NASA CR-
160663

DESIGN AND DEVELOPMENT OF
A HARD TUBE FLEXIBLE RADIATOR SYSTEM

- FINAL REPORT -

2-30320/OR-52416

25 April 1980

CONTRACT NO. NAS9-14776
DRL: T-1213, LINE ITEM 3
DRD: MA-1837TA

Submitted to:

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
JOHNSON SPACE CENTER
HOUSTON, TEXAS

by

VOUGHT CORPORATION
DALLAS, TEXAS 75265

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1.0 SUMMARY

This report details the construction and operational characteristics of an extended life flexible radiator panel designed and fabricated by the Vought Corporation under contract NAS9-14776 to NASA-Johnson Space Center. The radiator panel consists of a flexible fin laminate and stainless steel flow tubes designed for a 90 percent probability of surviving 5 years in an earth orbit micrometeoroid environment. The radiator panel (Figure 1-1) rejects 1.1 kW_t of heat into an environmental sink temperature of 0°F. Total area is 170 square feet and the panel extends 25 feet in the fully deployed position. When retracted the panel rolls onto a 11.5 inch diameter by 52 inch long storage drum, for a final stored diameter of 22 inches.

2.0 INTRODUCTION

Vought has conducted studies on promising flexible radiator concepts dating back to 1973. Flexible radiators can be modularized and thus may be developed and qualified independently of a mission. Inherent in the flexible radiator concept is a compact storage volume which dictates some method of deploying the radiator panel into the radiating configuration. When the deployment system also includes a controlled retraction capability, the panel area can be varied to produce a wide heat rejection range.

Vought first constructed and tested engineering models of flexible radiators in 1975. More recent activity has been in the area of designing and constructing full-size prototype flexible radiator systems (Figure 2-1a,b). The latest, an extended-life flexible radiator panel including a deployable/retractable capability, is the subject of this report. Drawing 221-60022 defines the detailed design and Appendix B gives panel weight for flight unit.

3.0 DESIGN CRITERIA

This section describes the guidelines and criteria used to design the extended-life flexible radiator system. The flexible radiator system is part of a heat rejection module concept which consists of three identical deployable/retractable radiator panels and associated fluid system components. Module heat rejection was selected as 4 kW_t based on anticipated spacecraft or Shuttle Orbiter payload requirements. Each radiator panel is required to reject 1-1/3 kW_t. Micrometeoroid protection requirements were calculated based on the exposed transport fluid area of the three radiator panels. Table

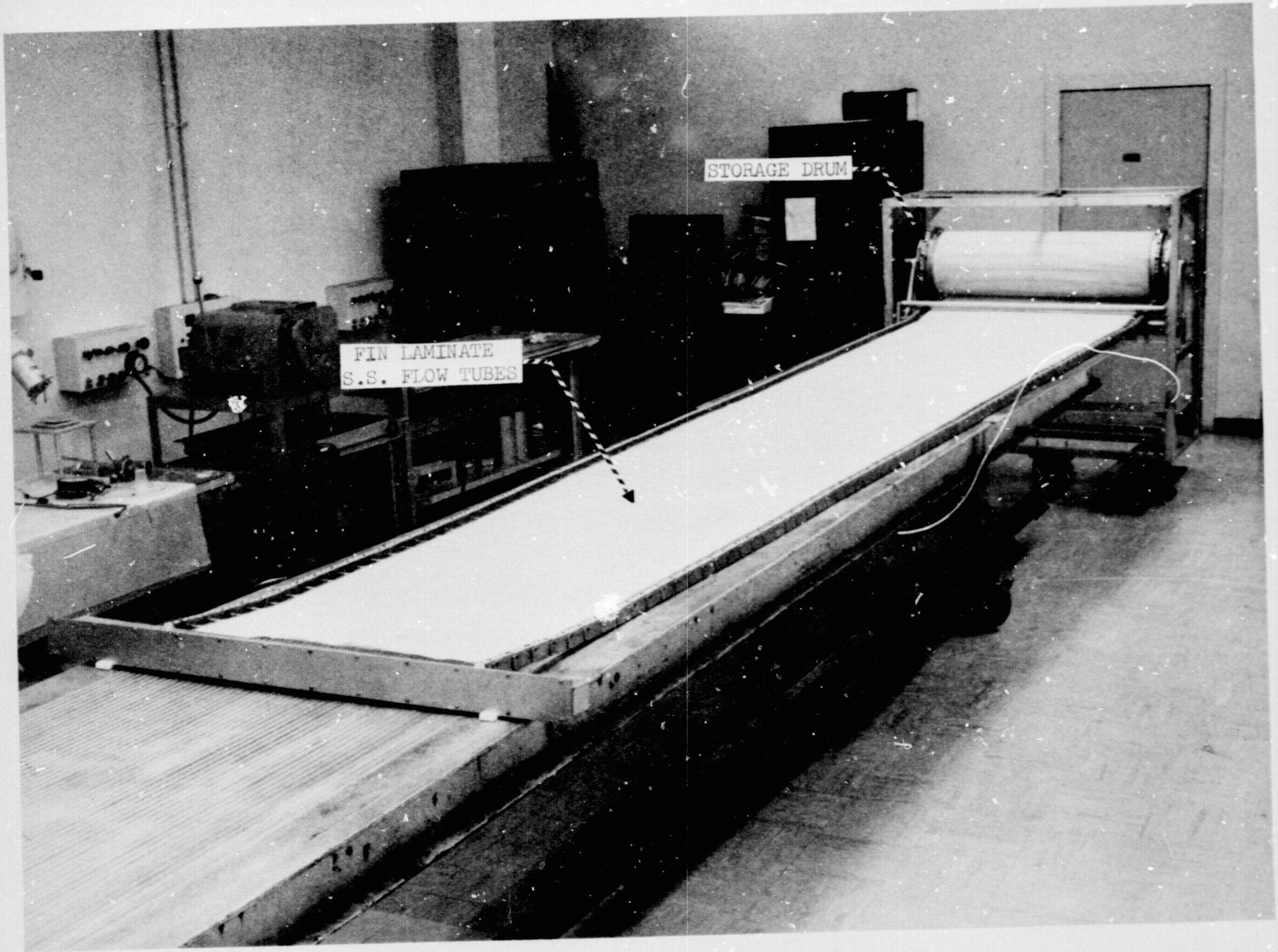


FIGURE 1-1 EXTENDED-LIFE FLEXIBLE RADIATOR - is armored for a 90 percent probability of surviving 5 years in micrometeoroid environment

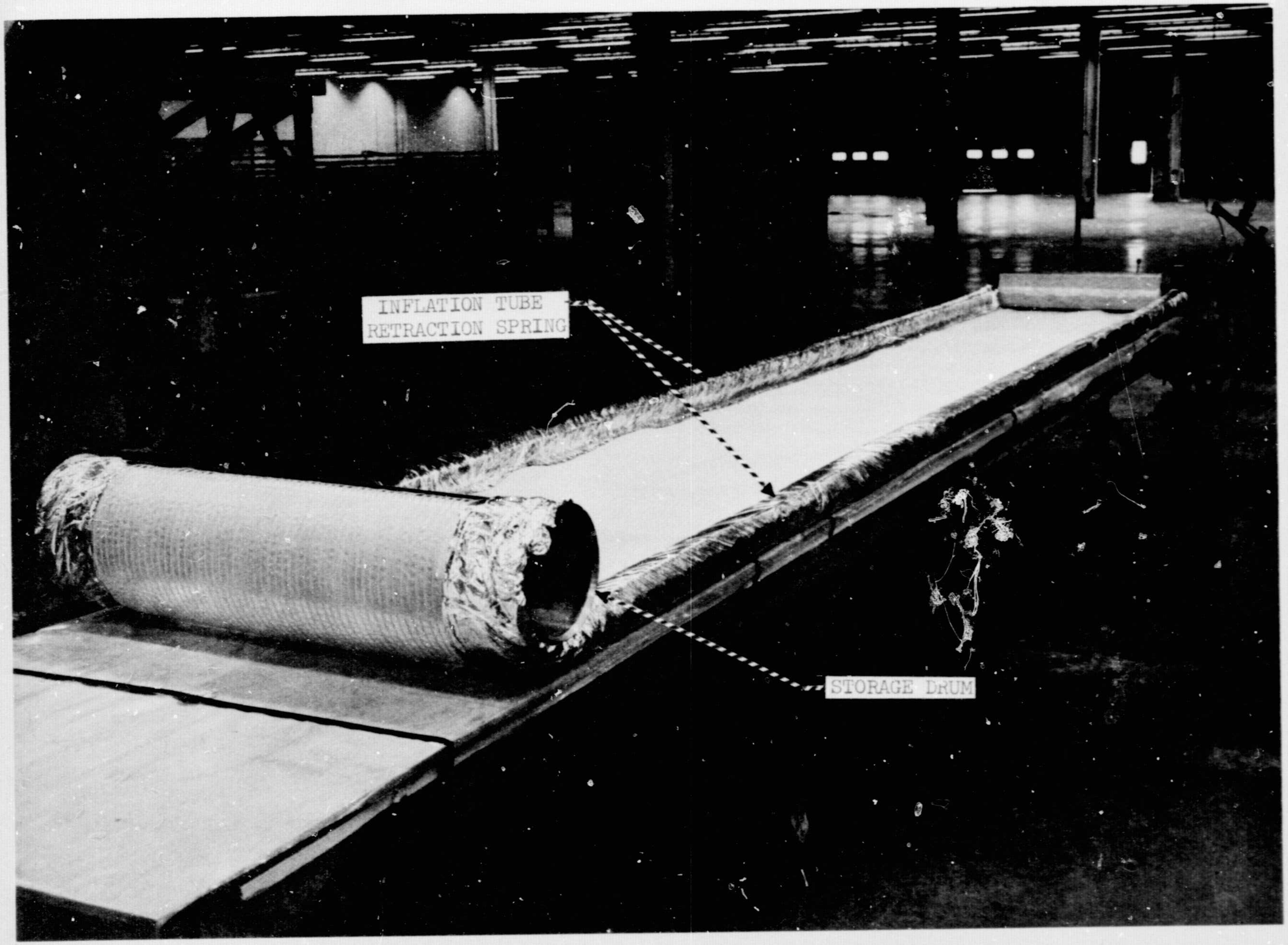


FIGURE 2-1a PROTOTYPE SOFT TUBE FLEXIBLE RADIATOR PANEL is designed for 30-day missions

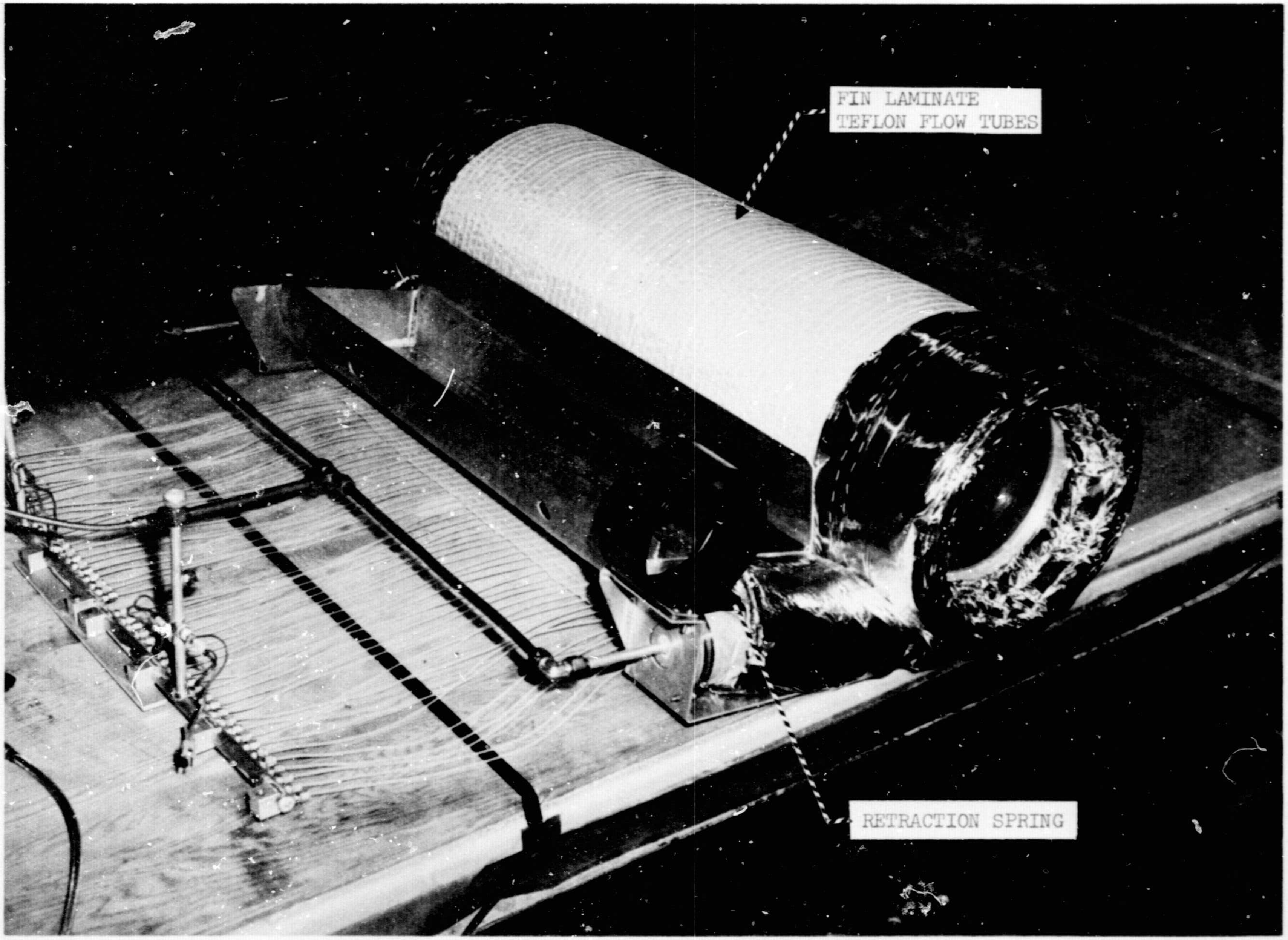


FIGURE 2-1b PROTOTYPE SOFT TUBE FLEXIBLE RADIATOR shows compact stowed configuration

3-1 summarizes the extended-life flexible radiator design guidelines.

