1-P

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-560

A Portable Hydrazine Attitude Propulsion Test System

Philip I. Moynihan

(NASA-CR-128342) A PORTABLE HYDRAZINE ATTITUDE PROPULSION TEST SYSTEM P.I. Moynihan (Jet Propulsion Lab.) 1 Sep. 1972 15 p CSCL 21H
N72-33745
Unclas
G3/28 44063

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

September 1, 1972

22

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. 33-560	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle A PORTABLE HYDRAZINE ATTITUDE PROPULSION TEST SYSTEM		5. Report Date September 1, 1972 6. Performing Organization Code
7. Author(s) Philip I. Moynihan		8. Performing Organization Report No.
9. Performing Organization Name and Address JET PROPULSION LABORATORY California Institute of Technology 4800 Oak Grove Drive Pasadena, California 91103		10. Work Unit No. 11. Contract or Grant No. NAS 7-100 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		

16. Abstract

This report describes the portable hydrazine attitude propulsion module that was designed and developed to support the attitude control pitch axis simulation tests that were performed on an air-bearing table in JPL's Celestarium facility for the Thermoelectric Outer Planet Spacecraft (TOPS) program. The propulsion module was a self-contained, liquid hydrazine propulsion system from which the exhausted gases were generated within the catalyst bed of either of two nominal 0.22-N (0.05-lb_f) opposing thrusters. The module, which was designed for convenient assembly onto and removal from an air-bearing table in the JPL Celestarium, was tested extensively to establish its operational safety. This test history and the very conservative design of the module enabled it to be "man-rated" for operation in the presence of personnel. The report briefly summarizes the system operations during air-bearing table tests, presents a detailed description of the propulsion module hardware, and discusses the system evolution.

17. Key Words (Selected by Author(s))	18. Distribution Statement
Propulsion, Liquid Thermoelectric Outer-Planet Spacecraft (TOPS) Attitude Propulsion	Unclassified -- Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	14	$3.00

HOW TO FILL OUT THE TECHNICAL REPORT STANDARD TITLE PAGE

Make items 1, 4, 5, 9, 12, and 13 agree with the corresponding information on the report cover. Use all capital letters for title (item 4). Leave items 2, 6, and 14 blank. Complete the remaining items as follows:

3. Recipient's Catalog No. Reserved for use by report recipients.

7. Author(s). Include corresponding information from the report cover. In addition, list the affiliation of an author if it differs from that of the performing organization.

8. Performing Organization Report No. Insert if performing organization wishes to assign this number.

10. Work Unit No. Use the agency-wide code (for example, 923-50-10-06-72), which uniquely identifies the work unit under which the work was authorized. Non-NASA performing organizations will leave this blank.

11. Insert the number of the contract or grant under which the report was prepared.

15. Supplementary Notes. Enter information not included elsewhere but useful, such as: Prepared in cooperation with... Translation of (or by)... Presented at conference of... To be published in...

16. Abstract. Include a brief (not to exceed 200 words) factual summary of the most significant information contained in the report. If possible, the abstract of a classified report should be unclassified. If the report contains a significant bibliography or literature survey, mention it here.

17. Key Words. Insert terms or short phrases selected by the author that identify the principal subjects covered in the report, and that are sufficiently specific and precise to be used for cataloging.

18. Distribution Statement. Enter one of the authorized statements used to denote releasability to the public or a limitation on dissemination for reasons other than security of defense information. Authorized statements are "Unclassified—Unlimited," "U.S. Government and Contractors only," "U.S. Government Agencies only," and "NASA and NASA Contractors only."

19. Security Classification (of report). NOTE: Reports carrying a security classification will require additional markings giving security and downgrading information as specified by the Security Requirements Checklist and the DoD Industrial Security Manual (DoD 5220.22-M).

20. Security Classification (of this page). NOTE: Because this page may be used in preparing announcements, bibliographies, and data banks, it should be unclassified if possible. If a classification is required, indicate separately the classification of the title and the abstract by following these items with either "(U)" for unclassified, or "(C)" or "(S)" as applicable for classified items.

21. No. of Pages. Insert the number of pages.

22. Price. Insert the price set by the Clearinghouse for Federal Scientific and Technical Information or the Government Printing Office, if known.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-560

A Portable Hydrazine Attitude Propulsion Test System

Philip I. Moynihan

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

September 1, 1972

Prepared Under Contract No. NAS 7-100
National Aeronautics and Space Administration

PREFACE

The work described in this report was performed by the Propulsion Division of the Jet Propulsion Laboratory.

ACKNOWLEDGMENT

The author wishes to thank Gregory Nunz, who designed the 0.22-N (0.05-lb_f) thruster, Ray Hagler, who provided the feed system component support, Roy Bjorklund, who gave active support to the overall program, and James Kizziar and James Allison, who gave extensive technical assistance.

