1980-11

Combustion behavior of solid fuel ramjets

Netzer, D.W.; Binn, B.A.; Scott, W.E.; Metochianakis, M.

NASA. Langley Research Center The 17th JANNAF Combust. Meeting, Vol. 1; p. p 531-551
https://hdl.handle.net/10945/60112

VOL. 15, NO. 3, MAY-JUNE 1978 J. SPACECRAFT

Combustion Behavior of Solid-Fuel Ramjets

C.J. Mady,* P.J. Hickey,† and D.W. Netzer‡
Naval Postgraduate School, Monterey, Calif.

Abstract

AN experimental investigation was conducted of the combustion behavior in solid fuel ramjets in order to determine the effects of configuration variables and operating conditions on combustion performance. Variables considered were fuel port flow rates, bypass dump momentum and geometry, and bypass ratio.

Contents

To be used in a tactical situation, the solid-fuel ramjet has to demonstrate combustion stability and high efficiency over the expected operating envelope of altitudes and Mach numbers. It must also show performance comparable to that of liquid-fuel ramjets and ducted rockets. Combustion studies on the solid-fuel ramjet have been underway at United Technologies—Chemical Systems Division since 1971.[1]

The solid-fuel ramjet has two distinct combustion zones within the fuel grain: the recirculation zone behind the sudden expansion inlet, which provides flame stabiliation; and a diffusion flame in the developing boundary layer region after flow reattachment.

Unburned gaseous fuel escapes from under the flame at the aft end of the fuel grain and results in decreased combustion efficiency. Aft mixing chambers and bypass air designs are being used to increase the efficiency.

A schematic of the solid-fuel ramjet is shown in Fig. 1. The apparatus employed a polymethylmethacrylate (PMM) fuel with a fuel port to dump inlet area ratio of 9.0 and a fuel port to nozzle throat area ratio of 4.0. The exit area of the grain was held fixed at the initial port area by using a thin orifice plate. The aft mixing chamber had a length to diameter ratio of 2.93. The aft mixing chamber consisted of three interchangeable sections such that the axial location and angular orientation of the bypass dumps could be varied. A summary of the test conditions is presented in Table 1.

Figure 2 presents data obtained without bypass air. The regression rate expression indicates a weaker dependence on pressure than the earlier data of Boaz and Netzer.[2]

Figure 3 presents data obtained with bypass air. A slightly stronger dependence on pressure was shown while regression rate indicated very little or no dependence on air flux for the values tested.

In the bypass situation, the mass flux through the grain is low but the pressure is maintained high, due to the total mass flux through the nozzle throat. These conditions minimize the convective heat flux to the fuel surface. For lower mass flux through the grain, the regression rate increases relative to the air flux; thus, more gas with radiative properties (fuel rich) is present. These results indicate that using bypass with PMM fuel changes the principal wall heat flux mechanism from convection to radiation.

In Fig. 4 are plotted the cases from both Figs. 2 and 3. For the non-bypass runs, a decrease in air flow caused a slight decrease in combustion efficiency. While maintaining the same air flux through the grain, injecting bypass air into the mixing section brings a further decrease in performance. Decreasing the air flux through the fuel grain increases the percentage of fuel that must be burned in the aft mixing chamber. Apparently, the mixing chamber was not of sufficient length and/or the bypass air caused quenching of the mixing chamber combustion.

Every form of bypass used caused a decrease in combustion efficiency. Essentially equal decreases in performance were obtained with the dump air injected both behind and in front of the reattachment point. When the bypass momentum was increased to where the flow disturbed the fuel-rich layer between the recirculation region and the air-rich central core,

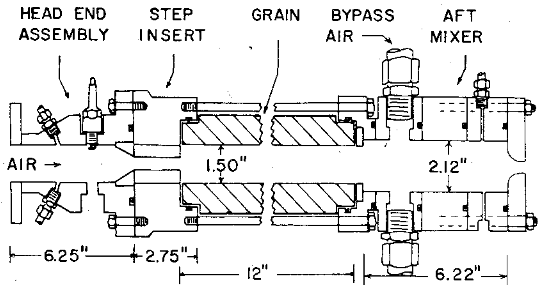

Fig. 1 Schematic of solid-fuel ramjet.

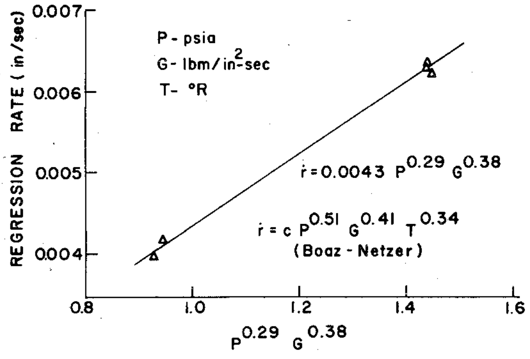

Fig. 2 PMM regression rate—non-bypass.