4.0 RADIATOR PANEL

The panel is 300 inches long and tapers uniformly from 51.7 inches at the base to 35.7 inches at the panel tip. These dimensions are from the centerlines of the inlet and outlet manifolds which run the length of the panel along the panel taper. One hundred-one cross flow tubes span the panel and are brazed to the manifolds at fluid tees called "knuckles". Silver wire mesh (sealed in Teflon) sandwiches the flow tubes to create a flexible, radiating fin. Flexible manifolds are formed by lengths of convoluted tubing which interconnect the knuckles (Figure 4-1). The manifold convoluted tubing and knuckles are not readily visible on the assembled panel, being enclosed in the link boxes which are part of the panel erection system.

4.1 Flow Tubes

The radiator panel has 101 flow tubes spaced 3 inches apart which flow in parallel. Each flow tube is cut to a different length to coincide with the panel taper at its location. The type 316 stainless steel tubing is 1/8 inch outside diameter with a 0.049 inch wall. This size tubing was selected 1) to ensure panel pressure drop is controlled by the cross flow tubes and not the manifolds, and 2) to provide micrometeoroid protection for the fluid loop as it crosses between the manifolds. Combined pressure drop in the manifold convoluted tubing and the flow tubes cause the long flow tubes to receive the greater flow. The long flow tubes have larger associated radiating areas and panel performance is improved by the naturally skewed flowrates toward the long flow tubes. Panel pressure drop is estimated to be 8.8 psi at 301 pph Freon 21.

4.2 Fin Laminate

Silver wire mesh (120 x 120 x .0034 in. dia.) is sandwiched over the flow tubes to conduct heat away from the tubes and radiate that heat to a temperature sink. The mesh is encapsulated in layers of FEP Teflon film which serves two purposes: 1) provides the mechanical attachment for the wire mesh/flow tube interface, and 2) seals the silver to prevent tarnishing and the associated degradation of the solar wavelength reflectance. The fin material layup is shown in Figure 4-2. The Teflon/silver mesh layup is fusion bonded in a vacuum bag.

TABLE 3-1

DESIGN GUIDELINES

PROTOTYPE ARTICLE	-	REPRESENTATIVE OF FLIGHT ARTICLE IN ALL CRITICAL AREAS
THERMAL ENVIRONMENT	-	HOT: 0°F EQUIVALENT SINK TEMPERATURE COLD: -300°F EQUIVALENT SINK TEMPERATURE
FLUID	-	FREON 21
FLUID INLET	-	100°F
OUTLET	-	40°F
MAXIMUM OPERATING TEMPERATURE	-	250°F
HEAT REJECTION	-	APPROXIMATELY 1-1/3 KW, HOT CASE, PER PANEL
LIFETIME	-	5 YEARS AT 90% PROBABILITY OF METEOROID SURVIVABILITY (SP8013) (3 PANELS)
STOWAGE ENVIRONMENT	-	CONCEPT FOR SHUTTLE CARGO BAY THERMAL AND VIBROACOUSTIC ENVIRONMENTS, WITHOUT ACTUAL DESIGN/DEMONSTRATION
WEIGHT	-	MINIMUM CONSISTENT WITH PROTOTYPE NATURE OF ARTICLE
FLUID GIMBALS	-	AVOID ROTATING SEALS AS FEASIBLE
FLOW DISTRIBUTION	-	EQUAL INDIVIDUAL TUBE OUTLET TEMPERATURE
MULTIPLE DEPLOYMENT AND RETRACTION CAPABILITY		

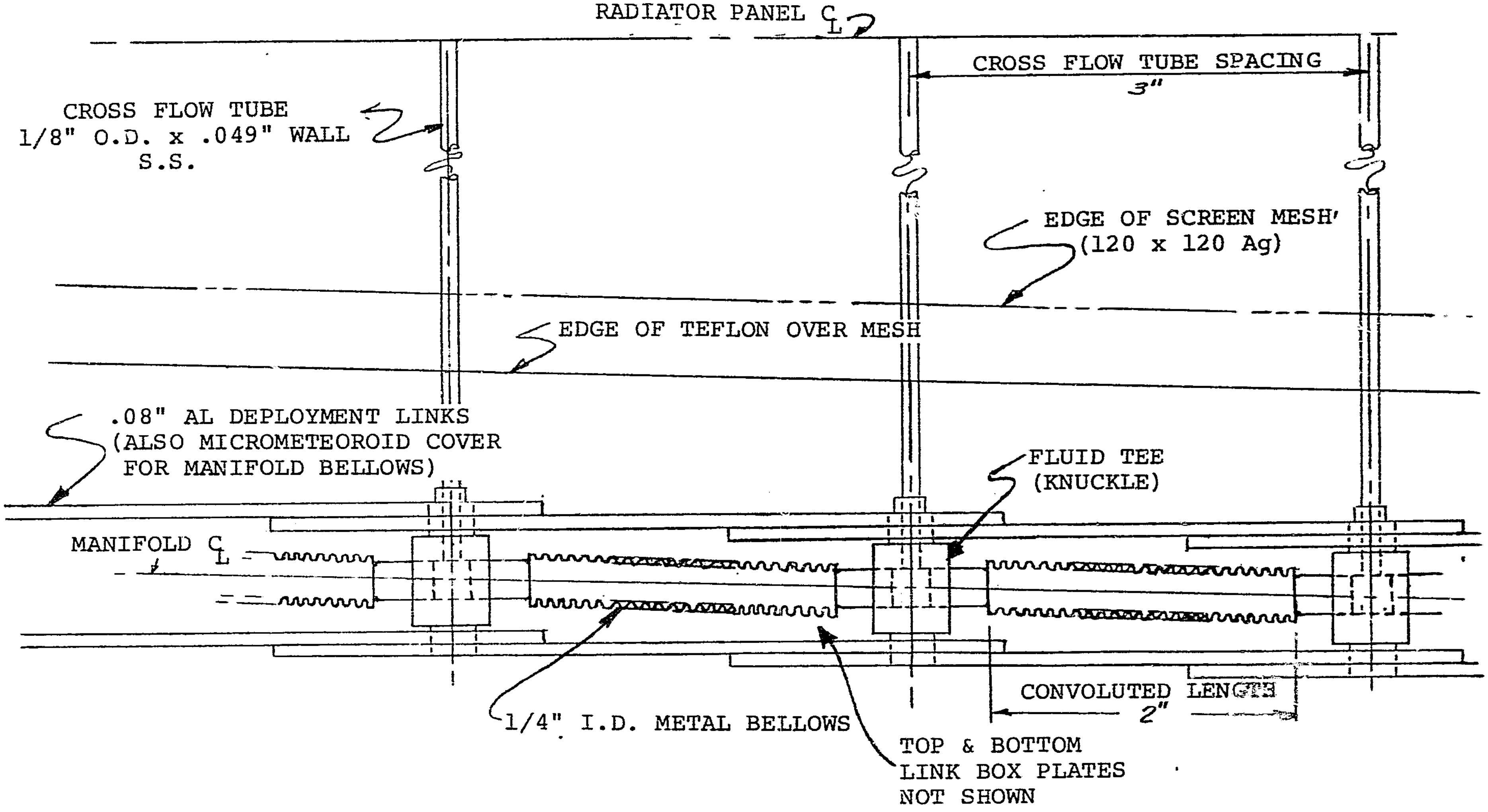


FIGURE 4-1

RADIATOR PANEL DETAILS - EXTENDED-LIFE FLEXIBLE RADIATOR

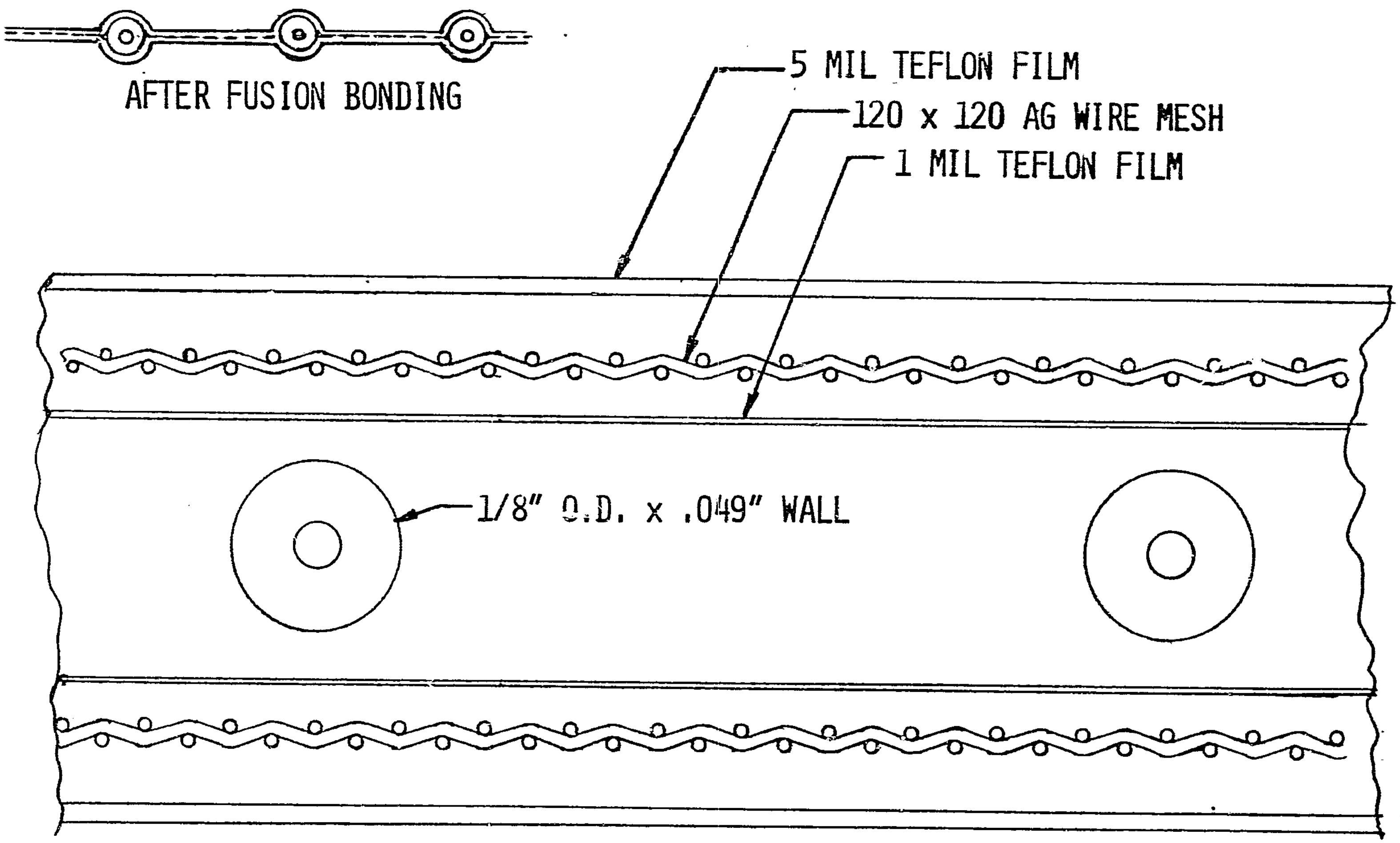


FIGURE 4-2 FLEXIBLE FIN LAYUP EXTENDED-LIFE FLEXIBLE RADIATOR

Stability of the Teflon/silver mesh laminate under exposure to ultraviolet radiation was demonstrated in a test conducted at NASA in November 1978. No visible sign of Teflon degradation was discovered after 100 hours of testing. Solar reflectance measurements on the fin laminate cannot be obtained directly with the Gier-Dunkle Model DB100 portable reflectometer because the fin laminate is partially transparent to the source beam. The measurement technique developed involves taking two reflectance measurements while the transparent laminate is backed by a different reflective surface of known reflectance for each measurement. The data is then used to calculate an apparent reflectance and transmittance from which a solar absorptance value is obtained. Solar absorptance values calculated by the above method equal 0.20 ± .02.

