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SMALL ROCKET RESEARCH AND TECHNOLOGY

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SUMMARY

Small chemical rockets are used on nearly all space missions. The small rocket program provides propulsion technology for civil and government space systems. Small rocket concepts are developed for systems which encompass reaction control for launch and orbit transfer systems, as well as on-board propulsion for large space systems and Earth orbit and planetary spacecraft. Major roles for on-board propulsion include apogee kick, delta-V, de-orbit, drag makeup, final insertions, north-south station-keeping, orbit change/trim, perigee kick, and reboost. The program encompasses efforts on Earth-storable, space storable, and cryogenic propellants. The Earth-storable propellants include nitrogen tetroxide (NTO) as an oxidizer with monomethylhydrazine (MMH) or anhydrous hydrazine (AH) as fuels. The space storable propellants include liquid oxygen (LOX) as an oxidizer with hydrazine or hydrocarbons such as liquid methane, ethane, and ethanol as fuels. Cryogenic propellants are LOX or gaseous oxygen (GOX) as oxidizers and liquid or gaseous hydrogen as fuels. Improved performance and lifetime for small chemical rockets are sought through the development of new predictive tools to understand the combustion and flow physics, the introduction of high temperature materials to eliminate fuel film cooling and its associated combustion inefficiency, and improved component designs to optimize performance. Improved predictive technology is sought through the comparison of both local and global predictions with experimental data. Results indicate that modeling of the injector and combustion process in small rockets needs improvement. High temperature materials require the development of fabrication processes, a durability data base in both laboratory and rocket environments, and basic engineering property data such as strength, creep, fatigue, and work hardening properties at both room and elevated temperature. Promising materials under development include iridium-coated rhenium and a ceramic composite of mixed hafnium carbide and tantalum carbide reinforced with graphite fibers. Component designs to optimize performance indicate that gains of 10 to 20 seconds specific impulse are possible with Earth-storable propellants. Further gains of 5 to 10 seconds are expected with designs which operate at high chamber pressure such that frozen flow losses in the nozzle are minimized and combustion efficiency possibly increases. Components designed for space-storable propellants are expected to provide an additional 15 to 20 seconds specific impulse over Earth-storables due to the more energetic nature of these propellants. Small cryogenic rockets are proposed only for those systems where integration is possible. Systems analyses indicate a significant payload benefit for vehicles with integrated propulsion systems. Both LOX/liquid hydrogen and GOX/gaseous hydrogen are candidate propellants. Tests with GOX/gaseous hydrogen are conducted for materials tests and predictive

technology development as a matter of convenience as well as to supply performance data on these high performance propellants. This program provides the opportunity to study fundamental rocket phenomena in testbed, as well as, prototype engines, not just subscale models, and may be an economical approach to providing subscale data of general value to all rockets.

EARTH STORABLE ROCKET DESIGN, FABRICATION, AND TEST

Small rocket chambers are usually radiation-cooled for simplicity. Radiation-cooled operation, in general, requires extensive fuel film cooling with its associated combustion/performance losses. This design practice reduces chamber temperature and limits thermal soakback to the injector. Small rockets require larger percentages of their fuel for cooling than large rockets because of their larger surface-to-volume ratios. They, therefore, stand to benefit the most from high temperature material technology. Design issues which must be addressed in the use of iridium-coated rhenium for rocket chambers include

a) thermal management of the high temperature chamber, especially at the injector interface

b) injector design to minimize oxidizer contact with the iridium

c) chamber design to accommodate launch induced stresses in heavy annealed material

d) basic material property data

e) metallurgical joining techniques for rhenium with other materials

Radiation-cooling of the rhenium chamber is accomplished by the application of a high emissivity coating of dendritic rhenium to the outside surface by CVD. Thermal management of the injector-chamber interface is accomplished through the use of film coolant along with increased thermal resistance or path lengths in the rhenium material. Alternatively, fuel regenerative cooling of the interface is also used. Injectors are designed such that oxidizer momentum is either axial or away from the walls. Iridium has a finite oxidation rate and material loss escalates in the presence of oxidizer and at elevated temperatures. Combustion interactions with iridium is the subject of great uncertainty in the design process. Both liners fabricated from platinum-10rhodium and stainless steel regenerative sections were successfully used to prevent iridium oxidation at the head end of the combustion chamber. At the throat, where temperatures require the use of iridium (melting point 2720 K), increased iridium thickness is the only route to additional life, but lack of oxidation data makes this design purely empirical. Designing the chamber for adequate strength at operating temperature and fatigue life during launch is crucial. The former requires elevated temperature (2200 K) strength, creep, and low cycle fatigue data. The latter requires room temperature strength, fatigue, and work hardening data. These data are presently the subject of considerable contractor and NASA efforts. Designing the chamber to survive the launch loads is accomplished either by using lighter materials such as silicide coated niobium or ceramic composites for nozzle skirts, where temperatures permit, or by increasing material thickness at the throat. Investigations of metallurgical joining techniques required for flight type hardware yielded furnace brazing with Palcusil 25 or Nioro filler metals as a suitable technique. A form of electron beam (EB) welding called parent metal braze is suitable for joining rhenium to stainless steel. Joining techniques are the subject of continuing investigations.

