NASA Technical Paper 1465

Description and Orbit Data of Variable-Conductance Heat-Pipe System for the Communications Technology Satellite

Louis Gedeon

AUGUST 1979

NASA

NASA Technical Paper 1465

Description and Orbit Data of Variable-Conductance Heat-Pipe System for the Communications Technology Satellite

Louis Gedeon
Lewis Research Center
Cleveland, Ohio

National Aeronautics
and Space Administration

Scientific and Technical
Information Branch

1979

SUMMARY

On February 8, 1976, the Communication Technology Satellite was turned on. The Satellite transmits 200 watts of radiofrequency power to Earth from a synchronous orbit. A variable-conductance heat-pipe system (VCHPS) was used to control temperatures of the traveling-wave tube (TWT) and the power processor.

The VCHPS, designed and built by TRW, has been operating in space for 3 years. The system consists of three variable-conductance heat pipes that transfer about 150 watts of heat from the TWT to a radiator fin. Each heat pipe uses methanol as the working fluid, and contains two arteries and a central wick to transport the liquid.

The system had been designed to transfer 196 watts of heat while maintaining a temperature of 50° C or less. The system has performed as designed with the exception of four anomalies that occurred during the equinox seasons. During these times the arteries of all the heat pipes apparently deprimed, which reduced the capacity of the heat pipes and resulted in an increase of the TWT body temperatures to above the desirable operating temperature. The mechanism that triggered the depriming of the arteries has not been determined and is still under investigation.

INTRODUCTION

The Communications Technology Satellite (CTS), a joint effort of the Canadian Department of Communication (DOC) and NASA, was launched in January of 1976. The DOC was responsible for the design, fabrication, integration, and testing of the spacecraft. NASA provided the launch vehicle, a 200-watt traveling-wave tube (TWT) with associated power processor and its primary heat-rejection system (three variable-conductance heat pipes and a radiator fin).

The CTS was positioned in a stationary Earth orbit at 116° west longitude. The thermal design and testing for the spacecraft, which included the design for the parking and transfer orbits, are discussed in references 1 and 2. This report presents the description and design criteria of the variable-conductance heat-pipe-system (VCHPS). The VCHPS was used to reject waste heat from the TWT. Also reported are VCHPS thermal data for a 2-year period, obtained during near-steady-state TWT performance for four relative Sun positions.

On four occasions, the arteries of all three heat pipes deprimed, resulting in activation of the TWT over-temperature alarm. A study of the anomalies by Alexovich and Curren (ref. 3) presents the details and the analysis that determined that the heat pipes had deprimed. Another study was done by B. D. Marcus of TRW (ref. 4). The cause for the heat-pipe depriming has not been determined.

VCHPS DESCRIPTION

The variable-conductance heat-pipe system (VCHPS) consisted of three heat pipes, an evaporator saddle, condenser saddles, a radiator fin, and a heat-pipe simulator. These major components are identified in figure 1. The general dimensions for the VCHPS are shown in figure 2; a photograph of an engineering model VCHPS with a thermal model of the power processor and TWT is presented in figure 3.

The heat pipes contain methanol as the heat transport fluid and a noncondensible gas of 90 percent nitrogen and 10 percent helium (helium provides a means for leak detection) as the control gas. The noncondensible gas provides variable thermal control between the heat source at the evaporator and the radiator fin. The methanol vapor pressure in the evaporator, which is established by evaporator temperature, determines the gas vapor front position in the condenser for a given reservoir temperature. As the evaporator temperature varies according to the quantity of heat input, the gas-vapor front varies directly and increases or decreases the effective condenser length. In this way the amount of heat rejected by the radiator fin is matched with the amount of heat input at the evaporator.

The reservoirs of each heat pipe provide the necessary volume for the noncondensible gas. The amount of fluid required for the heat pipes was determined by the requirement that the heat pipes be able to reprime near the freezing point of methanol. The reservoir also provides a location for the excess liquid during normal heat-pipe operation.

The stainless-steel heat pipes are soldered to a common aluminum evaporator saddle and to common and individual condenser saddles. The evaporator saddle was located between the TWT and the spacecraft south panel. Heat from the TWT, the power processor (located adjacent to the evaporator), and the south panel was transferred through the heat pipes to the condenser saddles and radiator fin and then radiated to space. The mechanical interfaces to the evaporator and condenser saddles have a thin layer of GE RTV 566 to enhance thermal conduction by filling in voids.

The radiator fin formed from aluminum sheet was parallel to the spacecraft south panel (fig. 4). It was attached to the edge of the south panel at five points with fiberglass fittings and to the forward panel at three points with fiberglass struts. Fiberglass was used to minimize heat flow through the support structure.

During a phase of spacecraft testing, the heat pipes were positioned with the evaporator much higher than the condenser and would not function. The evaporator saddle contains a heat-pipe simulator for 1-g spacecraft testing. The simulator was a tube positioned between the three heat pipes and looped over the center tube at one end of the condenser as shown in figure 1. The simulator was equipped with AN fittings for connection to an auxiliary cooling supply. Therefore, when it was necessary to operate the TWT during a period when the heat pipes were inoperable, a coolant was circulated through the simulator to remove the heat. The AN fittings were cut off before launch to reduce the launch weight of the VCHPS.

A sketch of the internal structure of the heat pipes is shown in figure 5. The internal grooves of the stainless-steel tube provide additional heat-transfer area in the evaporator; in the condenser section the grooves collect and transport the liquid methanol to the metal felt wick. The wick and the two wire-mesh arteries transport the liquid to the evaporator. A priming foil attached to the evaporator end of the artery was used as a priming aid by allowing entrained gases to vent. The thickness of the priming foil and the hole size in the foil were sized to force menisci coalescence in the region of a gas bubble, allowing the gas to leave the artery.

The design details for the VCHPS are listed in table I.

DESIGN RESULTS

The thermal requirement for the VCHPS was a dissipation capability of 196 watts or greater for an evaporator saddle temperature of 50° C with two of the three heat pipes operating (one heat pipe redundant). Less than 3 watts of heat was to be transferred whenever the evaporator saddle temperature was 10° C or less. This requirement would prevent components mounted on the south panel from being cooled below a low-survival temperature when the heat dissipation was low. The temperature control range at the evaporator saddle was from 20°, for all heat pipes off, to 50° C, for a normal thermal load to three heat pipes. Because the operating temperature could vary 30° C, the reservoir temperature was designed to vary passively, depending on sink conditions. A constant temperature (heated) reservoir would have been required if operating temperatures had been restricted to a 5° C variance.

The spacecraft was placed in an Earth synchronous orbit with the forward panel facing Earth. The Sun load on the radiator varies throughout the day and changes from day to day. For about 1 month during the equinoxes the spacecraft is in the shadow of Earth for a few seconds to 72 minutes. During the summer the Sun load varies from direct sunshine on the radiator plus reflected sunshine from the forward panel to no sunshine when the radiator is completely in the shadow of the spacecraft. To reduce the reflected heat load on the radiator, the radiator area inboard of heat pipe 1 and facing the forward panel was covered with a multilayer thermal blanket. The heat load on the radiator is greatest at winter solstice when the Sun shines on the radiator and the south panel. Because the VCHPS evaporator is connected to the south panel, the heat absorbed by the south panel is transferred to the radiator fin.

