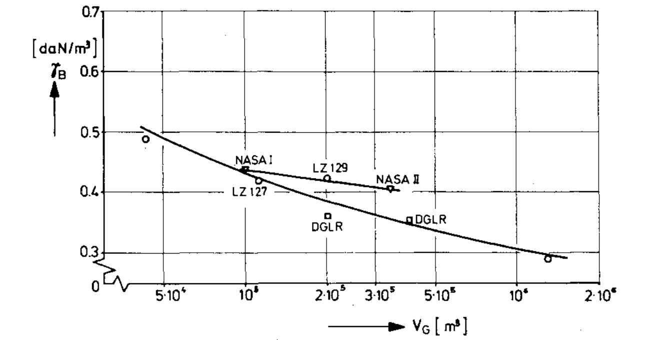

Fig. 1 Relative weights of various airships vs gas volume.

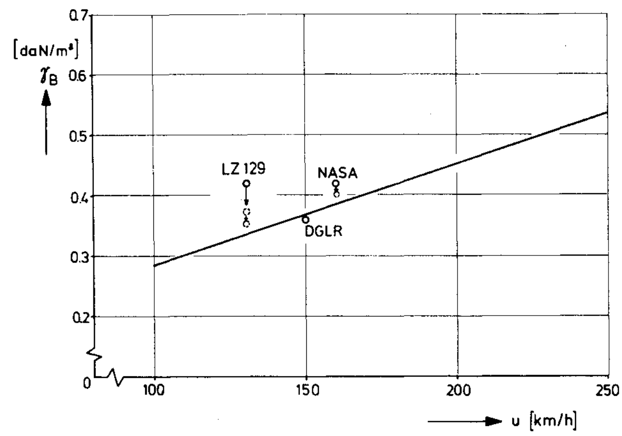

Fig. 2 Relative weights of several airships vs cruising speed.

Thus, the three combined-fueled hybrid Zeppelins have gas volumes of

$$V_{G4} = 252{,}000 \text{ m}^3$$

$$V_{G6} = 278{,}000 \text{ m}^3$$

$$V_{G8} = 304{,}000 \text{ m}^3 \tag{40}$$

which lead accordingly to higher body volumes, surfaces, and weights.

To calculate the performances of the Blaugas-fueled hybrid Zeppelins, the vehicles with the new bodies are optimized as described in Sec. III. B. From the fuel weight [Eq. (18)], the Blaugas-equivalent

$$W_{BE} = \frac{\lambda_{Blg}}{\lambda_{ker}} \rho_{Blg} V_{Blg} \tag{41}$$

is subtracted, and with the "landing weight"

$$W_L = W_M - (W_F - W_{BE}) \tag{42}$$

the corresponding required engine output N_{Blg} and the range on kerosene

$$R_{ke} = R - u \frac{V_{Blg}}{N_{Blg} \cdot \omega_{Blg}} \tag{43}$$

are computed.

In the next step, the weight of kerosene required to cover the range R_{ke} is obtained from Eqs. (14-18) and the payload from Eq. (9).

The propeller efficiency was kept at

$$\eta = 0.8 \tag{44}$$

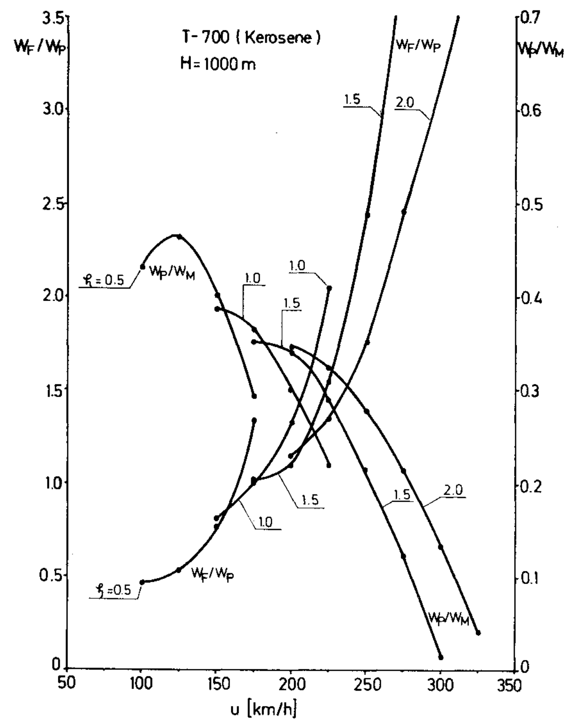

Fig. 3 Payload factor and relative fuel consumption for kerosene-fueled hybrid Zeppelins with various lift ratios vs cruising speed.

