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FUEL-RICH PLUME COMBUSTION.(U)
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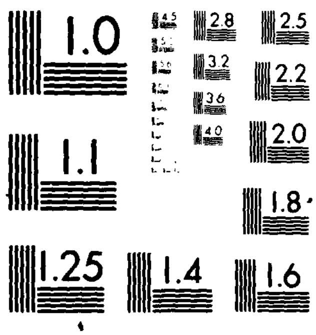

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NAVSEA Propulsion Research Program

Program Element 61153N

Fuel-Rich Plume Combustion*

K. C. Schadow

Naval Weapons Center

China Lake, California 93555

Annual Progress Report

1 October 1979 - 30 September 1980

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*Starting FY 1981 the project will be partly funded by Air Force Office of Scientific Research.

Background:

The understanding of fuel-rich plume combustion in a subsonic or supersonic airstream is critical for improving combustion efficiency and widen operational limits of various airbreathing systems such as gas generator ramjets and external burning propulsion.

Our previous work related to gas generator ramjets with solid boron propellants resulted in a new understanding of the fuel-rich, particle-laden plume ignition process in a subsonic airstream. Tests showed that as long as the gaseous fuel components from the gas generator can be made to react with the air in the ramjet combustor before excessive mixing occurs, the resulting gas-phase combustion temperatures will be high enough to initiate high boron reaction rate.[1-3] In these tests with coaxially mixing fuel and airstreams, two situations occurred in which the gas-phase combustion process produced insufficient temperatures. First, particularly at low secondary chamber pressure, the gaseous fuel components did not ignite in the fore-end of the mixing region where theoretical near-stoichiometric gas-phase combustion temperatures prevail. When gaseous fuel components ignited further downstream, the gas-phase combustion temperatures were too low because excess air mixing had already taken place. Second, although the tested mixing and flameholding device established a gas-phase flame at the beginning of the mixing region, the mixing was too rapid and the temperatures were again generally too low. Work in the reporting period (FY 1980) included non-coaxial mixing studies related to gas generator ramjets with side mounted inlets.

In the previous work, experimental methods have been qualitative (e.g., motion picture coverage) and intrusive (e.g., thermocouples and gas sampling probes). Also, two-dimensional experimental hardware was used. To properly model the fuel-rich plume ignition process, data from quantitative and nonintrusive methods using axisymmetric hardware are demanded.

Our previous work related to external burning propulsion (base drag reduction) has shown that external burning in the supersonic airstream is only attractive with additional combustion in the subsonic near wake region.[4-5] This new concept of combined external burning/base burning is being pursued under Air Force funding.[6-9] In the reporting period of this NAVSEA program, external burning was further investigated in combination with contoured aft-bodies instead of blunt bases used in the earlier studies. Preliminary analysis by Vought Advanced Technology Center, Dallas, Texas, has shown that higher base pressures are achievable with external burning in conjunction with properly contoured aft bodies than with blunt bases.[10]

Technical Objective:

This program will investigate the mixing, ignition, and combustion of a primary fuel-rich plume, with and without particulate fuels, in a secondary subsonic airstream. The purpose is to obtain a basic understanding of these phenomena to permit application to ramjets.

Approach:

Experiments are being performed using a windowed laboratory ramjet combustor and a water flow tunnel. For various fuels and mixing characteristics, first a qualitative insight into the mixing and combustion phenomena will be gained. Subsequently, detailed measurements will be made to obtain quantitative measurements of important flow and combustion parameter. Intrusive probes and novel non-interfering optical diagnostic techniques will be used. Experimental data will be compared with newly developed analytical models.

Accomplishments (FY 1980):

Subsonic Airstream

A qualitative experimental understanding was gained of the phenomena involved in non-coaxial mixing and combustion of a fuel-rich plume and a subsonic airstream.[11] Both the water flow tunnel and the windowed combustor were used.

