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Abstract

Space platforms are planned for the early 1990's which can be serviced by the Shuttle Orbiter, and at a later date, via the Space Station. Man-tended platforms are smaller than the manned Space Station and have significantly lower requirements for propulsion total impulse. Nonetheless, the basic requirements of integration with the Space Transportation System, altitude maintenance, reboost, attitude control, and collision avoidance must be met. The selection of a propulsion system for the man-tended platform has been influenced by the planned use of resistojets for drag make-up on the manned Space Station. For that application, a resistojet has been designed that is capable of operation with a wide variety of propellants, including water. This paper discusses the reasons for selection of water as the propellant, performance of resistojets using water, and describes the man-tended platform and its mission requirements.

Introduction

The purpose of this paper is to present a novel design for a man-tended platform and the design and integration of a resistojet propulsion system. These man-tended space platforms will be serviced initially by the Shuttle Orbiter and at a later date from the Space Station. This paper presents the design of one such man-tended platform, its various subsystems, and the use of a resistojet using water as the propellant to achieve all of the propulsion required for this platform.

Many studies have been conducted in the past concerned with propulsion on small, man-tended platforms or Space Stations.[1,2] These studies have examined the use of the low-thrust resistojet as the means to provide the functions of orbit keeping and control moment gyro (CMG) desaturation. These studies have shown that there are operational advantages for a low thrust propulsion system, especially one that has the capability to utilize the wastes from various subsystems and attendant experiments or payloads.[3,4] A resistojet has been designed which has demonstrated the ability to operate for long periods of time on a wide variety of propellants.[5-7] The present Space Station program has baselined that resistojet for the low-thrust propulsion system.

Recently, Space Industries, Inc. of Houston, Texas has designed a man-tended space platform that is planned to be in orbit in the early 1990's. This will be a man-tended facility, launched and serviced by the Space Shuttle Orbiter and permanently located in low-Earth orbit. Based on the studies that were done previously, the resistojet has been selected to be the prime propulsion system for this platform.

This paper will present reasons for the selection of water as the propellant for the propulsion system, describe the operation of the man-tended platform and its propulsion requirements, and review the status of long-life resistojets and present their expected performance. A possible propulsion system will be presented that includes propellant storage, distribution, and power processing.

Background

Resistojets have been baselined for the Space Station propulsion system to provide drag makeup and reaction control.[6,8] The multipropellant resistojet can provide low levels of thrust while disposing of a variety of fluids expected to be present in excess quantities on the Space Station core. Using waste fluids for propulsion results in a significant cost saving associated with propellant resupply and waste fluid disposal by return from orbit. The basic technology is in place to operate multipropellant resistojets for periods in excess of 10^4 hr on hydrogen, methane, steam, air, carbon dioxide, and inert gases.[5,9] Propellants for the current Space Station are derived from the Environmental Control and Life Support System (ECLSS), Materials Technology Laboratories (MTL), attached payloads, or the Shuttle Orbiter.

In the 1965-70 period, NASA pursued development of a Manned Orbital Research Laboratory (MORL) to support Earth surveys, basic sciences, and the technology for space systems and operations. Figure 1 is a sketch of the MORL. Eight multipropellant resistojet modules were to provide the laboratory orbit keeping and control moment gyro desaturation functions. The selected propellants were carbon dioxide, methane, and steam. Thrust levels per thruster were about 120 mN at the resistojet heater power level of 100 to 150 W. Table 1 itemizes some of the subassemblies that comprised the resistojet module. In addition to the thrusters, power controllers, flow controls, and propellant storage and distribution were also provided.

The selection of the biowaste resistojet system for the MORL was the result of detailed system trade studies.[1,2] The resistojet system was selected because it used excess ECLSS effluents, provided near zero gravity environment, minimized external contamination, and was adaptable to changing mission requirements. In addition to trade studies, a resistojet system study defined the thruster subassemblies and the biowaste storage feed systems, thus providing direction for subsequent system development and qualification.[3,4] A ground test demonstration of a resistojet propellant management and control system was one of the basic elements of the MORL propulsion program. The storage and feed system test bed shown in Fig. 2 included compressors, pumps, a steam generator, and flow control elements capable of supplying propellant to the thruster module. Preliminary evaluation of basic components including thrusters, steam generator, pumps, and compressors was undertaken, but the system demonstration was not completed because the MORL program was terminated.

From 1984 through 1987, a propellant resistojet effort has been an integral part of the propulsion portion of the Advanced Development Program for the Space Station.[6] In 1986, the resistojet, along with high-thrust hydrogen-oxygen thrusters, was baselined as the Space Station propulsion system. These propulsion concepts were selected after extensive cost/trade analyses indicated significant savings in both life cycle costs and up and down weight logistics.[10,11] Preliminary studies were performed to define the design of a resistojet propulsion module, and how it might integrate with a candidate waste fluid management system.[8,12] The propulsion module consisted of two identical subassemblies, one of which is redundant, Fig. 3. Each subassembly consists of four multipropellant resistojets with flow control components, power controller, and a steam generator. The resistojet propulsion module would be located at the end of an extended boom, behind the Space Station common modules as illustrated in Fig. 4. In practice, the resistojets would be used to maintain the altitude of the Space Station. The operational duty cycle would depend markedly on the total-impulse requirements for each solar year and the amount of waste material to be expelled.

Propellant Selection

Water has been selected as the propellant for the resistojets on the man-tended space platform. This selection is a distinct departure from previous propellant choices for resistojets on free flying space systems. In the past, resistojets have primarily used hydrazine as the propellant because it represented the best compromise between performance in terms of specific impulse and storage and distribution. Resistojets for satellite applications using hydrazine propellant generally required relatively short operating lifetimes in terms of total-impulse. Maximum attained specific impulse was the primary requirement.

The propulsion requirements for space platforms in low-Earth orbit represent an entirely new set of criteria for the selection of the propulsion system. First, long operating lifetimes will be a dominant factor, so thrusters must be capable of achieving the desired levels of total impulse so as to minimize on-orbit replacement. Second, the propulsion system need not optimize specific impulse as total spacecraft weight is not as crucial a factor for platforms in low-Earth orbit as for high-altitude spacecraft. Third, the propellant should be non-toxic and safe to minimize impacts of handling, loading, storage, spillage, and contamination of surroundings. Fourth, it should be dense, to minimize tankage, and it should be readily available in the required purity. Finally, the propellant must be totally compatible with the thruster materials or the desired levels of life will not be obtained.

