NASA TECHNICAL NOTE

NASA TN D-6875

c 1

NASA TN D-6875

TECHNIQUES ASSOCIATED WITH THERMAL-VACUUM TESTING OF THE OAO C HEAT PIPES

by James P. Marshburn

Goddard Space Flight Center
Greenbelt, Md. 20771

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • AUGUST 1972

1. Report No. NASA TN D-6875	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Techniques Associated With Thermal-Vacuum Testing of the OAO C Heat Pipes		5. Report Date August 1972
		6. Performing Organization Code
7. Author(s) James P. Marshburn		8. Performing Organization Report No. G-1065
9. Performing Organization Name and Address Goddard Space Flight Center Greenbelt, Maryland 20771		10. Work Unit No.
		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 Note
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The three circular heat pipes of the OAO C spacecraft are designed to isothermalize the structure and are experimental in nature, each of a different internal design. Two are used to transport high-heat loads and the third is for low-heat loads. The mechanical problems associated with testing the two high-heat-load pipes are discussed in this paper; the testing of one pipe is given in detail. It was tested three times before being accepted. In the first test, noncondensable hydrogen gas prevented the pipe from functioning properly. The test was repeated successfully after all the gas had been removed. Because the epoxy binding agent between the saddles and the pipe had decomposed during the testing, saddle modifications were necessary and the test was run a third time, with results similar to the second test.

The test problems discussed concern the specially designed heat-removal devices, the mobile tilt table, the table position indicator, and the heat input mechanisms, all of which were necessary to conduct a high-heat-load, thermal-vacuum test. The final results showed that the techniques were adequate for thermal-vacuum testing of heat pipes.

17. Key Words (Selected by Author(s)) Thermal-vacuum testing; OAO C heat pipes; Heat removal; Heat input; Tilt table		18. Distribution Statement Unclassified—Unlimited	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 7	22. Price* $3.00

*For sale by the National Technical Information Service, Springfield, Virginia 22151.

CONTENTS

	Page
Abstract	i
INTRODUCTION	1
TEST SETUP	1
THERMAL DATA RETRIEVAL	4
TEST RESULTS	4
Reference	7

TECHNIQUES ASSOCIATED WITH THERMAL-VACUUM TESTING OF THE OAO C HEAT PIPES

by

James P. Marshburn
Goddard Space Flight Center

INTRODUCTION

The three OAO C heat pipes, illustrated in Figures 1 and 2, were designed and built to isothermalize the spacecraft structure and are experimental in nature. All three pipes are made of 6061-T6 seamless aluminum tubing, and the working fluid in each is anhydrous ammonia with a specified purity of 99.995 percent with less than 50 ppm of H_2O. The two high-heat transport pipes were designed to (1) operate for 12 000 hr or more (Reference 1), (2) carry the spacecraft heat load of 12.70 W-m (500 W-in.) along the entire pipe with a maximum delta temperature (ΔT) of 1.6 K, (3) carry an auxiliary heat load of 111.8 W-m (4400 W-in.) with a maximum ΔT of 6.7 K, and (4) carry 178 W-m (7000 W-in.) in a 1*g* field, with the evaporator elevated 1.9 cm (0.75 in.) above the condensers, at a maximum ΔT of 11.1 K. The low-capacity heat pipe was designed to meet requirements (1) and (2). Satisfactory performance of these conditions in the temperature range of 233 to 303 K (-40° to 30° C) must also be demonstrated.[1]

Each pipe forms a torus 1.191 m (46.9 in.) in diameter, with a nominal 10.2-cm (4-in.) gap. The wall thickness is 0.089 cm (0.035 in.) and the pipe o.d. is 1.270 cm (0.500 in.). Only the hollow artery and the spiral artery pipes were thermal-vacuum tested. Because test problems for both pipes were similar, only the problems associated with the testing of the spiral artery pipe are discussed.

TEST SETUP

To meet the four basic requirements in the 233 to 303 K temperature range, it was necessary to utilize a vacuum-rated tilt table (Figure 3), a variable-control heat-removal device, and vacuum-rated heaters.

