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CTS-TYPE VARIABLE CONDUCTANCE HEAT PIPES FOR SEP FM/PPU

CONTRACT NAS 3-21130

FINAL REPORT

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1. INTRODUCTION

Under Contract NAS3-21130, TRW Defense and Space Systems Group has fabricated six variable conductance heat pipes (VCHP's) and assembled them into two modules of three heat pipes, soldered into a common aluminum saddle. THese heat pipes have individual capacities of at least 220 watts at 50^{o}C and are over 310 centimeters long. This heat pipe design was evolved from the VCHP design which TRW built for NASA Lewis Research Center as a part of the Transmitter Experiment Package for the CTS spacecraft.

This report documents the activities conducted under contract including development effort, complete design details and test results.

2. BACKGROUND

TRW Defense and Space Systems Group has been active in heat pipe development since 1964, and has had considerable experience with flight heat pipes on CTS, Viking, OAO-C, sounding rockets and other spacecraft. The use of variable conductance arterial heat pipes on CTS represents the first time that gas loaded heat pipes have been used in the primary thermal control system of a spacecraft. THe heat transport capacity of the individual CTS heat pipes is approximately 7500 watt-inches.

Recognizing the potential application of this technology to systems such as SEP FM/PPU which have stringent weight limitations, TRW pursued an Independent Research and Development Program in 1974 and in 1975 to implement improvements in the CTS design aimed at doubling the capacity. During the IRAD program, two heat pipes were fabricated, one with 0.70-inch-diameter arteries and one with 0.080-inch-diameter arteries, both using 0.0027-inch priming foils with a single row of 0.0067-inch-diameter venting holes. The arteries were placed low in the pipe cross-section such that a 0.020-inch gap was maintained between the artery and the tube wall. The lower placement of the arteries was to improve the ability of the arteries to prime in earth gravity. In addition, a new priming foil design was conceived that did not impede the liquid entering it and thus allow priming with a low fluid charge. These changes in the CTS design were successful in terms of capacity increases but artery priming was unreliable. The capacity was increased to 14,300 watt-inches at 0.3-inch evaporator elevation which corresponds to the capacity predicted in zero gravity. This increase in capacity resulted from the use of larger diameter arteries and smaller venting holes in the priming foil. The lower placement of the arteries, however, was believed to be responsible for the unreliable artery priming.

In 1977, TRW was awarded contract NAS3-21130 by NASA Lewis Research Center to conduct a two-phase program to develop and test two prototypes and subsequently, six flight-type variable conductance CTS-type heat pipes each with a 14,000-watt-inch capacity for SEP application. A two phase program was called for to confirm that recommended changes in the heat pipe design would successfully resolve the priming problems encountered in the IR&D program. During Phase I, two methanol/stainless steel heat pipes, one with 0.070-inch-diameter arteries and one with 0.80-inch-diameter arteries, were to be developed and tested. In addition, since the SEP design calls for an overall heat pipe length of 122.5 inches, the activities during this phase were to include the development of a technique to splice the arteries.

Contingent upon successful results from these Phase I development activities, a design would then be selected for the fabrication of six variable conductance heat pipes during Phase II. The heat pipes were to be soldered to aluminum saddles as the final fabrication step.

3. PHASE I DESCRIPTION

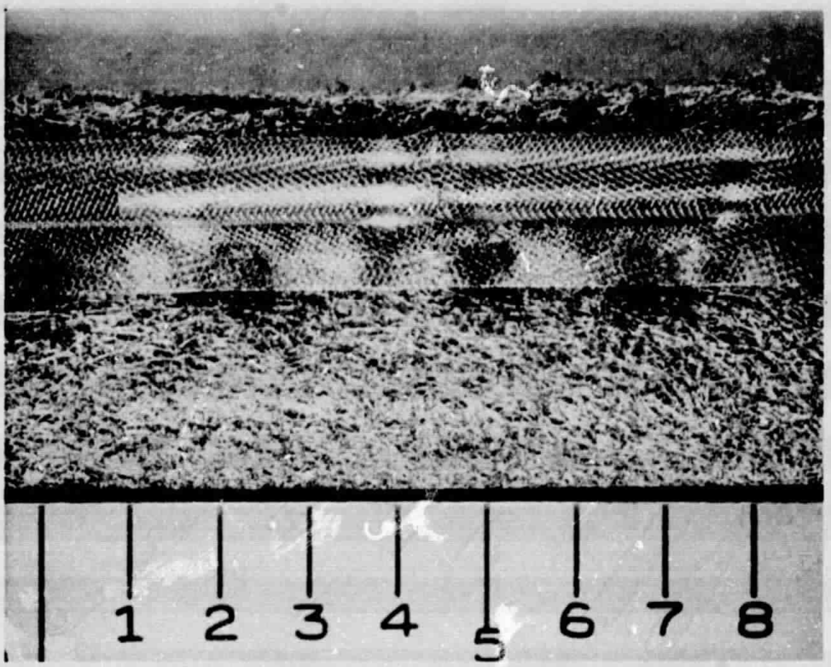
The objective of this phase of the program was to fabricate and test two variable conductance heat pipes which incorporated developments expected to lead to the 14,000 watt-inch capacity goal and to reliable artery priming.

3.1 ARTERY SPLICING

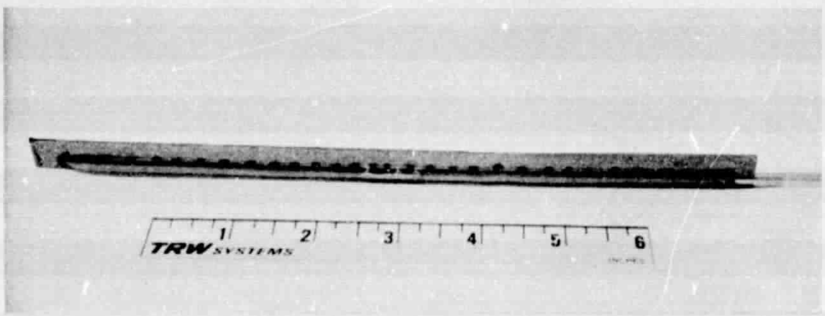
One of the first activities in this program was the development of a technique to splice the arteries mandated by the SEP design calling for an overall length of over 122 inches.

The arteries are fabricated from 150 mesh stainless steel screen, made using 0.0026-inch-diameter wire. This material is only available in 60-inch width. This fact impacts the fabrication of arteries for the SEP application since it is mandatory to cut the screen on a 45-degree bias to prevent collapse of the arteries when the 90-degree bend in the heat pipe is formed between the PPU and the radiator. The longest single piece of material that is obtained with this mesh pattern is approximately 80 inches; hence, it was necessary to splice the artery at some point in the wick structure. Although the slab wick which supports the arteries also required a splice, a technique for that splice had already been developed and tested during the CTS program.

A method for splicing the artery was developed and tested. The concept is to seam weld a 0.75-inch-wide strip of 0.0005-inch stainless steel foil to the two sides of a butt joint in the mesh screen. The spliced screen is then used to form the artery following standard manufacturing techniques. The drawing of a test specimen is shown in SK77040 in the Appendix. As shown, the foil in the region of the splices is inside the artery. The specimen proved to be sufficiently strong to render unnecessary the use of an additional section of foil on the outside of the artery. Photographs of the splice sample are shown in Figure 1.



A. Splice Region



B. Overall Sample

Figure 1. Artery Splice Test Sample

Concurrent with these development activities, detailed drawings for the two heat pipes were prepared. The complete set of drawings is included in the Appendix. Certain features of the SEP design are discussed below.

3.2 ARTERIES

The design uses 0.070-inch-diameter and 0.080-inch-diameter arteries. For the same capillary pressure these arteries can be expected to have a capacity 1.5 times and 2.5 times respectively larger than the 0.063-inch-diameter arteries in the CTS design. Following the recommendation made after the 1974 and the 1975 IRAD programs, the arteries are located in the tube cross-section such that a 0.040-inch gap exists between the arteries and the tube wall. The locations of the SEP arteries are shown schematically in Figure 2 where they can be compared to the CTS design. This configuration yields essentially the same safety factor for artery priming as the CTS design. The safety factor is a measure of the ability of the arteries to prime in earth gravity, which is taken as the ratio of the capillary pressure of the open artery to the hydrostatic pressure based on the distance from the bottom of tube to the center of mass of the artery.

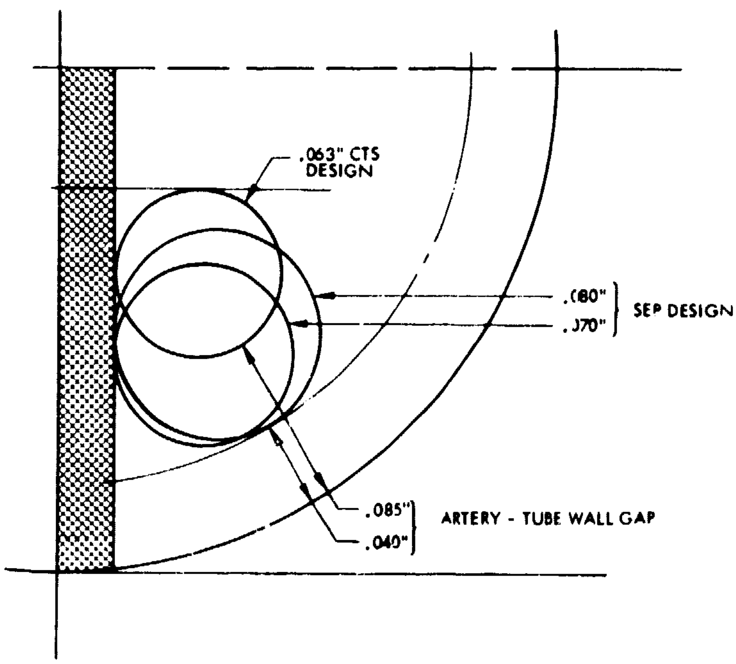


Figure 2. Artery Locations in CTS and SEP Designs

The capillary pressure of the arteries is established by the 0.0067-inch-diameter venting holes in the priming foil. This capillary pressure is approximately 50 percent greater than the capillary pressure of the CTS arteries. The SEP priming foil design uses a 0.00027-inch-thick stainless steel foil section with a single row of venting holes. This foil is spot welded on the inside of a short stainless steel tube over a window cut in it.

The inside diameter of the priming tube is 0.001 inch larger than the inside diameter of the arteries in order to prevent the foil region from filling with liquid by capillary pressure before the artery primes. This priming foil design is similar to the one developed during the 1974-1975 IRAD program. Tests have shown that this design does not impede the liquid from entering it, thus requiring in principle a lower fluid inventory for artery priming.

3.3 GAS RESERVOIR

The volume of the gas reservoir is identical to that of the CTS reservoir, which is 8.22 cubic inches. Although the reservoir-to-condenser volume ratio is approximately 1, compared to the 1.5 to 2.0 ratio in the CTS design, a tighter control range is achieved (26^{o}F versus 52^{o}F). The improved temperature control range is due to the fixed, and low, sink temperature of -102^{o}F. Based on the flat gas front theory, a gas inventory of 6 x 10^{-6} lb-moles should provide a control range from full off at 91°F to the full on at 117°F.

3.4 ARTERY PRIMING TESTS

Before the arteries were attached to the slab wick, bubble point tests were performed to establish the integrity of the arteries and the priming foil.

Subsequently, the slab wick/artery assemblies were subjected to priming tests in a glass tube containing acetone. Tests results with the 0.080-inch-diameter arteries using 0.081-inch-I.D. priming tubes were satisfactory. However, priming tests with the 0.070-inch-diameter arteries using 0.071-inch-I.D. priming tubes showed that priming occurred consistently through the priming cap region and gas was vented through the screen. It is believed that the small difference in radii (0.070 inch versus 0.071 inch) was insufficient to allow a safety margin, and slight deformation in either the tube or foil during the priming cap installation could have resulted in the priming foil region having a smaller effective radius than the artery. As a means of guaranteeing that the priming tube would be last to prime, the 0.081-inch-I.D. priming tube was also installed on the 0.070-inch-diameter arteries. Subsequent tests showed this design change resulted in reliable priming of the 0.070-inch-diameter arteries.

3.5 LIQUID INVENTORY

A change in the design of the two heat pipes was made in which the last 4 inches of the evaporator, including the priming foil caps, was exposed by cutting the tube short. This was done to allow observation of priming and depriming during the evaluation tests. One of the heat pipes, complete with heater tape and thermocouples, is shown in Figure 3. The evaporator end was closed with a glass tube and a Swagelok fitting using Teflon ferrules as shown in Figure 4. Figures 5 and 6 show the exposed wick and artery in more detail.

