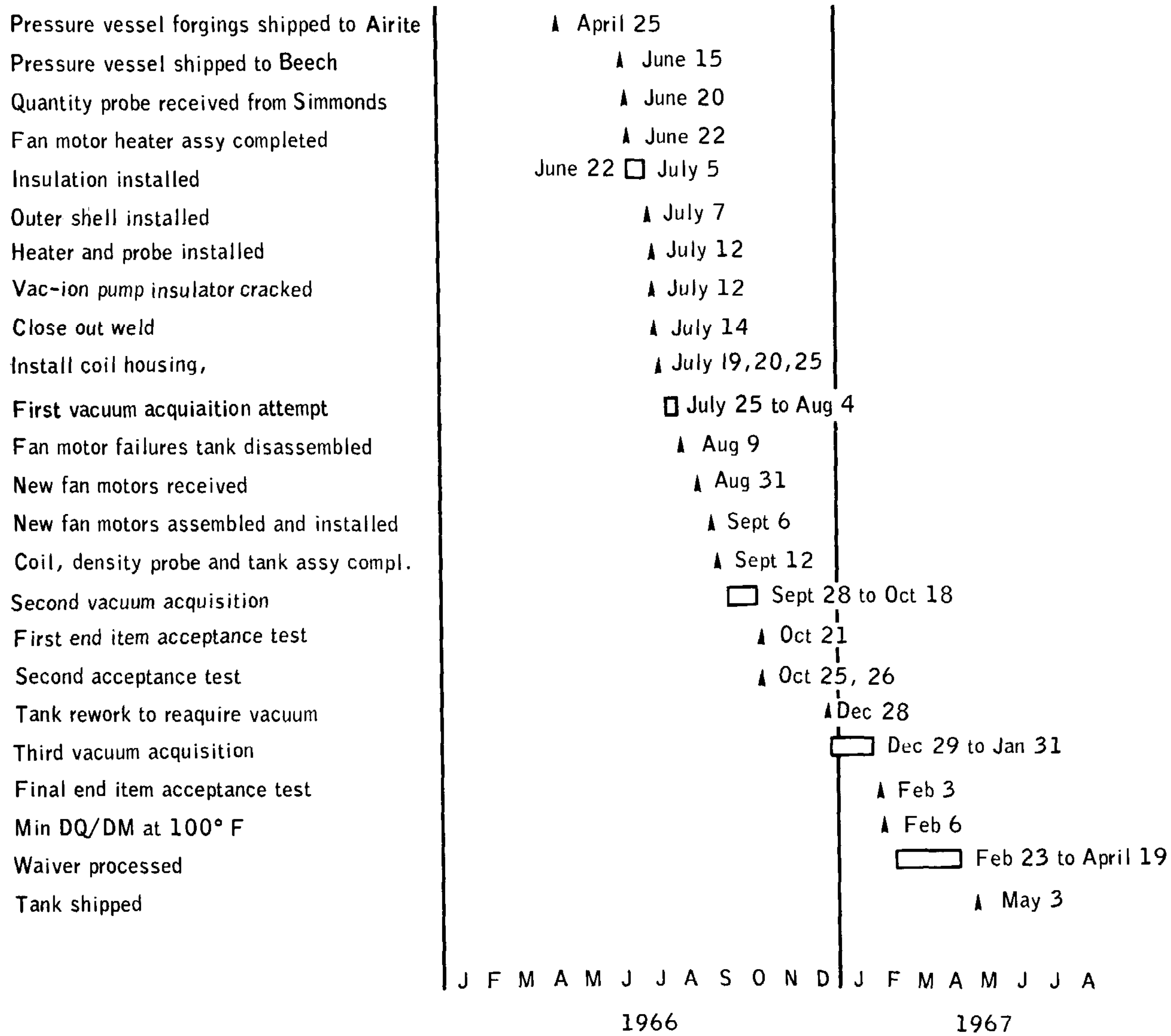


Figure C4-48.- Manufacturing and test flow for the oxygen tank at Beech.

TABLE C4-I.- WITHHOLDING FORMS (INSPECTION DISCREPANCIES)

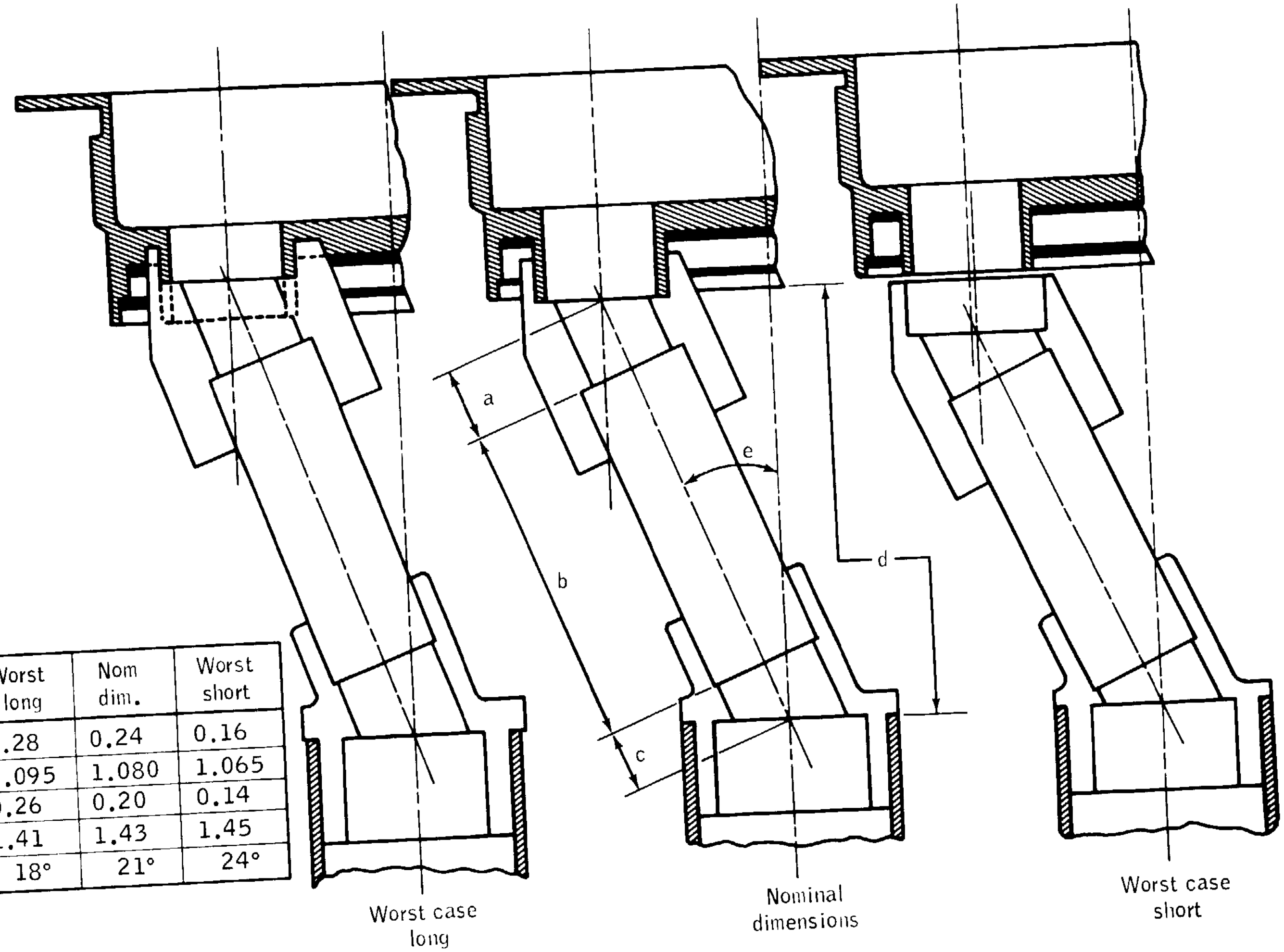
Date	Part name	Part number	Tag number	Reason	Disposition
3-14-66	Heater tube assembly	13532-3527-3	B 00659	Oversize rivet hole 0.132 to 0.128 diameter, 0.006 inch oversize	Acceptable as is
3-28-66	Electrical support	13532-3187-3	C 78515	The 0.180 to 0.190 holes are 0.230 diameter	Acceptable as is
3-28-66	Lower shell assembly	13532-2011-13	C 55461-B	Two oversize pieces of porosity	Grind out and reweld X-ray and leak check
5-10-66	Hemisphere P.V.	13532-3109	C 10846	Out of tolerance condition in clamp ring area - Oversize	Machine to print
5-11-66	Motor fan assembly	13532-4505-3	BO-1133	Motor draws excess current and emits a loud rough noise	Replace
6-1-66	Valve seat	13532-4029-3	B 01073	Valve seat damage when removed per PARR C-55461A	Scrap valve
6-30-66	Coil housing assembly	13532-2086-9	C 43101	Insulator has two cracks along side the weld bead	Replace
7-7-66	Porcelain insulator	13532-4075-1	B 00613A	Parts damaged beyond use	Replace
8-16-66	Motor fan assembly	13532-4505-3	B 01140	Motor failed after 4 hours of operation REFERENCE ONLY	Return to vendor Not acceptable
8-16-66	Motor fan assembly	13532-4505-3	B 01142	Insulation scraped from wire exposing bare conductor REFERENCE ONLY	Return to vendor for repair or replacement
8-23-66	Tank assembly	13532-1501-3	B 01184	Upper motor assembly noisy	Replace
9-2-66	Tank assembly	13532-1501-3	B 01238	MRR voided	Misinterpretation - shadow was thought to be contamination
10-18-66	Heater assembly	13532-2515-3	B 500147	Voided; No W/F required	
12-28-66	Tank assembly	13532-1501-3	B 500016	Flow rate not to specification Call out (CSM 0044)	Waiver approved April 19, 1967

of the step-by-step process, three assembly examples were witnessed within the clean room areas. Specifically, the installation of a lower motor into the heater tube was observed. The assembly of the quantity probe to the tank tube adapter fitting was witnessed. In this particular case, two attempts were required to properly position the small fill tube parts. The entire wire routing process was witnessed. A tank with a large hole in the side provided visibility to the witnesses but not to the assembly technicians. The installation of the heater fan assembly and then the quantity probe provided an appreciation of the real challenge to workmen, that of avoiding damage to the insulation of the wires. This could not have been learned from a study of the drawings alone.

A 10-times-size layout was made of the fill tube connection situation with the parts at the various limits of size permitted by the engineering drawings. In addition to the length tolerances permitted by the drawing dimensions, the diametral clearance also permits the parts to assume angles beyond the ranges stated on the drawings. As an aid to check all the various positions to which these parts could move, individual cutout paper parts were made for the two Teflon bushings and the interconnecting Inconel tube. Figure C4-49 shows that the worst-case short tolerance parts can fall out of position as the tank is moved about. At the other extreme, parts that are at the high end of the permitted tolerances will not assemble. This is shown on the left-hand view. The nominal case provided little or no axial clearance but still does not provide gas-tight seals at the various diameters.

In addition to the tolerance condition that can exist for the fill tube connecting parts, the center tube of the quantity probe could move downward due to Teflon cold flow. The center tube is supported in the axial position by two Teflon bushings installed in the center tube and a semi-tubular rivet. Prolonged heating, such as the vacuum pumpdown cycles (three cycles for this tank assembly resulting in a total of 1532 hours at 190 to 220° F), could result in the thin walls of the center tube slowly cutting into the Teflon bushings.

Table C4-II shows the range of diametral clearances that can exist at ambient conditions (73° F) and at a typical detanking condition (-278° F, which corresponds to the saturation temperature of liquid oxygen at 40 psia). The fit between the Teflon bushing and the tank adapter fitting can result in a maximum 0.003-inch interference. The only other clearance that results in an interference fit occurs if the minimum size holes are provided where the Teflon bushings slide on the 3/8-inch Inconel tube. Tests at liquid nitrogen temperature (-320° F) indicate that the Teflon is not overstressed and does not crack when subjected to interference fits of this type.



Part	Worst long	Nom dim.	Worst short
a	0.28	0.24	0.16
b	1.095	1.080	1.065
c	0.26	0.20	0.14
d	1.41	1.43	1.45
e	18°	21°	24°

Figure C4-49.- Extreme and nominal tolerance cases for fill tube connection parts.

TABLE C4-II.- RANGE OF DIAMETRAL FITS

Zone	Ambient Condition, +73° F			Detanking Condition, -278° F		
	Metal size	Teflon size	Clearance	Metal size	Teflon size	Clearance
Tank adapter fitting to Teflon bushing	0.432 0.456	0.465 0.460	0.033 0.004	0.431 0.455	0.457 0.452	0.026 -0.003
Teflon bushing to Inconel tube (Both ends)	0.375 (Commerical tube size)	0.390 0.380	0.015 0.005	0.374 0.374	0.383 0.373	0.009 -0.001
Teflon bushing to aluminum gaging tube	0.652 (Commercial tube bore)	0.641 0.646	0.011 0.006	0.649 0.649	0.630 0.635	0.019 0.024

Throughout the normal manufacture and test of a cryogenic oxygen storage tank, no intentional procedure calls for the thermostats to interrupt a load. The acceptance testing by the thermostat vendor uses approximately 6.5 V ac to power a small lamp bulb which draws about 100 milliamperes. The fan and heater assembly component acceptance test by Beech uses the thermostats to complete the circuit of Wheatstone bridges to measure the heater resistance values. All other testing by Beech applies power (65 V ac) when tank conditions are such that the thermostats should be closed and remain closed, or momentarily applies a lower power (30 ± 10 V ac) to verify that thermostats are open.

INTEGRATION, SYSTEM TESTING, AND PRELAUNCH CHECKOUT OF THE CRYOGENIC OXYGEN STORAGE TANKS

Summary of Nominal Processes and Procedures

North American Rockwell, Downey, California.- The build-up of an oxygen shelf assembly at NR begins* many weeks before insertion of the cryogenic oxygen tanks with the fabrication of a pie-shaped aluminum honeycomb sandwich structural shelf with large circular cutouts matching the equatorial girth rings of the spherical tanks. On this shelf are next mounted the valves, pressure transducers, flowmeters, and tubing to interconnect these with the fill and vent panel and the storage tanks. Then the tanks are inserted, no. 1 inboard and no. 2 in the outboard position to the left of the fill panel and the valve module (fig. C4-50). To complete the shelf assembly, more tubes and the electrical cabling are added. The Beech signal conditioner assembly for each tank is mounted underneath the shelf.

All oxygen system tubing joints brazed by NR are subjected to X-ray inspection and reheated if necessary to achieve satisfactory joints.