A mechanical interface requirement was that the south panel loads should not be transmitted to the forward panel by way of the radiator structure. By using pinned and sliding connections, the only loads reacted through the support structure were those associated with the radiator mass. The maximum size of the radiator was determined by the radiation pattern from the spacecraft antennas and by the launch vehicle shroud dynamic envelope. The radiator fin was bolted to the heat-pipe condensers and to its support structure to allow removal while mounted to the spacecraft.

Vibrations transmitted by the launch vehicle are (1) pogo (or z) axis vibration input of 17 to 23 hertz, (2) spacecraft-plus-adapter first lateral (x and y axis) cantilever resonant mode of 17 hertz, and (3) spacecraft-plus-adapter axial mode in the region of 35 to 70 hertz. The mechanical vibration requirements are listed in tables II to IV.

The nominal weight allocation for the VCHPS was 7.2 kilograms (15.9 lb). The final assembled weight was actually 7.5 kilograms (16.5 lb).

Specific material requirements to satisfy CTS environmental and operational conditions include resistance to moisture, fungus, and corrosion, limited outgassing and specific thermal radiation properties. Table I lists the materials used.

Silvered Teflon tape covered both sides of the radiator, the heat pipes, and the condenser saddles to give thermal radiation properties of high emissivity and low absorbtivity. In a space environment an electrical charge may build up on the surface of the tape. Tests indicated that the electrical charge on large pieces of tape would be small if the tape adhesive were electrically conductive. The tape used was 5.08 centimeters wide (2 in.) and had a conductive adhesive coating composed of 8 parts by weight of silicone rubber and 1 part of silver powder.

Qualification Testing

Five VCHPS were designed and built by TRW for NASA Lewis. The first two units built were engineering model assemblies; the third and fourth were flight and flight backup assemblies. The fifth was used in an ambient environment life test which is continuing.

To verify the design and fabrication of the VCHPS, thermal and mechanical qualification tests were performed for individual components, for the VCHPS assembly, and for the assembly mounted to the spacecraft. A brief description of the tests is presented:

(1) Thermal tests on individual components

(a) Manufacturer's performance test - Before assembly, the heat pipes were individually tested for heat-transfer capacity and temperature control range.

(b) Silvered Teflon adhesive tests - Samples of silvered Teflon tape mounted on a sample radiator-fin heat-pipe assembly were thermal cycled in a vacuum.

(c) Heat-pipe - saddle soldered-assembly tests - A sample of stainless-steel heat-pipe material soldered to an aluminum saddle was temperature cycled to verify the integrity of the soldered assembly.

(d) Electrostatic tests - Samples of silvered Teflon tape on an aluminum plate were exposed to plasma to determine static charge buildup and optical property degradation effects.

(2) Thermal tests on an assembled VCHPS

(a) Manufacturer's performance tests - Tests were performed to measure the system thermal capacity.

(b) NASA thermal vacuum tests - Thermal tests were performed in a vacuum chamber using an electric resistance heater mounted to the evaporator for a heat source and a cold plate (cooled by liquid nitrogen) mounted adjacent to the radiator face to cool the radiator. One objective of the test was to freeze the methanol (M.P., -98° C) by cooling the radiator fin to -120° C to verify that such freezing does not damage the heat pipes.

(c) In-air functional test - VCHPS assemblies were acceptance tested in air to establish reference thermal data. The turn-on temperatures were noted, and the gas-vapor front locations were determined for 300 watts of heat input at the evaporator. This air functional test was repeated after each major thermal, vibration, and spacecraft integrated test.

(d) Life test - The fifth VCHPS received was used in a life test. Heat was supplied by resistance heaters mounted to the evaporator. The heater-evaporator assembly was insulated to minimize heat loss. This life test VCHPS has been operating almost continuously for over 3 years with 150 watts being transferred to the radiator in a temperature-controlled room. The occasional interruptions have been necessitated by functional tests (above) or electric power failures.

(3) Thermal tests for the VCHPS integrated with a spacecraft

(a) CTS south-panel thermal-vacuum tests - The test consisted of a mockup of the spacecraft south-panel using resistance heaters to simulate heat-dissipating electronic components and included an engineering model VCHPS. The test was performed in a vacuum chamber. Reference 1 describes the test configuration and results.

(b) Engineering model spacecraft thermal vacuum test - Most of the flight type electronic components and the engineering model VCHPS were used for this test. Space environment conditions were simulated to check out the electronic and thermal designs.

(c) Engineering model solar simulation test - The engineering model spacecraft was tested in the NASA Goddard Sun simulator tank. Because VCHPS rotated in a vertical plane, the heat pipe simulator was used to cool the TWT. The aluminize Mylar used as thermal insulation on the four fiberglass struts from the radiator to the forward panel, crumbled during the test. This was replaced with a multilayer insulation with Kapton as the outer layer.

(d) Flight spacecraft thermal vacuum test - The flight model spacecraft was tested in a vacuum chamber for final verification of the electronic and thermal designs. Environmental conditions provided simulations of the transfer and synchronous orbits.

For each of the spacecraft integrated tests, except the flight spacecraft test, the heat pipes tilted slightly, that is, the end of the condenser was 0.75 centimeter (3/8 in.) lower than the level evaporator. This reduced the heat pipe capacity to that expected during operation in space. With no heat load at the evaporator, part of the condenser would go to below -100° C (-98° C is the melting point of methanol). In a 1-g field and with the heat pipes tilted, the heat pipes would not reprime. Gravity forces associated with ground testing are absent in space. Therefore, testing was done in two phases: to verify the heat-transfer capability of the BCHPS, the heat pipes were tilted and the condenser was kept warmer than -70° C; to verify restart capability, the heat pipes were leveled and the condenser temperature allowed to fall below -100° C.

During all the thermal tests, the heat pipes functioned as required, transferring heat when there was a load at the evaporator and turning off when there was no load. At evaporator heat inputs associated with maximum radiofrequency (rf) output to the output stage tube, the baseplate temperature was below 50° C. The heat pipes reprimed during tests conducted with the heat pipes level.

(4) Mechanical vibration tests

(a) VCHPS test - The VCHPS as a component by itself was vibration tested for conditions listed in table II. The interface connections to the spacecraft (five at the south-panel and three at the forward panel) were assumed to be structurally fixed points. All vibration-induced loads were within the design range.

(b) Spacecraft integrated test - The VCHPS integrated with the spacecraft vibration test showed an excessive load due to the vibration of the radiator at the reservoir support structure. The support was stiffened by bolting another fiber glass epoxy box section member to it. The addition of this box section resulted in a decrease in acceleration loads to acceptable levels.

As part of the inspection procedure, the VCHPS was X-rayed to determine its as-received condition. If a heat pipe had malfunctioned during the thermal vacuum freezing test or vibration tests, the X-rays could have been used to help determine the failure mode.

POST LAUNCH OBSERVATIONS

On February 8, 1976, about 3 weeks after launch (Jan. 17, 1976) the output-stage TWT was turned on; it transmitted at 200 watts of rf output power. The VCHPS operated in a completely nominal manner. All three heat pipes were turned on, transferring heat from the evaporator under the tube to the radiator.