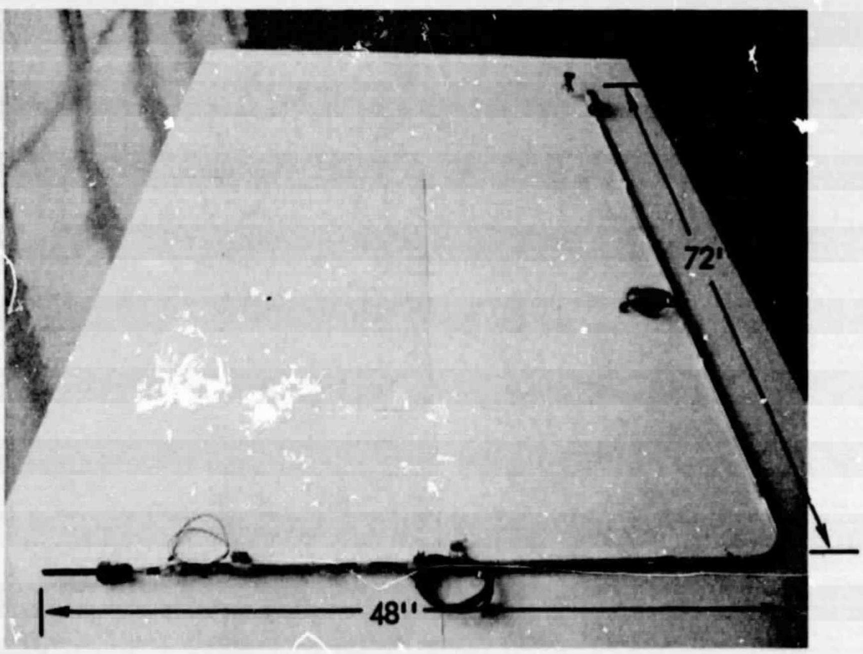


Figure 3. Completed SEP FM/PPU Development Heat Pipe

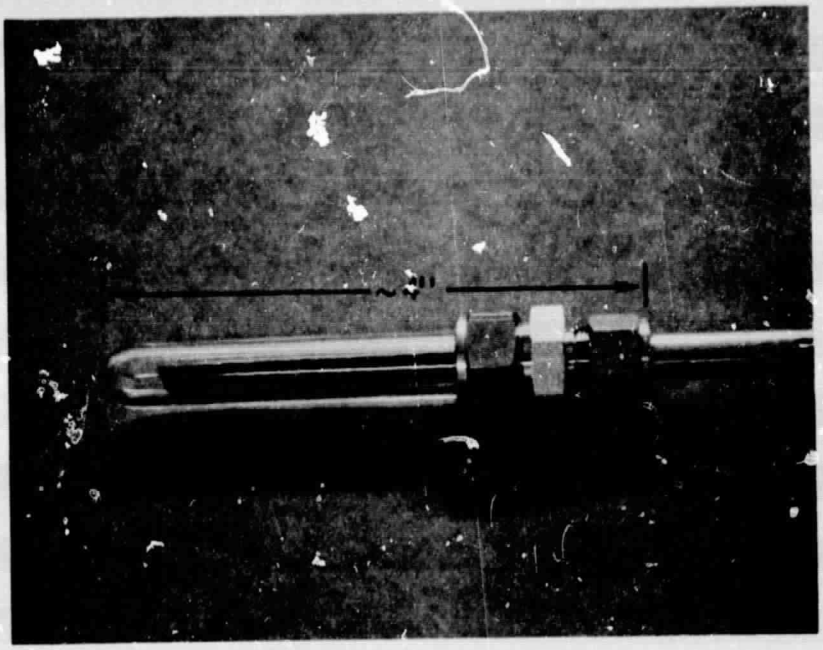


Figure 4. Priming Foil Visible at Evaporator End

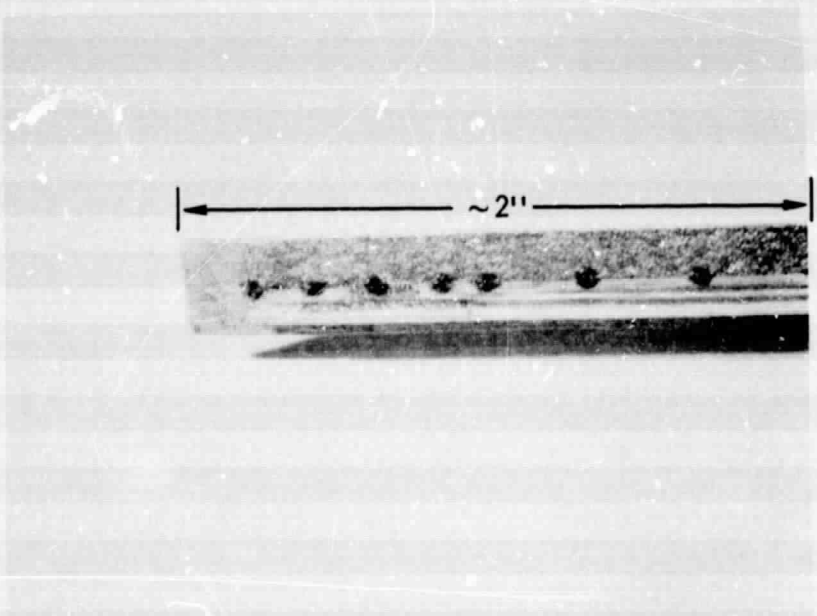


Figure 5. Priming Cap Attachment

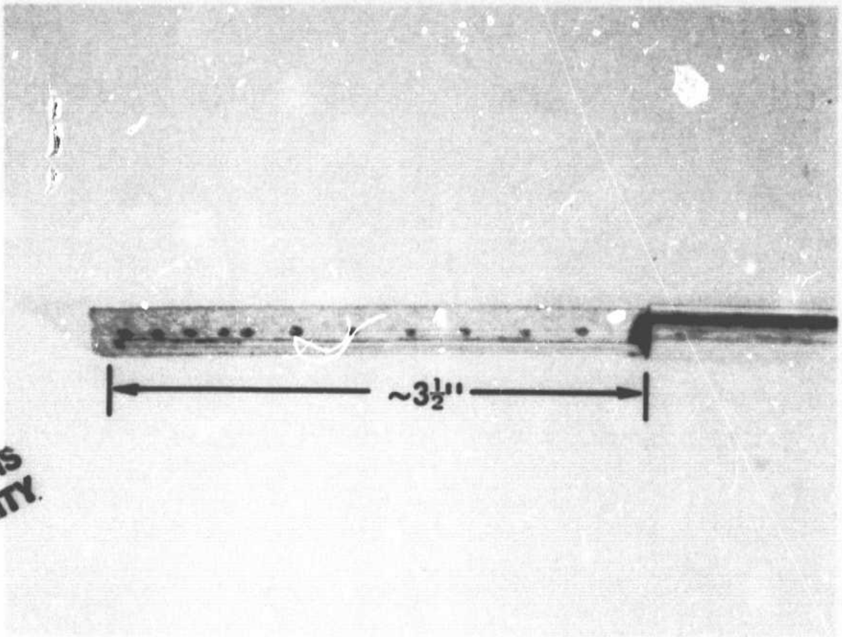


Figure 6. Exposed Evaporator End of Heat Pipe

Preliminary tests were performed on both heat pipes to determine the minimum fluid change required for priming. This value was determined by level priming tests, observing priming at increasing inventories until repeatable priming occurred. The required inventory was 120 cc which, correcting for the additional length of the SEP heat pipes, is approximately 20 percent less than the CTS inventory.

3.6 PERFORMANCE TESTS

The heat pipes were instrumented with 18 thermocouples, wrapped with an electrical heater over a 38-inch length and mounted over a 48-inch length to a temperature-controlled baseplate using a grooved condenser block with aluminum foil in all interfaces. The test configuration is shown in Figure 7. Data were taken in the temperature range of 88^{o}F to 120^{o}F. The results of tests with the 0.070-inch-diameter artery heat pipe using 0.081-inch-I.D. priming tubes are shown in Figure 8. The solid points shown in the figure have been corrected using capacity versus temperature results from tests on the 0.080-inch-diameter artery heat pipe. The dashed line is the performance predicted by the Multiwick program and can be seen to be in good agreement with the measured values. The zero gravity prediction from the Multiwick program

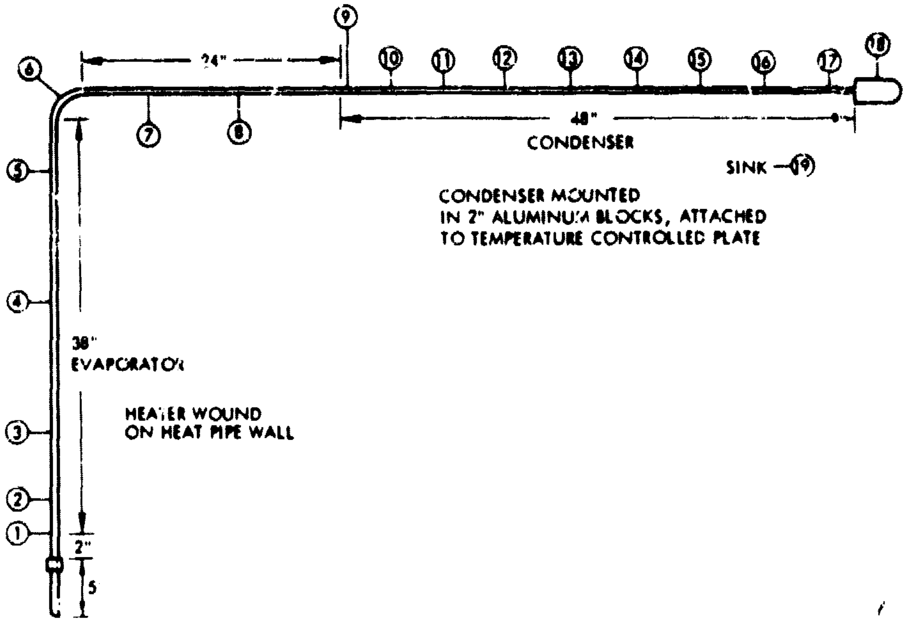


Figure 7. Test Configuration - SEP H.P.

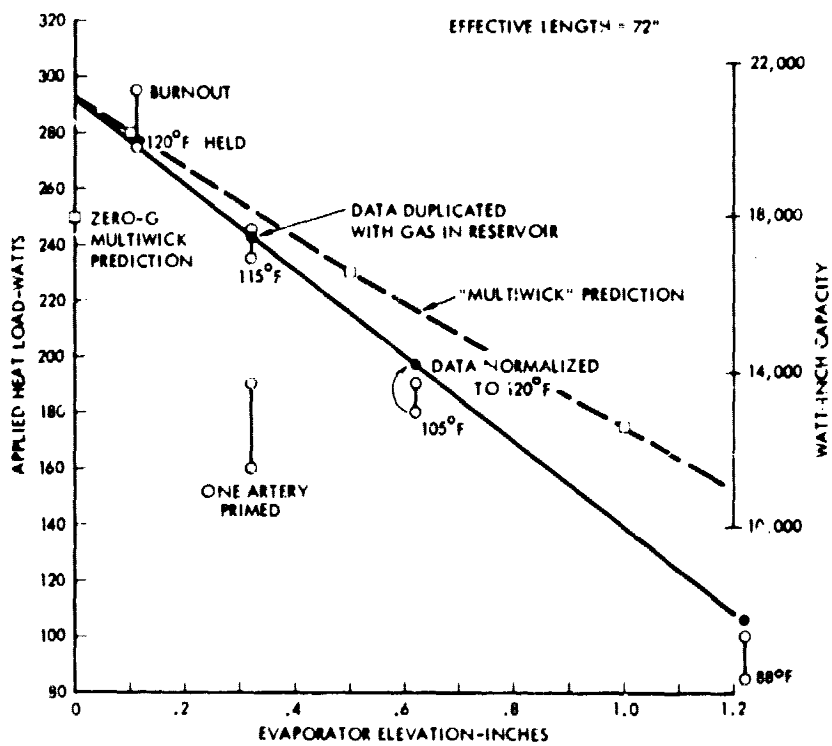


Figure 8. Capacity of 0.070-Inch Artery Heat Pipe

corresponds to the result at 0.3-inch evaporator elevation. The fact that the zero gravity prediction is lower than the earth gravity results at no evaporator elevation is due in part to the contribution from fillets and excess fluid natural reservoirs which aids significantly the performance in one-g, but not in zero-g.

The capacity measured at 0.3-inch evaporator elevation was 245 watts. As noted in Figure 8, the effective length of the test heat pipe was 72 inches which corresponds to 17,640 watt-inches. Since the effective length of the heat pipe for actual SEP application is about 64 inches, the capacity of the production SEP heat pipes would therefore be 275 watts. Also shown in the figure is the capacity of a single artery. This result was obtained by raising the heat pipe until one artery was observed to deprime and then applying a heat load.

Tests were also performed on the 0.070-inch-diameter artery heat pipe containing gas in order to verify the effect of gas on priming and capacity performance. At 0.32-inch and 1.23-inch evaporator elevations, the capacity with gas was identical to that without gas. Priming was consistent with or without gas. Figure 9 shows the temperature profiles in the heat pipe at nearly off and fully on conditions. Data for the 0.080-inch-diameter artery heat pipe are shown in Figure 10. The capacity at 0.30-inch evaporator elevation was 310 watts, which corresponds to 22,300 watt-inches. This capacity is 15 percent lower than Multiwick prediction. The discrepancy is attributed to the impaired function of one of the arteries. The fact that one of the arteries did not prime reliably during priming tests seems to indicate that this artery sustained some damage during heat pipe assembly. This heat pipe underwent X-ray inspection but the source of the problem could not be identified.

A number of data points with one 0.080-inch-diameter artery primed showed high capacity (14,000 watt-inches) at burnout. Groove dryout or partial slab wick dryout was evident with only one artery primed. For example, at 0.25-inch elevation, temperature gradients began to appear in the evaporator at 160 watts, yet burnout (depriming of the artery) did not occur until 210 watts were applied.

