N76-15026

BASIC RELATIONSHIPS FOR LTA TECHNICAL ANALYSIS

Raymond A. Ausrotas*

ABSTRACT: An introduction to airship performance is presented. Static lift equations are shown which, when combined with power requirements for conventional airships, allow parametric studies of range, payload, speed and airship size. It is shown that very large airships are required to attain reasonable speeds at transoceanic ranges.

INTRODUCTION

The performance equations for airships are presented as a basic introduction to the technology of LTA. The lift equations are based upon aerostatic lift principles; the drag equations assume airship fineness ratios (length to diameter) of past airships and conventional fuel sources and engines. It is shown then that the Lift-to-Drag ratio is proportional to $C^{1/3}/V^2$, where C is capacity and V is the velocity of the airship, indicating that to maintain the same L/D ratio while increasing speed calls for a huge expansion of airship size.

---

*Associate Director, Flight Transportation Laboratory, Massachusetts Institute of Technology, Cambridge, Mass. 02139

AIRSHIP PERFORMANCE

Lift

Aerostatic lift is the basic means of carrying a payload in LTA craft. According to Archimedes' Principle a body immersed in fluid is bouyed up with a force equal to the weight of the displaced fluid. The object of the airship game is to displace a large weight of air--the bouyant force obtained being equal to the weight of the air displaced. Although the ideal airship would be a vacuum vessel, obvious structural problems inhibit this solution, and some lighter than air gas is used to maintain the structural integrity of the airship. Thus the gross lift capability of an airship is equal to the bouyant force minus the weight of the ship, or

$$L_{gross} = \rho_{air} V_{body} - \rho_{body} V_{body} \quad (1)$$

or, neglecting structural weight,

$$L_{gross} = (\rho_{air} - \rho_{gas}) V_{body} \quad (2)$$

Since ρ_{air} = 0.077 lb/ft^3 and ρ_{helium} = 0.011 lb/ft^3, a thousand cubic feet of helium "lift" about 66 lbs.

This is at standard air temperature and pressure conditions. Corrections are usually made for water vapor and impurity of the lifting gas, as well as percentage of inflation of the gas cells at liftoff.

At 5,000 feet the density of air is about 86% of sea level density, and at this altitude one thousand cubic feet of helium lift only 54 lbs. (Changes in temperature and barometric pressure at any height also affect lift, sometimes producing the condition of "false lift.") The ship will continue to rise until the altitude at which the bouyant force of air will just support the total weight of the airship (including the weight of the helium). This is the operational static ceiling.

"Pressure height" is reached when the gas cells of the airship are completely full; as the ship rises, reduction in barometric pressure permits the helium to expand; flight at a higher altitude produces helium loss, either by purposeful venting or destruction of the gas cells. In the past, airships have cruised at about 2,000 feet with a pressure altitude of about 6,000 feet. While this procedure saved helium, it reduced the payload and resulted in routing problems in mountainous areas.

"Superheat" is another common lifting phenomenon in LTA. Positive superheat exists when the temperature of the lifting gas is greater than the ambient air temperature; negative superheat is the reverse. An increase in gas temperature results in decreased density of lifting gas and increased gas volume. A superheat of +4.3°F results in a 1% increment of lift when the airship is lower than its pressure height[1,2].

In addition to static lift, an airship can obtain a certain amount of dynamic lift from the engines. This varies depending on the power of the engines and the shape of the airship. Dynamic lift in the past has been about 10% of static lift. Dynamic lift can allow an airship to "take off heavy" from a runway similar to heavier than air vehicles, but it also requires additional power and fuel, negating some advantages of LTA.

