Engineering Notes

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Feasibility of Simple Bipropellant Blowdown Systems

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Introduction

THE performance advantages of bipropellant relative to monopropellant propulsion systems have often been outweighed by the complexities of the bipropellant system and the unavailability of low-thrust engines for spacecraft applications. However, thruster advances in the past few years have led to the development of bipropellant engines which have the required characteristics (≤ 5 lb_f) and the ability to operate over a relatively wide range of feed pressures and mixture ratios.[1,2] Thrusters have been employed for stationkeeping and attitude control spacecraft applications,[3,4] and studies have indicated potential advantages for the bipropellant blowdown mode of operation.[5] This Note examines the feasibility of a simple bipropellant blowdown system which dispenses with the requirement for active components such as pressure regulators and check valves, and minimizes the number of other components including isolation valves, fill valves, and instrumentation. In addition, this study assumes that the propellant management and expulsion function is performed by a passive surface tension device in the tank rather than a movable diaphragm or bladder; this feature provides more flexibility in terms of the size and shape of the propellant tanks, and increases the potential for reuseability.

Discussion

A computer program was developed to model a bipropellant blowdown system using monomethyl hydrazine (MMH) and nitrogen tetroxide (N_2O_4). Both orbit adjust (OA) and reaction control system (RCS) functions are incorporated, and performance and flow characteristics of typical engines in the 300 lb_f and 5 lb_f thrust categories were used in the model. Either orifice or cavitating venturi flow control can be selected for the OA engine; for venturi operation the flow characteristics are slightly modified to assure cavitation over the entire 300-100 psia blowdown range.

The output of a program run is a time history of tank pressures, propellant masses, OA and RCS chamber pressures, and mixture ratios for OA and RCS. Parameters which can be specified include the loading conditions, on-orbit temperatures, OA flow control option (orifice or venturi), pressurant gas, tank repressurizations, gas solubility, and the amount of RCS usage. The degree of pressurant gas solubility in the propellant is a function of temperature and pressure,[6] and is an important factor in the determination of system feasibility since the propellant and pressurant are in contact. An expression was derived to calculate both the change in the ullage gas quantity and the resulting pressure as propellant is expelled. For RCS operation a fuel lead results due to the lower density and inertia of the MMH; therefore, a provision is made for specifying a mixture ratio shift when the RCS is operating in the pulse mode.

Based on the desired use of identical tanks for fuel and oxidizer, the design point mixture ratio for the engines was assumed to be 1.65 at the loaded condition of 70°F and 300 psia. The gas solubility in the propellant after loading was assumed to be zero since tank pressurization usually occurs shortly before launch and it may take weeks for saturation to be achieved. Figures 1 and 2 show the pressure blowdown for nitrogen and helium under the assumption that saturation is achieved early relative to the length of the mission. The lower initial pressure relative to the loading pressure is the result of gas solubility. The high solubility of nitrogen in N_2O_4 is especially evident, and the dispersion between fuel and oxidizer pressures illustrates the disadvantage of using nitrogen in this type of system. The potential impact on engine stability due to gas ingestion is also a consideration. The narrowing of the pressure differences near the end of the blowdown is a result of gas coming back out of solution.

Figure 3 shows the operating characteristics required of the OA engine for both orifice and venturi flow control. The effect of gas solubility on tank pressure causes the mixture ratio to move off the selected design point, although the use of

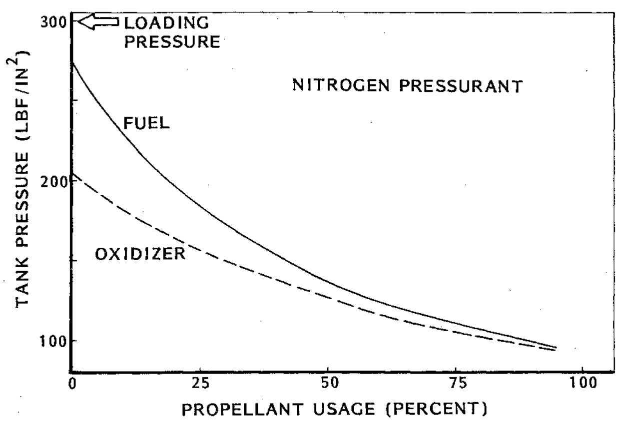

Fig. 1 Tank pressure blowdown using nitrogen.