In the water flow tunnel, flow pattern characteristics for side dump combustors were simulated. The "air" (simulated by water) was laterally injected through two side inlets; the "fuel" was axially injected. The mixing patterns were observed by air bubbles in the water simulating the "fuel." Parameter varied included "air" and "fuel" injection momentum; "air" inlet angle, position, and cross-section; and "air"-to-"fuel" ratio.

With the windowed side dump combustor using nonmetalized solid propellants, combustion efficiency and flame characteristics were determined as function of the same combustor parameter as described for the water tunnel tests. In addition, primary chamber temperature and secondary chamber pressure were varied.

Between the water tunnel and the combustion chamber, both with a square cross section (6 x 6 inches), similarities of geometry, Reynolds number, air-to-fuel ratio, and air-to-fuel momentum ratio were maintained.

Twenty-four parameter combinations were studied in the water tunnel; fourteen were investigated in the combustor. For corresponding test conditions, a relationship between mixing characteristics, as determined in the water flow tunnel, and flame characteristics/combustion efficiency, as determined in the combustor tests, was established. Based on this relationship, an understanding of the effect of mixing/combustion on combustion efficiency was gained. The following major conclusion was made. To achieve high combustion efficiency, two processes are critical: (1) fuel-rich plume ignition in the extreme fore-end of the fuel/air mixing region near the fuel injector to achieve highest, near stoichiometric local combustion temperatures before excessive air mixing occurred, and (2) good penetration of the ignited, reacting plume into the airstream to achieve good mixing and combustion. The following examples illustrate this conclusion.

At high air momentum (90-degree side dump) and low fuel momentum, poor combustion efficiency was achieved. Although plume ignition was achieved immediately downstream of the fuel injector (high local combustion temperatures), the ignited and reacting plume did not penetrate into the airstream (poor mixing).

At high air momentum and high fuel momentum, poor combustion efficiency again was achieved. Although the fuel-rich plume penetrated into the airstream (good mixing), plume ignition occurred after excessive air mixing had taken place (low local combustion temperatures).

At two injection conditions, high combustion efficiency was achieved with plume ignition immediately after the fuel injector and good fuel penetration into the airstream. These conditions were (1) low injection momentum for fuel and air for the 90-degree side dump and (2) high or low fuel momentum for the 30-degree side dump.

These results are extremely important for selection of fuel and air injection conditions for achieving high combustion efficiency over a wide range of air-to-fuel ratios.

<u>Supersonic Airstream</u>

Two-dimensional wind tunnel tests to study external burning with contoured aft-bodies (EB/BC) were performed and evaluated in cooperation with Vought Advanced Technology Center, Dallas, Texas.

Figure 1 shows the effective base pressure ($p_{b,eff}/p_1$), as function of the injection parameter (I) or normalized propellant mass flow, for two tests with EB/BC using a 20% by weight magnesium (Mg) propellant in comparison to three tests with combined external burning/base burning (EB/BB) using a 65% Mg propellant. The $p_{b,eff}/p_1$ includes thrust components both by the axial injection momentum and pressure rise in the base and along the body contour due to combustion. Higher $p_{b,eff}/p_1$ was achieved by EB/BC than EB/BB due to injection of the fuel-rich propellant in thrusting direction.

Figure 2 shows a bar graph comparison of the total thrust coefficient for various aft-body configurations and propellant injection techniques. EB/BC (20% Mg) is superior to EB/BB (65% Mg), and also better than an ideal thrust nozzle with the same propellant properties.

The specific performance ($p_{b,eff}/p_1$ divided by I) of EB/BC was significantly improved using a 65% Mg propellant.

