Open access • Proceedings Article • DOI:10.2514/6.1984-1326

Space station propulsion analysis study — Source link

R. M. Donovan, J. S. Sovey, N. B. Hannum

Institutions: Glenn Research Center

Published on: 01 Jan 1984

Topics: In-space propulsion technologies, Life support system and Propulsion

NASA TM- 83715

NASA Technical Memorandum 83715
AIAA-84-1326

Space Station Propulsion Analysis Study

R. M. Donovan, J. S. Sovey,
and N. B. Hannum
Lewis Research Center
Cleveland, Ohio

Prepared for the
Twentieth Joint Propulsion Conference
cosponsored by the AIAA, SAE, and ASME
Cincinnati, Ohio, June 11-13, 1984

SPACE STATION PROPULSION ANALYSIS STUDY

R. M. Donovan, J. S. Sovey, and N. B. Hannum
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

Abstract

This paper summarizes the impacts on the weight, volume and power usage of a manned space station and its 90-day resupply for three integrated, auxiliary propulsion subsystems. The study was performed in coordination with activities of the Space Station Concept Development Group (CDG). The study focused on three space station propulsion high-low thrust options that make use of fluids that will be available on the manned space station. Specific uses of carbon dioxide, water and cryogen boiloff were considered. For each of the options the increase in station hardware mass and volume to accommodate the dual thrust option is offset by the resupply savings, relative to the reference hydrazine system, after one to several resupplies. Over the life of the station the savings in cost of logistics could be substantial. The three options are examples of alternative technology paths that, because of the opportunity they provide for integration with the environmental control life support system (ECLSS) and OTV propellant storage systems, may reduce the scarring which is required on the early station to meet the increasing propulsion requirements of the growth station.

Introduction

This paper summarizes the impacts on the weight, volume and power usage of a manned space station and its 90-day resupply for three integrated, auxiliary propulsion subsystems. The purpose of the study was to explore propulsion options that can meet plausible propulsion requirements for the initial through the growth space station in a manner advantageous to the total station system. The study was performed in coordination with activities of the Space Station Concept Development Group (CDG). This preliminary study considered only incremental impacts on station and resupply quantities. These were estimated in terms of increased or decreased weight, volume and power of station and resupply for a station that uses the selected subsystems as compared with use of a reference hydrazine subsystem. Comparisons of these impacts are made for a limited set of propulsion impulse requirements. The three propulsion options considered the use of a low thrust (less than 1 lbf) subsystem for orbit maintenance and a high thrust (tens of pounds) subsystem for attitude control functions. Focus of the study was on the use of available fluids. These included CO_2 from the life support subsystem, and hydrogen and oxygen gases from either water electrolysis or cryogen storage boiloff.

The study focused on three space station propulsion high-low thrust options that make use of fluids that will be available on the manned space station. These options offer the opportunity to provide increased flexibility in the selection of station subsystems while reducing resupply logistics. The manned station will require periodic resupply of water, oxygen and nitrogen and disposal of waste water and carbon dioxide. The resupply interval assumed is 90 days. The quantities of the fluids will vary with the size of the crew, the degree of life support system closure and the amount of leakage of cabin atmosphere. On the growth station the storage of cryogenic hydrogen and oxygen for orbit transfer vehicle (OTV) refueling will yield large quantities of hydrogen and oxygen gas boiloff. The amount of boiloff will vary with the size of the storage facility and the insulation technology. Specific uses of carbon dioxide, water and cryogen boiloff are considered; modification or combinations of these uses may be more appropriate to overall station requirements.

Propulsion Requirements

While the space station configuration has not been fully defined, it was assumed that the initial station will have a 75 kW electric load and the growth station 150 kW. Propulsion will be required on the space station for a number of functions: altitude maintenance to counteract the loss of altitude due to atmospheric drag; desaturation of the control moment gyros (CMG) or other momentum management devices; correction of relatively large, but infrequent, accelerations caused by orbiter docking and module transfers; and, possibly, attitude control while the orbiter is docked and for special maneuvers such as debris avoidance and end of life disposition. Some of these functions may be eliminated or reduced to very modest requirements as a result of design and operations definition. For this study only the propulsive impulse required for altitude maintenance, CMG desaturation and the infrequent, large disturbance corrections were considered. These constitute the major impulse requirements.

The three propulsion system options studied use a high-low thrust approach. The low thrust resistojets were assigned to altitude maintenance; the higher thrust level H-O thrusters to attitude control functions of CMG desaturation and disturbance corrections. A high thrust (tens of pounds) level is mandatory if correction of the large disturbance is to be achieved in reasonably short times of 10 to 20 sec. The low thrust system could be used for frequent, CMG desaturation simultaneously with altitude maintenance. Simultaneous altitude maintenance and CMG desaturation could reduce overall propellant usage and has the potential for reduction in the number of CMGs if their requirement is sized by secular momentum accumulation. Operating strategies beyond the simple, functional assignment of thruster subsystem were not considered in this study.

The propulsion requirements for orbit altitude maintenance and station attitude control will be affected by the size and the configuration of the solar arrays, by the selected operational orbit altitudes, by the solar activity effect on atmospheric density and by the propulsion strategy and propulsion subsystem characteristics.

Table I summarizes the impulse requirements considered for this study. Two station, end-of-life power loads were selected, 75 and 150 kW. These were used as representative of initial and growth station power requirements, and were used to size gallium-arsenide (GaAs) solar arrays of 1300 and 2600 m^2, respectively. The solar array area is the principal contributor to aerodynamic drag that necessitates altitude maintenance. The altitude maintenance impulse required for a 90-day period assumes a station altitude of 500 km (270 n mi.) for nominal atmosphere in 1992, the maximum solar activity period of the next solar cycle. The altitude maintenance impulse is 0.42×10^6 N-sec (0.94×10^5 lbf-sec) for the "75 kW" station; twice this for the "150 kW" station. It was assumed that altitude maintenance would be accomplished about the 500 km altitude by frequent firings of low thrust resistojets.

