NASA Technical Memorandum 100756

Development and Integration of the Capillary Pumped Loop GAS and Hitchhiker Flight Experiments

D. Butler and R. McIntosh

April 1990

(NASA-TM-100756) DEVELOPMENT AND INTEGRATION OF THE CAPILLARY PUMPED LOOP GAS AND HITCHHIKER FLIGHT EXPERIMENTS (NASA) 17 p CSCL 22B

N90-21790

Unclas

G3/18 0279016

NASA

NASA Technical Memorandum 100756

Development and Integration of the Capillary Pumped Loop GAS and Hitchhiker Flight Experiments

D. Butler and R. McIntosh
Goddard Space Flight Center
Greenbelt, Maryland

NASA
National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, MD

1990

PREFACE

The Capillary Pumped Loop (CPL) is a thermal control system with high density heat acquisition and transport capability. A small spaceflight version of the CPL was built and flown as a GAS experiment on STS 51-D in April 1985 and STS 51-G in June 1985, and as a Hitchhiker-G experiment on STS 61-C in January 1986. The purpose of the experiments was to demonstrate the capability of a capillary pumped system under micro-gravity conditions for use in the thermal control of large scientific instruments, advanced orbiting spacecraft, and space station components. The development, integration, and test activities of the CPL are described.

INTRODUCTION

The development of larger spacecraft and the space station has resulted in the need for new thermal control systems that can handle large amounts of power and carry heat over long transport distances. Two-phase systems are being developed that require substantially less weight and power than existing single-phase systems. Two-phase thermal control systems can also maintain nearly constant temperatures over wide power ranges, and can be used to supply heat as well as remove it.

One type of two-phase control system is the Capillary Pumped Loop (CPL). The CPL is unique in that it has no moving parts. The original CPL concept was pioneered by F.J. Stenger of NASA/Lewis in the mid-1960's (ref. 1) and has been under development at Goddard since the late 1970's. A schematic of the CPL is shown in Figure 1. The evaporator contains a porous wick material (high density polyethylene, Porex) which produces the pumping action in the closed loop system via capillary forces. The ammonia liquid is drawn through the wick to the metallic shell of the evaporator where it vaporizes and then travels to the condenser, thus transporting the heat via the latent heat of vaporization. The heat is removed at the condenser and the vapor is returned back to a liquid state. The liquid then returns to the evaporator pumps to continue the cycle.

Another important feature of the CPL is the two-phase reservoir. By controlling the reservoir temperature, the saturation temperature of the loop is controlled as well. This means that the evaporators stay at a relatively constant temperature regardless of the heat load or condenser temperature variation. The evaporator temperature can be varied simply by raising or lowering the reservoir temperature to the desired level. The reservoir also provides for automatic fluid inventory control in the loop by supplying or storing ammonia liquid as required. The CPL also has an isolator located near the evaporator pump inlets. The isolator allows the evaporators to function individually within the loop and prevents vapor from flowing out of a non-operational evaporator into other evaporator pumps.

The CPL system has been undergoing development and testing for the past several years (see ref. 2). Ground systems have demonstrated heat transport capabilities ranging from 100 watts to 25 kilowatts over distances of 10 meters. Verification of the CPL under micro-gravity conditions was also pursued, since fluid behavior and evaporative and condensing heat transfer coefficients can be largely influenced by gravitational forces.

CPL/GAS FLIGHT EXPERIMENT

The next step in CPL development was the construction of a micro-gravity experiment. Drop tower and low-g aircraft flights were considered but rejected because they only offered short durations at low gravity (25 seconds or less). Since CPL startup requires 2 to 3 minutes, another approach was required. Review of shuttle carrier options showed that the Get Away Special (GAS) carrier should be chosen for the initial experiment due to its low cost, ease of integration, and frequent flight opportunities. The GAS carrier consists of a cylindrical container with internal dimensions of 51-cm diameter by 71-cm long. GAS experiments must be completely self-contained with no shuttle services available. Power, data, and control functions must be carried along as part of the experiment. Nonetheless, the GAS carrier is well-suited for small, basic research experiments at the proof-of-concept phase of their development.

The CPL/GAS experiment was developed utilizing existing hardware where possible (see Figure 2). The support structure and battery were identical to those used for the STS-3 GAS Flight Verification Payload. The electronics and tape recorder were flown previously on the Atomic Oxygen Monitor GAS experiment flown on STS-8 and STS-11. Use of existing hardware can significantly reduce costs and shorten development schedules.

Unfortunately, the space available for the CPL experiment was constrained due to the volume requirements of the battery and electronics. Nonetheless, a working mini-CPL was developed that mounts directly to the GAS top plate between the structural support struts. It measured approximately 36 cm by 36 cm by 10-cm high and maintained most of the features of the large ground systems. Figure 3 shows the mini-CPL experiment both before and after installation of the heaters, wiring, instrumentation, and electronics.

The CPL/GAS has two evaporator pumps mounted in parallel, with heaters attached directly to their outer surfaces to provide the experiment heat load. The system was charged with approximately 150 grams of ammonia. A single condenser tube, a temperature controlled two-phase reservoir, and an isolator are also included in this system. The boxes seen in Figure 3 contain additional electronics for reservoir temperature control and over-temperature limitstats to prevent overheating of the experiment (via heater cutoff). The entire system was mounted to a 7-kg condenser plate which was attached directly to the 11-kg GAS container top plate to provide the system radiator/heat sink. The major portions of the experiment were constructed of aluminum due to its light weight and high thermal conductivity. The reservoir and isolator were fabricated from stainless steel due to its higher strength.

The CPL required 220 watts of power when it was in operation, with the power supplied by a Yardney LR130 silver zinc battery. The battery was quite large, with a weight of 50 kg and external dimensions of 29 cm by 20 cm by 46 cm. It supplied 4 kilowatt-hours of energy to the CPL/GAS experiment.