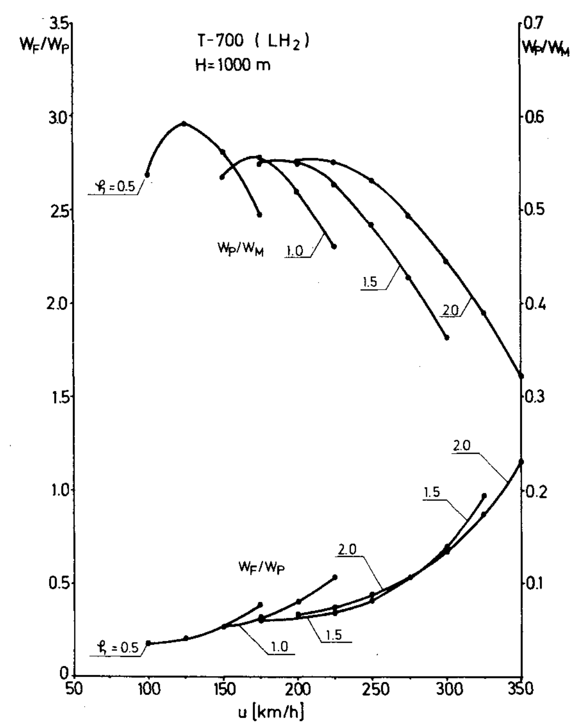

Fig. 4 Payload factor and relative fuel consumption for LH_2-fueled hybrid Zeppelins with various lift ratios vs cruising speed.

IV. Results and Discussion

All results of the computations, together with a listing of the computer program, are collected in an unpublished paper.[32] Here, only a few graphs of the characteristic performance parameters are shown. Payload factor W_P/W_M and relative fuel consumption W_F/W_P vs cruising speed at an altitude $H = 1000$ m are plotted for the engines fueled with kerosene alone in Fig. 3.

It shows that with increasing speed the payload factor W_P/W_M decreases, whereas the relative fuel consumption increases, which is a result of the required higher engine power ratings. For very low cruising speeds, the same tendency is discernible—to generate a certain aerodynamic lift at low speeds, a large and, therefore, heavy wing is required which reduces payloads and increases fuel consumption. With liquid hydrogen (LH_2) as a fuel, the performance data are much more favorable (Fig. 4). Payload factors well above 50% seem available and the relative fuel consumption is distinctly lower. Although liquid hydrogen is a somewhat exotic fuel, the technological problems arising from cryogenic temperature are solved and low density poses no difficulties, since the inside of an airship provides ample space for the large tanks.

Figure 5 demonstrates the influence of the operating altitude on the performance parameters for both kinds of liquid fuels. It is obvious that the performance in general decreases with increasing altitude, which means that the hybrid airship should cruise as low as possible just as the old Zeppelins did.

The second, unusual fuel considered here is Blaugas, which was utilized very successfully with LZ-127 "Graf Zeppelin" in the 1920's and 1930's.[26,33] In Fig. 6, the parameter payload factor and specific energy consumption

$$\varphi = \frac{\lambda_{ke} \cdot W_F + \lambda_{Blg} \cdot V_{Blg}}{W_P \cdot R} \tag{45}$$

are plotted against cruising speed for the 278,000 m^3 hybrid airship, which is fueled by a combination of kerosene and 60,000 m^3 of Blaugas. In Fig. 7, the same quantities are plotted against the lift ratio ζ. The graph demonstrates that the performance of (partially) Blaugas-fueled hybrid Zeppelins lies between those of kerosene and LH_2-fueled vehicles.