A range of desaturation impulse requirements was selected by considering two different, sun-pointing solar array geometries on the earth-pointing stations. These are referred to as the paddle configuration array and the balanced- or H-configuration array. Figure 1 illustrates the two solar array geometries. Paddle-configuration arrays have commonly been assumed in past space station studies and are used on many existing smaller spacecraft. For large, array-hinge angles, which are required periodically when tracking the sun from an earth-pointing station the station with paddled arrays experiences large, gravity gradient torques that lead to correspondingly high CMG desaturation requirements. The H-configuration has been analyzed by Boeing Aerospace, as part of a continuing study of space station propulsion requirements.[1]

The desaturation impulses shown in Table I are based upon preliminary estimates in the Boeing study of the gravity gradient and aerodynamic torques experienced at maximum array-sun angle. These impulse values assume a thruster moment arm of 10 m. Only cases A, B and C were carried for the propulsion option comparisons; the torques associated with case D configurations were judged too extreme for the design to be likely.

External disturbances due to orbiter docking and module transfers were estimated to require a 90-day impulse of 30 000 N-sec (6740 lbf-sec). Orbiter docking and module transfer angular momentum impulses of 5000 and 2000 N-m-sec per occurrence, respectively, were estimated in the Boeing study. The 90-day impulse values assumed 3 or 4 occurrences of each activity and a 10 m thruster moment arm.

Available Impulse from Station Fluids

Carbon dioxide from ECLSS: There will be approximately 1 kg of carbon dioxide (CO_2) produced per crew person each day. The ECLSS removes the CO_2 and either collects it for return to earth, or vents it overboard if this is acceptable. Figure 2 illustrates the CDG baseline ECLSS that includes water filtration, treatment and monitoring and a regenerable CO_2 collection and liquifying function. This system was designed by Hamilton Standard[2] and presented to the CDG as a first step toward closure of the ECLSS and reduction of resupply logistics. An alternative use of the CO_2 is as a propellant in a low temperature resistojet. At a temperature of 1250° C, the resistojet requires 60 W to produce 0.05 N thrust at a specific impulse (I_{sp}) of 130 sec. The 1250° C temperature is sufficiently low to expect long life for the components. A 0.05 N thrust level is about the annual average drag force on the "75 kW" station at an orbit altitude of 500 km (270 n mi.). The daily average drag force may reach twice this level.

The quantity of CO_2, required as propellant in these resistojets for altitude maintenance, is shown as function of orbit altitude in Figs. 3 and 4. Each of these figures displays annual propellant required for nominal, +2 sigma and -2 sigma atmospheric conditions for a "75 kW" station. Figure 3 is for the 1992 (the highest solar activity year of the solar cycle) projected atmosphere; Fig. 4 is for 1998 (with lowest solar activity conditions). The available ECLSS CO_2 is indicated for a crew of 4 and for a crew of 8. The uncertainty in the prediction of future solar activity, and hence of atmospheric density, has a significant effect on the estimate of propellant required. For the nominal (50 percentile) atmospheric density an eight person crew produces enough CO_2 for altitude maintenance of the "75 kW" station at an altitude as low as 444 km (240 n mi.) for the high period of the solar cycle, and as low as 370 km (200 n mi.) for the low period (1998). At the reference 500 km (270 n mi.) altitude a crew of 4 to 8 produces enough CO_2 for a broad range of atmospheric densities.

Water Electrolysis: Water can be electrolyzed to provide oxygen for life-support, hydrogen and oxygen for the high thrust engines and hydrogen for the low thrust resistojets. The impulse available from the high thrust subsystem and from the low thrust subsystem using the products of water electrolysis, while supplying sufficient life-support oxygen for a crew of eight, is illustrated in Fig. 5. The minimum amount of water that must be electrolyzed during a 90 day period to supply the total needs of the crew is 763 kg. This provides 678 kg of oxygen and makes available 85 kg of hydrogen that can be used in the CO_2 resistojets for a 90-day impulse of 0.42×10^6 N-sec, indicated on the abscissa. The CO_2 resistojets operating at the 1250° C temperature with H_2 provides a specific impulse of 500 sec. Additional electrolysis beyond that required to meet the O_2 life-support could be used for high thrust at an oxidizer-fuel ratio of 8 or at a reduced oxidized-fuel ratio by blending all or part of the 85 kg H_2. The latter approach increases the I_{sp} of the high thrust subsystem and reduces the quantity of H_2 available for low thrust.

Figure 5 illustrates the amount of impulse available from the high and the low thrust subsystems as a function of the amount of water electrolyzed and the amount of H_2 blending. The high thrust subsystem I_{sp} will range from 359 sec at an 8:1 oxidizer-fuel ratio (no H_2 blending) to 437 sec I_{sp} at a 4:1 ratio. The 90-day impulse required for the three example cases are indicated on Fig. 5. Cases A and B (the "75 kW" station cases) fall along the 8:1 ratio line. This indicates that the 85 kg H_2 is just sufficient to provide the altitude maintenance impulse for that station. Case C (the "150 kW" station case) would require twice the available "crew of 8" H_2, if altitude maintenance is to be accommodated solely with the low thrust H_2 subsystem. To accommodate the impulse requirement of case C, it would be necessary to alter the propulsion strategy from that considered for this figure, such as using the high thrust for part of the altitude maintenance or supplementing the H_2 propellant with CO_2 from the ECLSS or with other gases. Any number of strategies could be considered to accommodate other impulse/fluid scenarios.