Flight telemetry restrictions permitted only six temperature sensors on the VCHPS (see fig. 6, HP1T to HP6T). With only six temperature sensors, it was impossible to determine the complete performance of the heat pipes. Only on-off conditions and temperature levels could be indicated. Three sensors are at the adiabatic section of the heat pipes (HP1T, HP2T, and HP3T). The fourth sensor (HP4T) was on the condenser section of heat pipe 1 (the shortest heat pipe) about 7.5 centimeters (3 in.) from the adiabatic section. The fifth sensor (HP5T) was about 4 centimeters (1.5 in.) from the reservoir of heat pipe 1 and indicated when the heat pipe was full-on. The sixth sensor (HP6T) was on the heat pipe 1 reservoir. Sensors HP4T, HP5T, and HP6T were covered with multilayer insulation. At the 200-watt output power (1) the gas-vapor front for heat pipe 1 would normally be slightly past one half the distance between the bend and the reservoir, (2) that for heat pipe 3 would be located near the pipe bend, and (3) that for heat pipe 2 would be located between that of 1 and 3.

Figure 7 is a time-temperature plot for the first four sensors mentioned for the first orbit turn-on of February 8, 1976. Included is the temperature of the tube body and the power input to the power processing unit. The heat pipes turned on in numerical order. The temperature behavior was similar to the results of ground tests. The actual heat pipe turn-on temperature is dependent on environmental conditions, such as, sink temperature, evaporator temperature, spacecraft temperature, etc. Therefore, the temperatures recorded were not exactly the same as for ground tests.

The total electrical input power curve indicates the relative amount of heat generated by the TWT. At 480 watts of input power about 150 watts of heat is dissipated, and the body temperature should be around 50° C. Temperature sensors HP5T and HP6T were not noticeably affected by the tube turn-on. During the time span shown, sensor HP5T changed from -50° to -73° C, and HP6T sensor changed from -38° to -53° C. Thus, the warm methanol in pipe 1 never reached the reservoir. Again, this was according to design. Heat pipe 1 would not be fully on as long as heat pipes 2 and 3 are operational. The irregularity in the power input curve was due to the cautious first-time operation in orbit of the TWT.

For about 2 months communications tests were performed to determine operational characteristics and health of the TWT's. On April 20, 1976, the test requirement was that power be applied in five steps from 0 to 200 watts in rf output over an extended time (in this case, $4\frac{1}{2}$ hr). Again, the heat pipes turned on at about 30° C, the same as for

February 8, 1976 (fig. 8). But just before turn-on, the temperature sensors showed a significant temperature drop followed by a rapid recovery. This abrupt temperature change was apparently due to cold methanol being drawn to the evaporator section as the heat pipes began to function. The sensors are on the pipe in line with the wick and therefore would tend to read liquid temperature. The temperature drop associated with a normal tube turn-on to full power in 2 to 3 minutes was only 0° to 5° C.

STEADY-STATE DATA

For 2 years the performance of the TWT was periodically tested at the four spacecraft orbital positions shown in figure 9. Absolute steady-state conditions could not be attained because of the relative movement of the Sun. Therefore, for each performance test, the TWT was turned on 2 hours before the designated Sun position and remained on at constant power. Also, Sun positions relative to the equatorial plane varied with the season $\pm 23.5^{\circ}$ resulting in daily changes in sink conditions. Therefore, test conditions could be duplicated on a yearly basis only. Tests were conducted for rf output power levels of 0, 100, and 200 watts (tube saturated) and with frequency variations including center, lower, and upper band operation. Figure 10 shows the temperatures recorded for six temperature sensors during tests of approximately 200 watts rf output power. Also shown is the corresponding power input. Figure 10 is divided into four parts ((a) to (d)) for spacecraft orbital positions of 0°, 90°, 180°, and 270°. Each plot shows the variation due to seasonal Sun angle changes, and a crossplot of the data using figure 10 for any day would show the daily temperature change.

Examination of figure 10 indicates that the operating temperature of heat pipe 1 did not change significantly in the 2 years of operation. A thermal model of the VCHPS (including optical property degradation), the tube, and the power processor indicated that for 2 years in orbit, about a 5° C rise in baseplate operating temperature could be expected. Exposure to the space radiation and plasma should have caused a degradation in the spacecraft insulations and the silvered Teflon tape covering the radiation fin. Thermal absorbtivity values should have increased, resulting in an increased heat load for the radiator fin. The data in figure 10 indicate a possible rise in baseplate temperature, but much less than expected. A more noticeable change in operating temperature occurred for sensors HP5T and HP6T: With an increase in radiator heat load, due to a possible increase in radiator absorbtivity, the gas-vapor fronts would move farther along the radiator, closer to sensors HP5T and HP6T. These sensors would then show higher temperature.

THERMAL ANOMALIES

On four occasions during 1977, the temperature of the TWT unexpectedly increased from about 60° to 75° C. The power to the TWT had been constant and all operating conditions seemed normal before the anomalies. Three anomalies occurred during the eclipse season of the vernal equinox (days 75, 82, and 101), and one during autumnal equinox (day 253). Common characteristics for all four anomalies were that

(1) They occurred during the spacecraft-Earth eclipse seasons, the vernal and autumnal equinoxes

(2) They occurred between 14:20 and 19:25 Greenwich Mean Time (GMT) (At these times the heat pipes and the gas reservoirs are in the shadow of the spacecraft.)

(3) All had been preceded or accompanied by an abnormal difference in the temperatures between the adiabatic sections of heat pipes 3 and 1 (The difference was as high as 7° C; whereas the normal difference was, at most, 3° C.)

(4) In each case, the system operated normally the next day, indicating that no permanent change in the thermal or electrical characteristics of the spacecraft had occurred.

After the thermal anomaly of day 75, an attempt was made to induce an anomaly by repeating the thermal and electrical operating conditions before and during the day 75 anomaly. On day 113, the heaters used to maintain a 20° C power processor baseplate temperature when the tube was off were turned off to allow the radiator temperature to fall lower than normal; the anomaly did not recur.

For the first three anomalies, the power had been reduced, thus decreasing the tube operating temperature (i.e., heat-pipe tube evaporator temperature), and the TWT continued to function satisfactorily at the reduced power. The anomaly of day 82 was discovered accidentally after a computer data search for temperature differences between HP1T and HP3T of more than 4° C. The tube power level had been reduced to zero by the user before the body temperature alarm limit had been reached. After the anomaly of day 101, a spacecraft operational plan was formulated by TRW and NASA Lewis to attempt to determine the cause(s) of the anomalies. This plan was implemented during the anomaly on day 253 as described below.

Presented here are some of the facts of day 253 as reported by Alexovich and Curren (ref. 3). The anomaly of day 253, September 10, 1977, began at 1420 GMT. The tube temperature increased from 57° to 70° C while essentially constant tube power operating conditions were maintained. Lewis' operation of the tube had begun at about 1245 GMT, when it was driven to a saturated rf output power level of about 200 watts.

The tube had been in a standby status for about 2 hours. At 1245 GMT none of the heat pipes were active: that is, the adiabatic sensors of each heat pipe were below 20° C. Also, the gas reservoir temperature was at -61° C. At 1337 GMT the heat pipes became active, and by 1412 GMT the tube body temperature had stabilized at 51° C. The difference in adiabatic temperatures of heat pipe sensors 3 and 1 was 0.

