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Ignition of Liquid Fuel Jets in a Supersonic Air Stream

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Abstract

SEVERAL propulsion concepts, such as scramjets and external burning, involve ignition and combustion at supersonic air velocities. Volume considerations have focused attention on liquid fuels; and fuel distribution, cooling, and drag studies indicate that fuel will be injected transversely from the walls. High air velocities lead to low residence time and low static temperature and pressure which means long chemical times, so spontaneous ignition becomes problematical.

The primary, unclassified references are presented in tabular form in the backup paper. Results with CS_2 (because of low auto-ignition temperature under no-flow conditions), kerosene, JP-5, Pentaborane, TEA, HiCal and some blends are listed showing that ignition is a problem under conditions of interest.

References 1 and 2 describe studies of the autoignition process for transverse liquid jets in hot, supersonic air streams. The studies of no combustion cases in Refs. 3 and 4 served as motivation. It had been found that injectant accumulated in a layer on the wall near the injector. It was postulated that residence times near this layer would be long and that ignition might initiate there. No clear evidence of ignition with CS_2 or kerosene was found up to conditions where the temperature under the layer was higher than the no-flow, ignition temperature for CS_2 in the literature.

The present study extended the work to higher air temperatures, a wider range of $\bar{q}$ and other injection angles. Reference 5 showed that the layer and the separation region ahead of the jet increased for upstream angles.

Contents

The "air" temperature necessary to simulate supersonic flight was produced by a special facility consisting of two components. The first is an Inconel 601 tube heated via electric resistance. The second is an ethylene-fired preburner used to obtain air temperatures higher than 1200 K. The ratio of ethylene to oxygen was determined so that the products maintained the ratio of oxygen to combustion products equal to the ratio of oxygen to nitrogen in air. The temperature profiles leaving the preburner were found to be quite uniform. It is felt that the high static temperature and pressure and the long chamber length combine to insure complete combustion in the preburner.

The test nozzle was designed to produce a $M = 1.65$ at the injection station. At this cross section are two surface thermocouples. One is located adjacent to and slightly downstream of the injection port; the other is located circumferentially 90 deg from the injector.

The liquid fuel issued into the airstream via a 0.76 mm diam port. At the same injection pressure and air temperature, the $\bar{q}(\equiv \rho_j U_j^2/\rho_\infty U_\infty^2)$ for water injection is close to that for kerosene and the $\bar{q}$ for CS_2 is higher.

The instrumentation included thermocouples, both wall and in-flow, pressure taps and a camera, a video camera and an infrared Thermovision thermographic camera. This camera senses the infrared radiation emitted by a heated surface, processes these images internally and produces 10-color, isothermal band images on a color television screen. The exact temperature represented by each isothermal band is a function of emissivity of the object and the "shape factor" of the surface. These values are difficult to estimate for the liquid jet plume and surface layer here. Nonetheless, this method can be used to qualitatively observe the flow. The viewing path for the optical observations was down at an oblique angle from the rear at the emerging jet plume.

Tests were performed with water, kerosene, and CS_2 at air temperatures from 1230 K to 1530 K and a fuel pressure of 9.2 atm. At the highest temperatures, each liquid was also injected at 20.4 and 30.6 atm, and the fuels were injected at lower pressures. For kerosene, 9.2 atm corresponds to $\bar{q} = 2.4$ at $T_0 = 1300$ K. The liquids were injected both normal and oblique upstream (45 deg) to the main flow. All the photographs and data are in AFOSR-TR-78-1098.

A front-lighted photograph for 90 deg injection is shown in Fig. 1. The air flow is from left to right, and the injectant is directed out of the page. It has proven difficult to detect ignition from either this or the direct luminosity type of picture. Studies utilizing the Thermographic pictures and wall and in-stream temperature measurements failed to show unequivocal evidence of ignition up to air temperatures of 1480 K at any flow rate.

