NASA TECHNICAL MEMORANDUM

NASA TM X-1908

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PERFORMANCE OF RADIATION-COOLED MAGNETOPLASMADYNAMIC ARC THRUSTERS

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • OCTOBER 1969

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SUMMARY

Results are given for performance tests on three different radiation-cooled magnetoplasmadynamic (MPD) arc thrusters. These are the Avco X-7CR and the McDonnell-Douglas X-4A and X-7. All were developed under contract to NASA Lewis Research Center. The results are compared to those obtained by the contractors.

INTRODUCTION

If MPD thrusters are to have a role in future electric propulsion missions, completely radiation-cooled versions must be developed. Progress in this direction has been made by Avco and McDonnell-Douglas, both under contract with Lewis Research Center. The thrusters developed under these contracts were tested at Lewis Research Center at lower pressures than were possible in contractor facilities. The results are given herein and compared to those obtained by the contractors.

APPARATUS AND PROCEDURE

All experiments were performed in a 15-foot-diameter, 65-foot-long vacuum tank (ref. 1). The thrusters tested were the Avco X-7CR (ref. 2) and the McDonnell-Douglas X-4A and X-7 (ref. 3). The Avco X-7CR is shown schematically in figure 1. It is described in some detail in reference 2. The McDonnell-Douglas X-4A is shown in figure 2 and schematically in figure 3. The McDonnell-Douglas X-7 is shown in figures 4 and 5. The X-4A and X-7 are described in reference 3. Measurements were made of thrust, arc current, arc voltage, magnet current, and propellant flow rate. These parameters were then used to calculate specific impulse and thrust efficiency given, respectively, by

$$I_{sp} = \frac{T}{\dot{m}g} \tag{1}$$

$$\eta_T = \frac{T^2}{2\dot{m}P_A} \tag{2}$$

where T is the thrust, $\dot{m}$ the mass flow rate, g the gravitational constant, and P_A the electrical power supplied to the arc. The efficiency η_T is only an arc efficiency; that is, it does not include magnet power.

THRUST AND MASS FLOW RATE MEASUREMENTS

The thrust measurements were made using a parallelogram-pendulum thrust stand. The electrical power to the thruster and magnet coil was brought onto the stand through coaxial lines terminating on coaxial mercury pots. The power was supplied by commercially available welding power supplies. Deflection of the stand was sensed by a linear differential transformer with output indicated on a strip-chart recorder. The system was calibrated by a weight and pulley arrangement which could apply known forces to the stand. A 25-centimeter diameter steel bucket or ''thrust killer'' (ref. 4) was mounted on a shaft on the thrust stand and could be swung down in front of the thruster to cancel the directed energy of the beam. The thrust was measured by blocking the exhaust beam momentarily with the thrust killer and observing the change in thrust stand deflection.

As a check on the thrust killer technique the stand deflection resulting from turning off the arc current was measured at a number of operating points. This value was corrected for current tare (obtained by shorting anode to cathode) and cold flow tare. Comparison of these results with the corresponding thrust killer measurement produced agreement within 5 percent. Gaseous propellant flow rates were measured by the use of small jeweled sonic orifices calibrated for flow rate against upstream pressure.

BACKGROUND PRESSURE MEASUREMENT

The tank pressure was measured by a Bayard-Alpert type ionization gage at pressures below 1 micron. Above 1 micron a thermocouple gage was used. Both gages were calibrated on air and a correction factor is conventionally applied for other gases. In many experiments the tank contained a mixture of two or more gases in unknown ratios.

For this reason correction factors were not applied to the gage readings.

Pressures quoted are therefore accurate to approximately a factor of 3.

RESULTS AND DISCUSSION

Avco X-7CR

The Lewis data for the Avco X-7CR are shown in figure 6. The tank pressure was about 2×10^{-4} torr. The magnetic field at the cathode tip was 0.125 or 0.166 tesla. Performance did not appear to depend on magnetic field. Data were taken for ammonia flow rates of 0.014, 0.02, 0.03, and 0.05 gram per second.

Also shown in figure 6 are data obtained by Avco on the same thruster (ref. 2). The data at mass flow rates of 0.020, 0.023, and 0.026 gram per second are taken from figure 23 of reference 2. The data at 0.036 gram per second were computed from data given in table XII of reference 2. The magnetic field was varied from 0.088 to 0.250 tesla. Tank pressures were in the 1/10 torr range.