At 1420 GMT the tube body temperature began to rise while the operating conditions remained unchanged. At 1422 GMT the body temperature was at 52.2° C, and the difference of sensors 3 and 1 was 2° C. At 1432 GMT the body temperature was 55.5° C, and the temperature difference of sensors 3 and 1 was 3.9° C. By 1550 GMT the tube temperature had risen to 70° C. For the next several hours, the anomaly characteristics were studied in real time as functions of rf power output and VCHPS temperatures by using the special spacecraft operating plan. The tube body temperature was reduced twice by reducing the rf output power, and then increased, which retriggered the anomalous temperature conditions. By manipulating the tube power level, the maximum heat rejection capability of the VCHPS in the anomalous mode was about 106 watts. This corresponds to about 140 watts of rf output power. This 106 watts capacity is about the estimated capacity of the heat pipes for an open artery condition on all three heat pipes.

The real time anomaly test indicated that the arteries of all the heat pipes had probably deprimed. Also, a two-step change in temperatures had been noted indicating that the arteries of pipe 1 deprimed first and the arteries of pipe 3 failed last.

Ground tests were performed to verify the conditions of the deprimed arteries using the flight backup model of the VCHPS. Electric resistance heaters were mounted to the evaporator section of the heat pipes. The evaporator was thermally insulated to minimize heat loss. With about 150 watts of power applied, all three heat pipes were operational. Each heat pipe was then turned off in order by heating the gas reservoir and forcing the gas-vapor fronts into the evaporator section of the heat pipes. This test reproduced the anomalous temperatures symptoms. At a reduced input power of about 105 watts (the open artery capacity of three heat pipes) the system became stable.

Although it had been determined that the arteries of each heat pipe had probably deprimed, causing the temperature increases in the tube body, the fluid mechanics processes that explain this action have not been determined. There are many days during the equinox seasons having essentially identical environmental conditions to the day of the anomalies; yet the heat pipe deprimed on only four occasions.

It is not understood how operation at 200 watts rf output power was possible throughout the equinox period (except for the anomaly days). Perhaps there are other common factors in anomaly days that have not been identified. Time relationships of some unidentified factors may be important, even many hours before the limited spacecraft instrumentation indicates an anomalous condition.

Studies into the cause of the anomalies are being made by both NASA Lewis and TRW. The effective use of variable conductance heat pipes for space application requires that spacecraft environmental conditions associated with the CTS thermal anomalies be better understood to avoid the probable depriming of the arteries.

CONCLUSIONS

TRW designed and built a variable-conductance heat-pipe system for the Communications Technology Satellite, which was launched in December 1975. The heat pipes were first turned on in space on February 8, 1976, and have been operational for 3 years. The following observations have been noted in the performance of the VCHPS.

1. During ground prelaunch tests, the heat pipes performed as required, transferring heat on demand and turning off at no power load.

2. With the exception of four flight thermal anomalies, the heat pipes functioned as designed, maintaining the baseplate temperature of 50° C.

3. The increase in tube body temperature that occurred during the four anomalies was probably the result of all the heat-pipe arteries depriming.

4. The flight thermal anomalies have caused no apparent heat-pipe degradation. The heat pipes were functional to full load capacity soon after each anomaly.

5. The fluid mechanics processes which probably caused the depriming of the heat pipes have not been determined.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, February 13, 1977,
506-22.

REFERENCES

1. Stipandic, E. A.; Gray, A. M.; and Gedeon, L.: Thermal Design and Test of a High Power Spacecraft Transponder Platform. AIAA Paper 75-680, May 1975.
2. Caswell, R. D.; and Edelman, E. A.: Thermal Testing of a High Powered Communications Satellite. AIAA Paper 76-459, July 1976.
3. Alexovich, Robert E.; and Current, Arthur N.: Thermal Anomalies of the Transmitter Experiment Package on the Communications Technology Satellite. NASA TP-1410, 1979
4. Marcus, B. D.: CTS TEP Thermal Anomalies: Heat Pipe System Performance. (TRW Defense and Space Systems Group; NASA Contract NAS3-21012.) NASA CR-159413, 1977.

TABLE I. - HEAT PIPE AND VCHPS DESIGN DETAILS

Tubes	304 SS[a], 1.270 o.d. by 0.071 cm wall, internally threaded with 39.4 threads/in., 0.013 cm deep, 40° included angle grooves
Reservoirs	304 SS, spun helispherical cap with 4.445-cm o.d. cylindrical center section. Reservoir to condenser volume ratio varies from 1.5 to 2.0
Wicks:	
Reservoir	304 SS metal felt, 0.051 cm thick, spot welded to interior walls
Tube	304 SS metal felt, 0.127 cm thick, interference fit across diameter of tube
Arteries	59 wires/cm, 316 SS screen formed and welded to 0.160-cm-i.d. tubes and spot welded to diametral wick
Priming foils	0.00127-cm thick 304 SS foil with 0.0254 holes, formed and welded to 0.160-cm i.d. tubes and spot welded to ends of arteries and diametral wick
Saddles	6061 Al alloy extrusion soldered to tubes
Working fluid	Methanol, spectrophotometric grade
Control gas	90 Percent nitrogen, 10 percent helium, research grade
Radiator	6061-T6 Al alloy, 0.102 cm thick
Radiator coating	0.0127-cm thick silver-coated Teflon attached to radiator by silver-loaded electrically conductive silicone adhesive
Radiator coating blue protective covering	Mystic PD570A (removed before launch)
Radiator support struts	Tubular fiberglass (epoxy resin; 1.905-cm i.d. by 0.071-cm wall) with aluminum end-fittings
Radiator support struts covering	Multilayered, aluminized Kapton, each layer electrically grounded
Heat-pipe saddle and radiator interface material	RTV 566

[a]SS denotes stainless steel.

TABLE II. - VCHPS MECHANICAL ENVIRONMENTS

Environment	Criteria
Ultimate load	75 g in any axis[a]
Yield load	60 g in any axis[a]
Sinusoidal vibration	Withstand levels in table III
Random vibration	0.045 g^2/Hz for $20 \leq f \leq 2000$ Hz at 2 min/axis
Acoustic	Withstand loading in table IV for 1 min/level
Acceleration	Spacecraft centrifugal loads of 132 rpm during ground tests
Aerodynamic	No requirements

[a]Safety margin ≥ 1.0.

TABLE III. - VIBRATION - SINUSOIDAL

Axis[a]	Frequency, Hz	Acceleration, g's (0 to peak)
Z (thrust)	5 - 25	1.27-cm DA[b] slope to 16.0
	25 - 70	16.0
	70 - 2000	5.0
Y (normal to panel)	5 - 15	1.27-cm DA slope to 6.0
	15 - 40	6.0
	40 - 100	10.0
	100 - 2000	5.0
X (along panel)	5 - 15	1.27-cm DA slope to 5.0
	15 - 2000	5.0

[a]Sweep rate, 2 octaves per minute.
[b]Double amplitude.

