Engineering Notes

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Hovercraft Range

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Nomenclature

A = const = $P_4/(P_{1i} + P_{2i})$
B = const = $(P_3 + P_5 + P_6 + P_7)/(P_{1i} + P_{2i})$
C = const = $[d(s/si)]/[d(PT/P_{Ti})]$
P = engine power, ft-lb/sec
R = range, miles
s = specific fuel consumption, lb/bhp-hr
$\bar{s}$ = average specific fuel consumption, lb/bhp-hr
t = time, hr
v = true ground speed, fps
w = craft gross weight, lb
ϵ = specific resistance = P_T/wv
ϵ_i = initial specific resistance = P_{Ti}/w_iv

Subscripts

i = initial
T = total
1 = air cushion
2 = stability jet
3 = ancilliary equipment
4 = inlet momentum
5 = profile
6 = skirt contact
7 = wave

Analysis

For a hovercraft operating at a constant hoverheight, wave drag, and auxiliary power requirement, it can be shown here, Ref. 1, that, for invariant environmental conditions,

$$R = \frac{375}{\epsilon_i s_i} \int_{w/wi}^{1} \frac{d(w/w_i)}{P_T/P_{Ti}[1 + C(P_T/P_{Ti} - 1)]}$$

$$= \frac{375}{\epsilon_i s_i} \int_{w/wi}^{1} \frac{[1 + A + B]^2\, d(w/w_i)}{[(w/w_i)^{3/2} + A(w/w_i)^{1/2} + B] \times \{(1 + A + B)(1 - C) + C[(w/w_i)^{3/2} + A(w/w_i)^{1/2} + B]\}} \quad (1)$$

Further simplification is effected by using an average specific fuel consumption instead of the linear power/specific fuel consumption relationship. Then,

$$R = \frac{375}{\bar{s}\epsilon_i} \int_{w/wi}^{1} \frac{(1 + A + B)d(w/w_i)}{(w/w_i)^{3/2} + A(w/w_i)^{1/2} + B} \quad (2)$$

Even for the most extreme case considered ($A = B = 0.5$; $w/w_i = 0.3$), the foregoing simplification introduces an error of less than 3% in R for a 30% variation of specific fuel consumption during operation. Equation (2) therefore has been used for the evaluation of range, by numerical integration, for A = 0.5, 1.0, 1.5, 2.0; B = 0.5, 0.75, 1.0, 1.25, 1.5. On this basis, the range of hovercraft is simply obtained from Figs. 1a–1d using the relevant values of the constants A and B, the initial specific resistance, the average specific fuel consumption, and the ratio (w/w_i).

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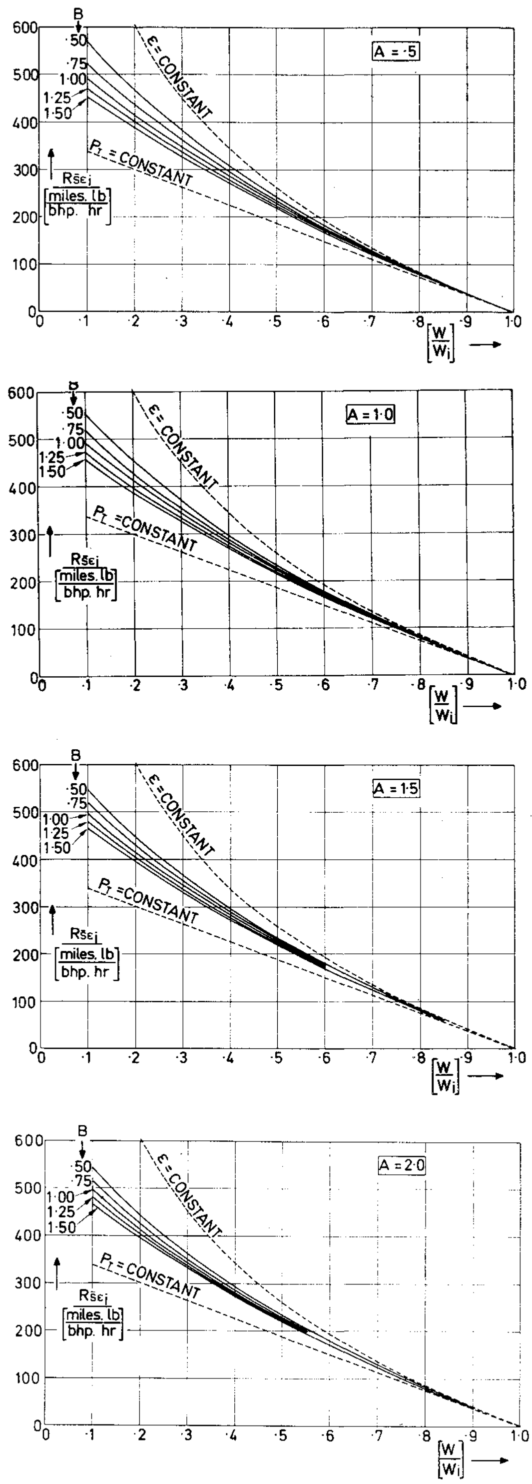

Fig. 1 Effect of design efficiency on range.