Figure 6 shows that, at low specific impulse, the performance obtained in the low-pressure Lewis chamber is higher than that obtained by Avco at higher pressure. Conversely, at higher specific impulse (also lower mass flow rate) the measurements obtained by Avco indicate higher performance. This trend is consistent with studies made of the interaction of the propellant with the background gas as reported in reference 5. At high mass flow rates measured performance tends to degrade with increasing tank pressure due to collisions between beam and background gas. This has been noted up to pressures of about 0.5 torr. At lower mass flow rates there is a spurious thrust augmentation which increases with tank pressure. This is due to entrainment of background gas.

McDonnell-Douglas X-4A

In figure 7 arc efficiency is plotted against specific impulse for the McDonnell-Douglas X-4A operating in the Lewis facility. Data are shown for a magnetic field of 0.1 tesla and ammonia flow rates of 0.02, 0.04, and 0.06 gram per second. The tank pressure was about 10^{-4} torr. As shown in figure 7 the performance improves with increasing mass flow rate.

Figure 8 shows Lewis data on the X-4A and data obtained by McDonnell-Douglas on the same thruster at mass flow rates of 0.02 and 0.03 gram per second. The McDonnell-Douglas data were obtained at tank pressures around 10^{-2} torr. The Lewis data were taken at approximately 10^{-4} torr. Figure 8 shows good agreement between the two sets of data.

As an additional check the performance of the X-4A was measured in the Lewis facility over both pressure ranges of interest. The results are shown in figure 9. The results do not appear to vary significantly between the two pressure ranges. This is consistent with the agreement noted in figure 8.

McDonnell-Douglas X-7

Figure 10 shows arc efficiency against specific impulse for the McDonnell-Douglas X-7 operating in the Lewis facility. Data are shown for ammonia mass flow rates of 0.015, 0.03, 0.06, 0.149, and 0.203 gram per second. The magnetic field was 0.14 tesla at the cathode tip. Again good agreement is obtained between McDonnell-Douglas data at 10^{-2} torr and the Lewis data at 10^{-4} torr as is shown in figure 11. In figure 11 all data were taken with a mass flow rate of 0.03 gram per second.

The McDonnell-Douglas X-7 was also operated in the higher pressure range as an additional check. Results are shown in figure 12. The ammonia flow rate was 0.03 gram per second and the arc power was 25 kilowatts. Again the dependence of performance on tank pressure was small enough to be consistent with the good agreement between Lewis data and McDonnell-Douglas data. This is true at least within the expected cumulative error in the two experiments. It should be noted that the pressure in the McDonnell-Douglas vacuum chamber was usually less than 10^{-2} torr. This is not high enough to strongly affect the performance measured at moderate propellant flow rates. The fundamental mechanisms of thruster operation may be affected, however, in a manner which produces little or no <u>net</u> effect on the thrust produced (see ref. 5). The data reported by Avco on their X-7CR was obtained at much higher tank pressure, in the 10^{-1} torr range. In this range even the thrust is strongly affected. Hence, their data deviates considerably from that obtained at much lower tank pressure (10^{-4} torr).

CONCLUDING REMARKS

Thruster performance was measured for three different radiation-cooled MPD arc thrusters operating at 10^{-4} torr in the Lewis facility. The Avco X-7CR performed better at low specific impulse and worse at high specific impulse than reported by Avco at higher background pressure. The McDonnell-Douglas X-4A and X-7 performance was in agreement with data published by McDonnell-Douglas, at least within the expected cumulative error in two different experiments.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, August 4, 1969,
120-26.

REFERENCES

1. Finke, Robert C.; Holmes, Arthur D.; and Keller, Thomas A.: Space Environment Facility for Electric Propulsion Systems Research. NASA TN D-2774, 1965.
2. Bennett, S.; Enos, G.; John, R.; and Powers, W.: Magnetoplasmadynamic Thruster Research. Rep. AVSSD-0272-67-RR, Avco Corp. (NASA CR-72345), May 21, 1967.
3. Esker, D. W.; Kroutil, J. C.; and Checkley, R. J.: Radiation Cooled MPD Arc Thruster. Rep. H296, McDonnell-Douglas Aircraft Corp. (NASA CR-72557), 1969.
4. Ducati, Adriano C.; Muehlberger, Erich; and Giannini, G.: High Specific Impulse Thermo-Ionic Acceleration. Paper 64-668, AIAA, Aug. 1964.
5. Connolly, D. J.; and Sovie, R. J.: The Effect of Background Pressure and Magnetic Field Shape on MPD Thruster Performance. Paper 69-243, AIAA, Mar. 1969.