The payload that an airship can lift, then, depends upon the "capacity" of the airship (the cubic feet of volume of the lifting gas), the structural (fixed) weight of the airship (hull, engines, coverings, instruments), plus ballast, crew, equipment and fuel. Airships have had a 50/50 ratio of useful payload to structural weight; the weight of the hull alone for rigid airships has been approximated as[1]

$$W_{hull(tons)} = 11C \quad (3)$$

where C = capacity in millions of cubic feet. Assuming the 50/50 ratio to hold and further assuming that the hull accounts for the great majority of the structural weight, the useful lift available for payload and fuel is, in tons,

$$L_{net} = 11C \quad (4)$$

This formula agrees approximately with the experience of the past, where the useful payload has been about 30% of the gross lift, since assuming incomplete inflation, gas impurities, etc., gross lift of a helium airship is about 60 lbs per 1,000 cubic feet, or, in tons

$$L_{gross} = 30C \quad (5)$$

Given technological improvements in structures, an airship designed today would probably have a higher payload/structure ratio and hence lift a somewhat greater useful load.

Power

The drag for an airship can be formulated similarly to that of HTA craft. For airplanes

$$D = C_D \, \rho/2 \, S \, V^2 \quad (6)$$

where D = drag
ρ = density of air
V = airspeed
S = area
C_D = dimensionless drag coefficient

For airships, then

$$D = K_A \rho/2 \, C^{2/3} V^2 \qquad (7)$$

where K_A = whole ship drag coefficient
C = capacity of airship $(C^{2/3} = S)$
V = velocity of airship

The power required to overcome the airship drag is

$$P = \text{Drag} \times \text{Velocity} \qquad (8)$$

or, defining a new "drag" coefficient, k_a, $(k_a = K_A/550)$,

$$\text{Maximum Horsepower} = k_a \, C^{2/3} V^3 \qquad (9)$$

where V = maximum airspeed

Equation (9) allows trade-offs between horsepower, speed and capacity to be made, once k_a is known.

From the data on actual airships built, k_a can be determined. Table 1 shows the characteristics of past airships 3,4,5.

Table 1

Principal Characteristics of Past Airships

Airship	Fineness Ratio	Capacity (m.cu.ft.)	Horse-power	Max. Speed (mph)	k_a
LZ126 Los Angeles	7.3	2.5	2,000	73	2.79×10^{-3}
LZ 127 Graf Zeppelin	7.8	3.7	2,650	80	2.17×10^{-3}
R.100	5.4	5.6	3,960	82	2.28×10^{-3}
ZRS 4/5 Akron/Macon	7.9	6.5	4,480	84	2.17×10^{-3}
LZ 129 Hindenburg	4.4	7.1	4,100	88	1.63×10^{-3}

As an approximation (for large airships) k_a is assumed to be 0.002. Thus, from equation (9),

$$HP = 0.002\ C^{2/3}\ V^3 \qquad (10)$$

For range estimation, the specific fuel consumption must be known. This can be taken as 0.5 lb. per BHP hour.[1,6] The weight of fuel used per hour at any speed, converting to tons/hour, is:

$$W(\text{fuel/hour}) = 0.00025\ HP \qquad (11)$$

The maximum endurance of the airship, E (in hours), will come about when the payload consists totally of fuel.

Assuming that total net lift is used for fuel, from equation (4),

$$11C = (0.00025\ \ HP)E \qquad (12)$$

or

$$E = \frac{11C}{0.00025\ HP} \qquad (13)$$

or, substituting equation (10)

$$E = 2.2 \times 10^7\ C^{1/3}\ /\ V^3 \qquad (14)$$

Then the maximum range of the airship is (excluding headwinds)

$$R_{max} = E \times V \qquad (15)$$

or

$$R_{max} = 2.2 \times 10^7\ C^{1/3}\ /\ V^2 \qquad (16)$$

One item neglected in this discussion is the cruise altitude--it is assumed that an airship operator would choose the lowest altitude possible since there is a sharp loss in range with increased operating altitude, independent of all other factors.

