NASA Technical Memorandum 86999

Space Station Propulsion: The Advanced Development Program at Lewis

(NASA-TM-86999) SPACE STATION PROPULSION:
THE ADVANCED DEVELOPMENT PROGRAM AT LEWIS
(NASA) 14 p HC A02/MF A01 CSCL 21H

N85-25366

Unclas
G3/20 21139

Robert E. Jones
Lewis Research Center
Cleveland, Ohio

Prepared for the
Twenty-first Joint Propulsion Conference
sponsored by the AIAA, SAE, and ASME
Monterey, California, July 8–10, 1985

SPACE STATION PROPULSION: THE ADVANCED DEVELOPMENT PROGRAM AT LEWIS

Robert E. Jones
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

Abstract

Before the Space Station will become a reality, many technical problems must be solved. A Reference Configuration has been established for the Initial Operating Capability (IOC) station. That reference configuration has assumed hydrazine fueled thrusters as the propulsion system. This has been done to establish costing and as a reference for comparison when other propulsion systems are considered.

An integral part of the plan to develop the Space Station is the Advanced Development Program. The objective of this program is "to provide advanced technology alternatives for the initial and evolutionary Space Station which optimize the system's functional characteristics in terms of performance, cost, and utilization." The Marshall Space Flight Center has been designated as the lead center for Space Station propulsion and will be involved in the fabrication and performance testing of various propulsion systems. The Lewis Research Center will directly support Marshall by conducting propulsion system component research and supplying thrusters for the Marshall test bed programs. This paper presents the portion of the Advanced Development Program that is concerned with auxiliary propulsion and, specifically, highlights and discusses research and programmatic activities conducted by the Lewis Research Center.

E-2544

Introduction

The purpose of this paper is to present the NASA Lewis portion, of the Advanced Development Program, related to propulsion. The planned program will be presented in detail and the status of the various programmatic efforts and procurements will be addressed.

An integral part of the plan to develop the Space Station is the Advanced Development Program. This program has the objective to "provide technology alternatives for the initial and the evolutionary Space Station which optimize the system's functional characteristics in terms of performance, cost, and utilization,".[1] A reference configuration has been established for the Space Station,[2] and has selected a high thrust (~50 lbf) propulsion system using hydrazine as the propellant. The Advanced Development Program has as its charter the investigation, evaluation, and development of viable propulsion options for initial or future use on the Space Station. The Marshall Space Flight Center has been given the lead responsibility for propulsion and will be actively managing the entire propulsion effort. MSFC will have primary responsibility for the conduct of propulsion system studies and the design, development, and evaluation of the propulsion system test bed. The Lewis Research Center is working closely with the Marshall Center and the focus of our efforts is in the area of component technology.

The objectives of the research conducted by NASA Lewis are twofold. First; to provide the technology for a propulsion system consisting of both a high and low thrust capability that can be employed on the IOC Space Station. Secondly; to provide prototype thrusters and components of the propulsion system to the Marshall Space Flight Center for systems testing in the appropriate test beds.

The schedule for the Advanced Development Program and the Space Station is shown in Fig. 1. The Phase B contracts for the Space Station are shown along with two intermediate milestones. The Phase B effort consists of the design definition of the entire Space Station; propulsion being just one of the many areas being studied. The MSFC Test Bed Program is indicated as well as the Component Technology Program being conducted at Lewis. Several critical dates are indicated in this schedule. The first in the Phase B Systems Requirements Review (SRR), scheduled for March 1986. The goal of the Lewis plan is to demonstrate, insofar as is possible, the technology readiness of propulsion options by the time of that review. This is an extremely short time period that provides a difficult challenge. By the time of the System Design Review (SDR), in December 1986, the plan is to provide documented data on the ability of the optional propulsion systems to meet the Space Station goals of performance and life.

Propulsion Component Technology Program

Space Station Propulsion System Options

In October of 1985, it was decided that the propulsion system options that would be pursued in the Advanced Development Program were the following: first, the propulsion system would consist of high thrust (25 to 50 lbf) and low thrust (0.050 lbf) thrusters. The propellants for the high thrust system would be hydrogen or hydrogen/oxygen, utilized in conventional warm gas thrusters or chemical rockets. The low thrust system would be resistojets, using hydrogen gas or other gases that might be available from the Environmental Control and Life Support System (ECLSS). These gases might be mixtures of CO_2 and/or CH_4 and possibly water. The ability of the resistojet to utilize a variety of propellants makes its use on Space Station especially attractive. The decision was also made that all of these propellants would be gaseous. No liquid cryogens would be considered at this time for use on the IOC station. The use of liquid cryogens on evolved versions of the Space Station will depend on the results of many study efforts.

This decision then pointed toward the conceptual design of a system to the extent that likely components could be identified and technology efforts planned.

The conceptual design of such a system is shown in Fig. 2. Propellants, hydrogen and oxygen are stored as supercritical fluids in tanks similar to the PRSA tasks (Power Reactant Storage Assembly) presently employed on the Space Shuttle. Propellants withdrawn from these tanks would be gassified and stored in a low pressure accumulator. From there, the propellant would be pressurized by a small compressor (pressure ratio of 4 for H_2) and stored for ready use in the high pressure accumulator. When needed, the propellants would be distributed as high pressure gas to the thrusters. The pressure would be reduced to the desired working level by a regulator ahead of each thruster. A heat exchanger is shown in the system for the H_2 thruster as it may be desirable to increase the temperature of the propellant. This design is only conceptual and in no way represents the detail or redundancy required for the final system. It does, however, identify the major and likely components of such a gaseous propellant system.