Water has been selected as the propellant for this man-tended platform. Water meets all of the requirements mentioned above and with suitable planning can be made available by utilizing water from environmental control systems, either on the Space Shuttle Orbiter or the platform itself. Such plans to utilize waste water have also been formulated for the manned Space Station.[6,8]

The disadvantages of using water are that it must be very pure and, like most standard propellants, it must be kept from freezing. Additional power must be supplied to vaporize the water either in the resistojet or in a separate steam generator. There are also two potential problems with water exhaust. Water vapor is a good absorber of electromagnetic emissions, and the plume from the resistojet could cause interference with certain observation experiments. Secondly, there is concern that some of the water (steam) might condense on spacecraft surfaces, particularly solar cell panels. Special attention must, therefore, be paid to the positioning of the resistojets and their operation to minimize plume impact. Plume studies are underway that will define both the extent of the plume from the resistojet and the size, shape and orientation of shields that can protect the platform.[6,13]

Thruster System Characteristics

The multipropellant resistojet adds electrical energy to the propellant through convective heating as the gas passes through the narrow heat exchanger passages. The heated gas is expelled through a nozzle designed primarily to minimize contamination of the Space Station and interfere minimally with optical observations. Heating the gases increases the specific impulse of the exhaust jet while also assuring that none of the propellant will condense in the plume.

The multipropellant resistojet proposed for use on the Space Station is shown in cross section in Fig. 5 and as a photograph in Fig. 6. This resistojet has been designed and built for NASA by Rocketdyne and Technion. The resistojet consists of a sheathed heater, heat exchanger, nozzle, and a radiation shield pack. These components are described in more detail in Table 2. The material selection and design of the heater were based on the use of platinum sheathed heaters in the commercial glass industry at temperatures up to 1400 °C. The heat exchanger, nozzle, and inner shields were constructed of grain-stabilized platinum for improved creep-rupture properties and compatibility with all propellants. Many potential propellants have been tested for compatibility with grain-stabilized platinum for periods of up to 2000 hr.[7] Grain-stabilized platinum tubes have been heated to 1400 °C in environments of hydrogen, nitrogen, steam, and carbon dioxide. Material lifetime limits were assumed to be a 10 percent mass loss. Based on these tests projected lifetimes range from 5 to 90 years of continuous usage, depending upon the type of propellant. Propellants containing methane or air will have to be operated at temperatures of 500 °C or less. At that temperature, methane will not degrade to produce carbon and the platinum-methane combination will yield a lifetime in excess of 10 years. Similarily, the oxygen in the air will react so slowly with platinum at 500 °C, that long lifetimes are assured.

Nominal input power to the resistojet is 500 W. The multichannel heat exchanger is both conductively and radiatively heated by the sheathed heater and the gas is convectively heated as it passes through the 36 milled channels of the heat exchanger. Detailed design criteria and fabrication methods are described in Ref. 5. Evaluations of the thruster performance were undertaken with eight propellants, including steam, at an inlet pressure of 28 N/cm^2 and a heater current maintained at 23 A. Table 3 presents the results obtained with each propellant. Thrust levels varied from 285 to 356 mN, depending on the propellant flow rate and power level. High and low values of specific impulse of 318 and 117 sec were obtained with hydrogen and argon, respectively. Since the heater current was fixed, the voltage, input power and resulting specific impulse are dependent on the propellant thermal properties.

Thruster performance with steam, at a fixed inlet pressure of 21 N/cm^2 is shown in Table 4. As the thruster heater power was changed from 73 to 692 W, the specific impulse increased from 115 to 184 sec. The thrust level with steam was about 230 mN. At a heater power of 426 W and a steam flow rate of 0.53 kg/hr, the temperature of the heater and gas near the nozzle throat are estimated to be 850 °C and 700 °C, respectively. Continuous operation of a thruster for one day would provide an impulse of 2×10^4 N-sec. and nearly 13 kg of water would be used. At these temperature levels, the operational lifetime of the heater and the resistojet itself would be in excess of 20 000 hr. Of greater concern is the question of water purity for such an extended period. Small levels of contaminants over an extended time could plug the resistojet nozzle or other flow passages. Extended testing with water, presently underway, will provide some information on the levels of deposits that might be expected.

The steam was supplied to the thruster from a laboratory type steam generator which required from 470 to 710 W of power during steady-state operation depending upon the water flow rate. The vaporizer design was similar to the device developed during the MORL program.[3] A cartridge heater was used to couple the energy to a heat exchanger filled with small copper pellets which provided a large surface area and tortuous path for the water/steam.

Figure 7 presents the thruster thermal response using carbon dioxide, which has a heat capacity close to that of steam, as the propellant. The thruster was preheated for 5 min before the flow was initiated. After the flow was begun, the inlet pressure reached 93 percent of its maximum value in 1 min. The thruster heater and heat exchanger reach about 90 percent of maximum temperature within 30 min. The variation in heater temperature over its total length is about 15 percent of the maximum temperature.[14] Since the average resistojet heater temperature is linearly related to its resistance, then the resistance can be effectively utilized as the primary control and health monitor.

Preliminary design studies have generated schematics of fluid management systems that might be used for the Space Station core or for free-flying platforms.[12] Figure 8 shows a typical water storage and feed system comprised of tanks, redundant latch valves, quick disconnects, pumps and gas generators. The figure shows only one propulsion module which contains a steam generator and four thrusters. The platform may require eight such modules to perform reaction control functions as well as drag makeup.[4] The propulsion module is designed with quick disconnects to facilitate on-orbit replacement.

One of the key components of the feed system is the steam generator. Vaporizers using cartridge heaters have been evaluated at Lewis Research Center and in the MORL preflight resistojet program.[3] The output steam temperature was sensed at the vaporizer outlet and power to the generator was controlled via the outlet temperature. During resistojet operation, a steam generator will require about 500 W to produce a flow rate that would yield 0.23 N of thrust. Waste heat from the platform might be used to heat the water propellant. While such heat has little impact on the resistojet efficiency. the use of the propellant as a heat sink can assist in the thermal control of the platform. With minor modifications, the engineering model thruster could accept water directly for boiling and superheating. The integration of the water boiler as an integral part of the resistojet should offer some significant advantages in the design and operation of a power processor. Design studies are being done to verify that such an integration would also simplify resistojet and heater construction.

Although some fluid system component development work will be required, many components such as valves, filters, water pumps, and quick disconnects are available from commercial sources and qualified for space flight. The four-thruster propulsion module has a component mass estimated to be about 17 kg based on the study of Ref. 12. Redundant steam generators could be provided with a mass penalty of less than 2 kg.

Simple power controllers for resistojets have been developed by RCA for satellites with a low-voltage, direct-current power bus.[15] Such controllers could also provide power to the water vaporizers. The solid state controller regulates the current flow to the heater using two banks of resistors in series with the resistojet heater. The controller's primary function is to avoid excessive current spikes at start-up. The resistor banks are switched out of the power circuit as the load comes to thermal equilibrium.

