Table 1 Comparison of drop size for circular and noncircular orifices at engine operating conditions

Orifice type		D_{0z},[a] μ	D_f,[a] μ
Circular	unlike doublet	43	65
Triangular	unlike doublet	65	91
Rectangular	unlike doublet	60	98
Self-atomizing		63	102

[a] At V_r — 200 fps; corrected for physical properties.

For rocket engine designs with contraction ratios of 3 to 4, the average combustion gas velocity acting on the spray fan is about 200 to 300 fps. For purposes of comparison, a relative velocity of 200 fps has been chosen ($\theta = 4.0$).

Drop sizes were computed by first determining the drop size for each element type from Fig. 3 at a relative velocity (V_r) of 200 fps and then applying the physical property correction shown in Eq. (6) for each propellant. The resulting drop sizes are shown in Table 1; the circular element has smaller drop sizes than noncircular elements.

To determine the overall predicted c^* efficiency, the mixing-limited c^* efficiency and the vaporization-rate-limited c^* efficiency are combined in the first-order approximation;

$$(\eta_{c^*})_{\text{predicted}} = (\eta_{c^*})_{\text{mixing}} \times (\eta_{c^*})_{\text{vaporization}} \tag{7}$$

The atomization and mixing results, shown in Table 1 and Fig. 5 were input into the mixing-limited and vaporization-rate-limited combustion models to predict the over-all c^* performance characteristics for both optimized circular and noncircular orifice elements. The results are shown in Fig. 6 in terms of $\Delta\eta_{c*}$ and characteristic chamber length (L^*). The $\Delta\eta_{c*}$, predicted is defined as

$$(\Delta\eta_{c^*})_{\text{predicted}} = (\eta_{c^*})_{\substack{\text{predicted}\\ \text{noncircular}}} - (\eta_{c^*})_{\substack{\text{predicted}\\ \text{circular}}} \tag{8}$$

Predictions were made for N_2O_4/50–50 and contraction ratio 4.0. The results show that the rectangular orifice unlike-doublet element will operate between 1 and 6% higher in c^* efficiency than the conventional circular unlike-doublet element over the range of L^* between 15 and 60 in. In addition, the triangular unlike doublet will perform about 1% lower than the circular element at an L^* of 15 in.; however, at increased L^*'s the triangular element performs at a higher level than the circular (4% at 60-in. L^*). The self-atomizing element performs about 6% lower than the circular unlike-doublet element at an L^* of 15 in., and 3% higher at an L^* of 60 in.

The contraction ratio 4.0 yields results that are rather pessimistic with respect to the benefits which could be derived from noncircular elements. Higher combustion gas velocities produced by lower contraction ratios would decrease the drop sizes for the various elements and consequently, the performances of the noncircular elements would be greatly improved.

Conclusions

Program results to date have indicated that noncircular orifice configurations can, under some conditions, produce performance characteristics that are superior to those of the conventional circular shape. This is especially true with respect to propellant mixing. The correlations developed suggest that for liquid-liquid propellants, it is possible to retain the simple unlike-doublet element configuration for any propellant combination and operating mixture ratio if noncircular orifices are used, since these designs can accommodate the density and flowrates involved by appropriate adjustments in aspect ratio keeping one side of each rectangule equal. Therefore, noncircular orifice elements supply the desired mixing and atomization levels while maintainng the simplicity of an unlike doublet.

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Disintegration of a Supersonic Jet Impinging Normally on a Flat Plate

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Nomenclature

$b_{1/2}$ = collision radius $\{b_{1/2} = r[p - p_\infty = \frac{1}{2}(p_s - p_\infty)]\}$
D = nozzle exit diameter
H = distance between nozzle exit and flat plate
p = static pressure
p_s = stagnation pressure on flat plate
p_∞ = ambient pressure
r = radial coordinate

Introduction

THERE have been many studies of the structure of a supersonic freejet in relation to jet noise. In the case of a highly underexpanded freejet, very strong directional sound called "screech" is generated. It was shown that the highly under-expanded jet disintegrates when this screech is generated. Powell[1] first described and explained this disintegration in terms of a mechanism involving the pattern of shock waves. But in this Note, it is proved that, for the case of a supersonic jet of almost correct expansion (nozzle exit Mach number 1.6) impinging normally on a flat surface, similar disintegration also occurs with strong screech when the normal shock wave in front of the flat surface is in a decelerating region of the jet.

Air was supplied continuously by a 10 *HP* compressor to a round Laval nozzle preheated to 175°C. The expansion in the nozzle was always checked by four static pressure taps at the nozzle wall during the experiments, and no odd change in pressure distribution was observed. The nozzle exit of the diameter D of 5.00 mm was located in the center of a brass disk baffle of 76.0 mm diam, that is, this nozzle had an acoustic reflector, as in the work of Glass,[2] normal to the nozzle axis. A square flat plate of 30-cm side-length is set normally to the jet axis as the jet impinging target at the

