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# MODIFIED APOLLO CRYOGENIC OXYGEN TANK DESIGN

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## ABSTRACT

Assessment of the Apollo 13 mission indicated that some design changes be incorporated into Apollo cryogenic oxygen storage tanks. These changes broadly fit into three categories. They were: deletion of the fluid equilibration motors and redesign of heater assembly, material changes for internal tank wiring and density sensor, and the addition of a heater assembly temperature sensor. Development of a cryogenic oxygen tank incorporating these changes is presented.

## PRELIMINARY EVALUATION

Analysis of required design changes (reference Figure 1 which illustrates the original tank design), indicated that the heater assembly would be the key element and that the primary development problem was to incorporate metal sheathed wiring. A solution to this problem dictated the following general criteria for sheathed wiring:

1. Small diameter to:

   (a) mimimize conducted heat leak,

   (b) keep the containing conduit diameter small to allow installation in the existing pressure vessel neck opening and provide low conducted heat leak in short conduit lengths, and

   (c) provide maximum flexibility since the sheathed wires would have to be pulled through the containing conduit at installation.

2. Good handling resistance.

3. Completely compatible with silver solder brazing temperatures (1325°F).

4. LOX-GOX compatibility for all materials.

5. Appropriate electrical characteristics such as current carrying capacity with acceptable self-heating, insulation properties and capacitance.

These criteria were then used to screen available metal sheathed wiring and resulted in the selection of a sheathed wire produced by the Rosemount Engineering Company of Minneapolis. The wire produced by Rosemount had shown superior characteristics in the areas of flexi bility, handling tolerance, and internal materials. An additional bonus was realized with this wire selection in that heater elements could be fabricated with integral cold leads inside a continuous metallic sheath. This capability eliminated the need for heater lead terminations on the heater assembly.

Construction details of the selected metal sheathed wiring are illustrated in Figure 2. Figure 2 also shows a cross section of the sheathed wire. The outer sheath material is 321 stainless steel. Nominal finished outside diameter is 0.059 inch with 0.010 inch wall thickness. The insulation material is crushed and compacted Refrasil which is fused silicon dioxide or quartz. The Refrasil is applied as a woven braid of fused quartz fibers and is crushed and compacted when the metallic sheath is drawn. The conductor materials are 0.0158 inch O.D. Nichrome V for heater elements and 0.020 inch O.D. nickel-clad copper for cold leads. Figure 2 illustrates the manufacturing process used to fabricate the sheathed wire and shows how cold leads and heater elements are joined so that they can be enclosed in a single continuous sheath. Figure 2 also illustrates how a completed heater element is terminated with hermetically sealed headers.

## CONCEPT DEVELOPMENT AND SELECTION

The selection of a specific metal sheathed wire and preliminary compilations of its design application parameters allowed detailed engineering development of the required design changes. This in turn led to the comprehensive hardware development and design verification testing program presented in Table I. The resulting new design is illustrated in Figures 3 and 4.

In addition to the items shown in Table I, a development program to eliminate teflon materials from the tank density sensing probe was pursued. Two development density sensors were fabricated using insulating materials other than teflon. The materials were fused quartz and Alsimag ceramic. Subsequent testing of these two probes indicated that both materials were feasible; however, considerable further work would be required to perfect them to production design status. The main problem areas were: moisture sensitivity and particle generation.

## DESIGN AND PRODUCTION DEVELOPMENT

BAC encountered four significant manufacturing process development problems during the fabrication of these initial tanks. They were:

1. Perfection of tooling and brazing techniques for installation of Rosemount heater elements on the heater assembly support tube. These spirally wrapped elements were difficult to keep in place and simultaneously allow a smooth continuous braze with uniform temperature distribution. The problem was resolved by more sophisticated retaining tools and the incorporation of a preheater into the brazing tool.

2. Maintenance of dry sheathed leads throughout the manufacturing cycle. The sheathed wiring readily wicked air moisture in any process which heated and cooled the leads in an unsealed condition. Moisture in the leads would result in their insulation resistance and dielectric strength being less than specification requirements. This problem was resolved by minimizing the occurrence and duration of leads being in an unsealed condition and when leads were required to be unsealed all work was done in dry boxes or under hot dry blanket purge conditions.

