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DESIGN AND FABRICATION OF SHADOW SHIELD SYSTEMS FOR THERMAL PROTECTION OF CRYOGENIC PROPELLANTS

ARTHUR D. LITTLE, INC.

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA LEWIS RESEARCH CENTER
Contract NAS 3-10292
James R. Barber, Project Manager

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FINAL REPORT

DESIGN AND FABRICATION OF SHADOW SHIELD SYSTEMS FOR THERMAL PROTECTION OF CRYOGENIC PROPELLANTS

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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NASA Lewis Research Center
Cleveland, Ohio
James R. Barber, Project Manager
Liquid Rocket Technology Branch

DESIGN AND FABRICATION OF SHADOW SHIELD SYSTEMS FOR THERMAL PROTECTION OF CRYOGENIC PROPELLANTS

ABSTRACT

A system of shadow shields for the long-term thermal protection of a liquid hydrogen propellant tank was designed and fabricated. The design was based on the results of a previous analytical study in which several conceptual designs were evaluated for a spaceborne upper-stage configuration in which the shadow shields were located between a sun-oriented, 10-foot-diameter payload and liquid hydrogen tank. This report describes the design and fabrication of a scaled-down, 4 1/2-foot-diameter shadow shield system which will be used in ground-based experiments to determine the effectiveness of a shadow shield system in reducing propellant boil-off.

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The technical staff at Arthur D. Little, Inc., who contributed to this phase of the program include:

Mr. F. Gabron - Program Manager
Mr. T. P. Cerulli
Mr. J. E. McCullough
Mr. R. W. Moore, Jr.
Mr. D. Nathanson

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1.0 INTRODUCTION

The long-term storage of cryogens in space has received a great deal of attention during the past decade, particularly with the advent of high specific-impulse, hydrogen-fueled, space propulsion methods. In general, a large effort has been devoted to the development of highly efficient multilayer insulations (MLI) as a means for minimizing the heat inleakage and resulting cryogenic propellant boil-off in the space environment. The use of MLI--applied directly to the outer surfaces of the cryogenic tankage--will be required for those missions where the vehicle is randomly oriented, especially in the vicinity of planets where the heat inputs from planet-emitted radiation, albedo and direct sunlight vary in time and direction over an orbit. However, the demonstrated reliability and capability of attitude control systems to accurately orient a spacecraft for long periods in deep-space missions, (e.g., Mariner IV which was sun-oriented, and more frequent use of high-altitude, sun-synchronous earth orbits) have stimulated interest in shadow shielding techniques which rely upon directional effects to minimize the heat inputs from a payload or direct sunlight.

The objectives of the subject contract are to evaluate six shadow shield systems and to deliver to NASA LeRC two selected systems together with a cold-sink calorimeter. This effort consists of two basic tasks:

- Conceptual Design and Analytical Evaluation of Shadow Shield Systems
- Test Apparatus Design and Fabrication of Thermal Scale Models of Two Selected Systems

The Interim Report on the subject contract (Ref. 1) summarizes the work which has been accomplished in the conceptual design and evaluation of six concepts which utilize shadow shielding techniques to reduce the heat flow to an LH_2 tank comprising part of a solar-vector-oriented spacecraft. The evaluation was based on total system weight (defined as the weight of the shadow shield system plus the weight of vaporized propellant due to heat leaks for operational periods up to 10,000 hours) and the inherent reliability based on mechanical and operation complexity. The concepts evaluated included:

- Space-erectable systems
- Ground-erected (fixed) systems
- Systems which provide for solar-vector misalignment

The vehicle chosen as a representative configuration for the study was ten feet in diameter with an 1160-pound capacity LH_2 tank suspended within the vehicle structure. The tank was a nine-foot-diameter oblate spheroid and weighed 200 pounds. The vehicle structure (between the LH_2 tank and payload) used to transmit the thrust loads of lower stages and inertia loads of the LH_2 tank was an open-frame truss, and the shadow shields were placed between the payload and LH_2 tank. The payload was assumed to be at a constant temperature of 520R (288K) with a mass of either 1500, 2500 or 4000 lbs.

This report deals with the design and fabrication of the shadow shield systems selected by NASA for use in a test program to evaluate the effectiveness of shadow shield systems for thermal protection of propellants.

