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SUMMARY

Four electric thrust devices and three chemical thrust devices are compared for the application of atmospheric drag cancellation on four assumed space station configurations. The devices are the contact ion rocket thrustor, the electron-bombardment ion rocket thrustor, the arc-jet, the resisto-jet, the liquid oxygen - liquid hydrogen (LO_2-LH_2) bipropellant rocket, the nitrogen tetroxide - unsymmetrical dimethylhydrazine (N_2O_4-UDMH) bipropellant rocket, and the hydrogen peroxide (H_2O_2) monopropellant rocket. The chemical propulsion systems require as much as five times the total system weight of the ion rocket systems for a 5-year mission even when solar cells are the source of electrical power. Electric power requirements for the electric rocket systems are on the order of a few hundred watts for the resisto-jet and range from 3 to 15 kilowatts for the ion rocket. Resisto-jets appear to be a satisfactory compromise between total system weight and power.

INTRODUCTION

Atmospheric drag causes a force on a manned space station, operating at altitudes of up to 300 nautical miles, that must be counteracted if the station is to remain at a constant altitude for any appreciable duration. The drag cancellation system can be a mass-expulsion thrust device of either the chemical or electrical type. This report is a comparison of the performances of the electric and chemical rocket thrust devices when utilized for atmospheric drag cancellation.

Placing payload weight in orbit is a costly operation; hence the weight of any orbiting system is a very important factor. Also of importance is the demand for electric power, since electric power presently is at a premium in space. Chemical and electric rocket systems operate at opposite ends of the weight-power spectrum. Chemical systems, because of their lower specific impulse, require larger propellant weight for long-duration missions. Electric systems, however, require larger amounts of electrical power.

This report compares the weights and the power requirements of several chemical and electric rocket systems that could be used to counteract the atmospheric drag on four assumed space station configurations. The space station configurations were selected from those evolved under NASA contracts (refs. 1 to 4). Comparisons are made for 1- and 5-year missions.

ANALYSIS

The characteristics of the four space station configurations in this study are given in tables I and II. The orientation refers to the direction of the longitudinal axis or axis of rotation. Frontal area is the projected area of the station on a plane perpendicular to the velocity vector. This area varies between a maximum and a minimum, depending on the orientation of the station. An estimation of the time-averaged area is indicated, and this value is used in further computations. All four configurations use solar cell panels for electrical power, and the power ratings of the arrays are given in table II. If electric thrustors are used, additional solar cells must be added unless some of the power already available can be diverted to the thrustor system as required.

TABLE I. - SPACE STATION CHARACTERISTICS

Space station configuration	Orientation	Frontal area, A, sq ft			Initial altitude, h_0, nm
		Minimum	Maximum	Average	
1	Local vertical	4000	11,000	8500	300
2	Sunline (rotating station)	3840	13,685	9000	260
3	Sunline	1600	2,800	2400	260
4	Orbit perpendicular	1900	2,900	2500	200

By using the exponential approximation to the atmospheric density indicated by the dashed line in figure 1 and a drag coefficient of 2.5, the drag impulse requirements for the four configurations were computed. These impulse-per-day requirements are shown in table III for the case of a continuous thrust to counteract the drag. The same values of impulse per day would also apply for the case of a periodic thrust delivered many times per orbit. If the altitude is allowed to decay a certain distance Δh and periodically boosted back to the initial altitude by means of a two-impulse minimum-energy Hohmann transfer, the impulse-per-day requirements have to be increased by the correction factors indicated in table III. This Hohmann transfer can only be accomplished by high-thrust chemical systems. Note that the impulse-per-day requirements are equivalent to the drag forces experienced by the space stations times 8.64×10^4, the number of seconds in a day.

TABLE II. - SOLAR PANEL CHARACTERISTICS

Space station configuration	Solar panel area, sq ft	Maximum power (no shade), kw
1	7000	64.0
2	7400	67.0
3	1126	8.17
4	1060	8.4