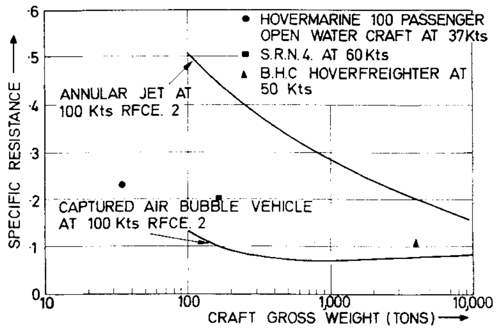

Fig. 2 Variation of specific resistance with craft design gross weight.

For existing hovercraft, values of A and B are approximately unity, and other constants may be taken to comprehend those anticipated, even for very large craft. Although the dependence of range is shown for values of (w/w_i) of 0.1 to 1.0, the lower of these values may be hypothetical, since it is very unlikely that, even for very large craft, values of less than 0.3 will be achieved.[2]

In Fig. 2, theoretical calculations of specific resistance of Fielding[2] are shown with those for other projected hovercraft. It can be seen that there is a beneficial size effect which favors the larger craft. This effect would be even more advantageous were it not that these large craft are designed to operate in the more adverse wind and wave conditions encountered on longer and more exposed routes.

The constant A is approximately proportional to the reciprocal of the cushion pressure. From structural and economic considerations[3] the larger craft will employ higher cushion pressures and thus will have lower values of A. From a comparison of Figs. 1a–1d it can be seen that these lower values of A will result in a slight increase in range capability. Thus there is again a beneficial size effect favoring the larger hovercraft.

The constant B is primarily a function of the reciprocal of the "daylight clearance." It is a matter of conjecture as to whether the present daylight clearances will be employed on very large craft, or, as seems more probable, the larger craft will employ greater clearances. Higher values of the daylight clearance result in lower values of B and increased range capability.

Also included on Figs. 1a–1d are results based on the assumption of 1) constant specific resistance, and 2) constant total power requirement. The former yields the expression

$$R = (375/\bar{s}\epsilon_1) \log_e(w_i/w) \text{ miles}$$

which is of the same form as the Breguet range formula for aircraft. However in the derivation of the Breguet formula, airspeed is not constant, whereas in the present instance it is. It can be seen that, for conventional hovercraft, in which the craft weight is almost completely supported by the air cushion, the Breguet formula overestimates range. Thus, although the formula draws attention to the importance of the "performance efficiency" $(1/\epsilon_i)$ and the "design efficiency" $\log_6(w/w_i)$ as per Mantle,[4] the formula should not be used to evaluate range.

Conclusions

The range of hovercraft operating at constant speed in an invariable environment is a function of the design efficiency, the way in which the total power is apportioned, and is directly proportional to the average specific fuel consumption and initial specific resistance. Larger hovercraft will have longer range primarily through achieving lower values of initial specific resistance and higher values of design efficiency. A secondary benefit for the larger craft is from the way in which the total power is apportioned.

References

[1] Burgess, A. J., "The Performance of Fans in Hovercraft. A Method of Reducing Experimental Results," R & M 3507, Nov. 1965, Aeronautical Research Council.

[2] Fielding, P. E., "Twentieth Century Yankee Clippers," *Hovering Craft and Hydrofoil*, Vol. 5, No. 2, Nov. 1965, pp. 6–17.

[3] Bingham, A. E., "The Hovercraft Ferry," *Hovering Craft and Hydrofoil*, Vol. 3, No. 7, April 1964, pp. 8–17.

[4] Mantle, P. J., "ACV Parametric Assessment," *Air Cushion Vehicles, Flight Supplement*, Vol. 8, No. 53, Nov. 1966, pp. 74–76; Vol. 8, No. 54, Dec. 1966, pp. 89–91.

Glass Submersibles

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Introduction

GLASS, which contains melted silica sand, one of the earth's more abundant materials, has been in use by man for as long as or longer than most common metals and far longer than such new metals as aluminum and titanium. Its use is confirmed by the discovery of glass artifacts in the ruins of nearly every ancient civilization. Yet, until recently, little or no structural use has been made of glass. Although according to legend Alexander the Great submerged in a glass barrel about 323 B.C., modern submersible applications of glass until very recently have been limited to its use for the viewing ports in the Japanese submersibles Kuroshio and Yomiuri.

Glass has significant advantages for underwater use. Its high intrinsic strength allows it to withstand pressures approaching 3,000,000 psi; glass fibers have supported as much as 1,000,000 psi in tension; and in tests made recently at the University of Vermont, uniaxial compressive loads of 500,000 psi were imposed.

This ability of glass to withstand compressive loads makes it an ideal material for submersibles, provided we can design configurations and joints in which practically no tension is allowed to exist in the glass hull. The fragility of glass is due primarily to its poor resistance to tensile stress. The strength of a glass hull under pressure is primarily limited by its ability to withstand compressive loads and is therefore enormous.

The purpose of this paper is to discuss the glass submersibles now under construction at the Naval Undersea Warfare Center. (Formerly NUWC was part of the Naval Ordnance Test Station, and the present NUWC submersible development groups began their work at NOTS China Lake as part of that Station's oceanographic research and development program.) Before speaking of present models, however, it will be helpful to review earlier submersibles in order to illustrate the need for current changes and modifications to design concepts.

Background

Deep Jeep, one of the first American-built deep-sea research vehicles, was designed, fabricated, and operated by my group when we were at NOTS. Deep Jeep was launched in Jan. 1964 and was operated to 2000-ft depths during part of its development test phase. Submarine rescue experiments and oceanographic research were conducted in several coastal areas off California with it. In Jan. 1966 it was the first submersible to reach the Mediterranean for use in the

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