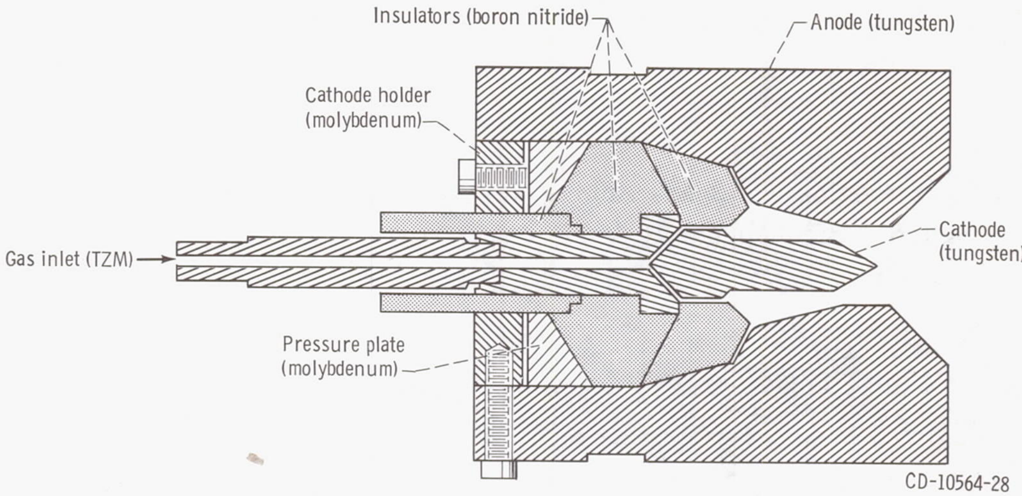

Figure 1. - Schematic drawing of Avco X-7CR radiation-cooled magnetoplasmadynamic arc thruster.

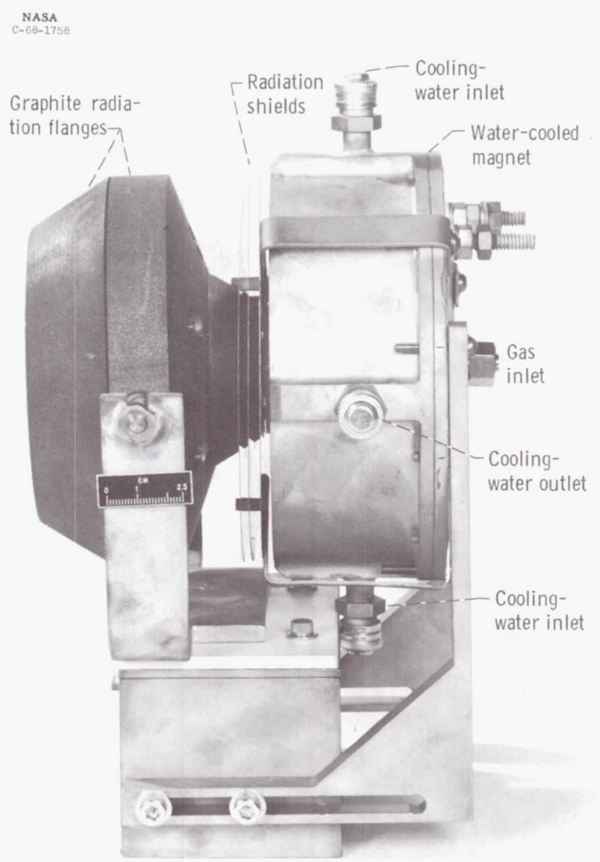

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Figure 2. - McDonnell-Douglas X-4A radiation-cooled magnetoplasma-dynamic arc thruster.