3. Brazing problems associated with installation of transition spline pins between sheathed wire hermetic headers and the original design Apollo main electrical connector. The problems

were primarily associated with small clearances between pins in the main electrical connector which made torch brazing very difficult and resulted in multiple reheat of some connector pins. This problem was eventually resolved by a new electrical connector design. The original and new design connectors are contrasted in Figure 5.

4. A problem occurred with the heater element platinum braze joint during component acceptance testing of heater assemblies. The problem was continuity failures in the platinum braze joints or close to the joint in the nickel-clad copper lead. Investigation of the problem traced the cause to inadequate wetting of the Nichrome V heater element wire during the joint braze operation, manual control of centering during the joint braze operation, and an extremely severe annealing operation following drawing of the wire sheath. All of these problems were resolved by changing the joint braze and annealing processes. The investigation also showed that the existing component acceptance tests would have screened out any heater assemblies with potentially defective heater elements. However, both BAC and Rosemount inspection and component acceptance tests were made more stringent as a result of this problem.

## DESIGN QUALIFICATION

Qualification of the new design oxygen tank commenced in mid-October. Table II indicates the items qualified, the tests conducted and a brief synopsis of the test results. One failure was encountered during vibration qualification testing. The bulk fluid temperature sensor MI cable separated where it entered to the sensor housing. The failure resulted in severe degradation of the first qualification tank (XTA0033) vacuum when sorbed gases in the magnesium oxide insulation were released into the tank vacuum annulus. This failure occurred prior to running the last axis of random design proof vibration. Investigation of this failure included re-evaluation of the vibration test levels and exposure times. Results of this re-evaluation indicated that the test requirements were unnecessarily severe especially in the area of exposure time. The test levels were redefined and a second qualification tank, XTA0037, was subsequently exposed to the new test requirements without incident.

Successful qualification of the new design oxygen tank was completed just a matter of days before launch of Apollo 14. In fact, the mission simulation test setup being used for the last qualification test of the tanks was recycled and used to "fly" a parallel mission with the tank system in Apollo 14.

Performance of the new design oxygen tanks was completely satisfactory. The performance ratings of the original design oxygen tank and the new design oxygen tank are compared in Table III.