Performance and life tests of 22, 62, and 440 N thrust class rockets using this technology were conducted with NTO/MMH propellants. Both steady state and pulse testing was performed and thermal management issues were successfully addressed. Performance and life results are shown in the following table.

THRUST CLASS (N)	PROPEL-LANTS	AREA RATIO	PERFOR-MANCE (sec)	TOTAL TIME (hr)	CYCLES	COMMENT
22	NTO/MMH	150:1	310	1.7	100,311	100,000 @ 20% duty
62	NTO/MMH	75:1	305	0.2	263	240 @ 10% duty
440	NTO/MMH	286:1	321	6.2	93	
550	NTO/AH	200:1	330			

The Earth storable liquid rocket technology developed to date uses relatively low system pressures compared to recent DOD programs aimed at short lived rockets. A program is currently underway to develop long-life, high-pressure rocket technology which takes advantage of the BMDO investment in high pressure propellant management and industry investment in high pressure tanks. High pressure tests of small rockets will be used to determine their combustion chamber efficiency when designed with high temperature materials. These materials may offer the thermal margin necessary to withstand the increased heat fluxes associated with high pressure rocket chambers, without paying a performance penalty for film cooling. Operation at high pressure also allows a reduction in size of rockets, which is potentially of value to microsatellites.

SPACE STORABLE ROCKET TECHNOLOGY PROGRAM

Efforts to improve the performance of small rockets through the use of more energetic propellants have focused on a class of propellants called space storables. These propellants are those which can be passively stored in space, within mission constraints, without active cooling or refrigeration. Space storable propellant candidates include liquid oxygen (LOX) and hydrocarbon fuels such as liquid methane, ethane, propane, and ethylene. Other candidate fuels are storable on Earth as well as space and include hydrazine and ethanol. Based on system analysis, LOX/hydrazine was chosen for rocket development at TRW using their pintle injector design. In addition, a facility is under construction at LeRC to test LOX/hydrocarbons in the event toxic propellants such as hydrazine fall out of favor. TRW's space storable pintle injector concept is shown in figure 1. LOX is injected as a film along the outside of the pintle and impinges on hydrazine, which is injected radially outward from slots in the pintle tip. Injector geometry is varied with shims, which alter the injection port geometry of both the fuel and oxidizer. In the initial tests, six fuel geometries were evaluated yielding lower than expected performance. A hybrid design injecting some fuel along the engine axis was then tested with better results, showing that the core flow was oxidizer rich. Tests to date have produced a maximum specific impulse of 346 seconds based on a 200:1 area ratio nozzle. They provide basic engineering information on combustion performance, thermal characteristics, stability, and ignition of LOX and hydrazine. Incorporation of high temperature materials is planned for the next phase of this development program and engine performance is expected to exceed 350 seconds specific impulse.

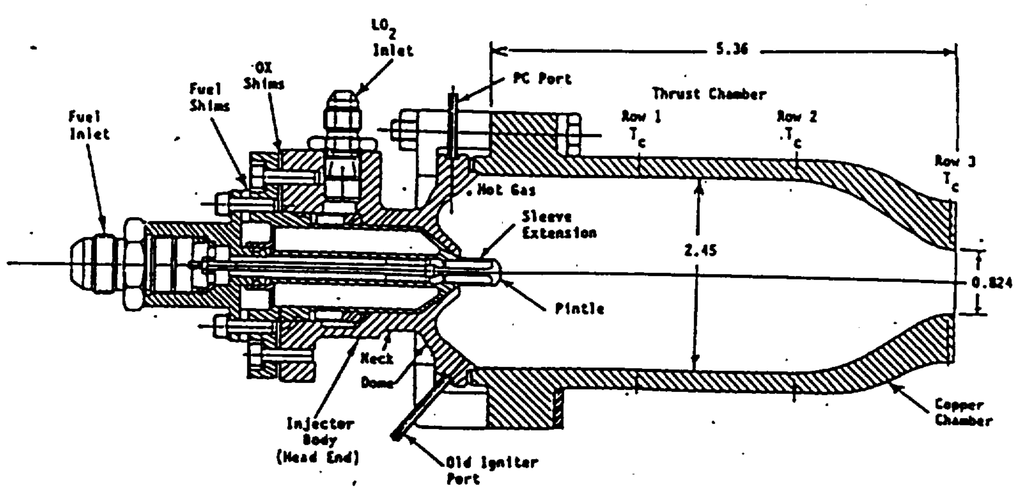

Figure 1. Baseline Injector with Workhorse Trust Chamber

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