CONTENTS

I. Introduction 1

II. Discussion 2

A. Celestarium Test Objectives 2

B. Tests Performed 2

C. Hardware Description 4

D. Background Safety Considerations 6

III. Conclusions 7

References 8

FIGURES

1. Portable hydrazine propulsion module 9

2. Celestarium air-bearing table angular velocity reduction rate, thruster SN 006P 10

3. Celestarium air-bearing table angular velocity reduction rate, thruster SN 004P 11

4. Hydrazine propulsion module feed system 12

5. Hydrazine propulsion module thruster/valve assembly 13

6. Conceptual drawing of thruster used in the Celestarium propulsion module 14

ABSTRACT

This report describes the portable hydrazine attitude propulsion module that was designed and developed to support the attitude control pitch axis simulation tests that were performed on an air-bearing table in JPL's Celestarium facility for the Thermoelectric Outer Planet Spacecraft (TOPS) program. The propulsion module was a self-contained, liquid hydrazine propulsion system from which the exhausted gases were generated within the catalyst bed of either of two nominal 0.22-N (0.05-lb_f) opposing thrusters. The module, which was designed for convenient assembly onto and removal from an air-bearing table in the JPL Celestarium, was tested extensively to establish its operational safety. This test history and the very conservative design of the module enabled it to be "man-rated" for operation in the presence of personnel. The report briefly summarizes the system operations during air-bearing table tests, presents a detailed description of the propulsion module hardware, and discusses the system evolution.

I. INTRODUCTION

As part of the overall Attitude Propulsion System (APS) technology program for the Thermoelectric Outer Planet Spacecraft (TOPS), the JPL Liquid Propulsion Section was requested to support the single-axis attitude control verification test program conducted by the JPL Spacecraft Control Section. This test program was conducted on an air-bearing table in the JPL Celestarium, a stellar simulation facility. The purpose of the program was to test a complete, integrated attitude control system (simulating a single spacecraft axis) on an air-bearing table. The responsibility of the Liquid Propulsion Section was to provide a self-contained "man-rated," liquid-hydrazine-fueled thrusting system with two 0.22-N (0.05-lb_f) thrusters facing in opposite directions. A liquid-hydrazine-fueled system had not been previously used for this type of test program at JPL. Several potential problems, primarily problems of propellant safety, were anticipated and made part of the overall program. Most of the safety questions were dispelled by investigation and education; the remaining problems were alleviated by proper design considerations of the propulsion module. The propulsion module was completed and available for integration with the attitude control electronics on November 25, 1970. The active phase of the air-bearing table test program began April 23, 1971, and continued until July 16, 1971. A summary of this overall effort is presented herein.

II. DISCUSSION

A. Celestarium Test Objectives

The objective of this program was to verify the performance of the TOPS baseline attitude control hardware by comparing collected test data to computer simulations in all anticipated modes of operation. The results of these tests are reported in Ref. 1 and are summarized below.

B. Tests Performed

The general procedures followed during the attitude control verification tests in the Celestarium are summarized in the following paragraphs. For each of these tests the portable hydrazine propulsion module was installed and active. The air-bearing table with the propulsion system installed is shown in the insert in Fig. 1.

1. Tipoff rate reduction and sun acquisition. The table was spun up to the desired initial rate (approximately 1 deg/s) with the torque generated by the hydrazine propulsion module. The system then accomplished the reduction of the simulated spacecraft tipoff rates, acquired the sun (simulated sun source), activated the reaction wheel (see 3 below), and disconnected the gyro output.

2. Bias sun sensors. A sun sensor bias was inserted while in the cruise mode, which caused the system to move to the offset position without activating the thrusters. This test was repeated for sun diameters corresponding to various distances from earth.

3. Wheel unloading. This phase of the air-bearing table tests was run to verify the normal reaction wheel unloading characteristics for both the wheel saturated mode and the command-to-unload mode for any wheel speed. (A reaction wheel is a momentum exchange device, which operates at a variable spin rate and was to provide the primary attitude control for the TOPS spacecraft. When the wheel reaches its maximum angular velocity, it is said to be "saturated." The angular velocity is taken out, or "unloaded," by despinning the wheel to a very low spin rate. The spacecraft position, meanwhile, is held by the action of an outside torque induced by a thruster firing at the end of a moment arm.) The test sequence was approximately as follows:

(1) With the attitude control electronics bypassed, the thrusters were actuated until the wheel was saturated. The attitude control system was then re-engaged and the wheel was unloaded.

(2) With the wheel below the saturation speed, an unloading command was input and the thrusters activated to successfully unload the wheel.

4. Commanded turns. With the reaction wheel unloaded, a turn angle requirement was introduced and the turn executed. All commanded turns were performed without activating the thrusters, since this test series had been designed before the commanded turn functions had been assigned to the APS by the TOPS project.

5. Cruise mode performance. Thruster limit cycle performance in the presence of various disturbance torque levels was determined over the range of minimum available to approximately 1000 dyne-cm, the worst-case solar torque at 1 AU. The thrusters were actuated to provide the initial disturbance torque.

6. Transient disturbances. The table was perturbed (by pulsing the thrusters) to simulate a transient disturbance large enough to require the thrusters to actuate. Recovery was observed.