OTV cryogen storage boiloff: Orbit-transfer vehicles based at the space station may use cryogenic hydrogen and oxygen propellant. There will be boiloff of gases from the cryogenic storage tanks. The rate of boiloff will depend on the type of storage tanks used. Depending on the amounts available, the boiloff gases could be used to meet a variety of space-station needs. Possible uses for the boiloff gases include the use of oxygen for life-support, hydrogen and oxygen in a fuel cell to produce drinking water and power, hydrogen and oxygen in a high-thrust propulsion system, and hydrogen in a low-thrust resistojet propulsion system. Depending on the relative amounts of hydrogen and oxygen available, some of these functions could be accomplished simultaneously.

Two levels of storage tank technology were considered, viz. levels 2 and 3 of a four level ranking.[3] The characteristics of Level 2 include 120 layers of multilayer insulation (MLI) and a vapor-cooled shield; this represents a minimal advance over current technology (Level 1). The characteristics of Level 3 include 120 layers of MLI, decoupled struts, passive orbital disconnect system, vented hydrogen para-to-ortho conversion, and multiple vapor-cooled shields; this represents a moderate advance over current technology. Level 4 would be the same as level 3 with the addition of refrigeration; this would represent a significant advance over current technology. Level 1 tanks were not considered because of the very large hydrogen boiloff rate of such tanks. Level 4 was not considered because tanks of this type are unlikely to be available in the mid to late 1990's when space-based orbit-transfer vehicles are likely to be put into operation.

The amount of boiloff from the storage tanks depends almost entirely on how much storage capacity has been provided. Figure 6 shows the hydrogen and oxygen boiloff rates in kilopounds per year for technology levels 2 and 3 as a function of total storage tank capacity. The boiloff rates for level 3 are about two-thirds the boiloff rates for level 2. The total amount of on-orbit cryogenic fluid storage capacity is varied over a range from 100 to 500 klb (45 000 to 225 000 kg). An amount of 100 klb is about the minimum necessary for two low-capacity orbit-transfer missions. The relative amounts of stored hydrogen and oxygen are appropriate for an orbit-transfer vehicle that uses oxygen and hydrogen in a mass ratio of 6:1.

Figure 7 shows the total impulse available to the space station from the combination high-low thrust system using all the available hydrogen and oxygen boiloff. The high-thrust system is shown using oxygen and hydrogen in a 4:1 and an 8:1 mass ratio with any remaining H_2-boiloff made available for resistojet operation at an I_{sp} of 600 sec. Also shown on the figure are the high and low thrust impulse requirements for the three example cases. It is assumed that the low-thrust system is used for altitude maintenance and the high-thrust system for momentum-storage device desaturation and to overcome docking disturbances. For all these configurations, the low-thrust impulse requirement can easily be met with the smallest amount of on-orbit cryogenic fluid storage considered. The high-thrust impulse requirement can be met with modest amounts of storage considered.

Comparisons with Baseline Propulsion

The three high-low thrust options, summarized in Table II, make use of low-thrust resistojets to provide the impulse necessary to offset the altitude losses due to aerodynamic drag and make use of the high thrust H-O engines to desaturate the momentum management subsystem and to compensate for docking and module transfer disturbances. The impact on station mass, volume and average power and on station resupply mass and volumes relative to the use of a reference hydrazine propulsion subsystem was estimated. No attempt was made to layout detail subsystems.

Each of the thruster subsystems was assumed to have three axis control. Primary and secondary (backup) thrusters were assumed to be mounted in clusters of four at the end of 10 m booms. This would permit use of either subsystem for altitude or attitude control regardless of its assigned function in this study. Thruster subsystem weight estimates included 24 thrusters, valves, filters, regulators, lines and mounts. The thruster subsystem weights of 75, 127, and 63 kg for hydrazine, hydrogen-oxygen and the resistojet subsystems, respectively, did not change from case to case.

Each of the high thrust subsystems consisted of 24 133 N (30 lbf) thrusters. The hydrazine subsystem had a specific impulse of 225 sec. The gas-gas H-O has a specific impulse of 436 sec at an oxidizer-fuel ratio of 4:1 and of 359 sec at an 8:1 ratio. The 24 resistojets each produce a maximum thrust of 0.22 to 0.89 N (0.050 to 0.200 lbf), depending upon the fluid used. The low temperature CO_2 resistojet can operate with a number of fluids, including H_2, CH_4, N_2H_4 and CO_2. At the 1250° C heater temperature the I_{sp} of the resistojet is 130 sec with CO_2 and 500 sec with H_2. The specific impulse lies at intermediate values for the other fluids. The power required per 0.45 N (0.10 lbf) thrust ranges from 525 to 1420 W for CO_2 and H_2, respectively.

Reference hydrazine: The reference hydrazine propulsion subsystem consisted of the thruster subsystem, tanked hydrazine and thermal control. The tanked hydrazine was assumed to be resupplied at the 90-day resupply interval; tankage was estimated at 12.5 percent of propellant weight. No residuals or pressurization weights were included in the hydrazine estimate. The subsystem was assumed to require 0.20 W/kg hydrazine to prevent freezing. The reference hydrazine propellant resupply was sized to provide the total impulse required for altitude maintenance and attitude control.

