instances. On the other hand, the effects of totally halogenated compounds are discrepant; both chlorotrifluoromethane and dibromotetrafluoroethane inhibit flames but sensitize detonations.

The detonation inhibition results for hydrogen-oxygen systems do not correlate well with the flammability limit data for hydrogen-air systems. For instance, while methyl bromide is an excellent flammability suppressant,[15] it has very little effect on formation of detonation (see Table 1). The fact that methyl chloride is a more efficient detonation inhibitor than either methyl bromide or methyl iodide is also at variance with flame-inhibition experience.

Results with hydrocarbons allow some correlations to be made with reaction kinetics. The data in Fig. 4 show that the two compounds containing methyl radicals ($CH_4$ and $CH_3Cl$) inhibit the formation of detonation, whereas the other three promote it. Although this result may suggest inhibition by removal of chain carriers (H, O, OH) by alkyl radicals, tests with unsubstituted hydrocarbons offer the stronger evidence that the important step is interception of carriers by molecules and not by radicals. First, the data with di-tertiary butyl peroxide (see Table 1) show that a profusion of methyl radicals does not result necessarily in inhibition. Second, if capture by methyl radicals were an important step, one would expect larger alkyl radicals to be even more efficient; but data in Fig. 2 do not show large alkanes to be more effective detonation inhibitors than small ones.

It thus appears that the inhibition effect of hydrocarbons may be accounted for by the occurrence of the reaction $RH + X \rightarrow HX + R$, where $R$ is a hydrocarbon radical and $X$ a chain carrier. Chemical kinetic data[13, 14] show the reaction rates of oxygen atoms with transbutene-2, isobutene, and cis-butene-2 (in that order) to be very high; with butene-1 and propylene appreciably less; with ethylene much less; and with alkanes quite low. Fundamental considerations indicate that the same order of reactivity should be expected of reactions of other active species (e.g., hydrogen atoms) with hydrocarbon molecules. The order of inhibition effectiveness by hydrocarbons thus correlates rather well with the ease of removal of a hydrogen atom from the hydrocarbon molecule.

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# Some Pressure-Drag Effects of Rounding the Leading Edges of Hypersonic Inlets


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### Nomenclature

| | | |
|---|---|---|
| $C_{D,b}$ | = | round leading-edge drag coefficient |
| $C_{p,t,2}$ | = | total pressure coefficient back of a normal shock at $M_\infty$ |
| $C_{p,t,\beta}$ | = | total pressure coefficient back of a normal shock at Mach number, $M_\infty \cos\beta$ |
| $d/D_c$ | = | ratio of leading-edge diameter to capture area diameter |
| $d/g$ | = | ratio of leading-edge diameter to gap of rectangular inlets |
| $l$ | = | distance from inlet to outlet |
| $M_\infty$ | = | freestream Mach number |
| $\beta$ | = | sweep angle of a rectangular inlet |
| $\delta$ | = | outer-surface cone half-angle |
| $\theta$ | = | angle of a normal to the surface measured relative to the freestream direction |
| $\theta_j$ | = | value of $\theta$ at juncture of the round leading edge with the straight surface |

STUDIES of the possible performance of external air-breathing engines require an estimation of the powerplant drag that must be subtracted from the computed internal-thrust forces. In this paper an axisymmetric powerplant is at first assumed with an outer surface of conical form terminating at an exit diameter larger than the inlet diameter. Charts for determining pressure drag and skin-friction drag for slender sharp-leading-edged bodies of this type were devised and are presented in Ref. 1.

In order to be realistic it must be admitted that at hypersonic Mach numbers the leading edge will be rounded to relieve stagnation-point heating. In the present paper, consideration is focused on pressure-drag effects on the rounded leading edge and the pressure-drag effects resulting from changes in pressure further back on the conical surface caused by rounding the leading edge. All computations are for a perfect gas with ratio of specific heats of 1.4.

Estimates were made of the external pressure-drag coefficients of selected ducted bodies at Mach numbers of 4, 12, and 15. The external pressure drag was considered to consist of the entire leading-edge pressure drag plus the pressure drag on an outer conical surface going from the leading edge back to the exit station. The drag coefficient was based on an inlet area bounded by the center-of-curvature line of the leading edges.

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The leading-edge drag was computed by summing the forces from the modified Newtonian expression for the local pressure coefficient. For equal inner and outer $\theta_i$ value, see Fig. 1:

$$C_{D,b} = 4C_{p,t,2}(d/D_c)(\sin\theta_i)(1 - \tfrac{1}{3}\sin^2\theta_i)$$

For $\theta_i$ of 90°, this reduces to

$$C_{D,b} = \tfrac{8}{3}C_{p,t,2}(d/D_c)$$

Rounding the leading edges would raise the pressures on the outer surface. Figure 3 of Ref. 2 provides means for obtaining a two-dimensional approximation for these pressures. Pressure coefficients were integrated over the outer conical surface to obtain corresponding drag coefficients.