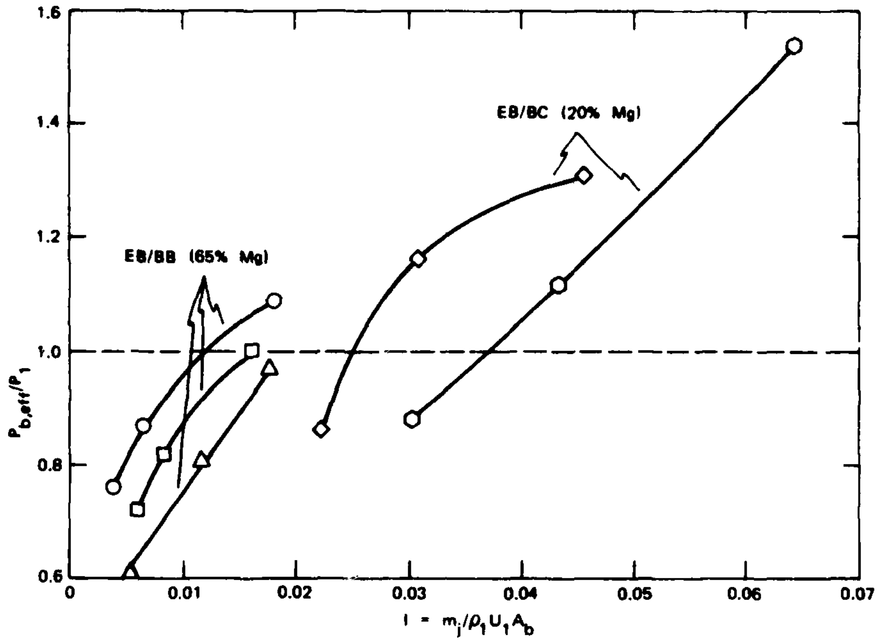

Figure 1. Normalized Effective Base Pressure Variation with Injection Parameter

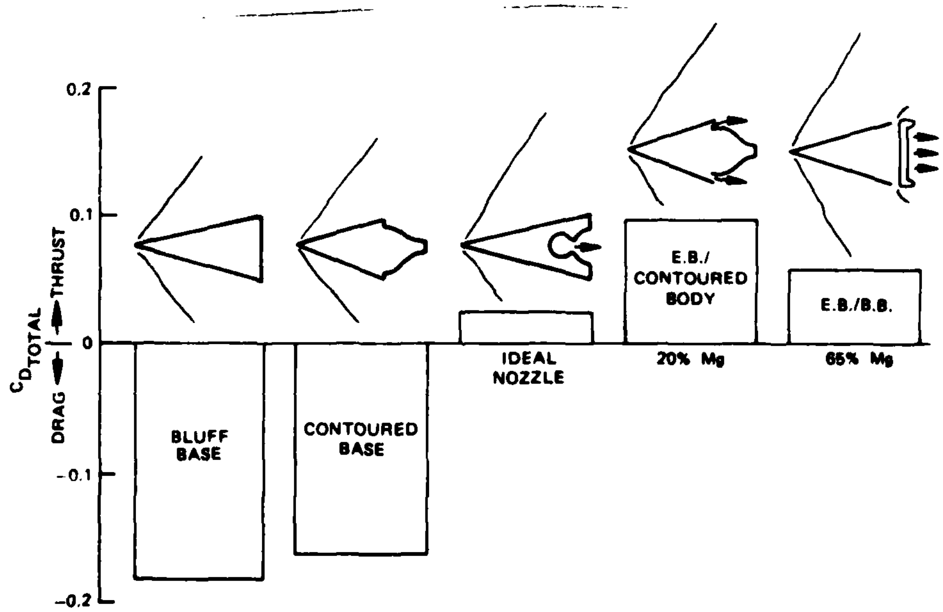

Figure 2. Relationship of Aft-Body Configurations With and Without External Burning

Plans (FY 1981):

As an extension of previous studies using two-dimensional hardware, from which a qualitative insight was gained into the critical processes of fuel-rich plume combustion in a subsonic airstream, quantitative measurements will be made to determine radial distributions of mean axial velocity, gas composition, total pressure and temperature for various axial stations in an axisymmetric laboratory gas generator ramjet. These detailed flow data, initially determined by probe measurement, will be analyzed and compared with existing and newly developed theoretical models at Science Application Inc. (SAI). Based on results from the experiment/model comparison, modifications will be made to the models and test conditions will be refined. In this process of interaction between the experimental and theoretical programs, experiments with non-interfering optical diagnostics techniques will be made to provide more detailed experimental information for model improvements.