Water electrolysis and CO_2: Propulsion subsystem option 1 considered the use of resistojets, supplied by CO_2, for altitude maintenance and gas-gas H-O thrusters, supplied from gas accumulators, for attitude control functions. A simple schematic of such a system is shown in Fig. 8. The CO_2 is obtained from the ECLSS. At the time of this study, the baseline ECLSS approach for the initial station provided that the CO_2 that was collected from the cabin atmosphere would be liquified and returned to earth in the logistic module. This is a means of avoiding intentional venting from the cabin. The approach of option 1 would make use of the nontoxic, nonoxidizing CO_2 propulsively. The gases are exhausted away from the station out of the orbit path. Presentations by Hamilton Standard to the Space Station Concept Development Group have supported the use of the CO_2 in resistojets as a possible low cost approach for the ECLSS.

The comparisons made with the reference hydrazine subsystem assume minimum change from the baseline ECLSS. CO_2 is collected and liquified as in the baseline ECLSS, but the liquification equipment (208 kg mass and 1.34 m^3 volume) is included as station equipment rather than as part of the resupply logistics module equipment. The resistojet propellants are drawn off this accumulated liquid CO_2 supply. An alternative approach might be the elimination of the liquification equipment and inclusion of gas accumulation equipment to supply the resistojet subsystem.

The H-O thruster subsystem is shown in Fig. 8 to be supplied by a pressurized gas accumulation system. In this schematic the accumulators are shown integrated with the H-O storage for an emergency power system. This illustrates a possible integration aspect that could be considered when evaluating options such as this subsystem. For the comparisons presented in this paper the 1000 psia accumulators were sized for a nominal 10 day propellant requirement. Spherical tanks of 6061-T6 Aluminum and a safety factor of 2 were assumed. The propellant accumulators are replenished by a water electrolysis unit. The electrolyzer employs technology common to that used in the regenerative fuel cell (RFC). The weight and power were estimated as 26 kg per kg/hr water flow and 4.6 kW per kg/hr water flow, respectively. The thrusters operate at an 8:1 oxygen-hydrogen mixture ratio, the same as water.

Table III summarizes the station and 90-day resupply savings (penalty) due to this option relative to the hydrazine reference. For each of the three cases there is an increase in station mass because of the use of two thrust subsystems instead of one; of the relocation of the liquification equipment from the logistics (resupply) module to the central station; and the addition of the electrolyzer and H-O accumulator tanks. For case C the resupply savings of 851 kg requires the availability of more CO_2 than would nominally be generated by a crew of eight. To achieve the savings shown, if the low thrust subsystem is to be used for the total case C altitude maintenance, it would be necessary that the crew size of the "150 kW" station be 16 persons or that other fuels, e.g., H_2, N_2 or N_2H_4.

For all three cases the penalty of increased station volume usage is offset by accumulated savings of reduced resupply volume in two or three 90-day resupplies. The station hardware increase is offset by the mass savings of a single resupply. For these comparisons the high thrust subsystem provided the entire attitude control impulse. If the results of case B and case A are compared, the impact of the use of H-O with gas storage is seen. The savings relative to the hydrazine reference in resupply mass resulting from the use of the higher I_{sp} H-O thrusters approximately offsets the one time station mass penalty associated with accumulator tanks and electrolyzer mass. However, the volume penalty of the H-O gas accumulators grows proportionately with the near tripling of impulse of case B relative to case A.

Station power load increases to meet demands of electrolysis; this would be accommodated by power management or by an increase in the station power system.

Water-based subsystem: The second propulsion option considered additional electrolysis to provide hydrogen gas, instead of ECLSS CO_2, to the low temperature resistojets and to provide oxygen to the life-support system. The resistojet and H-O thruster subsystems are the same as those considered for option 1. Additional water is electrolyzed to provide the H_2 for the resistojets, as well as hydrogen and oxygen for the high thrust subsystem. For this comparison the high thrust engines were assumed to run at a mixture ratio of 4:1. Excess oxygen was used for life-support. For the high-low thrust mix of impulses of the three cases there is sufficient oxygen to meet crew needs for 11 to 23 persons. A balancing of the total system by increasing mixture ratio or altering the high-low thrust assignments could meet lower crew-size needs and reduce accumulator and electrolyzer requirements.

Table IV summarizes station and resupply savings relative to the hydrazine reference. For all three cases the one-time penalty of increased station mass and volume usage is offset by savings accumulated within several resupplies. On the basis of mass and volume comparisons, option 2 appears attractive relative to the hydrazine baseline, but not as attractive as the option 1 use of the CO_2.

OTV propellant storage boiloff use: The third option uses boiloff from the OTV propellant storage facility instead of water electrolysis. The use of O_2 boiloff for life-support was not considered for this option. As previously seen in Fig. 7 there will be sufficient boiloff gases to meet a wide range of propulsion requirements. For this analysis it was assumed that the high thrust system would operate at an 8:1 mixture ratio and the low thrust resistojets at a heater temperature of 1750° C for an I_{sp} of 600 sec. Both of these assumptions minimize hydrogen use and limit the size of the hydrogen accumulators. Accumulators were sized for a two day contingency supply at 1000 psia. The availability and sizing of compressors to raise the boiloff gases to accumulator pressure were not addressed. Table V summarizes the savings (penalty) comparisons. For all cases the resupply savings greatly exceed the one-time station increment in mass and volume usage. Average power requirements for resistojets and compressors are very modest.

Conclusions

This examination of three propulsion system options demonstrates that the reduction in resupply requirements that result from the higher performance and from the use of available station fluids can readily offset the initial increase in station hardware mass and volume. Over the life of the station the savings in cost of logistics could be substantial. The three options are examples of alternative technology paths that, because of the opportunity they provide for integration with the ECLSS and OTV propellant storage systems, may reduce the scarring which is required on the early station to meet the increasing propulsion requirements of the growth station. The three systems considered use benign, station fluids and can be operated in a manner that alleviates contamination and acceleration concerns of experimenters.