Table I presents a listing of the Space Station propulsion requirements, the available technologies, and how both impact the requirements of the propulsion system. Paramount in importance are life, low maintenance, and simplicity. Performance, namely maximum specific impulse, is not nearly as important as the other requirements. As the Space Station grows in size and in mission difficulty, the relative importance of propulsion system performance should increase.

The program plans that have been formulated by the Marshall and Lewis Centers are addressing the technology status of such propulsion systems. The remainder of this paper discusses the Lewis plans for component technology.

High Thrust Propulsion System

The high thrust propulsion system is required to accomplish a variety of missions on Space Station. These are listed in Table II which gives the total impulse and the amount of propellant required for a warm gas H_2 thruster and an H/O rocket for the IOC station as defined in Ref. 2. The specific impulse for the hydrogen gas thruster was set at 258 sec for 540 °R gas. The specific impulse for the H/O thruster would be approximately 410 sec at an O/F ratio of 4 to 1. The functions that are categorized by "Resupply" are expected to be used every 90 days which is the initial resupply period. The propulsion system would be required to store sufficient propellant for ready use to handle at least one docking of the Space Shuttle. The propulsion functions identified as "contingency" would be performed infrequently. For instance, altitude transfer could be planned for and sufficient propellant stored well in advance of its actual need. Collision avoidance and attitude control are functions that might be utilized on an emergency basis. Contingency propellant must be available for such use.

The technology required for the warm gas hydrogen thruster resides primarily in the valve and the heat exchanger. There are no life related problems associated with the thruster itself. Valve technology will be a part of the Lewis program.

Hydrogen/Oxygen Rockets

The major emphasis of the work at Lewis is on the H/O rocket thruster. The technology goal is to achieve of life for such thrusters that attains or exceeds $2\text{x}10^6$ lbf-sec of total impulse. In real terms this would translate into approximately 4 to 10 yr of actual service life on the Space Station. The actual life, of course, is primarily dependent upon the propulsion scenario selected. If H/O thrusters are used on a regular basis for reboost (to counter altitude loss due to drag) then the $2\text{x}10^6$ lbf-sec would be obtained on each of four thrusters in about 4 yr. The addition of other high total impulse functions, such as altitude transfer would reduce the absolute thruster lifetime still further. Conversely, if resistojets were used to provide station drag make-up, then the thrusters would be primarily used for attitude control and a life in excess of 10 yr should be feasible. Contracts have been awarded to the Aerojet Tech Systems and Bell Aerospace companies. Each contractor is to design, build, and test small thrusters. Plans are to build three thrusters, one each for tests at MSFC and Lewis and one to remain with the company for extended life testing. The purpose of these tests will be to document thruster performance while attempting to attain a total-impulse of $2\text{x}10^6$ lbf-sec. Sufficient instrumentation will be included on each thruster to monitor pressures and temperatures as a means of identifying any "health" problems during these extended tests. In addition to the contracted efforts, extensive vacuum performance tests will be conducted at Lewis on a prototype IR D thruster provided to this program by Rocketdyne. All three thrusters will be operated on gaseous hydrogen and oxygen. Table III compares the major performance goals and design features of each thruster. The thrusters are very similar in size, thrust level, and chamber pressure. The Aerojet thruster is fully regeneratively cooled and has an area ratio of 100. Figure 3 is a photograph of a similar design aerojet thruster installed in a test stand. Figure 4 is a cross sectioned sketch of a Bell Aerospace thruster that employs the design concept that will be used on the 50 lbf thruster.

The present state-of-the-art in small rocket engines is summarized in Table IV along with the goals of this effort. Small thrusters have been built and operated at thrust levels from one-tenth to 1500 lbf. Demonstrated life is only a few hours, though total impulse at higher thrust levels does exceed the program goals. Demonstrated cyclic life also exceeds the nominal program goal. The present program is expected to show that all of these goals can be obtained or exceeded with present technology and that extensive research and development programs will not be required to provide viable thrusters for the Space Station.

Gas Compressor

A contract program will shortly begin to develop small gas compressors for hydrogen and oxygen. Such a compressor would be employed to compress gases for storage in the high pressure accumulator. Table V gives the expected characteristics required of such a compressor. The program plan will provide for the design, fabrication, and testing of two each hydrogen and oxygen compressors. One compressor set will be provided to the MSFC Test Bed and the other set will be extensively tested by the Contractor and later at Lewis. The design of these compressors are not expected to present any unusual technology challenges. The flow rates are low as there will be ample time on the Space Station to repressurize the high pressure accumulators. Since the propulsion use rate is low the duty cycle of the compressors will also be low.

Additional System Components

The remaining system components that are planned for study in the Lewis program are valves, regulators, and drive motors. High response valves for the control of gaseous propellants could be the life-limiting component in the system. A program is planned to examine the state of valve technology for this application and to address any area that may cause life to be limited. A gas regulator is required to reduce the pressure from the high pressure accumulator and to assure constant gas feed pressure to the thrusters. In addition to life, the problem here may be in obtaining the desired level of control accuracy in the delivered pressure. Drive motors for the gas compressors will also be investigated. The electric drive motors must be designed to operate on the voltage and frequency supplied by the Space Station power bus. Component efficiency is important here as the power level available may be constrained and heat rejection from the motor must be considered. The possibility of low duty cycles though, will ameliorate these design problems.