Figures 2a-c have black and white copies of the color Thermographic pictures comparing water, CS_2, and kerosene injected upstream at 45 deg. Each band in the picture represents a temperature range. The perturbation in the middle right of the photographs, breaking up the oval image of the nozzle exit, represents the jet with the injection orifice

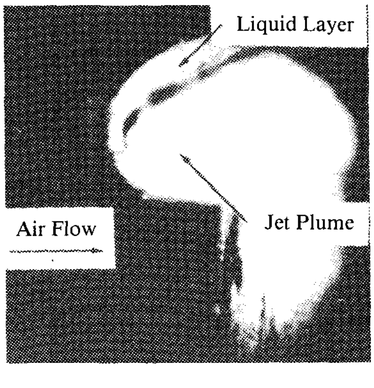

Fig. 1 Top view of front-lighted direct photographs of kerosene injection with $M = 1.8$ and $T_0 = 1140$ K from Ref. 9.

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Index categories: Combustion Stability, Ignition and Detonation; Airbreathing Propulsion; Combustion and Combustor Designs.

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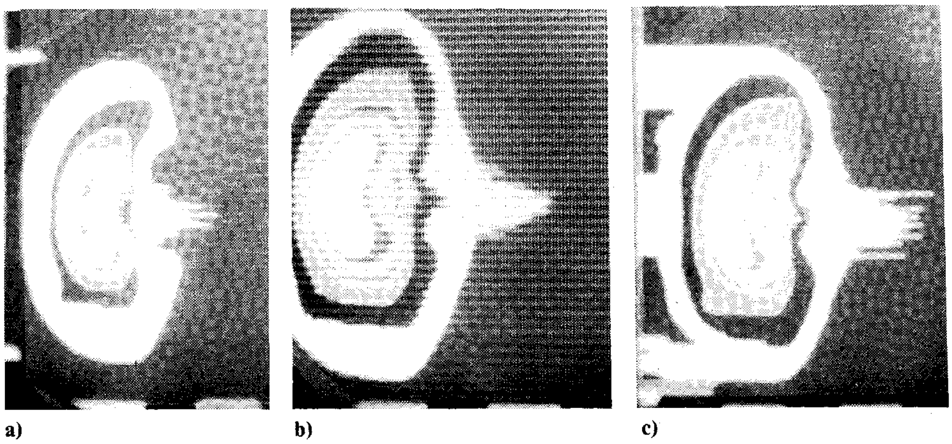

Fig. 2 Thermographic photographs of oblique upstream (45 deg) injection of various liquids at the same injection pressure, 9.2 atm: a) water, $T_0 = 1420$ K; b) kerosene, $T_0 = 1440$ K; and c) CS_2, $T_0 = 1440$ K.

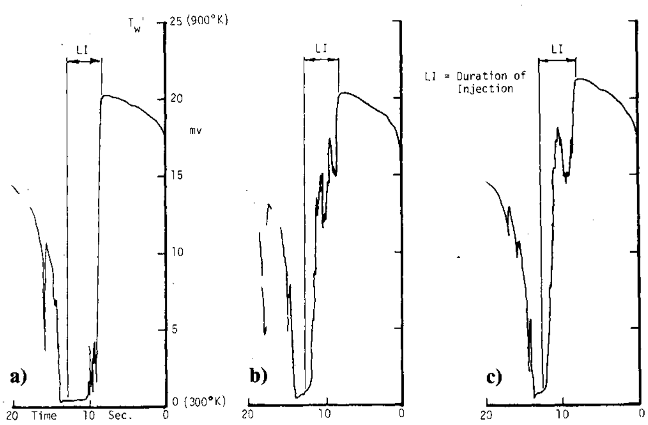

Fig. 3 Time history of wall temperature near the injection port (under the liquid layers) for oblique upstream (45 deg) injection of CS_2, $P_{inj} = 9.2$ atm: a) $T_0 = 1360$ K; b) $T_0 = 1380$ K; and c) $T_0 = 1440$ K.