Pressure and leak checks are conducted as are electrical checks of tank circuit elements, i.e., the vac-ion pump, the heater, motor fans, thermostats, and temperature sensor under dry gas conditions within the oxygen tanks. The thermostats are tested for both opening and closing temperatures by use of nitrogen gas purge with variable temperature control and monitoring each thermostat with a digital volt meter. Essentially no current is interrupted in these tests. Such tests are repeated in accordance with detailed Operational Checkout Procedures (OCP's) until all gas leaks or electrical wiring problems have been isolated and corrected and the oxygen shelf assembly is ready for installation in the

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*Use of the present tense in this section of the Panel report implies current practices as of 1967-68.

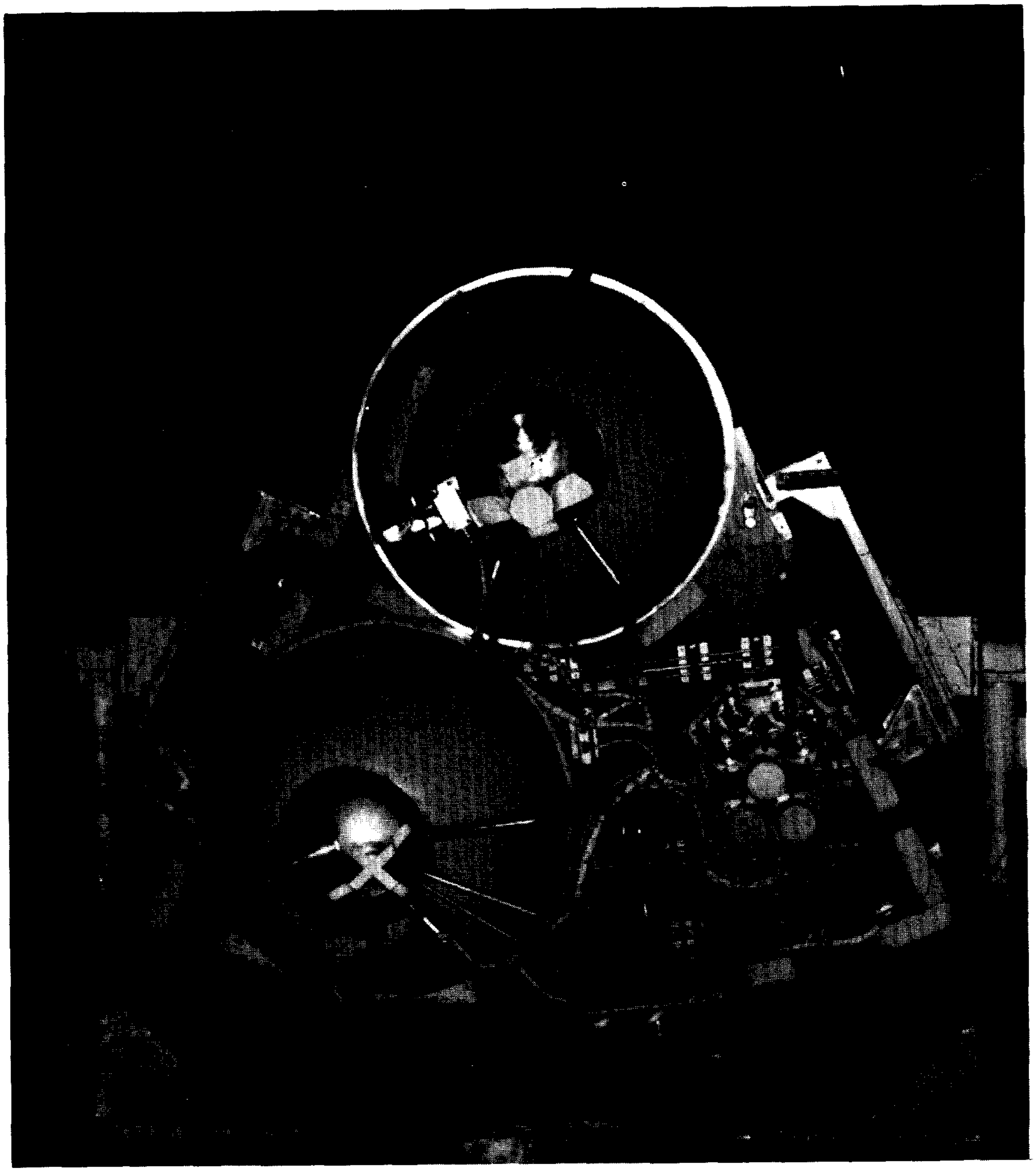


Figure C4-50.- Oxygen shelf with tanks 10024XTA0008 and 10024XTA0009 installed.

service module. A proof gas pressure of 1262 psi is used, followed by leak testing at 745 psi. The vac-ion pumps of the oxygen storage tank vacuum jackets are turned on at least twice during typical oxygen shelf checkout and oxygen system checkout at NR. These tests are conducted with an NR test engineer, manufacturing test conductor, technicians, and quality control personnel, and a NASA quality control representative present. No cryogenic oxygen is used in any of these tests.

After the oxygen shelf assembly is installed in the service module, various gas tubing and electrical connections are completed. The oxygen tank, tubing, and valves thereafter participate in oxygen subsystem testing of the service module, fuel cell simulator tests, and fuel cell interface verification in accordance with Detail Checkout of Systems (DCS's) requirements. Liquid nitrogen is used to introduce a cold nitrogen gas into the oxygen tank to cause the thermostats to close so that a heater circuit continuity test can be conducted. Spacecraft bus power (30 V dc) is applied to the heater circuits and an increase in current is used to verify thermostat closure. After water/glycol system test and final shelf inspection, cryogenic oxygen System Summary Acceptance is accomplished with NASA/MSC participation and recorded in the System Summary Acceptance Document ("SSAD book").

The discipline at NR, Downey, is that of controlled procedures and hardware traceability from the controlled material and equipment stores through assembly and test operations. This discipline produces requests for review or assistance from design engineering for instances of quality or test discrepancy considered to be significant.

Transportation from North American Rockwell to KSC.- Shipment of the service module from NR, Downey, is made on a pallet which holds the axis horizontal in the fore and aft direction of trucks and aircraft (fig. C4-51). The sector in which the oxygen shelf is installed is on the underside in this orientation so that the shelf centerline points vertically down. Shock and vibration instrumentation of various service module flights in the Pregnant Guppy and Super-Guppy special aircraft of Aero Spacelines have shown no peak vibration loads exceeding one-g for vibration-isolated movements of the service module.

Kennedy Space Center.- After command and service module mating, at the Manned Spacecraft Operations Building-KSC, the oxygen shelf assembly as a part of the service module participates in combined system test, altitude chamber test, systems integrated test, and flight readiness test in accordance with established Test and Checkout Procedures (TCP's). These tests are conducted as dry gas pressure and electrical function verifications similar to those of the factory OCP's and DCS's at Downey. No specific test is run to verify thermostat operation; however, during the conduct of a pressure switch test sequence, the thermostats may open the 28 V dc heater load.

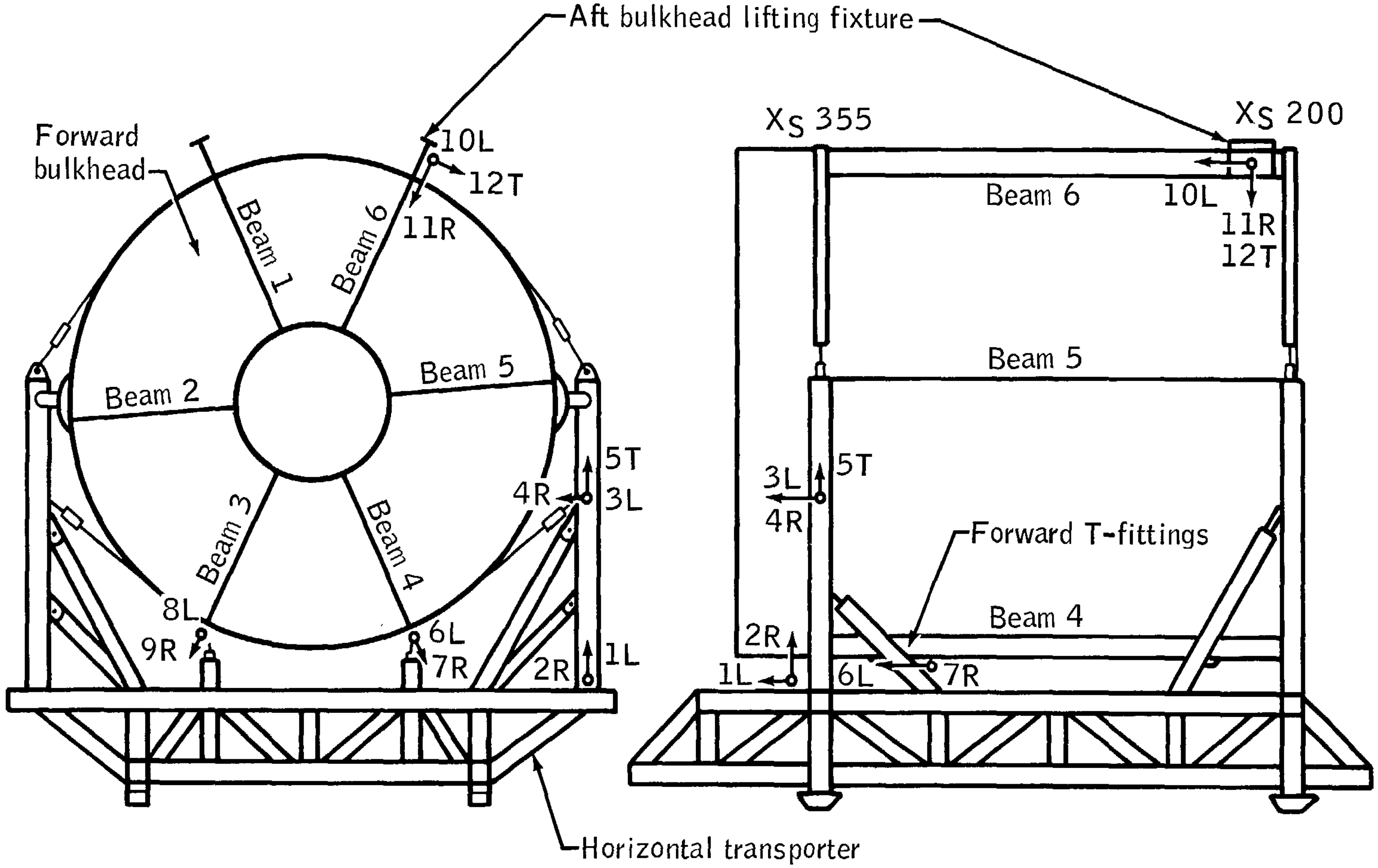


Figure C4-51.- Pallet holding axis horizontal in fore and aft direction of trucks and aircraft.

The vac-ion pumps of the oxygen storage tank vacuum jackets are normally turned on during three test periods at KSC including countdown. The circuit breakers to the vac-ion pumps are opened before launch.

After integration of the CSM with the Saturn launch vehicle in the Vertical Assembly Building, the complete vehicle is moved to Pad 39. As a part of the CDDT, which normally occurs 14 days before launch, the CSM storage tanks are fully loaded with liquid oxygen. The functioning of the fans is checked and heater operation verified by using a ground supply of 65 V dc to raise the tank pressure to about 300 psi. Shortly thereafter it is necessary to partly empty the oxygen tanks through a process known as "detanking." Two or three days later, at the conclusion of the CDDT, detanking is again used to empty the tank.

Initial detanking consists of two sequences. First, the internal pressure of the tank (residual to the CDDT) is vented through the vent. Next, warm gaseous oxygen is fed through the tank vent lines at 80 psia to expel liquid through the fill lines down to 50-percent full. Detanking for tank emptying proceeds similarly at the end of CDDT. Then warm gas is blown through to verify that the thermostats remain closed up to at least -75° F. This step employs the application of only 10 to 15 V dc to the heater circuit.

This loading, checkout, and detanking is the first time the cryogenic functions of the oxygen storage tanks are evaluated since the acceptance test at Beech Aircraft, Boulder, Colorado.

The oxygen tanks are filled to capacity during actual countdown in order to prepare for launch.

During the CDDT and during the final countdown, as long as the Mobile Service Structure (MSS) is connected to the Launch Umbilical Tower (LUT), the heaters are powered from the ground supply system. The power distribution station from where the heaters are powered is located at the base of the LUT. The voltage from this power supply is automatically regulated at 78 ± 2 V dc and recorded. There is approximately 13 volts line drop along the connecting leads, resulting in about 65 V dc across the heaters, producing a current of about 6 amps through each heater element. This higher power operation is used to more rapidly raise the tank pressure to the operating range.

The MSS is disconnected from the LUT at about 18 hours before T - 0 in both the CDDT and the final countdown. For operational reasons the power supply to the heaters is switched at this time to the busses of the spacecraft with 28 to 30 V dc (about 2.8 amperes through each heater element) which are powered through the umbilical from the ground supply system. At T - 4 hours, during the launch preparation, the busses of the spacecraft are switched to the fuel cells. The destratification fans are independent from the heaters and at all times powered from the spacecraft.

Summary of Significant Aspects of Serial No. 0008 Tank
Prelaunch Integration Test and Checkout History

North American Rockwell, Downey, California.- Oxygen storage tank 10024XTA0008 was installed in the no. 2 (outside) position of oxygen shelf S/N 06362AAG3277 at North American Rockwell, Downey, California, soon after receipt in May 1967. Two disposition reports were written during October 1967 to require reheat and reinspection of brazed tubing joints on the oxygen shelf found unacceptable in reading of X-rays. These joints were reheated and accepted. Completion of oxygen tank installation, including tank 10024XTA0009 in the no. 1 position, was accomplished March 11, 1968. Manufacturing and test flow for the oxygen shelf is displayed chronologically in figure C4-52.

Two disposition reports noting an "indentation" and a "ding" in the tank outer shell were filed and accepted--use as is--in March and April 1968.

During April and May 1968, 11 disposition reports were written to log tank no. 2 anomalies found during proof-pressure, leak-check, and functional checkout of the assembled oxygen shelf. Eight of these were ascribed to test procedure problems, two to a valve module (check valve) tubing leak and one to an electrical connector pin. The leak was rewelded by a Parker technician and passed leak test. The pin was repaired by NR and checked.

In accordance with the normal OCP and after leak and electrical repairs, the shelf assembly was completed and tested. It was installed in CSM 106 June 4, 1968. Thereafter, in compliance with several DCS's for subsystem test, a fuel cell simulator test, and fuel cell interface verification, the oxygen shelf participated in service module detailed checkout steps.