Low-Thrust Propulsion System

The low-thrust propulsion system consists of the multipropellant resistojet and its ancillary components. The low thrust of the resistojet allows its use for a variety of propulsion tasks with negligible impact on the operation of the Station.[3,4] Additionally, use of resistojets at the 50 mlbf level, or less, can easily cancel drag forces and permit the Space Station to maintain a near constant altitude. From the studies being conducted for us by the Jet Propulsion Laboratory, we have estimated the 90 day drag made total-impulse of the IOC Space Station to be 222 000 lbf-sec in 1992. Four 56 mlbf resistojets can provide this impulse operating on only a 12.5 percent duty-cycle. If the specific impulse is assumed to be 250 sec then 220 lb of propellant are required. For the growth station, again in the worst solar year, the total impulse requirement increases to $2.84\ 10^5$ lbf-sec. The duty cycle for the resistojet propulsion system increases to 16.1 percent and the required propellant to 285 lbs per each 90 days.

The primary propellant for the resistojet is hydrogen. However, the ability of the resistojet to utilize a variety of possible propellants means that its use can be integrated with other systems on the Space Station that may have excess or waste gas products.

Multipropellant Resistojet

The approach that has been taken to the resistojet has been to trade performance for long life. The resistojet will be constructed from grain-stabilized platinum, and a maximum heater temperature of 1400 °C has been selected. The compatability of the platinum with the various propellants is of paramount importance if long lifetimes are to be achieved. Table VI presents the technology status and goals of the resistojet effort. The life goal of 10 000 hr is especially challenging, though believed feasible due to the 1400 °C limit that has been placed on heater temperature. Resistojets that are presently employed on satellites such as Intelsat V and Satcom typically have total operational lifetimes of about 200 hr or less. For these resistojets, heater temperatures average about 1900 °C. Resistojets that had a 10 000 hr life capability would probably exhibit a useful lifetime on the Space Station of approximately 10 yr, again depending on the duty cycle employed and to some extent the propellant used.

NASA Lewis has contracted with Rocketdyne and their subcontractor, Technion, to design and fabricate the resistojets for this program. Figure 5 is a photograph of such a resistojet thruster. This particular thruster concept features a clad platinum heater coil surrounded by a platinum feed tube. Provision will be made for the thruster to fail operational by encapsulating the heater assembly. The predicted performance of this thruster is given in Table VII for the various propellants that may be used on Space Station. Included in this list are hydrazine decomposition gases, N_2 and H_2. The thought here is that if hydrazine remains the propellant of choice for the Space Station, then resistojets would still be a viable low-thrust propulsion system. The resistojets in this mode would receive hydrazine gas products from an accumulator, thus requiring only one catalyst bed for hydrazine decomposition. As the table indicates, the thrust level varies from 32 mlbf for hydrogen fuel to 91 mlbf for CO_2 and CO_2/CH_4 mixtures.

Control and Power Unit

An integral part of any successful resistojet propulsion system is the Control and power unit. The particular unit that will be utilized has been developed in-house and is used extensively for in-house tests of resistojets. The unit developed at Lewis has many unique features not found in present-day commercial systems. The power and control unit has been designed to sense and control the resistance of the resistojet heater element. This unique capability means that heavier, longer life (low resistance) heaters can be utilized. Resistance control means that the current surge during turn-on is controlled. In a similar manner the use of a blow-down fuel system and bus voltage changes are easily accommodated. These features are crucial if the heater temperature (lifetime) - performance trade is to be truly effective. Finally, the spacecraft ground can be isolated from the resistojet heater element. This has been achieved with a sizeable parts reduction over that of conventional control and power units. Figure 6 is a photograph of the breadboard model unit. During the course of the resistojet test program, the performance and life characteristics of these control units will also be monitored and documented.

Propellant Management System

As a part of the contract to develop and provide resistojets to Lewis and MSFC, Rocketdyne is also to supply a propellant management system to Lewis for use in the in-house life test program. The propellant supply and delivery system is shown diagrammatically in Fig. 7. This system is schematically similar to the hydrogen/oxygen system shown in Fig. 2. Again a low pressure and a high pressure accumulator will be used with a small compressor required to transfer the gases. Unlike the H/O system the gases in the low pressure accumulator may be at very low pressure, 1 to 30 psia. Consequently a multistage compressor would be required to maintain 300 psia in the high pressure accumulator. Also inducated in this figure are the locations in the system where various propellants might be supplied.

Schedule

The programmatic efforts that have been described above are the major activities that will be managed by the Lewis Research Center in this phase of the Advanced Development Program. It is our goal to show that the technology for hydrogen/oxygen and resistojet thrusters is mature, and that selection of these systems for use on the IOC and evolved versions of the Space Station will not give rise to extensive and expensive development efforts.

Figure 8 shows the schedule that has been developed for this work. The Phase B program effort is shown to provide a reference point for the programs being conducted at MSFC and Lewis. As before, the major Space Station milestones are indicated. The Marshall Test Bed program is shown and below that the various programs described in this paper. At the present time the contract efforts under way include H/O thrust chamber technology with Aerojet Tech Systems and Bell Aerospace companies. A total impulse of 500 000 lbf-sec is planned to be demonstrated by Aerojet by October 1, and by Bell near January 1. The goal of 2×10^6 lbf-sec should be attained in February and April by each company respectively.

The resistojet contract with Rocketdyne will supply thrusters for use on the Marshall Test Bed and for in-house characterization and life tests by March 1986. The delivery of other components will vary during CY 1986 and 1987, and as these components become available they will be supplied to Marshall for integration into the Test Bed. In-house research efforts with the Rocketdyne prototype H/O thruster will provide characterization data and some limited life-test data by December 1985. Laboratory models of the resistojet will also be undergoing in-house life tests during the later months of the year. Our goal is to have nearly 3000 hr of continuous operation completed by the end of the year.