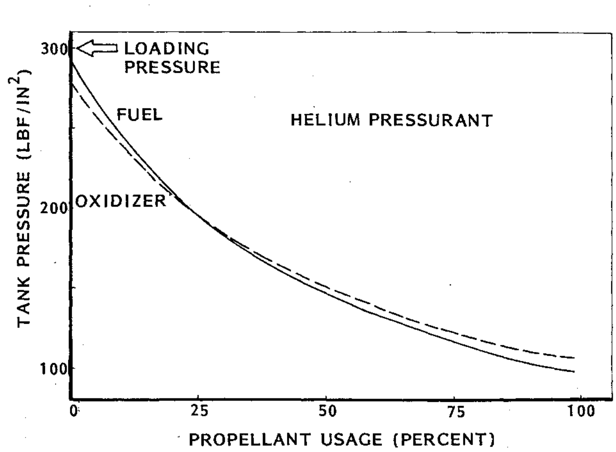

Fig. 2 Tank pressure blowdown using helium.

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Table 1 Propellant residuals using helium pressurant

Temperature differential fuel-ox., °F	RCS usage, %	RCS mixture ratio shift	Propellant residuals, % of total load
0	0	0	0.8
+20	0	0	1.5
-20	0	0	0.3
0	50	0	0.4
0	50	-0.2	1.6

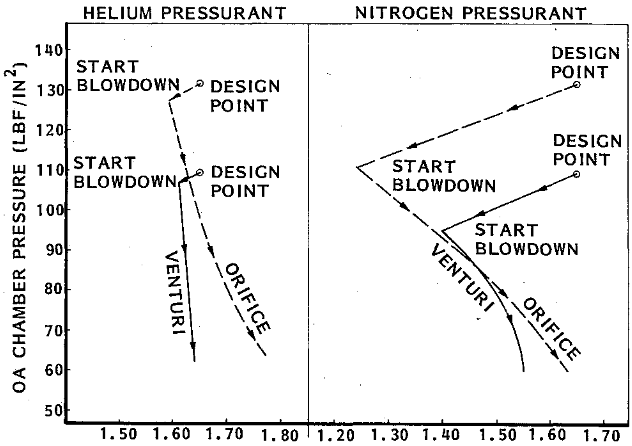

Fig. 3 Orbit adjust thruster performance requirements.

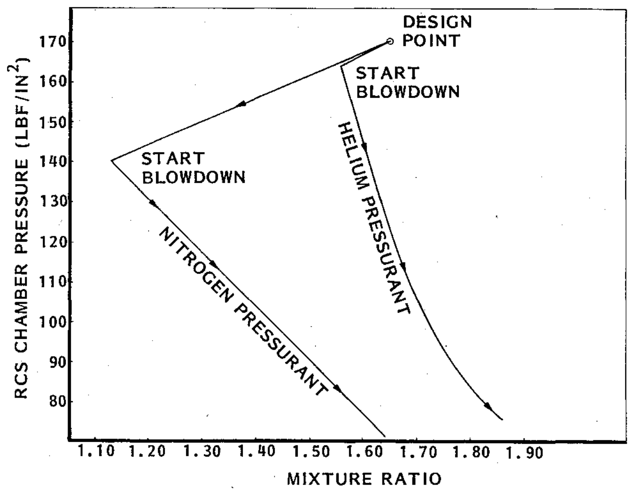

Fig. 4 RCS thruster performance requirements.

helium as the pressurant greatly reduces the total variation. Use of a venturi minimizes the required operating range for both thrust and mixture ratio. Figure 4 shows the corresponding RCS thruster performance map for a case where the RCS uses 50% of the total propellant. Of course, the required operating range can be shifted somewhat from that shown on these plots by varying the initial propellant loads or pressures, but the helium system still exhibits less variability and less sensitivity to changes in the operating environment. Table 1 summarizes the propellant residuals which resulted from various runs involving tank temperature differentials, RCS usage, and RCS mixture ratio shifts due to pulsing; use of helium appears to offer acceptable values. The blowdown system is also self-regulating to some extent in that a higher flow from one tank will cause a more rapid pressure decay which will bring the system back toward its design point mixture ratio. This feature minimizes the residuals in one tank when propellant depletion and gas ingestion occur in the other.

Conclusions

The feasibility of a bipropellant blowdown system depends on the ability of the engines to run stably and with proper thermal control over a range of feed pressures and mixture ratios. Detailed system studies or development would consider the question of combustion and feed system stability, especially at the low pressures in the latter portion of the blowdown. Performance evaluation would also include the efect of off-design conditions on combustion efficiency. However, a simple system using passive surface tension propellant management appears to be feasible in terms of propellant residuals and compatibility with demonstrated or expected engine capabilities. Helium as the pressurant is probably mandatory, and venturi flow control for large orbit adjust thrusters is suggested.

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