After installation of this oxygen shelf in SM 106, eight disposition reports were written during installation, additional tubing connection and subsystem line proof-pressure and leak check, and electrical cabling checking. Of these, two problems with a hydrogen relief line mounted adjacent to the oxygen shelf were solved by making up new tubing and later reheating a brazed joint to meet X-ray control requirements. Three oxygen subsystem leaks were solved by retorquing caps and a "B" nut on oxygen lines leading to fuel cell no. 2. The three remaining disposition records expressed questions concerning leak and electrical function testing of the oxygen shelf assembly which were held open pending the next opportunity for shelf assembly testing.

On October 21, 1968, in response to directives requiring rework of the vac-ion pump dc-to-dc converters to reduce electromagnetic

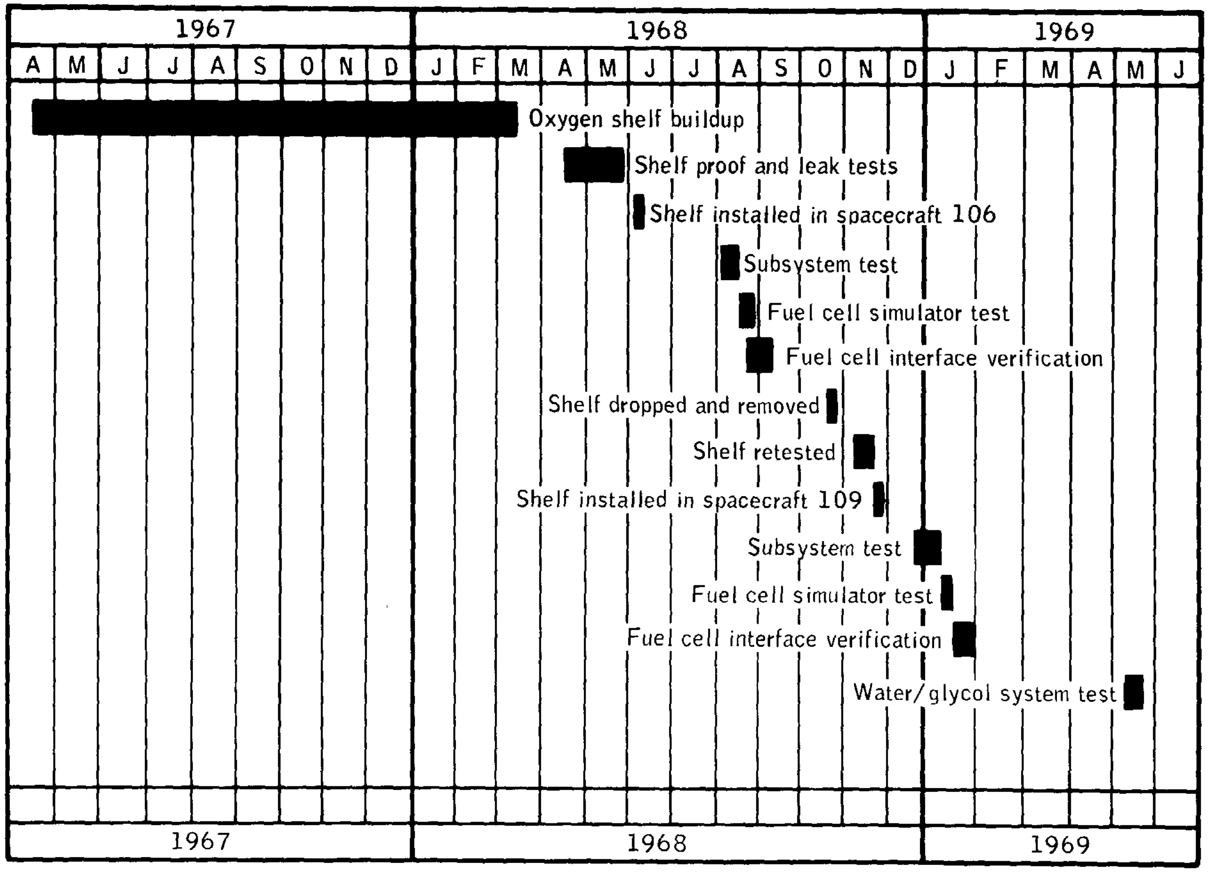


Figure C4-52.- Manufacturing and test flow for the oxygen shelf.

interference problems (a supplementary potting operation performed by Beech personnel at North American Rockwell), an attempt was made to remove the oxygen shelf from SM 106.

In preparation for this attempt, the 10 bolts attaching the shelf to the adjacent beams were removed. The existence of a small, 11th bolt introduced from underneath and behind tank no. 1 was overlooked by all persons involved. The factory crew brought into position a lifting fixture particularly devised for inserting tanks and shelves into sectors of the service module (fig. C4-53).

This fixture is composed of two parts joined at a bolted flange. The universal part is an adjustable counterbalance. The weights of this counterbalance are movable from the factory floor through endless chains. The particular part for handling to the oxygen shelf is a two-tined fork welded together from large thick-walled aluminum tubes. The tine tips are padded where they contact the underside of the shelf to support its inner portion. The outer edge of the shelf is fastened to the lifting fork by means of two screws passing through tabs on the top of the fork cross-member.

Under the particular circumstances of October 21, 1968, the unnoticed 11th bolt into the shelf served as a tie-down beyond the tips of the lifting fork such that raising the fixture produced rotation of the entire assembly, most noticeably the counterbalance. The 11th bolt still was unobserved. Attempts were made to balance the fixture by moving a weight and to lift the assembly by operating the overhead bridge crane. In these steps sufficient load was placed on the fixture to break it above the cross-arm of the fork.

The oxygen shelf moved and came to rest on the supporting beams through what was at the time described as a "2-inch drop". Observation of adjacent portions of SM 106 identified minor damage, including a dent in the underside of the fuel cell shelf above.

Figure C4-54 shows the repair patch over this dent immediately above the vacuum pinch-off cover can of tank no. 2 in the oxygen shelf that replaced the one undergoing the "shelf drop" incident in SM 106.

Further attention to the oxygen shelf containing tank 10024XTA0008 in the no. 2 position after its removal from SM 106 involved a number of quality, test, and repair actions. These were logged on 11 separate Disposition Records (NR numbered forms recording discrepancies observed through manufacturing inspection and test activities at Downey). One other such form was initiated at the time of the "shelf drop" and was treated primarily as a requirement to inspect, repair, and re-inspect the adjacent portions of SM 106, including specifically the dented fuel cell shelf.

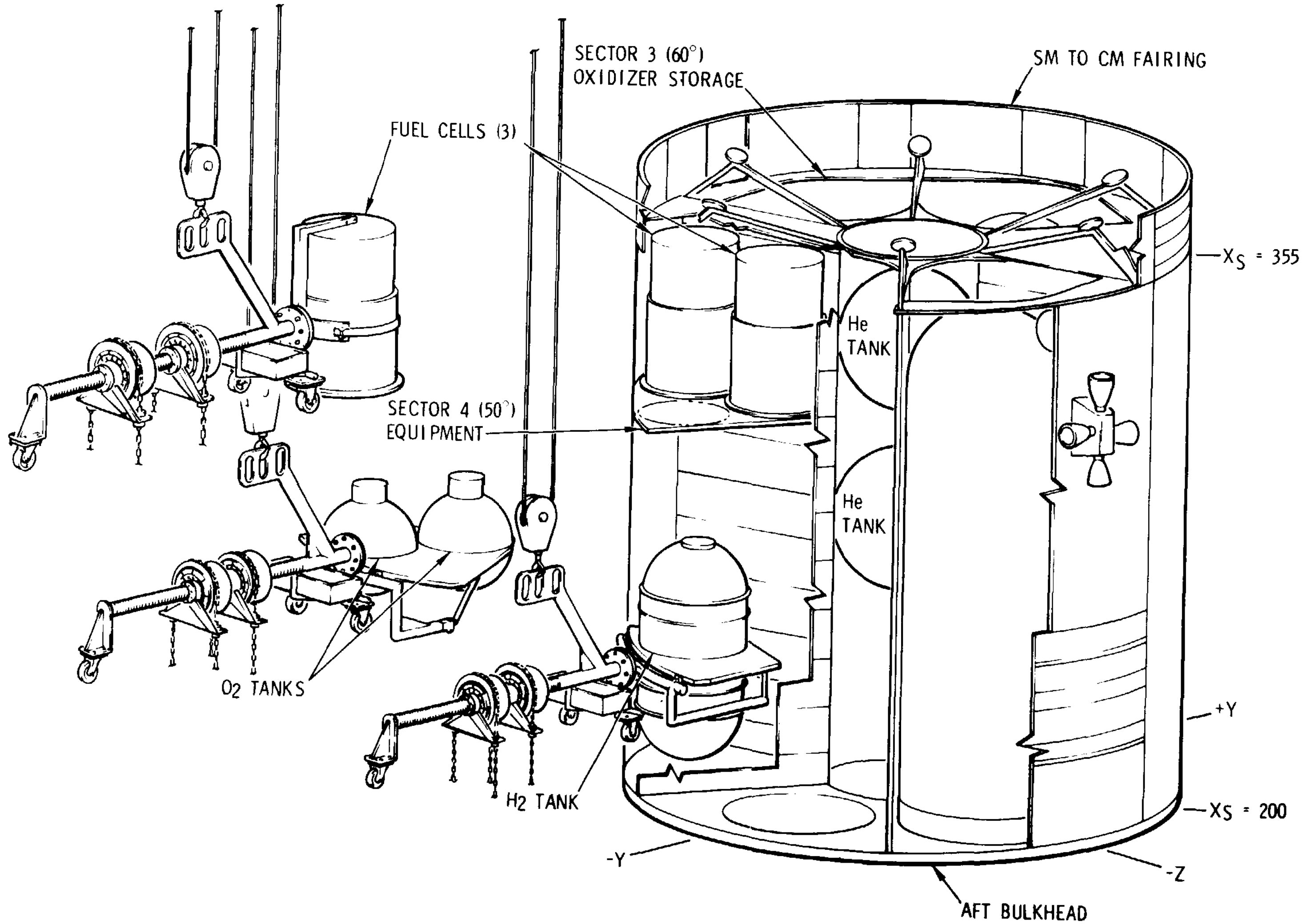


Figure C4-53.- SM bay 4 tank installation.

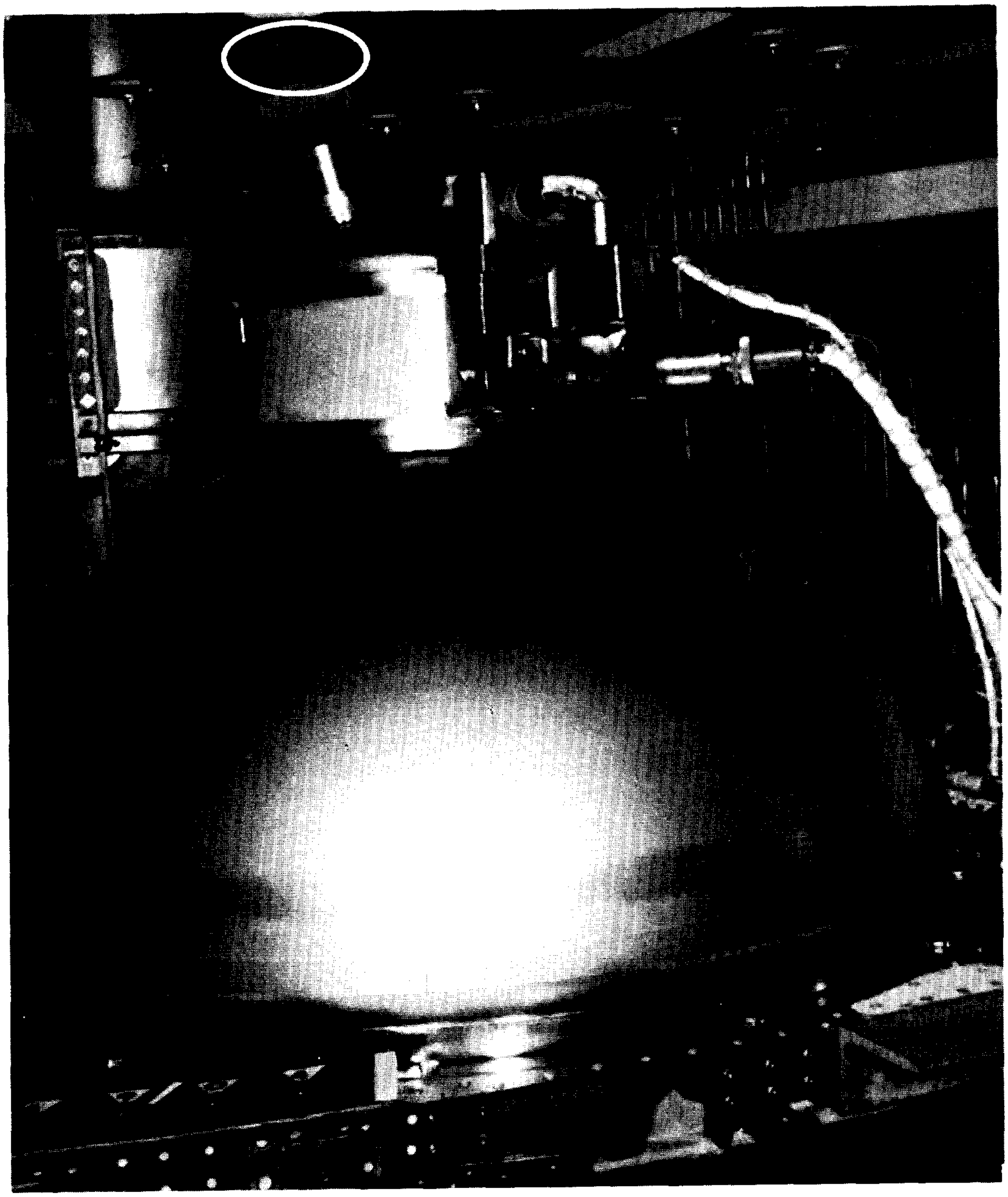


Figure C4-54.- Replacement oxygen shelf installed in Service Module 106. Note repairs to fuel cell shelf over oxygen tank no. 2.

Of the 11 DR's, five report anomalous conditions of detailed portions of the shelf assembly observed and recorded from November 1 to November 19, 1968. In response to these DR's, EMI tests and leakage tests were conducted, results were accepted, and some repairs were made. The leak tests of bent tubing carrying tank no. 1 pressure, upstream from valves, were accepted in material review. The latter involved polishing out tank outer shell scratches, adjusting several electrical connectors, replacing damaged cable clamps, and coating damaged potting. It is not certain but it is possible that some of these conditions relate to the "shelf drop" incident.