Concluding Remarks

Before the end of the Phase B contracts our plan is to show, in as conclusive a manner as possible, the technology readiness of the technology of H/O and resistojet thrusters. We will also be in a position to identify any areas in the technology where additional research and development is required. The programs that have been planned and are presently underway are addressing the major components in a gaseous propellant system and are attempting to demonstrate the life capability of each component.

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1. Space Station Task Force; "Space Station Program Description Document, Book 1, Introduction and Summary," NASA TM-86652, March 1984.

2. Anon; "Space Station Reference Configuration Description," NASA JSC-19989, August 1984.

3. Donovan, R.M., Sovey, J.S. and Hannum, N.B.; "Space Station Propulsion Analysis Study," NASA TM-83715, AIAA-84-1326, presented at AIAA Twentieth Joint Propulsion Conference, Cincinnati, Ohio, June 11-13, 1984.

4. Mirtich, Michael J., "Resistojet Propulsion for Large Spacecraft Systems," NASA TM-83489, November 1982.

TABLE 1. - FACTORS INFLUENCING PROPULSION SYSTEM DESIGN

Space station propulsion requirements ⇨	Propulsion system requirements	⇦ Technologies
ΔV propulsion	Increased life	Stable, compatible materials
RCS propulsion Propellant reserve	Minimum maintenance	Fabrication
Fail OPS/fail safe Selective inhibit	Simplicity	Propellant management
		Power and control
Limited EVA	Multipropellant adaptability	Pump performance
Simple maintenance		
Accept advanced technologies (evolvable)	Simple interfaces	Long-life design (life prediction)
90 day STS resupply		Diagnostics
	Health monitoring	
Operational during maintenance	Low contamination	
Clean surfaces	Performance	

TABLE 2. - SPACE STATION PROPULSION REQUIREMENTS

Propulsion Function	Total Impulse, lbf-sec	Propellant weight lb		Mode
		H_2 at 540 °R I_{sp} = 258 sec	H/O I_{sp} = 410 sec	
Translational requirements				
Collision avoidance Δv = 5 ft/sec	61 500	238	150	Contingency
Altitude transfer 20 nmi	831 000	3 221	2 027	Contingency
Reboost 90 days at 270 nmi	483 000	1 872	1 178	Resupply
Rotational requirements				
Altitude control 24 days-2 axis only	147 000	570	359	Contingency
Orbiter capture	1 700	7	4	Resupply
Orbiter berthing	17 000	66	41	Resupply
Module berthing	7 300	28	18	Resupply

TABLE 3. - H/O THRUSTER COMPARISON

	Rocketdyne	Aerojet	Bell
Thrust, lbf	25	25	50
Specific impulse, sec	415	440	410
Area ratio	30	100	40
Chamber pressure, psia	100	75	75
Throat diameter, in	0.42	0.5	0.69
Exit diameter, in	2.3	5	4.39
Type	Regen cooled	Regen cooled	Regen-film cooled

TABLE 4. - STATE-OF-THE-ART FOR SMALL H/O THRUSTERS

Technology	Status	Goal
• Thrust Level	0.1 to 1500 lb	25 to 100 lb
• Total Impulse	72 000 lbf-sec (5 lbf for 4 hr) 36×10^6 lbf-sec (5000 lbf for 2 hr)	2×10^6 lb/sec
• Cycles	50 000 demonstrated	15 000

TABLE 5. - PROPOSED COMPRESSOR CHARACTERISTICS

Propellant	Source	Supply		Discharge		Flow rate, lbs/day
		Pressure (psia)	Temperature (°R)	Pressure (psia)	Temperature (°R)	
Hydrogen	• PRSA (LPA)	250	50 to 450	1000	670	11
	• Water electrolysis	250	450	1000	670	1
	• OTV tank boiloff	∼10	200	250	412	22
Oxygen	• PRSA (LPA)	900	450	1000	464	43
	• Water electrolysis	250	450	1000	683	8
	• OTV tank boiloff	∼10	300	250	642	13
CO_2	• ECLSS	30	530	300	875	14.6
CH_4	• ECLSS	15	530	300	980	8

TABLE 6. - STATE OF THE ART FOR RESISTOJETS

Technology	Status	Goals
• Stable, compatible materials	Grain stabilized platinum SOA	Verify propellant compatibility at 1300 to 1400 °C
• Fabrication	FAB SOA	Verify braze, weld integrity
• Long-life design	Verified 1000 hr component life	Three year changeout; 10 000 hr life
• Propellant management	Components for gas fed systems SOA	Specify interfaces and long life components
• Control and power	SOA systems for 28 to 40 V buss	Tech ready converter for ∼200 V buss

TABLE 7. - PREDICTED PERFORMANCE OF LONG-LIFE MULTIPROPELLANT RESISTOJET

Propellant	Power, W	Isp, sec	Thrust, mlbf
Hydrogen	500	500	32
CO_2		130	91
CO_2/CH_4		160	91
H_2O		200	83
N_2H_4 (gas production)		250	50