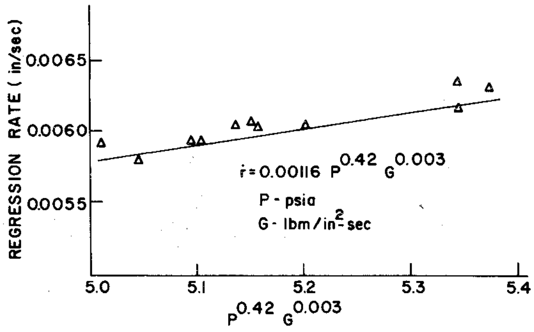

Fig. 3 PMM regression rate—bypass.

Received Sept. 21, 1977; synoptic received Feb. 1, 1978. Full paper available from National Technical Information Service, Springfield, Va. 22151 as N78-16091 at the standard price (available upon request).

Index categories: Airbreathing Propulsion; Combustion and Combustor Designs.

*Lieutenant, U.S. Navy.

†Staff, Department of Aeronautics.

‡Associate Professor, Department of Aeronautics. Member AIAA.

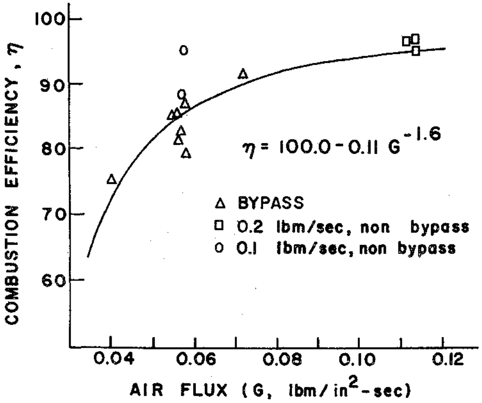

Fig. 4 PMM combustion efficiency vs air flux.

performance decreased. A major portion of the combustion process apparently takes place along this fuel-rich layer or the combustion downstream is highly dependent on the high temperatures in this layer. This agrees with the temperature data presented by Schadow[3] for an all-hydrocarbon fuel. These results imply that different optimum bypass configurations and momentum should be expected for different fuel systems.

It is known that the use of bypass improves performance in solid-fuel ramjets using all-hydrocarbon fuels. In the case of PMM, the lightweight unburned hydrocarbons that enter the aft mixing chamber apparently burn most completely when allowed to react slowly with the available oxygen in the hot flow from the core of fuel grain.

Table 1 Summary of experimental conditions

Air inlet temperature, K: 292, 389
Bypass dump location: forward and aft of flow reattachment
Bypass (% port/% bypass): 100/0, 65/35, 50/50, 35/65
Momentum ratio (dump/port)
for 50/50 bypass: 0.3, 0.5, 0.6, 1.0, 5.3
Dump configuration: none, 2 at 180 deg, 2 at 90 deg, 4 at 90 deg, 2 at 180 deg with swirl

With the use of bypass systems it is possible to set up combustor-feed systems coupling, dependent upon the effects of the bypass flow on the aft mixing chamber combustion process and on the fuel regression rate. Low-frequency oscillations were experimentally observed in some bypass runs. They did not occur for non-bypass runs.

The use of bypass systems increases the weight, cost, and complexity of the solid-fuel ramjet. The use of a fuel which has sufficient density impulse, regression rate, and flammability limits to minimize inlet total pressure losses has led to the use of all-hydrocarbon fuels. Although PMM does not meet the criteria for a good fuel, the results of this study indicate that future fuel studies may be fruitful if directed toward ones which contain low percentages of oxidizer and/or substances which unzip the hydrocarbon chain.

Acknowledgment

This work was sponsored by the Naval Wespons Center, China Lake, Calif.

References

[1] Jensen, G.E., Dunlap, R., and Holzman, A.L., "Solid Fuel Ramjet Flame Stabilization and Fuel Regression Studies," *12th JANNAF Combustion Meeting,* CPIA No. 273, Vol. II, Dec. 1975, pp. 425-439.

[2] Boaz, L.D. and Netzer, D.W., "An Investigation of the Internal Ballistics of Solid Fuel Ramjets," Naval Postgraduate School, Monterey, Cal., NPS-57NT73031A, March 1973.

[3] Schadow, K.C., Cordes, H.F., and Chieze, D.J., "Experimental Studies of Combustion Processes in Solid Fueled Ramjets," *13th JANNAF Combustion Meeting,* CPIA 281, Vol. III, Dec. 1976, pp. 245-259.