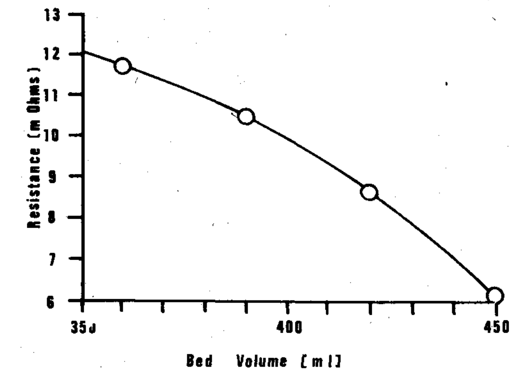

Fig. 3 Variation of resistance with bed volume.

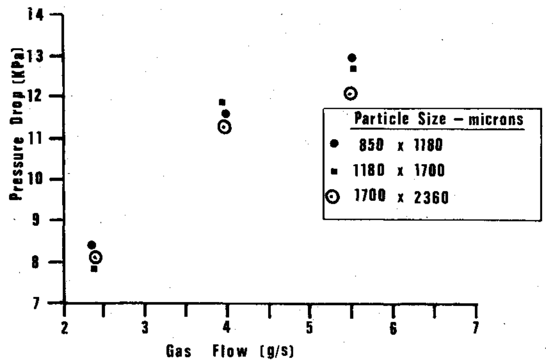

Fig. 4 Variation of pressure drop with flow.

Design Parameters

Characterizing the performance of such a bed is difficult because:

1) Electrical resistance depends upon the intergranular contact resistance which, in turn, depends upon temperature and intergranular force.

2) Electrical resistance under operating conditions is difficult to measure. Thyristor chopping of the electrical waveform was used as a current control device to control the heater. So, at another time, was a saturable reactor. In each case, simultaneous measurement of values for the distorted current and voltage waveforms was difficult. Moving iron instruments were used and it was recognized that, although the values obtained could be used for design purposes, the measurements would not be very accurate.

3) Electrical performance was found to depend strongly on the temperature history of the bed.

4) The bed performance was thought to depend upon the following parameters: bed geometry, chip size and shape, temperature variation in the bed, gas pressure, gas flow rate, and electrostatic forces near the bed surface resulting from the high currents. Consequently, because of the interdependence of these parameters, it is felt that any theory of bed behavior will require a multivariable regression on extensive data for its validation.

Such an extensive study has not been made, but some measurements are presented in order to permit design of further heaters.

Electrical Resistance

The effect of bed volume on electrical resistance for the geometry shown in Fig. 1 is illustrated in Fig. 3. Dependence upon gas flow, bed temperature, and bed particle size was not clear. However, for particles in the range of 850-2360 μm, temperatures of 500-1500°C, bed volumes of 360-450 ml, and nitrogen flows of 2-6 g/s, the electrical resistance remained within 0.005-0.015 Ω.

Pressure Drop

Figure 4 shows the variation of pressure drop with flow rate through the bed. Since the heated gas passed through a sonic throat of fixed diameter, the upstream pressure varied between 400 and 800 kPa to achieve the varying flow rates represented. Thus Fig. 4 should be recognized as merely suggesting the pressure drops which might be expected. The outlet temperature was held at 1000°C.

Conclusion

The heater reported shows a significant advance over previous heaters. It is simple and cheap to construct, allows continuous variation of pressure and temperature over a wide range (there is, in principle, no pressure limit), and can tolerate the oxidants found in commercially pure gases. It is robust in service and requires a minimum of attention. A fuller understanding of the heater's behavior will require a major investigative effort.

It is possible that the heater can be modified to handle oxidizing gases by the use of ferrochrome or silicon carbide chips instead of graphite chips. This will require sophisticated control of the power supply.

Acknowledgment

This research was sponsored by the C.S.I.R. of South Africa through its agency, C.S.P.

