WARM GAS PROPULSION FOR SMALL SATELLITES

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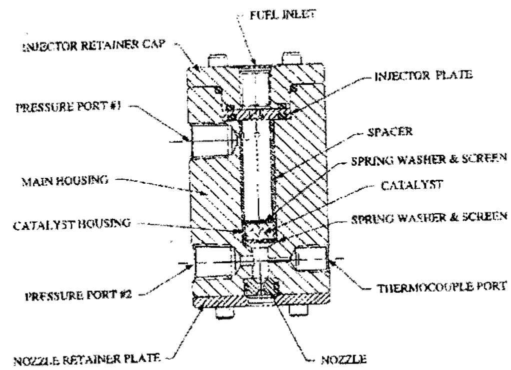
The purpose of this activity is to quickly develop miniature warm gas thruster technology for application to next generation microsatellite systems and to provide an industrial source for this technology.

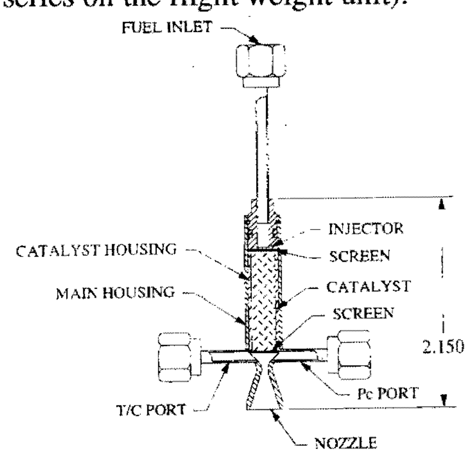
A brief assessment of the market was conducted and prior work evaluated in order to ascertain the state-of-the-art. Based upon this information, gas mixtures and catalysts were selected for evaluation. It was concluded that 0.5 lbf thrust hardware was suitably representative of the desired size range without being so small as to introduce excessive fabrication problems. A gas mixture providing a theoretical temperature of 1200F (1660R) was selected for the initial tests to provide compatibility with easily obtainable materials such as stainless steel. Higher performance mixtures were to be introduced once the catalyst screening phase was complete. Several types of catalysts were selected for initial evaluation.

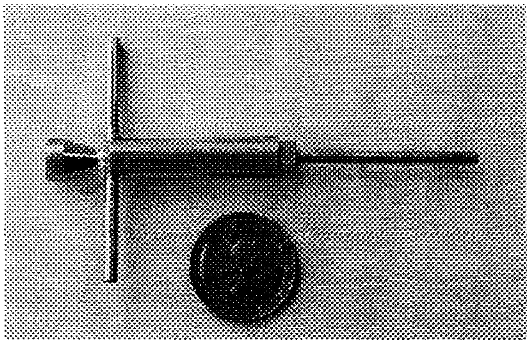
Initial testing was carried out in a heavy weight chamber designed for easy changeout of components and change of catalyst bed configuration.



Heavy Weight Thruster

Based on these results, a near flight weight unit was fabricated and tests conducted with that unit using the most promising catalyst configurations from the heavy weight tests. Eighty-six steady state firings (eleven on the flight weight hardware) were conducted as well as six tests consisting of multiple (approximately 30) short pulses (two series on the flight weight unit).





Flight Weight Thruster

The test results indicate that steady state vacuum specific impulse around 130 seconds is achievable with the gas mixture used and substantially higher values with more energetic mixtures. Pulse performance is not as well defined due to instrumentation limitations but it is clear that substantial improvement over cold gas is available there as well. Several suitable catalysts were found and indications for possible future improvements noted.

Based upon the results of the initial testing, it was concluded that the technology was sufficiently promising to warrant further investigation. Accordingly, a Phase 2 proposal will be submitted. We feel that this technology has excellent potential, not only as an enhanced attitude control effector but for larger units such as interceptor divert thrusters and orbit maintenance / correction thrusters. In addition, a number of non-thruster applications which have both military and commercial applications suggest themselves.