Other estimated properties of fin material: reflectance, $\rho = 0.58$
transmittance, $\tau = 0.22$
emittance, $\epsilon = 0.70$

The fusion bonding of the panel fin laminate was attempted in a single vacuum bagging operation. This developmental approach proved to be difficult to execute with the level of tooling available. The major complicating factor was handling and manipulating the panel size sheets of Teflon and Kapton. The layers of film and mesh were 49 inches wide at one end, 37 inches at the other and 25 feet long. Although the radiator panel is only 25 feet long, the film and mesh must follow the half-circumferences of 101 eighth-inch flow tubes. In addition to the 4 layers of Teflon film and 2 layers of wire mesh, Kapton vacuum bagging film also had to follow the contour of the 101 flow tubes. The wire mesh could be formed to the tubes easily and would maintain the shape of the tube; however, the large sheets of Teflon film were extremely difficult to manage. Positioning the Teflon film had to be done from outside the Kapton since the Teflon could not be held to the flow tube contour long enough to permit an additional step of laying out the large sheet of Kapton. The bagged radiator panel was heated to 570°F in a 30 foot long oven with six individually controlled heating zones. Thermocouples were placed next to the vacuum bag to insure the fusion temperature was obtained.

The Kapton bagging material formed a weak bond with the Teflon laminate in numerous areas during the fusion bonding process. This undesired bonding was not encountered with any previous bonding operation; all of which were performed in ovens much smaller than the oven required to bond the full size panel. Uneven (locally excessive) heating in the 30 foot long oven probably caused the Kapton/Teflon bond. Static charges on the film attracted airborne particles but the extent of this contribution to the Kapton/Teflon bond is not known. The larger particles charred and imbedded in the Teflon during bonding. Where the Teflon film was stretched across the tubes instead of following the tube circumference, the film tore leaving the silver mesh exposed. Also the vacuum bag did not provide the necessary pressure to extrude the Teflon film into wire mesh in many places. This could have been due to trapped air pockets which could not migrate (up to 12.5 feet) to the vacuum pumps located at the ends of the panel. The fin laminate as removed from the vacuum bag was ragged with areas of unbonded Teflon film and exposed silver mesh. A technique was devised to seal the areas of exposed mesh by fusing Teflon film over the areas with hand-manipulated heating irons.

4.3 Fluid Manifolds

The radiator panel fluid manifolds are created by 100 sections of convoluted tubing brazed between the fluid tees (knuckles) along each manifold. Each convoluted tube has a 0.4 inch straight cuff on each end which are brazed into the knuckles. The convoluted tubes (bellows) are manufactured for Vought by Metal Bellows Company and have the following characteristics:

Material	-	321 Stainless Steel
Size	-	0.25" I.D. x 0.35" O.D.
Wall Thickness	-	.005 in.
Operating Pressure	-	1200 psi
Cycle Life	-	7000 cycles
Axial Stroke	-	0.068 inches

The "axial stroke" value determines the minimum diameter storage drum the radiator panel can be rolled up on, consistent with an expected cycle life of the manifold bellows. Storage of the radiator panel on the drum deflects the manifold bellows approximately 27 degrees which is equivalent to a 0.060 inch axial deflection according to data (plotted in Figure 4-3) supplied by the Metal Bellows Company. From this figure, 9500 deployment/retraction cycles would be expected for the manifold bellows. The drum diameter was selected to balance bellows expected cycle life with packaging volume of the retracted and stowed radiator panel.

4.4 Link Boxes

The link boxes perform a dual function of stiffening the radiator panel as it is deployed and of providing micrometeoroid protection for the

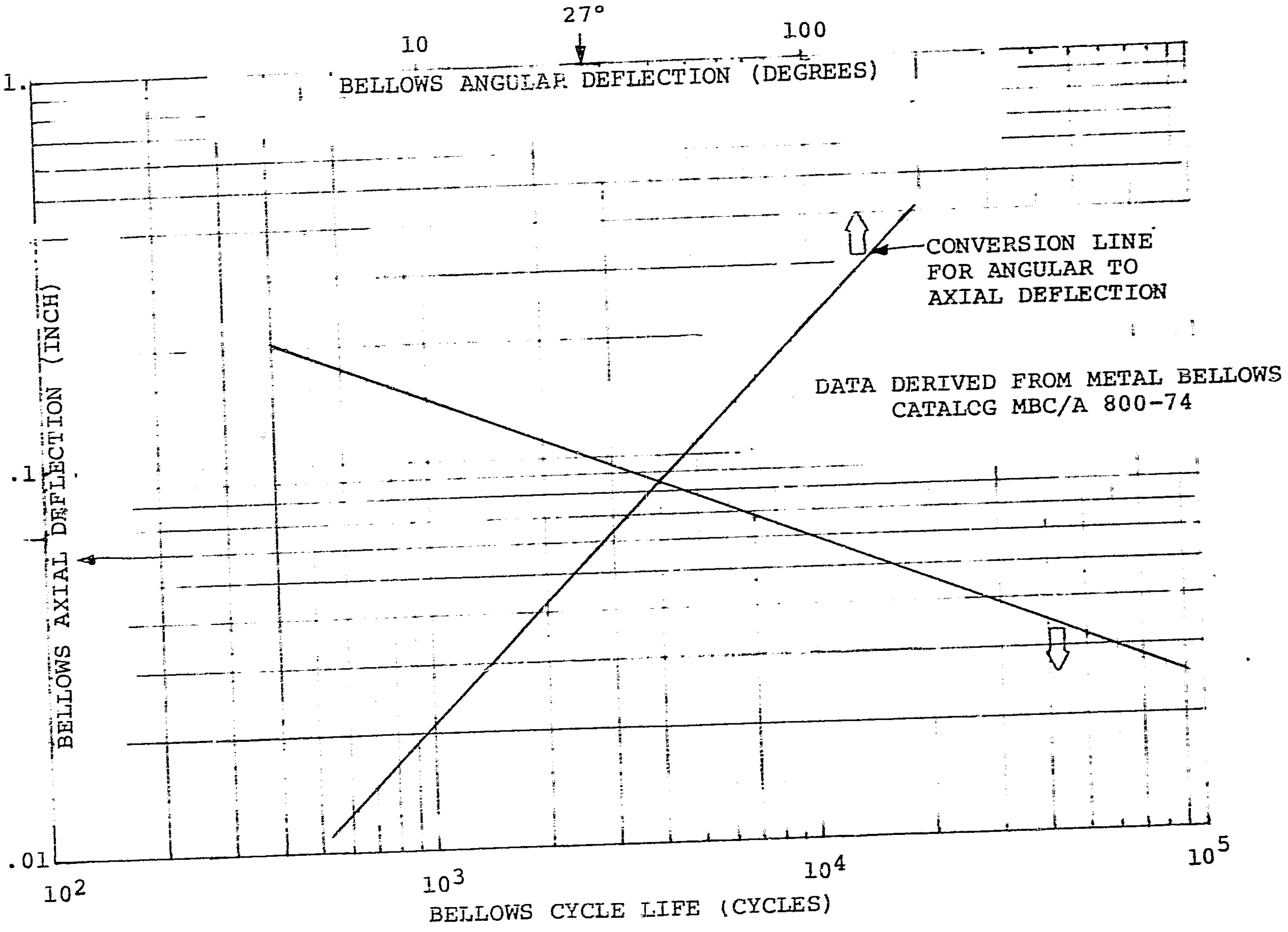


FIGURE 4-3 FLEXURE/CYCLE LIFE DATA FOR CONVOLUTED TUBING

manifold bellows. Micrometeoroid protection of the radiator is discussed in Section 6. The link boxes are of welded construction from aluminum parts shown in Figure 4-4. Top and bottom parts of the boxes are the same for both panel manifolds. The side plates of the link boxes are not identical between manifolds, as the machined slots create left-and right-hand opposite parts. Each side plate has an angle cut beyond the knuckles which bottoms out in the adjacent link boxes and protect the manifold bellows from excessive angular deflection.

Stiffening the link boxes to form an erect panel is accomplished by a 40 lb_f pull on an erection cable. This cable is threaded through drill rivets inserted in each link box top plate and attached to the last link box at the base of the panel. The rivets do not carry or transmit any loads but are used to position the sixteenth inch diameter erection cable along the top of the link boxes. The cable force causes the link boxes to rotate up and butt the end of the adjacent top plates forming a rigid column of link boxes. After the panel has been deployed and made rigid by the erection cable, an appropriate force applied perpendicular to a knuckle will cause the link boxes to open at that knuckle location while the other links remain rigid. This characteristic is used to rigidize the deployed portion of the radiator panel while the remainder of the panel stays on the storage drum.

5.0 RADIATOR DEPLOYMENT/RETRACTION/STORAGE

This section discusses the method of flexible radiator panel deployment, retraction and storage. Panel deployment is by electric motor/gearbox while the retraction force is applied by constant force springs. The panel is stowed on a drum as it is retracted.

5.1 Panel Deployment

The radiator panel is deployed from the storage drum by pulling two 1/8 inch diameter Nylon ropes which are interleaved with the wraps of panel (Figure 5-1). One end of the Nylon rope is attached to the storage drum at the innermost wrap of the panel and the other end is attached to a driven roller. The panel is deployed between the driven roller and a spacer roller (Figure 5-2). The driven roller is powered by an electric motor/gearbox through a chain and sprocket set. As the driven roller rotates at its predetermined speed, the Nylon rope pulls tangentially on the storage drum at the