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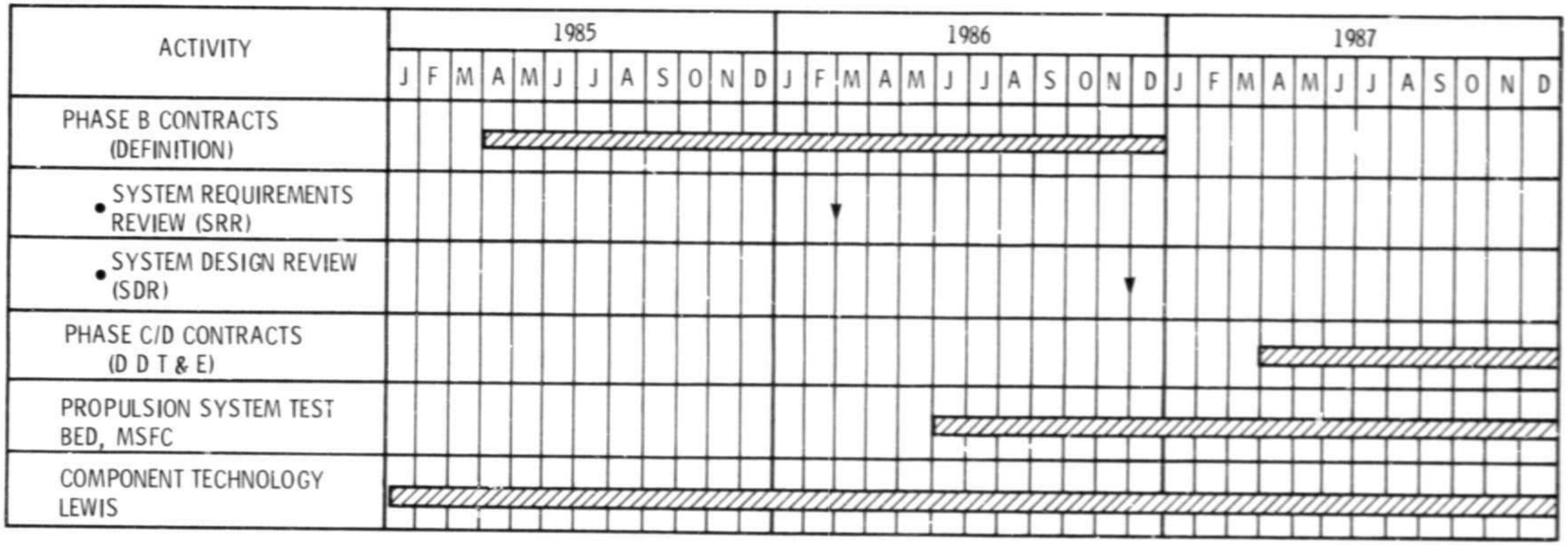

Figure 1. - Space Station Propulsion System Schedule.