The 1.32- by 1.32-m (52- by 52-in.) aluminum tilt table was elevated by an encased (sealed) slow-synchronous-speed vacuum-rated motor (Figure 3, lower center) with a heater. The heater was thermostatically controlled to keep the motor at 293 K throughout the test. To determine the tilt position, a vacuum-rated linear potentiometer was calibrated and used to monitor the table position throughout the test. The overall table levelness was ±0.079 cm (±0.031 in.) with a ±0.041-cm (±0.016-in.) positioning accuracy.

---

[1]*OAO-C Heat Pipe.* Goddard Specification OB-A-0086-C, Sept. 18, 1970.

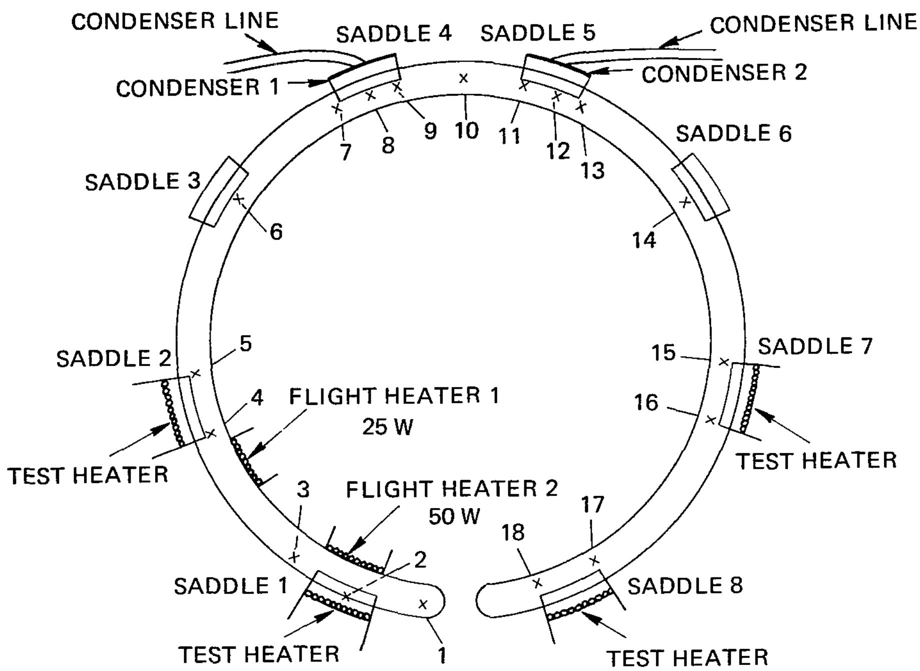

Figure 1—Heat pipe test setup. There are eight saddle supports; x indicates a thermocouple location.