The remainder of the DR's of the period relate to testing the oxygen shelf to revalidate it for installation into SM 109. A shortened version of the normal pre-installation OCP, including pressure and external leak testing and verification of electrical functions of most of the tank elements, was conducted. Fan motor, heater, fuel cell reactant valve, relief valve, pressure switch, and motor switch functional checks were omitted. Coupling leak checks and check valve internal leak valve checks were omitted. Signal conditioner checks, for density and temperature signals, were omitted. Verification of these matters was left for and accomplished in oxygen system tests at higher levels of CM and SM integration. The shelf was then installed (fig. C4-55). The upper one of the two accepted bent tubes shows at the extreme right of the figure. The lower one, bent 7 degrees as it joins the back of the fuel cell valve-module, is in the lower right corner.

In December 1968, after concern for a possible oil contamination of facility lines, GSE hose connections were checked for contamination and found acceptable. Vent line samples taken later, at KSC during cryogenic tanking, verified that no contaminants reached the spacecraft interfaces.

Engineering requests for recalibration of the oxygen system pressure instrumentation and the oxygen quantity signal conditioner of the assembly were responded to in January and February, 1969.

Final inspection and cleanup of the shelf in the service module was accomplished on May 27, 1969. The oxygen SSAD book was signed off June 6, 1969, and SM 109 was shipped to KSC.

Transportation from North American Rockwell to KSC.- Shipment of SM 109 from Downey to KSC was accomplished by the normal means, horizontal mounting on a vibration isolating pallet carried on ground vehicles and a Super-Guppy aircraft. No shock was observed in the instruments carried.

Kennedy Space Center.- The oxygen tank and shelf assembly participated in normal service module tests beginning with the Combined Systems Test. Test and checkout flow at KSC are shown chronologically in figure C4-56.

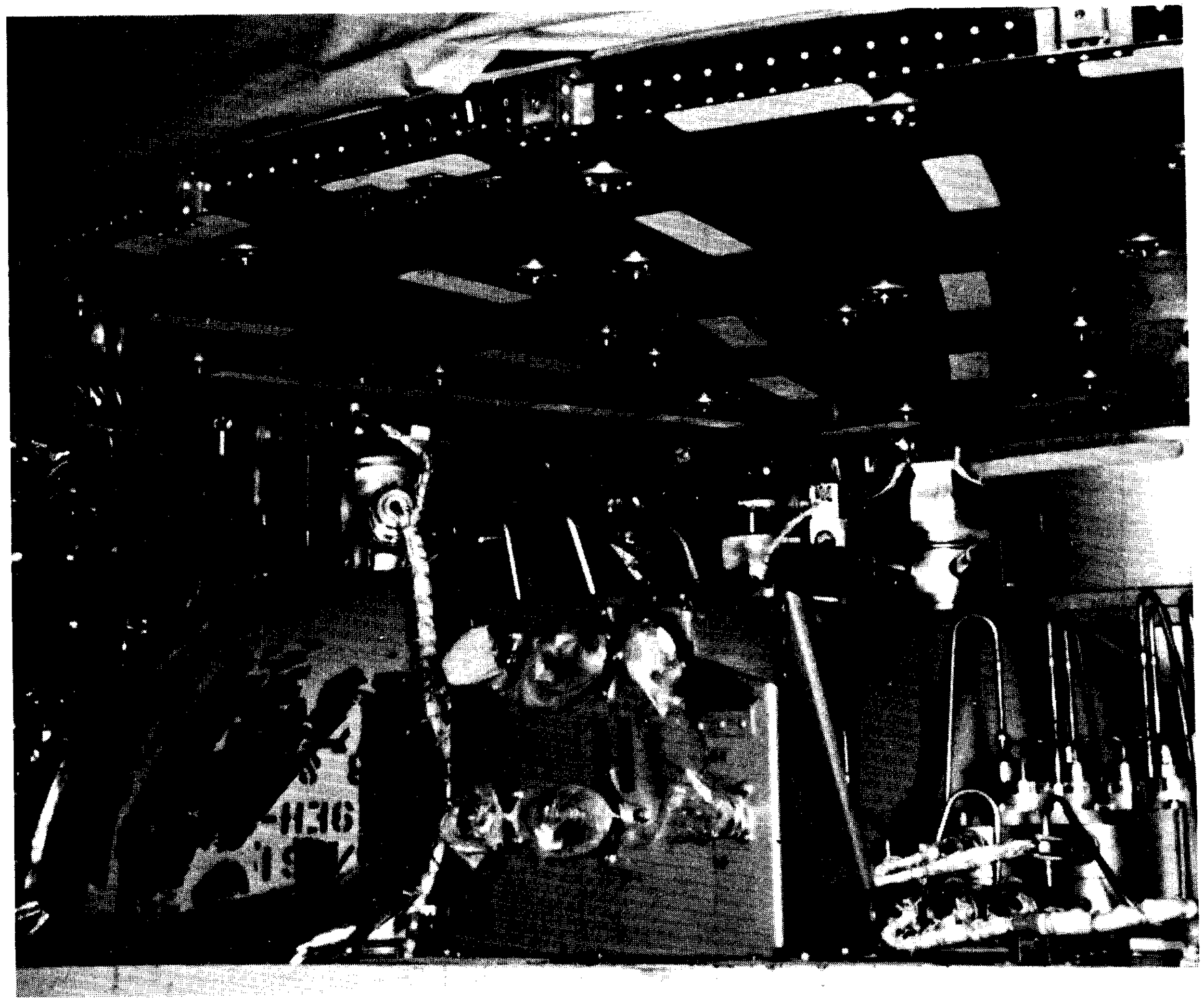


Figure C4-55.- Oxygen shelf installed in service module.

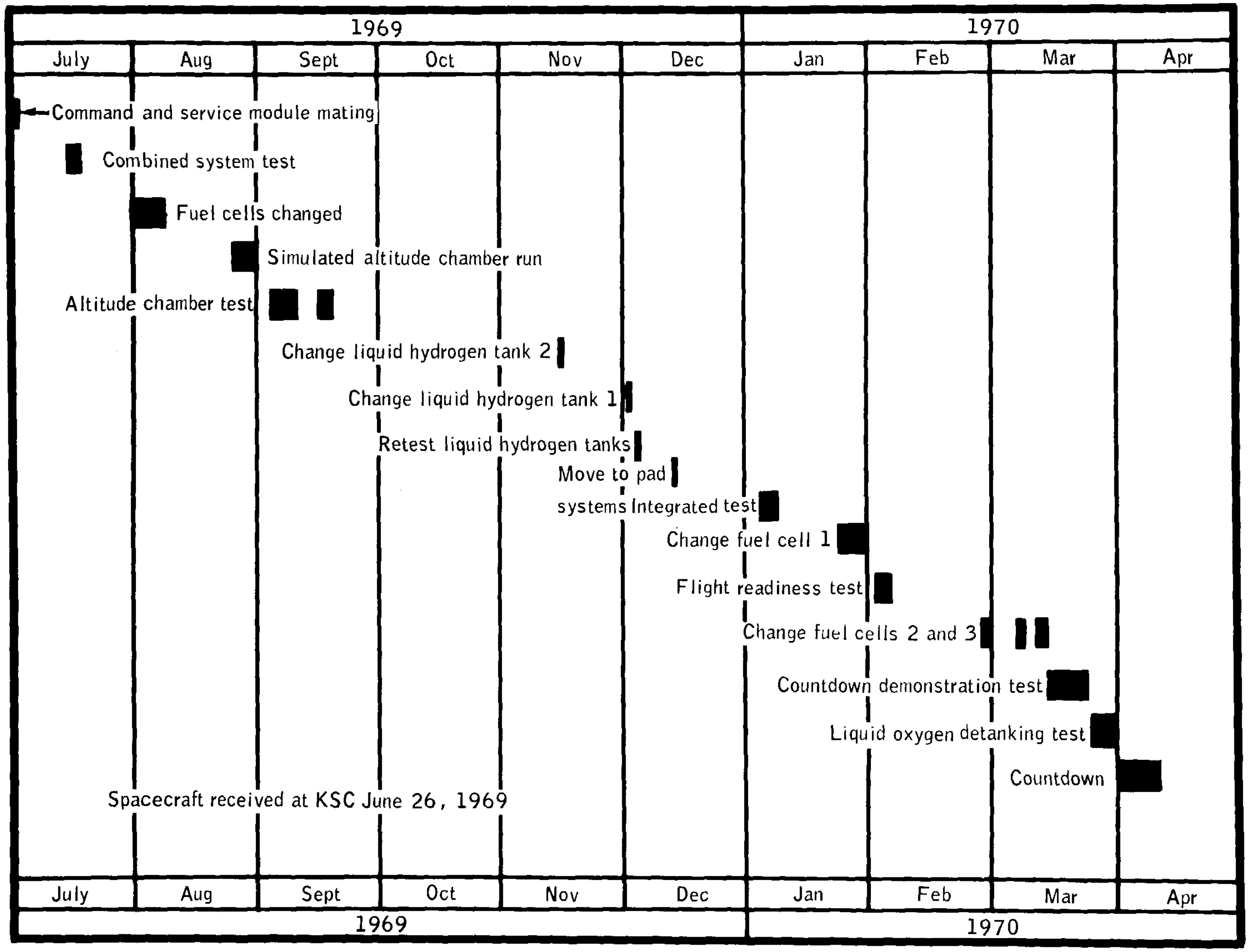


Figure C4-56.- Test flow for oxygen shelf at KSC.

A leak check was performed July 18, 1969, using helium at 94 psia in oxygen tank no. 2. Tank no. 2 was pressurized to 1025 psia to establish the relief valve cracking pressure and to verify the pressure switch operation. The pressure was decreased to 870 psia and then increased to 954 psia during the first integrated test with the launch vehicle simulator. The oxygen tanks no. 1 and no. 2 were evacuated to less than 5mm Hg, to dry the tanks, then pressurized to about 80 psia with reactant grade gaseous oxygen. Instrumentation was verified and fan motors were checked out.

A progress photograph (fig. C4-57) taken at KSC on November 14, 1969, shows the visible condition of the oxygen shelf with tanks, valves, tubing, and cables.

During the Flight Readiness Test in early February 1970, the pressurization cycle was repeated; vacuum to 5mm Hg and oxygen pressure to about 80 psia.

At the CDDT in March after activation of the fuel cells, the same cycle was followed: vacuum of the oxygen tanks to 5mm Hg followed by a gaseous oxygen pressure of about 80 psi. After the cooling of the fuel cells, cryogenic oxygen loading was normal and tank pressurization to 331 psia by using heaters powered from 65 V dc ground power supply was completed without abnormalities.

During these CDDT operations on March 23, tank no. 1 was detanked to the normal 50 percent within less than 10 minutes. Over the space of 45 minutes, tank no. 2 did not detank normally but was observed to retain more than 90 percent of its oxygen. Detanking was suspended until the completion of CDDT.

On March 27, detanking of tank no. 2 was again attempted. The tank had self-pressurized to 178 psia with a quantity of 83 percent indicated. By opening the fill line valve the pressure was depleted to approximately 36 psia in about 13 minutes. The quantity indication went down to about 65 percent (see fig. C4-58).

Next, during detanking attempts for both tanks, a comparison of tank no. 1 and tank no. 2 performance was made. The indicated oxygen quantity of tank no. 1 depleted from 48 percent to zero in less than 10 minutes. The indicated quantity in tank no. 2 remained above 60 percent over a 20-minute period.

Attempts were made over an 80-minute period to deplete the oxygen content of tank no. 2 by cycling up to various pressures and down, but did not reduce the indicated quantity below 54 percent (fig. C4-59). An attempt was made to expedite oxygen expulsion through the use of the tank heaters operated at maximum voltage and the fans. These were turned on for nearly 6 hours while the vent port remained open (fig. C4-60). Still the indicated quantity remained above 30 percent.

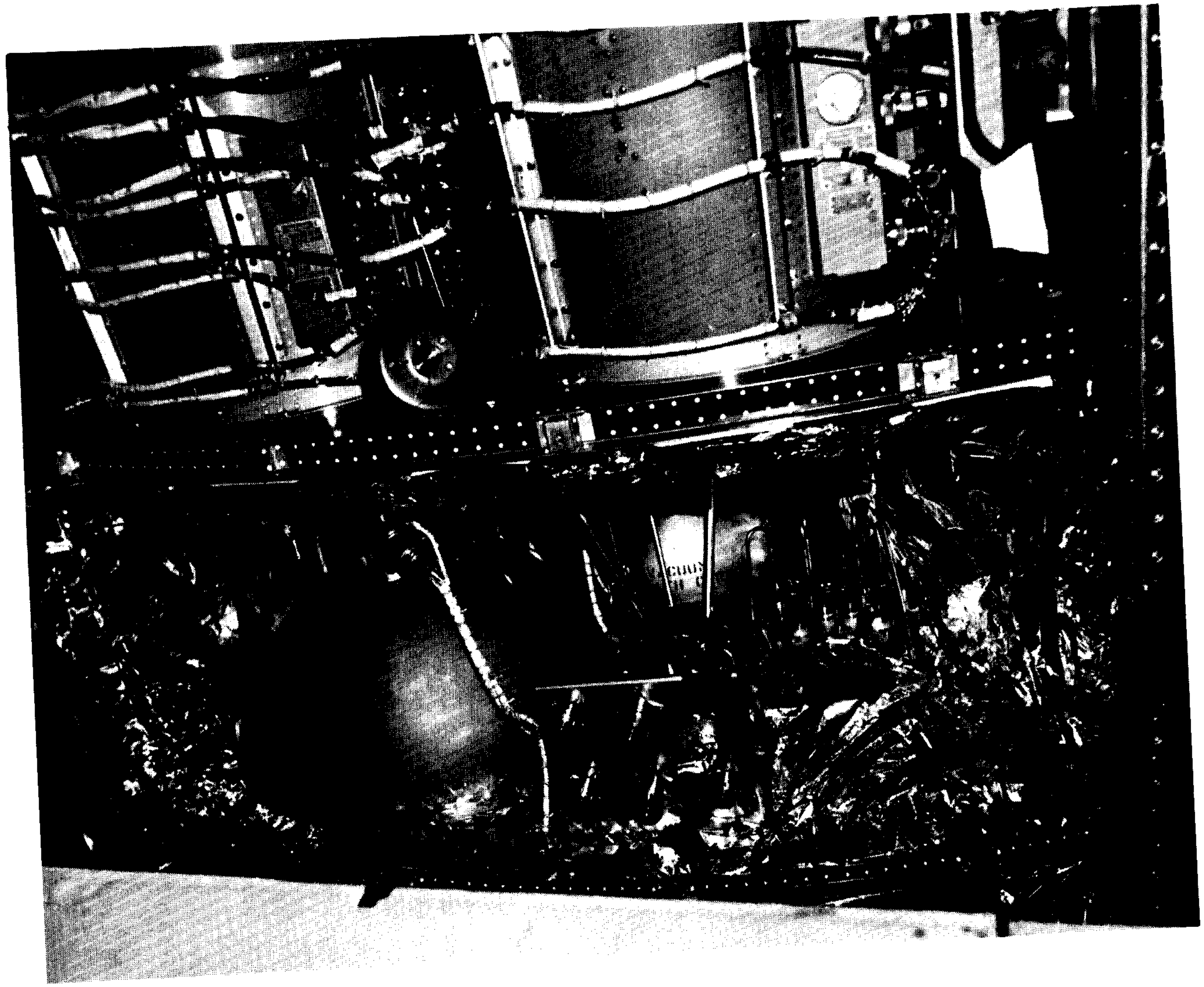


Figure C4-57.- Progress photograph of oxygen shelf taken at KSC
November 14, 1969