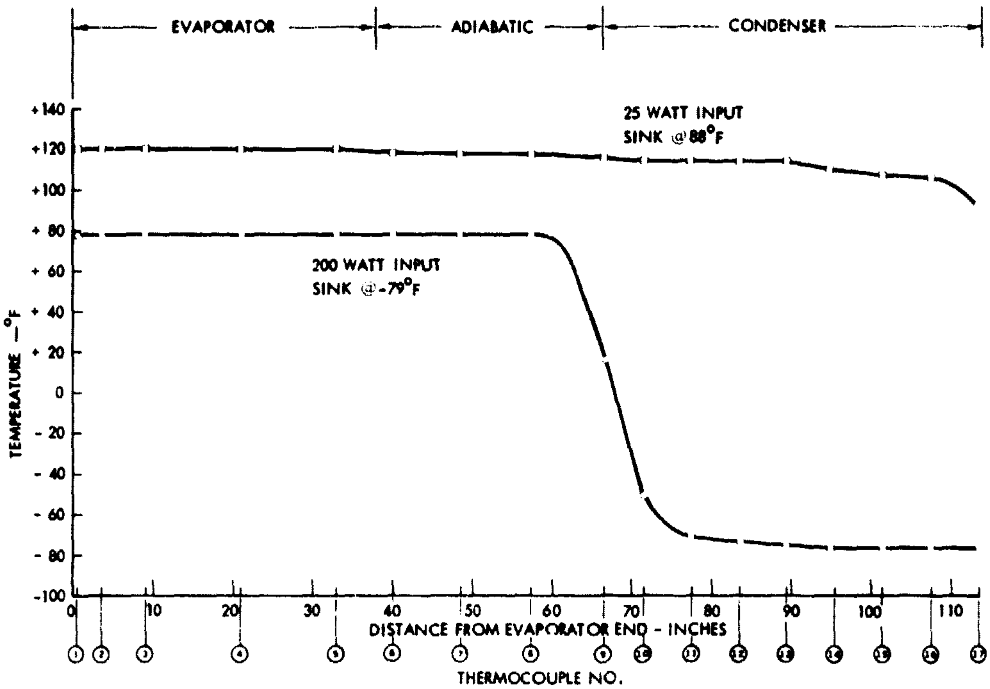


Figure 9. Temperature Profile of Gas Loaded 0.070-Inch Artery Heat Pipe

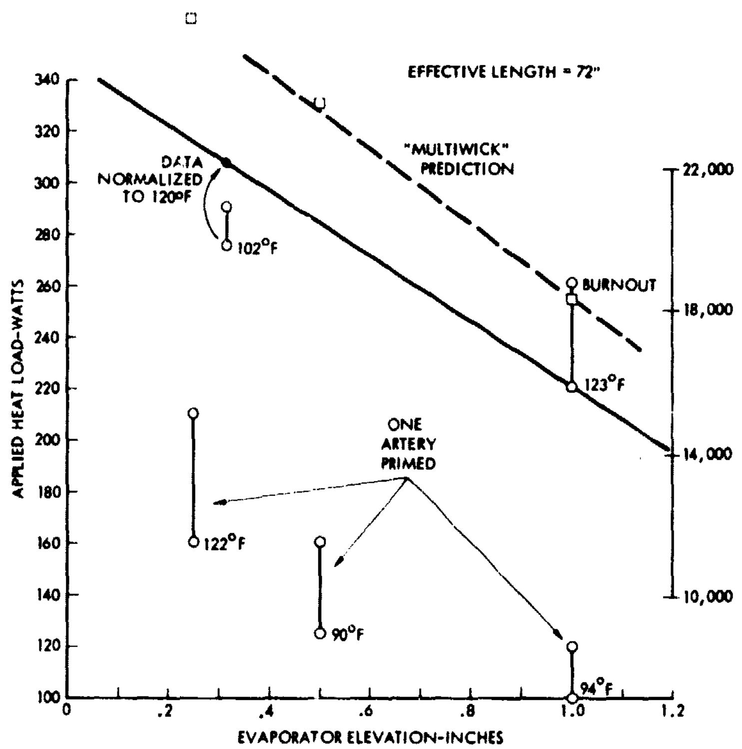


Figure 10. Capacity of 0.080-Inch Artery Heat Pipe

The capacity as a function of vapor temperature was measured for the 0.080-inch-diameter pipe. The data shown in Figure 11 were used to correct data taken at various adiabatic temperatures. Testing is more efficient timewise when the sink temperature is fixed and power is increased until burnout occurs. This results in burnout data at temperatures different from the design temperature of 122°F.

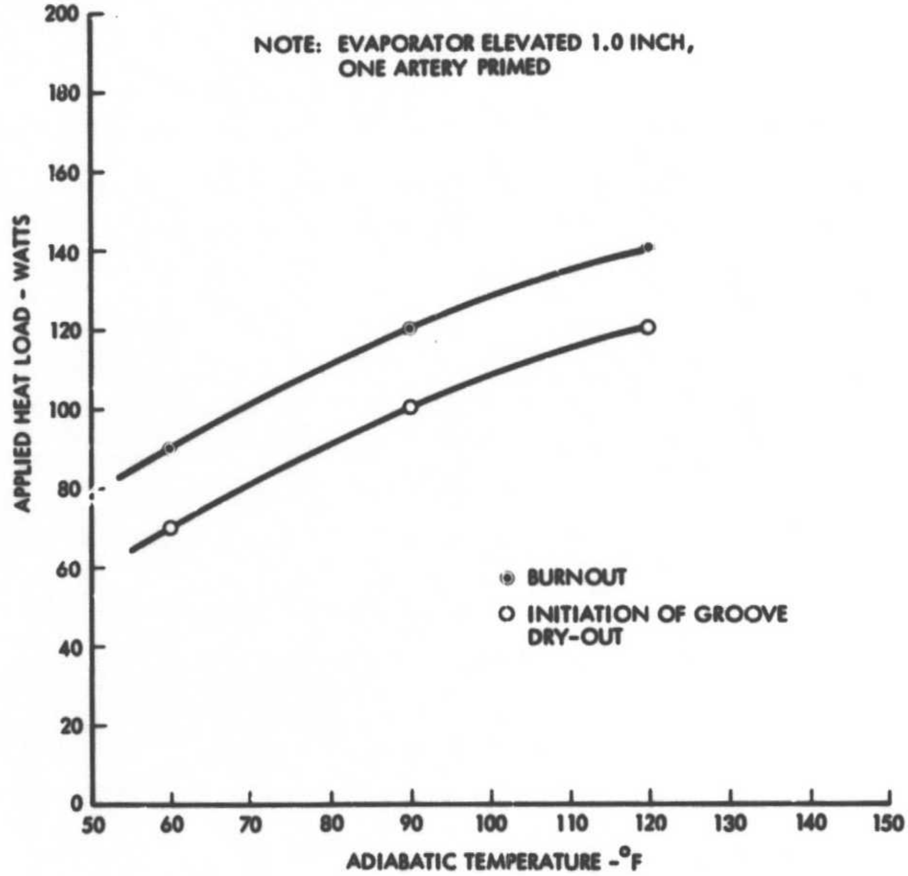


Figure 11. Capacity of 0.080-Inch Artery Heat Pipe as a Function of Temperature

3.7 SUMMARY

The performance of both heat pipes substantially exceeded the 14,000 watt-inch capacity goal of this program; however, only the 0.070-inch-diameter artery heat pipe with 0.081-inch-I.D. priming caps showed reliable artery priming. As a result, this design was selected for the fabrication of six deliverable heat pipes during Phase II.

4. PHASE II DESCRIPTION

The objective of this phase of the program was to fabricate six variable conductance heap pipes in a configuration suitable for inclusion in a development SEP FM/PPU test article.

4.1 FINAL HEAT PIPE DESIGN

As recommended from the development activities in Phase I, a heat pipe configuration with the 0.070-inch-diameter arteries and 0.081-inch-I.D. priming tubes was selected for the fabrication of six deliverable heat pipes. Detail drawings of the final design are shown in the Appendix. The drawings include the changes made during Phase I, primarily regarding the priming tube. The length of the evaporator was increased by 0.15 inch to allow the end cap weld to extend just beyond the end of the saddle when the modules are assembled. An assembly drawing of the modules is shown in SK78006 in the Appendix.

4.2 HEAT PIPE ASSEMBLY AND PROCESSING

All parts were cleaned per TRW procedure PR 2-28-1. The arteries were subjected to bubble tests to establish the integrity of the mesh screen and the priming tubes prior to installation of the arteries on the slab wick. Subsequently, the completed slab wick/artery assemblies were tested for priming reliability.

As a check of mechanical integrity and to identify any major leak, each heat pipe was pressurized with nitrogen to 50 psig and held for 15 minutes. In addition, each heat pipe was leak checked with a vacuum leak detector. No leaks were detected on any of the six heat pipes. Subsequently, the heat pipes were vacuum baked at 275^{o}F for 2 hours. Identification numbers, 1 through 6, were scribed on the end caps of each heat pipe.

4.3 LIQUID INVENTORY

Heat pipe number 3 (HP3) was selected for preliminary tests intended to establish the minimum fluid inventory required for reliable artery priming. Tests began with a 120 cc methanol inventory which was the one used in the Phase I heat pipes. Reliable priming was found at 138 cc, and to allow some tolerance, 140 cc were used for the other heat pipes. This inventory is proportionally the same as the CTS heat pipe inventory, correcting for increased length and larger artery diameter in the SEP design.

4.4 PERFORMANCE TESTS

The heat pipes were installed on a temperature-controlled base plate using 0.5-inch-thick grooved aluminum blocks with aluminum foil between all interfaces to assure good thermal contact. The evaporator heater was bonded to a grooved aluminum saddle which was bolted to the evaporator section of the heat pipe. A sketch of the test configuration and mounting details is shown in Figure 12. In this configuration, the effective length of the heat pipes was approximately 66 inches. A minimum of six thermocouples were used; more in some tests.

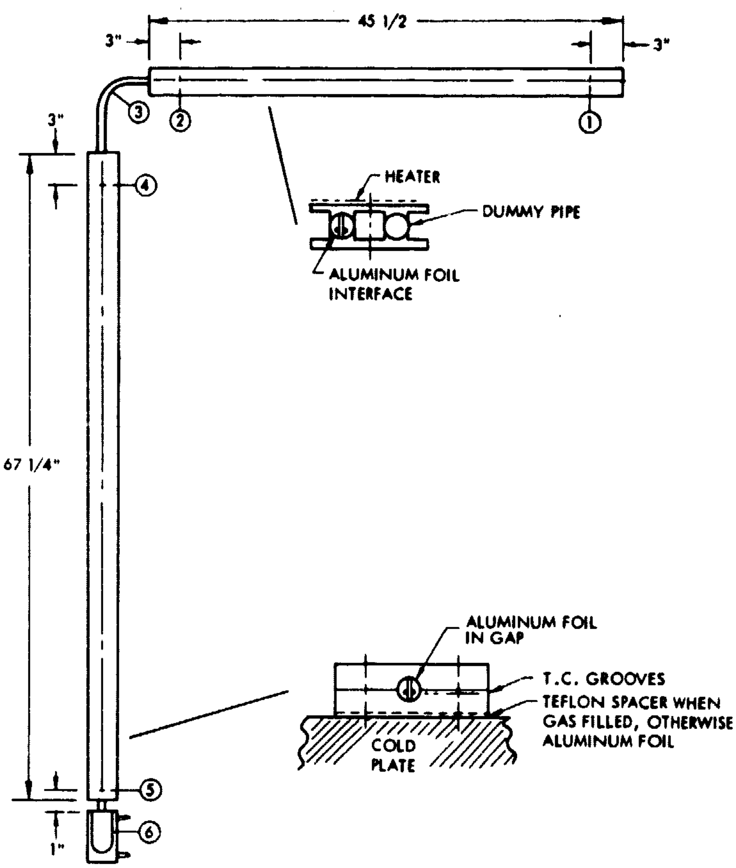


Figure 12. Test Configuration

The general test procedure was to level the heat pipe to ±0.010 inch using a cathetometer, apply 25 watts, tilt the heat pipe to the desired evaporator elevation and raise the power sequentially to 100 watts, 150 watts and 200 watts allowing 15 minutes to elapse between power changes. Thereafter, the power was increased in 20-watt increments until burnout occurred. In tests where the heat load exceeded 220 watts, some nonuniform evaporator temperatures were observed. These nonuniformities were indications that partial groove dryout was occurring in the evaporator without evidence of artery failure. The results of tests on all heat pipes at 0.30-inch evaporator elevation and 120^{0} $\pm 5^{0}$F adiabatic temperature are summarized in Table 1. As shown, the capacity of heat pipe number 6 is 150 watts, which is consistent with only one

Table 1. Test Results—Evaporator Elevation 0.3 Inch, Adiabatic Temperature = 120^{0}F $\pm 5^{0}$F (Effective Length of Pipes = 66 Inches)

Pipe Number	Configuration	Power Held (Watts)	Power at Groove Dryout (Watts)	Burnout (Watts)	Comments
1	1	220	---	230	138 cc inventory
2	2	270	310	None; stopped	140 cc inventory
3	1	220	---	230	First pipe tested 138 cc inventory
4	1	220	260	None; testing stopped at 300 watts	140 cc
5	2	280	290	300	140 cc
6*	2	>150	150	175	141 cc
7	2	300	220	320	140 cc

*Performance below specification.

artery operating. Repeated attempts to prime both arteries were unsuccessful. As a result, an additional heat pipe was fabricated and tested. Tests results on this heat pipe are shown as pipe number 7 in Table 1.

Additional tests were performed on heat pipe number 5 to establish the performance as a function of evaporator elevation, which is shown in Figure 13. The data show no evidence of excess fluid contribution to the capacity at 0.3-inch evaporator elevation, which is the one predicted in zero gravity. The test configuration was modified to allow testing of HP5 loaded with 6×10^{-6} lb-moles of nitrogen gas. A cooling block was installed on the gas reservoir and 0.25 inch of Teflon was inserted between the condenser block and the temperature-controlled base plate. With the reservoir temperature controlled between -90°F and -98°F, the heat pipe turned on at 97°F and was full on at 118°F. The improved temperature control range is attributed primarily to the larger reservoir-to-condenser volume ratio resulting from the excess fluid reducing the vapor spaces in the condenser section.