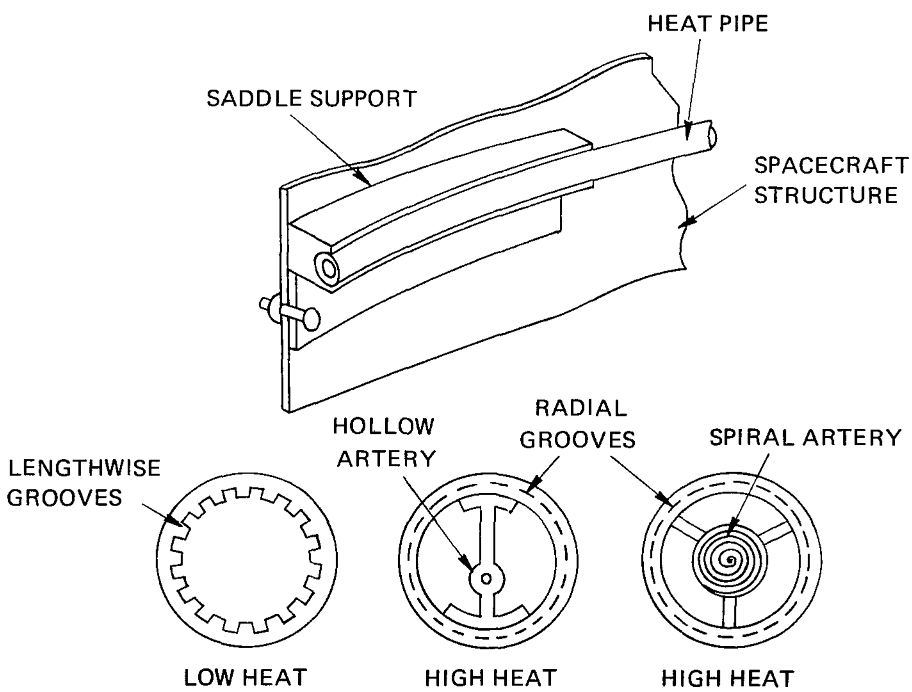

Figure 2—Three types of heat pipes used on OAO C. The fluid used is ammonia.

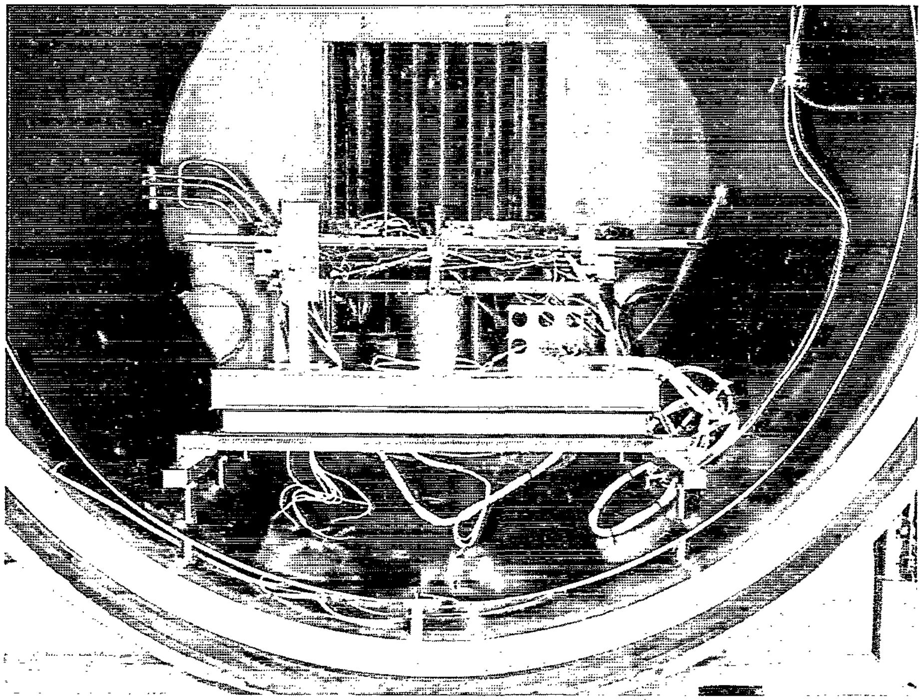

Figure 3—Mobile tilt table and heat pipe in thermal-vacuum chamber.