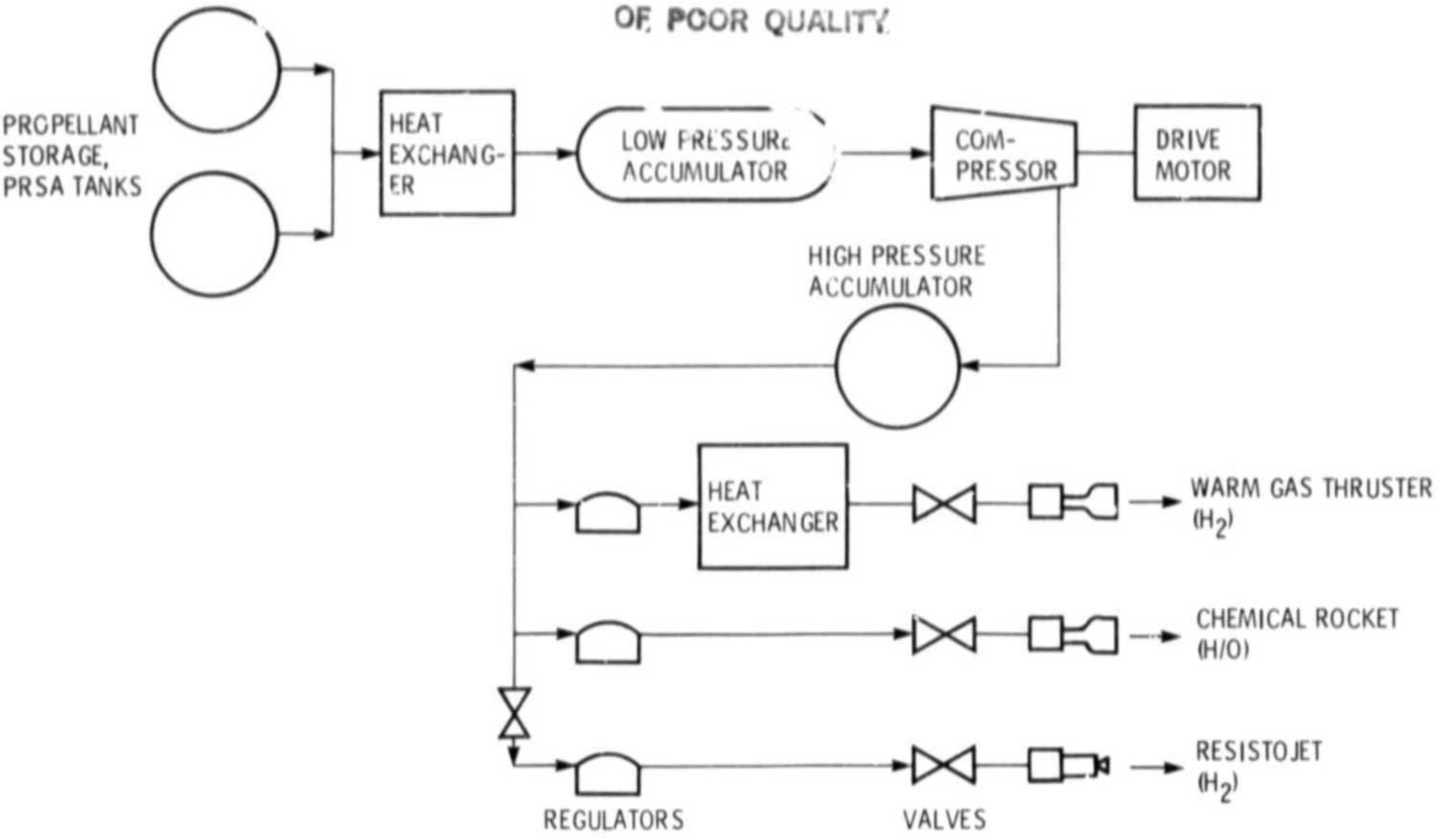

Figure 2. - Conceptual design of Gaseous H/O Propellant System.

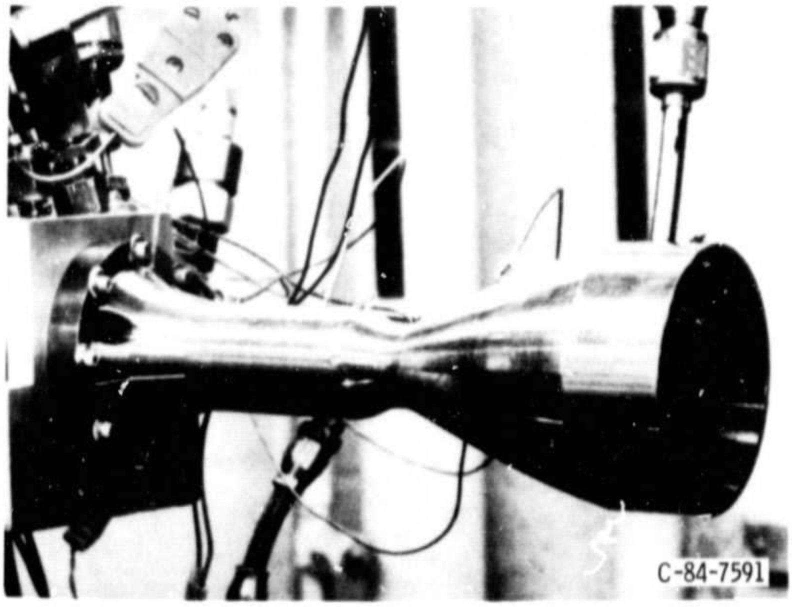

Figure 3. - Aerojet 25 lbf regeneratively cooled thruster.

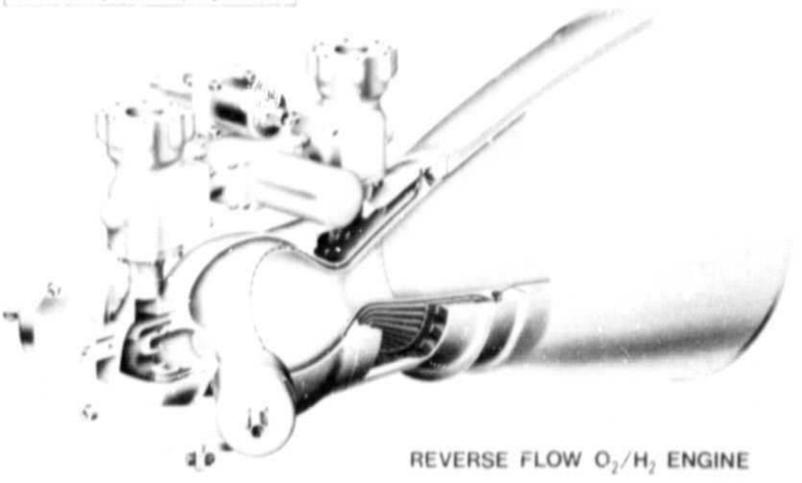

Figure 4. - Cutaway sketch of 50 lbf Bell Aerospace thruster.

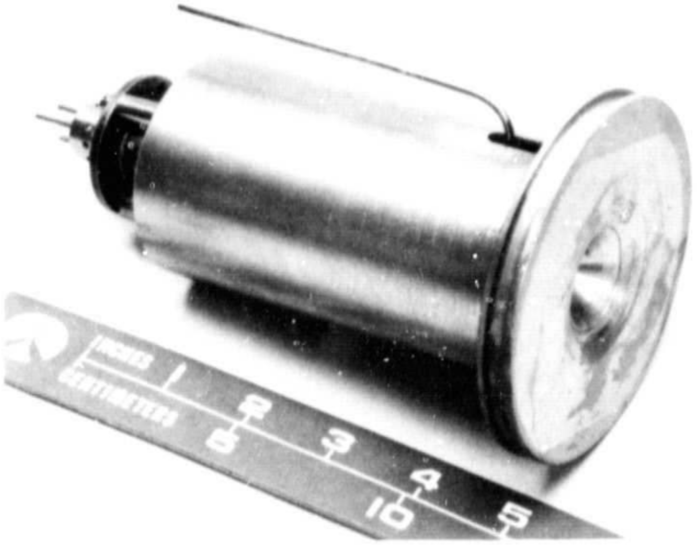

Figure 5. - Rocketdyne resistojet thruster.