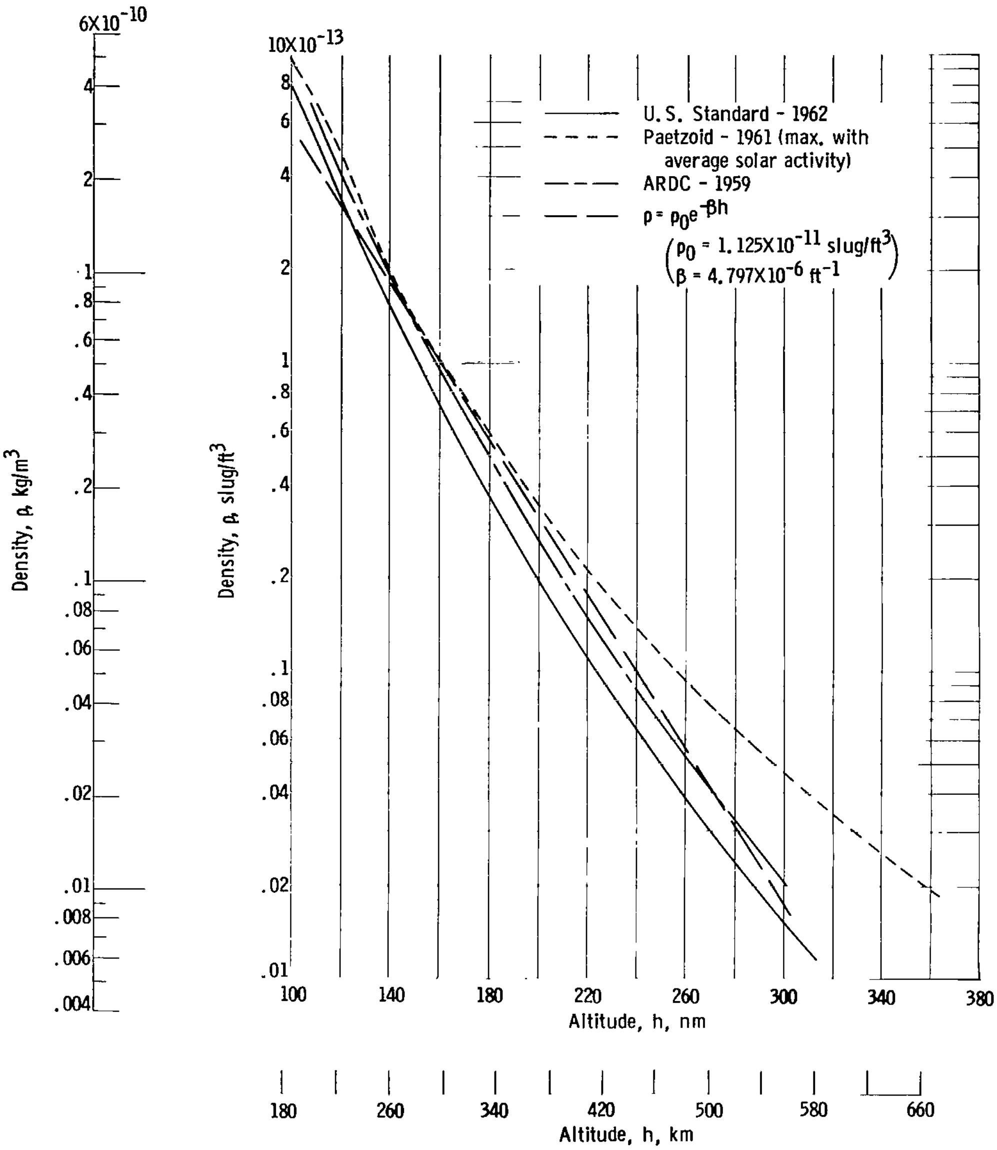

Figure 1. - Atmospheric density.

TABLE III. - IMPULSE REQUIREMENTS

Space station configuration	Impulse per day (Δh = 0, continuous thrust), (lb)(sec)/day	Correction factor[a]		
		Δh = 10 nm	Δh = 20 nm	Δh = 30 nm
1	1.006×10^3	1.15	1.32	1.50
2	3.47×10^3			
3	$.924 \times 10^3$			
4	5.63×10^3			

[a]Impulse per day ($\Delta h \neq 0$) = impulse per day ($\Delta h = 0$) × correction factor.