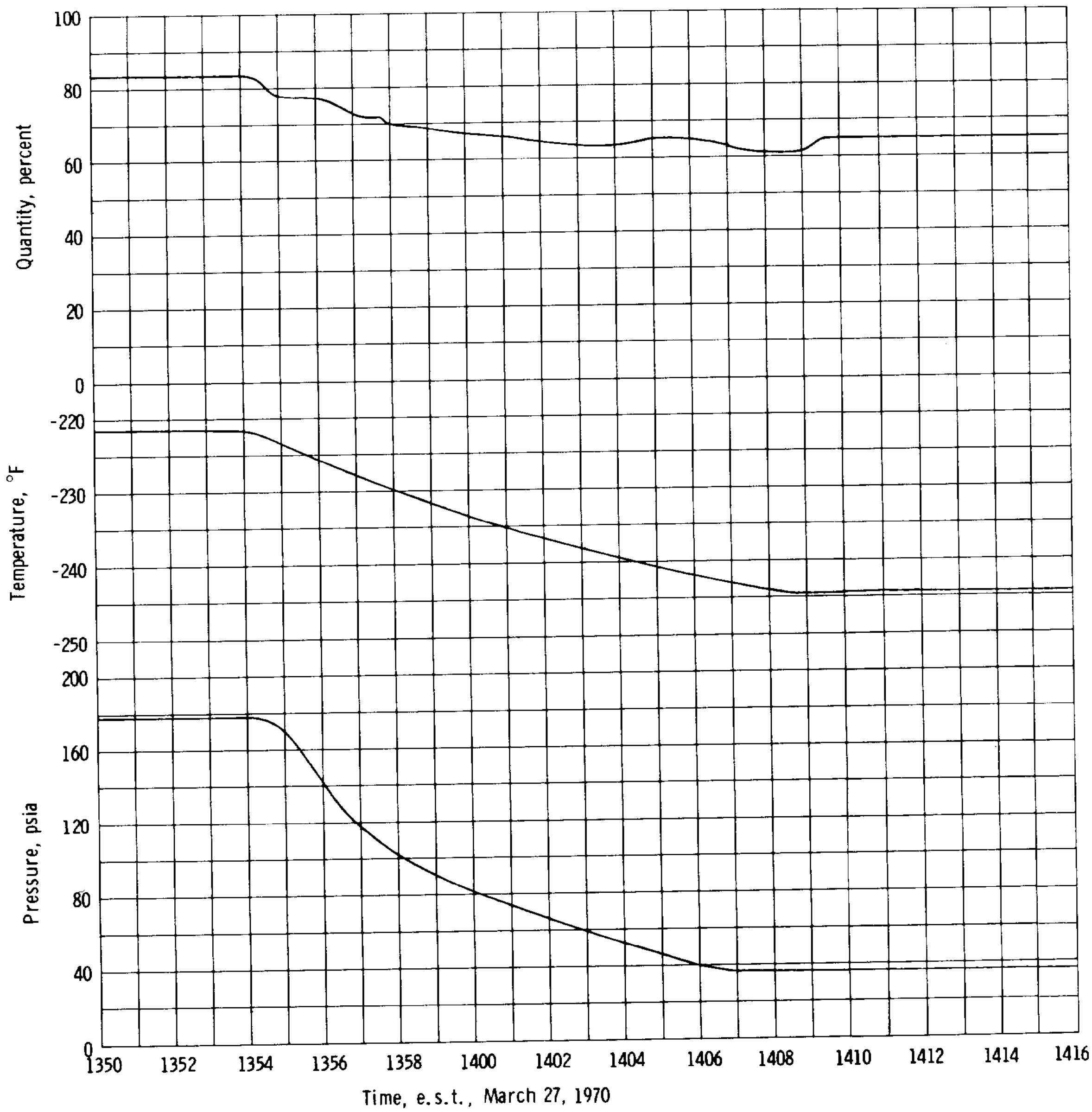


Figure C4-58.- Oxygen tank 2 detanking characteristics (pressure decay through the fill line - CDDT).

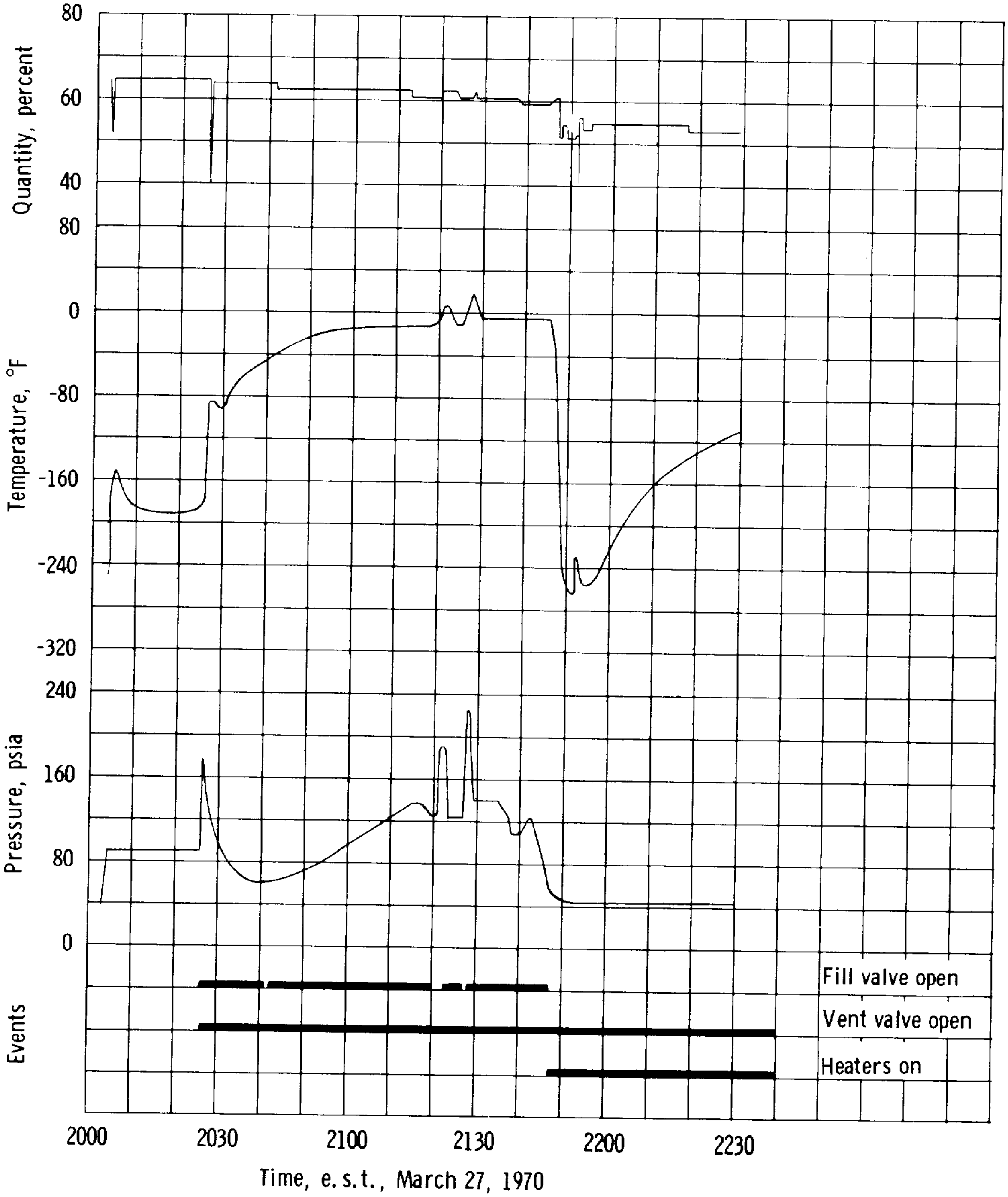


Figure C4-59.- Oxygen detanking attempt using varying purge pressure.

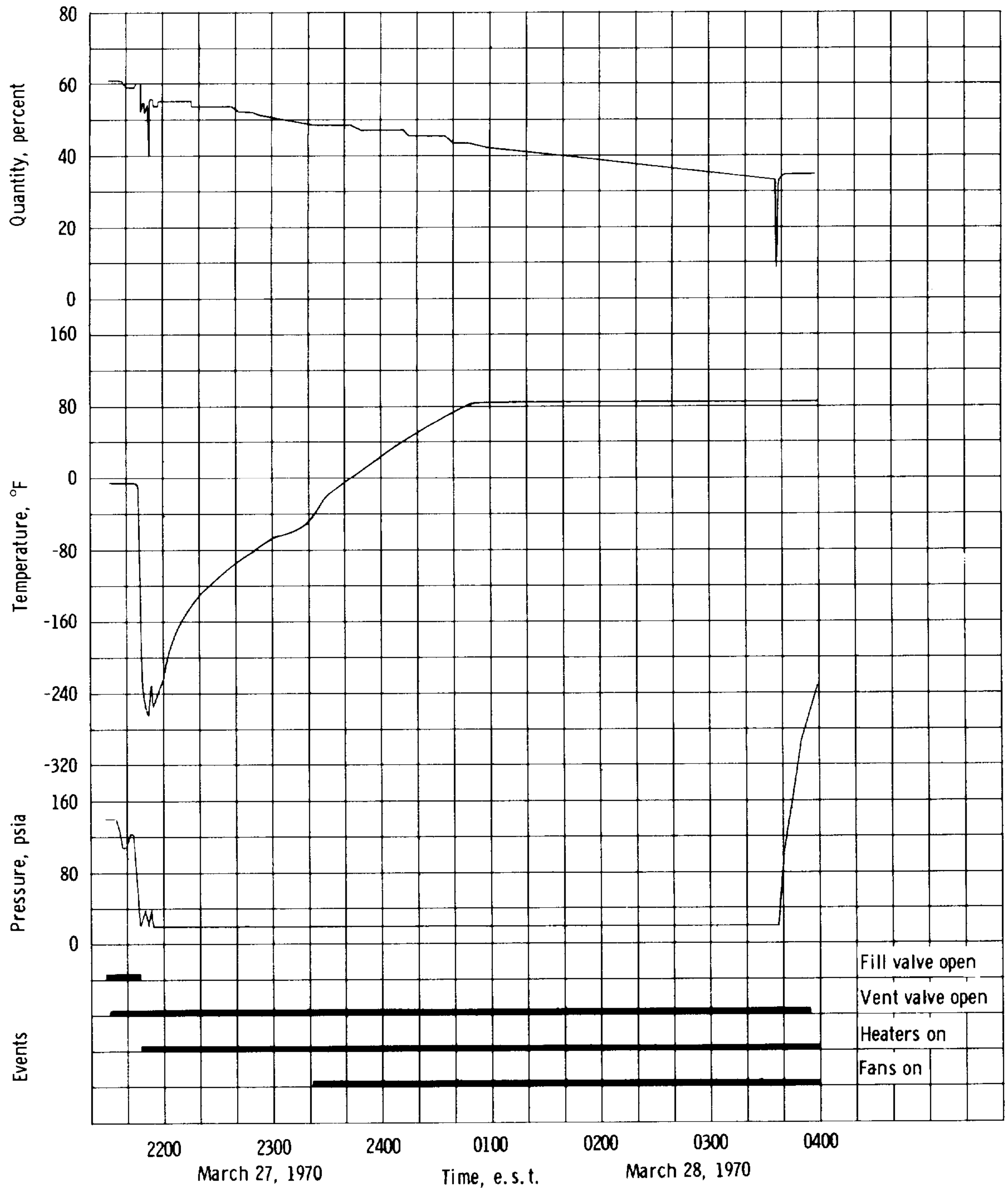


Figure C4-60.- Oxygen detanking attempt using tank heaters.

Then a pressure cycling technique was employed over a 2-1/2 hour period with maximum power being applied continuously to both tank heaters and fan circuits (fig. C4-61). This technique involved raising the tank pressure by external gaseous oxygen to approximately 300 psia and then opening the fill line to induce rapid boil-off. After five cycles, the oxygen tank quantity indicated zero.

Fan responses were observed to be normal throughout these operations. The temperature sensor on the quantity probe reached its indicating limit (+84° F) halfway through the 6-hour heating period. No observations of whether the heaters cycled on and off were made and subsequent review of the power supply voltage recording showed no indication of heater cycling.

Concern developed over two alternate hypothetical tank no. 2 conditions, a leakage path in the fill line within the tank or a clogged fill line.

Gaseous flow tests were used in one attempt to evaluate the latter. Both tank no. 1 and tank no. 2 were pressurized to approximately 240 psia and blown down through the fill lines with no significant differences in blowdown time (fig. C4-62).

A check of the Wintec filter in the GSE for oxygen tank no. 2 was made by the Wintec Corporation. No significant foreign material was found.

The alternate hypothesis, that the short segments of fill tube in the top of the quantity probe of tank no. 2 had large gaps or had become dislodged, was considered as were the operational difficulties associated with the use of a tank in this condition. The concern here was that the loading process might be hampered by the position of the fill line parts. It was noted that the filling was normal for the CDDT.

To verify this judgment and to assure countdown operability, both tanks were filled on March 30 to about 20 percent in approximately 2.5 minutes. Tank no. 1 detanked normally; tank no. 2 did not. Again the procedure of applying heat at maximum voltage and the cyclic application of gas pressure of approximately 250 psia and then venting was used. Five cycles were applied in a 1-1/4 hour period and tank no. 2 was emptied (fig. C4-63). The fan responses were observed to be normal and no indications of heater cycling were observed.

