Capabilities of Buoyant-Lift Vehicles in Planetary Atmospheres

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Nomenclature

B = buoyancy force
f = factor defined in Eq. (7)
g = local gravitational acceleration
M = mass
$\bar{M}$ = molecular weight
p = pressure
$\bar{R}$ = universal gas constant
T = temperature
V = volume
W = weight
ρ = density

Subscripts

a = atmosphere
g = lifting gas
v = vehicle (excluding lifting gas)

BUOYANT-LIFT vehicles, in particular the airship, have many attractive features and these have been well documented by proponents.[1] This Note examines the prospects for such vehicles in atmospheres other than that of the Earth. A stimulating study of a vehicle for operation in the atmosphere of Venus appeared over a decade ago.[2]

Although aerodynamic lift is used to augment, or at least control, the total lift, the basic requirement is that the buoyancy force on the vehicle balances the weight; thus

$$B = W \tag{1}$$

The buoyancy force is given by

$$B = \rho_a(V_g + V_v)g \tag{2}$$

The weight is given by

$$W = W_v + W_g$$

or

$$W = (M_v + \rho_g V_g)g \tag{3}$$

So, from Eqs. (1–3)

$$M_v/V_g = (\rho_a - \rho_g) + (\rho_a V_v/V_g) \tag{4}$$

It is noteworthy that the ratio of vehicle mass to lifting gas volume is independent of the local gravitational acceleration. Equation (4) is now further simplified by neglecting the term $(\rho_a V_v)/V_g$. The simplification is conservative.

This leads to the following relation:

$$M_v/V_g = \rho_a - \rho_g \tag{5}$$

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Making the usual assumptions that the gases are perfect gases, Eq. (5) can be written

$$M_v/V_g = (1/\bar{R})(p_a\bar{M}_g/T_a)[(\bar{M}_a/\bar{M}_g) - f] \tag{6}$$

where

$$f \equiv (p_g/p_a)\, T_a/T_g \tag{7}$$

In practice, the value of f will depend upon the small excess of p_g over p_a required to ensure that any leakage occurs from the lifting gas to the atmosphere, and on the energy exchange within the vehicle and between the vehicle and the surroundings. In this simplified treatment, we assume $f = 1$.

Equation (6) becomes

$$M_v/V_g = (1/\bar{R})(p_a\bar{M}_g/T_a)[(\bar{M}_a/\bar{M}_g) - 1] \tag{8}$$

Values of M_v/V_g for helium-supported vehicles in the lower atmospheres of Earth, Mars and Venus are presented in Table 1. For vehicles in the Earth's atmosphere, this simplified analysis gives $M_v/V_g = 0.0658$. Data on the Boston University nuclear airship[1] gives $M_v/V_g = 0.0640$. The discrepancy of 3% between the two figures presumably results from impurities in the lifting gas and from the simplifications used in this analysis. The correspondence is sufficiently close, however, to permit use of Eq. (8) for comparative purposes.

From Table 1 it is evident that the Martian atmosphere is unsuitable for buoyant-lift vehicle operation. The Venetian atmosphere, on the other hand, appears very attractive in regard to the M_v/V_g ratio attainable. The Venetian atmosphere is extremely hostile to man, and extensive environmental protection will be required for the crew and generally for the other payload. It may reasonably be conjectured, however, that payloads in the order of ten times those carried by buoyant-lift vehicles in the Earth's atmosphere are within the bounds of possibility.

The Venetian surface is obscured by clouds. It is not yet known whether the clouds extend right to the surface, nor is it known how turbulent the lower atmosphere may be. The atmosphere appears to be largely carbon dioxide so nuclear propulsion is clearly indicated. If the atmospheric conditions should not prove prohibitive, the airship may yet achieve its fulfillment in the atmosphere of our sister world.

References

[1] Morse, F., O'Hara, G. J., Pavlecka, V. H., Stehling, K. R., and Vaeth, J. G. "Dirigibles: Aerospace Opportunities for the '70s and '80s." *Astronautics & Aeronautics*, Vol. 10, No. 11, 1972, pp. 32–40.

[2] Godwin, F., *The Exploration of the Solar System*, Chapman and Hall Ltd., London, England, 1960.

Table 1 Ratio of vehicle mass to lifting gas volume for helium-supported vehicles ($\bar{M}_g = 4$)[a]

Planet	p_a lbf/in.^{2}	T_a °R	$\bar{M}_a$	M_v/V_g lb/ft^3	Ratio (Earth = 1)
Earth	14.7	520	29	0.0658	1
Mars	0.12	420	44	0.00106	0.016
Venus	1400	1300	44	4.01	61

[a] Atmospheric data is typical and approximate.