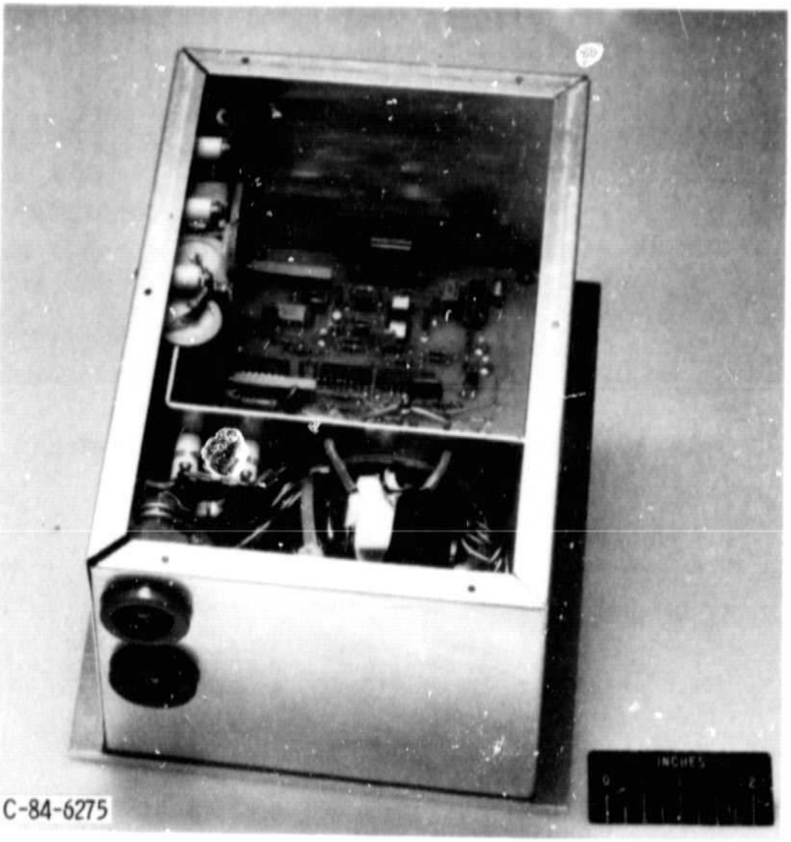

Figure 6. - Breadboard control and power unit.

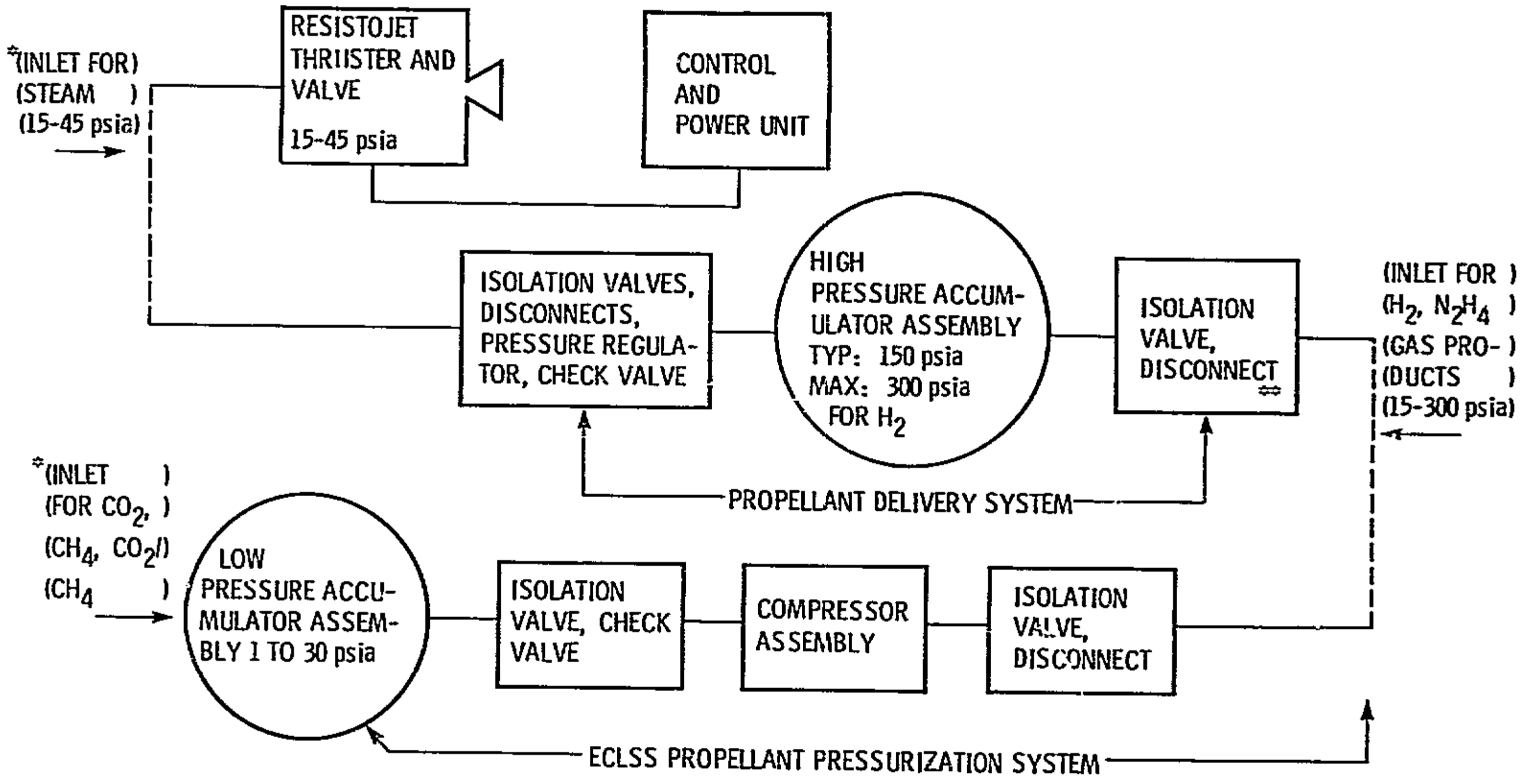

Figure 7. - Resistojet Propellant Supply System.