Another option is the switching regulator which has been developed for propulsion applications under NASA technology programs.* DC power is converted to a low-voltage, high-current pulse width modulated quasi-square wave by using a non-dissipative switching regulator. Regulators of this type have flown on spacecraft for the last two decades. The regulator matches the power bus to the heater as the resistance, in the case of the resistojet, changes by about a factor of three during the heat-up period. Nominal power level, efficiency, and mass of such a power switching regulator are 500 W, 93 percent, and 2.6 kg, respectively.

*Personal Communication, R.P. Gruber, NASA Lewis Research Center, Cleveland, Ohio, 1987.

Significant attention has been given to the development of the critical components for the resistojet propulsion and propellant management system. The thruster, power controller, and propellant feed system components are considered "technology ready." Further development is necessary to qualify such components for the man-tended platform flight program.

Man-Tended Platform

Description

The man-tended platform that has been proposed by Space Industries, Inc. is shown in Fig. 9. The proposed Industrial Space Facility (ISF) is a man-tended, free-flying platform that provides the required power, cooling, and support services for space-based activities. The platform is equipped with a docking system so that it can mate to the Shuttle Orbiter during resupply visits. The facility is designed to operate as an in-space research laboratory and multipurpose manufacturing facility. Materials processing and research are planned as well as the capability to serve as a systems test bed. Eventually, such platforms could operate in tandem with the Space Station, by providing special purpose building and production facilities. As presently conceived, the Shuttle Orbiter will visit the platform once every 4 or 6 months to resupply the facility and to recover any manufactured items.

The platform is roughly a cylinder, 10.7 m long and 4.42 m in diameter. The pressurized volume available for use is approximately 71 m^3. Power is supplied by two photovoltaic arrays mounted on either side of the facility module. The total array area is approximately 232 m^2, providing a maximum power level of 14 kW of which up to 11 kW will be available for users. Power storage also exists with batteries having the capacity to store and supply up to 30 kW/hr. Waste heat will be radiated to space through a 93 m^2 radiator. The total mass of the facility module and payloads is 14 844 kg. An additional 2565 kg of equipment is required to adapt the module to the Shuttle; the heaviest items being the Shuttle docking system and the retention fittings. Payload masses are presently estimated to be up to 4388 kg. Once in orbit, the platform would be resupplied by the Shuttle which would carry a fully loaded resupply module to the facility. The resupply module has a pressurized volume of 51 m^3 and would mate to the side of the ISF. The module carries the needed gases and liquids required for facility operation and altitude maintenance.

The principal systems on the facility module are the solar arrays, power storage and thermal systems already discussed. The propulsion system is the multipropellant resistojet using water as the primary propellant with air being available for pressurization and attitude control purposes. The guidance and control is obtained by augmented gravity gradient stabilization and reaction control wheels, with the resistojets providing desaturation as needed. The other component of the propulsion system is a cold gas attitude control system using air as the propellant. Other systems include communication which will be accommodated using the TDRSS satellite and navigation by GPS/ground update. User experiments and payloads will be accommodated within modular racks similar to those planned for the Space Station to assure future commonality.

The types of payloads to be accommodated are yet to be determined. Opportunities exist for many of the same kinds of user payloads that would be installed on the Space Station. Capability exists for a manufacturing facility, a storage facility, a research laboratory, and as a test bed for those experiments requiring low gravity and/or vacuum environment.

Orbital Operations

The Industrial Space Facility attempts to capitalize on the capabilities of the Space Shuttle Orbiter. While the final orbit altitude has not been selected, an attempt will be made to select that altitude that makes rendezvous with the Shuttle simple. It has been proposed that the rendezvous occur at an altitude of 296 km. This is a standard direct insertion orbit for the Shuttle Orbiter and provides the opportunity for an increased number of visits and simplifies flight planning.

Following rendezvous and resupply, the facility would be boosted to a higher orbit utilizing the water resistojets. The facility would then drift, slowly decreasing in altitude over a period of 4 to 6 months to the 296 km altitude, where scheduled resupply would occur. This mission profile is illustrated in Fig. 10. If a resupply is missed, or a longer period between resupply is desired, the facility has sufficient water on board to raise itself again to a higher orbit. Sufficient water is on board for a second rendezvous attempt. If the second attempt is missed, there is still sufficient propellant to place the facility into a safe, high orbit. This orbit is high enough so that resupply could be missed for 3 years. Operation in the normal, contingency, and emergency modes is illustrated in Fig. 11. As shown, the safe, 3-year orbit is obtained by raising the platform to an altitude of 478 km and orienting the ISF in a minimum drag attitude.

Propulsion System

The propulsion requirements for the Industrial Space Facility are listed in Table 5. These total-impulse estimates are given for each solar year assuming an initial launch date of 1992. This calculation is based on the NASA Standard Atmosphere mean values of density, the platform projected area of 47 m^2 and a drag coefficient value of 3.0. The total-impulse values are given for reboost and assume three reboosts per year. In 1992, the first reboost is for the platform alone. The second and third reboosts that year, and all subsequent years, are for the platform with the resupply module attached. The resupply module has a mass of 5450 kg. Also shown in Table 5 is the amount of water propellant required for the resistojets. This is a yearly estimate based on the performance of the resistojet from Table 4 and makes no accounting of the number of resupply visits that might occur within 1 year. These estimates assume that the platform is raised from the nominal 296 km resupply altitude to 363 km. altitude during the first year. An attempt has been made to account for the year-to-year variations in solar flux in the calculation. Thus, the final altitude, time per reboost, and the propellant required all vary over the projected 11-year cycle. Propellant mass requirements for attitude control, collision avoidance and contingencies have not been estimated, and are not included in this tabulation.

A typical reboost profile for the first year of operation is illustrated in Fig. 12. After resupply and man-tended operations are completed, the platform would be raised to an altitude of 363 km. Approximately 5.5/6 days of continuous resistojet operation are required at total thrust level of 1.66 N. Approximately 2500 W of power are required and 528 kg. of water would be expended as propellant.

Figure 13 is a schematic of the propulsion system showing the propellant storage and distribution system. Water propellant would be stored in bladder tanks, pressurized by the high-pressure air system and distributed to the four resistojet modules. Additional water is stored for contingency purposes and in emergency the high pressure air can also be utilized as propellant.

