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INHERENT STABILITY OF CENTRAL ELEMENT COAXIAL LIQUID-LIQUID INJECTORS

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Most TRW liquid bi-propellant rocket engines built over the past thirty-plus years have employed a central element coaxial pintle injector and have operated with liquid/liquid propellant injection. This injector is a patented design exclusive to TRW and has unique features that make the rocket engine combustion characteristics different from those of other types of injector engine designs. Its many benefits include excellent combustion performance, efficient deep throttling, adaptability to low cost manufacturing, and high reliability. Approximately 200 pintle injector engines of various sizes and operating on a variety of propellants have been flown without a single in-flight failure.

An especially important feature of the pintle injector engine is its apparent inherent combustion stability. In over thirty years of development, testing and production, TRW has never experienced combustion instability in any of its pintle injector engine designs. This has been true of engines operating over a range of thrust from 5 to 250,000 lbs. on earth-storable hypergolic propellants and a large number of smaller engines operating on a variety of propellants (21 combinations) in long duration-firing, pulsing (down to 2 msec) and deep throttling (as much as 19:1) modes. Operating chamber pressures have ranged from 10 to 3,500 psia.

This record is particularly impressive given that typical TRW design practice does not consider combustion instability as an issue and no pintle engine has ever employed stability-enhancing features, such as baffles or acoustically resonant chambers. In spite of this, TRW engines have operated stably in regimes not possible with other types of injectors.

Various physical explanations and combustion process models for this favorable stability characteristic have been postulated. However, a definitive study that unequivocably establishes the important stabilizing mechanisms still remains to be conducted.

The basic pintle injector concept is illustrated in Figure 1. It consists of a closed cylindrical element that projects into the combustion chamber and has ports machined into the cylindrical surface that allow the center propellant to flow radially into the chamber. The center propellant may be either oxidizer or fuel. The propellant port configurations typically range from discrete primary and secondary jet slots to a continuous gap. Selection of a particular configuration is governed by a number of factors including the propellants to be used, the required combustion chamber wall thermal environment, desired combustion performance, and whether the injector is intended to operate in continuous flow, throttling, or pulsing modes.

The other propellant enters the chamber flowing axially along the exterior of the cylindrical element. Mixing of the propellants occurs where this axial-flowing cylindrical sheet meets the radial flow issuing from the central propellant slots. The genesis of the pintle injector is traceable to the Apollo program. It provided a means to perform deep throttling, needed for a controlled descent to the lunar surface, while maintaining good stable combustion performance and mixture ratio control. Once Apollo got underway, TRW work on the pintle injector

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attracted NASA interest and resulted in its selection for the Lunar Module Descent Engine (LEMDE). LEMDE was an ablative-cooled, pressure-fed engine having a maximum thrust of 10,500 lbs. with a chamber pressure of 100 psia and a 10:1 throttling range operating on NTO/A-50 propellants. This engine proved to be very stable throughout the development, qualification and flight phases of the Apollo program. It successfully landed on the moon six times and saved the crew of Apollo 13.

In the mid 1970's, a fixed thrust variant of the LEMDE was produced and designated as the TR201. It flew 75 successful missions as the second-stage engine on the Delta launch vehicle. During the late 1960's and early 1970's, the basic LEMDE concept was scaled up to 250,000 lbs. thrust and operated on NTO/UDMH propellants. In addition, 50,000 lbs. thrust engines were operated on IRFNA/UDMH, LOX/RP-1 and LOX/Propane. Smaller engines having 3000 lbs. thrust were tested on FLOX/LCH_4, FLOX/GCH_4 and FLOX/(LC_3H_8 + LCH_4) propellants. In all cases, explosive-induced disturbances were well damped and no evidence of spontaneous instabilities were observed even under liquid/liquid injection conditions.

In recent years, TRW pintle engines have also operated on gelled hypergolic propellants up to 1500 lbs. thrust and LOX/LH_2 up to 16,400 lbs. thrust. No spontaneous instabilities have been observed in either case. In the LOX/LH_2 tests, both propellants were injected at near normal-boiling point conditions for which conventional injectors are spontaneously unstable. Explosively produced disturbances were found to be well damped in this case.

Our current efforts in this area involve testing a 40,000 lbs. thrust (sea level) LOX/LH_2 demonstration engine at NASA LeRC. Tests are due to start in early September, 1993. Future plans include scaling this engine up to 400,000 lbs. thrust.

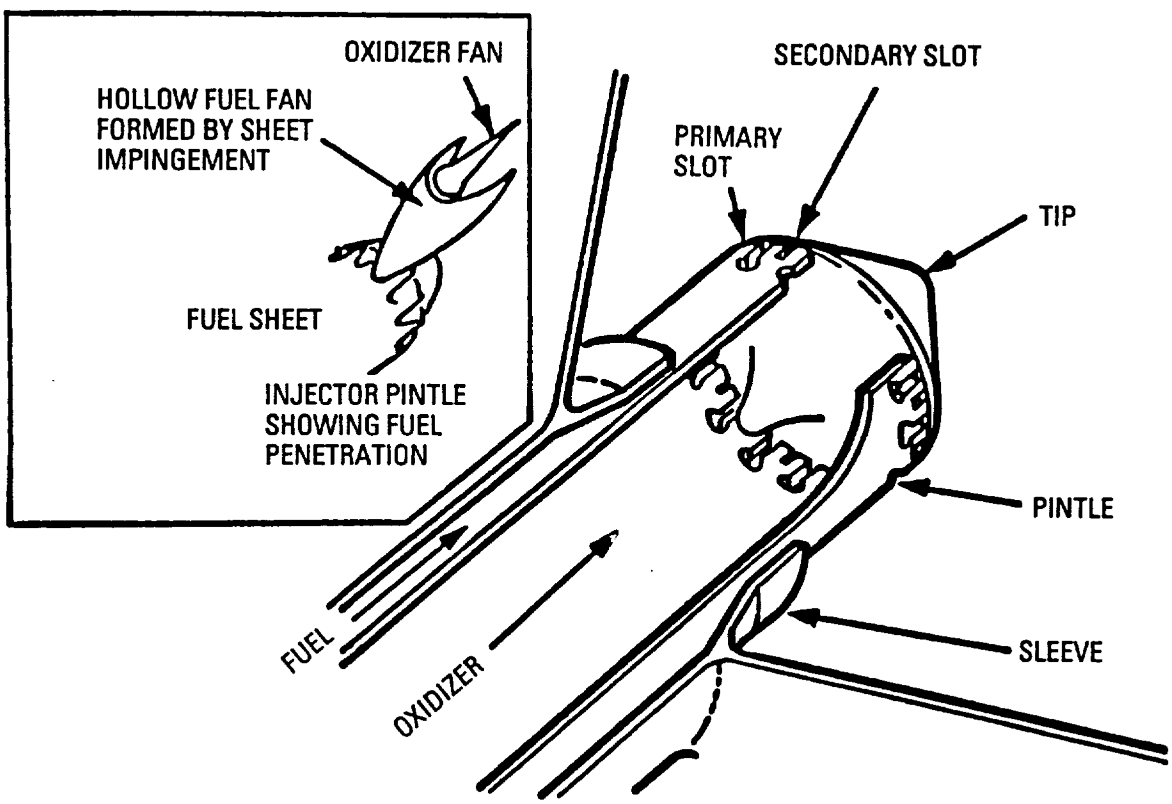

Figure 1. TRW Coaxial Pintle Injector Concept