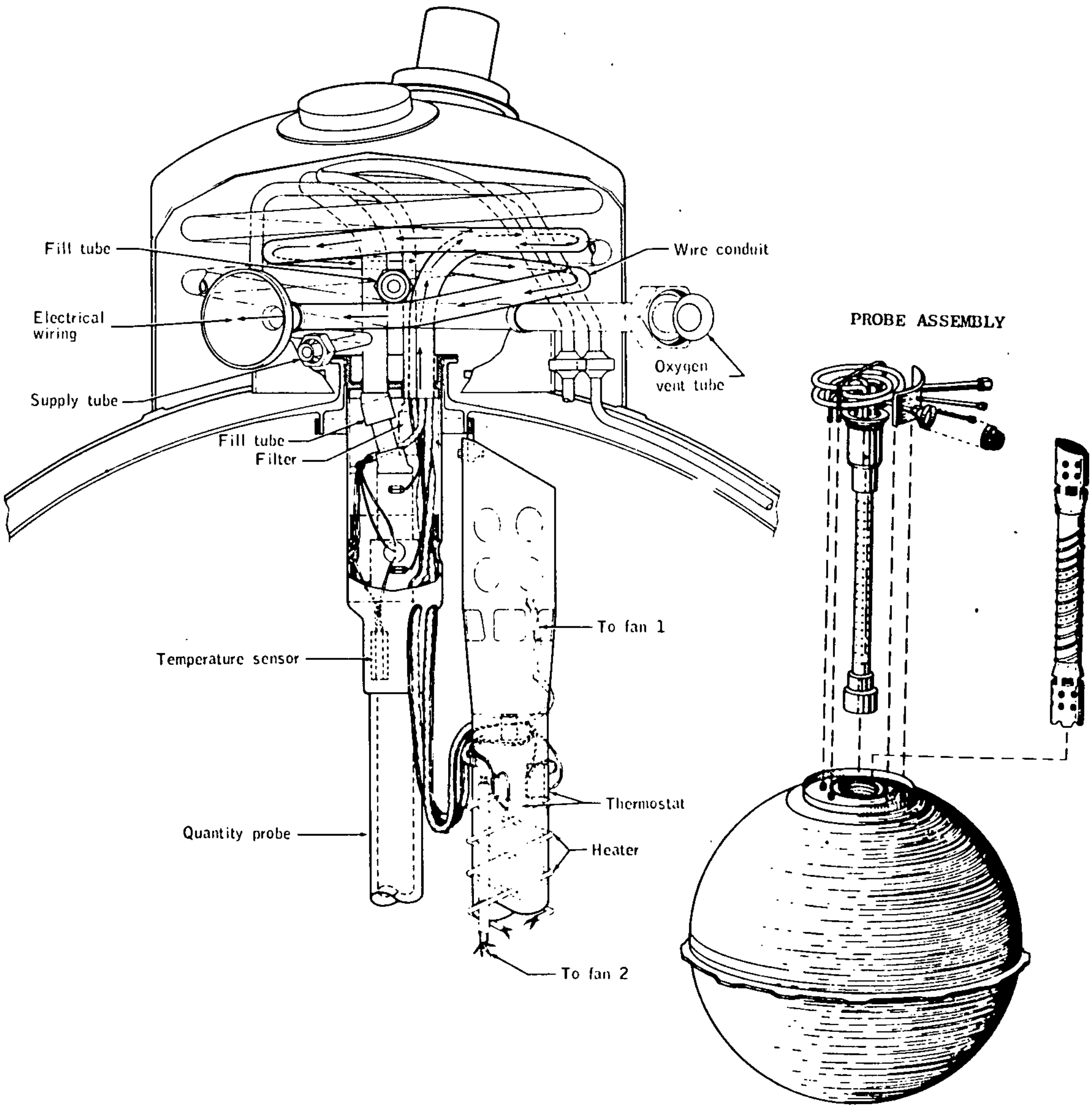



Figure 1

ORIGINAL BLOCK II OXYGEN TANK

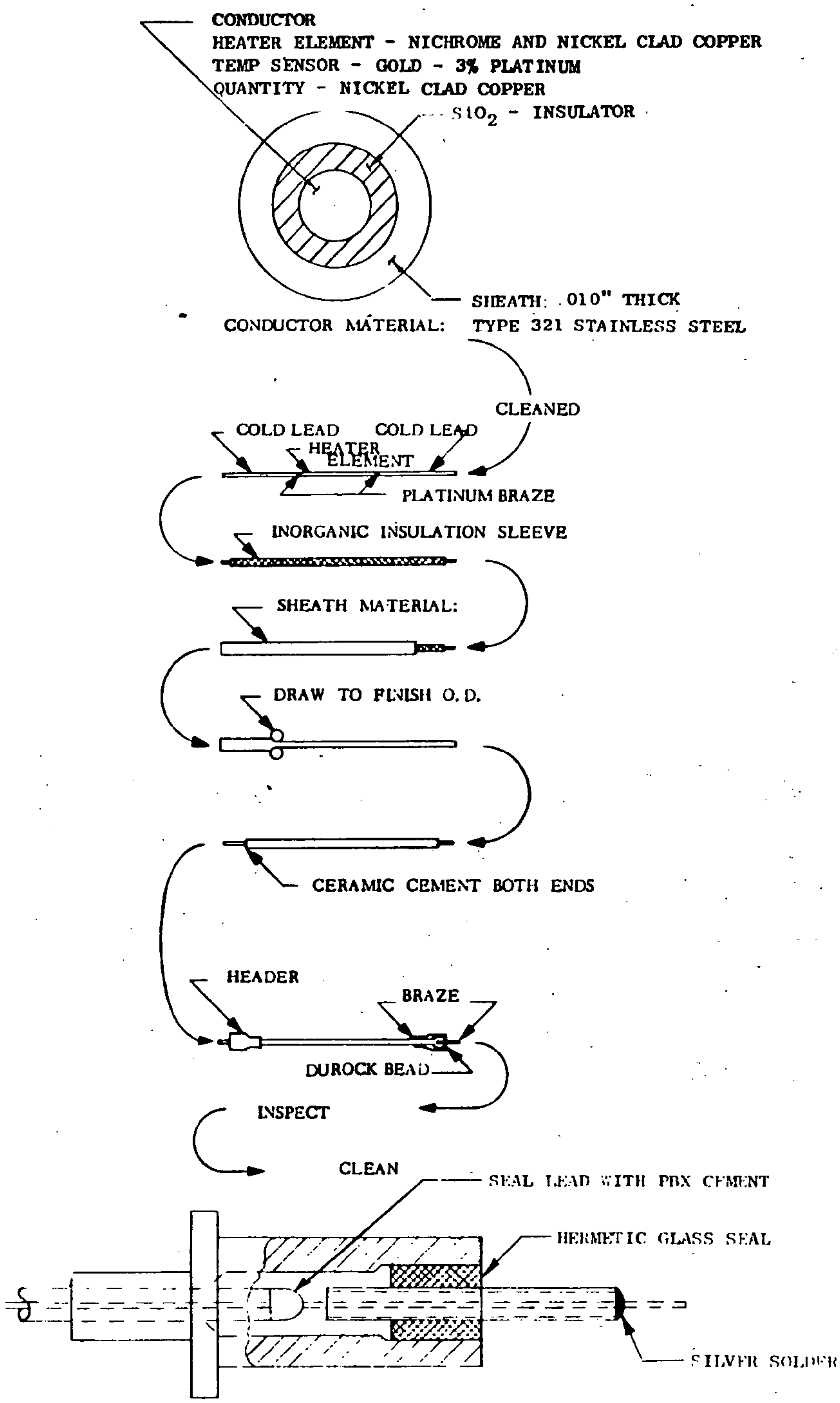



Figure 2

SHEATHED WIRING

TABLE I

SYNOPSIS OF NEW DESIGN DEVELOPMENT & DVT TESTING

| TEST ITEM | TYPE OF TESTING | REMARKS |
|---|---|---|
| Sheathed Wiring & Heater Elements | 1. Tensile tests with headers | 150 lb - fails in sheathed lead. |
| | 2. Leak test (length of lead) | 10cc He in 80 minutes 15 psid. |
| | 3. Vibration | Completely acceptable. |
| | 4. Handling & flexibility | Triple 5/8 dia reverse rolling bend. |
| | 5. Particle generation | Acceptable. |
| | 6. Minimum bend radius & restraighten and ding effects | 1/8 inch radius. 0.005 to 0.250. Radius dings to 50% of dia. pass. |
| | 7. Thermal shock | +140$^{o}$F to $LN_2$ no effect. |
| | 8. Drying techniques | Is dryable without complications. |
| | 9. Resistance & resistance temperature | Met design requirements. |
| | 10. Capacitance | 72.5 pf/ft. |
| | 11. Dielectric strength | 10 $\mu$a, one time 1000vdc, 500vdc unlimited. |
| | 12. Ruptured heater in high pressure oxygen | No ignition or operation problems. |
| Hermetic Headers | 1. Thermal shock | +140$^{o}$F to $LN_2$ no effect. |
| | 2. Leak tests | 3 x $10^{-8}$ scc He. |