During the countdown, April 8, 1970, the pressurization of oxygen tank no. 2 was hampered by a leak through the vent line pressure-operated disconnect. Installation of the first cap stopped the leak and the pressurization of tank no. 2 was normal with no anomalies noticed during the completion of the countdown.

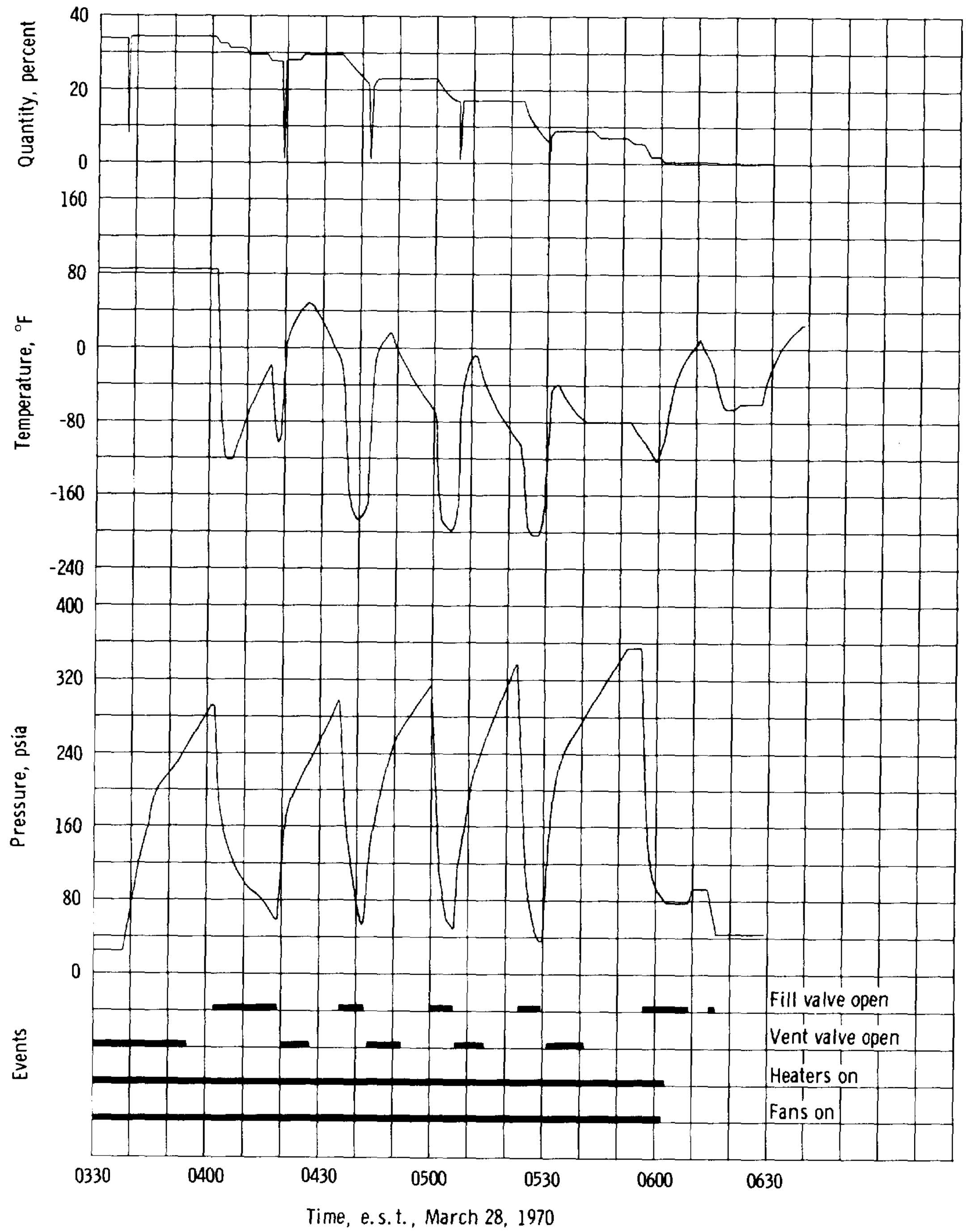


Figure C4-61.- Oxygen detanking using pressure cycles and tank heaters.

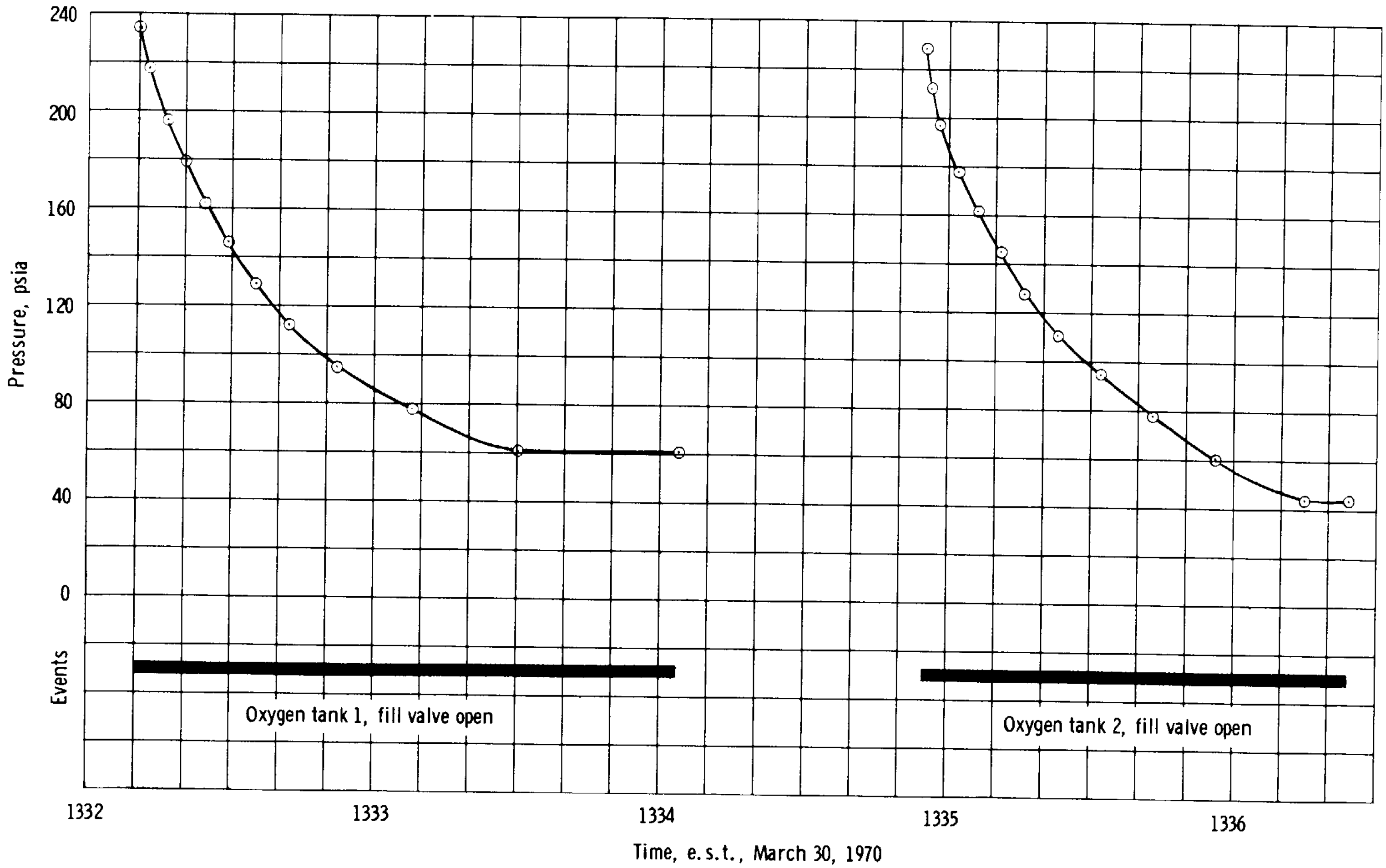


Figure C4-62.- Gaseous oxygen blowdown test, spacecraft 109.

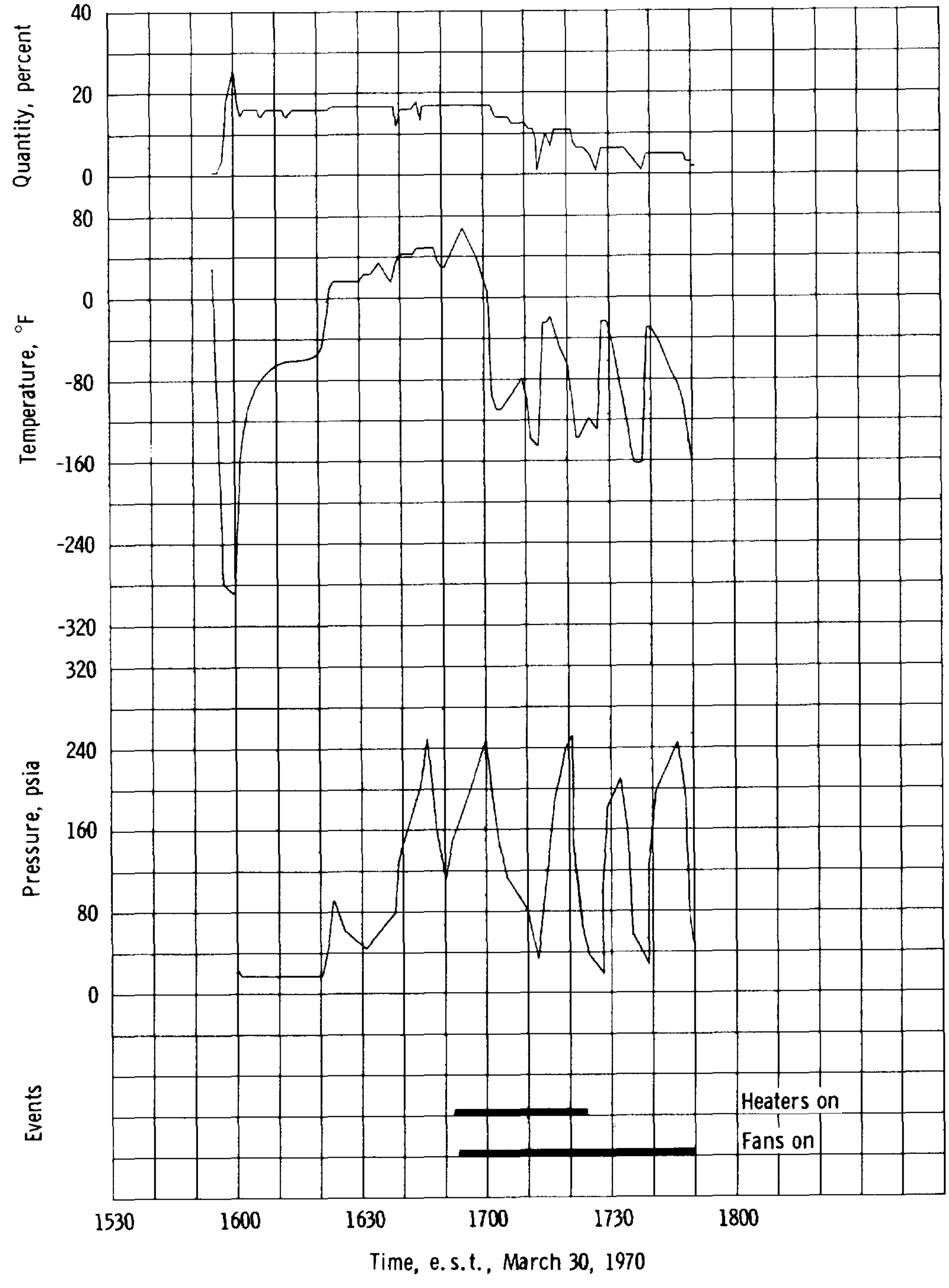


Figure C4-63.- Oxygen detanking using pressure cycles and tank heaters.

Several items of overall tank test and checkout experience should be noted.

Contaminants: Liquid, as well as gaseous, oxygen which entered tank no. 2 was verified by sample analysis. Nothing indicates that contaminants did enter the oxygen tanks. The samples taken from the vents during the servicing met the specification requirements and did not give an indication of tank contamination.

Quantity probe: Throughout all tests, during a period of 11 months resulting in 167 hours 8 minutes operating time including 28 fan on/off cycles over the 17-day period of CDDT and launch count, the quantity gaging system in tank no. 2 exhibited less sensitivity to noise and transients than that of tank no. 1.

Oxygen tank no. 2 pressure cycling: At no time during the testing of oxygen tank no. 2, in systems and subsystems, were the specified pressure limitations or allowable tank cycles exceeded.

Testing of oxygen tank fans: Test records were reviewed of all fan motor operations at KSC for any indications of ac bus transients. Tank no. 2 fans were powered 30 times. No electrical transients were found except those normally connected with fan starting or stopping. Fan motor performance was considered normal.

Investigation and Supporting Work

Causes of detanking difficulties.- Review of information from the Beech acceptance test logs and review with the Beech personnel in charge of these tests does not indicate that the detanking was abnormal. Contrarywise, the data are not substantive to prove that the liquid was expelled through the fill line. No weight or quantity measurement is recorded at the completion of the liquid expulsion; however, the procedure calls for continuing the application of vent line pressure until both the weighing system and the quantity probe indicate the tank is empty. The final tank empty condition is based on the final exit temperature of the warm nitrogen gas purge. At the time, no one indicated that the response of the tank to the procedures was anything but normal, and today careful review of existing data, discussions with the responsible Beech Aircraft and North American Rockwell personnel, and a special test at Beech Aircraft indicate that the detanking of the 0008 tank was most probably normal.

Each oxygen storage tank is stored at NR, Downey, in its shipping container until removal for installation in the assigned oxygen shelf. Thus it is retained in a vertical position until any motion takes place in the shelf assembly fixture.

The shelf assembly fixture used at Downey (fig. C4-50) aligns tank no. 1 so that the fill tube segments in the top of the quantity probe assembly lie nominally in a plane transverse to the axis of fixture rotation. Thus the fixture in the normal position holds the tubes upright but otherwise can rotate them through a full circle, exposing them to dislodging forces in the plane of their nominal location. The situation for tank no. 2 is nearly a right angle to the tank no. 1 situation so that the tube segment plane is nominally parallel to the trunnion axis of the assembly fixture. Thus in all positions other than vertical or inverted, a lateral dislodging force exists relative to the plane of their nominal location.