TABLE IV. - CHARACTERISTICS OF THRUST DEVICES

(a) Electric rocket systems

Thrust device	Specific impulse (actual), I_{sp}, sec	Solar panel specific weight, α_{sc}, lb/kw	Power conditioning specific weight, α_{pc}, lb/kw (a)	Thrustor efficiency, η	Power conditioning efficiency, η_{pc}	$\frac{\text{Solar panel power}}{\text{impulse per day}}$, $\frac{\text{kw}}{\text{(lb)(sec)/day}}$
Contact ion thrustor	6000	200	25	0.61	0.90	2.75×10^{-3}
Electron-bombardment ion thrustor	5000	↓	25	.66	.90	2.12×10^{-3}
Arc-jet	1200	↓	0	.33	1.00	$.917 \times 10^{-3}$
Resisto-jet	800	↓	0	.70	1.00	$.288 \times 10^{-3}$

(b) Chemical rocket systems

Thrust device	Specific impulse (actual), I_{sp}, sec	Tankage weight allowance
O_2-H_2	425	10 percent of propellant weight
N_2O_4-UDMH	300	
H_2O_2	165	

[a]Includes thrustor weight.

The characteristics of the thrust devices used in this comparison are listed in table IV. These numbers are near present state-of-the-art values. In the case of the electric rocket systems, the specific impulses have been "weight optimized" for a 5-year mission. This optimization process involved varying the specific impulse and observing how the total system weight, including propellant, varied with the dependent variable efficiencies. The specific impulses that gave the lowest total system weight for a 5-year mission and their associated characteristics are the ones listed.

The solar panel specific weight α_{sc} of 200 pounds per kilowatt is the same for all four electric systems. Since this value was determined by surveying existing and proposed solar panel arrays, it should at least be near the state-of-the-art value. The power conditioning specific weight α_{pc} was obtained in a similar manner. The value α_{pc}, which includes the weight of the thrustors, is approximately zero for the arc-jet and resisto-jet indicating that direct connection of the thrust device to the solar panel may be possible. This results in zero weight, 100-percent efficient power conditioning for these two thrust devices.

Since the chemical systems do not require large amounts of electric power, their main system weight, less propellant, is due to tankage. This weight is assumed to be 10 percent of the propellant weight required between space station resupply periods. This tank weight is probably conservative for the case of cryogenic propellants. If propellant and other expendables are resupplied to the station periodically, the propellant tanks will not have to be larger than necessary to hold the amount required for operation between resupply periods. In this study, the resupply interval was assumed to be 60 days and the tanks were sized accordingly.

RESULTS

As might be expected, the electric rocket systems with their higher specific impulse provide lighter overall system weights for the 5-year mission even when the weight of the power source is included (see fig. 2). Contact ion

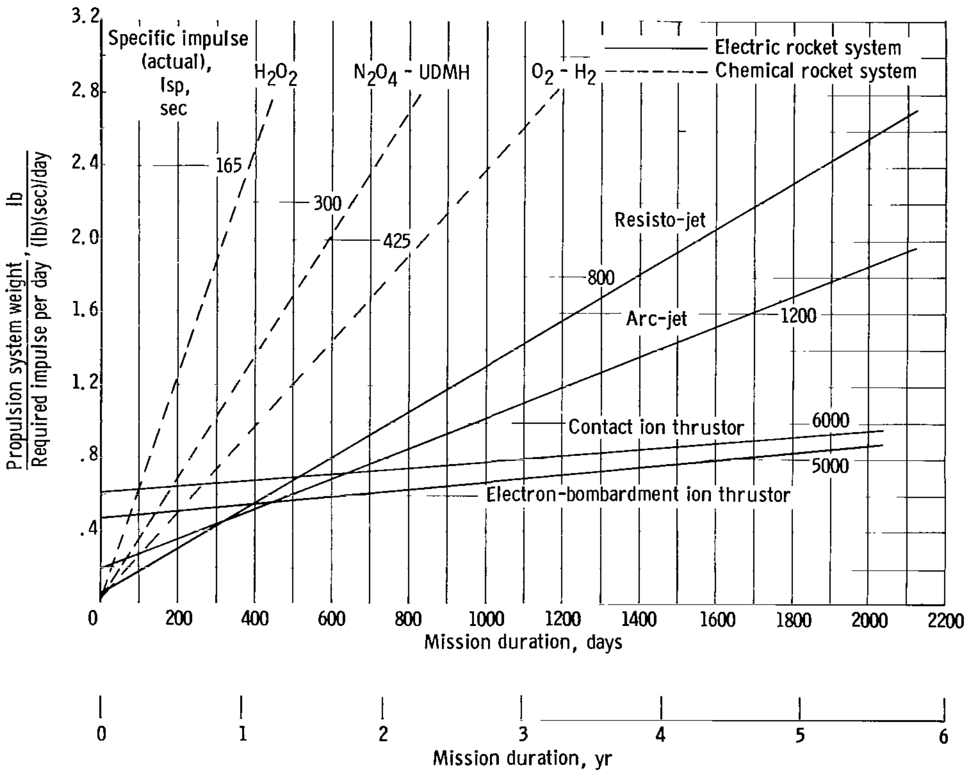

Figure 2. - Propulsion system weight.

thrustors and electron-bombardment ion thrustors require almost identical system weights, based on the characteristics listed in table IV (which are near state-of-the-art values). If either ion rocket can show improved efficiencies, it can then provide a lighter system.