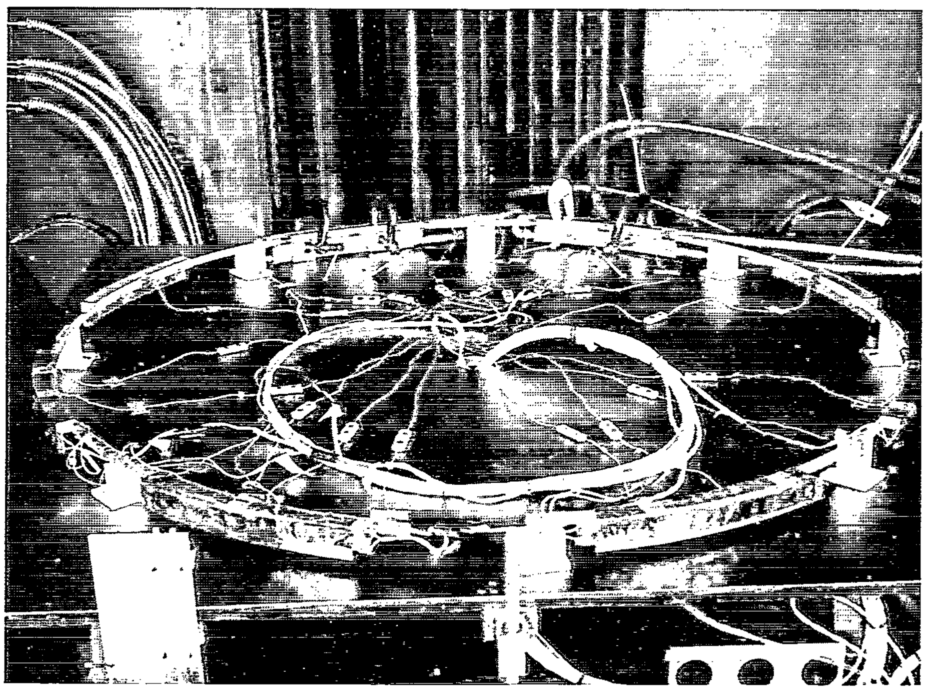

Figure 4—Heat pipe on tilt table.

The heat-removal system consisted of two auxiliary cooling units or condensers, the tubes of which can be seen in Figures 3 and 4 near the C-clamps that bind the two condenser plates to the two saddles. The cooling units were capable of temperature control between 208 and 323 K with an accuracy of ±2 K. This accuracy is essential because heat pipes function differently at different thermal levels.

Four vacuum-rated heaters (capable of 100 W output each) were mounted on saddles on the outer circumference of the pipe, equidistant from the gap in the pipe, and two flight heaters were permanently mounted on the inner circumference, both on one side of the gap, as seen in Figures 1 and 4. Thermocouple locations are also shown in Figures 1 and 4.

Because the heaters had a different absorptivity/emissivity (α/ϵ) value than the aluminum tube, they were first coated and bonded to the pipes with kapton tape and then wrapped with aluminum foil tape. The kapton tape proved to be necessary in the first heat pipe test because the aluminum tape showed signs of burning. The kapton tape was able to withstand the heater temperatures, and prevented the aluminum foil tape from burning.

THERMAL DATA RETRIEVAL

After functionally achieving a workable test setup, it was essential to have a flexible data retrieval system. Several methods were used during the heat pipe tests. The first method utilized an independent thermistor system with twisted shielded pairs of wires; but because of solenoid switching in the test complex, the twisted pairs picked up noise spikes that falsely indicated changes of ±3 to 5 K. The second method used thermocouples and a programed time-sharing computer system. This method successfully avoided the noise spikes, but increased the data retrieval time per channel from approximately 20 to 90 s. However, pipe average temperatures and ΔT values were easily calculated with the computer system, whereas the former system required hand calculations. In a later heat pipe test, the computer system in conjunction with a recorder[2] was used very successfully. The computer was used to calculate ΔT values and average pipe temperatures while the recorder monitored the thermal trends. A slight modification of this system was used in a fourth test. This consisted of using a thermocouple thermometer system,[3] which retrieves data faster than the time-sharing computer system and can average up to 36 data channels at the push of a button. The only drawback to this latter system was the lack of a printout data system.

TEST RESULTS

The spiral artery pipe was tested three times. The first test indicated an excessive amount of noncondensable gas within the heat pipe, which prevented the pipe from functioning properly; the gas blocked the condenser (heat removal) areas of the pipe. This caused the pipe to overheat; i.e., it exceeded its upper acceptance limit of 327 K. Test methods showed that the blockage was due to noncondensable gas and not excess fluid. This was concluded because the blocked area could be diminished by increasing the internal vapor pressure and because blockage would recur after the pipe was

[2]A Brown recorder was used.
[3]A Doric thermocouple thermometer system was used.

tilted beyond its capillary pull limit (evaporator 3.81 cm (1½ in.) higher than the condenser).[4] This problem was resolved by opening the pipe, removing all the gas, and recharging the pipe. When the gas was removed, hydrogen gas was discovered, which apparently was introduced when the pipe was originally charged and sealed. The charging procedure required the utmost care because the inclusion of any water vapor could lead again to the generation of hydrogen gas.