Figures 1-5 present a parametric study of large airships based upon the given assumptions. It can be seen that exceedingly large airships are required to reach oceangoing ranges at higher speeds: an airship of 30 m.cubic feet capacity is needed to cross the Atlantic at speeds above 125 mph, given some fuel reserve requirements. An airship of 7.5 m.cubic feet can carry a payload of 25 tons at 80 mph 5,000 miles. If the speed is increased 50% to 120 mph the range that the same payload can be carried drops to 2,000 miles. To be able to achieve the same payload-range combination at the higher speed, an airship capacity of more than 30 m.cubic feet is required.

It is also interesting to look at the lift to drag ratio for airships. From equations (5) and (7),

$$L/D = K\ C^{1/3}\ /\ V^2 \quad (17)$$

This provides another illustration of the penalty of high speed in airships. If the cruising speed were to be doubled and the designer wished to maintain the same L/D ratio, the capacity of the airship would have to be expanded by a factor of 64. If the same gas volume is maintained, on the other hand, the L/D ratio drops by a factor of 4.

FIGURE 1

Horsepower vs. Capacity

(Velocity (max.) in mph)

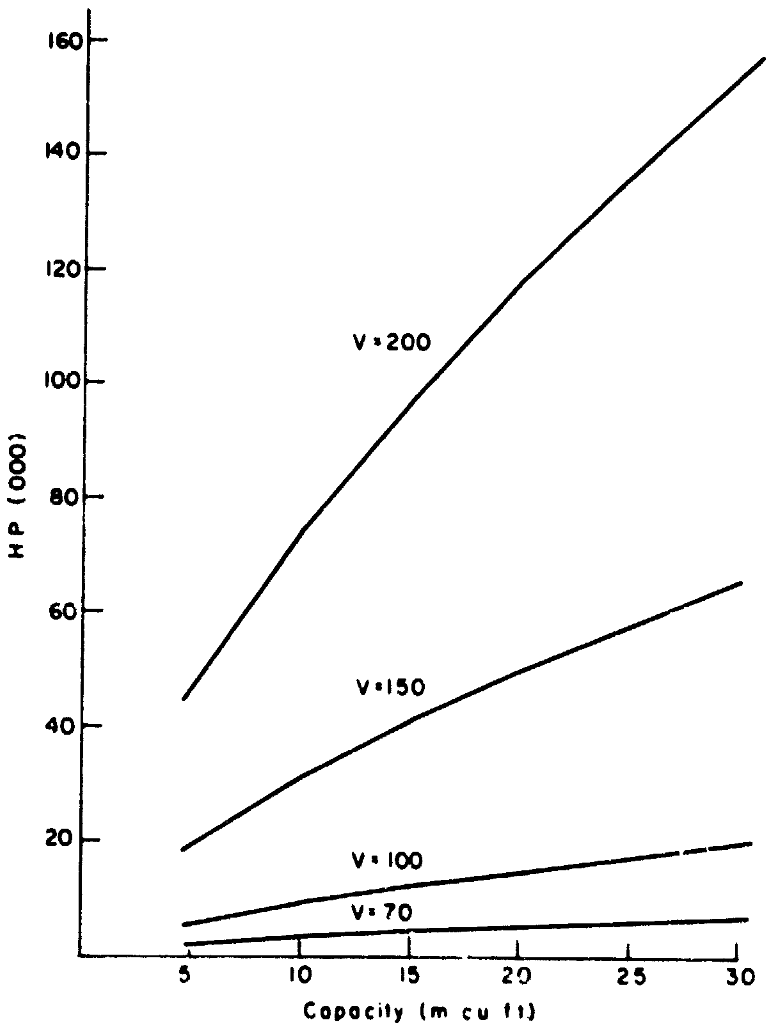


FIGURE 2

<u>Maximum Range Capacity</u>

(Velocity in mph)