The highest elevation of the tank assembly, and thus the first area of contact with the underside of the fuel cell shelf at the time of the lifting fixture breakage and the shelf dent, was the cover over the upper vacuum pinch-off tube (fig. C4-55). This point was to the left of the mass centers and lifting forces involved as the counterbalance rotated and broke away from the fork portion of the lifting fixture. (See Appendix D.) Some rotation to lift the outer right corner of the shelf (lower right in fig. C4-55) higher than the outer left would be expected from this configuration. An uneven fall to the shelf supports would follow.

In figure C4-55, showing the installation of the oxygen shelf in SM 109, the condition of the farthest right tubing in the lower part of the picture reflects the comments of two DR's that one tube had a "slight bend" at the valve module and another (lower) was "badly bent." As the highest tubes, farthest from the 11th bolt and the high point of tank no. 2, these two may have participated in the "shelf drop" incident. Neither was found to be in need of repair after leak check.

No mention could be found in review of these DR's of any concern for the condition of the tubes, wires, or motors internal to the oxygen storage tank except as verifiable through routine external gas and electrical testing with NR factory OCP's.

Shipment of SM 109 from NR/Downey, with the SM axis horizontal during ground and air transporation, afforded the next major opportunity for fill tube segment lateral dislodgment.

It appears pertinent to this review to note that during SM transportation the fill tube segments within the upper portion of the oxygen tank no. 2 quantity probe assembly lay with the tank-exit end of the fill tube segments about 20 degrees above the horizontal, if they were still in place after previous handling and the "shelf drop." Neither the wires nor the feed line filter were below it to restrict rotation of the fill tube about the central tube of the quantity probe (fig. C4-64).

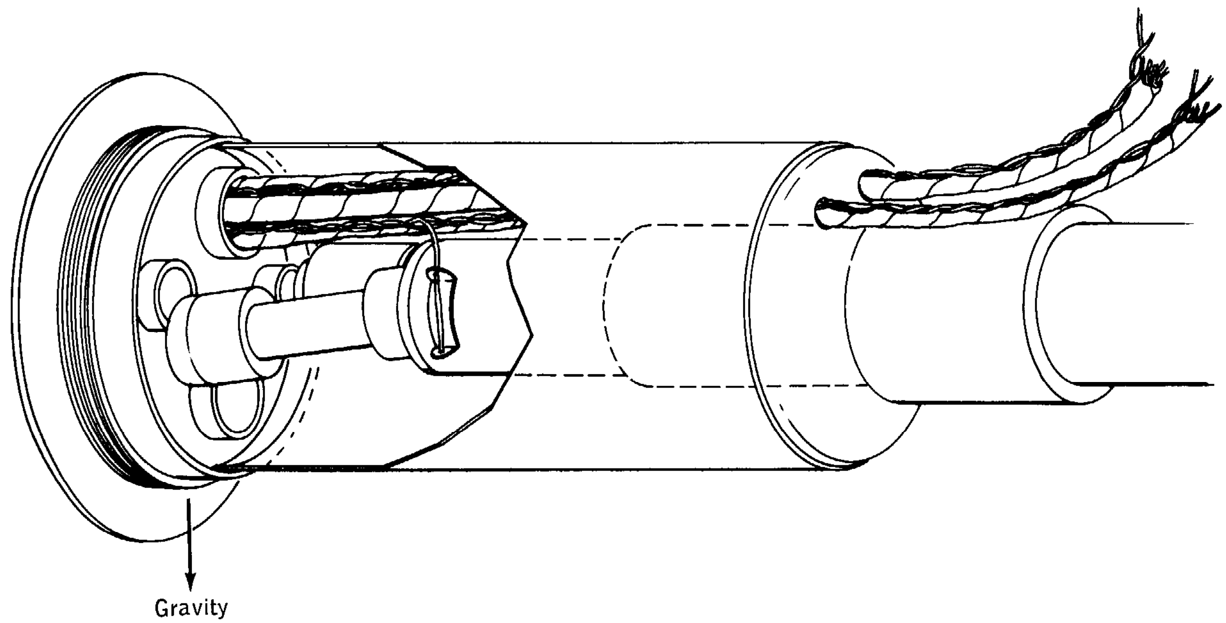


Figure C4-64.- Isometric sketch of quantity probe head as oriented during SM transportation.

This history of exposure of the tank fill tube segments to an unusual dislodgment environment sequence was not recorded during the detanking incidents at KSC nor during the presentation of CSM 109 history reviews to the Apollo Spacecraft Program Manager through either reliability and quality assurance or engineering channels at MSC. However, it does corroborate the recorded real-time judgment of Beech, MSC, and KSC engineers that the tank fill line parts may have been out of place in tank 10024XTA0008 during the detanking problems of March 23-30, 1970.

Since the fill tube parts have dimensional tolerances that could allow these parts to fall out of place, a calculation was made to attempt to establish the configuration of the tank during the detanking operations at KSC. The data from the first detanking attempt of March 27 were used to test the hypothesis that the fill tube parts were disconnected such that no liquid was expelled from the tank. A simple heat balance equation of the tank from the initial condition to the end condition shows that all the mass lost by the tank can be explained by vaporization and it is likely that no liquid was expelled. Figure C4-58 and table C4-III show the data upon which these calculations were based. At the initial and final point the temperature indicated in the data is too warm for the pressure indicated. The saturation temperature was used for each case.

Possible effects of special detanking procedures at KSC.- The use of special detanking procedures at KSC to empty tank no. 2 of CSM 109 has created concern these special procedures may have altered significantly the condition of the oxygen tank.

A number of special tests have been run and other tests are yet to be run in an attempt to determine the nature and degree of degradation that may be expected to occur to the tank internal components and wiring resulting from exposure of this type. The most significant finding to date is the fact that the thermostats fail by welding closed almost immediately when attempting to interrupt 65 V dc.

Several tests were run to determine the temperature that would occur at various points on the heater tube as a result of operation at ground power level as the liquid in the tank is boiled off. These tests were run at MSC using a similar sized tank with an actual flight-type heater fan assembly. The test setup is shown on figure C4-65. Liquid nitrogen was used in the tank for safety reasons. The initial run was made with a later model heater fan assembly that does not utilize thermostats; however, it was felt that as long as liquid nitrogen was present it was not likely that the thermostats would be called upon to operate. During this test very high temperatures were encountered on many locations on the heater tube (figure C4-66). These conditions were considered to be very unrealistic, so the test was rerun using a heater fan assembly equipped with thermostats. When the test was started, one thermostat indicated an open circuit at the initial fill condition. It was decided that a satisfactory test could be run since an extra lead had been extended from the heater elements so that the heaters could be manually operated to coincide with the functioning of the operable thermostat.

TABLE C4-III.- THERMODYNAMIC BALANCE CALCULATIONS

	Initial condition	Final condition
Quantity, lb	274 (83% indic.)	212 (65% indic.)
Pressure, psia	178	36
Temperature, ° F Temperature, ° R	-236.5 223.2	-280 179.7
Density of liquid, lb/ft^3	58.4	68.0
Volume of liquid, ft^3	4.70	3.10
Volume of gas, ft^3	.05	1.65
Weight of liquid, lb	273.85	210.9
Weight of gas, lb	0.15	1.1
Enthalpy of liquid, Btu/lb	88	68
Enthalpy of gas, Btu/lb	158	155
Total enthalpy of liquid, Btu	24,112	14,341
Total enthalpy of gas, Btu	24	171
Heat capacity of metal, 44 lb $\Delta T^\circ = 43.5^\circ$ F, sp. ht. 0.086	(Reference Cond.)	-164
Heat capacity of boil-off gas 62 lb at 156.5 Btu/lb	0	9,703
Total enthalpy, Btu/lb	24,136	24,051

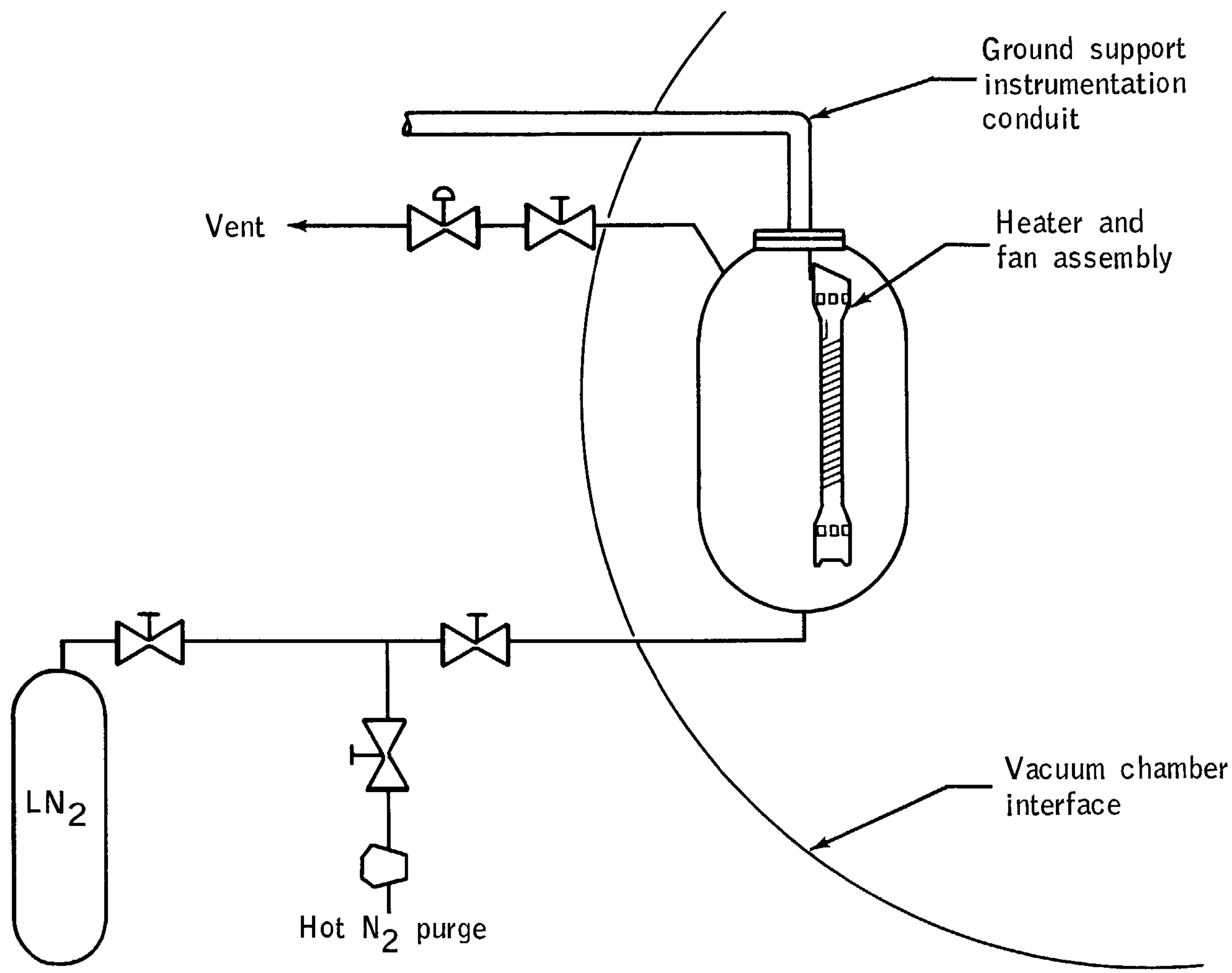
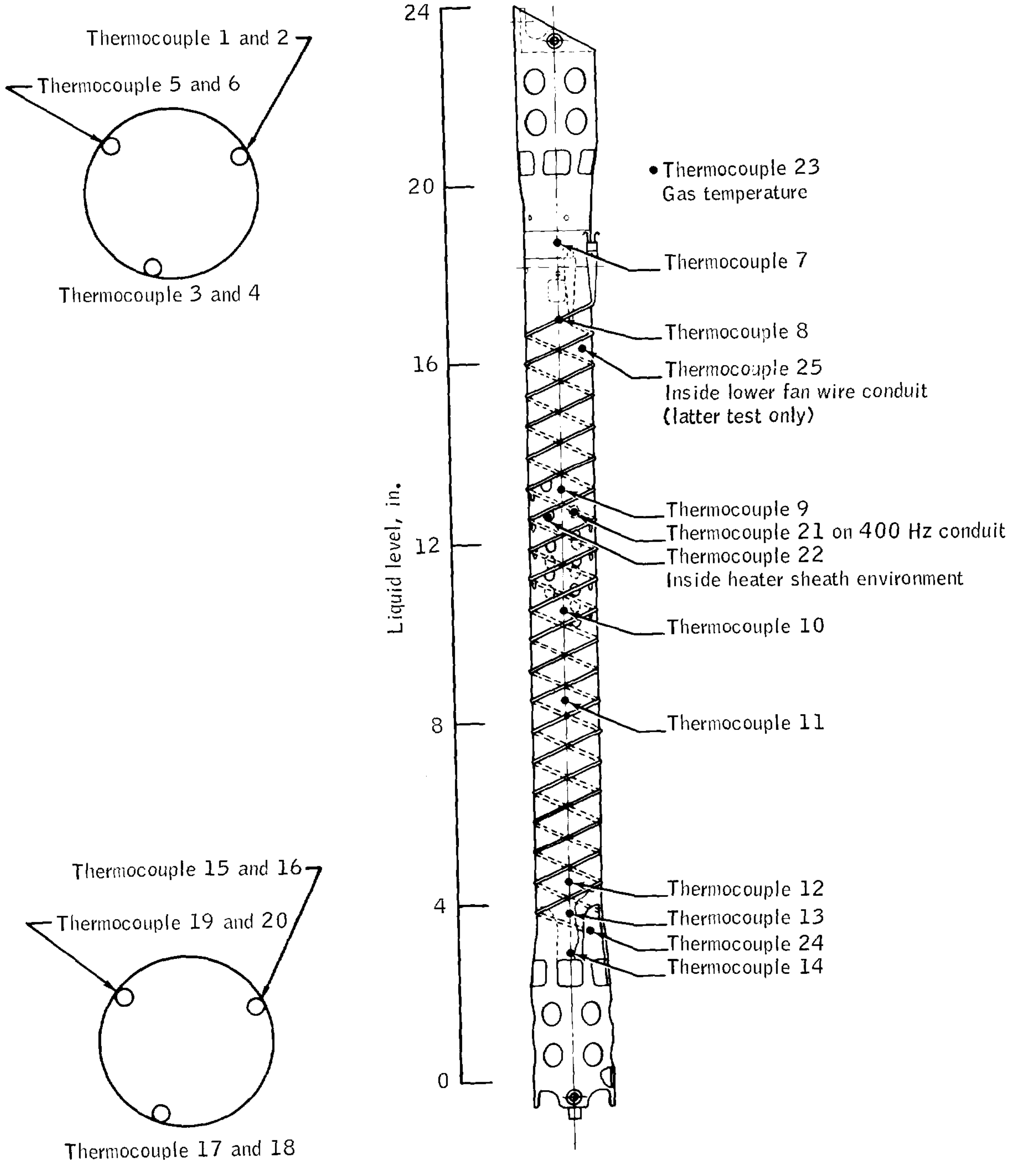
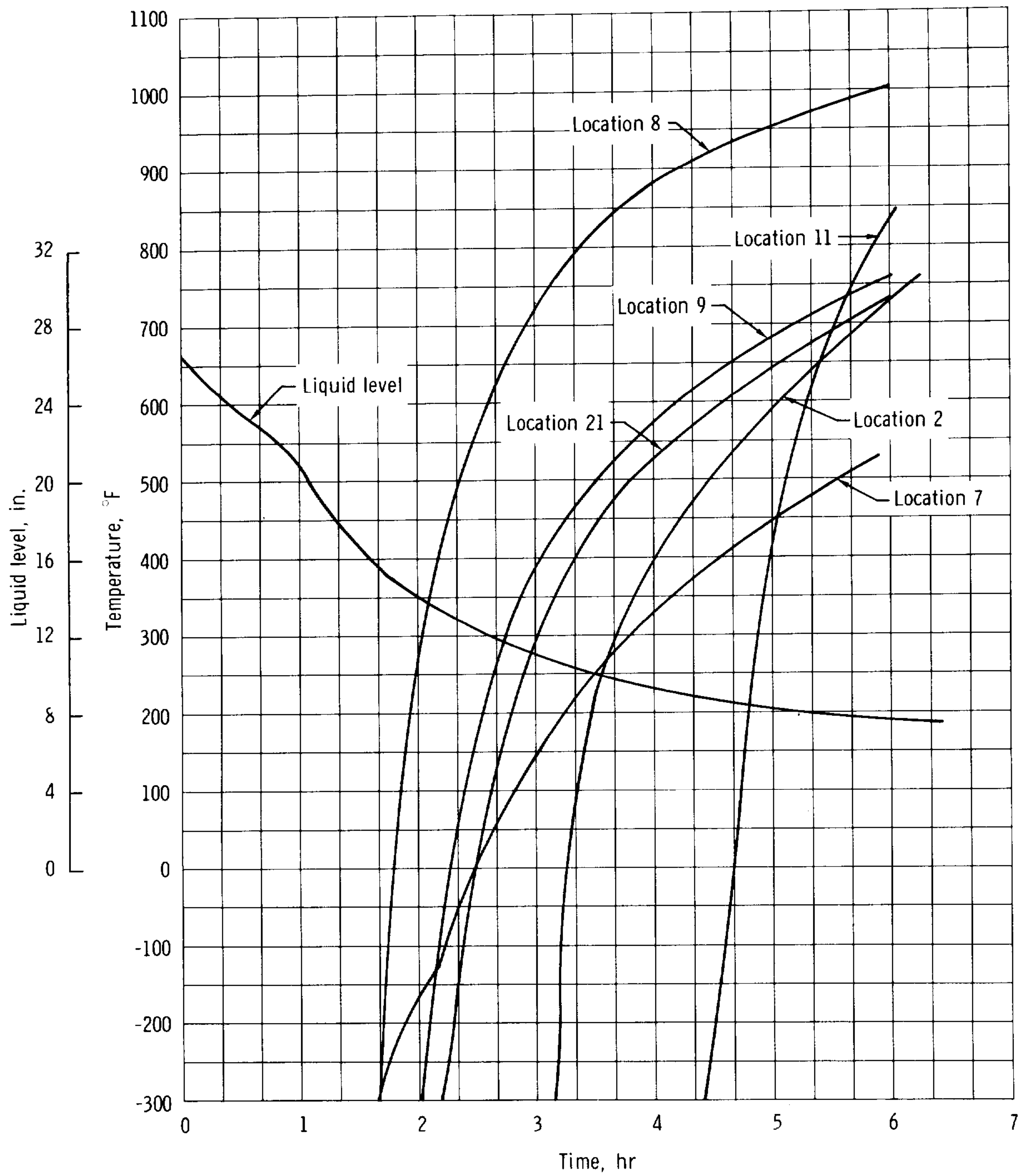