7. Thrust measurement. Since the air-bearing table was very well balanced (nominally well within 600 dyne-cm), a special test was performed to determine the actual torque output (and hence thrust) of the propulsion module. These results are presented in Figs. 2 and 3. The test consisted of establishing an initial table angular velocity, followed by the steady-state actuation of the thruster opposing the direction of rotation until the table was stopped. The change of angular velocity as a function of time was recorded by an x-y plotter on an expanded time grid. The reduced data is presented in Figs. 2 and 3. The values for the theoretical torques presented in Figs. 2 and 3 were derived from the assumption that the design thrust level for each thruster is 0.22 N (0.05 lb_f) at a tank pressure of 2.06×10^6 N/m^2 (300 psig). This force, acting at the end of the module 2-ft moment arm, results in a torque of 0.136 N-m (0.1 ft-lb_f). This was defined as the design theoretical torque, which was corrected for the lower tank pressures that existed at the time of the angular velocity reduction rate tests.

Because 15 tank refuelings had occurred with thruster SN 004P installed but only eight since thruster SN 006P had been installed, thruster SN 004P has approximately twice the accumulated quantity of starts. Hence a decline in thrust level (as well as performance) was anticipated. However, the magnitude of the decline (~39%) is greater than that which might be projected by merely performance decay. A flow restriction caused by excessive thermal cycling of the downstream bend in the thermal stress relief section of the injector tube was observed at the completion of the program. This reflects a design weakness; so future JPL thrusters in this size range will incorporate a different thermal stress relief concept.

C. Hardware Description

The self-contained, completely enclosed, portable propulsion module which was delivered to the Celestarium is shown in Fig. 1. The module was composed of a 0.3 × 0.15 × 0.33-m (12 × 6 × 13-in.) enclosure for the feed system and a 0.23 × 0.1 × 0.08-m (9 × 4 × 3-in.) container for the solenoid valves, capillary tubes, and thruster supports. These aluminum enclosures were joined by a 0.46 × 0.04-m (18 × 1.5-in.) diameter tube which functioned both as a support member and as an enclosure for the propellant feed tube. All surfaces were black anodized for minimum light reflection during sun sensing operations. The larger section of the module enclosed the feed system (Fig. 4), which consisted of a propellant tank containing less than 1/2 liter of hydrazine, a 5-μm (absolute) filter, a hand-operated shutoff valve (shown between the liquid and gaseous nitrogen fill valves), and related tubing. The smaller enclosure contained the two opposing thrusters (shown protruding from each end in Fig. 5), the solenoid valves, and the pressure-dropping/flow-metering capillary tubes. The thrusters were insulated for better performance in the atmosphere. The propulsion module is shown assembled on the air-bearing table in the Fig. 1 insert, where it has been photoretouched (lightened in tone) for clarity.

The feed system was assembled from components designed to sustain very high pressures. The propellant supply tank had been ASME coded for a 2.75×10^7 N/m^2 (4000 psig) working pressure with a 4:1 safety factor and proof-tested to 4.125×10^7 N/m^2 (6000 psig). (The other components had larger safety factors.) The maximum pressure ever to be experienced during the air-bearing table tests was 2.75×10^6 N/m^2 (400 psig). This ample margin of safety, combined with a history of safe operation, led to a "man-rating" for the module so that it could be operated in the presence of personnel. This action greatly facilitated the checkouts and demonstrations of the equipment on the air-bearing table.

The thrusters used for the Celestarium tests were identical replicas of a design which had sustained (on a single thruster) more than 30,000 starts with an accumulated on-time on the order of 8000 s. A conceptual drawing of this thruster is presented as Fig. 6. The penetrant injector element was the design selected for the Celestarium module. Details of the thruster test program are available in Ref. 2. These delivered thrusters were acceptance-tested for approximately 1000 starts and less than 1000 s of on-time in order to provide a sufficient life margin for the duration of the single-axis tests. The number of starts required of each thruster for the single-axis tests was initially estimated to be approximately 5000. The actual number, however, exceeded this by a factor of 20 on one thruster and by a factor of almost 40 on the other, for an accumulated on-time in excess of 4 hours. This thruster (SN 004P) was estimated to have experienced on the order of 180,000 starts; it had been operational for 15 tank refuelings at a duty cycle of 0.1 s on with a variable off line.

The original mate to this thruster (SN 005P) was removed after seven tank refuelings because of what sounded like an excessive popping noise. This did not constitute a personnel hazard, but a potential reduction in thruster life was visualized. The thruster was then instrumented and tested at atmospheric conditions in a liquid propulsion test facility (Bldg. 117). The checkout test consisted of operating at both the 2.75×10^6 and 1.38×10^6 N/m^2 (400 and 200 psig) steady-state inlet pressure limits and sweeping through low to high pulse mode duty cycles (percent on-time per total cycle time). At no time could the popping be repeated, and no anomalous performance behavior was indicated on the oscillograph. One possible explanation for the original occurrence of the sound is that it may have been caused by gas in the thruster feed line due to an improper priming. This thruster/valve assembly was set aside as a usable spare.

The propellant tank contained a maximum of 0.86 kg (1.9 lb_m) of liquid anhydrous hydrazine (0.425 liter). As a safety precaution, no propellant transferring was performed in the Celestarium. The module was brought into the Celestarium fully loaded and pressurized and was removed to a liquid propellant handling area for refueling.

D. Background Safety Considerations

The portable hydrazine attitude propulsion system was designed such that the propellant was completely contained within the feed system and exposed only to the nitrogen pressurant; neither propellant nor pressurant was handled in the Celestarium. This was done to avoid concern over the presence of exposed liquid hydrazine in the Celestarium. The "splash-shield" outer enclosure was also added as a precaution in the unlikely event of any liquid leakage, whereupon it would serve as a container.