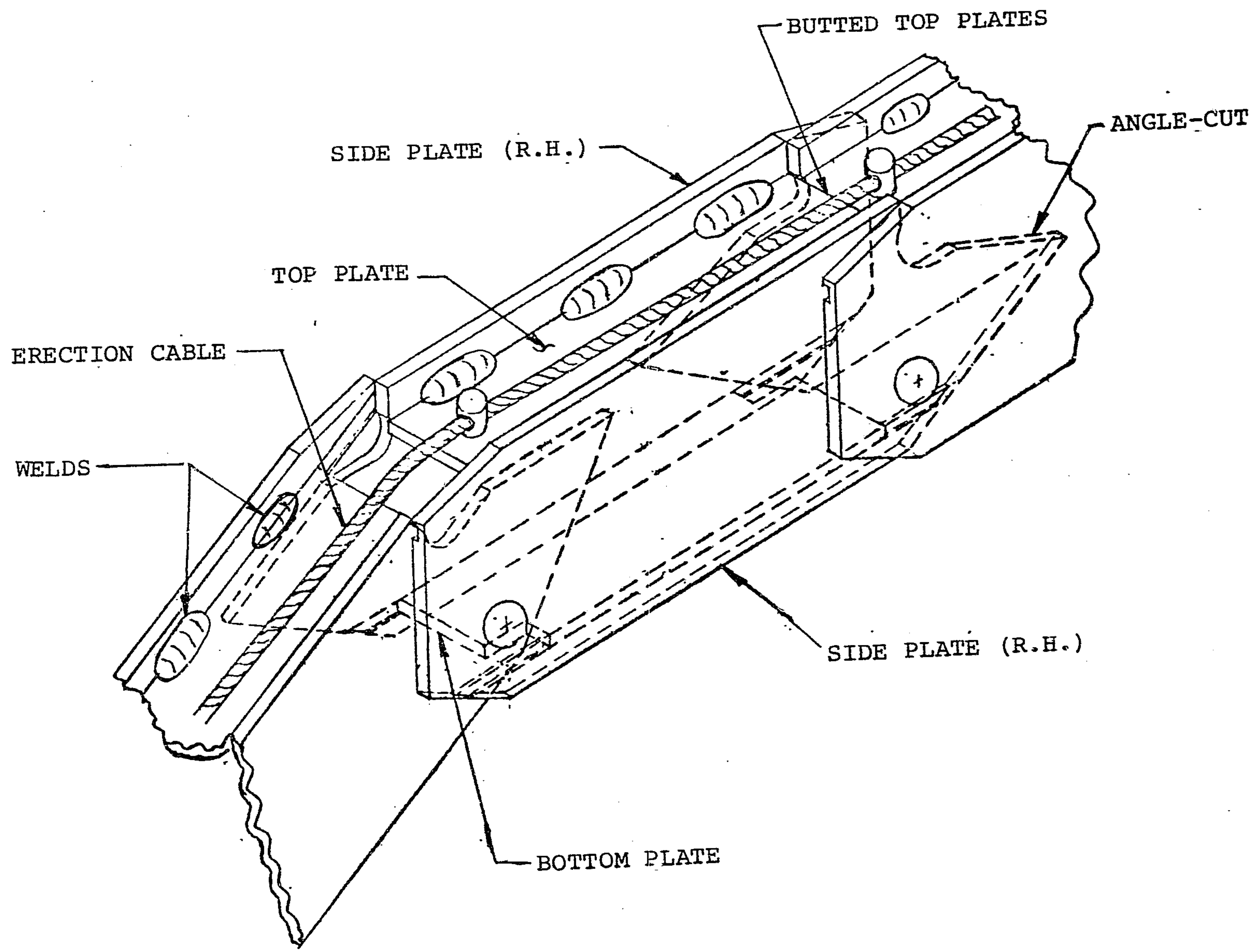


FIGURE 4-4 FLEXIBLE RADIATOR ERECTION LINKAGE

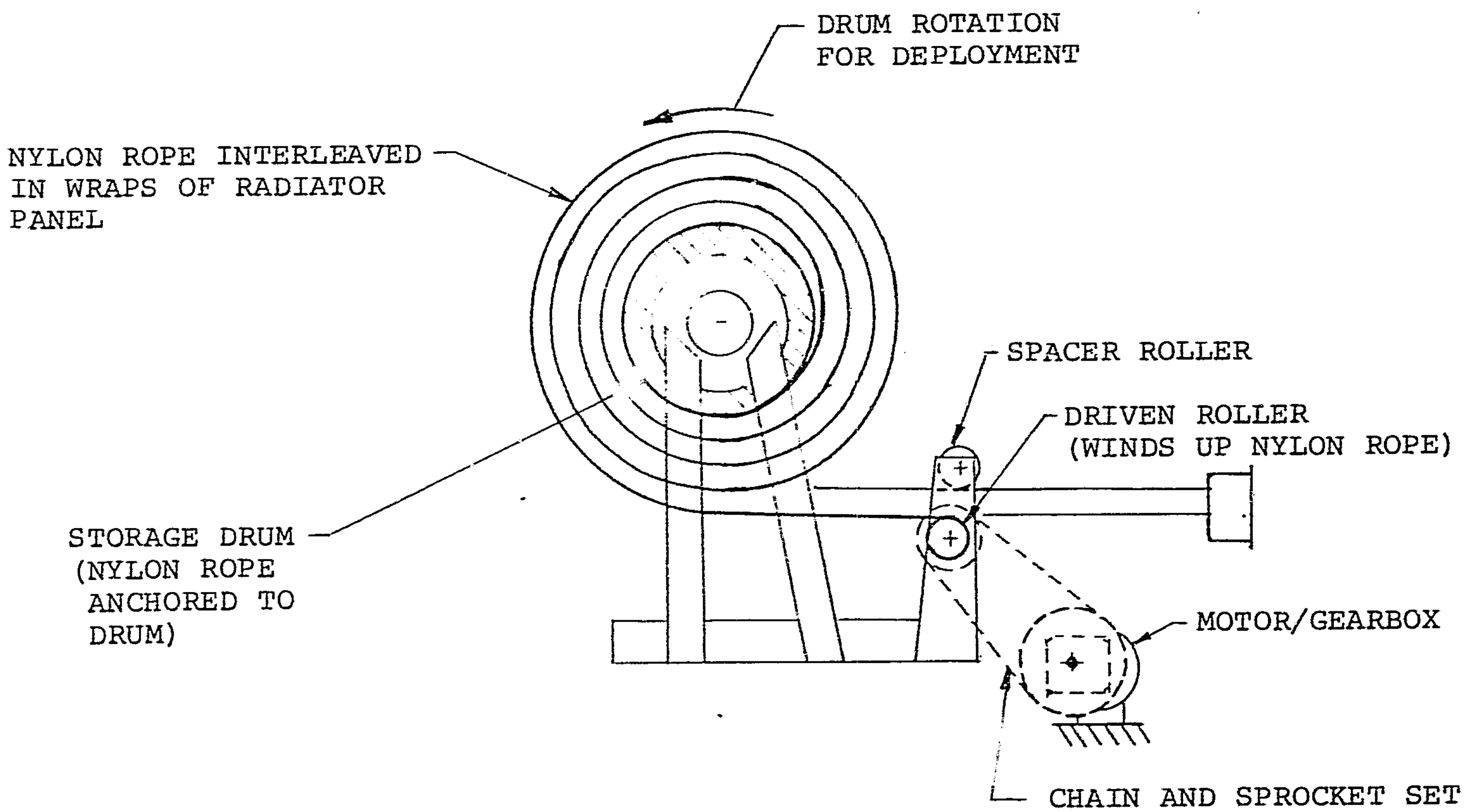


FIGURE 5-1 FLEXIBLE RADIATOR DEPLOYMENT is accomplished by rotating the storage drum with a Nylon rope

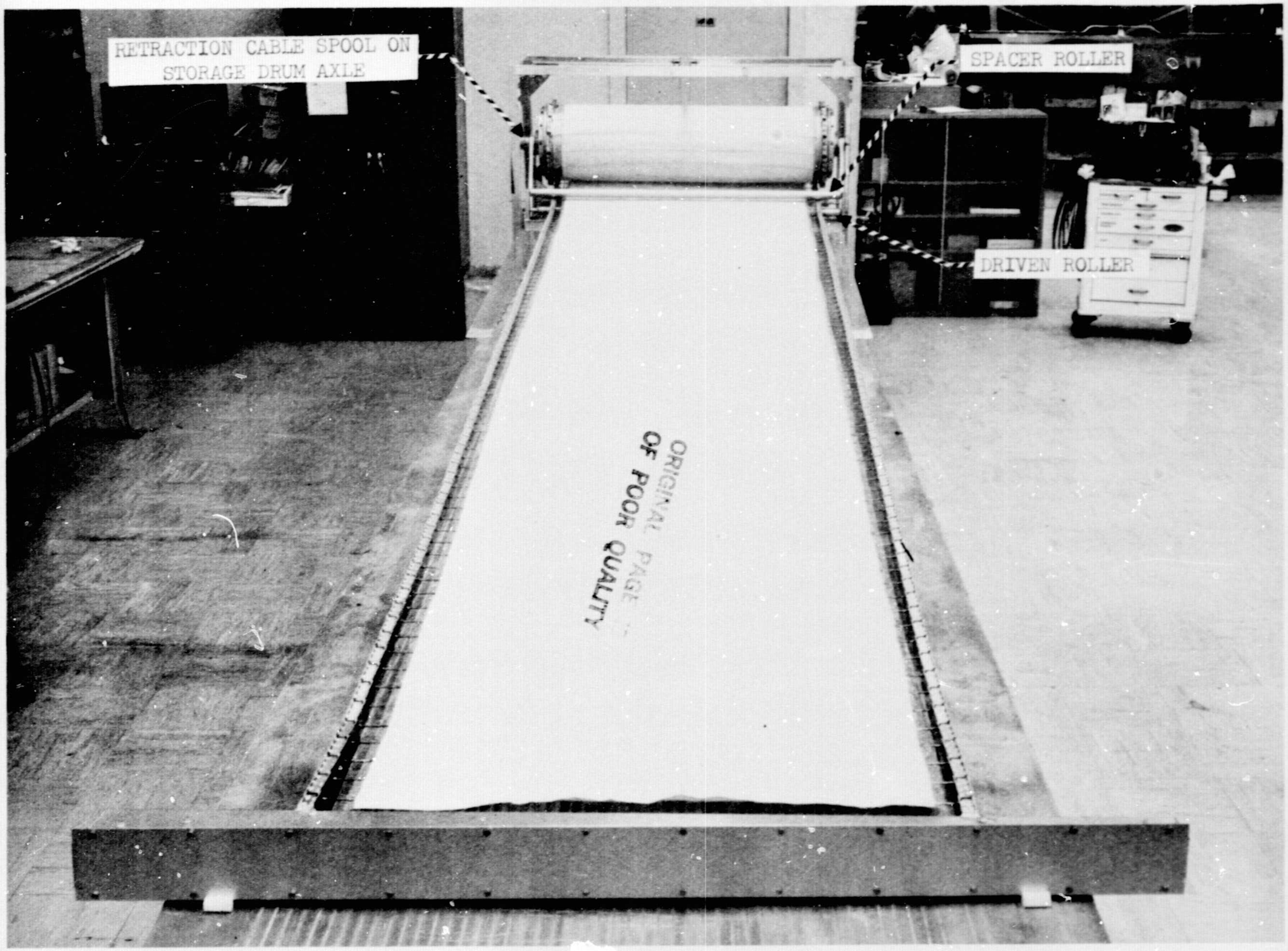


FIGURE 5-2. FLEXIBLE RADIATOR DEPLOYMENT ROLLERS

point where the panel leaves the drum. The rope winds up on the driven roller. Full deployment of the panel is accomplished in 5.8 revolutions of the storage drum. Deployment speed is approximately 165 inches of panel length per minute which allows full panel deployment to be completed in less than 2 minutes.

5.2 Panel Retraction

As the radiator panel is deployed, retraction springs (Figure 5-3) are extended by a 1/16 inch stainless steel cable which winds up on a cable spool attached to the storage drum axle. Panel retraction torque is a constant torque applied by a set of springs through the cable to the storage drum axle. This torque remains constant throughout panel deployment and retraction. Since the storage drum always has a restoring torque applied, panel retraction is initiated by reversing the rotation of the driven roller discussed in Section 5.1. Panel retraction speed is determined by the rate the Nylon rope releases the storage drum which is set by the motor, gearbox, and sprocket set. When the panel is fully retracted, the retraction springs have minimum extension and the Nylon rope is interleaved with the radiator panel and ready to deploy the panel.

The panel retraction torque eventually was increased to 320 in-lbs_f, double the initial design by a second set of retraction springs. The deployment/retraction operation involved considerable friction and while not a hindrance for deployment by the electric motor; panel retraction could be overcome and halted by the frictional loads. In addition to increasing the panel retraction torque, Molykote lubricants were used at the knuckle/link box pivot points. The original design employed only bushings but high frictional loads near the retraction cable spool necessitated bearings which proved very successful. Some of the frictional loads encountered in one-g testing of the panel retraction will not occur in zero-g application. One very significant frictional force working against one-g panel retraction is the friction between the panel and the test structure which supports the deployed panel.