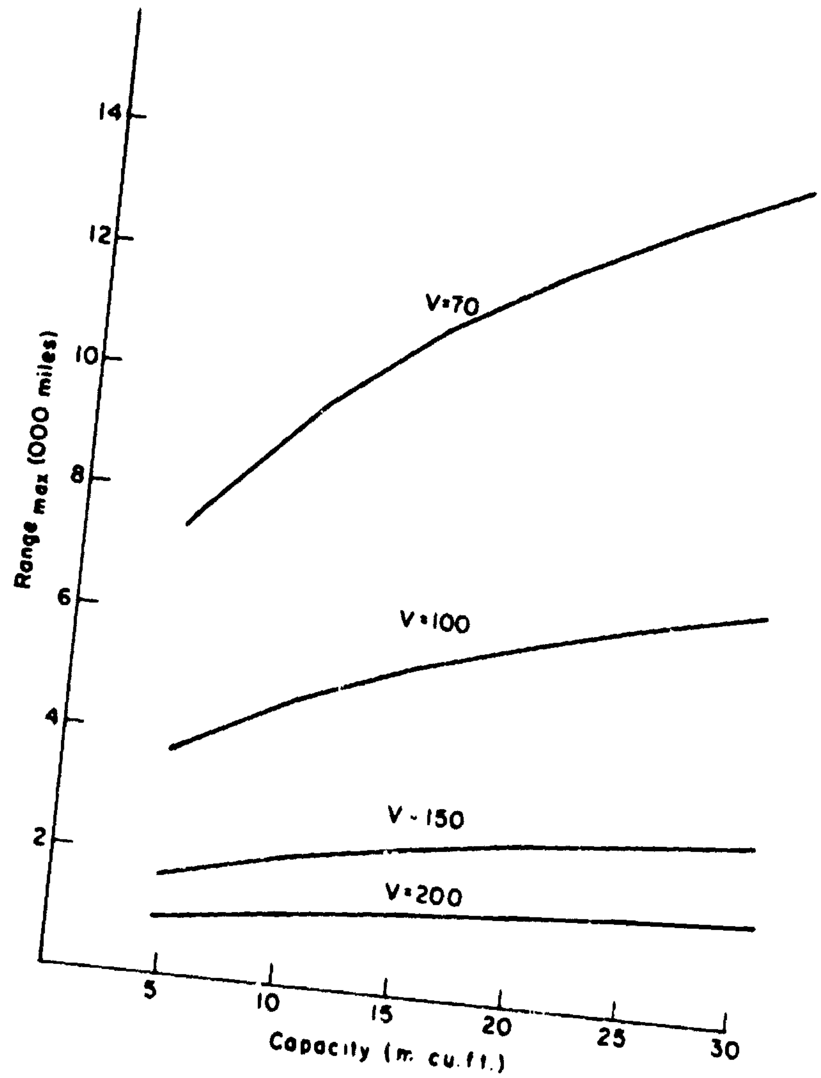


FIGURE 3

Payload vs. Range

(7.5 m. cubic feet airship)

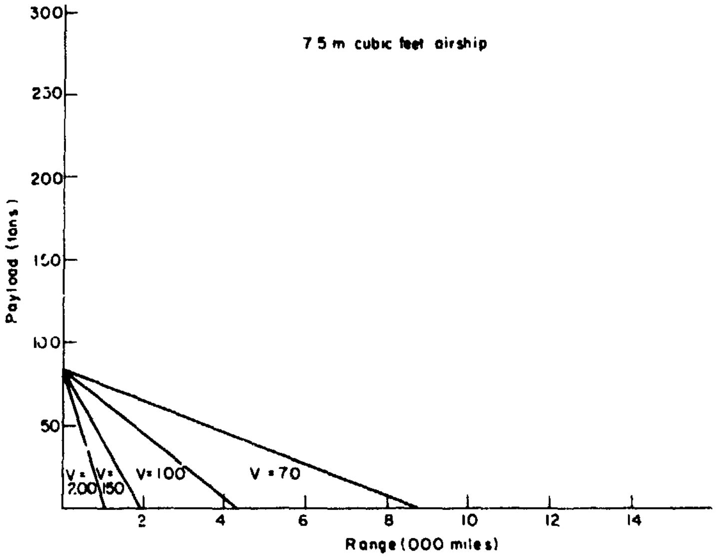


FIGURE 4

Payload vs. Range

(10 m. cubic feet airship)