An investigation was made of the quantity of ammonia that may be generated by the thrusters during operation in the Celestarium and of its effect on personnel and adjacent electronic components. The ventilating system was modified to provide one complete air change in 8 min.

It was estimated that the maximum quantity of ammonia that would be present within the stellar simulation room of the Celestarium after a 5-min continuous thruster operation without venting would be approximately 16 parts per million. An ammonia environmental test was devised for which representative electronic components and other materials of concern were exposed to an average of 17.4 ppm of ammonia for 191.5 h, a time estimated to exceed the total accumulated exposure to ammonia throughout the entire single-axis validation test program. The results, detailed in Ref. 3, indicate that there was no danger of corrosion or deterioration of peripheral equipment from ammonia at this concentration. This was later substantiated by the tests on the air-bearing table.

The propellant feed system was continuously exposed to propellant from July 1970 to July 1971, the end of the test program.

III. CONCLUSIONS

Throughout the entire Celestarium test program the propulsion system operated successfully and without incident. This incident-free operation not only contributed to the success of the simulated attitude control program with the air-bearing table, but also demonstrated an approach to "man-rating" this class of liquid hydrazine propulsion system for this type of activity. It further demonstrated a lifetime performance for the thrusters and associated components far in excess of their design life.

REFERENCES

1. Smith, L. S., "Single-Axis Simulation Test Report," JPL internal report, IOM 344-356, Jet Propulsion Laboratory, Pasadena, Calif., Aug. 16, 1971.

2. Nunz, G. J., "Experimental Evaluation of a Miniature Catalytic Hydrazine Thruster," AIAA Paper 71-706 presented at the AIAA/SAE 7th Propulsion Joint Specialist Conference, Salt Lake City, Utah, June 14-18, 1971.

3. Roselli-Lorenzini, F. G., and Moynihan, P. I., "Ammonia Compatibility Test for TOPS Attitude Control System Electronic Equipment," JPL internal report, IOM 344-212, Jet Propulsion Laboratory, Pasadena, Calif., July 9, 1970.