To select the most economical hybrid airship with respect to variations of lift ratio, cruising speed, and fuel type, a few additional conditions must be considered.

For geometrical reasons, the wing span must be larger than the body mean diameter and the center chord length

$$l_c = 2b/\Lambda \tag{46}$$

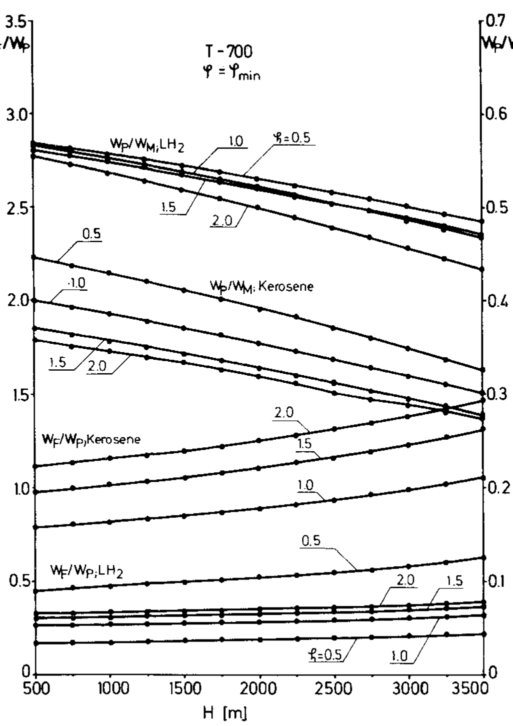

Fig. 5 Payload factor and relative fuel consumption at minimum specific energy consumption for kerosene and LH_2-fueled hybrid Zeppelins with various lift ratios vs cruising altitude.

smaller than the body length; that means

$$D < b < (L \cdot \Lambda)/2 \tag{47}$$

The angle of attack must be kept small enough so as not to infringe on the validity of the slender-body theory:

$$\alpha < 7 \text{ deg} \tag{48}$$

In addition, the application of a GRP wing bounds the wing loading

$$L_D/S \leq 35 \text{ daN/m}^2 \tag{49}$$

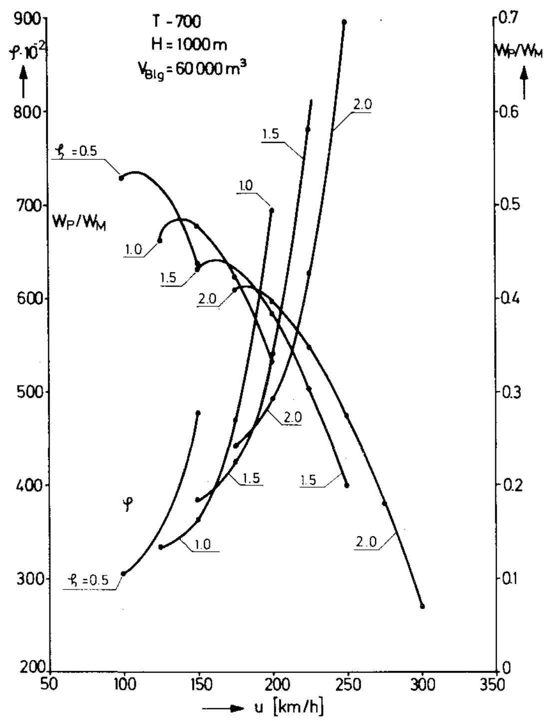

Fig. 6 Payload factor and relative energy consumption for kerosene-Blaugas-fueled hybrid Zeppelins with various lift ratios vs cruising speed.