The power for the resistojet would be drawn directly from the photovoltaic array. Operation of resistojets on direct-current is very simple from the control standpoint. A power controller similar to the type used by RCA could be effective, as few parts are required.[15]

Concluding Remarks

The Industrial Space Facility proposed by Space Industries, Inc. presents a unique opportunity for the early deployment and use of the multipropellant resistojet as the propulsion system for a space platform. The acceptance of the resistojet concept by the Space Station and the preliminary work that has been accomplished, assure that the resistojet is "technology ready." Space Industries has taken a low-risk approach toward the propulsion system and no serious technical difficulties are foreseen in applying the resistojet to their platform. Information gathered and experience gained will be to great advantage in the development and integration of the resistojet propulsion for the Space Station.

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TABLE I. - SUBASSEMBLIES OF THE MORL RESISTOJET SYSTEM

- Thruster module
  - Four modules at each end
  - Four thrusters per module
  - Thrust level, 44.5 mN
  - Power level, 150/W
  - Automatic and manual control
- Flow control
  - Dual (backup) regulator for each propellant
  - Any propellant combination can be used
- Power control and distribution
  - Control of thruster firing
  - Select power/thrust level
  - Conditions power from 260 V bus
- CO_2/CH_4 collection and storage
  - Four, two-stage pumps
  - 50 W power; 8.2 kg/day pump capacity
  - Four tanks, 0.76 m diameter, 9.1 kg each (dry)
  - Two days storage capability
  - Separate or combined storage
- Water supplement
  - Two tanks, 0.61 m diameter, 8.2 kg each (dry)
  - 205 kg capacity
  - Biowaste C)$_2$ as pressurant

TABLE II. - MULTIPROPELLANT RESISTOJET COMPONENTS

- Heater
  - Platinum center conductor, Pt-10 percentage Rh, 1.6 mm diameter
  - Platinum sheath, grain stabilized Pt, 4 mm OD, 0.5 mm wall
  - Insulation, MgO, 0.7 mm thick
  - Length, 3.2 m, before coiling
- Heat exchanger
  - Platinum, grain stabilized, 36 channels, 0.5 mm wide, 1.3 mm deep, 18.8 cm long
- Insulation
  - 10 radiation shields
    - 5 - 0.025 mm thick platinum
    - 5 - 0.1 mm thick nickel
- Outer case
  - Inconel
- Maximum electrical operating parameters
  - Power, 500 W
  - Resistance, 0.95 Ω
  - Voltage, 22 V
  - Current, 23 A
- Weight
  - 3.64 kg including mounting plate
- Envelope
  - 9.65 cm diameter, 23.9 cm long (excluding mounting plate)

TABLE III. - RESISTOJET PERFORMANCE CHARACTERISTICS

[Chamber pressure = 28 N/cm^2, current = 23 A.]

Propellant	H_2	He	CH_4	Air	N_2	Ar	CO_2
Power, W	251	322	324	432	430	490	405
Thrust, mN	311	285	356	329	334	307	342
Specific impulse, sec	318	247	155	145	140	117	119

TABLE IV. - RESISTOJET PERFORMANCE WITH STEAM PROPELLANT

[Inlet pressure = 21 N/cm^2.]

Thruster power, W	Steam generator power, W	Mass flow rate, kg/hr	Thrust, mN	Specific impulse, sec
73	708	0.77	240	114
181	621	.64	220	126
280	627	.60	240	147
426	490	.53	230	159
692	466	.45	230	188

TABLE V. - PROPULSION REQUIREMENTS FOR THE MAN-TENDED PLATFORM

[Specific impulse = 152 sec, 3 reboosts per year.]

Year	Total impulse, reboost N-sec/yr	Final altitude, km	Time per reboost, days	Propellant mass, kg/yr
1992	2.16 E+06	363	5.5	1 450
1993	2.11 E+06	356	5.0	1 416
1994	1.87 E+06	350	4.5	1 254
1995	1.63 E+06	342	3.7	1 093
1996	1.45 E+06	336	3.3	973
1997	1.21 E+06	330	2.8	812
1998	1.03 E+06	325	2.4	691
1999	1.03 E+06	325	2.4	691
2000	1.21 E+06	330	2.8	812
2001	1.63 E+06	342	3.7	1 093
2002	1.99 E+06	354	4.7	1 334
2003	2.34 E+06	363	5.5	1 573
	1.97 E+07			13 192

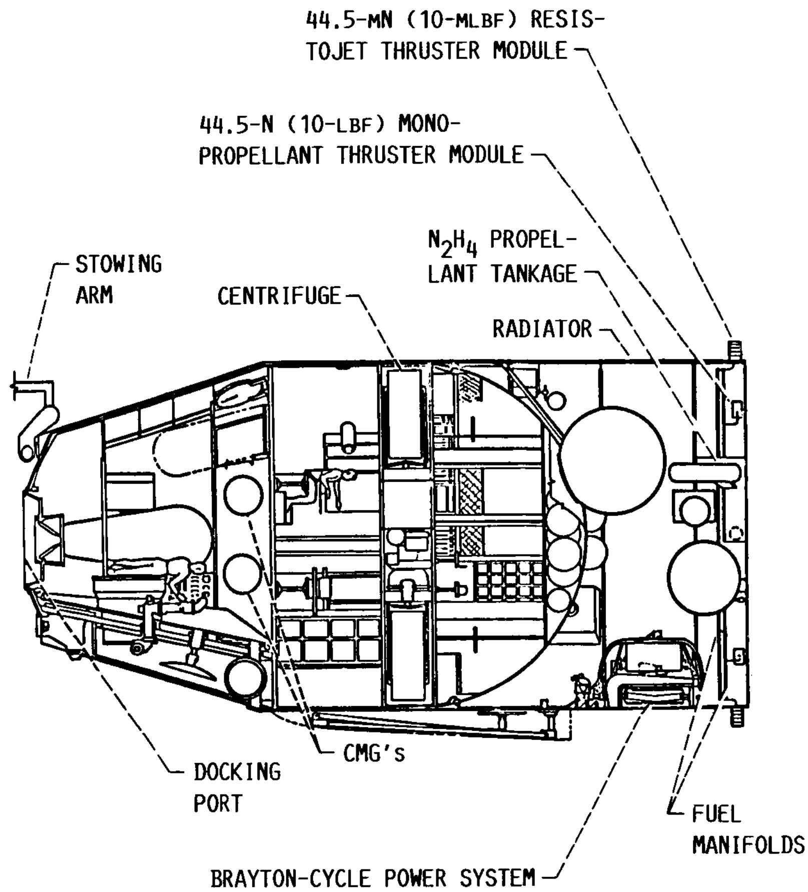

FIGURE 1. - SKETCH OF THE MANNED ORBITAL RESEARCH LABORATORY (MORL).