RESULTS OF PHASE I PROJECT

The Phase 1 portion of the SBIR was a highly successful effort to resurrect technology originally demonstrated during the 1960s for small warm gas attitude control thrusters. During Phase 1, some 86 steady state firings and a number of pulse series were conducted. Reliable repeatable operation was demonstrated. Thirteen catalyst types and configurations were evaluated. At least four were found to be suitable for use in spacecraft thrusters. Interestingly, some relatively low cost commercial catalysts were found to be quite competitive with much more expensive aerospace catalysts.

All tests were conducted with a nitrogen / hydrogen/ oxygen mixture designed to deliver a gas temperature of about 1200F (1660R). Temperature rise equivalent to 90% of theoretical was demonstrated.

A heavy weight thruster designed for approximately 0.5 lbf thrust was used for initial screening tests and a near flight weight configuration was demonstrated using the best catalyst and bed configurations derived from the heavy weight tests. Based just upon these results, it is clear that vacuum specific impulse on the order of 125 seconds during steady state firing can be delivered with the gas mixture tested. Higher temperature gas mixtures will offer better performance. While pulsing performance is less well defined due to limitations of Phase 1 instrumentation, it seems certain that warm gas thrusters will offer at least a 50% improvement in performance over cold gas.

PHASE II TECHNICAL OBJECTIVES

Several complimentary activities will be carried forward during Phase II. These are described in the following sections.

Task 1. Expanded Warm Gas Technology

Using the heavy weight and near flight weight thrusters developed in Phase 1, development of warm gas technology will continue. Areas of investigation will include but not be limited to different catalysts, different configurations, and different gas mixtures designed for higher temperatures.

The sensitivity of performance to catalyst surface characteristics and packing density will be further explored and selection of catalysts for operational applications will be made.

The configuration of the flight weight thruster from Phase 1 will be refined and matured into a final configuration in support of the other tasks discussed below.

Higher temperature gas mixtures will be evaluated to determine the maximum performance achievable with this technology . Most of this work will involve nitrogen as the inert component since the higher storage density is usually preferred for spacecraft applications.

Lower gas temperature mixtures using both helium and nitrogen as the inert component will be evaluated in support of tank pressurant applications. This activity will be carried out in cooperation with the Jet Propulsion Laboratory.

During Phase 1 it was observed, as might be expected, that there is a sensitivity to temperature in determining whether, and how rapidly, the reaction "takes off". Because of time and hardware constraints, this was not explored in any detail. Clearly this relationship is important for spacecraft design and operational considerations. One of the Task 1 activities will be to explore the relationship of catalyst temperature and gas temperature and the impact of each on start characteristics and performance. JPL will provide, on a no cost basis, a temperature controlled test chamber suitable for evaluation of the effect of catalyst temperature and incoming gas temperature on the startup and steady state operations of a warm gas system. This chamber, already in place at JPL, offers about a cubic meter of volume, is insulated and can be temperature controlled. Temperature down to -40F will be investigated. Feedthrough panels in the chamber walls allow for instrumentation and gas feed connections. Since JPL's interest is primarily in pressurization, the test system will be designed to represent a pressurant system however temperature sensitivity data obtained will be typical for all warm gas systems.

In support of possible applications where gas may be tapped off a launch vehicle stage pressurization system, to provide propellant settling or separation thrust, helium-based mixtures will be evaluated in thruster applications as well.

Task 2. Warm Gas Attitude Control Thruster

Based upon the successful work of Phase I as amplified by the development work in Task 1 of Phase II, we will proceed with design, fabrication and test of a prototypical warm gas thruster for spacecraft attitude control. This thruster will incorporate high response flight type valves, appropriate materials and will be sized appropriately for spacecraft attitude control. Thrust level is currently TBD but tentatively will be in the 0.1 to 0.5 lbf range.
Simulated altitude testing will be conducted using a specially designed vacuum chamber facility.

This portion of Phase II will be carried out in cooperation with Guidance Dynamics, Inc. Guidance Dynamics will provide the flight quality valves, valve drivers, and controllers for operating the thruster.