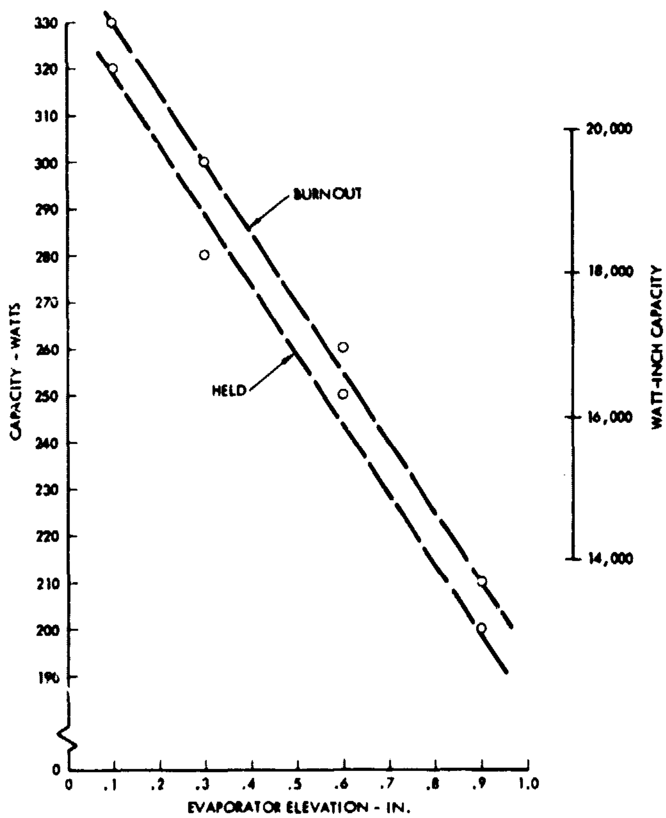


Figure 13. SEP Phase II – Heat Pipe No. 5 Capacity

4.5 INDIVIDUAL HEAT PIPE SUMMARY

Six out of seven heat pipes met, and some of them substantially exceeded, the 14,000-watt-inch capacity goal of this program.

Test results showed some differences in the performance between heat pipes in terms of burnout capacity and capacity at which partial groove dryout was observed. Differences in burnout capacity could be the result of a reduction in cross section at some point in an artery—possibly in the region of the 90-degree bend. Such a change in cross section would reduce the capacity of the arteries due to increased liquid flow resistance.

Differences in observed partial groove dryout could be due to nonuniformities in the configuration of the grooves resulting from variations in the tube inside diameter and/or wear of the threading tool. This phenomenon, however, should not impact the performance of the SEP heat pipe module since partial groove dry-out is observed only at capacities higher than the designed operating capacities of the SEP heat pipes.

4.6 MODULE ASSEMBLY

Two modules were assembled, each consisting of three heat pipes soldered to two aluminum saddle halves supplied by NASA LeRC. An assembly drawing of these modules, configurations A and B, are shown in SK78006 in the Appendix. Heat pipes number 1, 2, and 4 were used in module A. Module B used heat pipes 3, 5, and 7.

After the individual performance tests, the heat pipes were vacuum dried, backfilled with nitrogen to 1 atmosphere and pinched off before they were sent along with the saddles to an outside vendor for plating. The specifications for tin plating the stainless steel tube sections and the aluminum saddles are shown in SK77036-A and SK78011, respectively, in the Appendix. A special fixture for assembling the modules was fabricated. The fixture with a module at two different stages of assembly is shown in Figures 14 and 15.

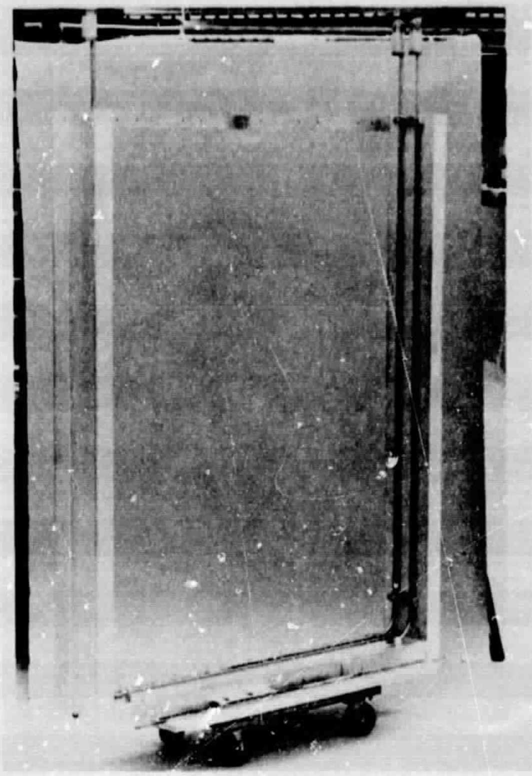


Figure 14. SEP Module Partially Assembled in Soldering Fixture

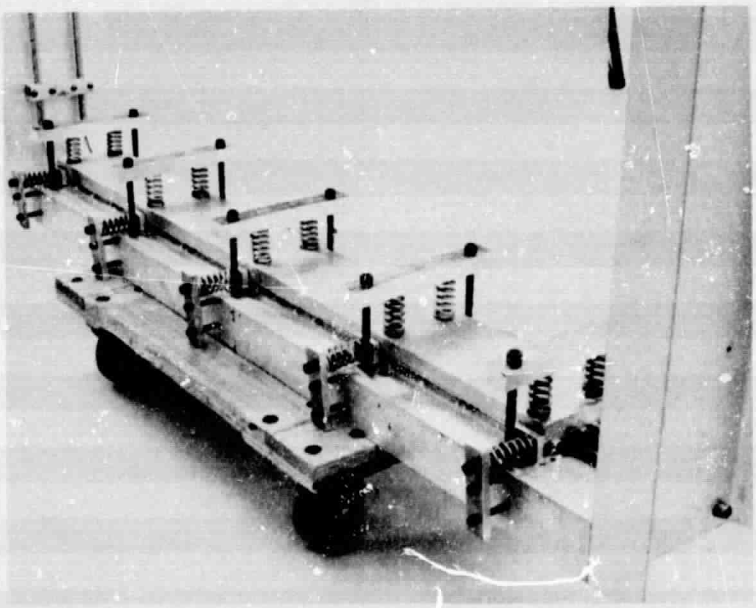


Figure 15. Assembled SEP Module Prior to Soldering

As shown in Figure 15, the saddles are spring loaded in order to help alignment during soldering. A partial view of a module baseplate after soldering is shown in Figure 16. The rectangular tubes extending beyond the end of the baseplate were soldered to the saddle halves to provide alternate cooling during ground tests of the SEP FM/PPU.

4.7 MODULE ACCEPTANCE TEST

The heat pipes of the assembled modules were individually tested. The basic test configuration is sketched in Figure 17.

Four heater tapes, each 0.375 inch wide and 45 inches long, were bonded to one side of the baseplate to provide nearly uniform heating of the evaporator saddle. As one heat pipe was being tested, the other two heat pipes were turned off by heating their gas reservoirs to $\sim 130^{\circ}F$. The condenser section of the test heat pipe was clamped between two 2.5-inch x 1.5-inch grooved aluminum blocks. Aluminum foil was used in all interfaces for good thermal contact. Heat dissipation from the condenser block to ambient air by natural convection was sufficient to allow steady-state operation of a heat pipe under a 220-watt heat load at an adiabatic temperature of about $110^{\circ}F$. To test the performance at higher temperatures the condenser block was partially insulated. A liquid-nitrogen-cooled block was mounted on the gas reservoir of the test heat pipe.

Twelve thermocouples were used during the tests, located as shown in Figure 17.

The three evaporator thermocouples were placed on the saddle directly above the heat pipe being tested.

Prior to the test of a module, the fill tube was cut open and each heat pipe was vacuum-leak checked, filled with 140 cc of spectral grade methanol and loaded with 6×10^{-6} lb-moles of 90 percent nitrogen - 10 percent helium gas. The procedure used to load a heat pipe with gas consisted in filling a 133 cc reservoir with gas to 25 psia at room temperature and then transferring gas into the heat pipe until a 7.2 psi pressure drop was observed in the transfer reservoir.

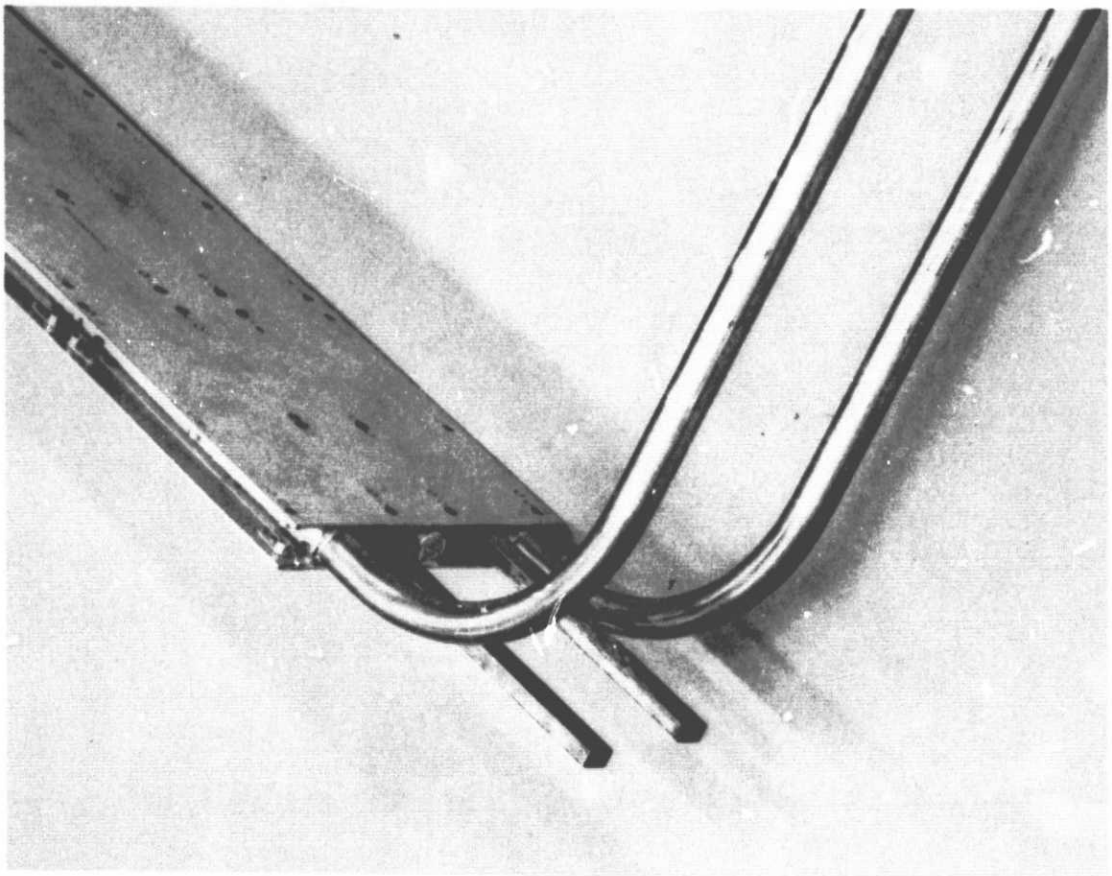


Figure 16. Partial View of SEP Module After Soldering

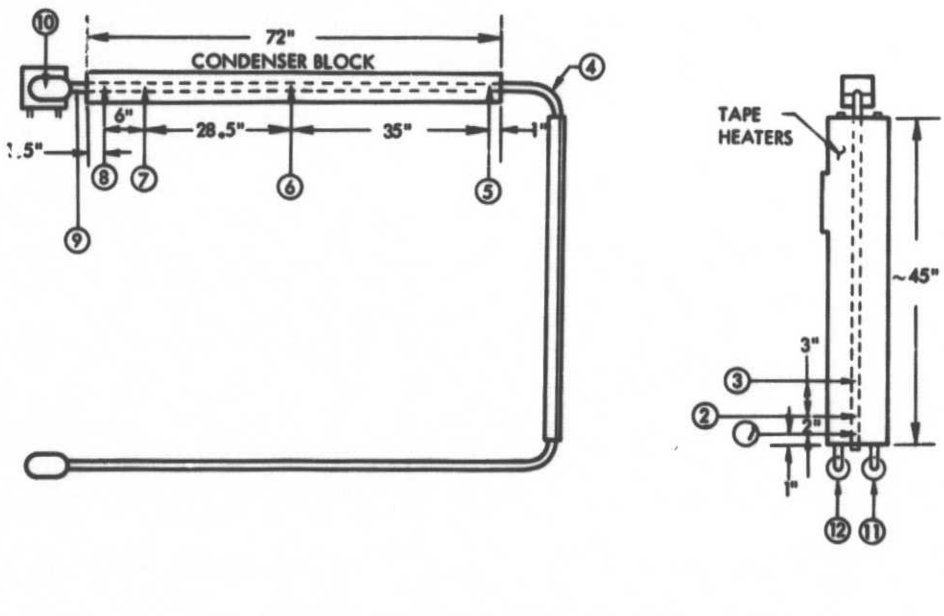


Figure 17. SEP Module Test Configuration

The acceptance test procedure is outlined below:

1) Heat gas reservoirs (TC11 and TC12) to $130^{\circ} \pm 5^{\circ}F$.

2) Cool gas reservoir of test heat pipe (TC10) to $-102^{\circ} \pm 5^{\circ}F$.

3) Raise evaporator end at least 3 inches, relevel and wait 5 minutes.

4) Elevate evaporator 0.30 inch and apply 220 watts.

5) Turn-on condition: TC1 $\geq 80^{\circ}F$ when TC4-TC5 $\leq 5^{\circ}F$. Full on condition: TC1 $\geq 118^{\circ}F$ when TC4-TC8 $\leq 5^{\circ}F$.

Tests on several heat pipes following the above acceptance test procedure were unsuccessful. These heat pipes failed under loads higher than 150 watts which is consistent with only one artery operating. Reevaluation of X-ray data taken on the modules revealed the possible cause of the priming problem. It was found that in the last few inches of the evaporator section of the failed heat pipes the arteries were not parallel to each other; i.e., one artery was higher than the other in the tube cross-section. The slab wick had apparently rotated in the pipe, possibly during the clamping/soldering operation. This misalignment was approximately 1/32 inch. A change in the test procedure was made in which the heat pipes were required to prime with the evaporator 0.040 inch lower than the condenser rather than being level. This change in the test procedure was successful because in subsequent tests all the heat pipes satisfied the acceptance criteria.

The turn-on and full-on temperatures of each heat pipe are shown in Table 2.

As a final step in the processing of the heat pipes, each fill tube was pinched off, welded and vacuum-leak tested.

The modules were delivered packed in individual wooden shipping containers.