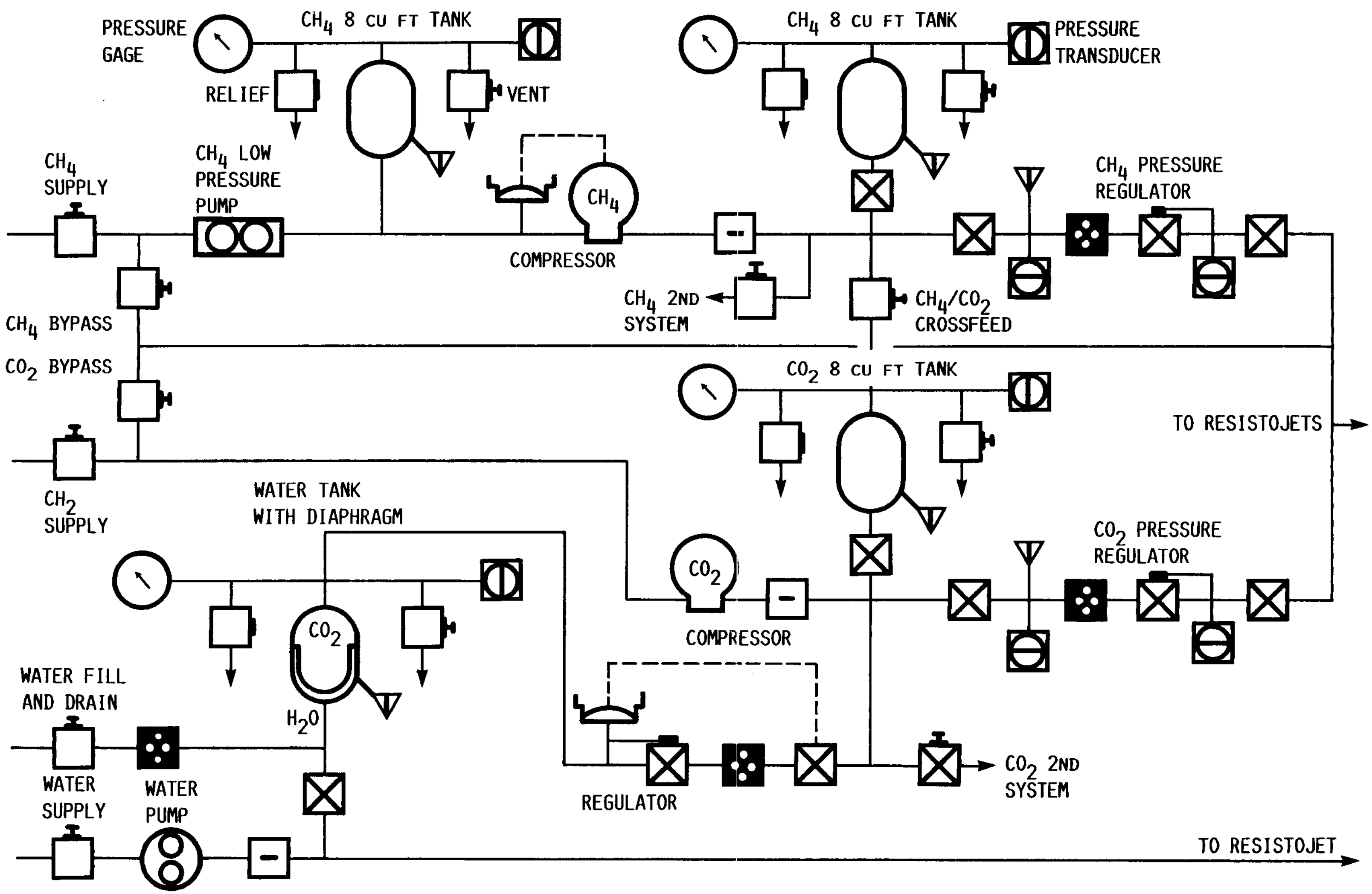

FIGURE 2. - MORL PROPELLANT COLLECTION STORAGE AND FEED SYSTEM ASSEMBLY TESTBED.

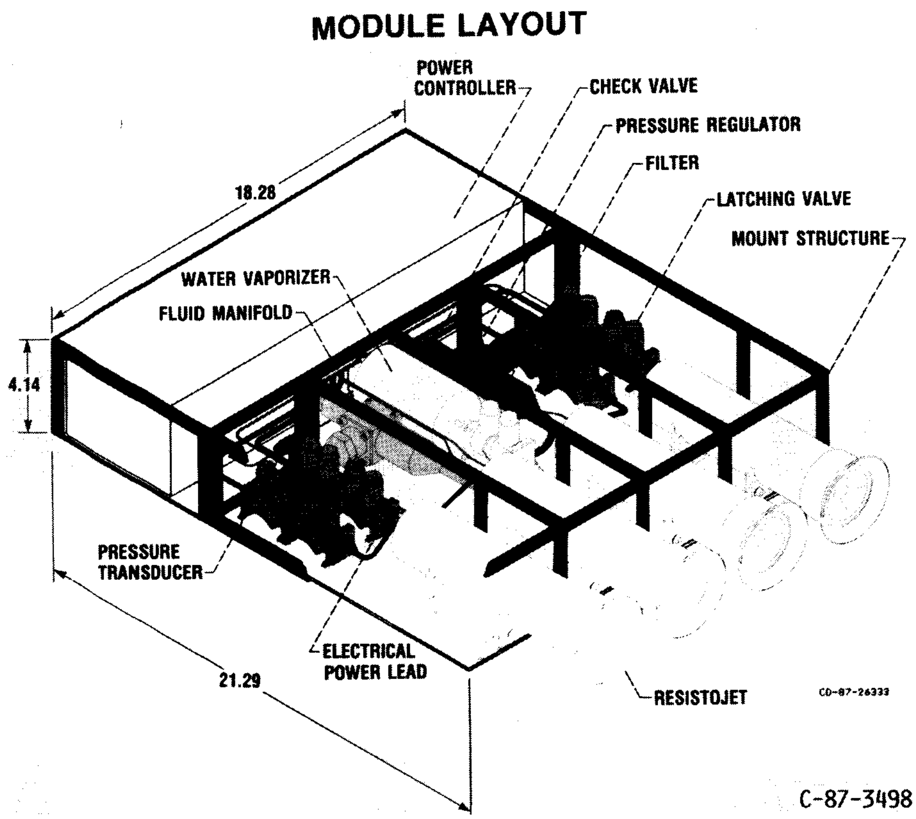

FIGURE 3. - RESISTOJET PROPULSION MODULE FOR THE SPACE STATION.