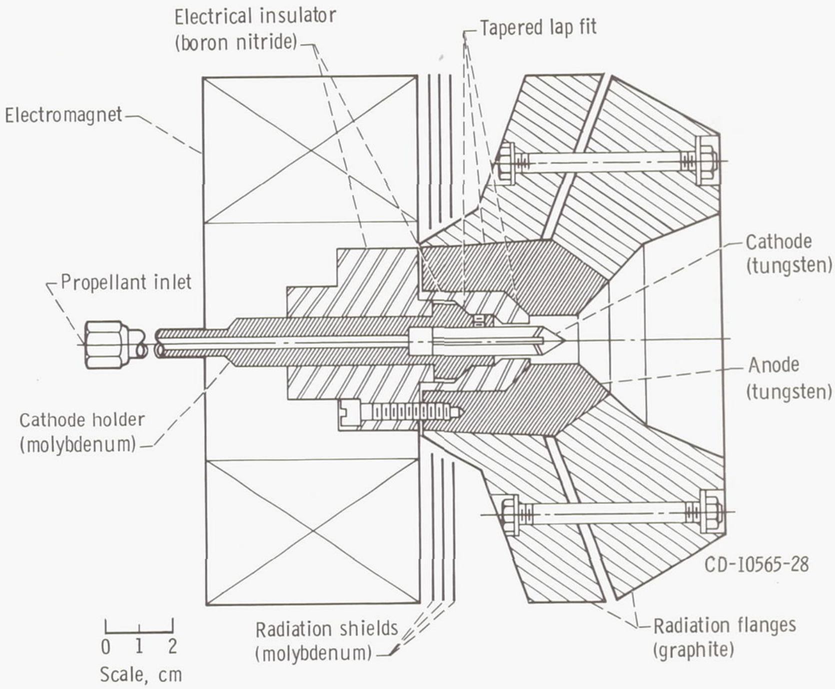

Figure 3. - Schematic drawing of McDonnell-Douglas X-4A thruster.

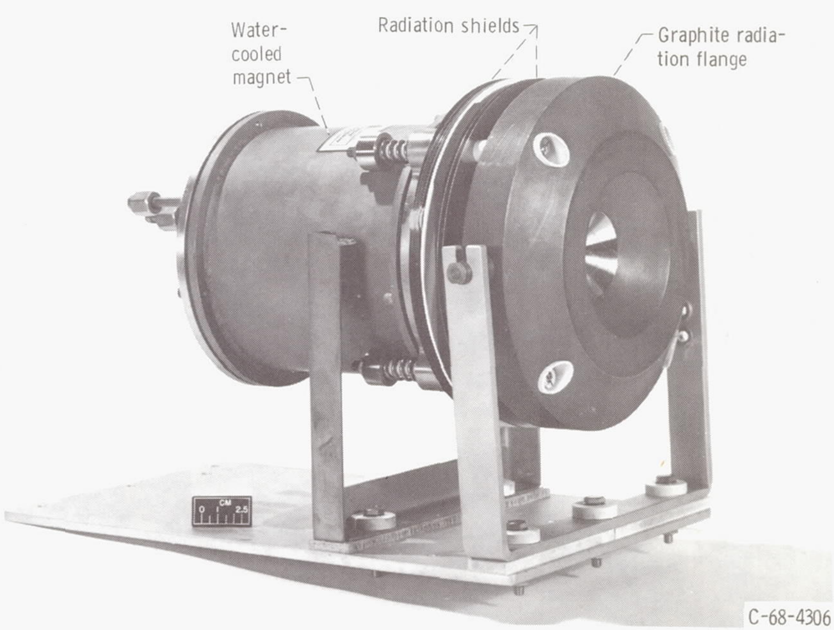

Figure 4. - McDonnell-Douglas X-7 radiation-cooled magnetoplasmadynamic arc thruster.