2.0 BACKGROUND

The basic concept of utilizing shadow shields to protect payloads or cryogenic storage vessels has been discussed in the literature for a number of different missions including solar probes, lunar and planetary orbiters, etc. A considerable portion of the literature on shadow shield systems has been devoted to shadow shield systems which are used to intercept solar energy--the main source of heat for extended duration interplanetary missions--by use of space-erected (mechanical or inflatable) shadow shields. The shadow shields in such cases are located in front of the oriented payload to be protected so as to intercept the collimated solar energy and reradiate the major fraction of the intercepted energy to outer space. A space-erected solar shield was utilized on the recent Mariner Venus 67 spacecraft to minimize the effects of the change in solar intensity which occur in the Earth-Venus trajectory.

The present study is directed (by contract) to shadow shield systems for reducing the heat flow between a payload, whose temperature is controlled to a fixed level, and an LH_2 storage tank. In this situation, the stage is oriented so that the payload faces the sun and the shadow shields are interposed between the payload and the LH_2 storage vessel. The shadow shields are used to protect the LH_2 tank from thermal radiation emanating from the payload, and the payload in effect thus becomes the shadow shield which intercepts the incident solar energy.

The concept of shadow shielding an LH_2 tank from payload radiation in the manner described above is discussed in Ref. 2. This preliminary analytical study showed that a few spaced shadow shields of low emittance could be used to eliminate any heat leakage by radiation from a room-temperature payload to an LH_2 tank. The advantages of using shadow shield systems as opposed to the use of multilayer insulations and the problem and application areas for lightweight thermal protection systems were discussed.

More recent publications (Refs. 3 and 4) present the results of a combined analytical and experimental study of the effectiveness of multiple, flat-plate shadow shields. Tests were made on a shadow shield system using a 12.75-inch-diameter LN_2 tank as a calorimeter and a heater plate (to simulate a payload) whose temperature could be controlled up to approximately 800R. The test results agreed reasonably well with analytical predictions, and provided an indication of the thermal interaction between the shadow shields and their supporting structure. The results of preliminary design studies for a shadow-shielded, 7000-lb., hydrogen-oxygen stage having a mission duration of 200 days were also presented. In this study a sun-oriented payload was maintained at 530R, and there was a 1-foot spacing between the payload and LH_2 tank. The results showed that the LH_2 boiloff due to support conduction could be appreciable and indicated the need for additional work to reduce that component of system mass penalty. It was also concluded that shadow shield systems offer potential weight savings for the storage of cryogens during long-term missions, in comparison to systems where the vehicle is oriented and multilayer insulation ("super insulation") is used for thermal protection.

The work undertaken in this contract is an extension of the work described in Refs. 3 and 4. Considerable effort was devoted to a detailed optimization study of flight-type thermal protection systems which included the following important variables:

- Tank-to-payload spacing dimensions
- Shadow shield system characteristics

    Surface optical properties
    Number of shields
    Location and attachment
    Shape

- Structural supports

    Materials
    Configuration
    Surface optical properties
    Improved cooling methods

The results of the conceptual design and analysis phase of the contract (Ref. 1) demonstrated that shadow shield systems with fixed payload support structures could be designed to have a small mass penalty and a small payload-to-tank spacing. The LH_2 boil-off mass for compact, fixed-structure concepts can be made small by: 1) using several low-emittance, low-conductance, circular shadow shields appropriately spaced between the payload and LH_2 tank to reduce the radiant heat flow to the LH_2 tank, and 2) properly selecting the configuration, materials and thermal control coatings for radiatively cooled structural supports to reduce the conductive heat flow to the LH_2 tank.

Figure 1 illustrates a typical hydrogen-oxygen upper-stage configuration in which a shadow shield system could be incorporated for thermal protection of the LH_2 tank. Figures 2 and 3 show the arrangement of two of the most promising shadow shield concepts evaluated in Ref. 1 (the LOX tankage and engine are omitted from these illustrations for clarity). Both concepts comprise a system of low-emittance shadow shields interposed between a 10-foot-diameter payload and a 9-foot-diameter LH_2 tank. The two concepts differ in the number and spacing of shields and the number, size and materials of construction used for the radiation-cooled structural supports. The differences result from an optimization based on minimizing the total mass penalty (mass of the shadow shield system including supports between the payload and LH_2 tank plus the mass of LH_2 boil-off) for a 10,000-hour sun-oriented mission.