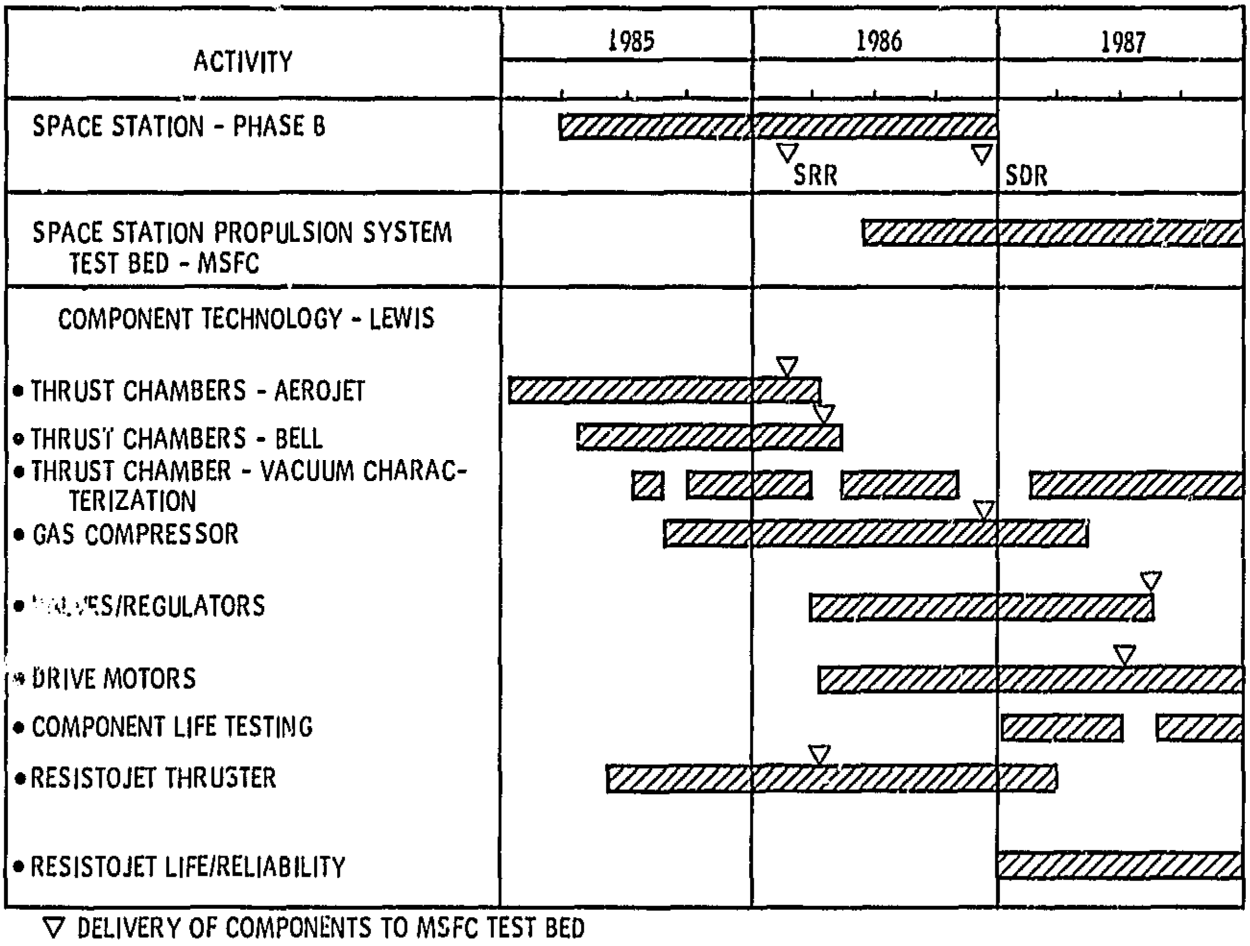

Figure 8. - Advanced Development Program Schedule.

1. Report No.
NASA TM-86999

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Space Station Propulsion: The Advanced Development Program at Lewis

5. Report Date

6. Performing Organization Code
482-50-22

7. Author(s)
Robert E. Jones

8. Performing Organization Report No.
E-2544

10. Work Unit No.

9. Performing Organization Name and Address
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

11. Contract or Grant No.

13. Type of Report and Period Covered
Technical Memorandum

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, D.C. 21546

14. Sponsoring Agency Code

15. Supplementary Notes
Prepared for the Twenty-first Joint Propulsion Conference, cosponsored by the AIAA, SAE, and ASME, Monterey, California, July 8-10, 1985.

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17. Key Words (Suggested by Author(s))
Space Station
Propulsion
Resistojet advanced development program

18. Distribution Statement
Unclassified - unlimited
STAR Category 20

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of pages

22. Price*

*For sale by the National Technical Information Service, Springfield, Virginia 22161