5.3 Panel Storage

The panel storage drum is approximately 11.5 inches in diameter. The actual cross-section of the drum spirals slightly to allow the panel to wrap over the inner layer with a smooth transition. To minimize package volume of the panel rolled-up on the storage drum, the radiator panel tapers from the base

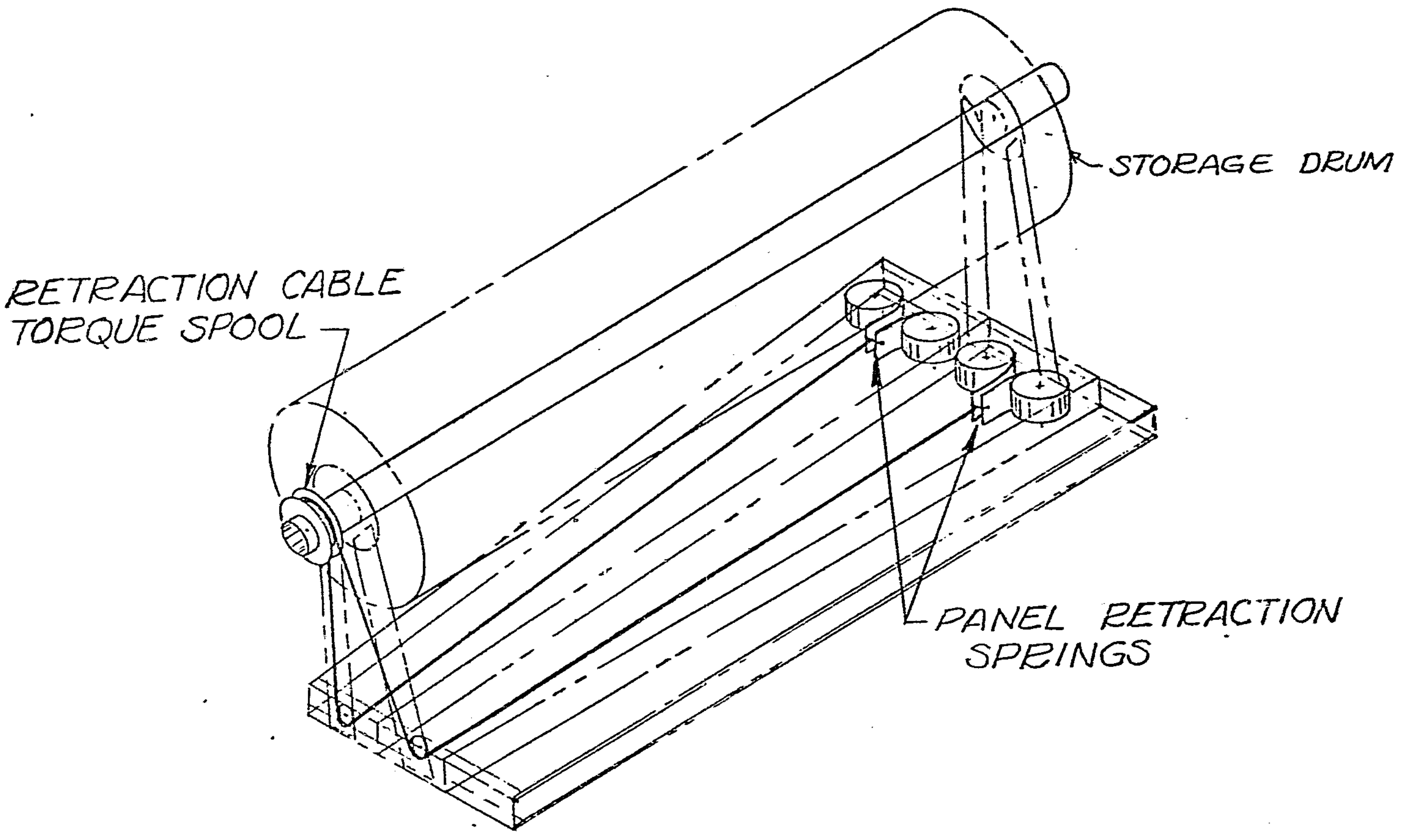


FIGURE 5-3 RETRACTION SPRINGS apply a panel retracting torque to the storage drum

to tip to allow the subsequent panel wraps to lay inside the wrap of link boxes already on the storage drum. Each wrap of the panel adds approximately one inch to the storage drum radius although the link boxes are 1.58 inches high. The radiator panel wraps are securely held to the storage drum by the Nylon deployment rope in combination with the retraction torque applied to the drum.

5.4 Coiled Flex Hose

Although the storage drum rotates to deploy the radiator panel, the transport fluid is delivered to and removed from the panel without the use of rotating seals.* The panel was fabricated with two flex hose devices (life of 250 cycles each) as the primary method to deliver the fluid. Provisions in the drum plumbing will permit a fluid swivel to be substituted on one side, if desired. The flex hose device (Figure 5-4) has all hard connections but still permits the panel storage drum to rotate the required 5.8 revolutions. This approach uses a reverse-wound coiled flex hose which moves between a rotating and a stationary hose drum.

Both hose drums are concentrically located on the panel storage drum axle and recessed in the ends of the storage drum. The rotating hose drum is attached to storage drum axle and rotates with the movement of the storage drum. The stationary hose drum is the tie-in point for structure which supports the ends of the storage drum axle. Each end of the storage drum contains a set of hose drums and a coiled flex hose, one for the entering fluid and one for the exiting fluid. Hose movement is from the inner, rotating hose drum to the outer, stationary, hose drum as the radiator panel is deployed from the rotating storage drum.

The coiled flex hose is a welded, helical convoluted metal hose covered with a stainless steel braid. A hose shuttle separates the hose wraps at the point the wraps reverse direction. The hose shuttle is a guide device which controls the hose as it moves between the rotating and stationary hose drums. When the radiator panel is retracted, the inner hose drum has 5 wraps. As panel deployment begins the wraps loosen and are pushed via the hose shuttle onto the stationary hose drum. This action requires a hose containment sleeve which maintains the position of the hose wraps. The hose containment sleeve is a metal tube which slips over the coiled flex hose and hose shuttle on the

*See Appendix C

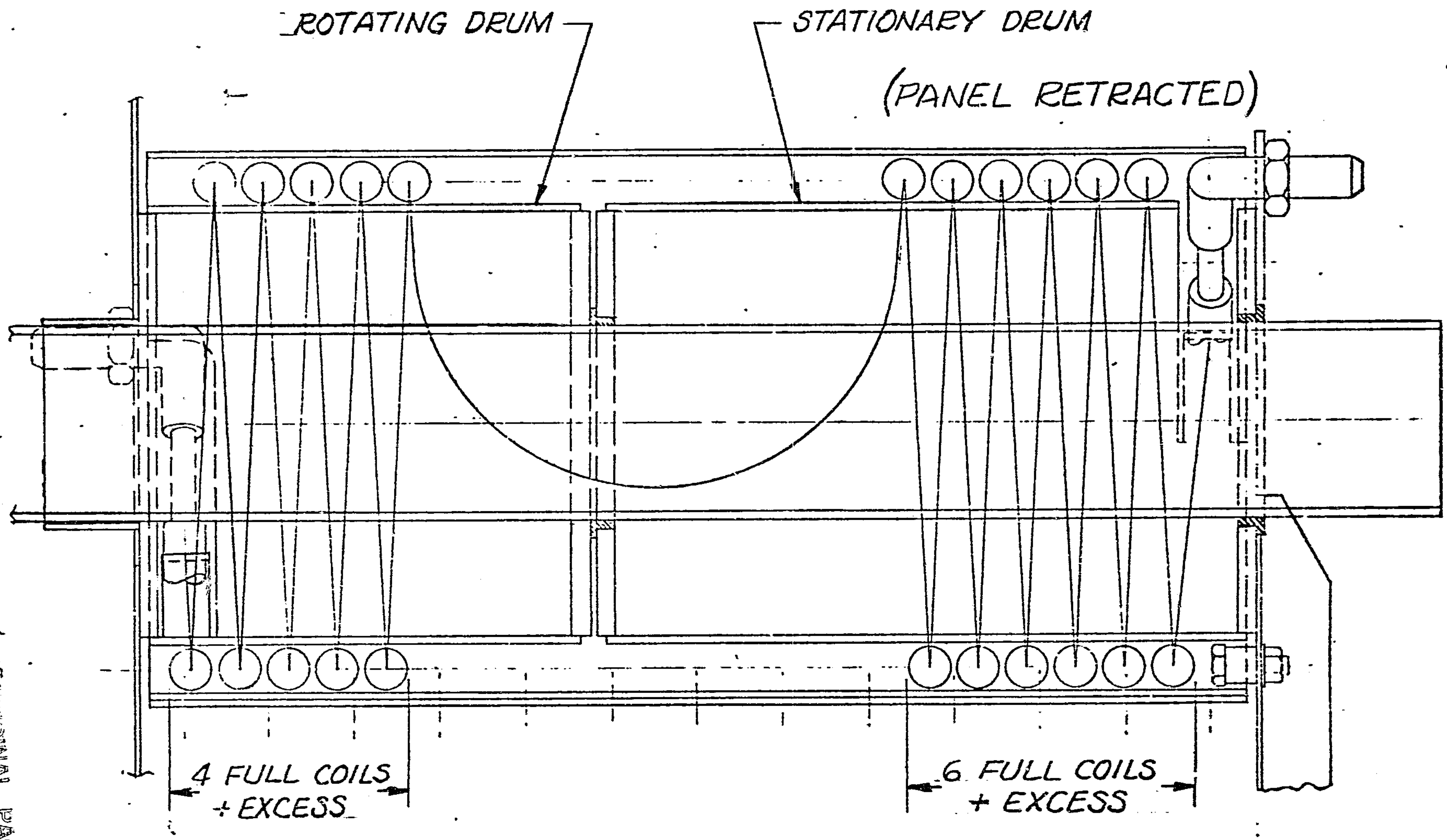


FIGURE 5-4 COILED FLEX HOSE transport the fluid across the rotating joint

hose drums. The sleeve floats over the coiled hose and will rotate when the radiator is being deployed.

6.0 MICROMETEOROID PROTECTION

When designing thermal control systems for long duration missions, micrometeoroid considerations have a significant impact on the design of the radiators and the coolant loop lines exposed to the space environment. The manifolds and parallel flow cross tubes must be designed to withstand micrometeoroid impacts.

The transport loop wall thickness must be sufficient to retain the transport fluid pressure after being struck by a micrometeoroid. The depth of the crater left by the most damaging meteoroid expected to strike the tubing during the designed operating life of the radiator is computed from a ballistic equation which is based on ground test data, and a meteoroid flux model derived from penetrations of metal foils in near earth orbits.

The mechanics of hypervelocity impacts are not completely understood, an equation given by Rittenhouse, Reference (1), correlates the existing data reasonably well. The equation is

$$t = 0.65 \left(\frac{1}{\varepsilon_t}\right)^{1/8} \left(\frac{\rho_m}{\rho_t}\right)^{1/2} (V_m)^{7/8} (d_m)^{19/18} \qquad (6\text{-}1)$$

where:

t	=	thickness of material penetrated (cm)
ε_t	=	percentage elongation of target material
ρ_t	=	mass density of sheet material (gm/cc)
ρ_m	=	mass density of meteoroid (gm/cc)
V_m	=	normal impact velocity (km/sec)
d_m	=	meteoroid diameter (cm)

Equation (6-1) generally predicts greater depths of penetration than other equations (Ex. References 2,3) derived for penetration of metals. Therefore the use of Equation (6-1) should provide a conservative thermal control system design when applied in conjunction with standard meteoroid environment models.

The radiator panel tubing wall thickness needed for survival of a given system design depends on the projected target area, the exposure time, and the required probability of success for the mission. The probability of no meteoroid penetrations is given by:

$$P_o = e^{-\zeta A \tau N} \qquad (6\text{-}2)$$

where:
ζ = shielding factor (% of area exposed)
A = projected area (m^2)
τ = time of exposure (sec)
N = meteoroid flux for particles capable of penetrating tubing (Particles/m^2-sec)

The tube wall thickness is computed from Equation (6-1) so that the number of particles determined from the meteoroid flux model having sufficient energy to penetrate the tubing gives the desired probability of success from Equation (6-2).

For a five year mission the tubing must be designed so that only relatively large meteoroids are capable of penetration. For large meteoroids the cumulative meteoroid flux model for sporadic and stream meteoroids from Reference (3) is

$$\log_{10} N = - 14.37 - 1.213 \log_{10} m \qquad (6\text{-}3)$$

Where N is the flux density for meteoroids having mass greater than or equal to "m". The meteoroid mass may be expressed in terms of quantities in Equation (6-1) as follows:

$$m = \frac{\pi}{6} \rho_m d_m^{\ 3} \qquad (6\text{-}4)$$

Equations (6-1) through (6-4) may be solved to give the tubing wall thicknesses required for a given design and required probability of success.

7.0 DEPLOYMENT TEST

The flexible radiator panel erection system is designed for a zero-g environment and can not support the panel weight in 1-g without deflecting and risking damage. To test this system in a 1-g environment requires a test fixture (Figure 7-1) which allows the radiator panel to unwind from the decreasing diameter storage drum onto a surface which supports the panel weight. Friction between the panel link boxes and the surface must be minimized lest the storage drum retraction torque be overpowered and panel retraction be impeded. As the panel is wound-up on the storage drum the drum must be raised to allow the panel to remain horizontal to the deployment table.