Task 3. Flight weight Attitude Control System Fabrication and Evaluation

Using the thruster developed in Task 2, a prototype warm gas attitude control system will be built and tested. The system will be designed as the attitude control system for the flight demonstration mission described in Task 5 and will be capable of providing 3-axis control for the instrumentation section of the flight vehicle. The thruster will be about 1 lb thrust for this application.

Valve drivers and controllers will be flight type units provided by Guidance Dynamics Corporation.

After initial checkout, the system will be put through a series of typical mission duty cycles The actual nature of these duty cycles is TBD but will simulate the number of pulses and total impulse which would be typical of a spacecraft mission. At least two such duty cycles would be conducted.

Task 4. Guidance Integration / Air Bearing Testing

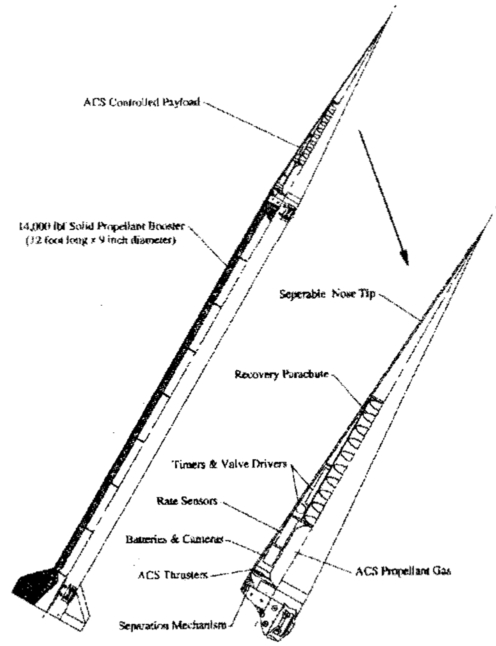
As a final ground demonstration, the system will be tested on an air bearing fixture owned by Guidance Dynamics. This will give improved understanding of thruster response and repeatability and will allow the best estimates of thruster specific impulse since impulse can be calculated from the moment of inertia of the test rig and the angular momentum imparted by a given duration of thrust. It is of doubtful practicality to attempt to directly measure such low thrust directly and for this reason such measurements are not proposed in the thruster tests discussed above. The air bearing will provide an interesting independent verification of predicted performance although operating in the atmosphere will cause flow separation which will make prediction somewhat questionable.

In order to clearly demonstrate the advantages of the warm gas system, identical duty cycles will be run using cold nitrogen and warm nitrogen and the results compared. Points of comparison will include but not be limited to: total impulse, thruster response, and repeatability.

Task 5 Vehicle Integration and Flight Test

The work proposed in Task 5 will concentrate on a flight demonstration of the components built and tested in the previous four tasks. As is often the case when new, lower cost flight components are developed, many potential customers are attracted by lower cost, but are concerned by the risks associated with being the first to fly a new and previously untried system. This task would mitigate that risk, somewhat, by demonstrating that the attitude control system components developed by Propulsion Development Associates could successfully withstand a very stressing flight environment (high accelerations, vibration environments, shocks, etc.) and then complete a predetermined attitude control mission. This flight worthiness demonstration would provide potential end users of these new thrusters another level of confidence in the warm gas attitude control system readiness to fly and would demonstration real world performance.

Task 5 would involve the following effort. The flight weight warm gas attitude control system built under Task 3 and extensively ground tested under Task 4 would be incorporated into a specially designed nose section of a solid propellant booster rocket. The nose will contain the warm gas attitude control system, the guidance package, electrical power, telemetry transmitter, two miniature video cameras, two independent 2.4 Ghz video transmitters, required antennas, a separation mechanism (to allow the nose to detach from its booster at the appropriate time in the flight), and a parachute recovery system. Any specialized ground equipment required in the field to support preparations of the system for flight will also be designed and built.