The CPL/GAS experiment is shown fully assembled in Figure 4. The CPL was covered with a multi-layered insulation blanket (MLI) which thermally isolates it from the battery and electronics. A thermostatically controlled heater was used on the battery to maintain its temperature above its lower limit of 0° C during potential cold case operations. The electronics box was covered with high-emittance Kapton tape to radiatively dissipate its internally generated heat, which was approximately 12 watts. The GAS container was flown without the insulating end cap used on most GAS payloads because of the large heat rejection requirements of the CPL. The top plate served as the radiator for the experiment and its outer surface was coated with silver Teflon to enhance its heat rejection capability.

Experiment sequencing was accomplished with the use of an electronic clock and pre-programmed, hardwired memory. The memory was a commercially available bi-polar fusible link 8K ROM built by the Harris Corporation. Experiment data was written onto a small Lockheed digital tape recorder contained in the large electronics box. The data included 32 thermistor readings, power levels, calibration voltages, and command status. Data was taken once a minute throughout the 5-day mission.

CPL/GAS TESTING AND FLIGHT QUALIFICATION

Since the CPL is a closed system containing ammonia, it is a pressure vessel and therefore subject to special design requirements as specified by the NASA safety office. These include design to a 2428-psi pressure for all of the pressure system components. The design pressure level is unique for each system, depending on the pressurant and the predicted maximum system pressure. The maximum pressure corresponds to a worst-case expected maximum temperature of 80° C, which only occurs during a shuttle abort re-entry and landing. The ammonia pressure at 80° C is 607 psi, and the CPL was designed to withstand 4 times that pressure, or 2428 psi. Also, two identical CPL units were fabricated and then burst tested in order to prove the design. Previously, there was more than one method that could be used to flight qualify pressure vessels (see reference 3). We chose the least expensive of the options available. Now, however, a newer version of the NASA safety document, NHB 1700.7B, has been prepared that restricts pressure vessel qualification to specific portions of MIL-STD-1522A. This will significantly impact the design and test of future pressurized systems for shuttle flight.

The CPL/GAS was subjected to testing which included a vibration test, thermal vacuum tests, and extensive functional tests. A workmanship-level vibration test (at 6.4 g's RMS) was conducted to verify the structural integrity of the experiment and to insure that it would endure the vibration loads that might be encountered during the flight. Qualification testing of the structure was not required since the support structure was previously qualified for earlier GAS flights. Detailed structural analysis was performed on all of the new components that were built for CPL/GAS.

A thermal vacuum test was performed to insure proper operation of the CPL under extreme temperature conditions and the vacuum environment of space. The CPL/GAS container was situated upside-down in the chamber to allow for proper operation of the CPL in the one-g earth environment. Temperature variations were accomplished with a thermally controlled cold plate. It served as a direct radiative heat sink for the GAS container top plate, which was the heat sink for the CPL experiment. The GAS container also had to be levelled so that gravity effects on the CPL would be minimized.

The thermal vacuum test was conducted over a 6-day interval. The first 2 days of the test included an experiment cooldown and cold case startup. The electronics were allowed to cool to −2° C and the condenser cooled to −20° C for a cold start check. These levels corresponded to the predicted cold case startup conditions. During the next 3 days of the test, a mission simulation was conducted. The thermal environment (chamber and cold plate temperature) was set at −10° C, corresponding to the expected shuttle payload bay temperatures for the earth viewing case. The mission profile included experiment heater cycles with power levels up to 220 watts (110 watts per pump) for operating times up to 1 hour, followed by cooldown periods lasting approximately 9 hours. These operation times were based on the thermal analysis of the CPL/GAS.

The CPL saturation temperature was controlled via the reservoir temperature which was set at 29° C. This temperature was selected based on a number of factors. The temperature level of future on-orbit thermal control systems will probably be near room temperature. Also, most of the ground tests on CPL systems have been run near this temperature level. Finally, the ability to reject heat from the GAS container improves with higher radiator temperatures. Therefore, 29° C was selected as the best compromise of all of these factors.

Prior to the start of each cycle, the CPL condenser was allowed to cool to approximately 5° C, then the CPL evaporator heaters were activated. Since the heater power input exceeded the heat rejection capability of the GAS top plate, the condenser temperature increased. When the condenser temperature reached the CPL operating temperature of 29° C, it could no longer absorb any more heat and the system was shut down and again allowed to cool. The heater cycle was then repeated after the condenser cooled to about 5° C. A lower condenser temperature would have allowed for a longer experiment duration. However, the cooldown portion of the cycle increases substantially as the shuttle environment (heat sink) temperature of −10° C is approached. Therefore, 5° C was established as the best compromise between CPL operation time and condenser cooldown duration. The mission simulation conducted as part of the test verified the heatup and cooldown times predicted by the thermal analysis.

The last part of the thermal vacuum test was a hot case operational check, with the environment set at 30° C. This test verified operation of the electronics at the expected hot case temperature. The CPL heaters could not be activated because they require a heat sink at a temperature below the saturation temperature of 29° C.

A low-cost, functional test setup was also pursued so that the CPL could be further tested at length. The CPL/GAS was again oriented upside-down, but now the GAS top plate rested on a continuously cooled cold plate that removed the heat from the experiment via conduction. This provided more test time since the top plate was cooled sufficiently to allow for continuous heater power application with no cooldown time needed. Although this setup was not a realistic simulation of the Shuttle environment, it did allow for low-cost, long-term experiment testing.

The functional testing continued for a total run time of approximately 8 weeks. Additional power profiles were developed and flight simulations were conducted. The value of testing cannot be overstated, especially for experiments dealing with new systems and technology development.

All shuttle payload organizations are required to submit detailed information about their experiments in the form of safety review packages. Three to four safety reviews are held throughout the design and integration process to insure that the experiments are safe for flight on the shuttle and will not cause any damage to the orbiter or crew. Every experiment component must be identified and design drawings, parts and materials lists, and supporting analyses must be submitted. Quality Assurance requirements must also be met, such as maintenance of certificates of material conformance and fabrication and test logbooks. The volume of documentation can often exceed the actual experiment volume by several orders of magnitude.