TABLE IV. - ACOUSTIC SPECTRUM

Frequency, Hz	Sound pressure level, dB (ref. 200 μPa)
37.5 - 75	130
75 - 150	135
150 - 300	138
300 - 600	140
600 - 1200	141
1200 - 2400	138
2400 - 4800	134
4800 - 9600	129
Overall	146

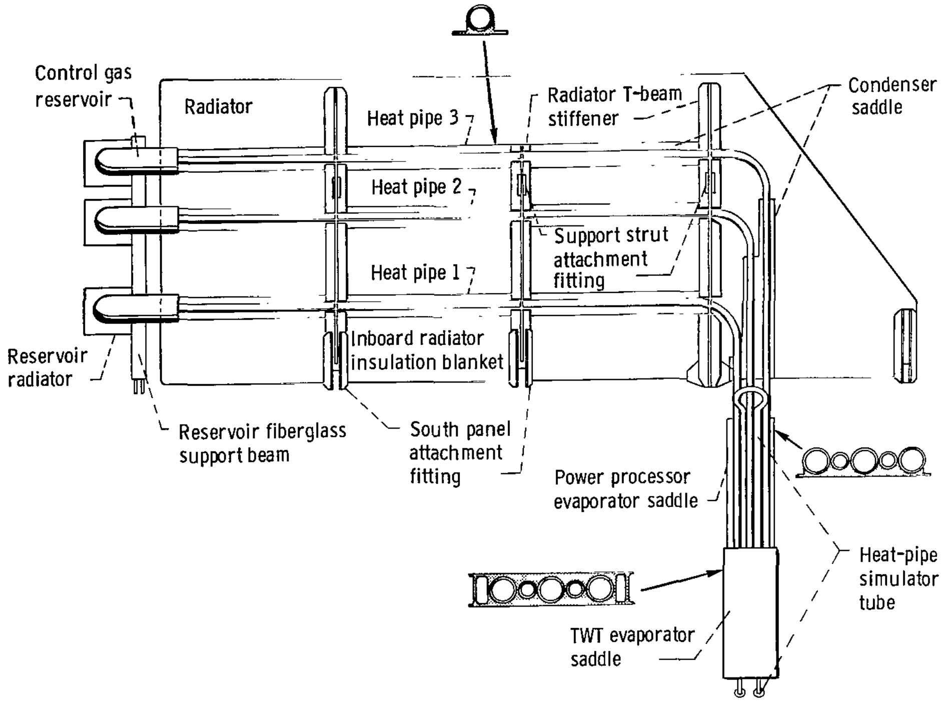


Figure 1. - Major components of VCHPS.

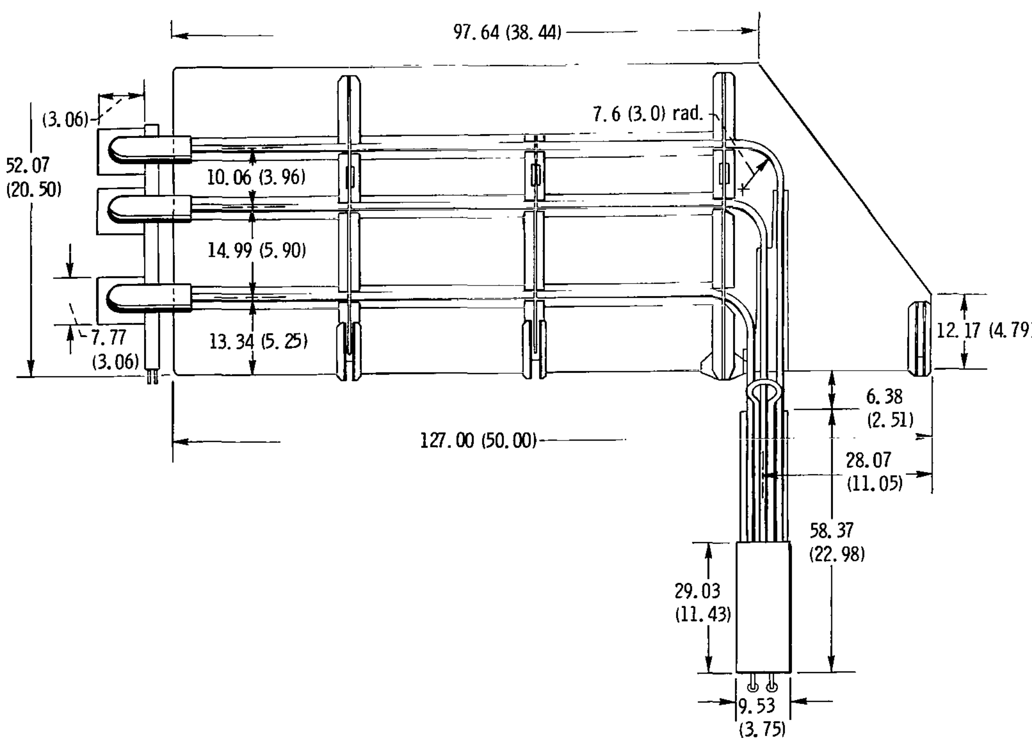


Figure 2. - Major dimensions of VCHPS. (All dimensions are in cm (in.).

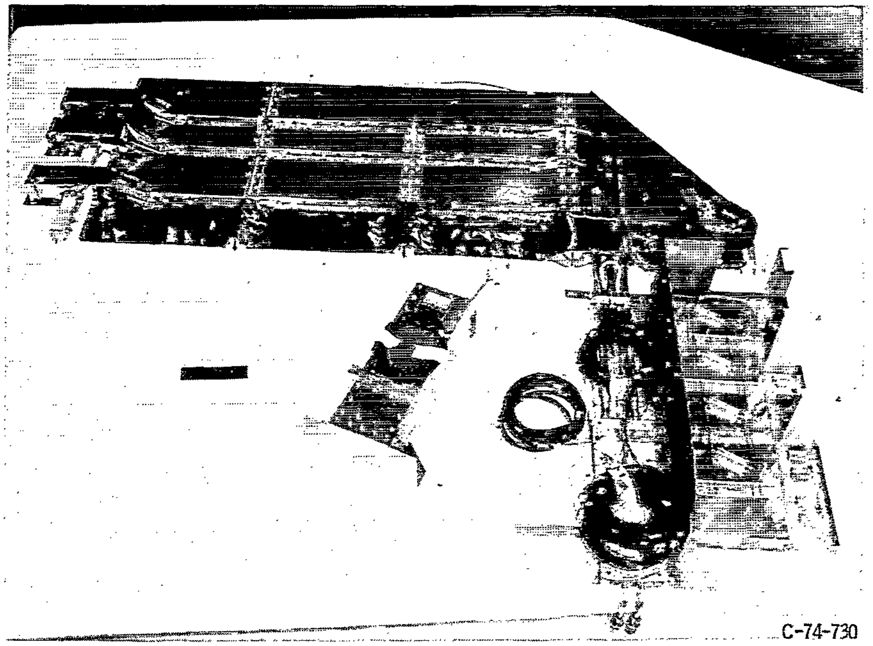


Figure 3. - Engineering model VCHPS mounted to thermal model of the power processor. Thermal model of traveling wave tube is shown in center of photograph. Assembly was being prepared for CTS south panel thermal vacuum test.