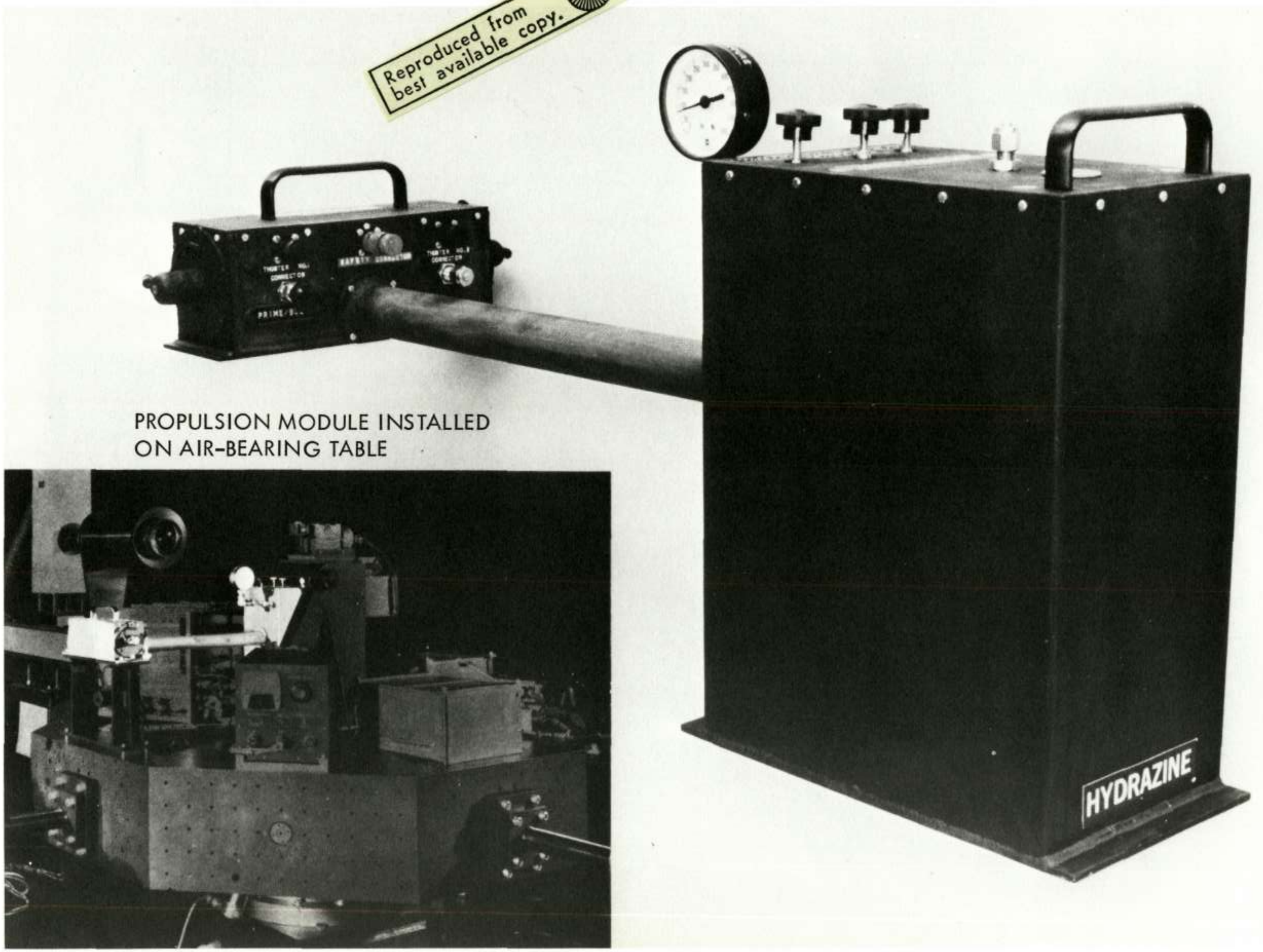

Fig. 1. Portable hydrazine propulsion module

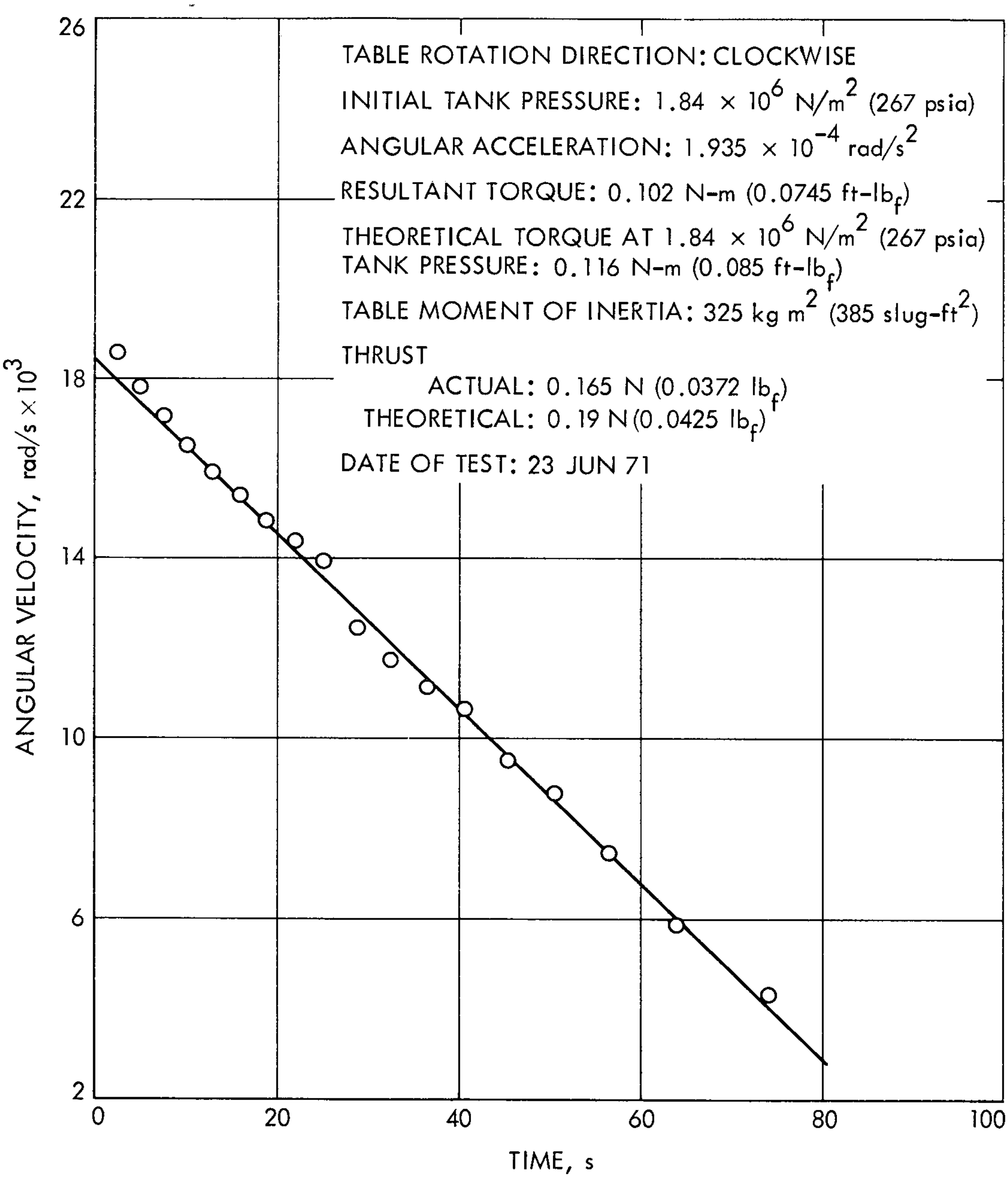

Fig. 2. Celestarium air-bearing table angular velocity reduction rate, thruster SN 006P