The parts and materials selected for spaceflight use are subject to unique requirements. The materials must be acceptable in terms of flammability, toxicity, freedom from stress corrosion cracking, vacuum compatibility, and outgassing characteristics. Lists of acceptable materials are available to experiment designers. All component parts must be vacuum compatible and able to withstand severe temperature extremes and high vibration loads. Commercial parts seldom meet these requirements, so special military standard or spaceflight quality parts are used instead. The prices for these items is often at least ten times the cost of the corresponding commercial part.

One can readily understand the high cost of spaceflight when reviewing the myriad of special requirements that have to be met in order to have a successful experiment. The CPL/GAS cost was estimated to be in excess of $500,000.00, and yet it was considered relatively "cheap" when compared to other flight experiments. Although the costs are high, the rewards are also high when an experiment performs successfully and returns data on a new technology.

CPL/GAS FLIGHT

The first flight of the CPL/GAS experiment occurred in April 1985 on STS-51D. Unfortunately, the GAS batteries that actuate the relay to energize the experiment failed, so the CPL could not be turned on during the flight. The failure was due to a bad batch of batteries that failed under a combination of vacuum and cold temperatures, even though they had passed qualification testing. The GAS project solved the problem by enclosing the batteries in a hermetically sealed box for all subsequent GAS flights. Fortunately for the CPL/GAS project, a reflight opportunity only 2 months later was available on STS-51G in June 1985. On this flight the GAS relays operated satisfactorily and the CPL experiment was very successful. The CPL operated for the entire 120-hour mission and 13 power cycles worked as planned.

An example of a power profile from the flight is given in Figure 5. As heat was added to the evaporators their temperatures increased rapidly to the saturation temperature as controlled by the reservoir. At that point, ammonia was vaporized and capillary pumping was started. The evaporator temperatures then stabilized near the saturation temperature until the heaters were shut off at the end of the cycle. The evaporators then cooled slowly until the cycle was repeated later on. The CPL/GAS experiment results are presented in detail in ref. 4.

The CPL/GAS flight demonstrated that a capillary pumped system can perform well in micro-gravity. No substantial differences between micro-g and one-g performance were noted. This was the first flight of a thermal control system of this type and the first shuttle experiment from the Space Station Advanced Development Program.

CPL/HH-G FLIGHT EXPERIMENT

A CPL follow-on mission on the Hitchhiker-Goddard (HH-G) was undertaken immediately after the successful CPL/GAS flight. The Hitchhiker carrier has additional capabilities when compared to the GAS carrier. These include shuttle power, real-time ground command and data, and additional volume and weight.

The same mini-CPL hardware developed for the GAS flight was reflown on HH-G, with some modifications. The power per evaporator was increased from 110 watts to 400 watts (800 watts total) so that the CPL could be tested at its maximum transport capability. The CPL was again flown in a GAS container, although no battery was needed. It was mounted to a specially designed 63-kg GAS container top plate in order to accommodate the increased heat load. The insulation was removed from the sides of the container as well to increase the radiative heat rejection capability. Figure 6 shows the CPL/HH-G experiment mounted along with the HH-G avionics and a PACS particle analysis experiment in the shuttle bay. Together they comprised the first HH-G carrier payload, with the flight aboard the Space Shuttle Columbia on STS-61C in January 1986.

Testing of the CPL/HH-G included functional, vibration, thermal vacuum, and electro-magnetic interference (EMI) tests. The EMI tests were not required for GAS since the experiment was not electrically connected to the shuttle. The tests are needed for HH-G since the shuttle provides electrical power, data, and command capability. The EMI tests involve measurement of conducted and radiated electrical emissions from the experiment, and the experiment's susceptibility to emissions from the shuttle. The purpose of the test is to insure that the experiment and shuttle do not interfere with one another electrically.

CPL/HH-G power profiles were defined during the functional tests. The profiles were similar to the CPL/GAS profiles, but at a substantially higher power level. The power cycles again consisted of 30 to 60 minutes of heater power activation followed by a long cooldown time. An upper power limit of 600 watts for the CPL-HHG was realized as a result of these tests. The thermal vacuum tests were used to verify proper operation in vacuum under a simulated shuttle thermal environment. Hot and cold experiment operations were verified and a mission simulation was conducted.

The CPL/HH-G flight was very successful and again demonstrated CPL operation in micro-gravity. Thirty-eight experiment power cycles were conducted over a 5-day mission. The CPL was monitored around the clock and heater power levels were controlled by ground command. This level of flexibility greatly enhanced the experiment data return. Additional power cycles were accomplished over the baseline plan when the shuttle's stay on orbit increased by two days. New power profiles were developed in real time based on the results obtained from previous cycles. Power profiles were adjusted in response to particular shuttle thermal attitudes. A sample of the CPL/HH-G data is given in Figure 7. The evaporator temperatures were higher than on the GAS experiment due to the much higher power levels used on HH-G. Again, ref. 4 provides a detailed summary of the CPL/HH-G flight results.

The CPL/HH-G flight again demonstrated similar CPL performance in both the micro-g and one-g environments. With HH-G, upper and lower power limits were established for the CPL flight unit. Post flight testing duplicated in-flight results and showed that the CPL had not degraded in performance as a result of the mission.

CONCLUSIONS

The CPL GAS and Hitchhiker flights successfully demonstrated the operation a capillary pumped two-phase thermal control system in micro-gravity. A much larger CPL flight experiment is planned that will demonstrate a heat transport capability of 1200 watts over a distance of 15 meters. This larger system is a prototype of the CPL thermal control systems that will be used on future platforms and spacecraft.

The design, integration, and test of shuttle flight experiments is a somewhat arduous task due to all of the special requirements of spaceflight. However, the excitement of flying an experiment in space and the rewards of a successful mission make it all worthwhile.

REFERENCES

1. F.J. Stenger, "Experimental Feasibility Study of Water-Filled Capillary-Pumped Heat-Transfer Loops", NASA TM X-1310, NASA Lewis Research Center, Cleaveland, Ohio, 1966.