Reference

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AIAA 82-4099

Performance of Underwater Vehicles Employing Lift to Reduce Drag

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Introduction

UNDERWATER vehicles operate in a medium whose density is comparable to that of their own and therefore experience high skin friction relative to their weight. Performance of such vehicles, in terms of maximum speed or range, is therefore severely limited by the necessary volumes of power plants or energy sources. Most of the smaller vehicles are launched from tubes whose diameters are determined by external considerations so that required volumes are achieved by very slender configurations whose high ratio of surface area to volume renders them hydrodynamically inefficient.

Considerable effort has been expended on the development of vehicles whose boundary layers are maintained in the laminar state at high Reynolds by means of shapes which develop favorable pressure gradients over their forward regions, or by heating of surfaces to stabilize the flow and, thus, delay transition to the turbulent regime. Such vehicles are generally axisymmetric and must possess surface finish and profile tolerances of extremely high order. As an example, Lauchle et al.[1] built a 0.3 m maximum diameter

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laminar flow vehicle with mean surface roughness of 0.8 μm (30×10^{-6} in.) and waviness of 127 μm/0.1 m. Operational problems associated with vehicles which demand such stringent surface finish criteria are likely to limit their deployment to special situations.

In certain instances, it is not necessary to restrict vehicle configurations to axial symmetry or to operate axisymmetric vehicles in such a mode. By increasing the densities and reducing the fineness ratios of vehicles, the surface area and total skin friction can be reduced significantly. Operation at a given depth is attained by lift resulting from an angle of attack due to control surfaces or balancing of the vehicle. With the recent achievements in microelectronics, the usual guidance and control systems represent a relatively small fraction of the total volume whose magnitude is now determined primarily by relatively dense components such as electric motors and batteries.

The present study represents a significant departure from the conventional approaches in this field and should be viewed as an exploration of conditions under which the reduction of frictional drag is not cancelled by the increased drag due to lift. At this stage, considerations are limited to ellipsoids with completely turbulent boundary-layer flows. It is realized that more effective lifting configurations could be adopted and that laminar flow could be maintained over smooth forward regions where favorable pressure gradients prevail. The results presented here, therefore, should be viewed as extremely conservative indications of the feasibility of the proposed approach. Establishment of the full potential of the concept will require a considerably more detailed parametric study.

Analysis

The vehicle configurations considered here are general ellipsoids with length $2c_0$, maximum width $2a_0$, and maximum thickness $2b_0$. Cross sections are given terms of the spanwise coordinate x and vertical coordinate y by the relation

$$x^2 + y^2/(1-e^2) = a^2 \tag{1a}$$

$$= a_0^2(1-(z/c_0)^2) \tag{1b}$$

with z the longitudinal coordinate and the eccentricity e defined by the local half thickness b and the half span a as

$$e = (1-(b/a)^2)^{1/2} \tag{2}$$

the local cross-sectional area is

$$A = \pi ab \tag{3}$$

and the local circumference is

$$C = 2\pi E(e)a \tag{4}$$

with E related to the elliptic integrals and taken here as

$$E = 1 - e^2(16+3e^2)/64 \tag{5}$$

The volume V and the surface area S are obtained by integration, and are found to be

$$V = 4\pi\lambda(1-e^2)^{1/2} a_0^3/3 \tag{6}$$

$$S = 2\pi a_0^2 E\Lambda \tag{7}$$

with

$$\lambda = c_0/a_0 \tag{8a}$$

$$\Lambda = 1 + \lambda A^{-1}\arcsin A \tag{8b}$$

$$A^2 = 1 - \lambda^{-2} \tag{8c}$$

The lift of the configuration consists of linear and nonlinear components as shown in Hoerner.[2] With $4a_0c_0$ as the reference area, the lift and drag coefficients at angle of attack α, C_L and C_D, respectively, may be expressed as