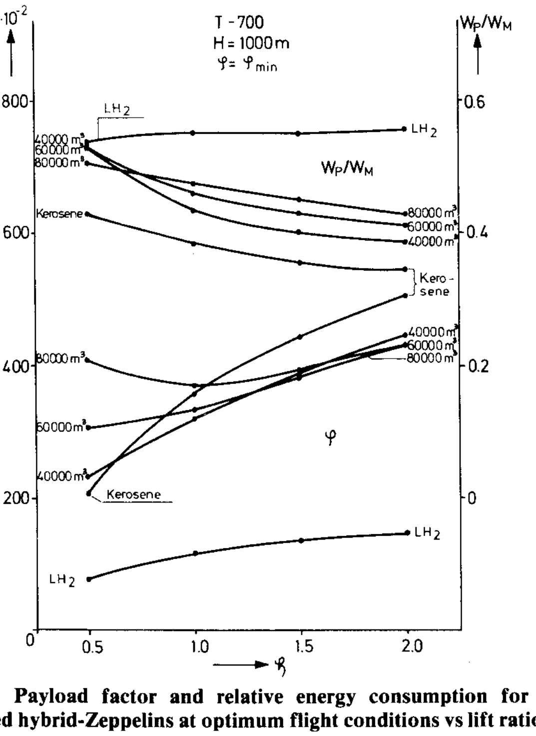

Fig. 7 Payload factor and relative energy consumption for the regarded hybrid-Zeppelins at optimum flight conditions vs lift ratio.

Table 1 Mean data of the regarded hybrid Zeppelins in comparison with those of other planned or existing aircraft

	GZ III (LH_2)	HZ (LH_2)	HZ (Blaugas)	HZ (kerosene)	Megalifter	C-5A
Length, L (m)	230	188.5	211	188.5	200	75.5
Diameter, D (m)	43.6	47.1	52.8	47.1	54×35	–
Buoyancy, L_S (kN)	2060	1785	1785	1785	2129	–
Aspect ratio, Λ –	–	1.5	1.5	1.5	20	8
Wing span, b (m)	–	115.9	109.3	115.9	162	68
Wing loading, L_D/S (daN/m^2)		19.9	22.4	19.9	314	596
Angle of attack, α (deg)	–	5.8	6.9	5.8	~4	~3
Range, R (km)	14,000	10,000	10,000	10,000	6700	6000
Engine	T-700	T-700	T-700	T-700	TF-39	TF-39
Power rating, N (kW)	3600	8156	9170	8156	~30,000	~70,000
Cruise speed, u (km/h)	165	150	150	150	360	900
Takeoff weight, W_M (kN)	2060	3572	3572	3572	6250	3434
Fuel weight, W_F (kN)	238	532	595	1128	1246	932
Payload, W_P (kN)	785	1974	1708	1380	1776	980
Payload factor, W_P/W_M(%)	38	55.3	47.8	38.6	27	29
Relative energy consumption $\varphi \cdot 10^2(-)$	227	118	363	359	458	694

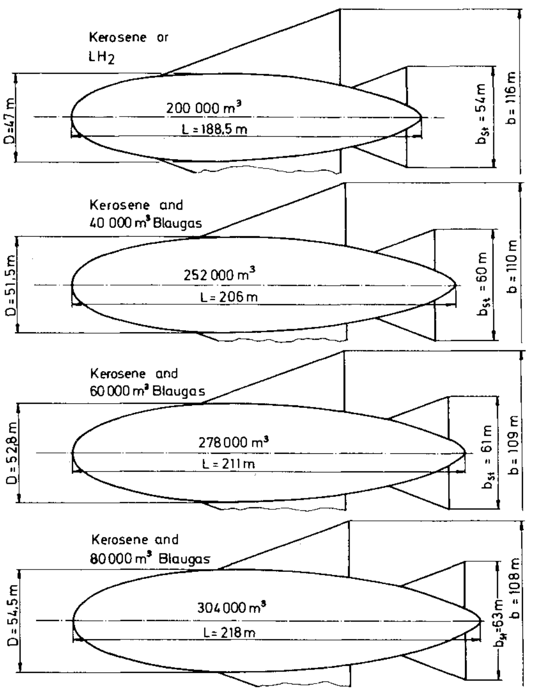

Fig. 8 Arrangement and dimensions of the regarded hybrid Zeppelins.