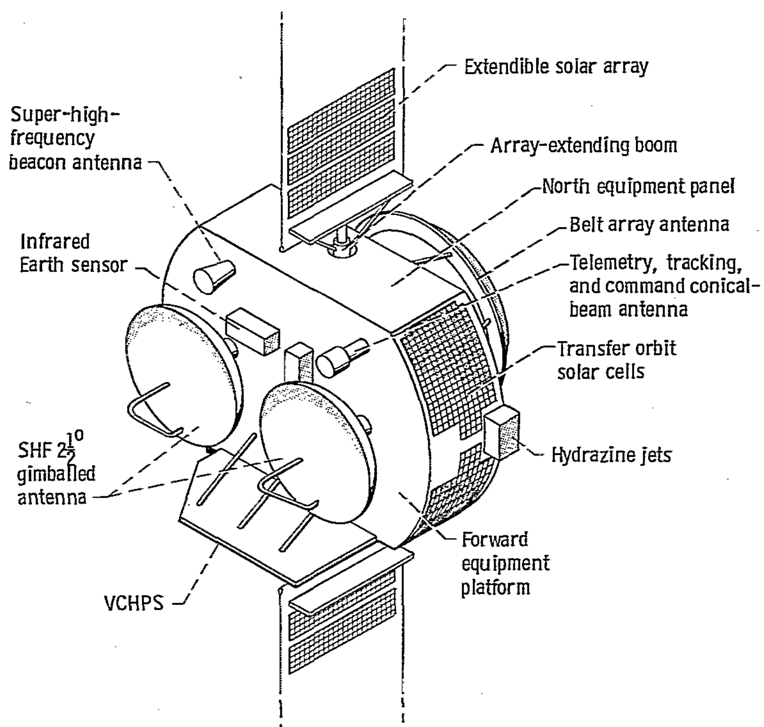


Figure 4. - CTS spacecraft with VCHPS.

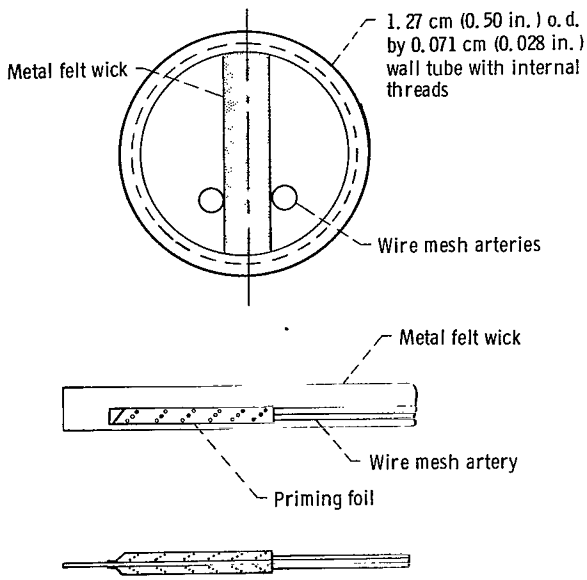


Figure 5. - Wick and priming foil arrangement in VCHPS.

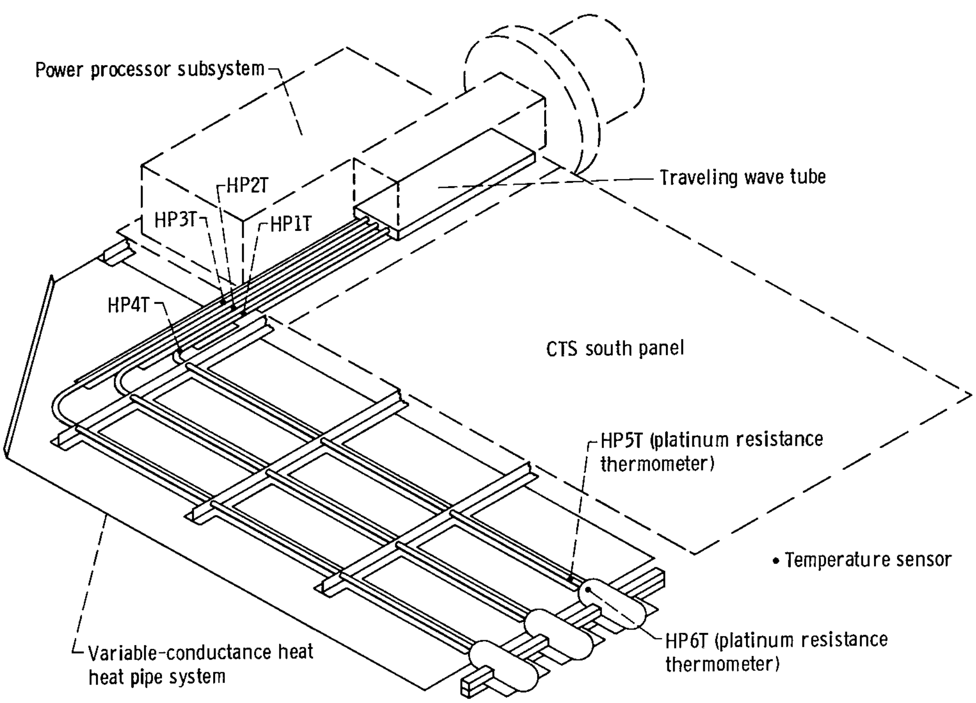


Figure 6. - Schematic of variable-conductance heat-pipe subsystem showing temperature sensor locations.

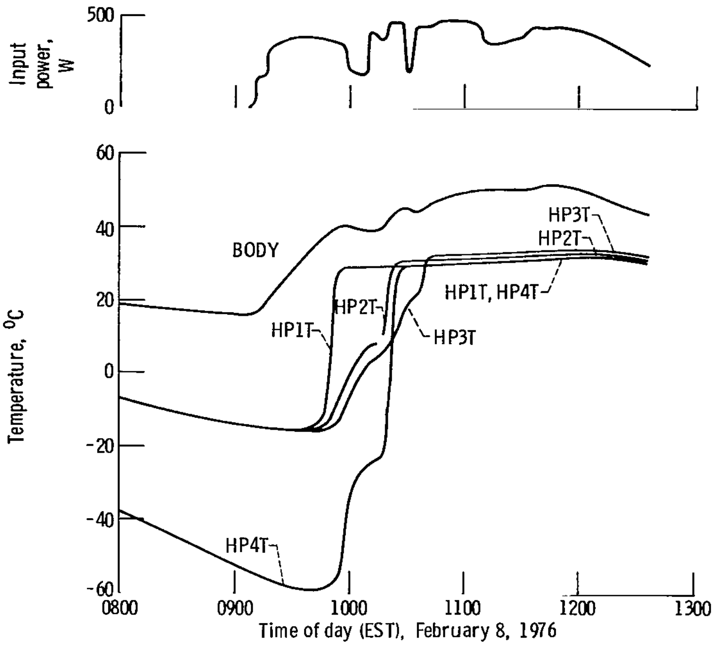


Figure 7. - Heat-pipe turn-on characteristics for first TWT turn-on and associated input power and TWT body temperature. (See fig. 6 for location of temperature sensors.)