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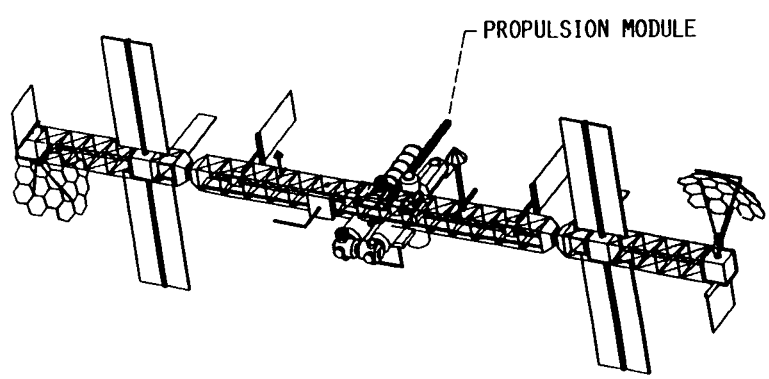

FIGURE 4. - RESISTOJET MODULE LOCATION ON BLOCK 1 SPACE STATION.

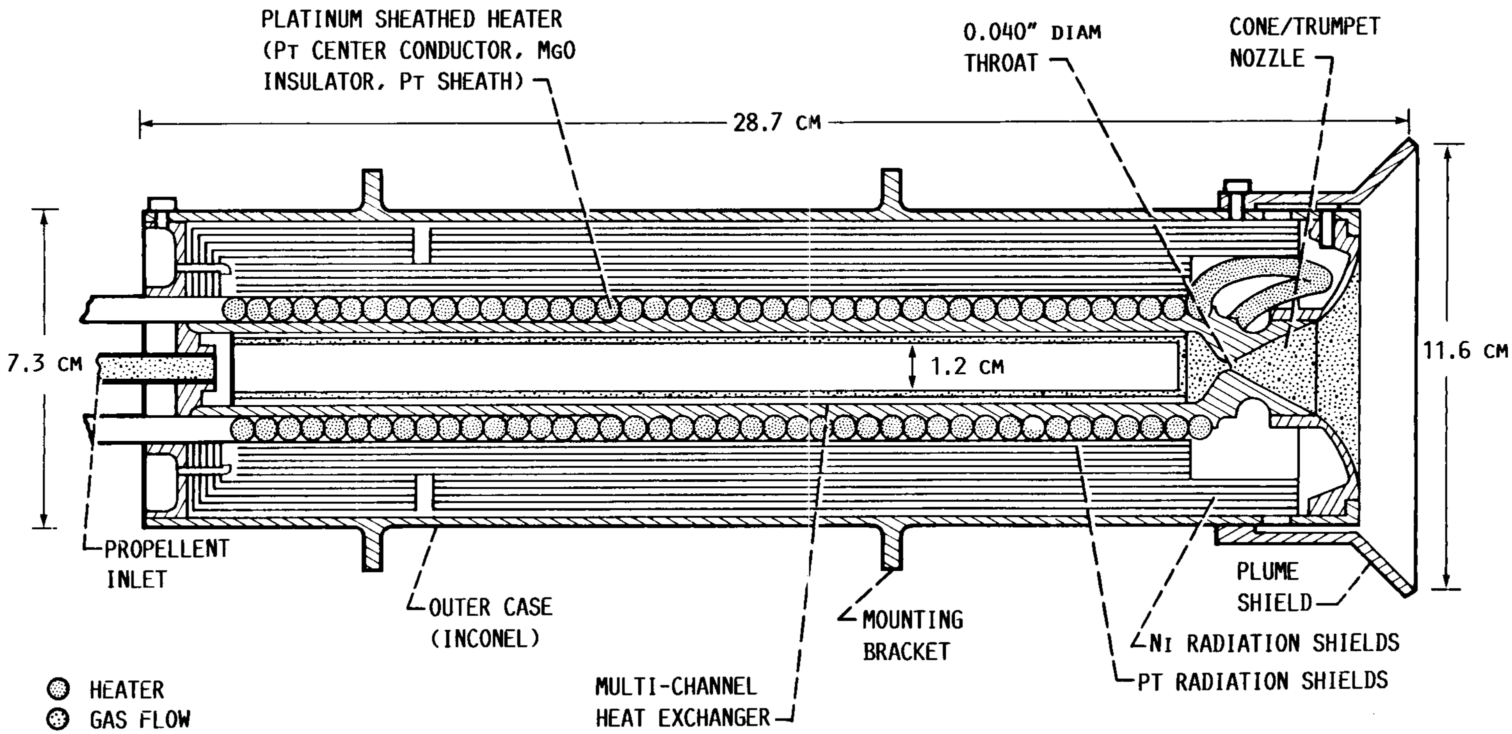

FIGURE 5. - CROSS-SECTIONAL SKETCH OF MULTIPROPELLANT RESISTOJET.

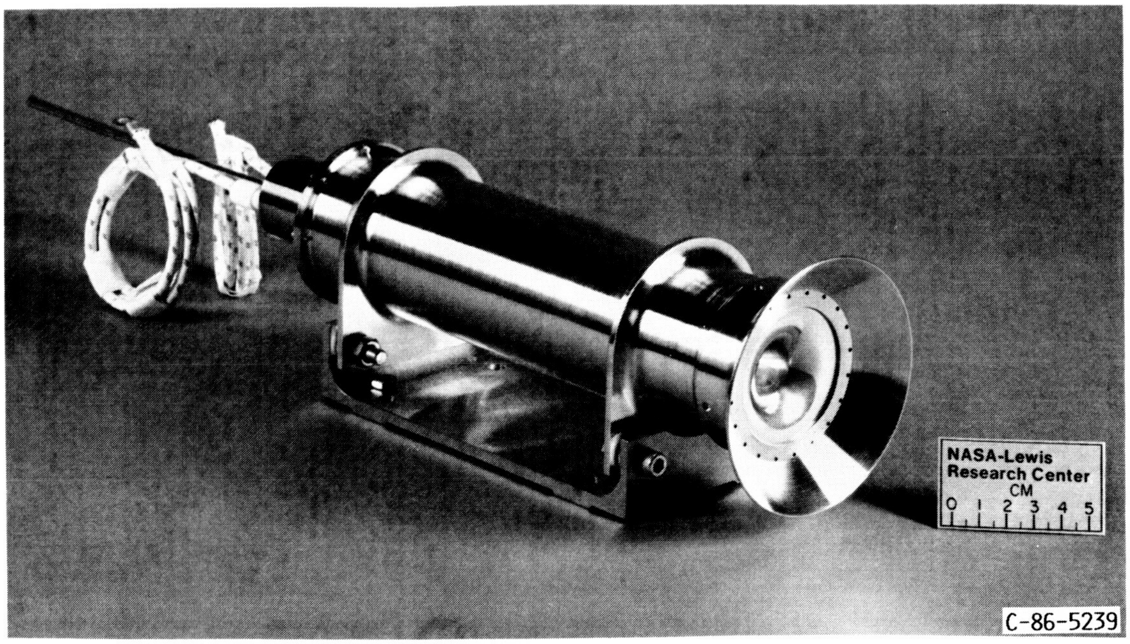

FIGURE 6. - PHOTOGRAPH OF MULTIPROPELLANT RESISTOJET MODULE.