Table 2. Turn-on and Full-on Temperatures of SEP Heat Pipes

Module Configuration	Heat Pipe Number	Temperature (^oF)	
		Turn on	Full-on
A	1	103	123
	2	103	121
	4	105	126
B	3	100	124
	5	100	125
	7	105	126

5. SUMMARY AND CONCLUSIONS

TRW Defense and Space Systems Group has completed a two-phase program under Contract NAS 3-21130 for NASA Lewis Research Center in which two variable conductance heat pipe modules were fabricated. Each module contained three methanol/stainless steel heat pipes with individual capacities in excess of 14,000 watt-inches at $50^{\circ}C$. A two-phase program was undertaken to demonstrate, with development heat pipes, that the design approach developed from earlier TRW Independent Research and Development (IRAD) was sound.

During Phase I of the program a new heat pipe design was conceived, based on the results of 1974 and 1975 TRW IRAD programs. Two versions of this design were built in configuration suitable for SEP application. These prototypes were tested to confirm that changes in the design would successfully resolve sporadic priming encountered during the IRAD programs.

Two heat pipes were fabricated, one using 0.070-inch-diameter arteries, and one using 0.080-inch-diameter arteries. The arteries were placed in the tube cross-section such that a 0.040-inch gap existed between the artery and the tube wall. The priming cap design consisted of a 0.00027-inch stainless steel foil with a single row of 0.0067-inch holes spot welded on the inside of a 0.75-inch-long stainless steel tube below a window cut in it. The inside diameter of this tube was 0.001 inch larger than the inside diameter of the artery to which it was attached.

The gas reservoir was identical to the CTS design which yielded a reservoir-to-condenser volume ratio of approximately 1.

In addition, a technique was devised to splice the arteries in order to accommodate the increased length (over 122 inches) of the SEP heat pipes.

Prior to the assembly of the two heat pipes, priming tests were performed on both prototype arteries, the results leading to the utilization of the 0.081-inch-I.D. priming tubes on the 0.070-inch-diameter arteries in order to achieve reliable priming.

With a 120-cc methanol inventory, the capacities of the 0.070-inch-diameter artery heat pipe and the 0.080-inch-diameter artery heat pipe at 0.30 inch evaporator elevation and 120^{o}F adiabatic temperature were 17,600 watt-inches and 23,200 watt-inches, respectively. Although both heat pipes substantially exceeded the capacity goal of 14,000 watt-inches, only the 0.070-inch-diameter artery heat pipe with 0.081-inch-I.D. priming tubes showed reliable priming. As a result, this design was selected for the fabrication of six deliverable heat pipes.

During Phase II of the program, seven heat pipes were fabricated and tested. The methanol inventories of the SEP heat pipes was 138 $\pm$1 cc. This inventory was determined from tests performed on a single heat pipe to which fluid was gradually added until reliable priming was observed. Acceptance tests were performed on all heat pipes, and six of seven met the 220-watt capacity requirement. A selected heat pipe was loaded with 6 x 10^{-5} lb-moles of nitrogen gas to determine the effect of the gas on the heat pipe capacity and establish its temperature control characteristics. It was found that the presence of gas had no effect on capacity and the temperature control of the heat pipe exceeded the design requirements (turn on at 80^{o}F and full on at 122^{o}F). This heat pipe carried up to 300 watts (36 percent over the required 220 watts), although partial groove dry-out was observed at high power levels.

The individual heat pipes were then emptied, back-filled with nitrogen and pinch-weld closed. The evaporator regions were tin plated and fused prior to installation in two heat pipe modules. Each module consists of three heat pipes whose evaporator sections are soldered to two half-aluminum saddles which form a baseplate.

After the module was soldered, the heat pipes were individually subjected to acceptance tests. Each heat pipe was filled with 140 cc of spectral grade methanol and loaded with 6 x 10^{-6} lb-moles of 90 percent nitrogen - 10 percent helium gas.

The final acceptance test procedure consisted of leveling the heat pipe to allow the arteries to prime, cooling the gas reservoir to -102°F, elevating the evaporator end 0.30 inch and applying 220 watts. The heat pipe was required to turn on at a temperature higher than 80^{o}F and to be fully on at a temperature higher than 118°F under the applied heat load. Several heat pipes failed this acceptance test because one of their arteries did not prime. During reevaluation of X-ray data taken on the module, it was found that in the last few inches of the evaporator section of the failed heat pipes the arteries were not parallel to each other; i.e., one artery was higher than the other in the tube cross-section. The slab wick had apparently rotated in the pipe, possibly during the clamping/soldering operation. This misalignment was approximately 1/32 inch.

Tests were repeated in which the heat pipes were allowed to prime with the evaporator end 0.040 inch lower than the condenser, and the results were successful.

The six heat pipes turned on at temperatures higher than 100°F and were fully on at temperatures higher than 121°F.

The improved temperature control range is attributed primarily to the larger reservoir-to-condenser volume ratio resulting from the excess fluid reducing the vapor spaces in the condenser section.

APPENDIX

DESIGN DRAWINGS

DRAWING NO.	TITLE
77030 A	TUBE AND PLUG, SEP HEAT PIPE
77031 A (1 of 2)	WICK ASSY, SEP HEAT PIPE
77031 A (2 of 2)	WICK ASSY, SEP HEAT PIPE
77032 A	PRIMING TUBE ASSY, SEP HEAT PIPE
77033	RESERVOIR WICKS, SEP HEAT PIPE
77034	RESERVOIR, SEP HEAT PIPE
77035	PRIMING FOIL
77036 B (1 of 3)	SEP HEAT PIPE ASSY. CONFIG. NO. 1
77036 (2 of 3)	SEP HEAT PIPE ASSY.
77036 A (3 of 3)	SEP HEAT PIPE ASSY. CONFIG. NO. 2
77040	ARTERY SPLICE TEST SAMPLE
78006	SEP HEAT PIPE/BASEPLATE MODULE ASSEMBLY
78011	SADDLE PLATING

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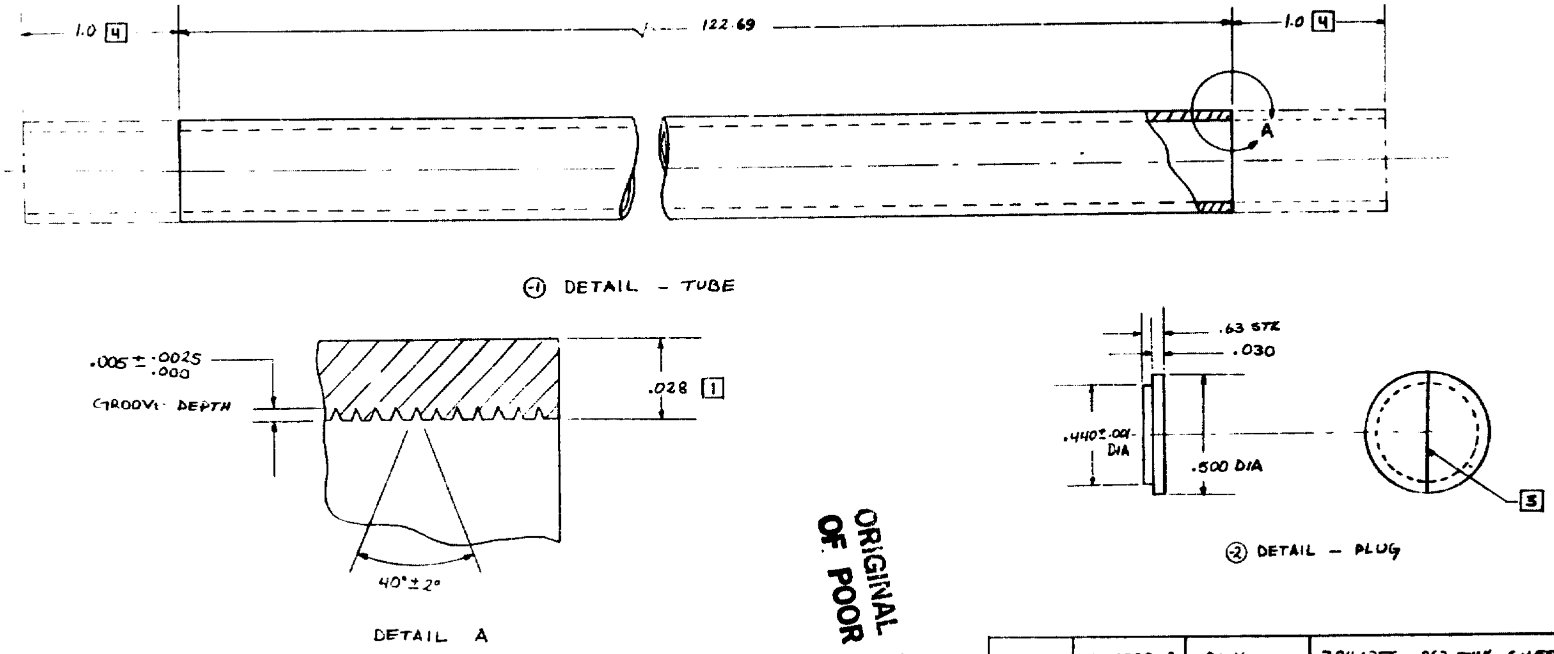
SK 77030 A

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED
A	CHANGE QTY TO -1 REQMT	6/9/78	EEL



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QTY PER ASSY	PART NO.	DESCRIPTION	MATERIAL	ITEM NO.
1	SK 77030-2	PLUG	304 CRES, .063 THK SHEET	2
1	SK 77030-1	TUBE, GROOVED	304 CRES, .500 O.D., .028 WALL	1

NOTES:

[1] SELECT TUBES FOR NOMINAL I.D. +.005 / -.000 DIMENSION

2. INTERNAL GROVE ENTIRE LENGTH AT 100 TPI PER SP-13B-02

[3] SCRIBE LINE

[4] ADDITIONAL LENGTH TO BE REMOVED AT COMPLETION OF GROOVING OPERATION

ENGINEERING SKETCH

TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

ORIGINATOR	DATE
D. ANTONIUK	
30079 - 01 RELEASE - EEL	6/9/78
MJO	

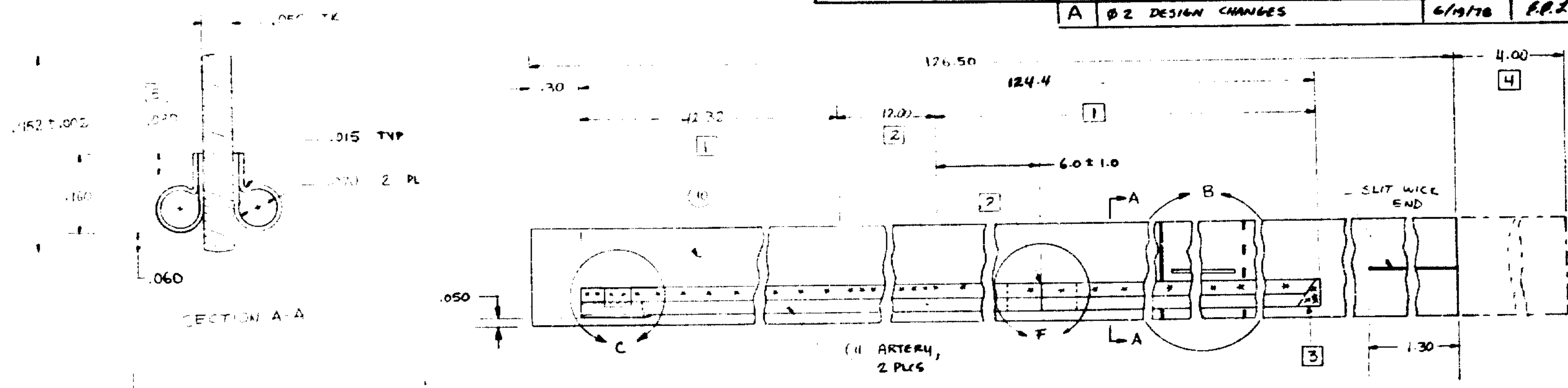
TUBE AND PLUG, SEP HEAT PIPE

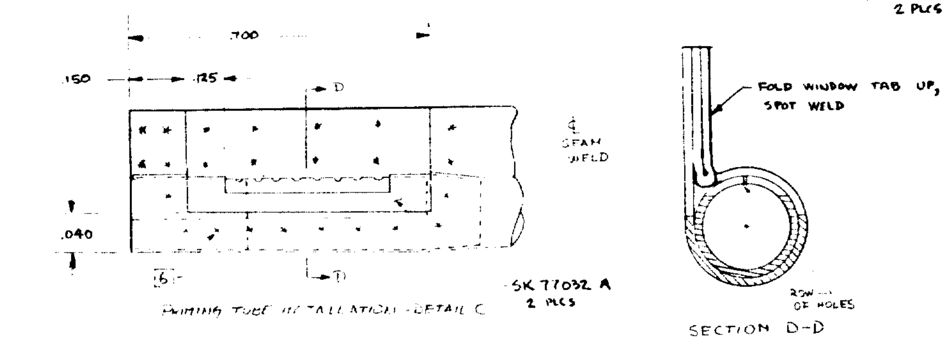
SIZE	CODE IDENT NO.	
B	11982	SK 77030 A
SCALE		SHEET 1 OF 1

SYSTEMS 1083 REV. 1571

SK 77031 A

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED
A	Ø2 DESIGN CHANGES	6/19/78	F.P.L.