2. E.J.Kroliczek, J.Ku, S.Ollendorf, "Design, Development, and Test of a Capillary Pump Loop Heat Pipe", AIAA-84-1720, AIAA 19th Thermophysics Conference, June 25-28, 1984.

3. "Safety Policy and Requirements, For Payloads Using the Space Transportation System (STS)", NASA NHB 1700.7 Rev.A.

4. J. Ku, E.J. Kroliczek, D. Butler, R.B. Schweickart, R. McIntosh, "Capillary Pumped Loop GAS and Hitchhiker Flight Experiments", AIAA/ASME 4th Joint Thermophysics Conference, June 2-4, 1986.

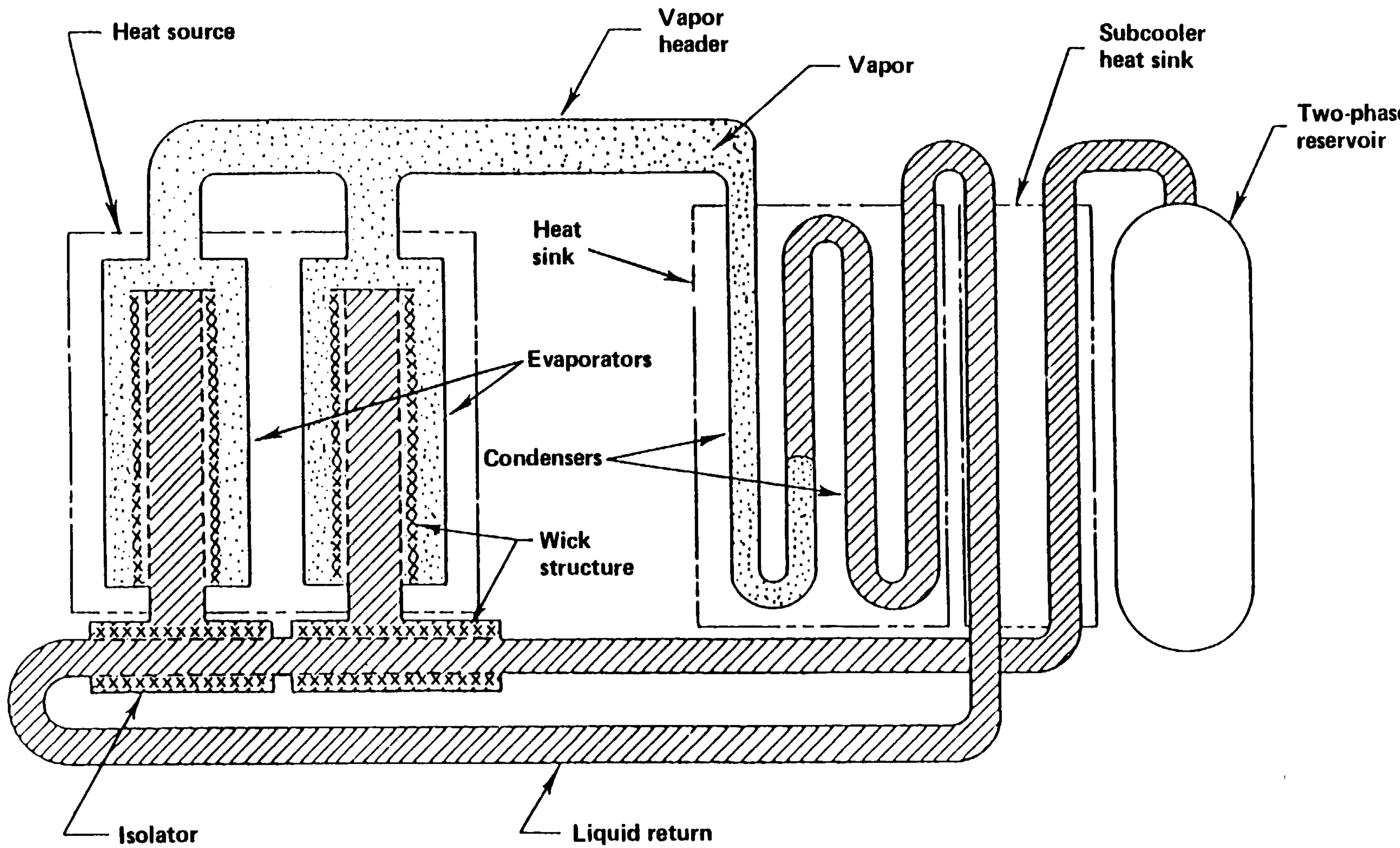

FIGURE 1. CPL FUNCTIONAL SCHEMATIC