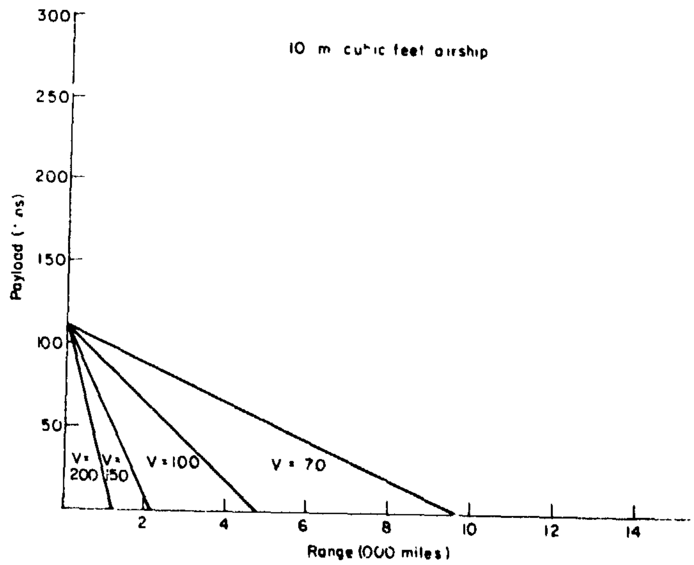
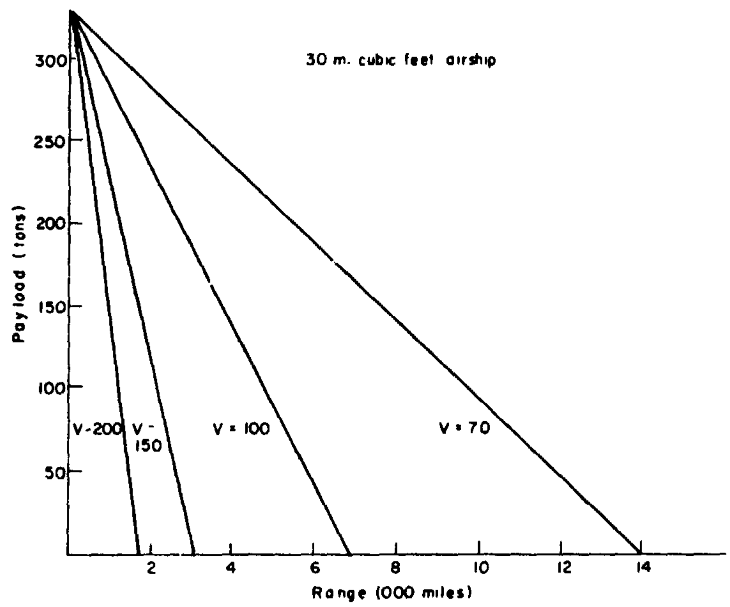


FIGURE 5

Payload vs. Range

(30 m. cubic feet airship)



REFERENCES:

1. E.H. Lewitt, The Rigid Airship, Sir Isaac Pitman & Sons, Ltd., London (1925).

2. Bureau of Aeronautics, Department of the Navy, Rigid Airship Manual, 1927, U.S. Government Printing Office, Washington, D.C. (1928).

3. Peter Brooks, "Transport Airships," Flight International, (December 25, 1959) p. 780.

4. Anon., Building the World"s Largest Airships, The Goodyear-Zeppelin Corporation, Akron, Ohio (1929?).

5. Carl B. Fritsche, The Metalclad Airship, The Royal Aeronautical Society, London (1931) Aeronautical Reprints No. 61.

6. E. Mowforth, "A Design Study for a Freight-Carrying Airship," The Aeronautical Journal of the Royal Aeronautical Society, Vol. 75, No. 723 (March 1971) p. 166.