The system shown in Figure 2 has an L/D of 0.15 and includes three intermediate shadow shields and a "Warren truss" structure having 16 fiber-glass supports (2" OD x 0.030" wall thickness). The system shown in Figure 3 has an L/D* of 0.25 and includes 2 shadow shields and a "Warren truss" structure having 12 titanium (6AL-4V) supports (2" OD x 0.017" wall).

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* L/D is defined as the distance between the payload and LH_2 tank divided by the payload diameter.

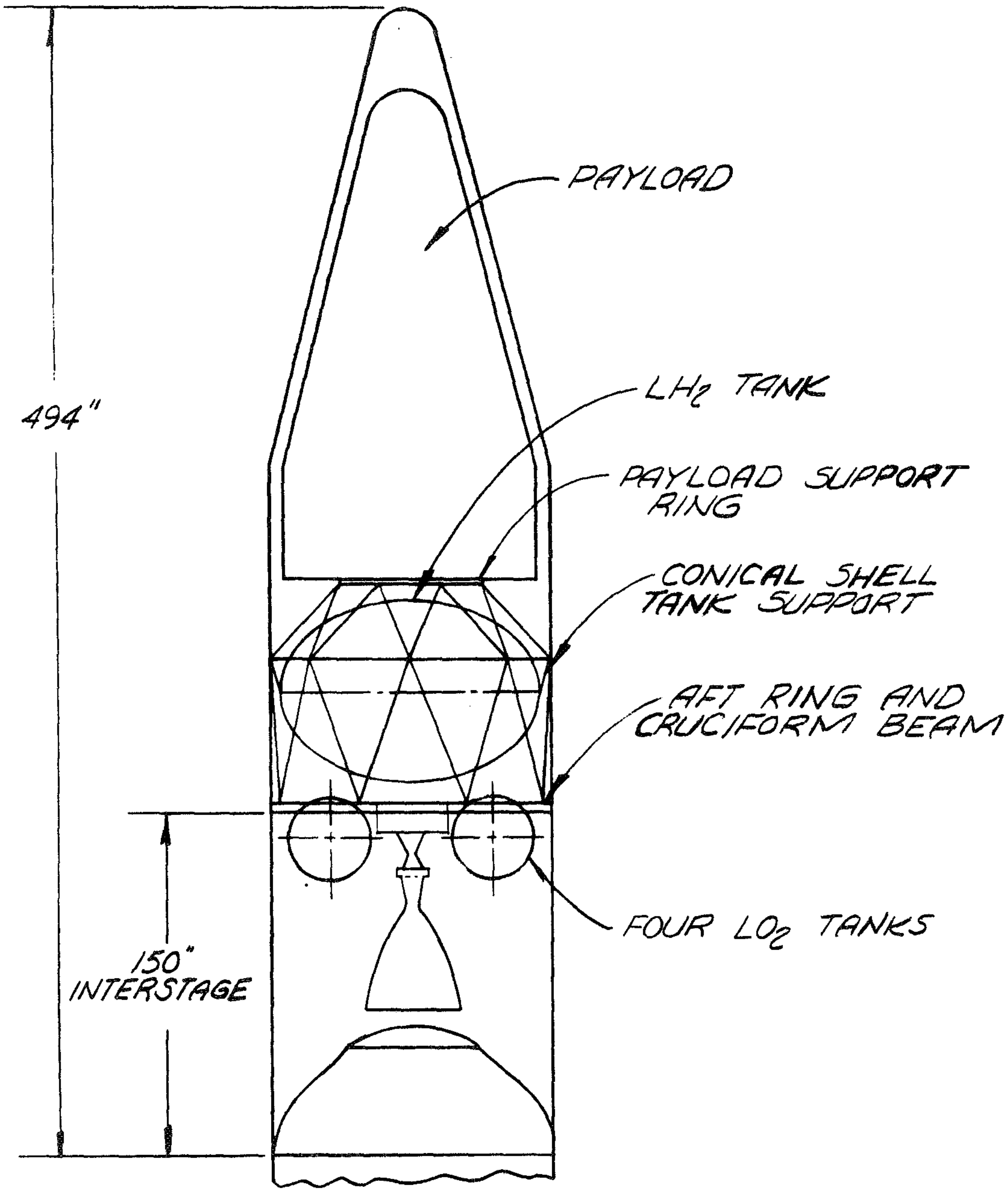

FIGURE 1 TYPICAL UPPER STAGE CONFIGURATION

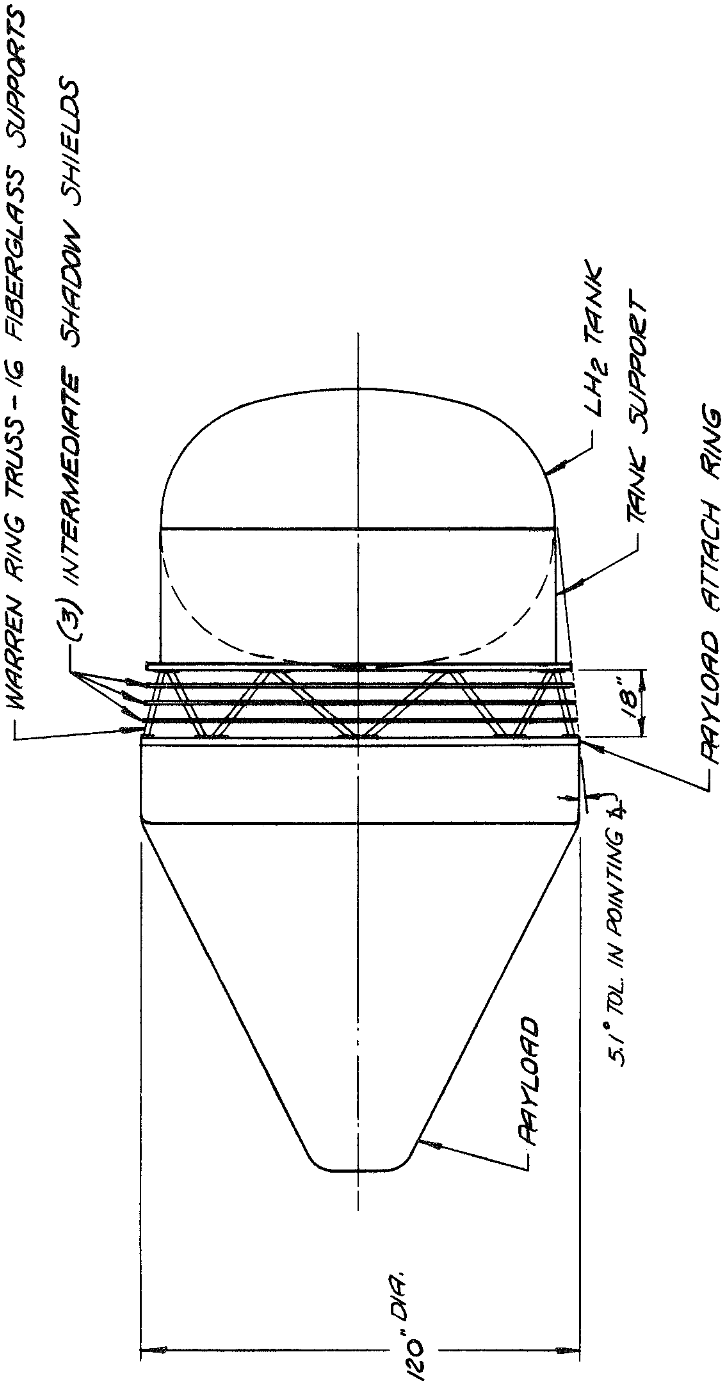

FIGURE 2 FIXED STRUCTURE, FIXED SHADOW SHIELDS
L/D = 0.15

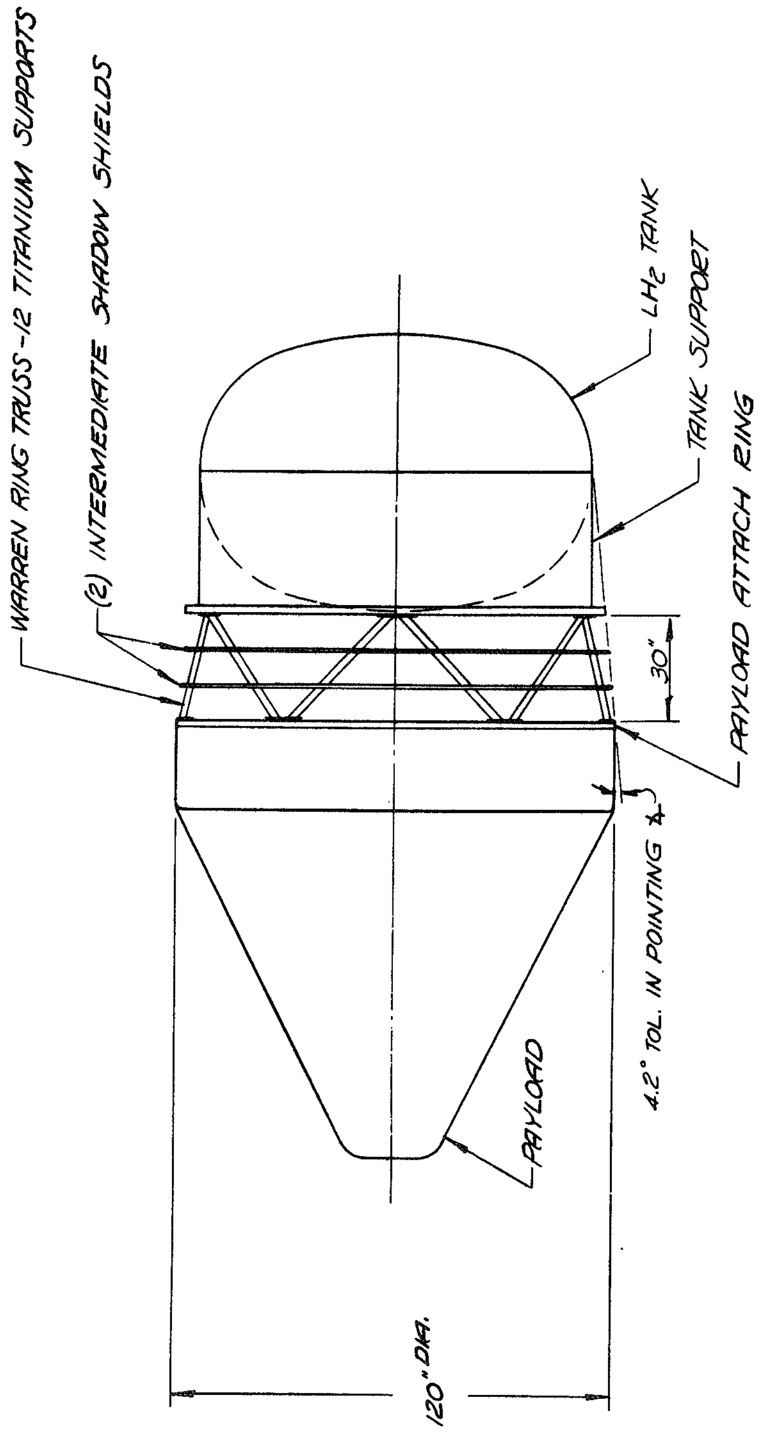