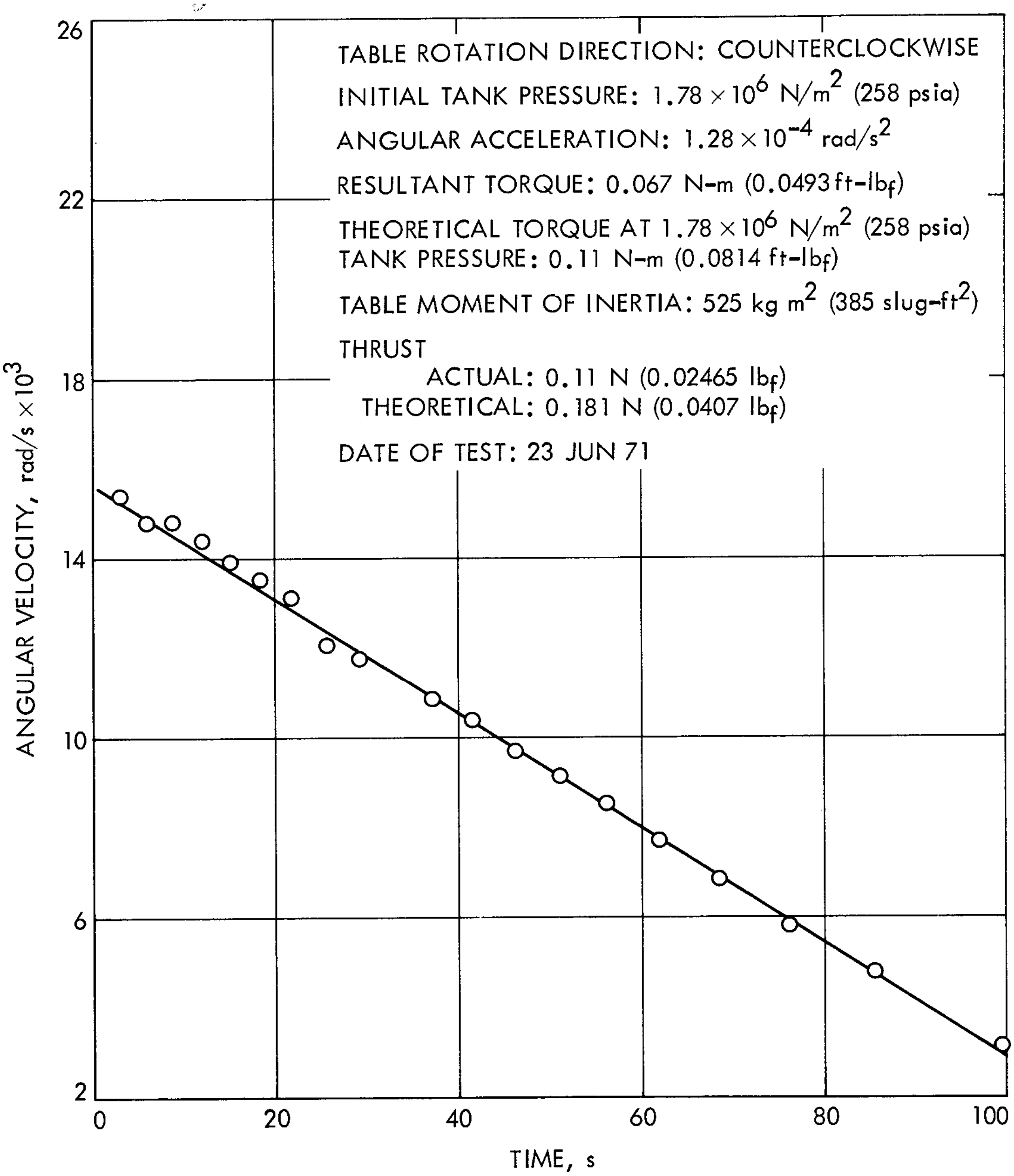

Fig. 3. Celestarium air-bearing table angular velocity reduction rate, thruster SN 004P