This study evaluated only mass, volume and power impacts of the three options relative to a hydrazine system, for a limited set of propulsion requirements and propulsion strategies. More detail studies are needed to evaluate tradeoffs, especially with respect to cost, for specific space station configurations and for a wider range of operational conditions.

References

1. "Space Station Propulsion Requirements Study," Boeing Aerospace Co., Contract NAS3-23353, Sept. 1982 - May 1984.
2. Brose, Harlan, "Environmental Control Life Support (ECLSS)," Presented to the Space Station Concept Development Group Workshop, Washington, D.C., September 27, 1983 (Hamilton Standard Document 83D010A).
3. Aydelott, John, "Cryogen Storage Technology Status". Presented to the OMV/OTV/Satellite Servicing Group of the NASA Space Station Concept Development Group, Washington, D.C., Nov. 1983.

TABLE I. - RANGE OF PROPULSION SYSTEM IMPULSE REQUIREMENTS

	Station EOL power, kW	Array configuration	Total 90-day impulse, 106 N-sec		
			Drag[a]	Desaturation[b]	Ext. disturbances[c]
Case A	75	Balanced	0.42	1.3	0.03
Case B	75	Paddle	.42	3.7	.03
Case C	150	Balanced	.84	1.5	.03
Case D[d]	150	Paddle	.84	12	.03

[a]Based on annual, average aerodynamic drag for nominal atmosphere at 500 km for maximum solar activity year.
[b]Estimated cumulative cmg desaturation requirement for maximum, array-hinge angle situation; thruster moment arm 10 m.
[c]Estimated cumulative requirement for docking and module transfer disturbances.
[d]Case D eliminated from further consideration.

TABLE II. - PROPULSION OPTION SUMMARY

Option	Low thrust	Source of propellant	High thrust	Source of propellant
Baseline	--	--	N_2H_4	Resupply
1	CO_2 Resistojet	ECLSS	GH_2/GO_2 thruster	Water resupply to Electrolyzer
2	H_2 Resistojet	Water supply to Electrolyzer	GH_2/GO_2 thruster	Water resupply to Electrolyzer
3	H_2 Resistojet	OTV storage tank boiloff	GH_2/GO_2 thruster	OTV storage tank boiloff

TABLE III. - MASS, VOLUME AND POWER SAVINGS (PENALTY) FOR 90 DAYS FOR WATER-ELECTROLYSIS/CO_2 OPTION NO. 1 RELATIVE TO HYDRAZINE REFERENCE

LOW THRUST: Low temperature resistojets using ECLSS accumulated CO_2

HIGH THRUST: Gas-gas H-O engines at 8:1 O-H ratio using accumulated gaseous O_2-H_2, provided by electrolysis of water

	Case A	Case B	Case C
Configuration[a]	75 kW/H	75 kW/paddle	150 kW/H-
Savings (penalty)			
Station mass, kg	(548)	(953)	(582)
Resupply mass, kg	608	944	851
Station volume, m^3	(2.6)	(4.9)	(2.8)
Resupply volume, m^3	1.7	1.9	1.9
Station Power, kW	(0.71)	(1.9)	(0.84)

[a]Station end-of-life power load and solar array configuration.

TABLE IV. - MASS, VOLUME AND POWER SAVINGS (PENALTY) FOR 90 DAYS FOR ALL WATER-BASED OPTION NO. 2 RELATIVE TO HYDRAZINE REFERENCE

LOW THRUST: Low temperature resistojets using ECLSS accumulated H_2

HIGH THRUST: Gas-gas H-O engines at 4:1 O-H ratio using accumulated gaseous O_2-H_2, provided by electrolysis of water

	Case A	Case B	Case C
Configuration[a]	75 kW/H	75 kW/paddle	150 kW/H-
Savings (penalty)			
Station mass, kg	(709)	(1212)	(1064)
Resupply mass, kg	328	789	434
Station volume, m^3	(3.4)	(6.3)	(5.4)
Resupply volume, m^3	1.1	1.9	1.8
Station Power, kW	(2.9)	(4.8)	(4.8)

[a]Station end-of-life power load and solar array configuration.

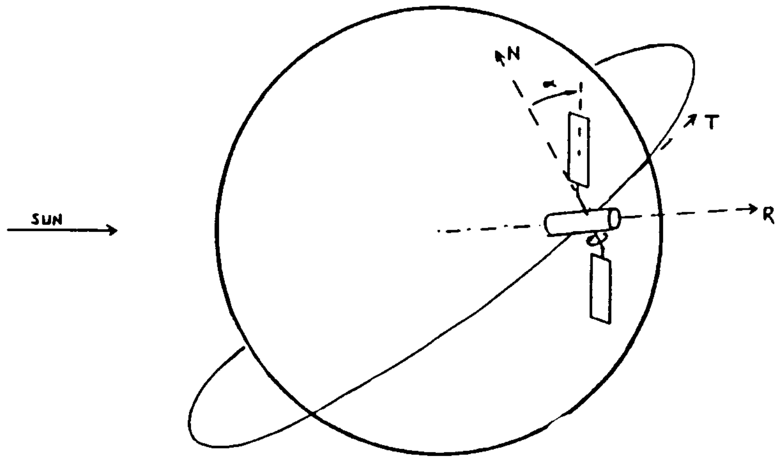
TABLE V. - MASS, VOLUME AND POWER SAVINGS (PENALTY) FOR 90 DAYS FOR CRYOGEN STORAGE BOILOFF OPTION NO. 3 RELATIVE TO HYDRAZINE REFERENCE