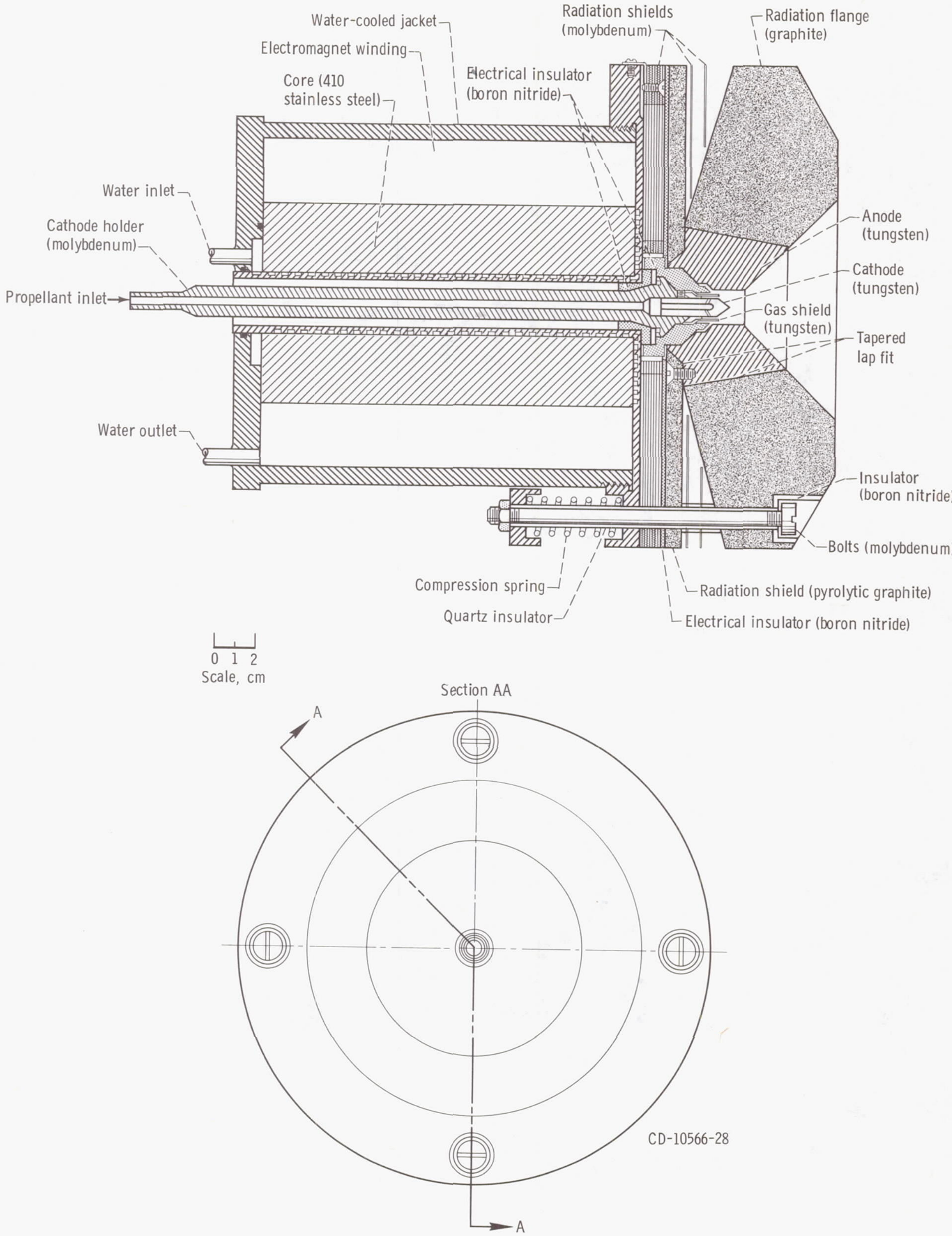

Figure 5. - Schematic drawing of McDonnell-Douglas X-7 thruster.