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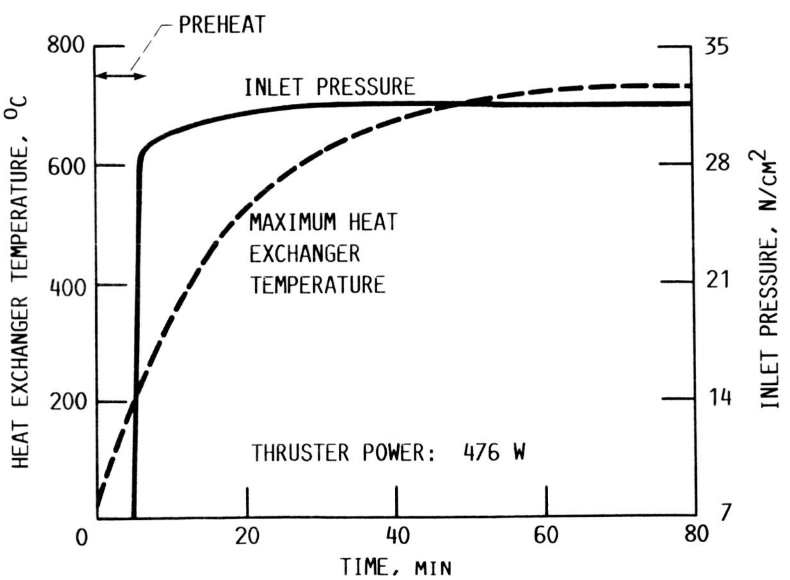

FIGURE 7. - THERMAL RESPONSE OF THE RESISTOJET WITH CARBON DIOXIDE PROPELLANT.

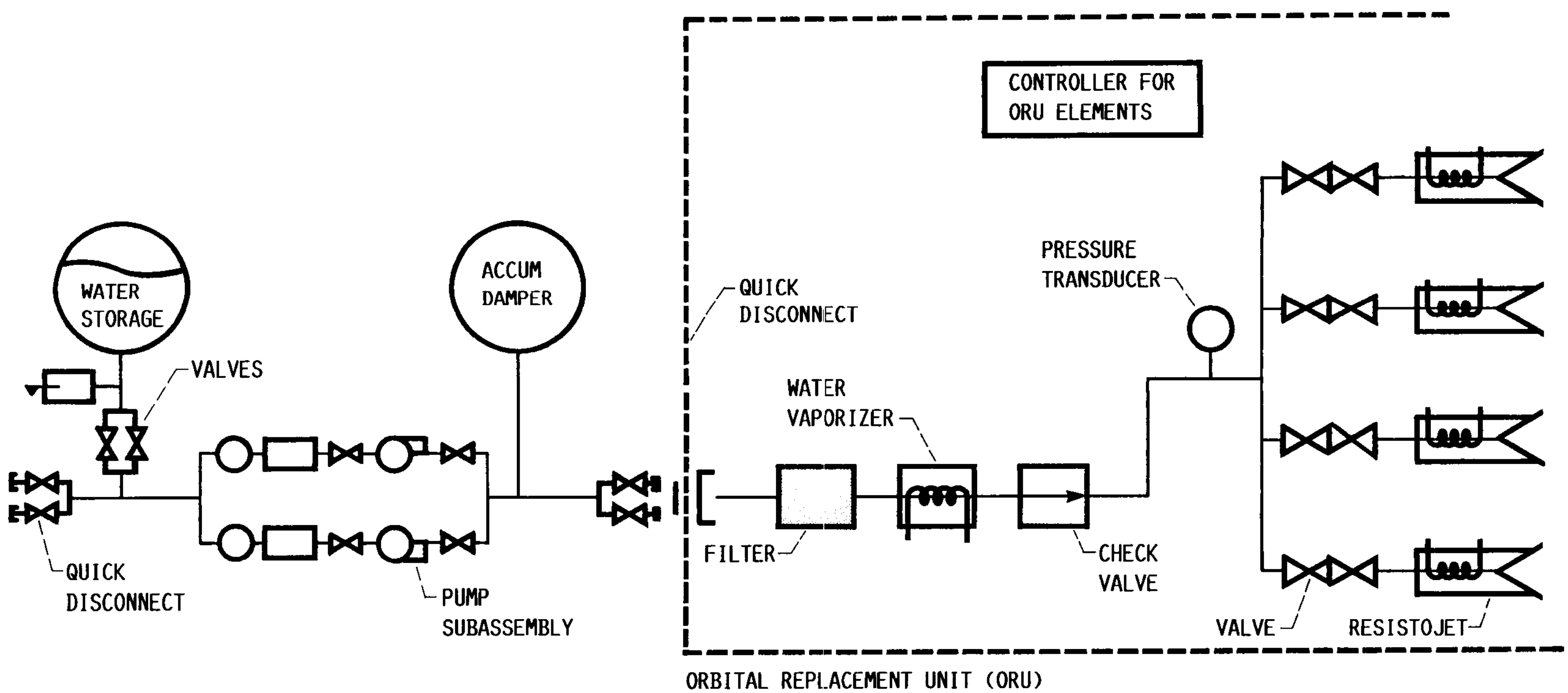

FIGURE 8. - WATER STORAGE AND FEED SYSTEM SCHEMATIC.