$$C_L = \pi(1+Z\alpha)\alpha/2\lambda \tag{9a}$$

$$C_D = \pi(1+2Z\alpha)\alpha^2/4v \tag{9b}$$

with

$$Z = 2k\lambda/\pi \tag{9c}$$

and k is the constant in the cross-flow force relation which Hoerner recommends to be taken as 1.1. Skin friction drag coefficient $C_{D,f}$ referenced to total surface area S, and dynamic pressure q is given by Goldstein[3] as

$$C_{D,f} = K(\log Re)^{-\gamma} \tag{10}$$

with Re the Reynolds number based on length, $K=0.455$ and $\gamma=2.58$. Equilibrium in the vertical plane requires a balance of the vehicle weight w by the buoyant force and lift which is expressed as

$$w = \rho g V + 2\pi a_0^2(1+Z\alpha)\alpha q \tag{11}$$

with g the gravitational constant and ρ the fluid density. Solution of the earlier relation for the angle of attack yields

$$\alpha = [(1+4YZ)^{1/2} - 1]/2Z \tag{12}$$

with

$$H = [3\lambda^2/(4\pi\Gamma(1-e^2)^{1/2})]^{1/3} \tag{13a}$$

$$I = H\Gamma(1-e^2) \tag{13b}$$

$$J = 3Re_0^2/4W_0 I \tag{13c}$$

$$Re_0 = UV_0^{1/3}/\nu \tag{13d}$$

The preceding definitions contain the groups

$$V_0 = \Gamma V, \quad W_0 = V_0 g/\nu^2, \quad Y = (\Gamma-1)/\Gamma J, \quad \Gamma = w/\rho g V$$

with U the vehicle speed and ν the kinematic viscosity of the fluid.

It should be noted that in the present formulation, the Reynolds number Re_0 and the size parameter W_0 are defined in terms of the volume V_0 of a vehicle with the same mass as the one under consideration, but a density equal to that of water. It should also be noted that the combination Re_0^2/W_0 is equivalent to a Froude number which appears because of the dynamic and gravitational effects. The drag coefficient will be calculated assuming that the skin friction relation [Eq. (10)] is independent of the angle of attack. This assumption is quite acceptable here because the parametric study is restricted to considerations of vehicles operating primarily in the range of angles of attack well under 10 deg. It is convenient to define the drag coefficient on the volume V_0 so that

$$C_{D,0} = D/qV_0^{2/3} \tag{14a}$$

$$= 2\pi\left(\frac{H}{\lambda}\right)^2 [K\Lambda E(\log 2HRe_0)^{-\gamma} + (1+2Z\alpha)\alpha^2/2] \tag{14b}$$

With the preceding definition, the drag coefficient achieved by a smaller, denser vehicle is related directly to the drag

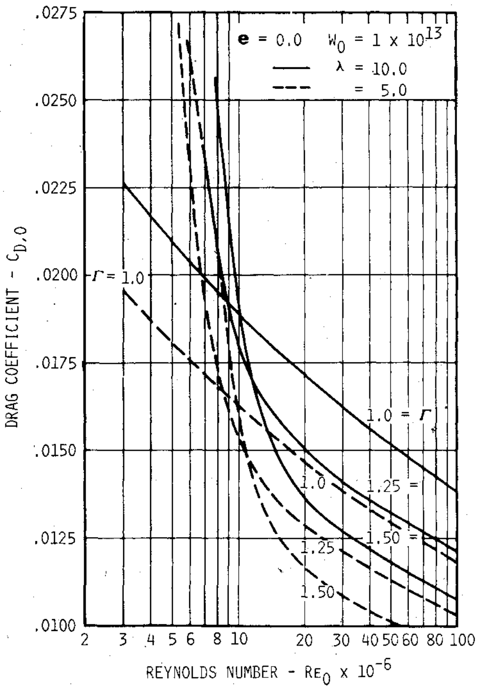

Fig. 1 Influence of vehicle density and fineness ratio on the nominal drag coefficient.