Figure C-4.65.- Heater tube assembly temperature test setup.



(a) Temperature sensor locations.

Figure C4-66.- Heater tube assembly temperature test.



(b) Typical test results.
Figure C4-66.- Concluded.

The test was started and after a few cycles in this mode the previously nonfunctioning (open) thermostat started indicating normal function. At this time it was decided to revert to the originally intended test configuration, i.e., the thermostats directly controlling the heaters. Data from that point on indicated that the thermostats were not cycling the heaters. The heater tube temperature data looked just like the nonthermostat test run. The test terminated at this point and the thermostats were removed and X-rayed. The X-rays indicated that the contact gap was bridged. One thermostat had its case carefully removed to examine the conditions of the contacts (fig. C4-67).

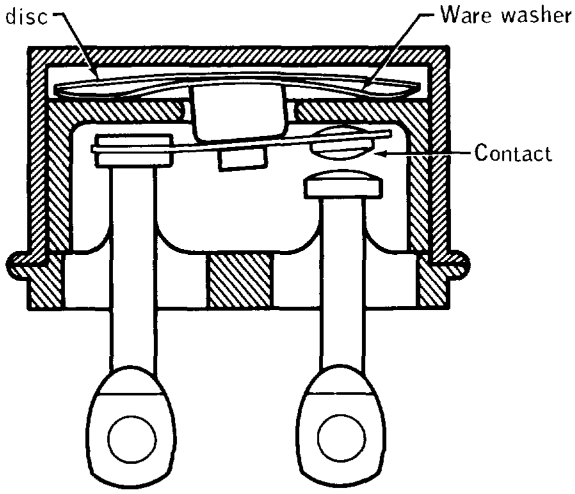
A review of the thermostat design and the manufacturer's ratings indicate that the thermostats are severely overloaded in current-interrupting capability at the ground power condition. Open contact spacing at 65 V dc is such that a sustained arc can be established and the contacts melted at this first attempt to interrupt power of this magnitude.

Inasmuch as thermostat failure would be expected at the first attempt to interrupt the ground power level, the conditions of heater tube temperature measured during the first test of this series would be indicative of those experienced during the KSC special detankings of March 27, 28, and 30. Since a review of the heater ground power supply voltage recordings made during the special detanking operations showed no indication of heater cycling, a special postflight test was conducted at KSC which showed that the cycled load equivalent to the heaters would cause a cycling in the voltage recording. Figure C4-68 shows sections of motor lead wire removed from the heater tube conduit.

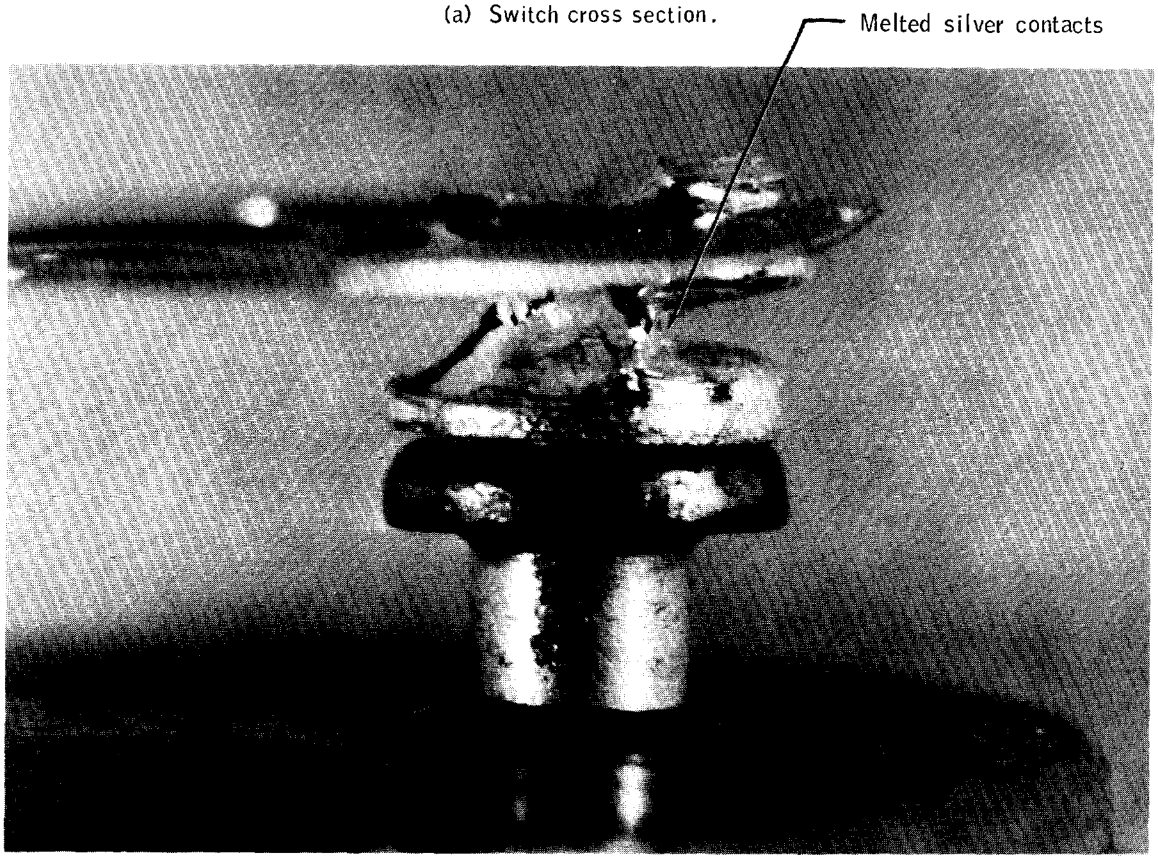
Other tests run at Ames Research Center (see Appendix F) indicate that Teflon-insulated wires run at similar temperatures in an oxygen atmosphere result in even more severe degradation.

A test is being run at Beech Aircraft to simulate all the tanking and detanking conducted on XTA-0008 at KSC. A Block I tank modified to the Block II configuration with the fill tube connecting parts rotated out of position is being used for this test. Temperature measurements on the electrical conduit in the vacuum dome area and posttest inspection will be utilized to evaluate the effects on the wiring of the special detanking operations.

At no time during standard checkout, prelaunch, and launch operations are these thermostats required to interrupt the 65 V dc ground power supply current. As far as could be determined, the special detanking operation was the only time that any thermostats were ever called upon to interrupt this load.



(a) Switch cross section.



(b) Welded contacts after test.

Figure C4-67.- Thermostat configuration and welded contacts.

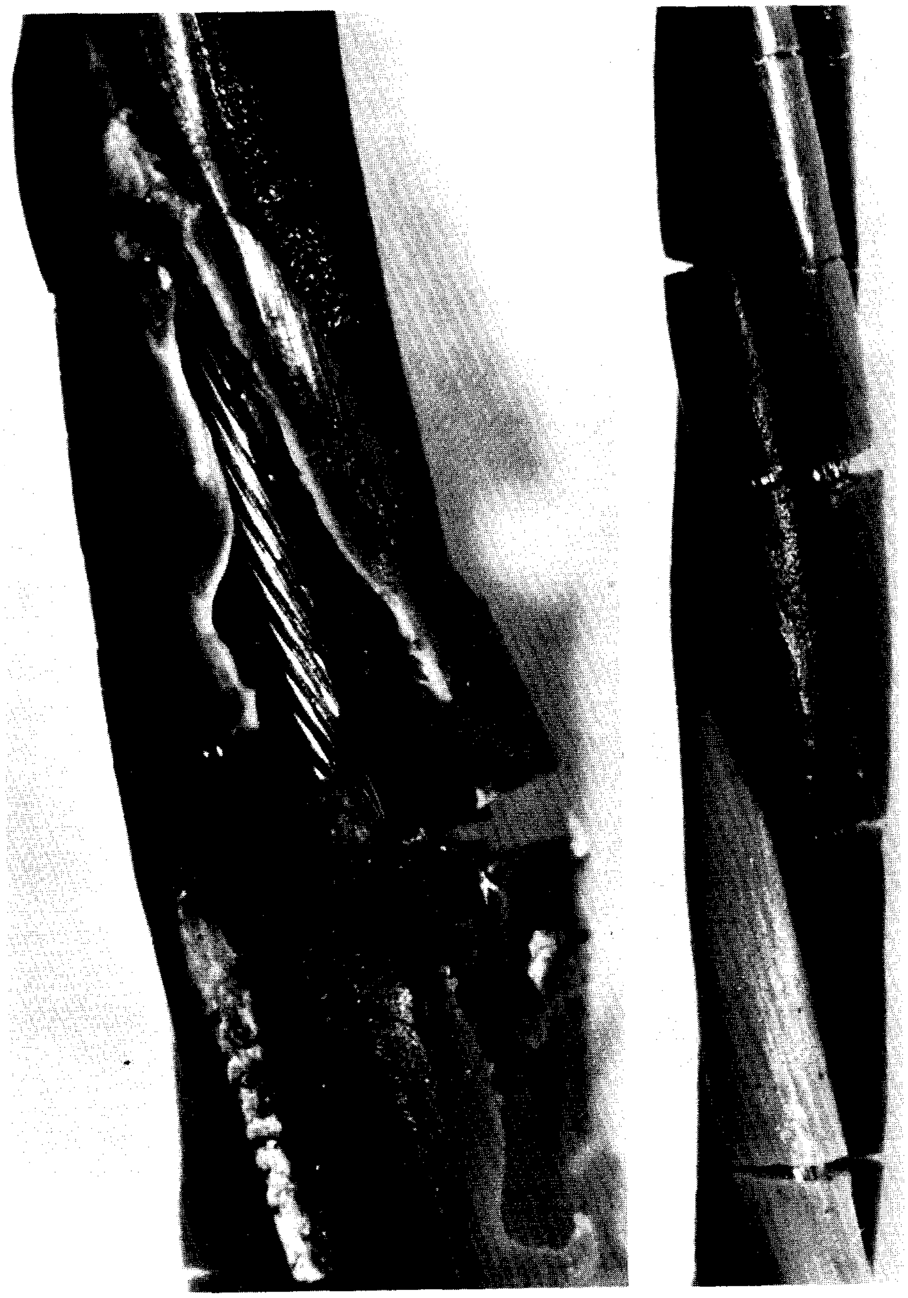


Figure C4-68.- Wire damage from heater tube assembly temperature test.