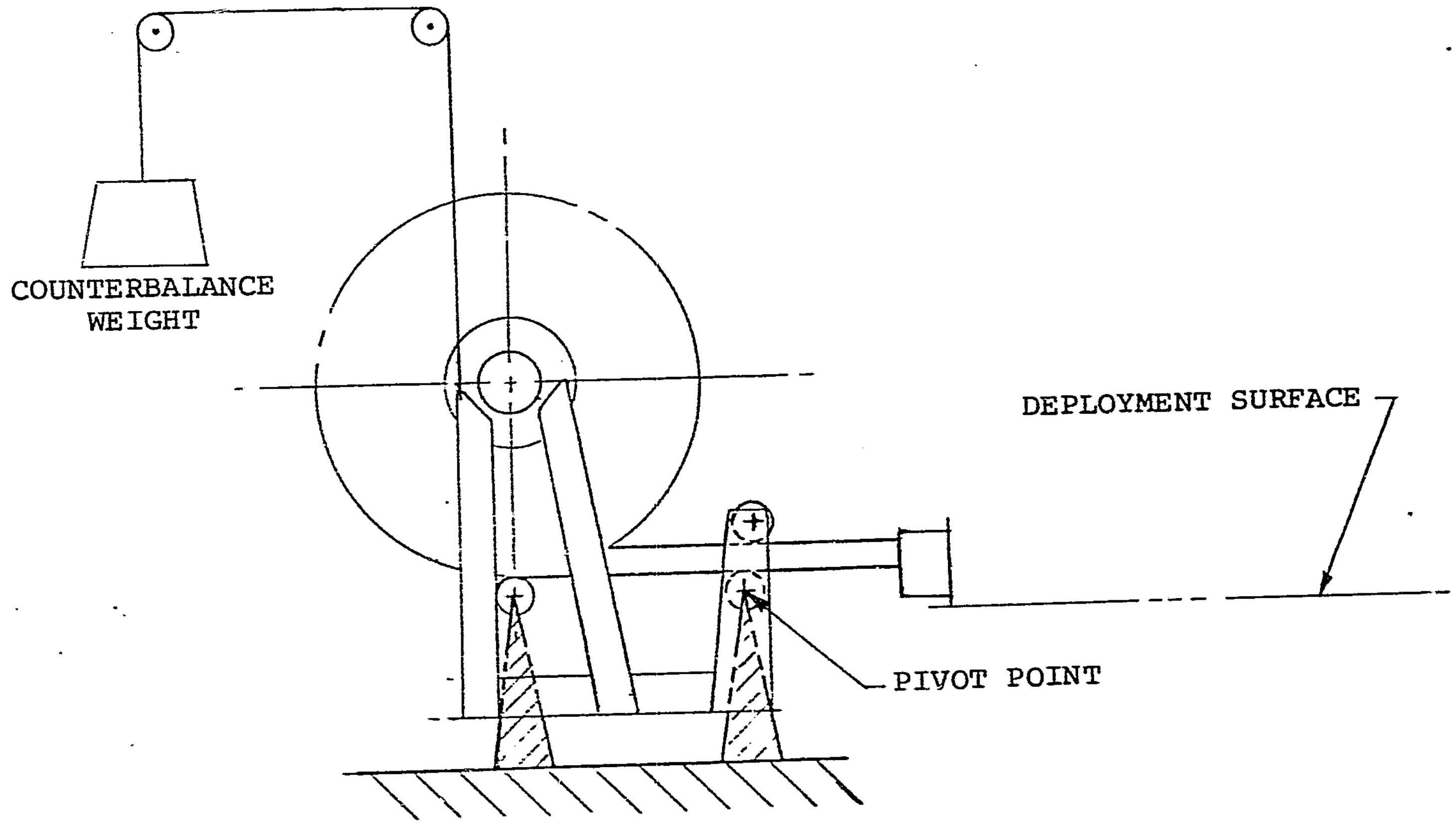


FIGURE 7-1 FLEXIBLE RADIATOR TEST CONFIGURATION

Deployment of the panel vertically, either up or down, would distort the retraction capability assessment and therefore was rejected. Another alternative 1-g deployment orientation is the radiator panel on its side. Edgewise panel deployment would require a series of supporting hangers which would carry the panel weight. This has not been seriously considered due to the requirement of an elaborate mechanism to make the transition on and off the storage drum. Ambient tests of the deployment/retraction capabilities in the horizontal position were witnessed by NASA personnel and recorded on motion picture film.

The radiator panel is instrumented with 50 thermocouples which are described in Appendix A. Thermal vacuum testing of the radiator panel is scheduled for the Fall of 1980. Test results from this test will be reported in future documentation.

8.0 REFERENCES

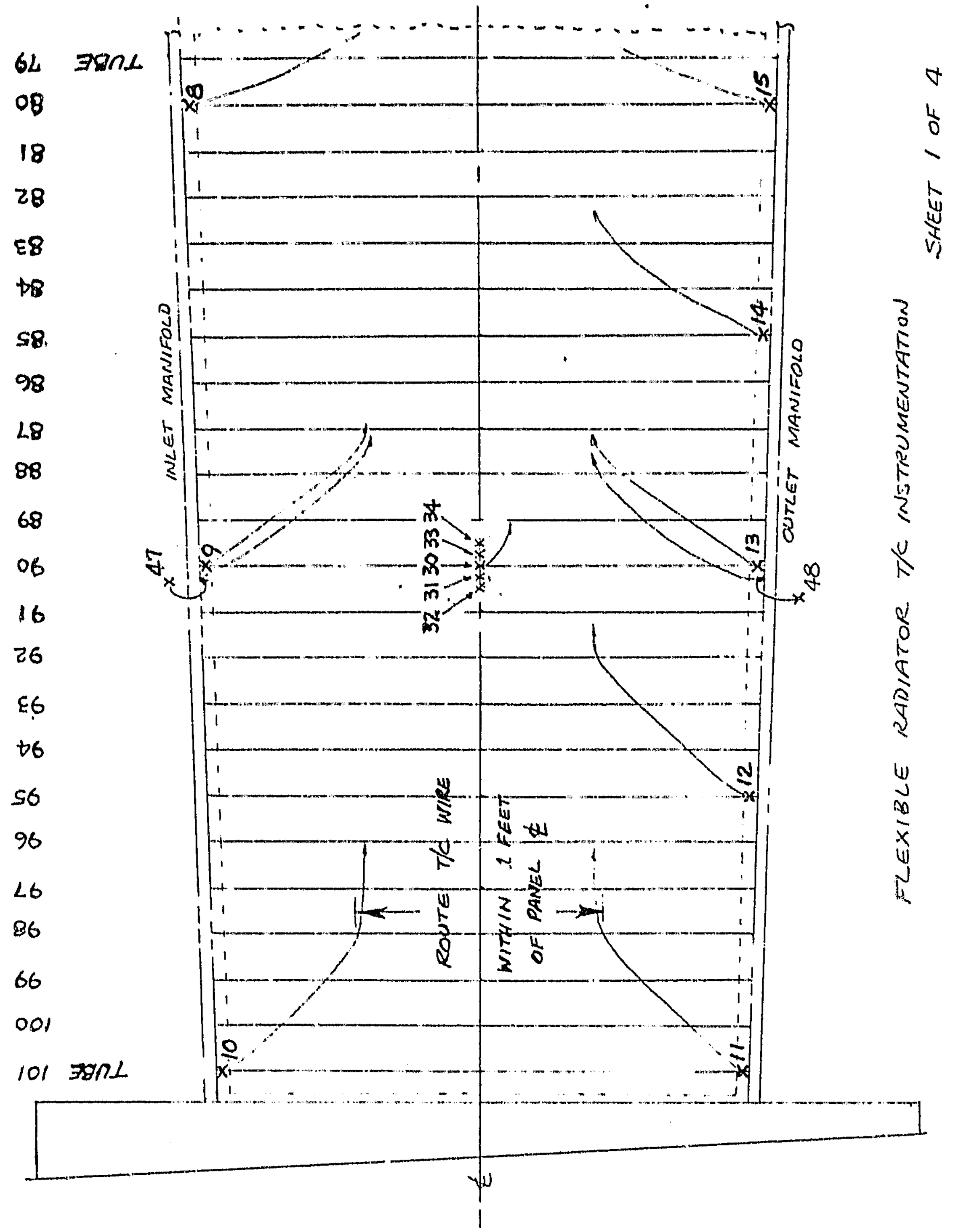
(1) Rittenhouse, J. B., "Meteoroids", Space Materials Handbook, 3rd ed., Addison-Wesley, Reading, Mass., 1968.

(2) Leont'ev, L. V., Tarasov, A. V., and Tereshkin, I. A., "Some Results of Research on High Velocity Impacts", NASA TT F-13, 740, August 1971.

(3) Cour-Palais, B. G., "Meteoroid Environment Model, Near Earth to Lunar Space", NASA SP-8013, March 1969.