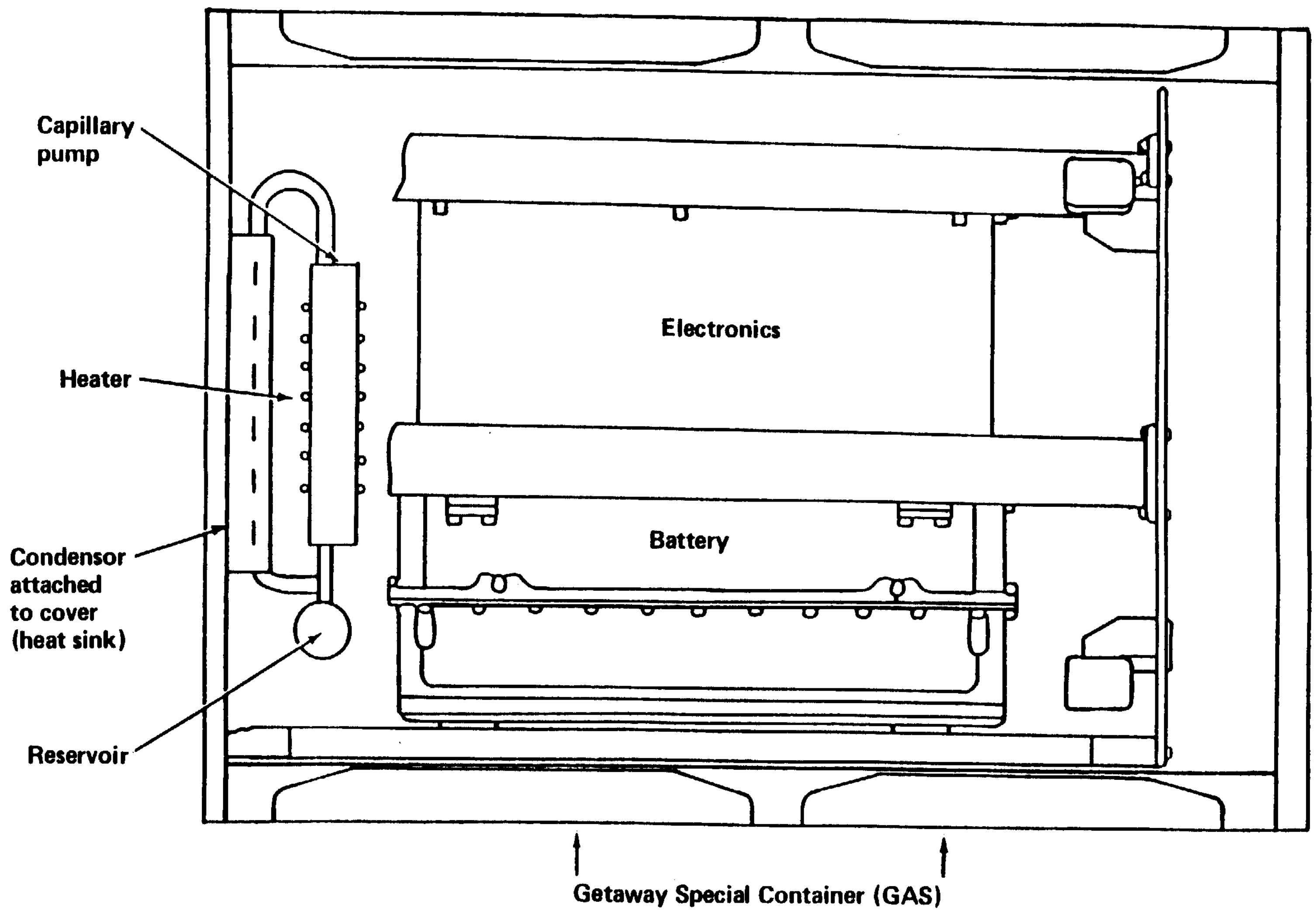

FIGURE 2. CAPILLARY PUMP PRIMING EXPERIMENT IN GAS CONTAINER

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

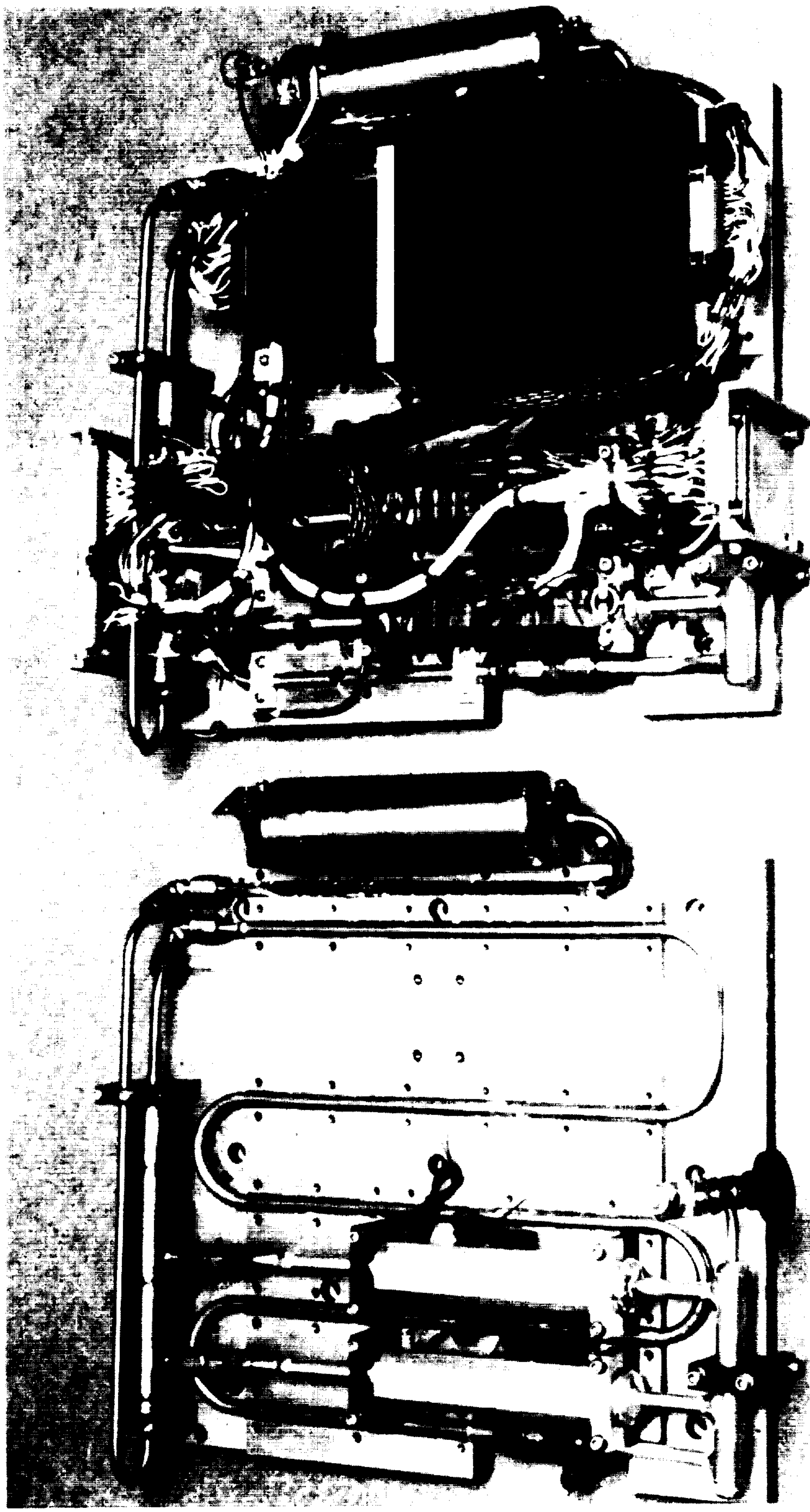

FIGURE 3. CPL EXPERIMENT

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

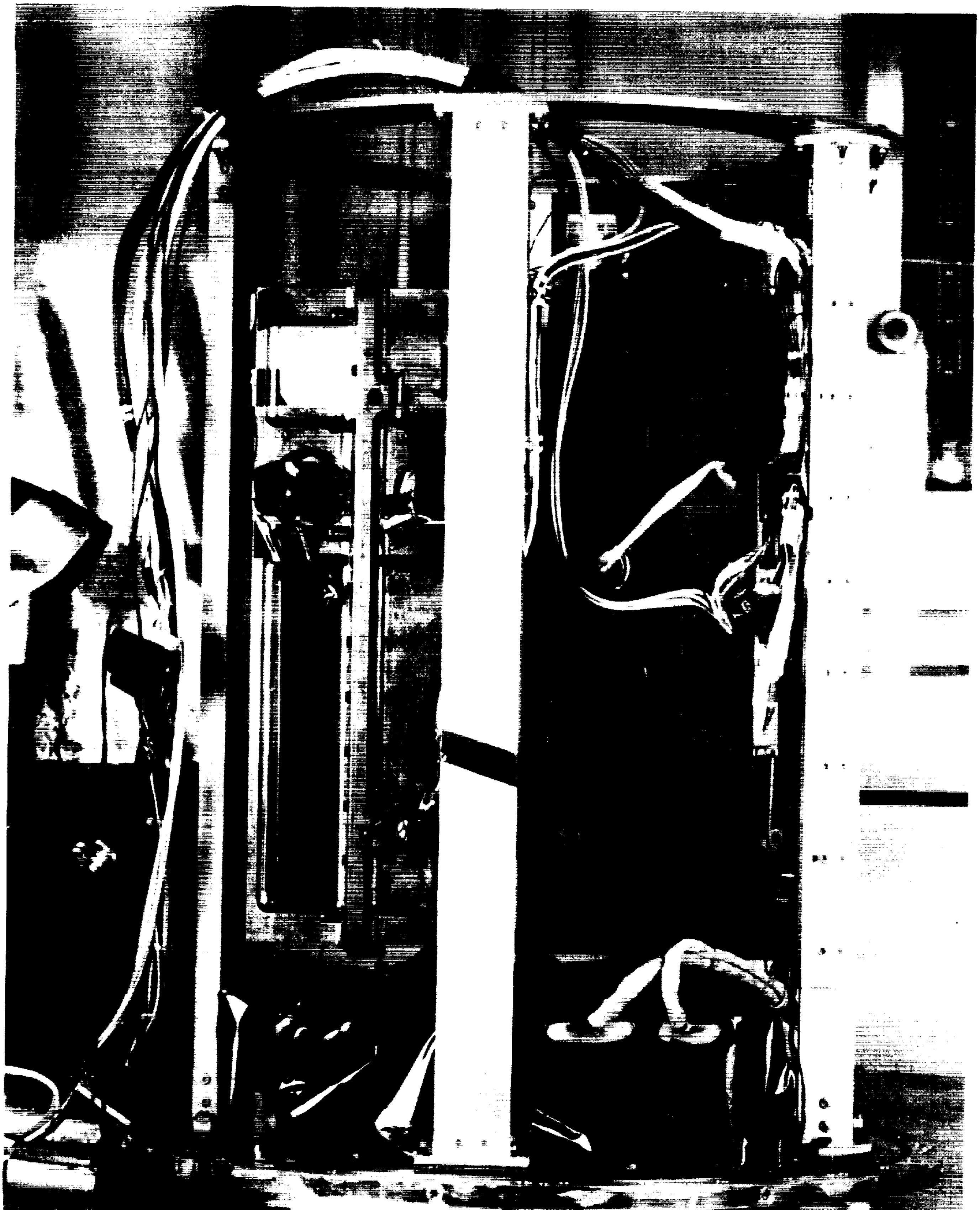

FIGURE 4. CPL EXPERIMENT ASSEMBLY

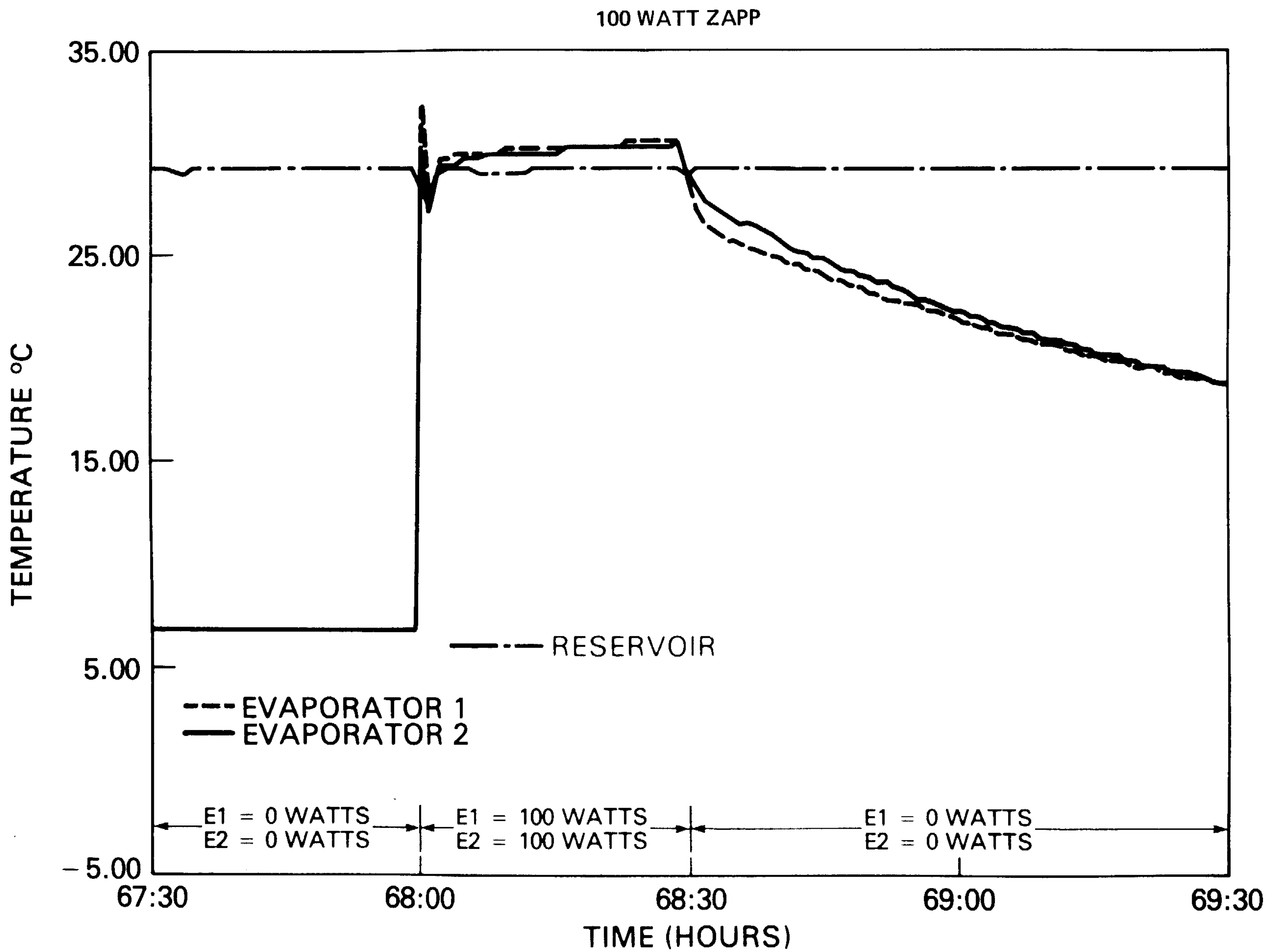

FIGURE 5. CPL-GAS FLIGHT DATA

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

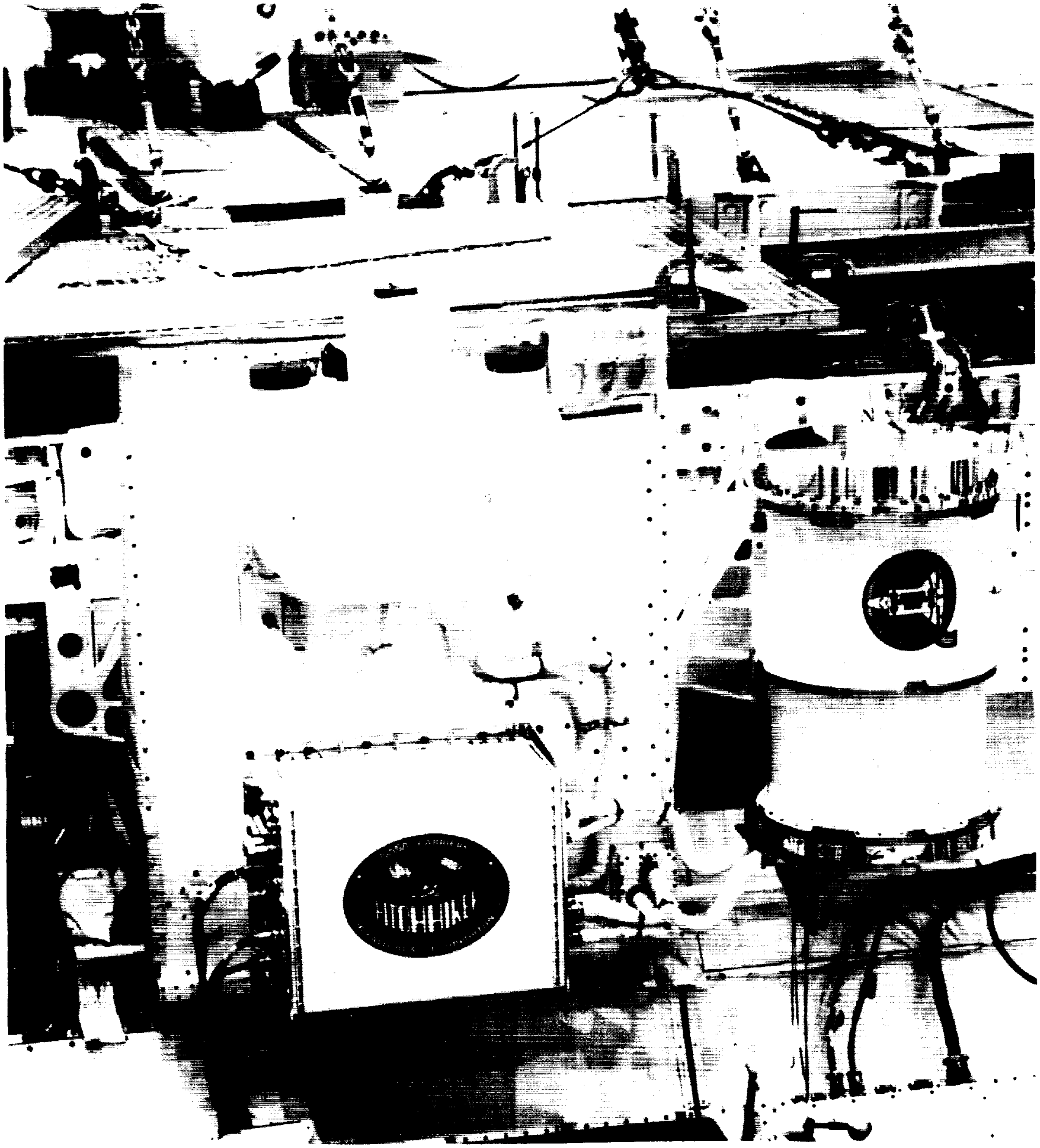

FIGURE 6. CPL HH-G CONFIGURATION

High power MET: 004:06:00:00 Cycle 27