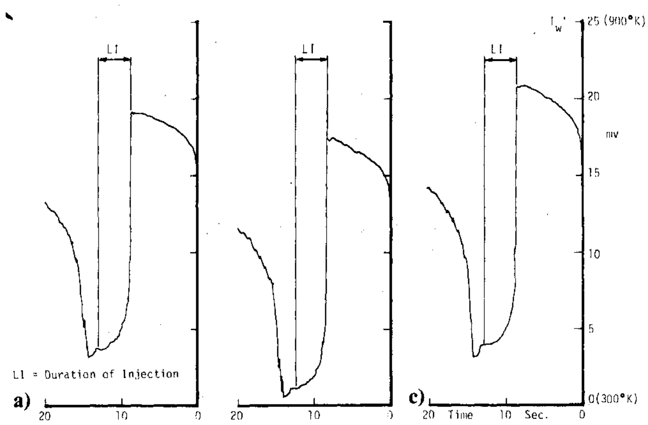

Fig. 5 Time history of wall temperature near the injection port (under the liquid layer) for oblique upstream (45 deg) injection of kerosene, $P_{inj} = 9.2$ atm: a) $T_0 = 1370$ K; b) $T_0 = 1390$ K; and c) $T_0 = 1440$ K.

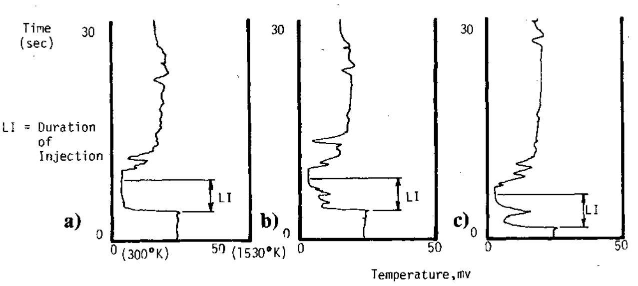

Fig. 4 Time history of downstream, in-flow temperature for oblique upstream (45 deg) injection of CS_2, $P_{inj} = 9.2$ atm: a) $T_0 = 1360$ K; b) $T_0 = 1380$ K; and c) $T_0 = 1440$ K.

located in the third isotherm from the outside at the vertical center of the perturbation. In the third isotherm from the outside in the injection area, the isotherm is perturbed for the kerosene and CS_2 injections and not for water. This might indicate ignition or it may be an indication of extra wall cooling for water injection. However, positive, correlating indications of ignition of CS_2 are found in the wall and in-flow temperatures just downstream of the injection port. Figure 3 has three tracings for CS_2. For $T_0 \geq 1380$ K, there are perturbations of the wall temperature all through the injection stage of the run. The in-flow temperatures downstream of the injector in Fig. 4 indicate the same thing. This did not occur for CS_2at higher injection pressures. Some CS_2 runs were made at lower pressures, and ignition was found down 5.4 atm.

Ignition of kerosene was not obtained for the same conditions as for CS_2. Wall temperature traces given in Fig. 5 for show no evidence of heat release.

Fruitful directions for further work include injection angles, preheating of the fuel and further attempts at finding helpful "blending" agents.

Acknowledgments

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References

[1] McVey, W. J. and Schetz, J. A., "Flowfield Near Liquid Fuel Jets Injected Transverse to a Hot Supersonic Air Stream," AIAA Paper 75-1230, Oct. 1975.

[2] Berbente, C. and Schetz, J. A., "Experiments on Combustion of Liquid Fuel Jets," Virginia Polytechnic Institute, Blacksburg, Va., VPI-Aero-054, Aug. 1976.

[3] Kush, Jr., E. A. and Schetz, J. A., "Liquid Jet Injection into a Supersonic Flow," *AIAA Journal,* Vol. 11, Sept. 1973, pp. 1223-1224.

[4] Joshi, P. B. and Schetz, J. A., "Effect of Injector Geometry on the Structure of a Liquid Jet Injected Normal to a Supersonic Airstream," AIAA Paper 74-1156, also *AIAA Journal,* Vol. 13, Sept. 1975, pp. 1137-1138.

[5] Baranovsky, S. I. and Schetz, J. A., "Effect of Injection Angle on Liquid Injection," AIAA Paper 79-0382, Jan. 1979.