APPENDIX A

FLEXIBLE RADIATOR
THERMOCOUPLE INSTRUMENTATION


TUBE 79
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99
100
TUBE 101
INLET MANIFOLD
OUTLET MANIFOLD
ROUTE T/C WIRE
WITHIN 1 FEET
OF PANEL ℄
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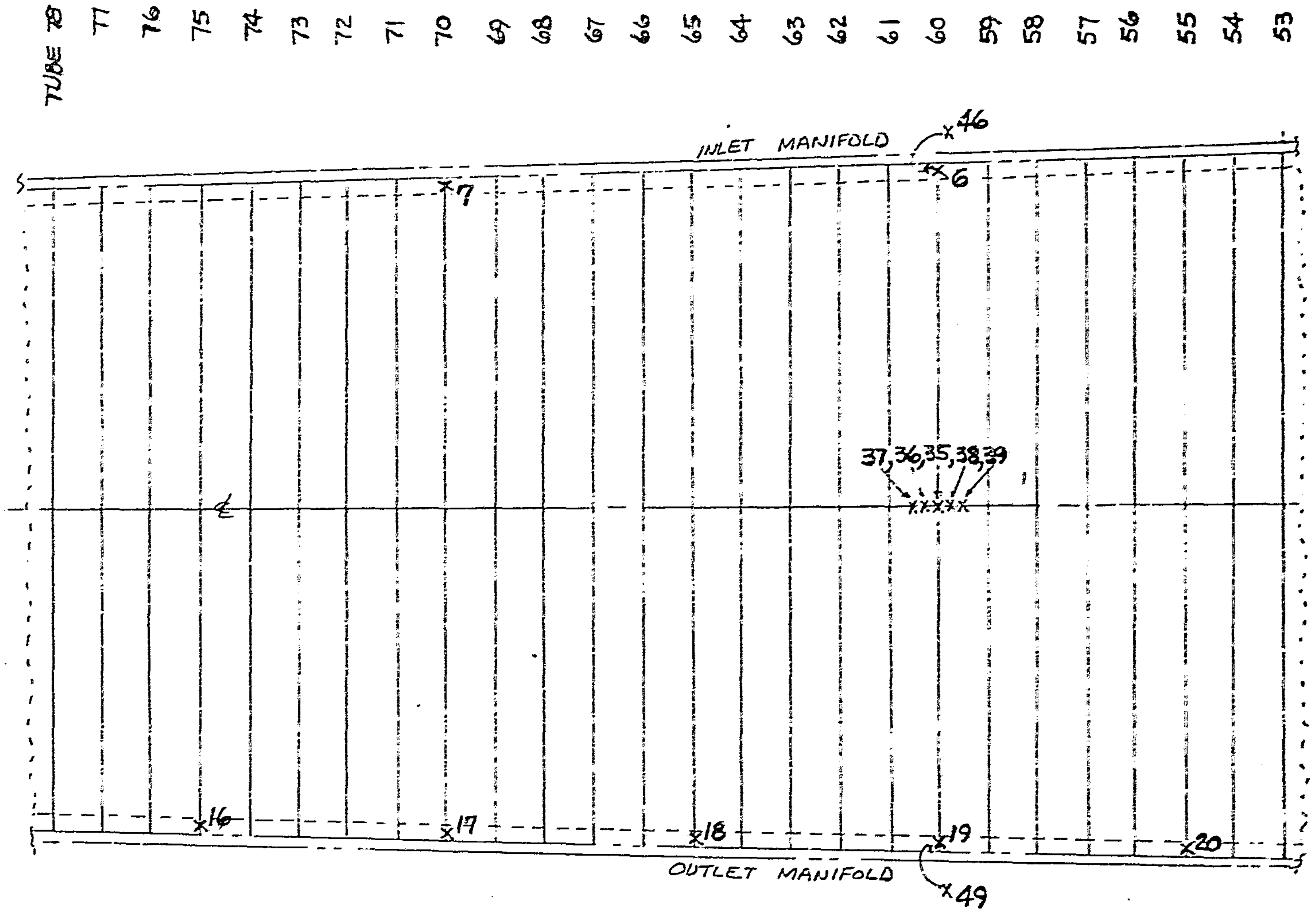
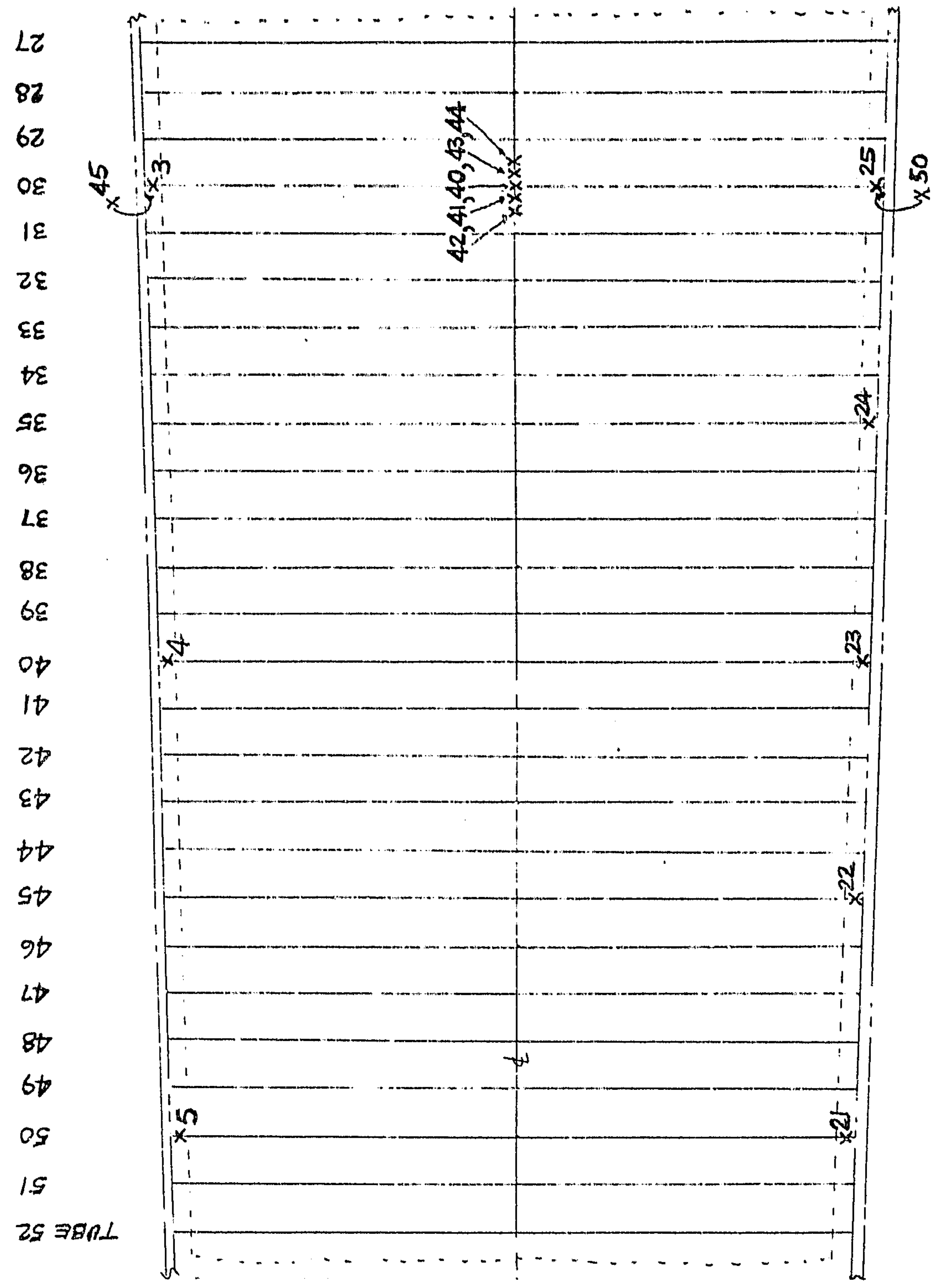
FLEXIBLE RADIATOR T/C INSTRUMENTATION
SHEET 1 OF 4