After the pipe was recharged, a second test was conducted. This one was very successful. Data were taken under the following three basic thermal conditions: (1) vacuum with chamber walls at 233 K and condensers at 218 K, (2) vacuum with chamber walls and condensers at 273 K, and (3) vacuum with chamber walls and condensers at 293 K. In each test, data were recorded at five different pipe tilt positions, with the condensers below the evaporators, at tilts of 0, 0.64, 1.27, 1.91, and 2.54 cm (0, ¼, ½, ¾, and 1 in.). The test results showed that the pipe functioned very well in all three thermal conditions;[5] it functioned better at the 1.91-cm tilt position than in the level position for 65 percent of the test cases.

Table 1—Test data for thermal condition 1 with flight heaters.

[Chamber walls at 233 K, condenser at 218 K]

Pipe Tilt (cm)	Power[a] (W)	Pipe Average Temperature (K)	Pipe ΔT (K)
0	25	231.2	0.4
	50	236.2	1.0
	75	241.2	1.0
0.64	25	233.2	.4
	50	237.7	1.0
	75	243.7	1.0
1.27	25	232.2	.4
	50	238.2	1.3
	75	244.2	1.0
1.91	25	231.7	1.0
	50	236.2	1.0
	75	–	([b])
1.27[c]	50	248.7	1.2
1.91[c]	50	249.2	1.1
	75	255.2	1.6
2.54[c]	25	245.7	.5
	50	249.7	3.0
	75	257.2	3.0

[a]25 and 50 W indicate that 1 heater was on; 75 W indicates that 2 heaters were on.

[b]Burnout. Pipe was allowed to reprime and burnout recurred under the same test conditions. Burnout occurs when the fluid is evaporated faster than the capillary structure can resupply it.

[c]Condenser at 233 K.

Table 2—Test data for thermal condition 1 with 4 saddle heaters.

[Chamber walls at 233 K, condenser at 218 K]

Pipe Tilt (cm)	Power per Saddle (W)	Pipe Average Temperature (K)	Pipe ΔT (K)
0	50	256.2	4.5
	70	261.7	4.5
	80	269.2	4.0
0.64	10	233.5	.7
	30	246.4	3.8
	50	256.8	4.0
	70	267.2	4.0
	80	273.7	4.5
1.27	10	233.2	2.3
	30	245.7	2.5
	50	257.2	3.5
	70	268.2	4.5
	80	270.2	7.0
1.91	10	233.2	1.5
	30	244.2	3.0
	50	259.2	4.0
	70	270.2	[a]14.0

[a]ΔT was increasing rapidly when all power was turned off.

[4]J. P. Marshburn: "Results of Thermal-Vacuum Testing of the Grumman OAO-C Structural Heat Pipe." Nasa Internal Memo to R. McIntosh, Nov. 10, 1971.

[5]J. P. Marshburn: "Test of the Redesigned Level-6 Spiral-Artery Heat Pipe Under Thermal Vacuum Conditions." NASA Internal Memo to R. McIntosh, Dec. 20, 1971.

Table 3—Test data for thermal condition 2 with flight heaters.

[Chamber walls and condenser at 273 K]

Pipe Tilt (cm)	Power[a] (W)	Pipe Average Temperature (K)	Pipe ΔT (K)
0	25	282.2	1.0
	50	287.2	1.0
	75	293.3	1.0
0.64	25	281.7	.5
	50	287.2	.5
	75	292.2	.5
1.27	25	282.2	.5
	50	287.7	1.0
	75	293.4	.9
1.91	25	283.2	.1
	50	288.0	.6
	75	294.2	1.2
2.54	25	282.8	.4
	50	288.2	1.2
	75	294.3	1.8

[a]25 and 50 W indicate that 1 heater was on; 75 W indicates that 2 heaters were on.

Table 4—Test data for thermal condition 2 with 4 saddle heaters.

[Chamber walls and condenser at 273 K]

Pipe Tilt (cm)	Power per Saddle (W)	Pipe Average Temperature (K)	Pipe ΔT (K)
0	10	280.7	2.0
	30	290.7	2.0
	50	299.7	3.0
	70	314.2	4.0
	80	319.2	5.0
0.64	10	280.2	1.0
	30	291.2	2.0
	50	302.2	3.0
	70	313.2	6.0
	80	319.7	7.0
1.27	10	281.7	1.0
	30	291.7	2.0
	50	301.2	3.5
	70	317.2	19.0
1.91	10	283.7	2.0
	30	295.2	2.5
	50	306.7	5.2
	70	317.2	19.5
2.54	10	284.2	1.2
	30	296.2	3.5
	50	306.7	[a]22.0
	70	–	([b])

[a]Possible burnout started before all power was turned off.
[b]Burnout.