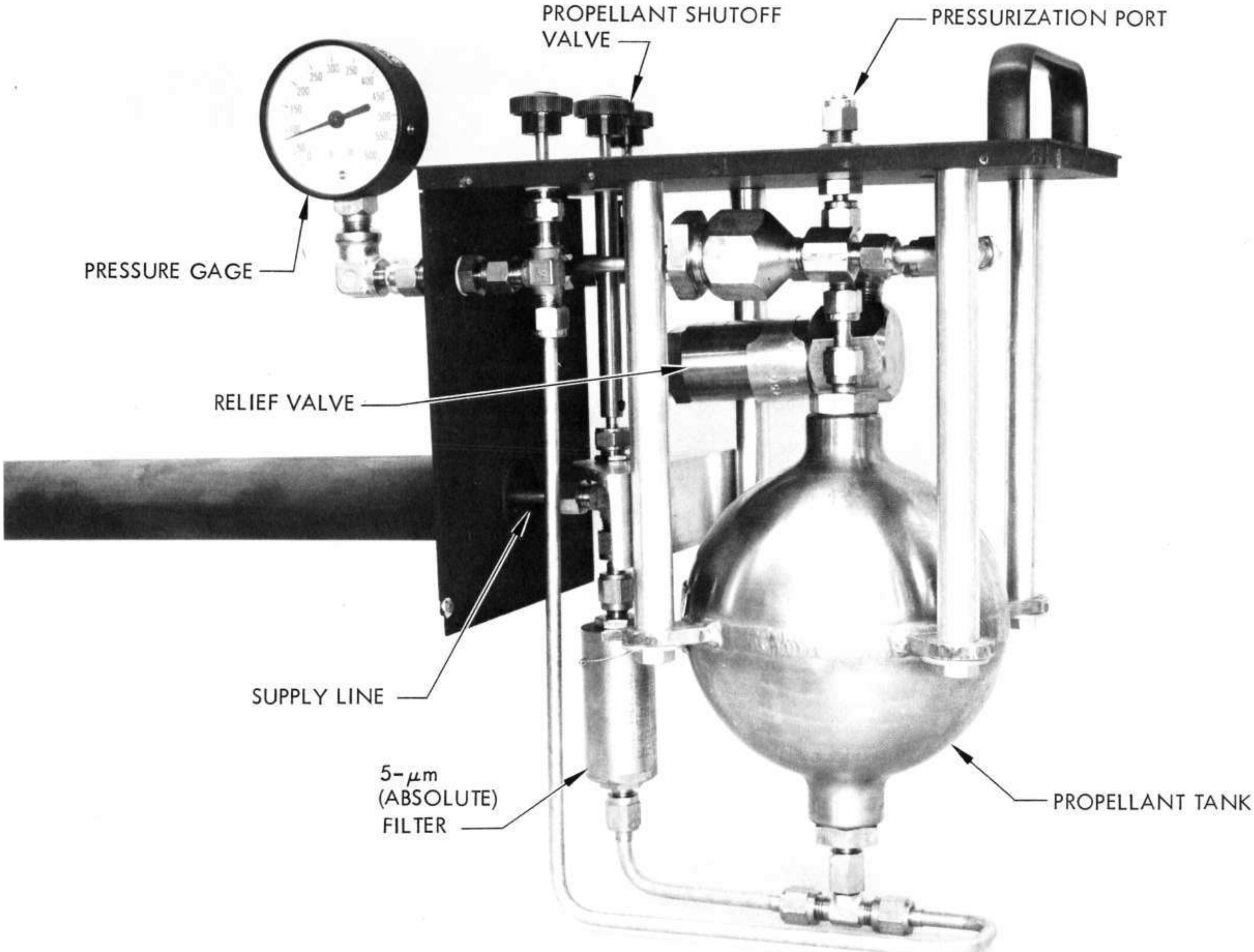

Fig. 4. Hydrazine propulsion module feed system

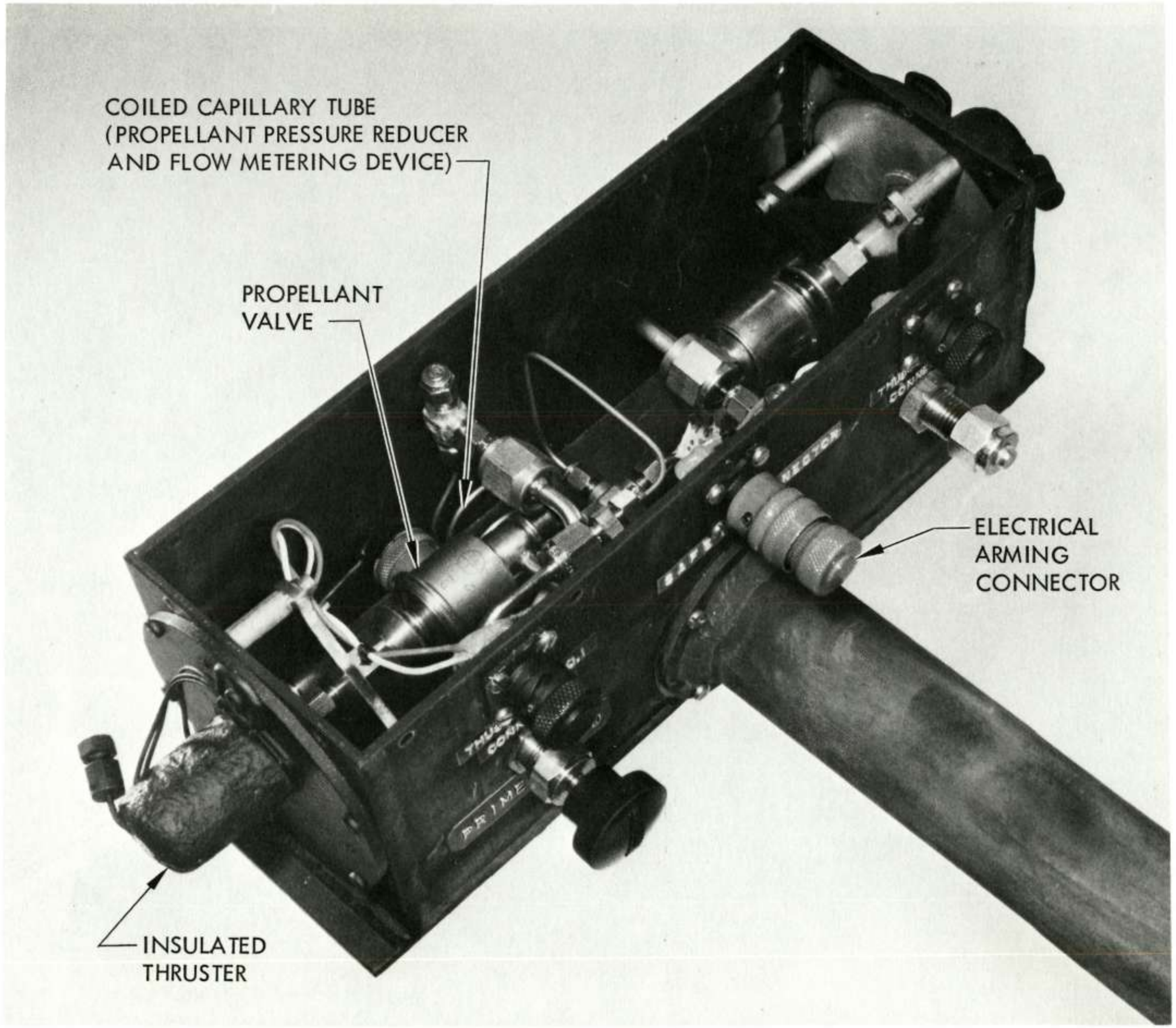

Fig. 5. Hydrazine propulsion module thruster/valve assembly