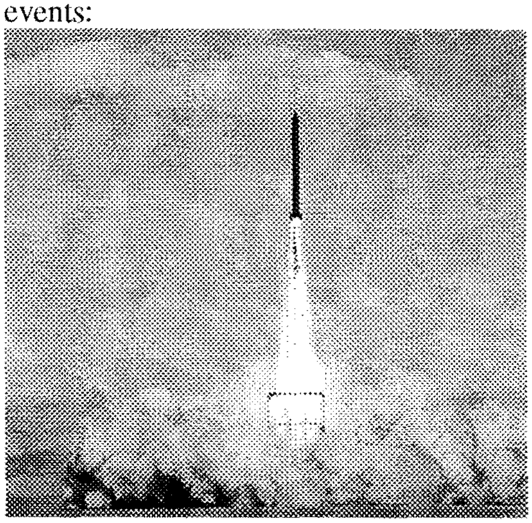


Flight Test System

The attitude control system gas storage bottle on board the flight vehicle will be sized to provide 150% of the planned mission total impulse required.

The booster used for this flight demonstration was recently developed for another application by the members of the Propulsion Development Associates team. The vehicle is nine inches in diameter, twelve feet long, and produces a peak thrust of 14,000 pounds. The motor produces approximately 60,000 pound seconds of total impulse. The booster is also completely field processable. Transported without propellant to minimize shipping cost and complexity, the rocket motor is loaded just prior to flight at the launch site. In a recent flight test, this booster was used to successfully loft a ballistic dart to a nearly 50 mile peak altitude An identical booster can be modified to accomplish the flight test required by this task. All necessary field processing and launch support equipment will be available to Propulsion Development Associates. The vehicle will be launched from an area used for private rocket launches and would not require the use (or cost) of a government range.

A launch of the test vehicle is shown below. The flight demonstration would involve the following sequence of events:



Test Vehicle Launch

After final assembly, fueling, and checkout of the vehicle, it will be loaded onto the launch equipment and set at the appropriate quadrant angle and azimuth. The rocket will be launched and the booster will loft the nose section, containing the attitude control system, to an altitude of approximately 35 miles (55 kilometers). At some point during the ascent phase of the flight, the nose section will be separated from the booster and will continue to fly toward peak. The onboard video cameras will function throughout the flight sending video imagery to the ground. At an altitude of 26 miles, the attitude control system will have sufficient control authority to begin a series of preprogrammed maneuvers commanded by the avionics package. The performance of the attitude control thrusters will be measured (in terms of vehicle response to commanded motion) by the avionics and data will be telemetered to the ground. As a back up, the on board video imagery being transmitted to the ground will give visual information about the vehicle attitude, stability, and compliance with the intended attitude maneuvers. The vehicle will have approximately 60 seconds of flight time in which to accomplish the planned maneuvers before dynamic pressure will again exceed the ability of the ACS to control vehicle attitude.

At some point in the descent, the parachute system will deploy a parachute and the nose section will be recovered. Task 5 will demonstrate that the attitude control system can withstand a severe flight environment and successfully perform required attitude maneuvers.

Task 6 Pressurant Systems

The warm gas system has substantial potential as a pressurant system, offering the possibility of reducing total pressurant gas requirements for a given spacecraft by a factor of two or more. This comes about by eliminating the cooling effect of expansion from high pressure storage down to use pressure. In addition, the pressurant gas can be operated at the maximum temperature which is compatible with the propellant and the tank material further reducing the required gas quantity and storage system mass.

The ability to accurately control pressurant temperature at moderate temperature, the rate of temperature loss to the tank walls and propellant, especially cryogenics, are questions which must be dealt with as is the amount of contamination of the propellant due to condensable combustion products (water) in the warm pressurant gas.

Tests will be conducted with a variety of gas mixtures designed to produce pressurant temperatures from ambient (in other words just compensating for adiabatic expansion) up to temperatures which probably represent practical upper limits of gas temperature based upon tank materials (say 400 F). Since helium is widely used as a pressurant, tests will be conducted using both nitrogen and helium as pressurant gases.

Tests will be conducted with room temperature liquids such as water or alcohol and with inert cryogens such as liquid nitrogen. Tests will include initial pressurization, hold under pressure, and expulsion. An existing 1.2 cubic foot tank will be used for all planned pressurization tests.