| | 3. External & internal pressure | To 6200 psia no failure. |

TABLE I (contd)

SYNOPSIS OF NEW DESIGN DEVELOPMENT & DVT TESTING

| TEST ITEM | TYPE OF TESTING | REMARKS |
|---|---|---|
| | 4. Resistance | Met design requirements. |
| | 5. Humidity effects | Does not collect, dries readily. |
| | 6. Brazing temperature distribution | Mfg. process causes no degradation. |
| Electrical Connector (extended pin) | 1. Thermal shock | $+140^{o}F$ to $LN_2$ no effect. |
| | 2. Vibration | Design proof, no problems. |
| | 3. Shock | 30 g's 11 milliseconds, no problems |
| | 4. Pressurization | System burst, no failure. |
| | 5. Leak test | Meets $1 \times 10^{-4}$ scc He at 1357 psia. |
| | 6. Dielectric strength | 10 $\mu$a at 1000vdc. |
| Heater Assembly including Heater Temperature Sensor | 1. Thermal shock | $+140^{o}F$ to $LN_2$, no effect. |
| | 2. Vibration | Margin considerably above design proof. |
| | 3. Acceleration | 7 g's + X axis, 3 g's all others. |
| | 4. Life cycle | 400 hours 10% duty cycle & cryo shock. |
| | 5. Temperature distribution | Verified design. |
| | 6. Off-limits cryo shock | $+700^{o}F$ to $LN_2$, no failure. |
| | 7. In tank operation | Development phase 755 hours, 425 cycles. |

TABLE I (contd)