Received September 4, 1970.
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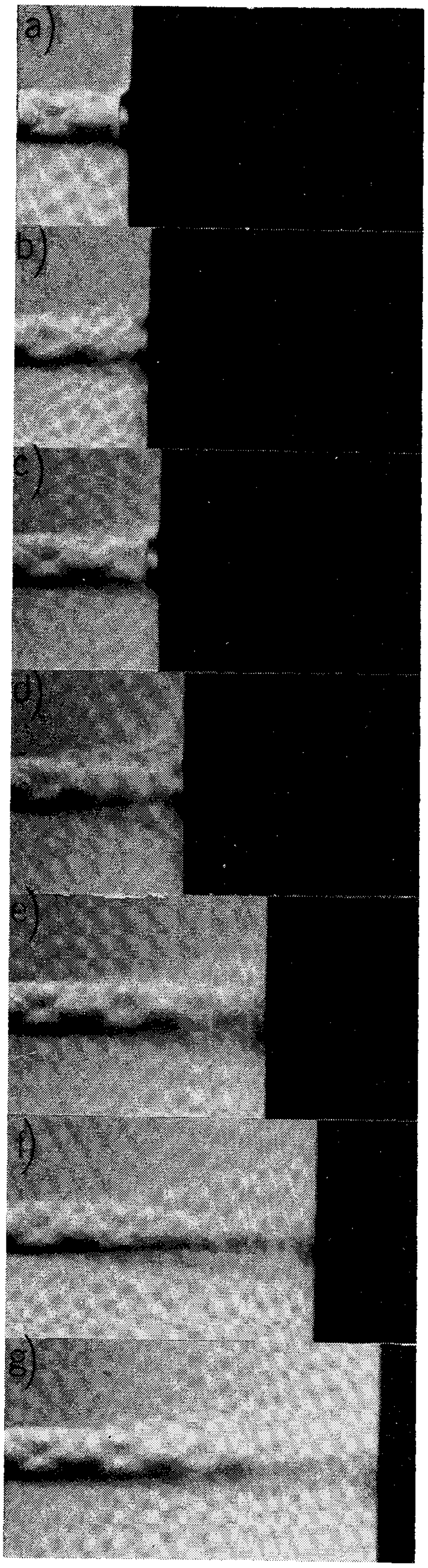

Fig. 1 Typical schlieren photographs of impinging supersonic round jet: a) H/D = 2.23; b) H/D = 2.64; c) H/D = 2.90; d) H/D = 3.43; e) H/D = 5.06; f) H/D = 6.0; g) H/D = 7.25.

distance H from the nozzle exit. The distance H was varied from 1 D to 24 D.

Results and Discussion

Typical schlieren photographs of the supersonic impinging jet are shown in Fig. 1. The disintegration of the jet occurs in Figs. 1–b, d, and f, and then it is observed that the jet is highly spread, and the normal shock wave on the flat plate becomes unsteady and oscillates, and the strong screech is generated. Figure 2a shows the stagnation pressure distribution on the plate, and Fig. 2b shows the radial pressure distributions for various H/D's. As H/D is increased, the pressure at the stagnation point repeatedly falls down when this disintegrations happen at some values of H/D. This seems very interesting in comparison with the case of highly under-expanded freejet without a target plate. In addition, when the plate goes near the nozzle exit with decreasing H/D value, the critical values of H/D where the undisintegrated flow changes into disintegrated flow or vice versa are a little bit different from that of former case. That is, this phenomenon has a nature of hysteresis.

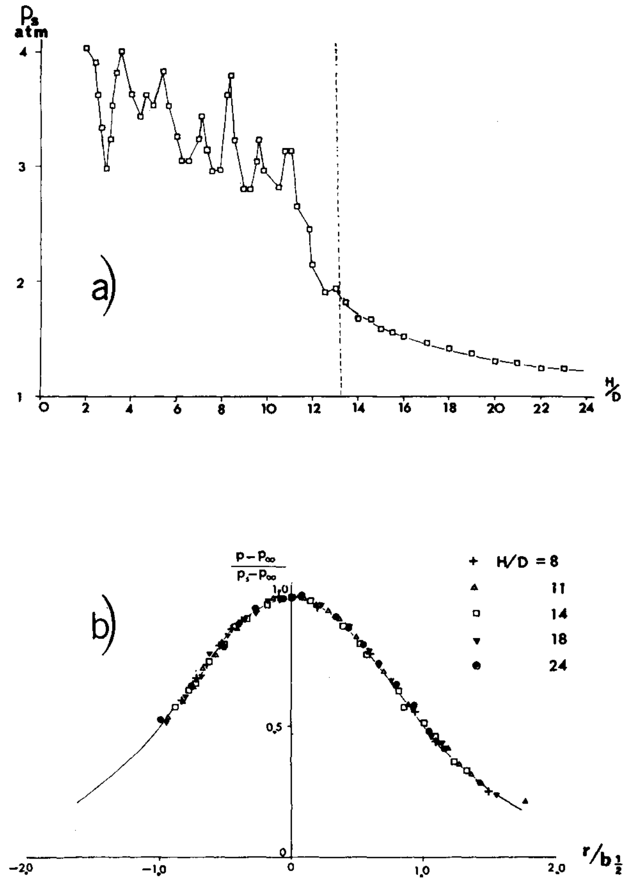

Fig. 2 Pressure distributions on flat plate: a) stagnation pressure vs normalized distance H/D; b) radial pressure distributions near stagnation point at various H/D.

It is well known that the disturbance in the flow emits strong acoustic pulse when it passes a shock wave, and in this case, the normal shock wave on the plate can be thought to be a very effective sound source. In addition to this, in some cases when the disintegration of this jet occurs, the resonance of the air between the baffle and the plate was clearly observed, that is, the flat plate may act as a sound reflector also. Thus, the intensified interaction of sound and flow in this acoustic field arround the jet may cause the new type of disintegration.

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