FIGURE 3 FIXED STRUCTURE, FIXED SHADOW SHIELDS
L/D = 0.25

The results of the analysis presented in Ref. 1 showed that both systems would result in an LH_2 boil-off during the 10,000-hour sun-oriented portion of the mission which is small by comparison to the estimated boil-off during ascent and earth-orbital operation.

Based on these concepts, NASA LeRC defined the following two prototype shadow shield systems which would be used as a basis for fabricating reduced-scale models.

1. Simulated LH_2 Tank

   Diameter = 9'

2. Payload Simulator

   Payload simulator (approx. 10' dia.) with heaters for adjusting the payload temperature between 520°R and 750°R.

3. Warren-Truss Support Structure

   a) Concept 1 - 12 3" OD fiber-glass struts.

   b) Concept 2 - 12 3" OD titanium struts.

4. Shadow Shield

   Two double-sheeted shadow shields located between the payload and LH_2 tank.

5. Tank Support Cone

   A support cone approximately 8" in length located between the LH_2 tank and termination of the truss support structure.

The requirements of the contract included the following specifications for the thermal modeling and fabrication of the reduced-scale shadow shield system.

1. Modeling Approach

   a) Provide for temperature preservation in model and prototype.

b) Use identical emittances in model and prototype.

c) Use identical materials in model and prototype.

d) Distort minor dimensions (tubular truss wall thickness) to preserve as closely as possible the conductive heat flow.