SYNOPSIS OF NEW DESIGN DEVELOPMENT & DVT TESTING

| TEST ITEM | TYPE OF TESTING | R E M A R K S |
|---|---|---|
| Fluid Temperature Sensor | 1. Thermal shock | +140$^{o}$F to $LN_2$, no degradation. |
| | 2. Pressurization | To 1537 psia, no failure. |
| | 3. Vibration | Design proof, no failure. |
| | 4. Acceleration | 7 g's + X axis, all others 3 g's. |
| | 5. Weld Temperatures | Mfg. process causes no degradation. |
| Density Probe | 1. Thermal shock | +140$^{o}$F to $LN_2$, no effect. |
| | 2. Vibration | Design proof, no failure. |
| | 3. Acceleration | 7 g's + X axis, all other 3 g's. |
| | 4. Capacitance effects | Sheathed leads & header cause no problem. |
| | 5. Tensile test | Lowest tensile 515 lb inner tube. |
| Development Tank LO-19 with Harness Assembly | 1. Cold shock & proof pressure | Tank met and is still meeting all design requirements. Has accumulated over 1087 hours. Cryogenic operating hours at pressure. |
| | 2. Design verification function test | |
| | 3. Optimum detanking | |
| | 4. Standby heat leak (140$^{o}$F & vacuum) | |
| | 5. Design proof vibration | |
| | 6. Optimum heater pressurization mode | |
| | 7. Mission simulations | |

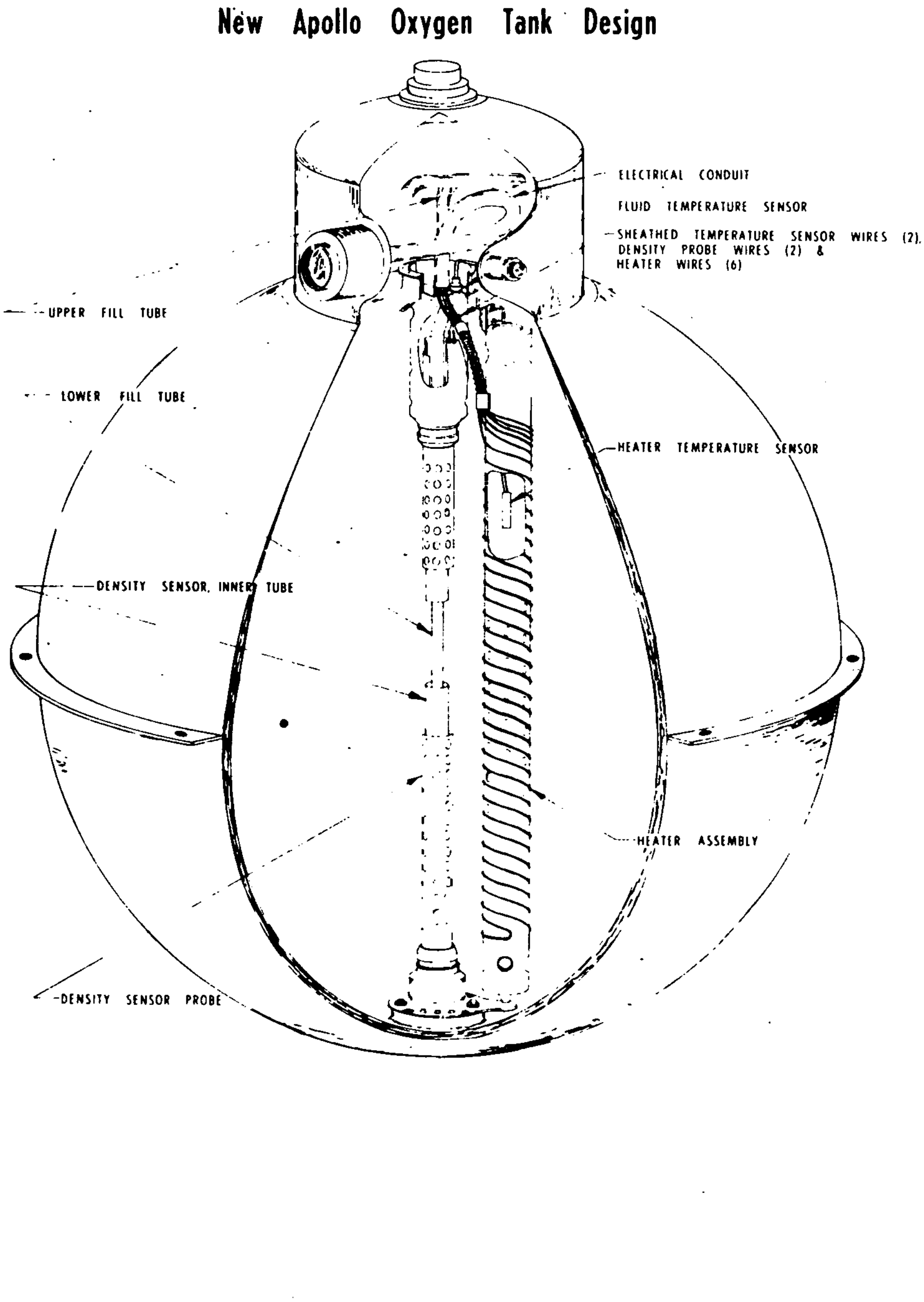
TABLE I (contd)