Table 5—Test data for thermal condition 3 with flight heaters.

[Chamber walls and condenser at 293 K]

Pipe Tilt (cm)	Power[a] (W)	Pipe Average Temperature (K)	Pipe ΔT (K)
0	25	301.2	0.7
	50	305.2	.7
	75	310.3	.9
0.64	25	300.4	.5
	50	304.8	.9
	75	310.5	.7
1.27	25	301.2	.6
	50	305.6	.8
	75	310.3	.9
1.91	25	301.2	.4
	50	305.9	1.0
	75	311.5	1.5
2.54	25	301.2	.9
	50	305.2	1.9
	75	310.1	2.1

[a]25 and 50 W indicate that 1 heater was on; 75 W indicates that 2 heaters were on.

Table 6—Test data for thermal condition 3 with 4 saddle heaters.

[Chamber walls and condenser at 293 K]

Pipe Tilt (cm)	Power per Saddle (W)	Pipe Average Temperature (K)	Pipe ΔT (K)
0	10	301.6	0.9
	30	312.2	1.8
	50	323.6	3.2
0.64	10	301.7	1.2
	30	312.2	2.1
	50	324.7	3.7
1.27	10	301.7	1.4
	30	314.8	2.4
	50	–	([a])
1.91	10	301.8	2.1
	30	314.9	3.7
2.54	10	301.8	6.0
	30	314.7	6.6

[a]Terminated power because the upper limit of 327 K was reached.

The first thermal test condition was the most extreme condition under which the pipe had to function. Burnout occurred when both flight heaters were on (75 W total) and the pipe was tilted 1.91 cm (Table 1). Raising the condenser temperature to 233 K allowed the pipe to function without burning out even at 2.54-cm tilt. This demonstrates the effect of the condenser on the pipe. Table 2 lists the test data for the four saddle heaters under this test condition. The 80 W/saddle case was unattainable.

In the second test condition, the largest gradient recorded for the flight heaters occurred at a 2.54-cm tilt, and was recorded as 1.8 K (Table 3). The limit recorded by using the four saddle heaters (based upon ΔT only) occurred with 70 W/saddle at a tilt of 1.27 cm. (See Table 4.)

In the third test condition, the highest flight heater ΔT 2.1 K (Table 5) was recorded at a 2.54-cm tilt position. The largest gradient with the saddle heaters occurred for 200 W (50 W/saddle heater) at a tilt of 1.27 cm. (See Table 6.)

Upon removing the pipe from the test chamber, it was noted that the bonding agent used to bond the saddles to the pipe had crumbled in some areas. Therefore, mechanical clamps were manufactured and the pipe was tested for a third time, with results similar to those of the second test.

In summary, the pipe has proven to be capable of handling high heat loads with small ΔT values, even with tilts of 2.54 cm. It has also been shown that the test setup and equipment were adequate for thermal-vacuum testing of these heat pipes.

Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland, January 21, 1972
831-41-25-02-51

REFERENCE

1. Ollendorf, S.; and Stipandic, E.: "Heat Pipes for Spacecraft Temperature Control: Their Usefulness and Limitations." *Proc. Aerosp. Mech. Conf. 6th* (Ames Research Center), Sept. 9-10, 1971.

NASA-Langley, 1972 —— 33

NATIONAL AERONAUTICS AND SPACE ADMISTRATION
WASHINGTON, D.C. 20546

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300

FIRST CLASS MAIL

POSTAGE AND FEES PAID
NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION

U.S.MAIL

NASA 451

018 001 C1 U 33 720721 S00903DS
DEPT OF THE AIR FORCE
AF WEAPONS LAB (AFSC)
TECHNICAL LIBRARY/DOUL/
ATTN: E LOU BOWMAN, CHIEF
KIRTLAND AFB NM 87117

POSTMASTER: If Undeliverable (Section 158 Postal Manual) Do Not Return

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION OFFICE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546