In the beginning the tests with optical diagnostic techniques, an existing Laser Doppler Velocimeter (LDV) will be used to determine radial and axial velocity and turbulence profiles for various axial stations. Other optical diagnostic techniques will be evaluated to determine feasibility for temperature and species concentration measurements.

In FY 1981, mixing and combustion of gaseous fuel-rich, particle-laden plumes will be studied in a coaxial-axisymmetric flow field with and without dump (see milestone chart in Figure 3).

In FY 1982 and 1983, quantitative measurements and experiment/model comparison will continue using liquid and slurry fuels and three-dimensional flow fields.

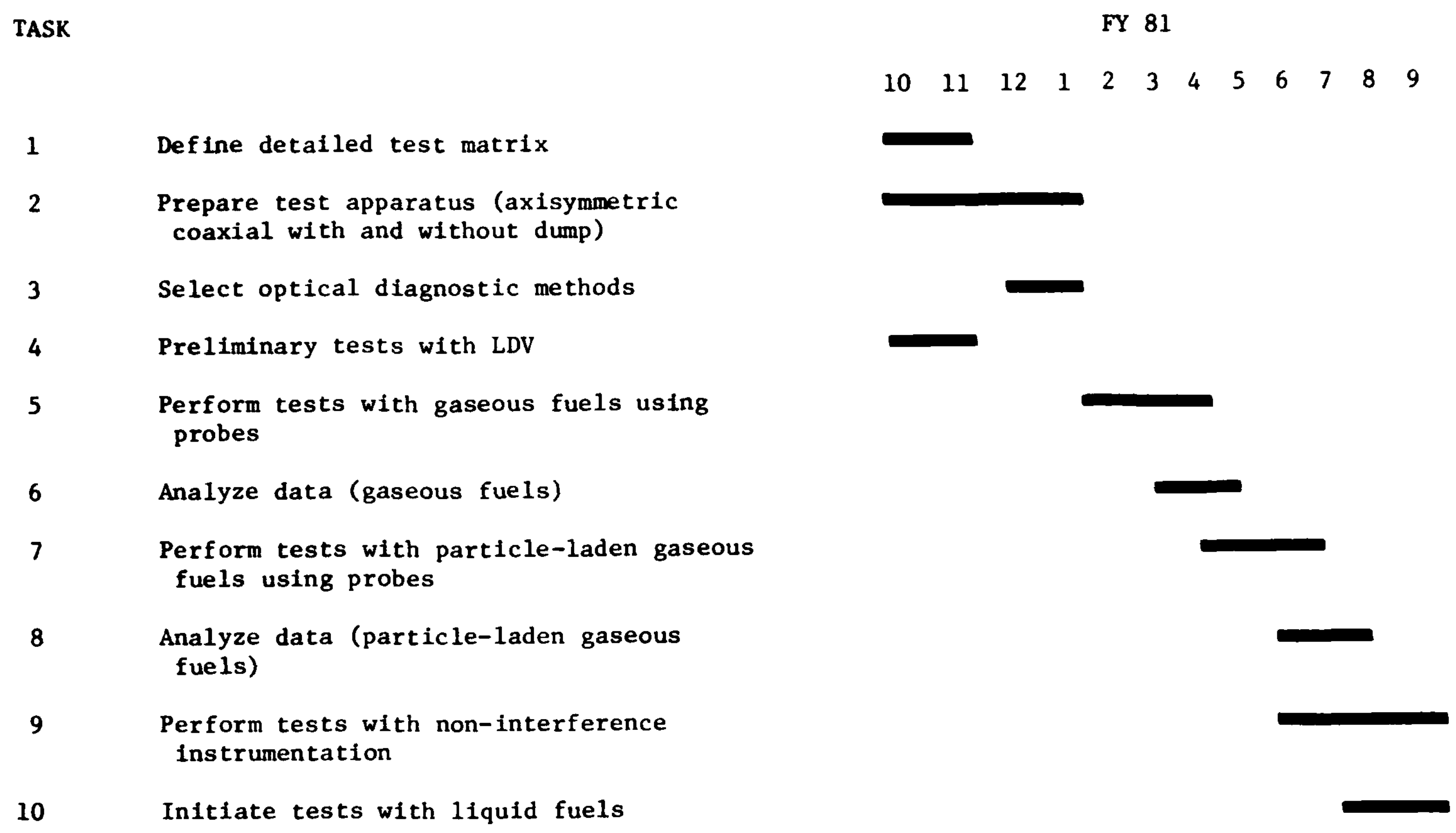

Figure 3. Program Schedule for FY 80 and FY 81

References:

1. Klaus Schadow. "Study of Gas-Phase Reactions in Particle-Laden, Ducted Flows," *AIAA Journal*, Vol 11, No. 7 (July 1973), pp. 1042-1044.

2. Abbott, S. W., Smoot, L. D., and Schadow, K. C., "Direct Mixing and Combustion Efficiency Measurements in Ducted, Particle-Laden Jets," *AIAA Journal*, Vol. 12, No. 3 (March 1974), pp. 275-282.

3. Klaus Schadow. "Fuel-Rich Particle-Laden Plume Combustion" *AIAA Journal*, Vol. 13, No. 12 (December 1975), pp. 1553-1554.

4. Schadow, K. C., and Chieze, D. J., "Simulation of External Burning in a Two Dimensional, Planar Wind Tunnel," *14th JANNAF Combustion Meeting, Volume II*. Chemical Propulsion Information Agency, Laurel, MD, CPIA, December 1977. (CPIA Publication 292, publication UNCLASSIFIED.)