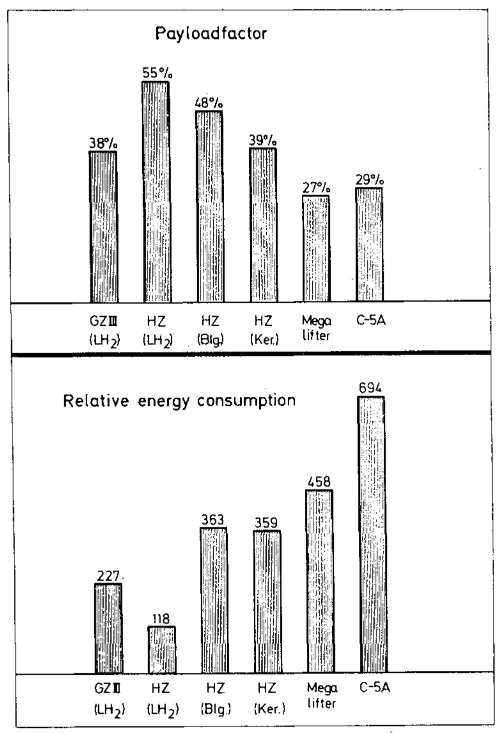

Fig. 9 Payload factor and relative energy consumption of the regarded hybrid Zeppelins in comparison with the corresponding data of other planned or existing aircraft.

To keep the hybrid Zeppelin "heavy" on the ground, even with no (liquid) fuel onboard,

$$L_D > W_F \tag{50}$$

must hold in all cases. Finally, the cruising speed has to be within a magnitude that allows a range of 10,000 km, which is sufficient to cross the North Atlantic (7000 km). Assuming a cruising altitude of 1000 m,

$$u \geq 150 \text{ km/h} \tag{51}$$

is adequate, a continuous headwind of 30 km/h during the entire journey would then reduce the covered distance to 7700 km, which still yields a reserve of 10%.

Considering conditions (47-51), a kerosene-fueled, an LH_2-fueled, and a partially Blaugas-fueled hybrid airship were selected from the data listed in Ref. 32. (The 60,000 m^3 Blaugas hybrid was chosen because, as shown in Fig. 7, an increase of the Blaugas volume beyond 60,000 m^3 leads only to minor advantages in performance.) Figure 8 gives an impression of the arrangement of the hybrid Zeppelins being considered. In Table 1 their technical data are compared with those of a modern rigid airship design, a proposed high aspect ratio wing hybrid, and an existing jet transport aeroplane, the C-5A. The "Graf Zeppelin III" (GZ III), one of the very few realistic proposals for a modern rigid airship,[34] combines modern materials and engines with the proven Zeppelin design and uses a combination of gaseous and liquid hydrogen as fuel, which facilitates the balancing of the ship. The "Megalifter"[8] is a semirigid airship hull combined with a high-aspect-ratio wing.

In Fig. 9, the main performance data of the six vehicles are depicted as columns. It can clearly be seen that the LH_2-fueled hybrid Zeppelin is superior to the modern rigid aerostat in the considered aspects and that even the kerosene-fueled hybrid has the same payload factor. The "Megalifter" and the C-5A are distrinctly inferior to the kerosene-fueled hybrid Zeppelin and all the more to the Blaugas-fueled one.

Nevertheless, there remains one substantial advantage of the C-5A—it works!

V. Summary

To increase the handling qualities of large airships, it has been proposed that a rigid airship of fineness ratio 4 be outfitted with a slender delta wing of aspect ratio 1.5. The optimization calculation with respect to the ratio wing span to body diameter leads to performance data which show that delta-winged hybrid Zeppelins are superior to modern conventional airship designs, as well as to other kinds of hybrids and existing jet airplanes. Depending upon the kind of fuel used, hybrid Zeppelins are able to carry payloads ranging from 40 to 55% of their takeoff weight (about 1/3 more than existing jet airplanes carry), with a cruising speed of 150 km/h at a range of 10,000 km, and consume 45% less energy than present jet aircraft require to cover comparable distances.

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