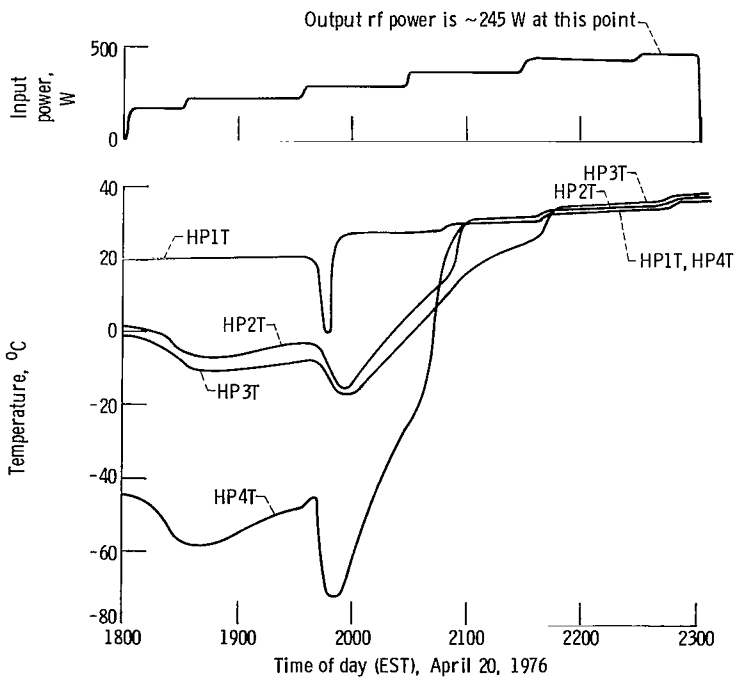


Figure 8. - TWT turn-on after 2 months of nonoperation during first eclipse season.

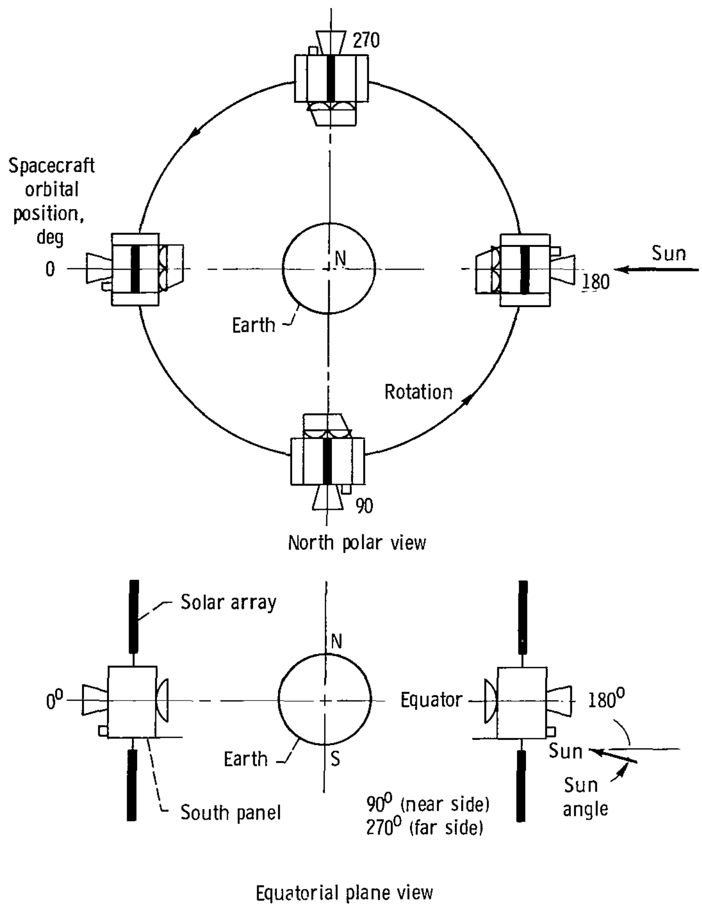
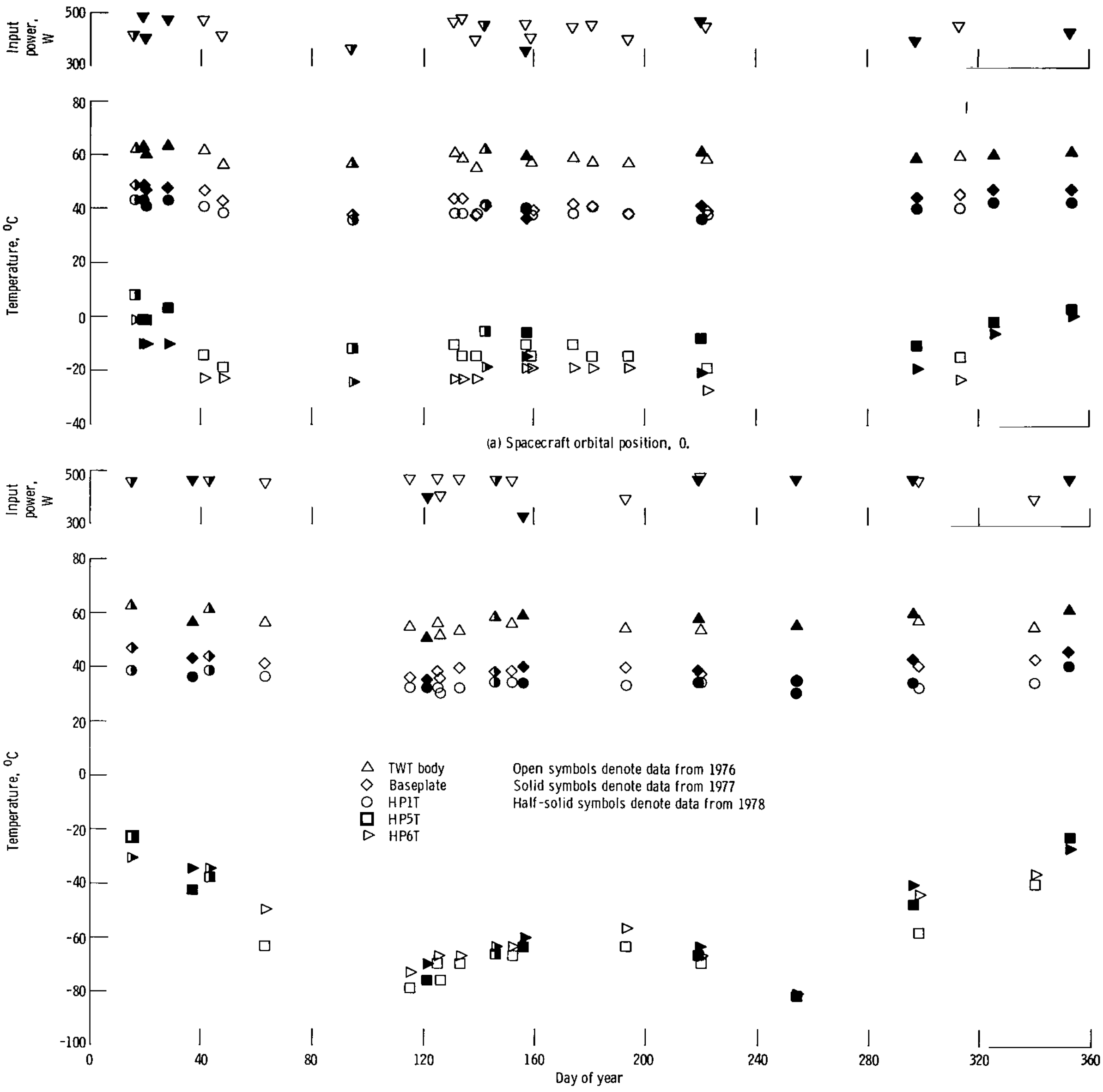
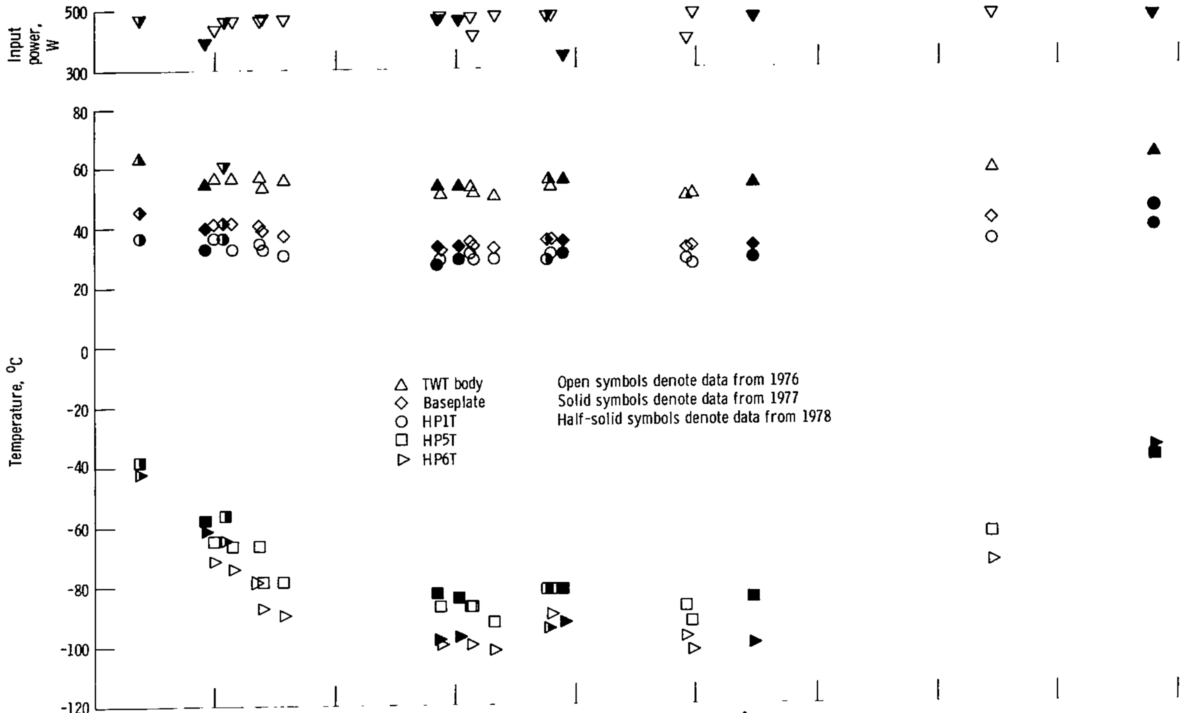