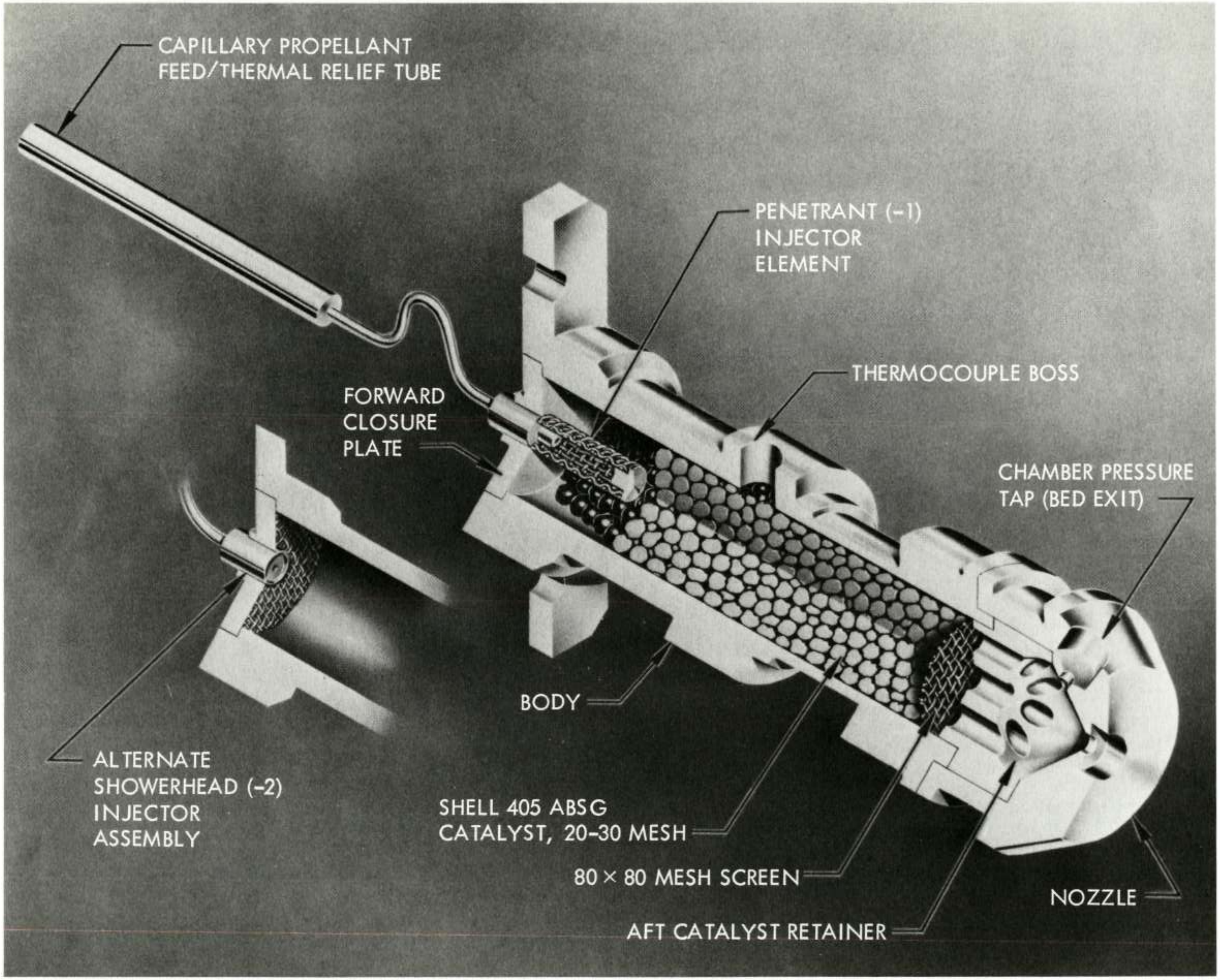

Fig. 6. Conceptual drawing of thruster used in the Celestarium propulsion module

NASA — JPL — Coml., L.A., Calif.