LOW THRUST: Resistojets using OTV storage H_2 boiloff

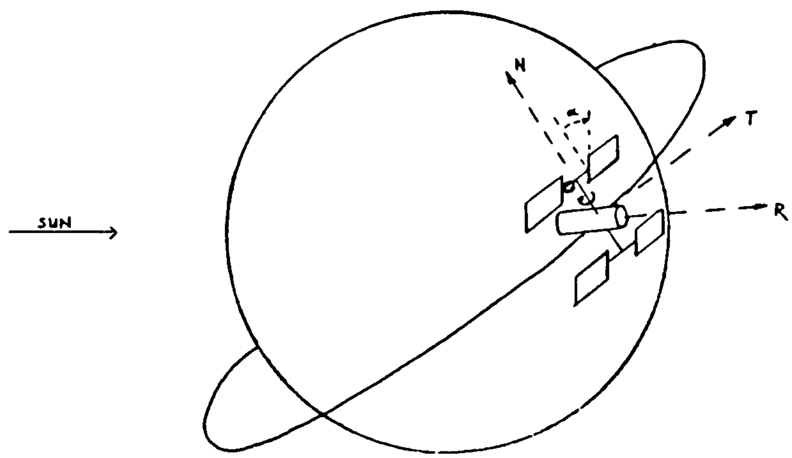
HIGH THRUST: Gas-gas H-O engines at 8:1 O-H ratio using accumulated gaseous O_2-H_2, provided by OTV storage boiloff

	Case A	Case B	Case C
Configuration[a]	75 kW/H	75 kW/paddle	150 kW/H-
Savings (penalty)			
Station mass, kg	(211)	(290)	(270)
Resupply mass, kg	892	2116	1209
Station volume, m^3	(1.2)	(1.7)	(2.2)
Resupply volume, m^3	1.0	2.4	1.4
Station Power, kW	(.22)	(.30)	(.42)

[a]Station end-of-life power load and solar array configuration.



(a) Paddle geometry array.



(b) Balanced geometry array.

Figure 1. - Earth-oriented station with sun-pointing solar arrays.

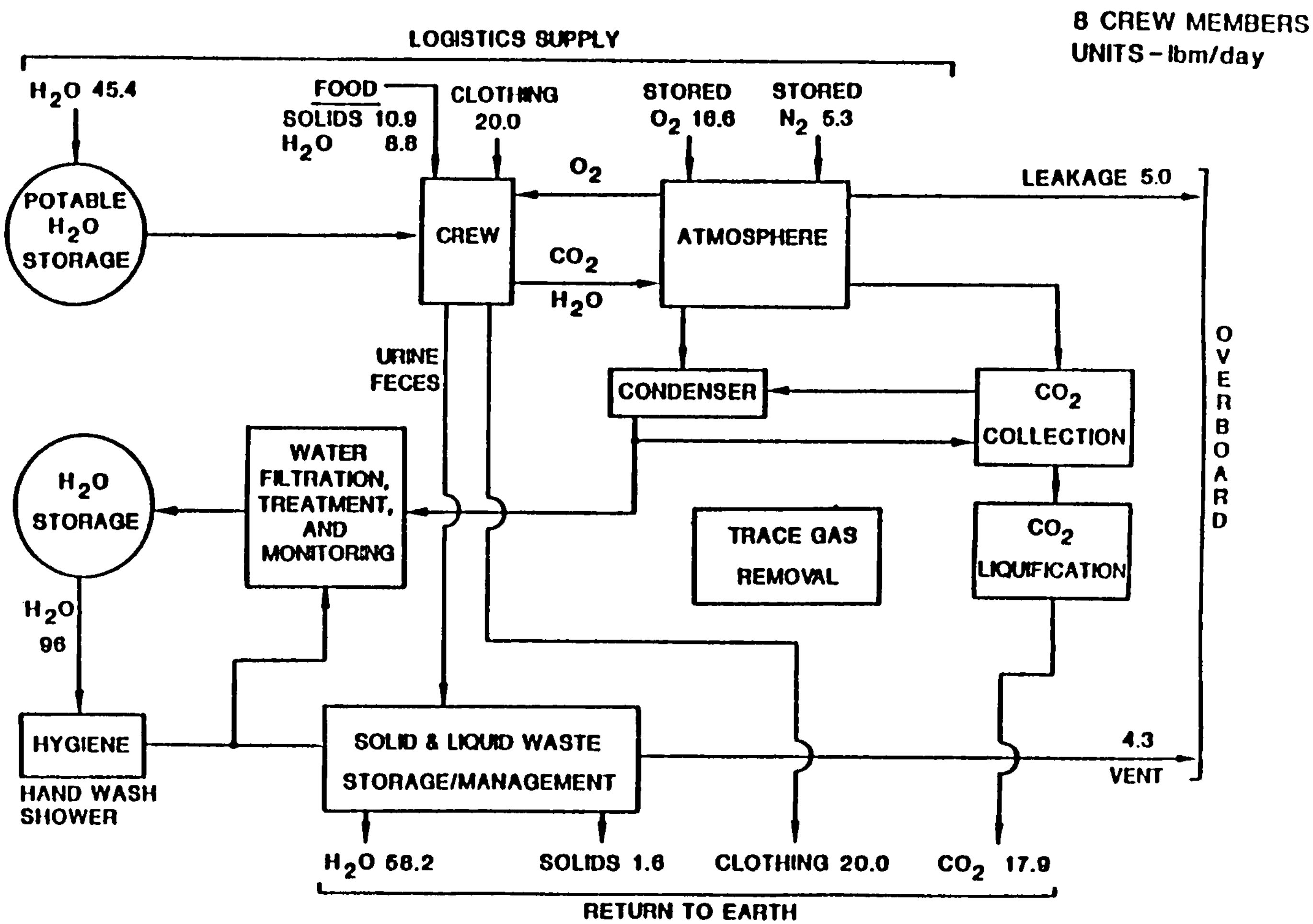


Figure 2. - Baseline environmental control life support system proposed by Hamilton Standard for initial station.