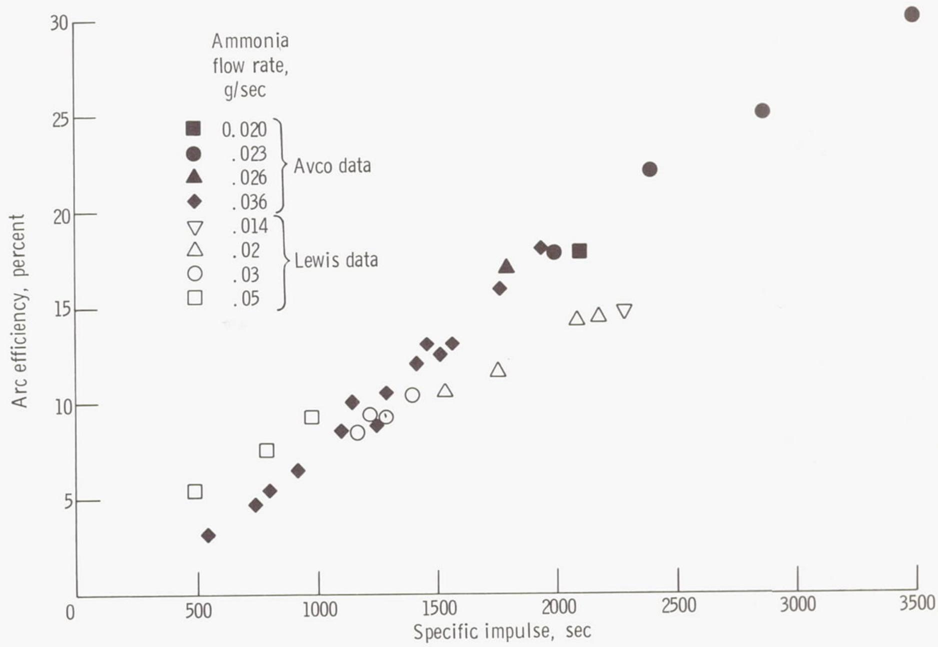

Figure 6. - Specific impulse as function of arc efficiency for Avco X-7CR thruster.

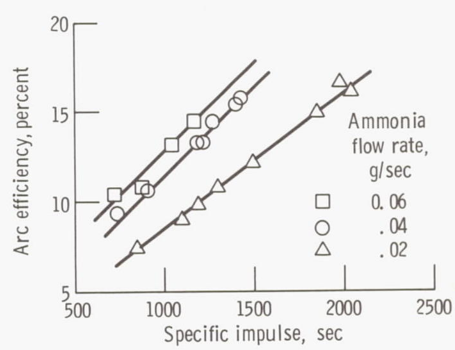

Figure 7. - Specific impulse as function of arc efficiency for McDonnell-Douglas X-4A thruster operating at 10^{-4} torr in Lewis facility.

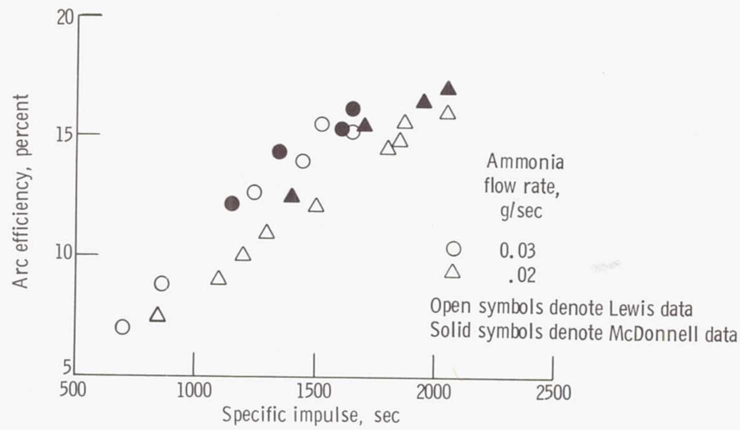

Figure 8. - Arc efficiency as function of specific impulse for McDonnell-Douglas X-4A thruster.

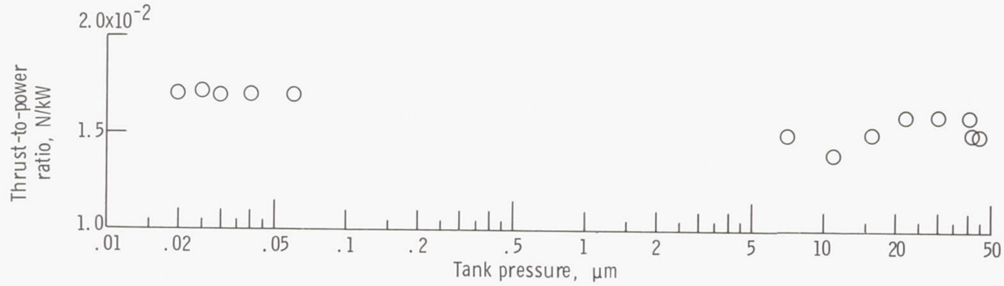

Figure 9. - Thrust-to-power ratio as function of tank pressure for McDonnell-Douglas X-4A thruster. Ammonia flow rate, 0.02 gram per second; arc power, ~25 kilowatts.