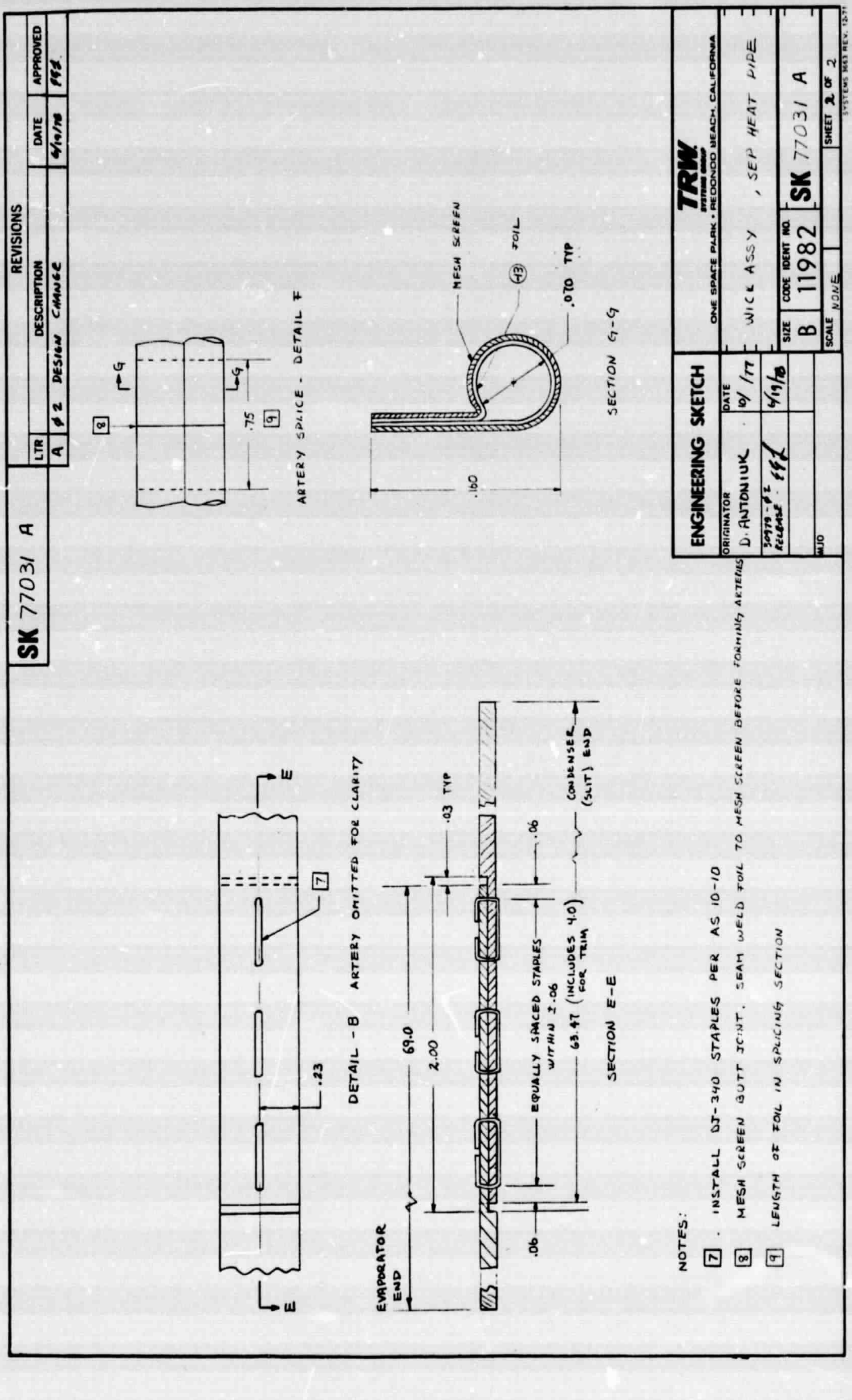


NOTES:

1. SPOT WELD PER AS 10-11 AT .50 PITCH IN THIS AREA
2. SPOT WELD PER AS 10-11 AT .12 PITCH IN THIS AREA
3. FAL ARTERY AFTER SPOT WELDING ARTERY TO WICK
4. EXCESS AMOUNT OF WICK TO FACILITATE INSTALLATION PRIOR TO FINAL TRIM
5. MINIMUM SEAM WELD WIDTH
6. SPOT WELD ARTERY SCREEN TO PRIMING TUBE AT A PITCH NECESSARY TO PREVENT GAPS LARGER THAN .007

QTY PER ASSY	PART NO.	DESCRIPTION	MATERIAL	ITEM NO
2	SK77032 A	PRIMING TUBE		5
2	-13	FOIL	304 CRES, .0005 THK FOIL	4
				3
2	-11	ARTERY	316 CRES, 150X150 MESH, .0026 WIRE DIA	2
1	-10	WICK	.050 THK, 304 CRES, K-13 WICK MAT'L	1

ENGINEERING SKETCH		TRW ONE SPACE PARK • REDONDO BEACH • CALIFORNIA 90278		
ORIGINATOR: D ANTONIUK	DATE: 10/77	WICK ASSY, SEP HEAT PIPE		
50979-Ø2 RELEASE - F.P.L.	6/19/78	SIZE: B	FSCM NO.: 11982	SK 77031 A
MJO		SCALE		SHEET 1 OF 2


SK 77031 A
REVISIONS
LTR
DESCRIPTION
DATE
APPROVED
A
φ2 DESIGN CHANGE
4/19/78
PBL
8
.75
9
G
G
ARTERY SPLICE - DETAIL F
MESH SCREEN
FOIL
13
.070 TYP
.180
SECTION G-G
E
E
7
.23
DETAIL - B ARTERY OMITTED FOR CLARITY
EVAPORATOR END
69.0
2.00
.03 TYP
.06
.06
EQUALLY SPACED STAPLES WITHIN 2.06
63.47 (INCLUDES 4.0 FOR TRIM)
CONDENSER (SLIT) END
SECTION E-E
NOTES:
7 . INSTALL DJ-340 STAPLES PER AS 10-10
8 MESH SCREEN BUTT JOINT, SEAM WELD FOIL TO MESH SCREEN BEFORE FORMING ARTERIES
9 LENGTH OF FOIL IN SPLICING SECTION
ENGINEERING SKETCH
ORIGINATOR
D. ANTONIUK
DATE
10/ /77
50979-φ2 RELEASE
PBL
4/19/78
MJO
TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA
WICK ASSY, SEP HEAT PIPE
SIZE
B
CODE IDENT NO.
11982
SK 77031 A
SCALE NONE
SHEET 2 OF 2

SK 77032 A

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED
A	ϕ2 DESIGN CHANGE	6/19/78	FFL

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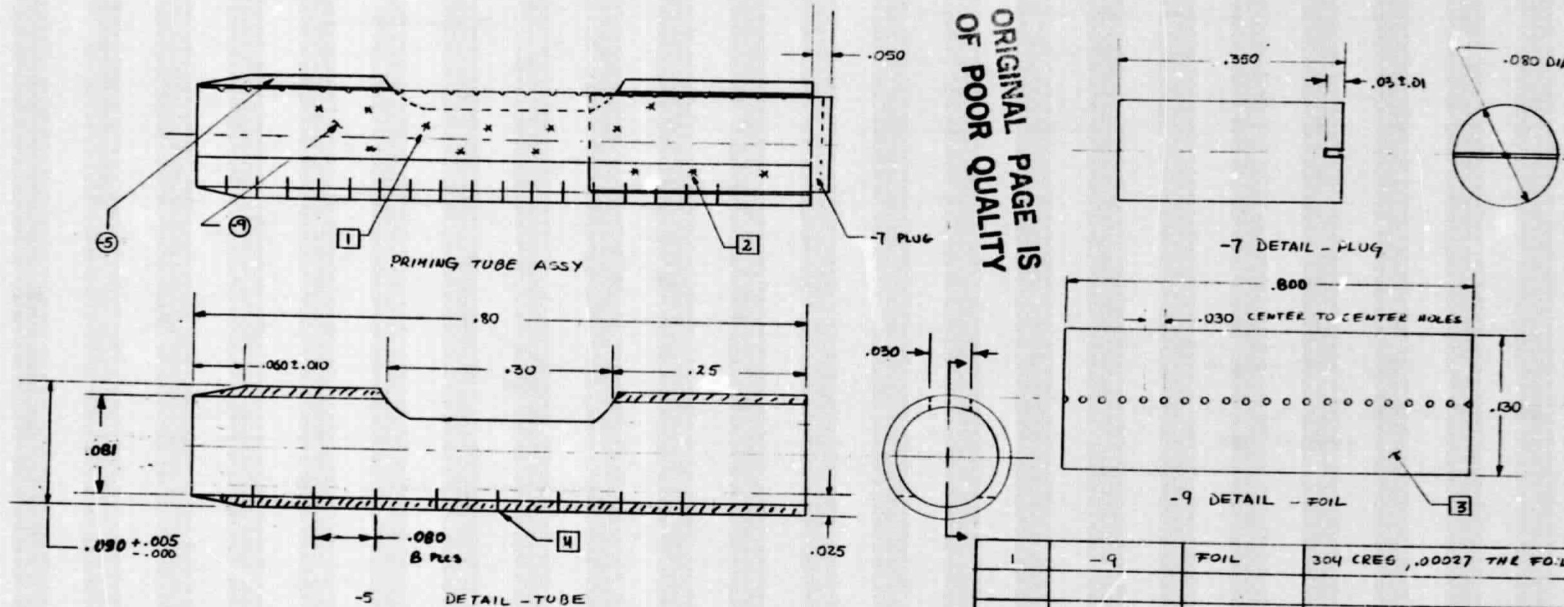


NOTES:

1. SPOT WELD FOIL TO TUBE AT PITCH NECESSARY TO PREVENT GAPS LARGER THAN .0066
2. SPOT WELD PLUG TO TUBE AFTER SPOT WELDING FOIL TO TUBE
3. CUT SECTION FROM SK-77035 FOIL
4. SLITTING-SAW CUTS .005 WIDE

QTY PER ASSY	PART NO	DESCRIPTION	MATERIAL	ITEM NO.
1	-9	FOIL	304 CRES, .00027 THK FOIL	5
				4
1	-7	PLUG	304 CRES, .080 DIA ROD	3
				2
1	-5	TUBE	304 CRES TUBE	1

ENGINEERING SKETCH

TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

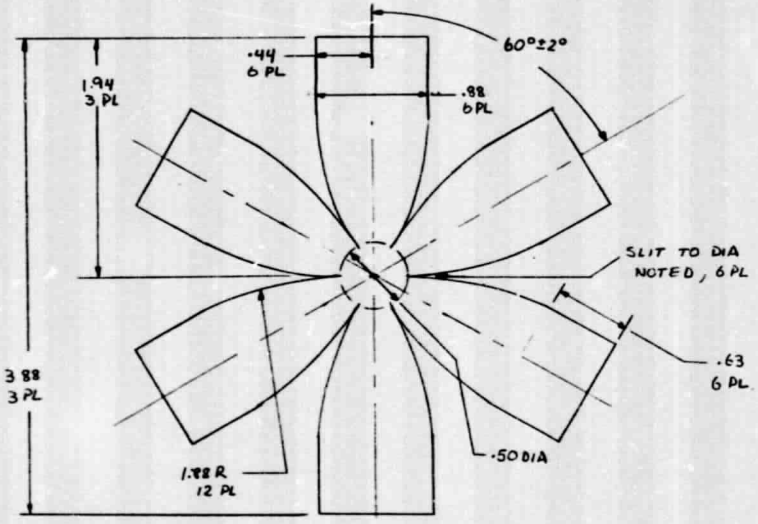
ORIGINATOR	DATE
D. ANTONIUK	11/ /77
30979 - ϕ2 RELEASE - FFL	4/19/78
MJO	

PRIMING TUBE ASSY, SEP HEAT PIPE

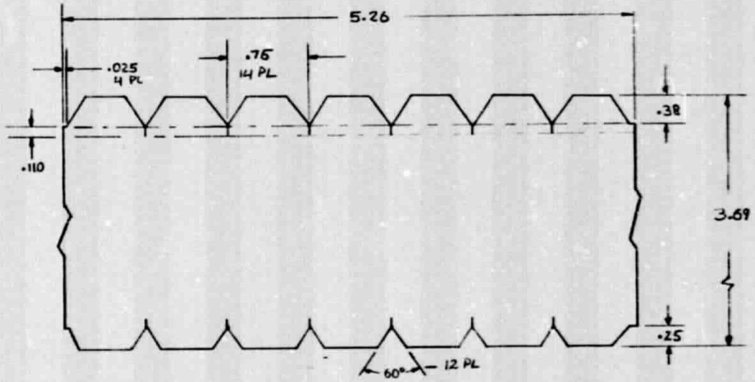
SIZE	CODE IDENT NO.	
B	11982	**SK** 77032 A
SCALE NONE		SHEET 1 OF

SYSTEMS 3663 REV. 12-71

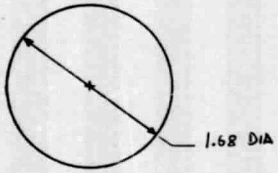
SK 77033	REVISIONS			
	LTR	DESCRIPTION	DATE	APPROVED



① DETAIL - WICK, RESERVOIR CAP



② DETAIL - WICK, RESERVOIR CYLINDER
NOT TO SCALE



③ DETAIL - WICK, RESERVOIR CLOSURE

QTY REQD	PART NO	DESCRIPTION	MATERIAL	ITEM NO.
2	SK 77033-3	WICK, CLOSURE	.020 THK, 304 CRES, WICKING MAT'L	3
2	SK 77033-2	WICK, CYL	.020 THK, 304 CRES, WICKING MATL	2
2	SK-77033-1	WICK, CAP	.020 THK, 304 CRES, WICKING MAT'L	1