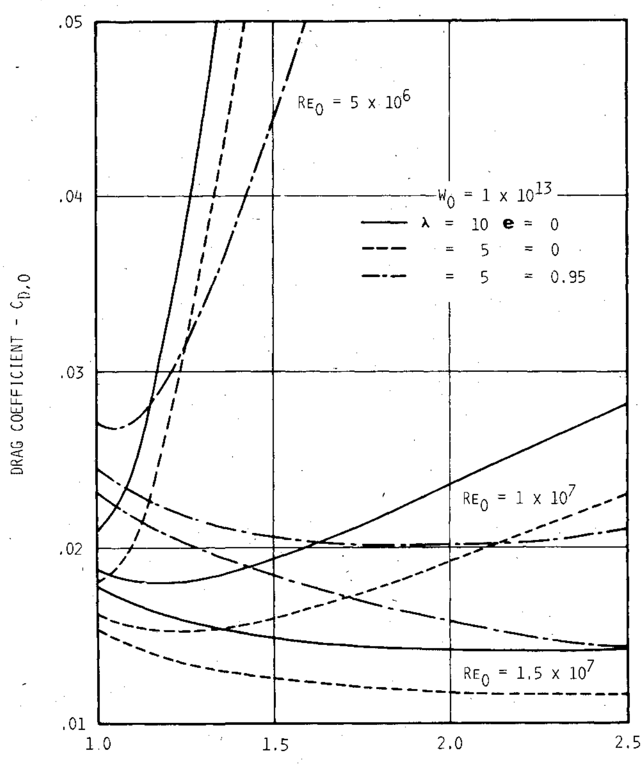

Fig. 2 Variation of the nominal drag coefficient with the vehicle density.

coefficient of a neutrally buoyant vehicle of equal mass. Representative results of parametric studies are shown in Figs. 1 and 2.

Results and Conclusions

The principal parameters in this study are the relative density Γ, the cross section eccentricity e, the fineness ratio λ, the Reynolds number Re_0, and the size W_0. Variation of the drag coefficient $C_{D,0}$ with the Reynolds number of a $\Gamma=1$ vehicle of identical mass is shown in Fig. 1. Effectiveness of the use of lift can be evaluated directly by comparing the results with those for $\Gamma=1$. The lifting vehicles are smaller and despite the larger skin friction coefficients have lower total skin friction drag due to the smaller size, but suffer from the effects of induced drag. It is clear that at low Reynolds numbers, the induced drag resulting from high angle-of-attack operation overwhelms the reduction of frictional drag and lifting vehicles are ineffective. At very high Reynolds numbers, the angles of attack are very small and the reduction in drag is due mainly to the smaller size. The significant benefits which can be realized from lower fineness ratios are clearly brought out. When the drag coefficient is plotted against the relative density in Fig. 2, it is seen that the minima exist in most cases at relatively modest values of Γ. The preliminary results exhibited here indicate that significant reductions in drag can be achieved through the use of dense vehicles employing lift. Considerable further gains could be realized through the use of more efficient lifting configurations.

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[2] Hoerner, S. F., *Fluid Dynamic Lift*, published by the author, Brick Town, N.J., 1975, Chaps. 17 and 19.

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Measurements of Conditioned Velocities in a Turbulent Premixed Flame

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Introduction

IT is customary when modeling turbulent fluxes in chemically reacting flows to use gradient or eddy viscosity formulations developed by analogy with those appropriate to cold flows. However, Libby and Bray[1] recently have pointed out that in weakly sheared ("normal") premixed flames the eddy transport mechanism is unsuitable and they propose an alternative closure avoiding gradient assumptions. To date there have been insufficient time-resolved data available from flames to test adequately such modeling hypotheses. Recent developments in the determination of scalar properties in conjunction with laser Doppler anemometry (LDA) permit increasingly detailed comparisons between model and experiment.

A knowledge of the joint probability density function for velocity and concentration is crucial to the alternative strategies for modeling the turbulent diffusion of species, $\rho u'' c''$, for example. Simplification of this pdf results if local burning zones are thin and, in consequence, the mixture states

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