5. ------. "Experimental Evaluation of External Burning Concepts," *1979 JANNAF Propulsion Meeting, Volume III*. Chemical Propulsion Information Agency, Laurel, MD, CPIA, July 1979. (CPIA Publication 300, publication UNCLASSIFIED.)

6. Schadow, K. C., and Chieze, D. J., "Experimental Study on Base Drag Reduction with Combined Lateral and Axial Injection," *AIAA Journal*, Vol. 16, No. 10 (October 1978), pp. 1084-1089.

7. Air Force Rocket Propulsion Laboratory. *Injection Study for External Burning/Base Burning*, by Klaus C. Schadow and Don J. Chieze. Naval Weapons Center, China Lake, CA, for AFRPL, Edwards, CA, April 1979. (AFRPL-TR-79-10, publication UNCLASSIFIED.)

8. Air Force Rocket Propulsion Laboratory, *Evaluation of External Burning/Base Burning for Base Drag Reduction. Part A: Two-Dimensional, Planar Wind Tunnel Tests, Part B: Axisymmetric Wind Tunnel Tests*, by Schadow, K. C. and D. J. Chieze, China Lake, CA, December 1980. (AFRPL-TR-80-74, publication UNCLASSIFIED.)

9. Schadow, K. C., "Experimental Investigation of Combined External Burning/Base Burning," *AIAA/SAE/ASME 16th Joint Propulsion Conference*, Hartford, Connecticut, June 30-July 2, 1980 (AIAA-80-1257, publication UNCLASSIFIED.)

10. Vought Advanced Technology Center. *A Design Study of Aft Body Contours for External Burning Configurations Using a Simplified Analytical Model*, by J. L. Porter an; D. B. Wallace. Dallas, TX, ATC, August 1979. (ATC Report No. R-91100/9CR-45, publication UNCLASSIFIED.)

11. Klaus Schadow, "Water Tunnel and Windowed Combustor as Tools for Ducted Rocket Development," *1981 JANNAF Propulsion Meeting*, May 1981, (To be presented.)

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