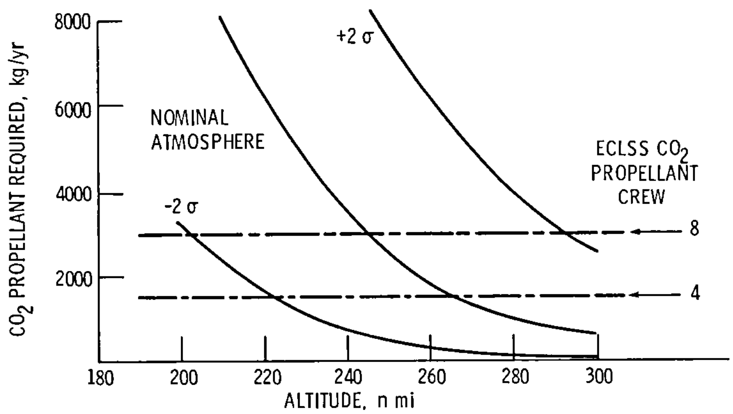


Figure 3. - CO_2 resistojet propellant required for altitude maintenance during high solar year (1992). 75 kWe station power; GaAs array/RFC storage.

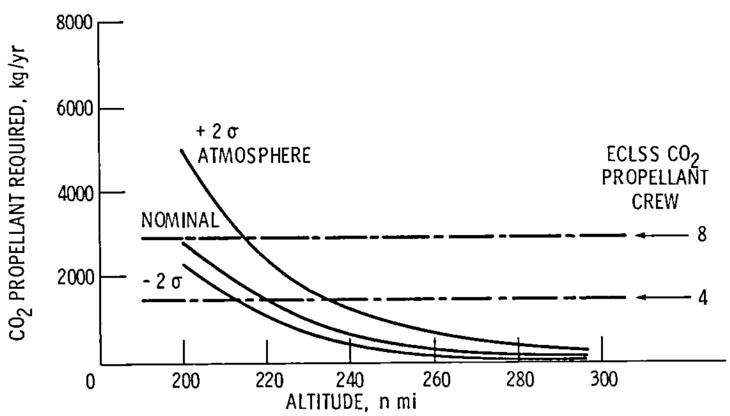


Figure 4. - CO_2 resistojet propellant required for altitude maintenance during low solar year (1998). 75 kWe station power; GaAs array/RFC storage.

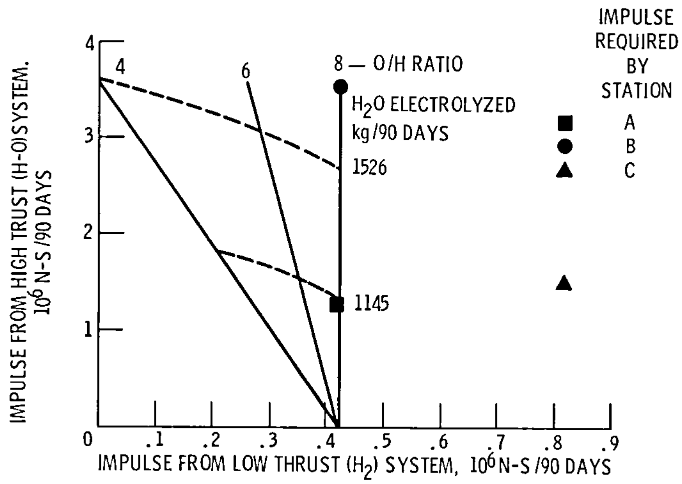


Figure 5. - Impulse available from products of water electrolysis while producing sufficient oxygen for a crew of eight.

LEVEL	DESCRIPTION
2	MINIMUM STORAGE TECHNOLOGY ADVANCE: 120 LAYERS OF ML I AND VAPOR COOLED SHIELDS
3	MODERATE ADVANCE: DECOUPLED STRUTS, PASSIVE ORBITAL DISCONNECT SYSTEM, VENTED HYDROGEN PARA-TO-ORTHO CONVERSION, MULTIPLE SHIELDS

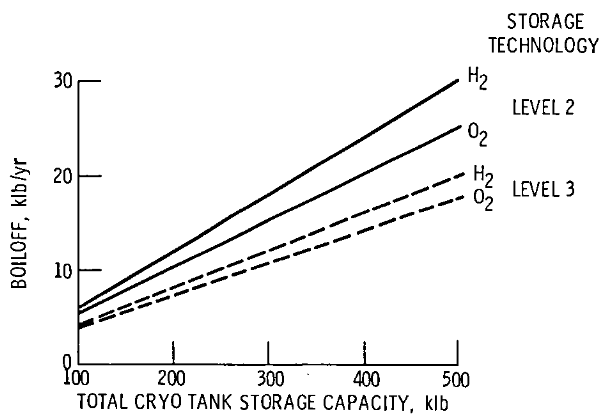


Figure 6. - Hydrogen and oxygen boiloff from cryogen storage tanks.