SYNOPSIS OF NEW DESIGN DEVELOPMENT & DVT TESTING

| TEST ITEM | TYPE OF TESTING | REMARKS |
|---|---|---|
| Heater Temperature Signal Conditioner | 1. Temperature-vacuum functional and accuracy tests | No loss of accuracy or failure. |
| | 2. Vibration | Eight times design proof, no failure. |

Figure 3

OXYGEN TANK ASSEMBLY



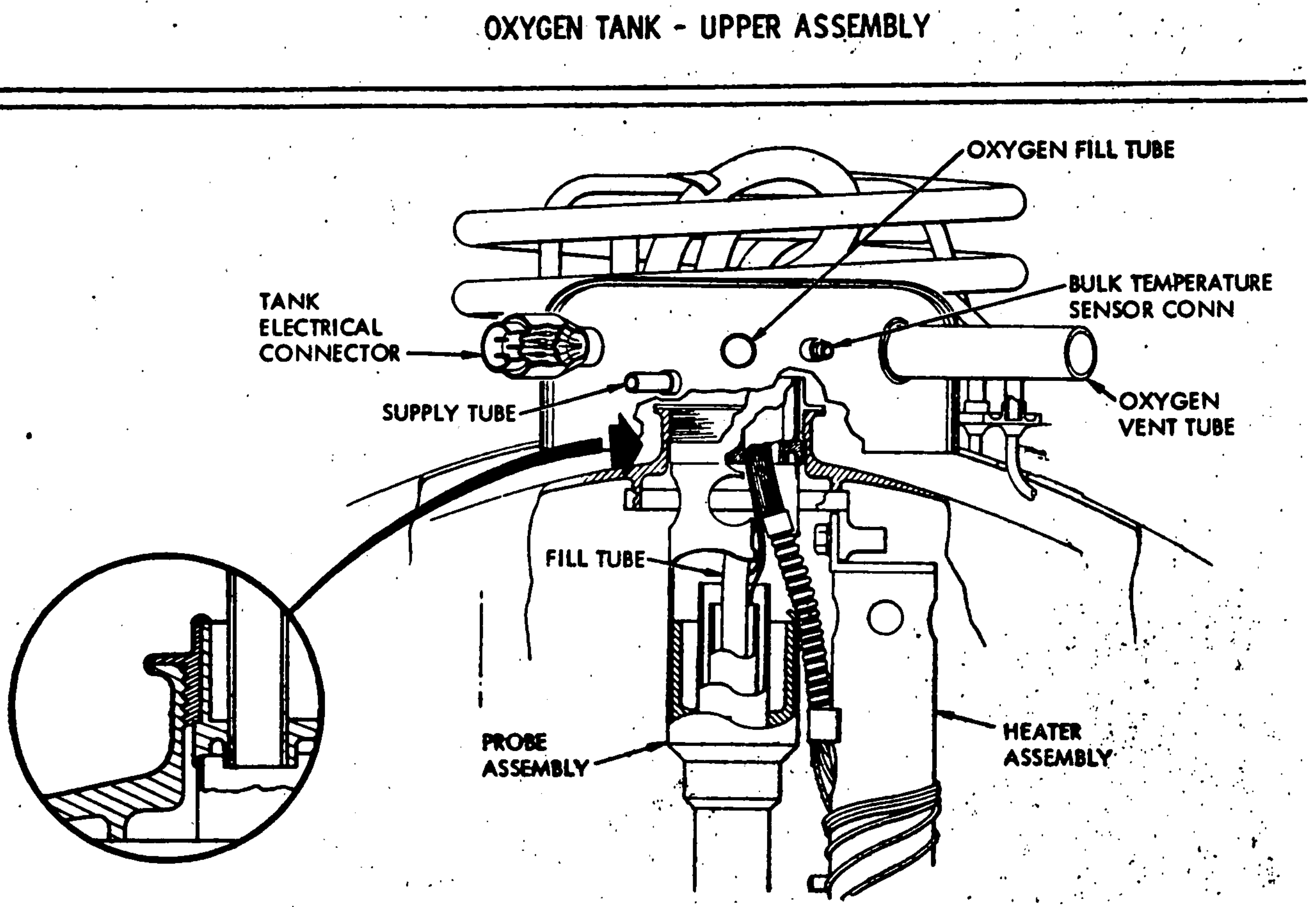
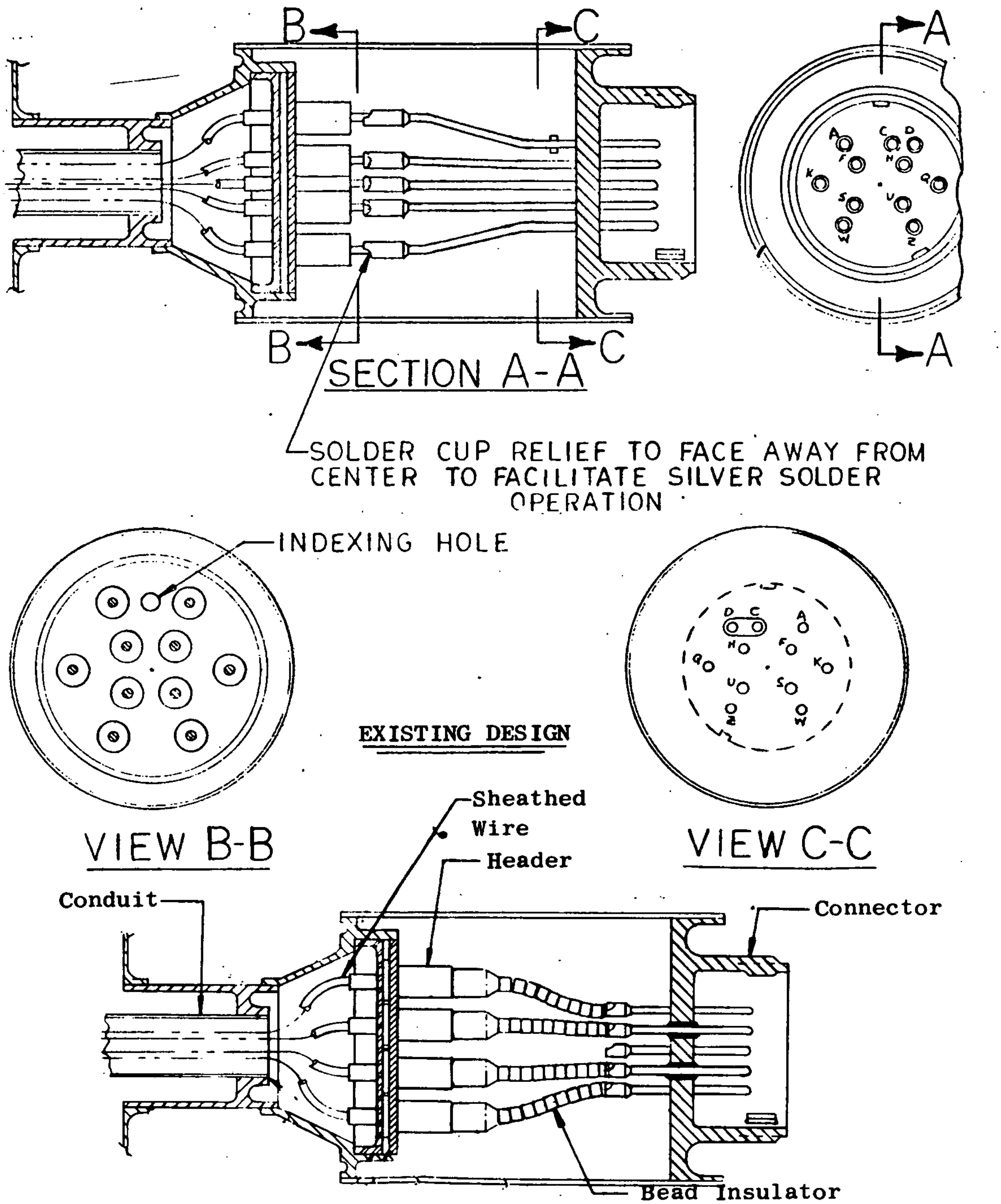