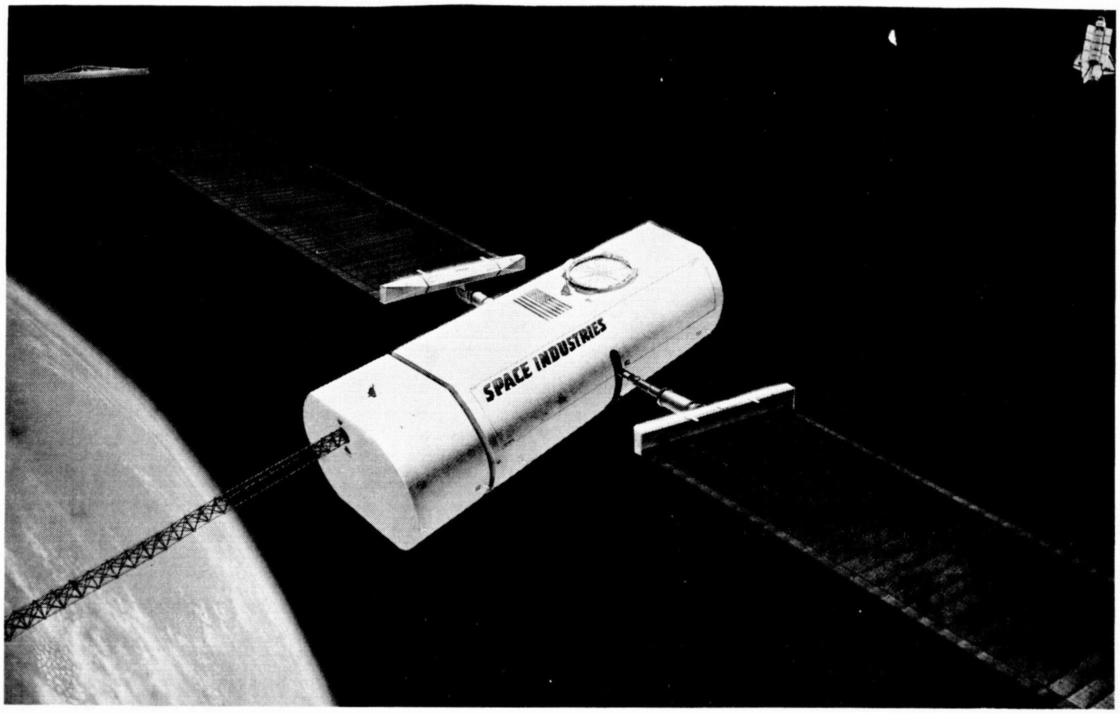

FIGURE 9. - SKETCH OF THE MAN-TENDED INDUSTRIAL SPACE FACILITY.

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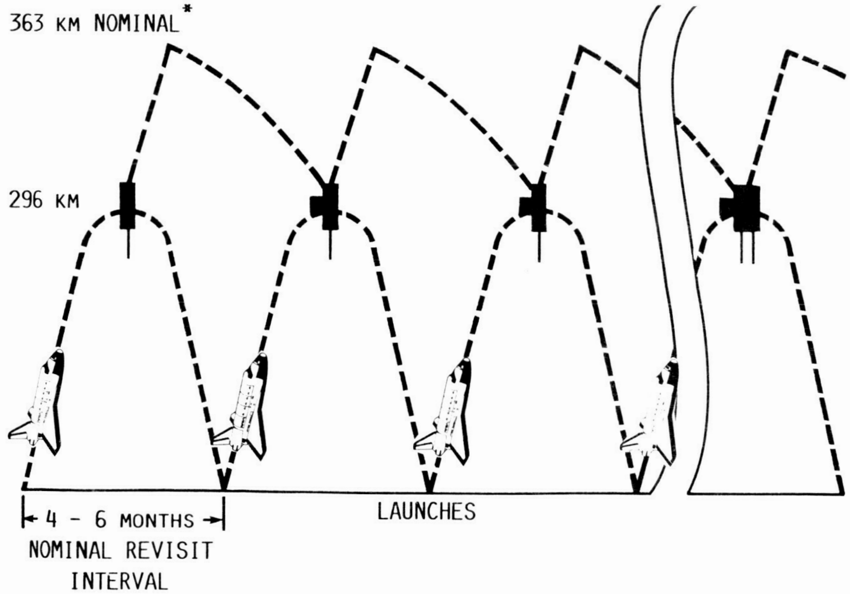

*DEPENDENT ON ATMOSPHERIC DENSITY AND REVISIT INTERVAL.

FIGURE 10. - TYPICAL MISSION PROFILE.

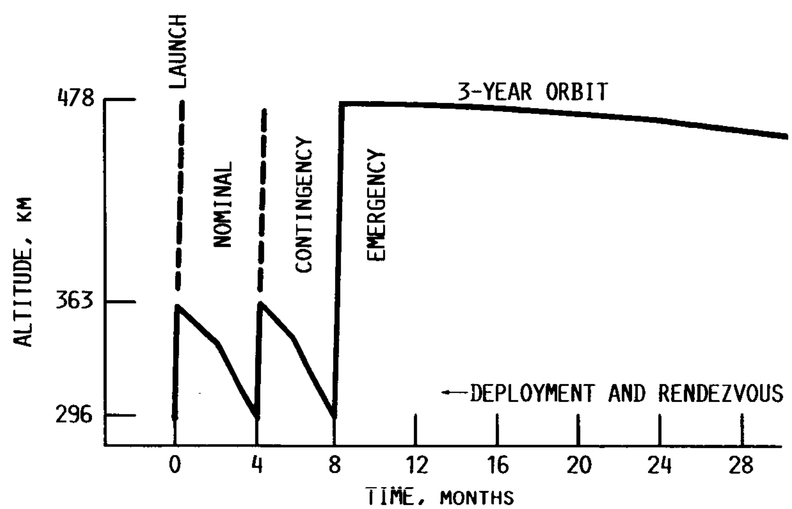

FIGURE 11. - EMERGENCY FLIGHT PROFILE.

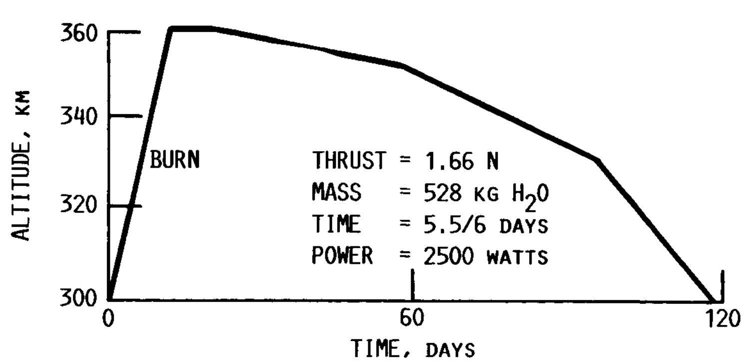

FIGURE 12. - REBOOST FLIGHT PROFILE.

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15. Supplementary Notes

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16. Abstract

Space platforms are planned for the early 1990's which can be serviced by the Shuttle Orbiter, and at a later date, via the Space Station. Man-tended platforms are smaller than the manned Space Station and have significantly lower requirements for propulsion total impulse. Nonetheless, the basic requirements of integration with the Space Transportation System, altitude maintenance, reboost, attitude control, and collision avoidance must be met. The selection of a propulsion system for the man-tended platform has been influenced by the planned use of resistojets for drag make-up on the manned Space Station. For that application, a resistojet has been designed that is capable of operation with a wide variety of propellants, including water. This paper discusses the reasons for selection of water as the propellant, performance of resistojets using water, and describes the man-tended platform and its mission requirements.

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