2. Fabrication Requirements

a) The payload simulator shall have a capability of being maintained at temperatures from 520-750°F.

b) The twelve support tubes for each concept used to simulate the Warren truss shall be arranged parallel to the tank-payload centerline and shall be 36" in length.

c) Five interchangeable, temperature-instrumented, double-sheeted shadow shields shall be provided. Each shadow shield structure shall be equipped with two sets of inserts for attaching the shield support structure to support tubes. One set shall have high thermal conductivity (metallic) and the other a low conductivity (non-metallic) to allow for altering the thermal bond between the shield and support tubes. Provisions shall be made for varying the spacing of the shields.

d) The tank support cone shall be designed so that the support can be varied in location along the length of the cylindrical portion of the 4' dia. GFE calorimeter tank used to simulate the prototype LH_2 tank. A good thermal bond shall be provided between the support and tank.

The following sections of this report describe the approach used in designing the experimental reduced-scale shadow shield systems and the details of the system design.

3.0 THERMAL SCALING AND DESIGN OF EXPERIMENTAL SHADOW SHIELD SYSTEM

There are several alternative techniques for preserving thermal similitude in model and prototype. The most appropriate is to make the temperatures in the model and prototype be identical at homologous locations.

We define a scaling ratio based on some characteristic length ratio in model and prototype:

$$R = \frac{L_m}{L_p} \qquad (1)$$

In this case the scaling ratio would be based on the tank diameters of model and prototype, - 4 ft. and 9 ft., respectively. If we geometrically scale all other <u>major</u> dimensions (payload diameter, truss length, etc.), it can be shown that the following relationships exist when the temperatures are made identical in model and prototype at steady-state thermal conditions.

$$\varepsilon_m = \varepsilon_p \qquad (2)$$

$$(q/A)_m = (q/A)_p \qquad (3)$$

$$q_m = R^2 q_p \qquad (4)$$

where

ε - emittance

q - rate of heat flow (Btu/hr)

A - area (ft^2)

R - scale ratio

In addition to these equations, it is necessary to consider the similitude relation for conductive heat flow in the truss supports and tank support skirt. When the conductive heat flow is either one or two-dimensional--which is the case in the present design--the appropriate scaling relationship where the thermal conductivity is a strong function of temperature is:

$$\bar{k}_m \, \delta_m = R^2 \, \bar{k}_p \, \delta_p \qquad (5)$$

where

$$k(T) \cong \bar{k} T^a \qquad (6)$$

a - arbitrary exponent
T - temperature
k - thermal conductivity

and δ is the thickness of the conductive path.

In cases where the thermal conductivity is a strong function of temperature and the temperature ranges large, it is necessary to use identical materials in model and prototype. Thus, Equation (5) becomes:

$$\delta_m = R^2 \, \delta_p \qquad (7)$$

For scaling the conductive heat flow component, one can therefore use distortions on the minor dimensions in accordance with the above equation. For example, in a thin-walled, tubular truss, with fixed end temperatures and the tube conducting heat along its length and the surface radiating to space, the outside diameter could be scaled in accordance with Eq. (1), the wall thickness in accordance with Equa. (7). If identical materials and emittances were used in model and prototype, the temperature distributions in model and prototype would be identical; and the heat flow rates would scale in accordance with Eq. (4).

It is concluded that the best approach to modeling the shadow shield design at 4/9 overall scale would involve the following:

- Provide for temperature preservation in model and prototype.
- Use identical emittances in model and prototype.

- Use identical materials, if possible, in model and prototype (titanium and fiber-glass truss supports).
- Distort the minor dimensions (tubular truss wall thickness) to preserve as closely as possible the conductive heat flow. In this instance, the allowable distortion is limited by commercially available tube sizes.
- If necessary, alter the number of truss supports in model and prototype.

Scaling the radiative heat fluxes through the shadow shields can be accomplished because the shadow shield material in the model can be made identical to that specified for the prototype design. The radial conductance of the aluminized Mylar-nylon-Mylar laminate is extremely small; therefore, the radial temperature distributions will not be altered because the same thickness of material is used in model and prototype specification. The surface emittances of the tubular truss can be easily made identical to those specified for the prototype design.