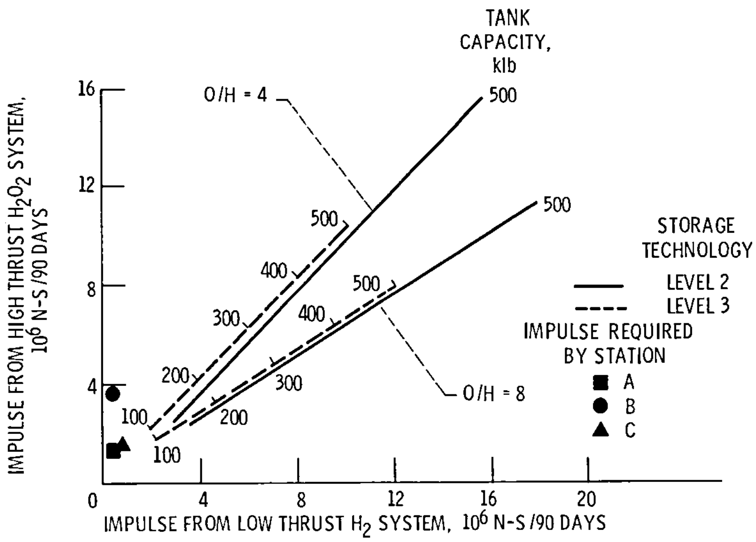


Figure 7. - Impulse available from cryogen storage boiloff.

OPTION 1 PROPULSION SYSTEM

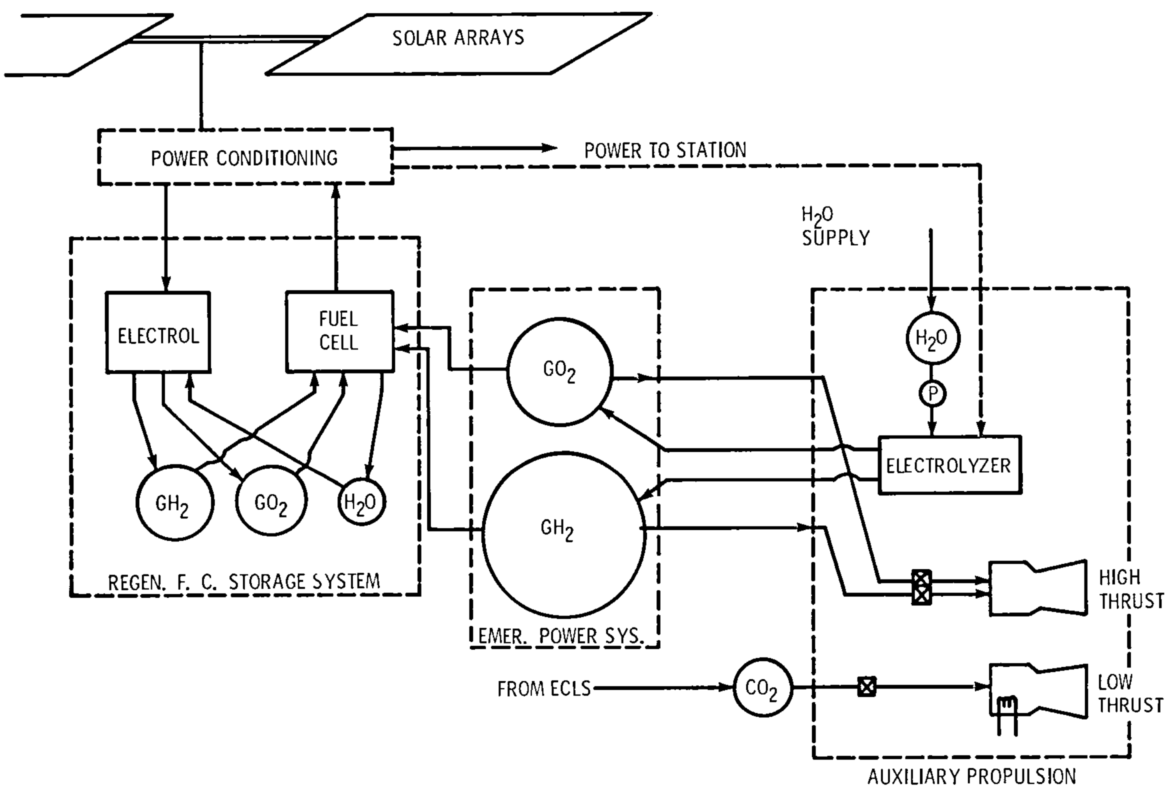


Figure 8. - Schematic of system interfaces of high-low thrust system using gaseous hydrogen and oxygen from water electrolysis and CO_2 from the ECLS system.

1. Report No. NASA TM-83715 AIAA-84-1326	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Space Station Propulsion Analysis Study		5. Report Date 6. Performing Organization Code None
7. Author(s) R. M. Donovan, J. S. Sovey, and N. B. Hannum		8. Performing Organization Report No. E-2180 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. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Prepared for the Twentieth Joint Propulsion Conference cosponsored by the AIAA, SAE, and ASME, Cincinnati, Ohio, June 11-13, 1984.

16. Abstract

This paper summarizes the impacts on the weight, volume and power usage of a manned space station and its 90-day resupply for three integrated, auxiliary propulsion subsystems. The study was performed in coordination with activities of the Space Station Concept Development Group (CDG). The study focused on three space station propulsion high-low thrust options that make use of fluids that will be available on the manned space station. Specific uses of carbon dioxide, water and cryogen boiloff were considered. For each of the options the increase in station hardware mass and volume to accommodate the dual thrust option is offset by the resupply savings, relative to the reference hydrazine system, after one to several resupplies. Over the life of the station the savings in cost of logistics could be substantial. The three options are examples of alternative technology paths that, because of the opportunity they provide for integration with the environmental control life support system (ECLSS) and OTV propellant storage systems, may reduce the scarring which is required on the early station to meet the increasing propulsion requirements of the growth station.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Space station Propulsion	Unclassified - unlimited STAR Category 20

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price*
Unclassified	Unclassified		

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