For purposes of this study a value of the hypersonic similarity parameter, $\tan\delta(M_\infty^2 - 1)^{1/2}$, of 0.3116 was used and a ratio of exit area to capture area of 3 was assumed. These assumptions produce slender bodies that increase in length as $M_\infty$ increases.

The results of the outer-surface pressure-drag coefficient and the total external pressure-drag coefficient calculations are shown in Fig. 1. The curves show that the leading-edge drag coefficient is high for even small amounts of leading-edge rounding. The effect of leading-edge bluntness on the outer-surface pressure-drag coefficient is minor. For even modest amounts of leading-edge rounding the leading-edge drag is the major portion of the total drag.

The high pressure drag of blunted leading edges may be reduced significantly by sweeping the leading edge; for instance, a rectangular inlet might be incorporated in the swept leading edge of a wing. An analysis was made of a unit length of leading edges and considered only the upper and lower leading edges. The upper and lower circular leading edges were assumed followed by flat surfaces parallel to the freestream. This simplification does not affect the leading-edge pressure-drag coefficient strongly and is justified by a lack of knowledge of the final geometry at this point. The analysis gave the expression

$$C_{D,b} = \tfrac{4}{3}(d/g)C_{p,t,\beta}\cos^2\beta$$

The effect of sweep angle on leading-edge drag coefficient is given in Fig. 2 for freestream Mach numbers of 12 and 15; increasing $M_\infty$ from 12 to 15 produced no significant effect on $C_{D,b}$. No consideration of the end boundaries of the rectangular inlets was made. It is probable with long rectangular inlets that intermediate vertical partitions would be required for structural and/or internal-flow considerations. Sweeping the leading edge from 0° to 70° reduced the drag coefficient by a factor of about 10.

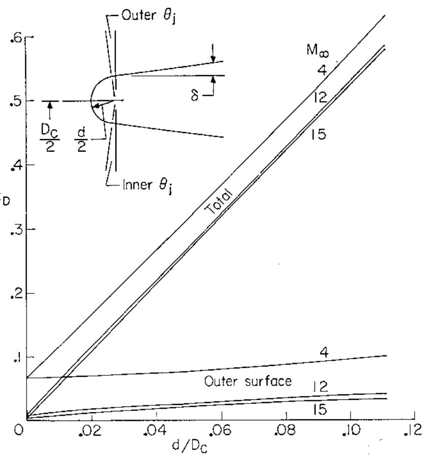


**Fig. 1 External pressure-drag breakdown; circular inlets; exit area to capture area ratio 3; $\tan\delta$ $(M_\infty^2 - 1)^{1/2}$, 0.3116; perfect gas.**

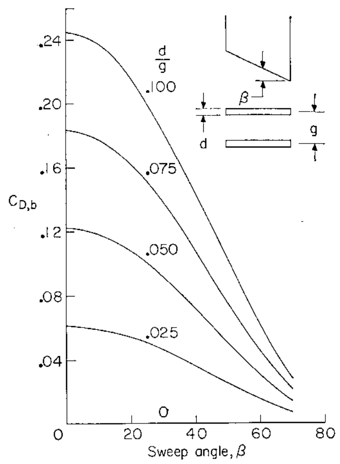


**Fig. 2 Leading edge pressure-drag coefficient; semicircular leading edges; modified Newtonian theory; perfect gas; $M_\infty$ = 12, $M_\infty$ = 15.**

In conclusion estimates have shown the increase in total external pressure drag caused by rounding the leading edges of conical ducted bodies to be considerable. Consideration of sweeping the leading edges showed possibilities of markedly decreasing the drag penalty deriving from the necessity of having rounded leading edges.

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# Reaction of Hydrazine and Nitrogen Tetroxide in a Low-Pressure Environment

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THE use of hypergolic propellants in space vehicle propulsion systems raises questions concerning the effect of a vacuum on the reaction of these propellants.

A preliminary study was made of the reaction of hydrazine and nitrogen tetroxide at pressures as low as $10^{-4}$ Torr (mm Hg). A steel vacuum tank served as a vessel wherein stoichiometric quantities of these propellants, separately encapsuled in glass tubing under atmospheric pressure and at room temperature, were broken simultaneously (see inset in Fig. 2).

The vacuum tank was 4 ft wide and 6 ft long with one end covered by a glass window for viewing purposes. The capsules were broken by a cleaver device that was remotely actuated by a solenoid release. Temperatures were recorded in the vicinity of the capsules, and tank pressure was measured by an ionization gage and a Pirani gage. High-speed motion pictures also were obtained.

Effects of varying the total propellant quantity on the tank pressure rise are shown in Fig. 1. In all cases, the initial tank pressure was about $4 \times 10^{-4}$ Torr. With small quantities of propellants (2.3 and 4.6 cm³), the pressure rose to a value predicted from perfect gas equations for complete

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