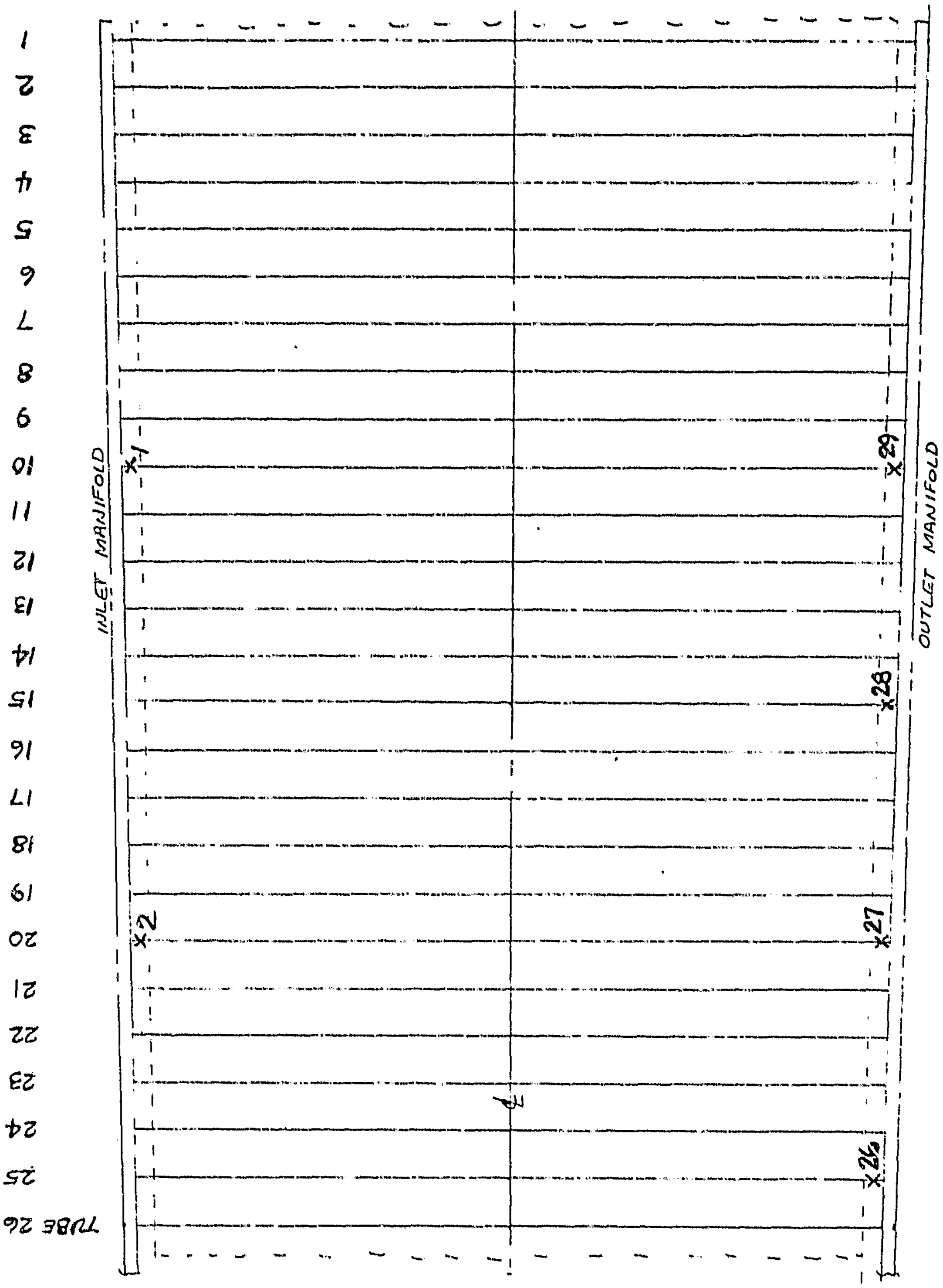
FLEXIBLE RADIATOR T/C INSTRUMENTATION

SHEET 2 OF 4



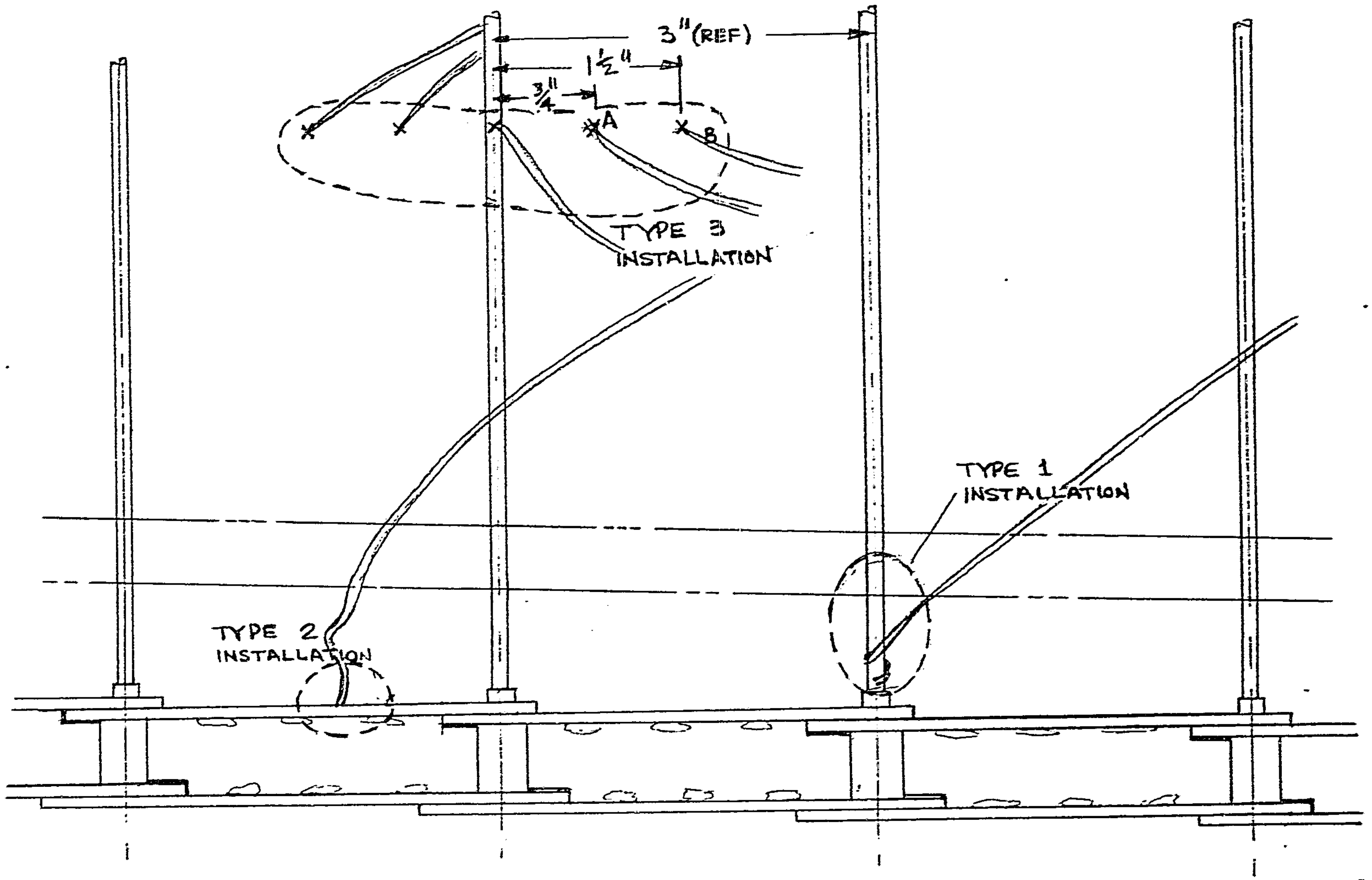
FLEXIBLE RADIATOR T/C INSTRUMENTATION

SHEET 3 OF 4

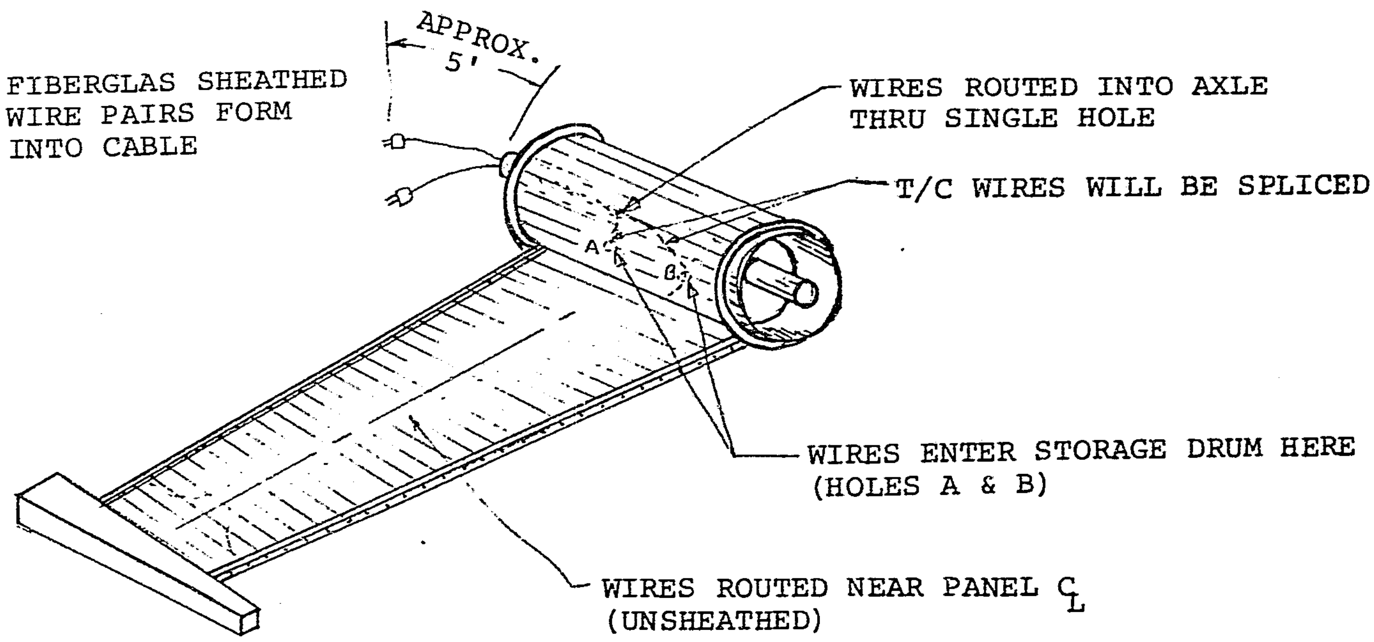


FLEXIBLE RADIATOR T/C INSTRUMENTATION

SHEET 4 OF 4



DETAILS OF THERMOCOUPLE INSTALLATION



TYPICAL THERMOCOUPLE WIRE ROUTING

EXTENDED-LIFE FLEXIBLE RADIATOR

APPENDIX B

LONG LIFE FLEXIBLE RADIATOR
REPRESENTATIVE FLIGHT UNIT DATA

LONG LIFE FLEXIBLE RADIATOR - REPRESENTATIVE FLIGHT UNIT - 1 WING

DIMENSIONS : Trapezoid, 25 ft. long by 52 in. x 36 in.

PROJECTED AREA : 85 ft^2

WEIGHT :

	DRY(LBS)	WET(F21)(LBS)
Panel & Meteoroid Protection	73.6	2.35
Deployment System	51.2	-
Fluid Transfer		
a) Fluid Swivel	2.0	.10
b) Coiled Hose	10.9	.66
TOTAL	126.6(a) 138(b)	2.45(a) 3.01(b)

STOWAGE VOLUME : 62 in. x 26 in. x 28 in.

HEAT REJECTION : 1.1 kW at 0°F sink, 100°F inlet
2.0 kW at -40°F sink, 100°F inlet

LIFE : 5 years at 90% probability

APPENDIX C

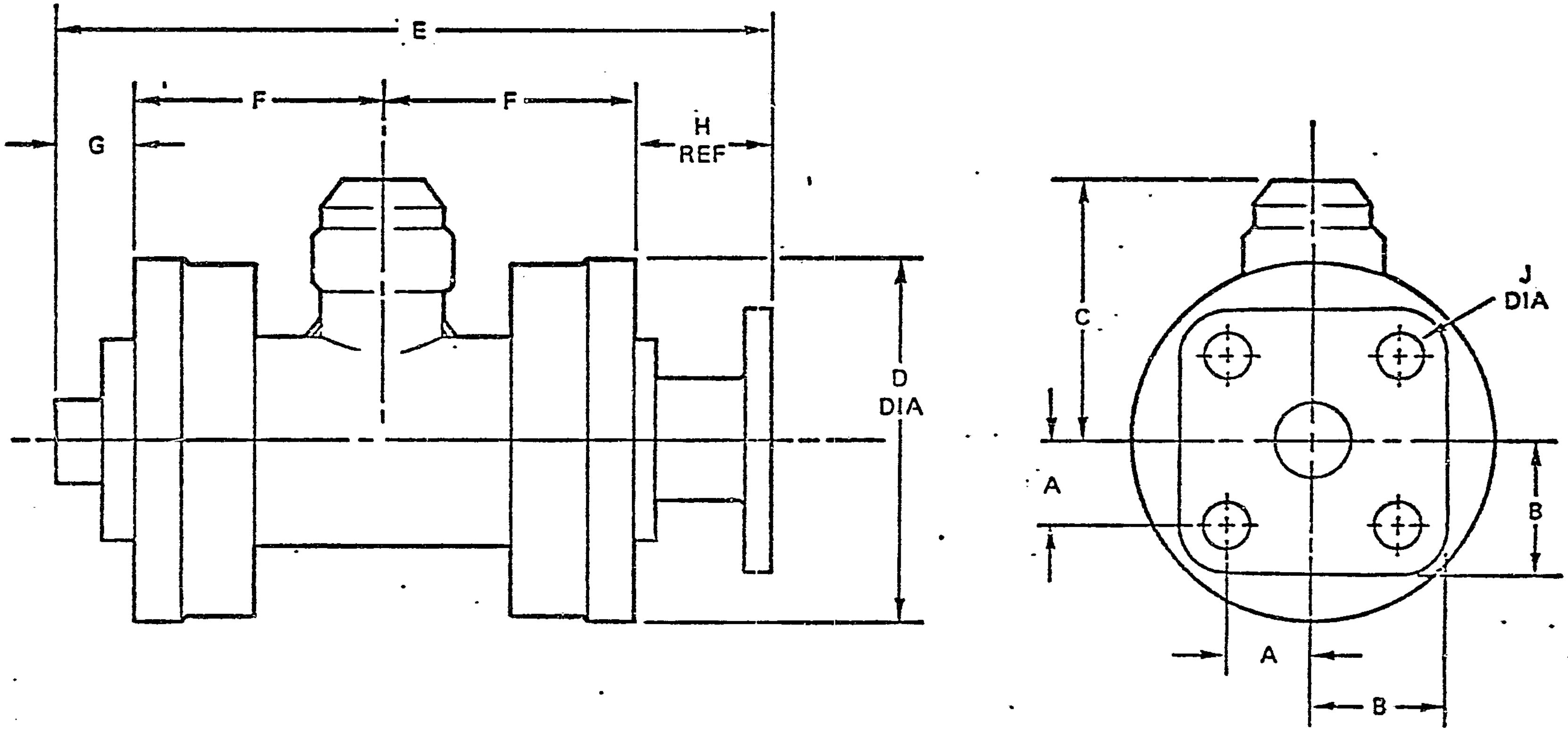
FLUID SWIVELS

Fluid swivels have been considered as candidates for fluid transport across rotating or gimbaled interfaces for several years. Under Contracts NAS9-13533 and NAS9-14408 Vought evaluated modifications to commercially available swivels for use with a dual mode radiator/refrigerator system for the Self-Contained Heat Rejection Module (SHRM) program. Results showed the swivel to work effectively in providing a compact hinge-line interface in a fold-out deployable radiator system, but exhibited sensitivity to side loading. A second generation version with redundant seals and ball bearings was subsequently evolved under Vought Independent Research and Development, with the following demonstrated performance:

- Fluid Diameter : 5/8"
- 1125 cycles thermal vacuum test, Freon 21 fluid
- -200°F to +200°F
- Side loads to 100 lbs
- Max torque : 30 in-lb at -200°F
- No measurable leakage

Parametric designs of two configurations of this swivel were developed and are presented in Figures C-1 and C-2.

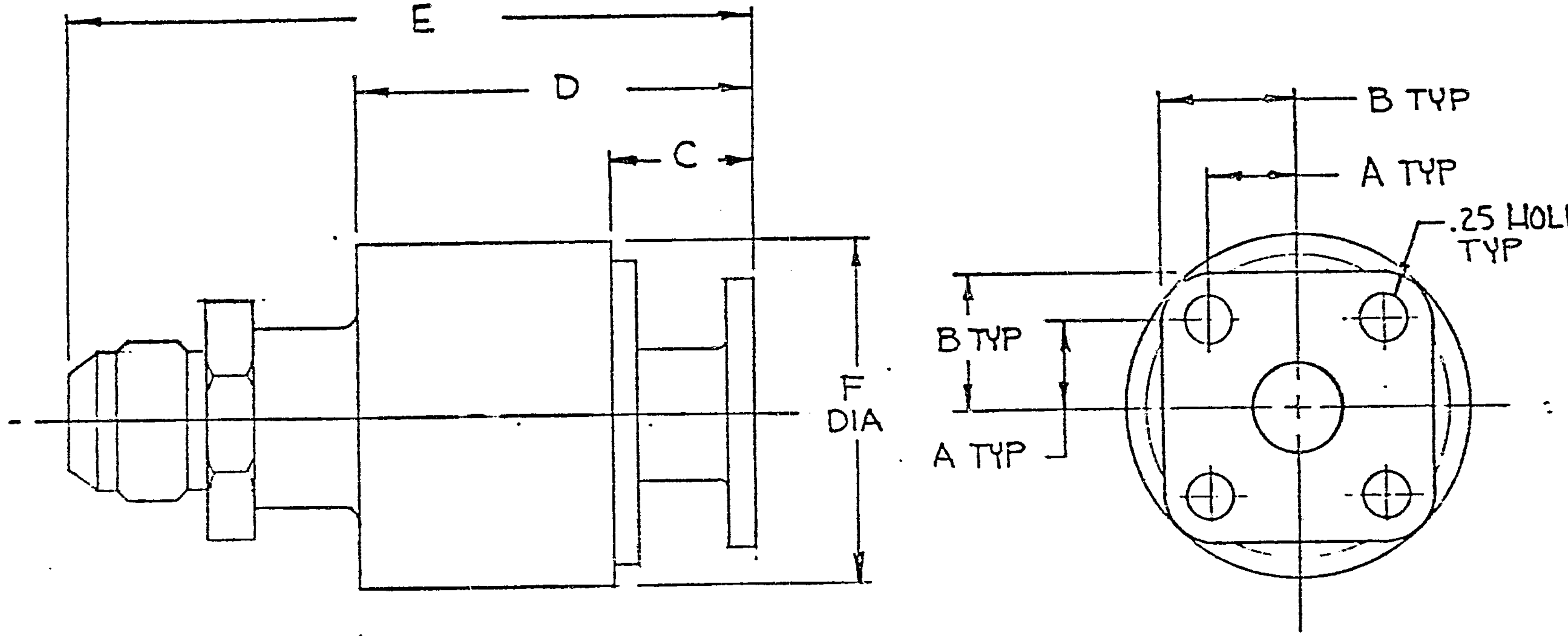
VOUGHT FREON SWIVEL
RIGHT ANGLE DESIGN



SWIVEL SIZE	WEIGHT *STEEL	WEIGHT AL	A	B	C	D DIA	E	F	G	H	J DIA
1/2	1.34	.80	.44	.72	1.40	1.36	3.81	1.34	.38	.75	.25
5/8	1.42	.85	.48	.74	1.44	1.36	3.94	1.44	.40	.66	.25
3/4	2.04	1.22	.56	.80	1.78	2.22	4.35	1.61	.40	.73	.25
1.0	2.69	1.61	.62	.87	2.00	2.46	4.50	1.68	.40	.74	.25

SWIVEL SHOWN → 5/8

STRIAGHT THROUGH DESIGN



SWIVEL SIZE	A	B	C	D	E	F DIA			WEIGHT	
									STEEL	AL
1/2	.44	.72	.76	2.13	3.58	1.66			.86	.60
5/8	.48	.74	.78	2.15	3.73	1.88			1.00	.70
3/4	.56	.80	.78	2.20	3.98	2.02			1.23	.87
1.0	.62	.87	.80	2.30	4.17	2.38			1.77	1.15

SHOWN