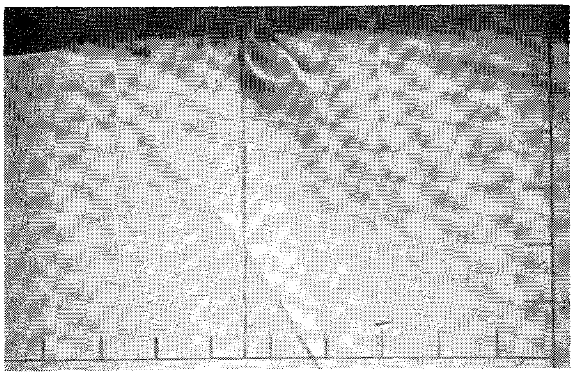

Fig. 5 Shadowgraph of shock system: $P_{0s} = P_{0p} = 100$ psig, $T_{0s} = 490°R$, $T_{0p} = 467°R$, and $A_s = 0.3663$ in.^{2} for normal injection.

based upon measurements of the static pressure on the walls of the nozzle. A typical pressure distribution is shown in Fig. 1. The pressure taps were located at the following distances (in.) downstream of the throat (the upstream edge of the injection shot was at 9.461 in.): full side: 4.658, 6.173, 7.678, 9.171, and 10.674; injection side: 4.938, 5.438, 5.916, 6.451, 6.936, 7.476, 7.951, 8.936, 9.861 + s, 10.301 + s, 10.791 + s, 11.285 + s, and 11.801 + s, where s is the injection slot width.

Some results of these experiments[9] are presented in Figs. 2 and 3 (for normal injection). The calculated results for the same conditions utilizing the theories developed by Wu et al.[1] and Broadwell[3] (in the reference article Broadwell also presents equations for the two-dimensional case) are also included in Figs. 2 and 3, and it is clear that, whereas the experimental results are strongly dependent upon the secondary stagnation pressure and the injection slot area, the amplification factor calculated from the theoretical models[1,3] appears to be independent of those parameters. It is also clear that both theoretical models seem to provide results comparable to the experimental values only for large mass flow rate ratios (large values of P_{0s}/P_{0p} and A_s/A_t).

Simultaneously, with the aforementioned measurements, shadowgraphs of the flowfield near the injection slot were obtained (e.g., Figs. 4 and 5; flow is from left to right). The following conclusions are drawn from such photographs and the experimental measurements. First, a separated region is caused by injection, and either a series of compression waves [for the weaker disturbances caused by low mass flow ratio injection (small A_s, Fig. 4)] or an oblique shock (larger A_s, Fig. 5) is caused by the separation. An "injection shock" occurs immediately upstream of the point of injection, and at low mass flow ratios (Fig. 3), the compression wave system merges with injection shock. Second, a second oblique shock appears downstream of the point of injection because of attachment of the (expanded) injected fluid and the consequent recompression of it. Third, the oblique shock at the point of separation is stronger than the injection shock at the higher mass flow rate ratios, and a portion of the nozzle wall downstream of the point of injection experiences a side force opposite in direction to that obtained upstream. This is because the downstream portion of the separation region (representing a region of jet expansion) persists longer.

References

[1] Wu, J. M., Chapkis, R. L., and Mager, A., "An approximate analysis of thrust vector control by fluid injection," ARS J. **31**, 1667–1685 (1961).

[2] Walker, R. E. and Shandor, M., "Influence of injectant properties for fluid injection thrust vector control," J. Spacecraft Rockets **1**, 409–413 (1964).

[3] Broadwell, J. E., "An analysis of the fluid mechanics of secondary injection for thrust vector control (revised)," Space Technology Labs. Rept. 6120-7744-MU-000 (March 1962).

[4] Hsia, H. T., Seifert, H. S., and Karamcheti, K., "Shocks induced by secondary fluid injection," J. Spacecraft Rockets **2**, 67–72 (1965).

[5] Zukoski, E. E. and Spaid, F. W., "Secondary injection of gases into a supersonic flow," AIAA J. **2**, 1689–1696 (1964).

[6] Charwat, A. F. and Allegre, J., "Interaction of a supersonic stream and a transverse supersonic jet," AIAA J. **2**, 1965–1972 (1964).

[7] Murthy, S. N. B., "The upstream effects due to injecting a jet of gas through the wall of an axi-symmetric nozzle," Purdue Univ., Jet Propulsion Center Rept. TM-63-3 (January 1963).

[8] Thompson, H. D., Hoffman, J. D., and Murthy, S. N. B., "Note on a parametric analysis of thrust vector control by secondary gas injection," Purdue Univ., Jet Propulsion Center Rept. TM-63-5 (February 1963).

[9] Guhse, R. D., "An experimental investigation of thrust vector control by secondary injection," NASA CR-297 (1965).

Estimation of Theoretical Performances of Torpedo Propellants

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CANDIDATE torpedo propellants often are screened through computed theoretical jet horsepower-hours per cubic foot for fixed-equilibrium expansion with sufficient free sea water added to the propellants to lower combustion temperatures to 1800°F[1,2] so that the working medium can be used directly in current heat engines. To accurately determine these, iteration computations are required, resembling those for theoretical rocket thrusts. However, as indicated in this note, they may be estimated sufficiently accurately for screening simply by multiplying theoretical heats of reaction to major products at 298°K/unit volume of the propellants ($-\Delta H_{r298}/V$) by empirical values that depend on the major species.

For an expansion ratio of 300 psia/1 atm and input energies in kilocalories/cubic centimeter, respective multiplying factors are 13.65 when all products are gases (as CO_2 plus H_2O), 12.94 when they contain a diatomic nongas [as $MgO(c)$], and 11.76 when they contain a penta-atomic nongas [as $Al_2O_3(c)$]. For stoichiometric magnesium-90% aqueous hydrogen peroxide as propellants, the reaction is $Mg(c) + H_2O_2 \cdot 0.2\ H_2O = MgO(c) + 1.2\ H_2O(g)$ where $-\Delta H_{r298} = [(0.0) + (-59.1)] - [(-143.7) + (1.2)(-57.8)] = 154.0$ kcal, and $V = (24.3/1.74) + (37.6/1.39) = 38.1$ cc. Theoretical power output is estimated as $(154.0/41.5)(12.94) = 48.6$ jet hp-hr/ft^3, which is less than 2% below the accurately computed value.

Although these empirical torpedo propellant factors appear to extend the empirical correlations previously discussed[3] for theoretical rocket thrust with shifting expansion to conditions with fixed expansion, this conclusion is not tightly drawn: the torpedo factors apply when sufficient free sea water is added to reduce reaction temperatures to 1800°F, whereas the rocket correlations have no such restriction.

References

[1] Greiner, L., "Introduction to the selection of high-performance propellants for torpedoes," ARS J. **30**, 1161 (1960).

[2] Brady, J. F., "Torpedo propulsion: 1964," Astronautics and Aeronautics **3**, 50 (1965).

[3] Greiner, L., "Further comments on correlations for shifting rocket thrust," J. Spacecraft Rockets **2**, 612 (1965).

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