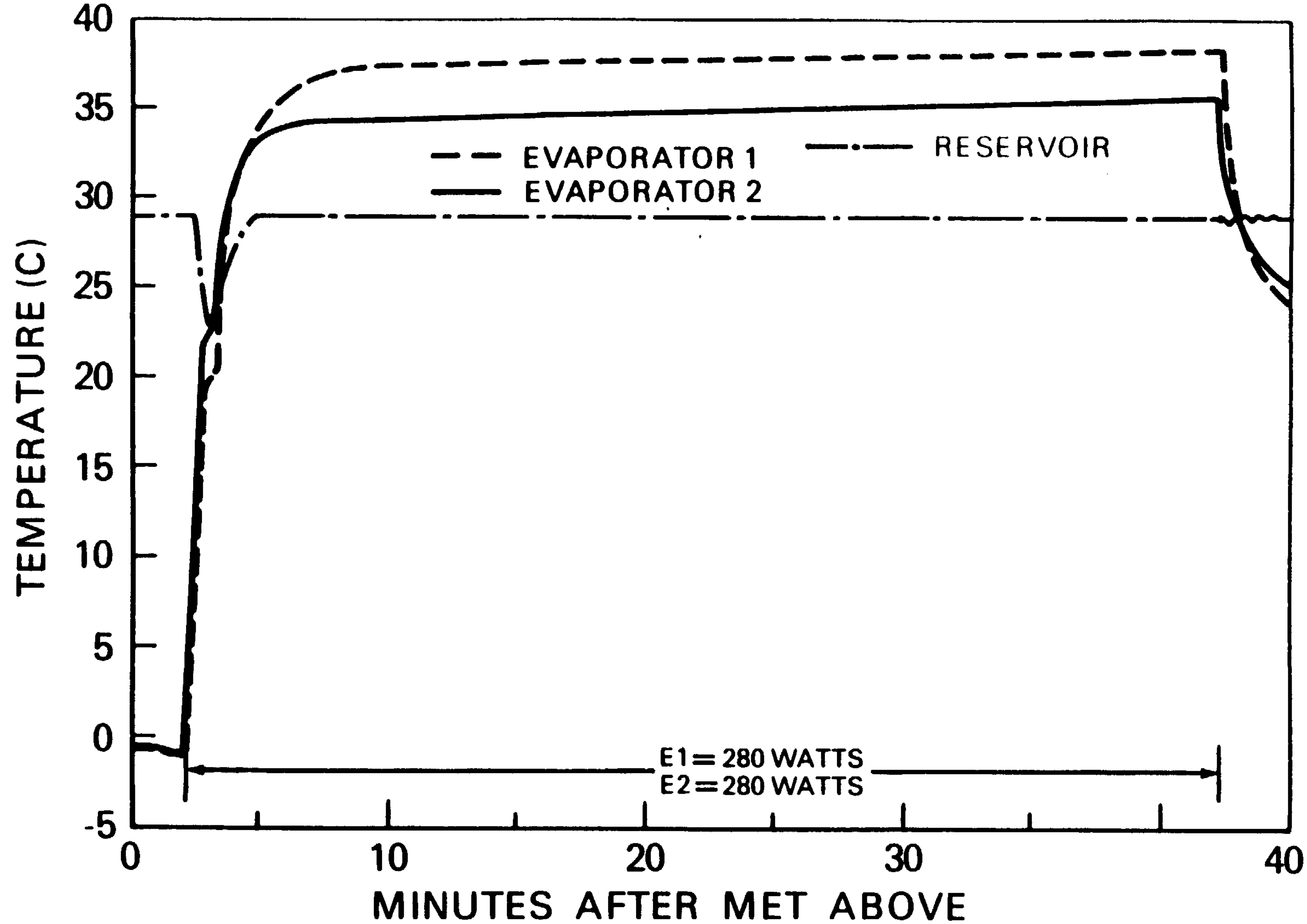

FIGURE 7. CPL HH-G FLIGHT DATA

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-100756		

4. Title and Subtitle	5. Report Date
Development and Integration of the Capillary Pumped Loop GAS and Hitchhiker Flight Experiments	April 1990
	6. Performing Organization Code 732
7. Author(s) D. Butler and R. McIntosh	8. Performing Organization Report No. 90B00081
	10. Work Unit No.
9. Performing Organization Name and Address Goddard Space Flight Center Greenbelt, Maryland 20771	11. Contract or Grant No.
	13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546-0001	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The Capillary Pumped Loop (CPL) is a thermal control system with high density heat acquisition and transport capability. A small spaceflight version of the CPL was built and flown as a GAS experiment on STS 51-D in April 1985 and STS 51-G in June 1985, and as a Hitchhiker-G experiment on STS 61-C in January 1986. The purpose of the experiments was to demonstrate the capability of a capillary pumped system under micro-gravity conditions for use in the thermal control of large scientific instruments, advanced orbiting spacecraft, and space station components. The development, integration, and test activities of the CPL are described.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Capillary Pumped Loop, Get Away Special, Hitchhiker-G, Thermal Control, Micro-Gravity, Two-Phase Heat Transfer, Reservoirs, Space Shuttle, Space Station, Polar Platforms, Evaporators	Unclassified - Unlimited Subject Category 18

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

NASA FORM 1626 OCT 86

National Aeronautics and
Space Administration

Washington, D.C.
20546

NASA