ENGINEERING SKETCH

TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

ORIGINATOR	DATE
D. ANTONIUK	10/ /77
304?? #2 RELEASE - EFR	6/19/78
MJO	

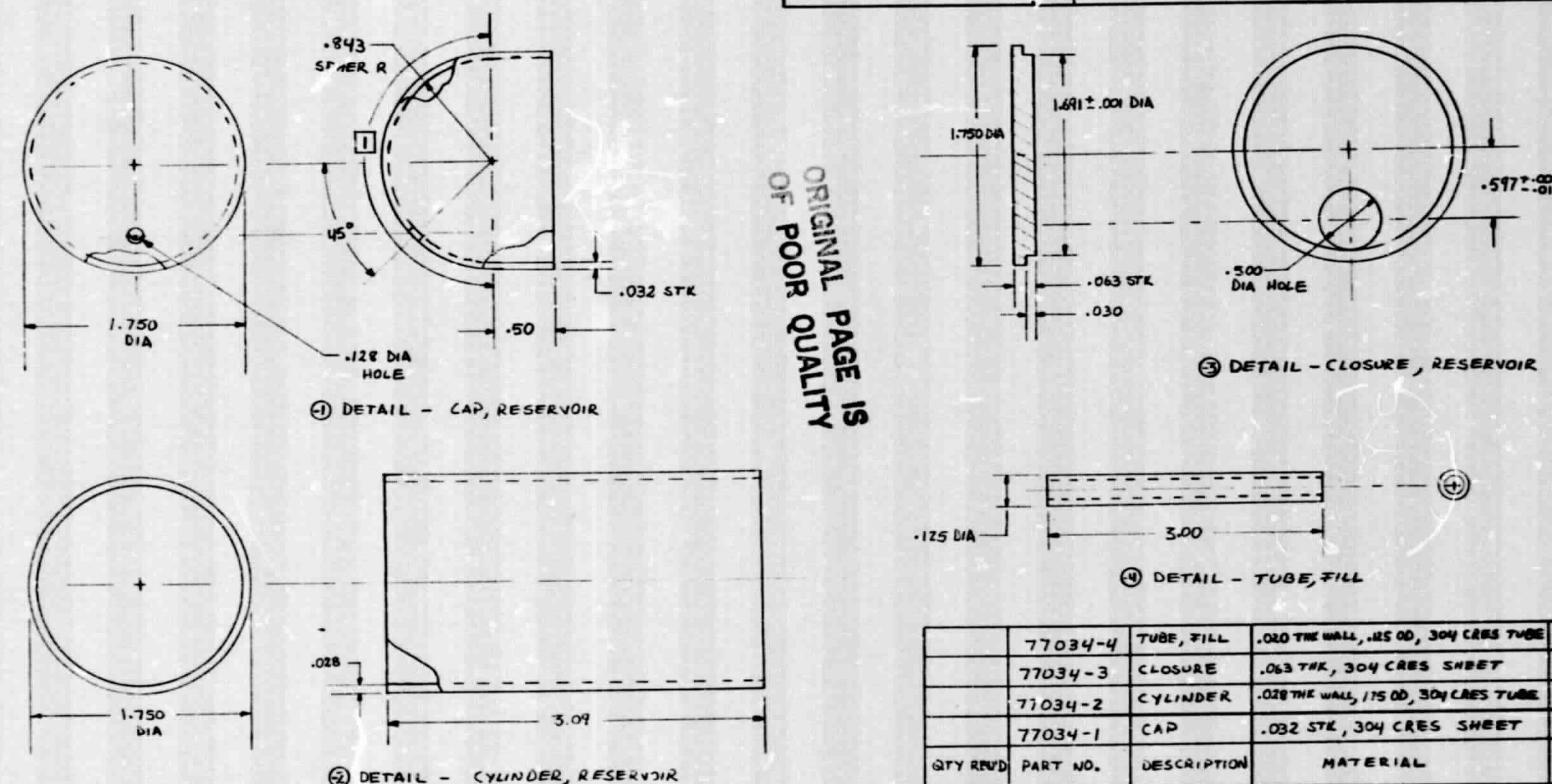
RESERVOIR WICKS, SEP HEAT PIPE

SIZE	CODE IDENT NO.	
B	11982	SK 77033
SCALE		SHEET 1 OF

SYSTEMS 3463 REV. 12-71

SK 77034

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



NOTES:

[1]. MATERIAL THICKNESS IN THIS AREA: .022 MIN

QTY REQ'D	PART NO.	DESCRIPTION	MATERIAL	ITEM NO.
	77034-4	TUBE, FILL	.020 THK WALL, .125 OD, 304 CRES TUBE	4
	77034-3	CLOSURE	.063 THK, 304 CRES SHEET	3
	77034-2	CYLINDER	.028 THK WALL, 1.75 OD, 304 CRES TUBE	2
	77034-1	CAP	.032 STK, 304 CRES SHEET	1

ENGINEERING SKETCH		TRW SYSTEMS GROUP — ONE SPACE PARK • REDONDO BEACH, CALIFORNIA		
ORIGINATOR	DATE			
D. P. TONNK	10/ /77	RESERVOIR, SEP HEAT PIPE		
304/4 - Ø2 RELEASE -	4/11/78			
		SIZE: B	CODE IDENT NO.: 11982	**SK** 77034
MJO		SCALE		SHEET 1 OF

SYSTEMS 3863 REV. 12-71

SK 77035

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

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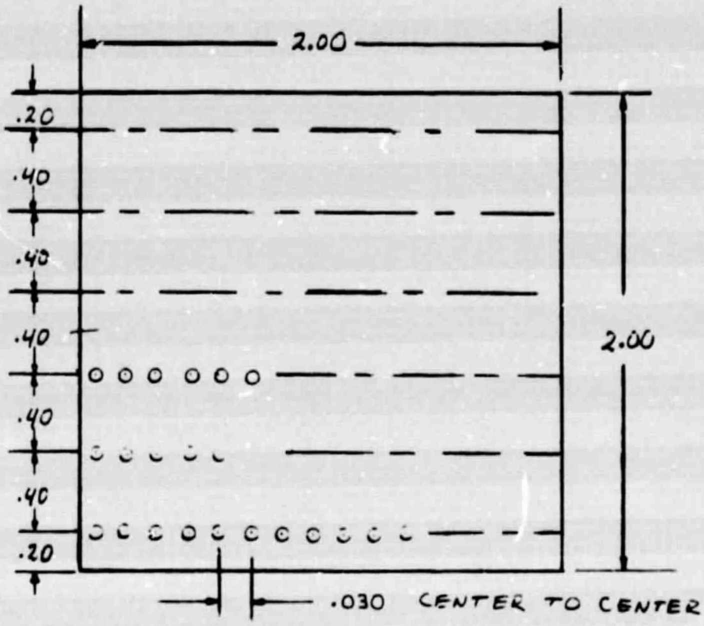


PRIMING FOIL DETAIL

		PRIMING FOIL	304 CRES, .00027 THK FOIL	1
QTY REQD	PART NO.	DESCRIPTION	MATERIAL	ITEM NO

ENGINEERING SKETCH

TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

ORIGINATOR	DATE
D. ANTONIUK	10/ /77
30979 ¢2 RELEASE - F.P.L.	6/9/78
MJO	

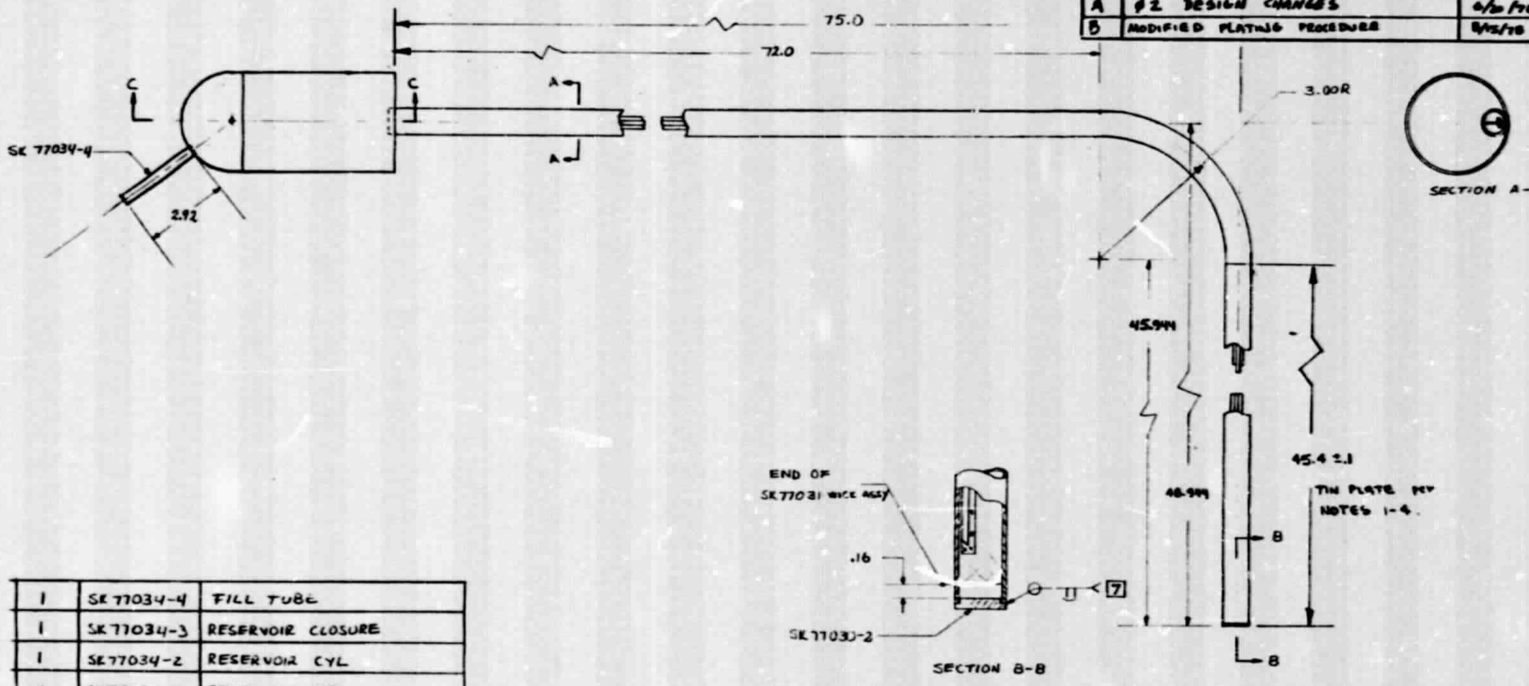
PRIMING FOIL

SIZE	CODE IDENT NO.	
A	11982	SK 77035
SCALE		SHEET 1 OF

SYSTEMS 523 REV. 12-71

SK 77036 B

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED
A	#2 DESIGN CHANGES	4/20/78	[illegible]
B	MODIFIED PLATING PROCEDURE	8/15/78	[illegible]



QTY REQD PER ASSY	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION
1	SK 77034-4	FILL TUBE
1	SK 77034-3	RESERVOIR CLOSURE
1	SK 77034-2	RESERVOIR CYL
1	SK 77034-1	RESERVOIR CAP
1	SK 77033-3	WICK, RESERVOIR CLOSURE
1	SK 77033-2	WICK, RESERVOIR CYL
1	SK 77033-1	WICK, RESERVOIR CAP
1	SK 77031A	WICK ASSY
1	SK 77030A-2	TUBE END PLUG
1	SK 77030 A	GROOVED TUBE

NOTES:

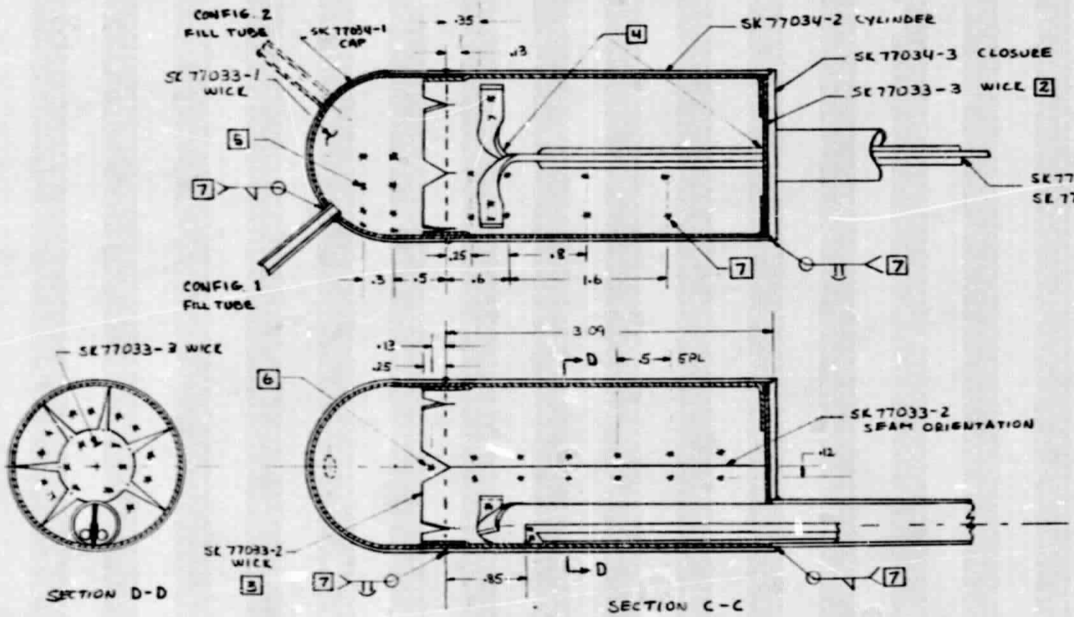
1. NICKEL STRIKE PER QQ-N-290
2. COPPER PLATE PER PR 6-33-3
3. TIN PLATE PER PR 6-18-4

ENGINEERING SKETCH		TRW SYSTEMS GROUP ONE SPACE PARK • REDONDO BEACH, CALIFORNIA
ORIGINATOR D. ANTONIUK	DATE 10/17	SEP HEAT PIPE ASSY CONFIG NO 1
50470 #2 RELEASE - [illegible]	4/17/78	SIZE B · CODE IDENT NO. 11982 · **SK** 77036 B
MJO		SCALE · SHEET 1 OF 3

SYSTEMS 3483 REV. 12-71

SK 77036

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



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NOTES

1. WICK ASSYS MUST BE INSTALLED IN SK 77030-1 PRIOR TO BENDING
2. SPOT WELD SK 77033-3 WICK TO SK 77034-3 CLOSURE PRIOR TO FUSION WELD SK 77034-3 TO SK 77034-2
3. INSTALL SK 77033-2 WICK IN SK 77034-2 PRIOR TO FUSION WELD SK 77034-3 TO SK 77034-2. ALSO COMPLETE SPOT WELDS (SK 77033-2 TO SK 77033-3 & SK 77034-3) PRIOR TO FUSION WELD SK 77030-1 TUBE TO SK 77034-3
4. CUT .5 DIA HOLE IN SK 77033-3, INSERT SK 77031 INTO OPENING, PART & FORM THE SPLIT ENDS AS SHOWN AND SPOT WELD SK 77031 (-1 & -2) TO SK 77032-2 PER AS10-11
5. SPOT WELD SK 77033-2 TO SK 77034-2 AND SK 77033-1 TO SK 77034-1 ; .5 ON CENTERS PER AS10-11
6. SPOT WELDS FOR SK 77033-1 TO SK 77034-1 ONLY
7. WELD PER PR3-1