Figure 4

NEW DESIGN OXYGEN TANK NECK & PROBE DETAIL




**DEVELOPMENT DESIGN**

**Figure 5**

**CONNECTOR ASSEMBLY**

TABLE II

SYNOPSIS OF NEW DESIGN QUALIFICATION TESTING

| QUALIFICATION ITEM | QUALIFICATION TESTS | R E M A R K S |
|---|---|---|
| New Design Tank Assembly | 1. Transportation Vibration | Actual over the road, empty tank in shipping container. |
| | 2. Sinusoidal Vibration | Filled tank & pressurized 5-30-5 Hz, $\pm$ 0.25 g peak. |
| | 3. Random Vibration | |
| | a. Space Flight | Filled tank & pressurized. Increase 3 db/octave 20-15 Hz, constant 0.0075 $g^2$/Hz 150 to 2000 Hz. 12-1/2 minutes each axis. |
| | b. Atmospheric Flight | Filled tank & pressurized.<br>Y & Z axes - increase 12 db/octave 20-35 Hz, constant 0.006 $g^2$/Hz. 35-105 Hz, increase 9 db/octave 105-200 Hz, constant 0.04 $g^2$/Hz 200-800 Hz, decrease 3 db/octave. 800-2000 Hz. For 75 seconds & +4 db increase for 10 seconds. X axis -- increase 6 db/octave 20-40 Hz, constant 0.01 $g^2$/Hz 40-125 Hz, increase 9 db/octave 125-200 Hz, constant 0.04 $g^2$/Hz 200-300 Hz, decrease 3 db/octave 300-2000 Hz. For 75 seconds & +4 db increase for 10 seconds. |
| | 4. Acceleration | Filled tank & pressurized. +X = 6 g's 5 minutes. -X = 2 g's 1 minute. $\pm$Y & $\pm$Z = 1.5 g's 1 minute. |

TABLE II (contd)

SYNOPSIS OF NEW DESIGN QUALIFICATION TESTING

| QUALIFICATION ITEM | QUALIFICATION TESTS | R E M A R K S |
|---|---|---|
| | 5. Mission Simulations | |
| | a. H-Mission | 107 hours prelaunch 216.2 hours mission, 3 oxygen tanks. Qual tank off loaded to 60%. |
| | b. J-Mission | 240 hours mission time 3 oxygen tanks. |
| Pressure Vessel Plug Assembly | 1. Pressure Cycling | 300 cycles each (fill to maximum relief pressure 1010 psig) at ambient and at $LN_2$ temperature. Proof pressure (1357 psia) and leak test each 300 cycles. |
| | 2. Burst Pressure | Pressurized to 1537 psia for one minute then increase to rupture (3375 psig). |
| Heater Temperature Signal Conditioner | 1. Salt Fog | MIL-STD-810, Method 509, Procedure 1 - 48 hours. |
| | 2. Explosive Atmosphere | Hydrogen-oxygen explosive mixture. Included complete external electrical harness and signal conditioners. |

TABLE III

PERFORMANCE RATINGS

| I T E M | BLOCK II DESIGN | NEW DESIGN |
|---|---|---|
| Tank Weight (pounds) | 80.85 | 79.7 |
| Heater Watt Density (watts/sq.in.) | 2.8 | 2.1 |
| Maximum Heater Temperature (12.5% density & after 1 hr.) (Degree F) | 580.0 | 490.0 |
| Maximum Flow (lb/hr) | 0.790 | 0.825 (measured LO-19) |
| Electrical Conduit Heat Leak (BTU/hr) | 1.93 | 2.29 |
| Fluid Temperature Sensor Heat Leak (BTU/hr) | 0.0 | 1.53 |
| Total Tank Heat Leak (BTU/hr) | 28.05 | 29.26 |