Also interesting to note is the fact that electrothermal arc-jet and resisto-jet systems are competitive or superior to ion systems on a weight basis for missions of 1 to 2 years. Likewise resisto-jets are lighter than chemical rocket systems for nearly all mission durations, while some chemical systems have a weight advantage over ion engines up to about 1/2 year.

TABLE V. - PROPULSION SYSTEM WEIGHTS

Thrust device	Configuration							
	1		2		3		4	
	Mission duration, yr							
	1	5	1	5	1	5	1	5
	Propulsion system weight, lb							
Contact ion thrustor	678	923	2340	3,180	623	847	3,800	5,160
Electron-bombardment ion thrustor	549	848	1890	2,900	504	773	3,070	4,710
Arc-jet	490	1,720	1690	5,920	450	1,580	2,740	9,600
Resisto-jet	517	2,350	1780	8,110	475	2,180	2,890	13,200
O_2-H_2	878	4,330	3030	14,900	806	3,970	4,910	24,200
N_2O_4-UDMH	1240	6,140	4280	21,200	1140	5,640	6,960	34,400
H_2O_2	2260	11,200	7800	38,500	2070	10,300	12,600	62,500

The actual system weights required by the four space station configurations are shown in table V for 1- and 5-year missions. Since the specific impulse for the electric systems was optimized for a 5-year mission, the weights shown are not necessarily minimum for a 1-year mission. For the 5-year missions, the liquid oxygen - liquid hydrogen chemical system is roughly five times as heavy as the ion systems. This difference may not be so important if the rendezvous propellant reserve of the resupply vehicle can be utilized in chemical systems on the space station.

The other side of the picture, that of electric power required by the electric systems, is given in table VI. A comparison of the power required and the power available (table II, p. 2) indicates that the average power required may be prohibitively large. This is especially true for the ion rockets when they are considered for configuration 4. Resisto-jets, on the other hand, require less electric power than ion rockets making them more desirable for this type of mission. Due to the lower specific impulse, however, the resisto-jet total system weight savings is not as great as that for ion rockets. The liquid oxygen - liquid hydrogen chemical rocket system was as much as five times heavier than the ion rocket system, but it is only twice as heavy as the resisto-jet system.

TABLE VI. - ELECTRIC POWER REQUIREMENTS

Thrust device	Configuration			
	1	2	3	4
	Power required (continuous), kw			
Contact ion thrustor	2.77	9.55	2.54	15.50
Electron-bombardment ion thrustor	2.13	7.35	1.96	11.93
Arc-jet	.92	3.18	.85	5.17
Resisto-jet	.29	1.00	.27	1.63

CONCLUDING REMARKS

A comparison of the chemical and electric rocket systems indicates that the electric rocket systems require total system weights in orbit that are only one-half to one-fifth as heavy as those required by the chemical systems. The lighter ion rocket systems require large amounts of electric power. Unless chemical propellant can be placed in orbit free of cost by utilizing the propellant reserve in the resupply vehicle, the resisto-jet seems to offer an attractive compromise between weight and power requirements. The resisto-jet system is lighter than the chemical rocket systems and requires less electric power than the ion rocket systems.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, May 27, 1964

REFERENCES

1. Anon.: Manned Orbital Laboratory (Zero-G) Saturn V Class. Final Rep., Missile and Space Systems Div., Douglas Aircraft Co., Inc., Mar. 1964.

2. Anon.: Study of a Rotating Manned Orbital Space Station. Final Rep., Spacecraft Organization, Lockheed-California Co., Mar. 1964.

3. Anon.: Manned Orbital Research Laboratory System. Phase I, Final Rep., Aero-Space Div., Boeing Co., Sept. 27, 1963.

4. Anon.: Report on a System Comparison and Selection Study of a Manned Orbital Research Laboratory. Final Rep., Missile and Space Systems Div., Douglas Aircraft Co., Inc., Sept. 1963.

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