ENGINEERING SKETCH		TRW SYSTEMS GROUP ONE SPACE PARK • REDONDO BEACH, CALIFORNIA		
ORIGINATOR D. ANTONIUK	DATE 11/77	SEP HEAT PIPE ASSY.		
30979-P2 RELEASE - E.F.	4/19/78			
		SIZE B	CODE IDENT NO. 11982	SK 77036
MJO		SCALE		SHEET 2 OF 2

SYSTEMS 3063 REV. 12/71

SK	REVISIONS			
	LTR	DESCRIPTION	DATE	APPROVED

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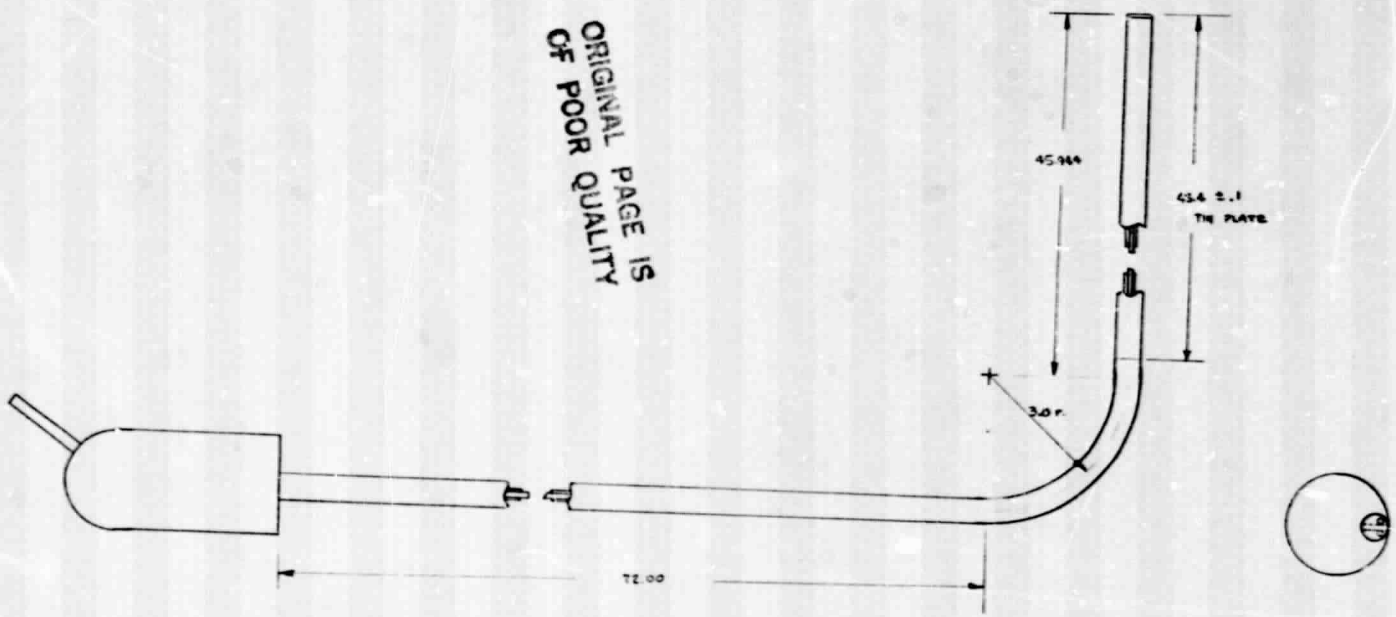
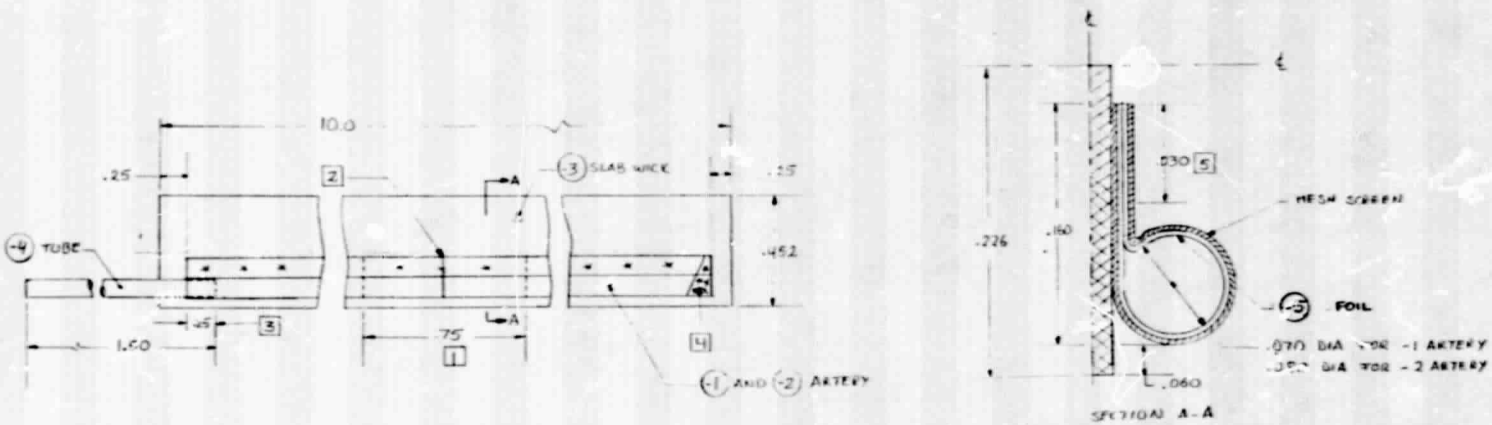


NOTES:

1. THIS HEAT PIPE CONFIGURATION IS A MIRROR IMAGE OF SK 77036 A, CONFIG NO. 1. ALL NOTES AND PARTS LIST APPLY TO THIS CONFIG

ENGINEERING SKETCH		TRW ONE SPACE PARK · REDONDO BEACH · CALIFORNIA 90278		
ORIGINATOR	DATE	SEP HEAT PIPE ASSY- CONFIG. NO. 2		
		SIZE B	FSCM NO. 11982	SK 77036 A
WJO		SCALE		SHEET 8 OF 9

SK	REVISIONS			
	LTR	DESCRIPTION	DATE	APPROVED



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NOTES:

1. LENGTH OF FOIL IN SPLICING SECTION
2. MESH SCREEN BUTT JOINT. SEAM WELD FOIL TO MESH SCREEN BEFORE FORMING ARTERIES
3. IN THIS SECTION SPOT WELD -1 OR -2 ARTERY TO -4 TUBE AT A PITCH NECESSARY TO PREVENT GAPS LARGER THAN .007"
4. SEAL ARTERY AFTER SPOT WELDING ARTERY TO WICK AT APPROX .5 PITCH
5. MINIMUM SEAM WELD WIDTH
6. SPOT WELD -1 ARTERY TO ONE SIDE OF -3 WICK AND -2 ARTERY TO OTHER SIDE OF -3 WICK

QTY REQD	PART NO.	DESCRIPTION	MATERIAL	ITEM NO.
1	-5	FOIL	0.0005 304 CRES FOIL	
2	-4	TUBE	.062 OD, WALL 304 CRES TUBE	4
1	-3	ARTERY	316 CRES, 150 X [illegible] MESH, .0026 WIRE DIA	3
1	-2	ARTERY	316 CRES, 100 X 150 MESH, .0026 WIRE DIA	2
1	-1	WICK	.050 THK, 304 CRES, X-13 WICK MAT'L	1

ENGINEERING SKETCH

TRW
ONE SPACE PARK • REDONDO BEACH • CALIFORNIA 90278

ORIGINATOR: D. ANTONIUK | DATE:

ARTERY SPLICE TEST SAMPLE

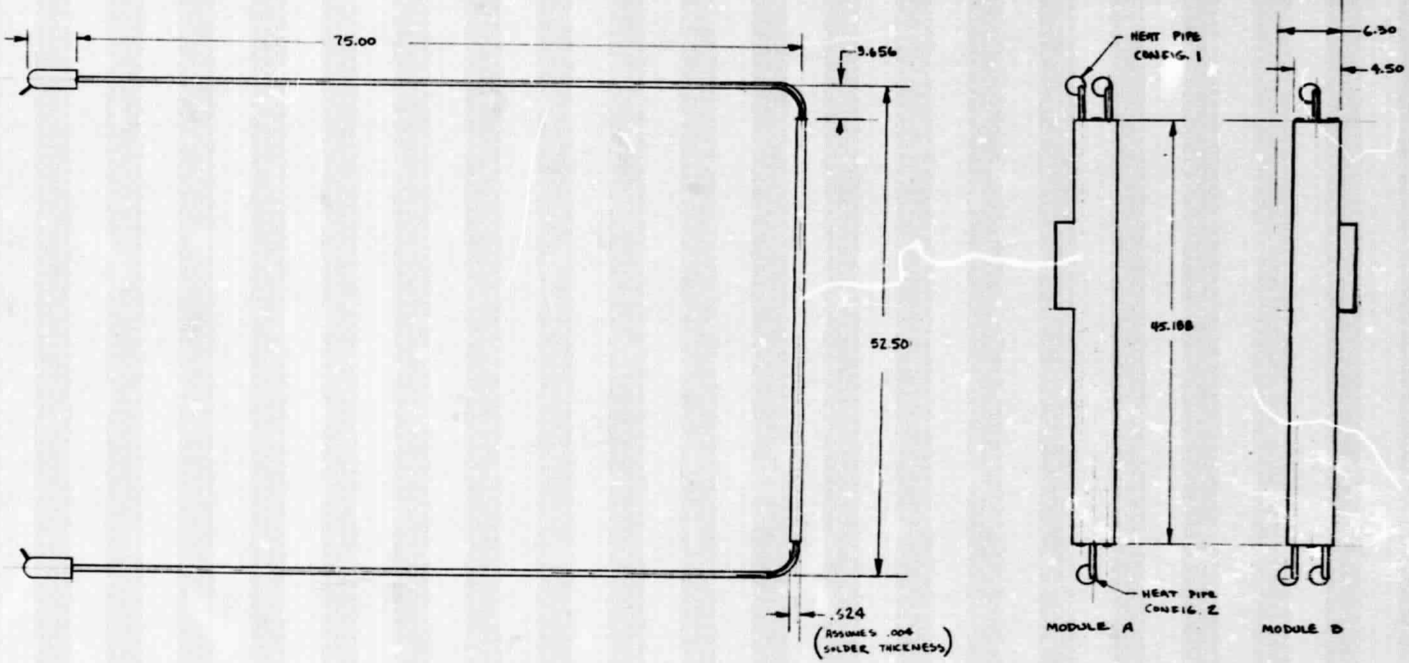
SIZE: B | FSCM NO.: 11982 | SK 77040

SCALE: | SHEET 1 OF

MJO

SK 78006

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED
A	CORRECTED SADDLE EXT - CONFIG A	6/4/78	E.E.L.



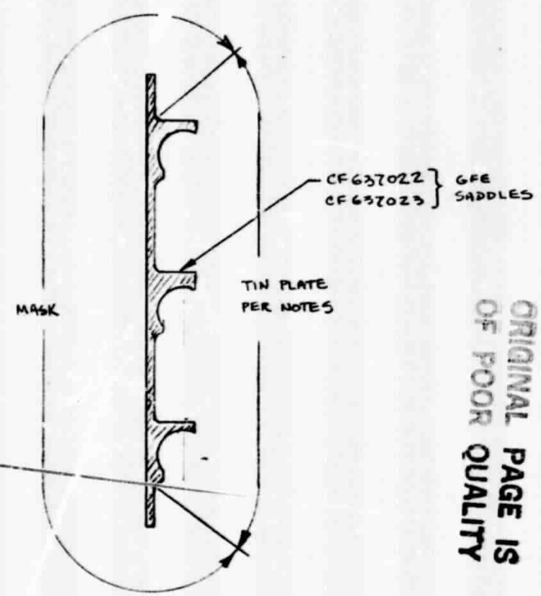
MODULE	QTY	PART NO.	DESCRIPTION
B	1	CF637023	
	1	CF637022	
	2	77036A-C2	
	1	77036A-C1	
A	1	CF637023	SADDLE
	1	CF637022	SADDLE
	1	77036A-C2	HEAT PIPE ASSY-CONFIG 1
	2	77036A-C1	HEAT PIPE ASSY-CONFIG 2

NOTES.
1. SOLDER PER
2. SADDLE TO BE FLAT WITHIN ±.010 per 10.0 INCHES WHEN UNRESTRAINED IN HORIZONTAL POSITION

ENGINEERING SKETCH		TRW ONE SPACE PARK • REDONDO BEACH • CALIFORNIA 90278		
ORIGINATOR E.E. LUEDKE	DATE 6/20/78	SEP HEAT PIPE/BASEPLATE MODULE ASSEMBLY		
30049 - Ø2 RELEASE -		SIZE B	FSCM NO. 11982	SK 78006
MJO		SCALE		SHEET 1 OF 1

SK 78011

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



NOTE

1. DOUBLE ZINCATE
2. COPPER STRIKE PER MIL C 14550
3. COPPER PLATE PER MIL C 14550, CLASS 2
4. TIN PLATE PER PR 6-18-4

ENGINEERING SKETCH		TRW ONE SPACE PARK · REDONDO BEACH · CALIFORNIA 90278		
ORIGINATOR E.E. LUEDKE	DATE 9/30/78	SADDLE PLATING		
		SIZE B	FSCM NO. 11982	SK 78011
MJO		SCALE NONE		SHEET 1 OF