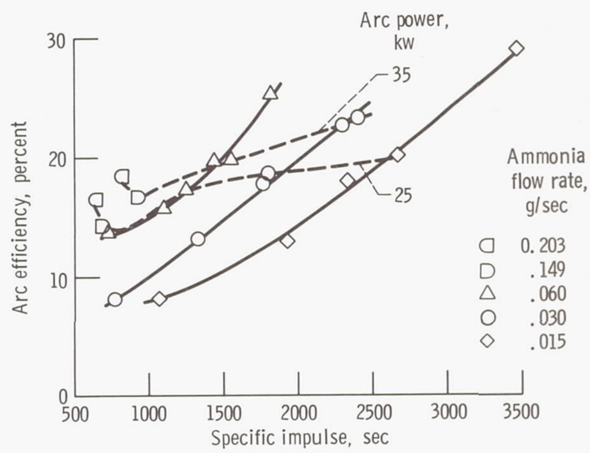

Figure 10. - Specific impulse as function of arc efficiency for McDonnell-Douglas X-7 thruster operating at 10^{-4} torr in Lewis facility.

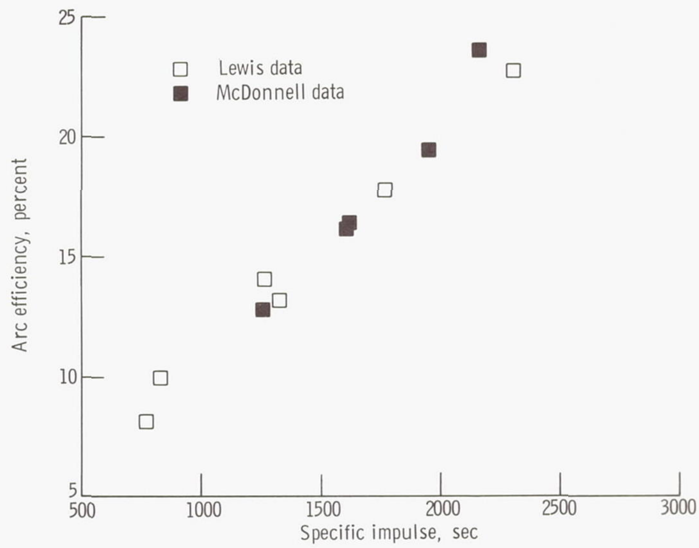

Figure 11. - Arc efficiency as function of specific impulse for McDonnell-Douglas X-7 thruster.

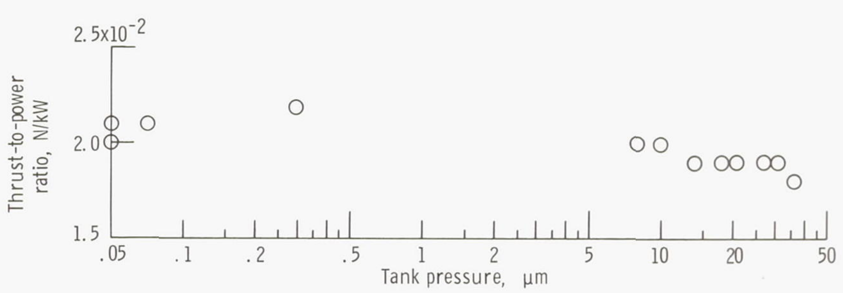

Figure 12. - Thrust-to-power ratio as function of tank pressure for McDonnell-Douglas X-7 thruster. Mass flow rate, 0.03 gram per second; arc power, 25 kilowatts.

1. Report No. NASA TM X-1908	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle PERFORMANCE OF RADIATION-COOLED MAGNETOPLASMADYNAMIC ARC THRUSTERS		5. Report Date October 1969
		6. Performing Organization Code
7. Author(s) Denis J. Connolly and Ronald J. Sovie		8. Performing Organization Report No. E-5216
9. Performing Organization Name and Address Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135		10. Work Unit No. 120-26
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		13. Type of Report and Period Covered Technical Memorandum
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

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17. Key Words *(Suggested by Author(s))* MPD thrusters		18. Distribution Statement Unclassified - unlimited	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassifed	21. No. of Pages 12	22. Price* $3.00

*For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151