Figure 9. - CTS spacecraft orbital positions.

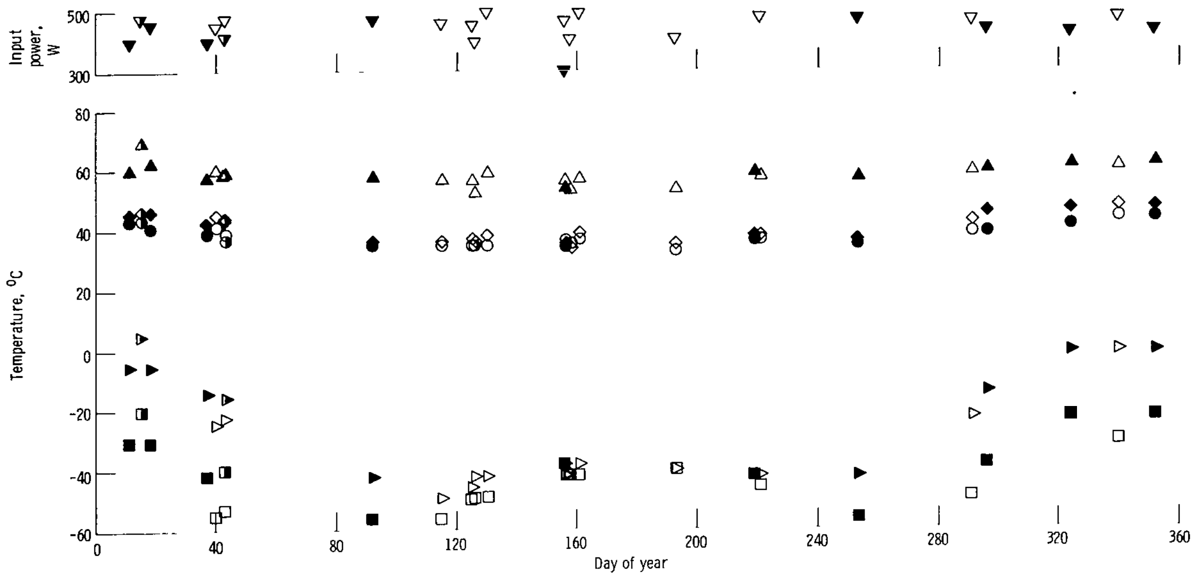


(b) Spacecraft orbital position, 90°.

Figure 10. - VCHPS performance near steady-state operation with radiofrequency power approximately 200 watts.



(c) Spacecraft orbital position, 180°.



(d) Spacecraft orbital position, 270°.

Figure 10. - Concluded.

1. Report No. NASA TP-1465	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle DESCRIPTION AND ORBIT DATA OF VARIABLE-CONDUCTANCE HEAT-PIPE SYSTEM FOR THE COMMUNICATIONS TECHNOLOGY SATELLITE		5. Report Date August 1979
		6. Performing Organization Code
7. Author(s) Louis Gedeon		8. Performing Organization Report No. E-9880
		10. Work Unit No. 506-22
9. Performing Organization Name and Address Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Paper
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A variable-conductance heat-pipe system (VCHPS) with methanol as the working fluid and a nitrogen and helium mixture as the control gas was used for the thermal control of a 200-W rf traveling-wave tube of the Communication Technology Satellite. Three stainless-steel heat pipes (one redundant) and an aluminum radiator were designed to transfer 196 watts for an evaporator temperature of 50° C. The system has operated for 3 years with no noticeable change in performance. On four occasions the heat pipes apparently deprimed. A short time after reducing the tube power, the heat pipes reprimed and the system continued to operate normally. A description, qualification testing, and orbit data of the VCHPS are presented.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Heat pipes CTS spacecraft	Unclassified - unlimited STAR Category 34

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	22	A02

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

National Aeronautics and
Space Administration

Washington, D.C.
20546

Official Business
Penalty for Private Use, $300

THIRD-CLASS BULK RATE

Postage and Fees Paid
National Aeronautics and
Space Administration
NASA-451

U.S.MAIL

2 1 1U,D, 080879 S00903DS
DEPT OF THE AIR FORCE
AF WEAPONS LABORATORY
ATTN: TECHNICAL LIBRARY (SUL)
KIRTLAND AFB NM 87117

NASA

If Undeliverable (Section 158
Postal Manual) Do Not Return