The primary problem in scaling the conductive components of heat leak to the cryogenic tank from the payload via the support truss is that the two prototype designs specified by NASA LeRC involve the use of low-conductivity, thin-walled tubing of fiber-glass and titanium, respectively. Tubing of any desired OD and wall thickness in these materials is not commercially available; and, therefore, non-scaled effects will be introduced because of material size limitations. Fortunately, the total heat leak to the cryogen via these supports is expected to be extremely small so that errors introduced by imperfect scaling are not particularly important, provided that the supports can be instrumented with thermocouples and the temperatures compared with theoretical predictions.

The particular problem common to the model design of both concepts is that the total conductive heat flow to the model calorimeter simulating the LH_2 tank will be larger than desired because of tube wall thickness limitations.

The tank support cone introduces a small additional thermal resistance in series with the tubular support structure. Precise scaling of this structure would result in very thin wall thicknesses which are impractical to fabricate. Previous studies have shown that the thermal resistance of the tank support structure has a negligible effect on the conductive heat leak, and for that reason the system need not be scaled.

In Table 1, a summary of the conductive heat leak in the support structure for the prototype systems is compared with the calculated heat leak for both an exact scale and a non-scaled model which is based on the utilization of available materials. It can be seen that the error introduced by imperfect scaling of the fiber-glass struts results in a conductive heat flow approximately an order of magnitude larger than an exact-scale model. However, the conductive heat flow is extremely small (0.016 Btu/hr) and is most likely smaller than the resolution of the instrumentation used in measuring the boil-off in the experimental apparatus. The error introduced by the imperfect scaling of the titanium support tube structure results in a conductive heat flow approximately 16 times greater than exact scale. The magnitude of the heat flow is approximately 1 Btu/hr and, again, will be small by comparison to measurement accuracy.*

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* For reference, the 4' tank calorimeter has been previously used for multilayer insulation studies. The lowest boil-off (heat flow) rate measured for any systems (between 300 and 77°K) was approximately an order of magnitude higher than the heat flow rates above.

TABLE 1

SUPPORT TUBE HEAT LEAKS FOR SCALE MODEL SYSTEMS

(Effective L/D of prototype truss = .32 and
tank-payload spacing of 12.0 inches)

Concept 1 - Fiber-Glass Supports

	N	OD (in)	δ (in)	$\frac{q_{\text{model}}\ (\text{non-scale})}{q_{\text{model}}\ (\text{exact-scale})}$	q_{model} (Btu/hr)
Prototype (Nema G-10)	12	3	0.034	-	
Exact Scale Model	12	1.33	0.0067	1.0	< .001
Non-scaled Model (Nema G-10)	12	0.875	0.015	16.0	.016

Concept 2

	N	OD (in)	δ (in)	$\frac{q_{\text{model}}\ (\text{non-scale})}{q_{\text{model}}\ (\text{exact-scale})}$	q_{model} (Btu/hr)
Prototype (6Al-4V Ti)	12	3	0.017	-	
Exact Scale Model (6Al-4V Ti)	12	1.33	0.0033	1.0	.073
Non-scaled Model (6Al-4V Ti)	12	0.875	0.015	16.4	1.2

where N - number of supports
OD - outside dia. of tubes
δ - wall thickness
q - rate of heat flow (Btu/hr)

In summary, the scaled-down models were designed as follows:

1. Identical shadow shield materials and emittances were used in the prototype.
2. The fiber-glass and titanium support tubes were imperfectly scaled due to material availability considerations. The errors introduced are expected to be small with respect to heat flow measurement accuracy.
3. The tank support cone was not scaled because the thermal resistance does not significantly influence the total heat flow to the simulated LH_2 tank.

4.0 DESCRIPTION OF EXPERIMENTAL SHADOW SHIELD SYSTEM

4.1 Shadow Shield and Cryoshroud Configuration

The overall arrangement of the shadow shield system, the calorimeter tank which will be used as a cold sink, and the 8'-diameter cryoshroud are shown in Figure 4. The entire experimental apparatus will be mounted in a large vacuum chamber at NASA Plumbrook Station for the experiments.

The calorimeter tank cold sink, equipped with appropriate guarding system for the fill, vent and support lines will be used for measurements of heat flow by measuring the boil-off rate of liquid nitrogen. The exterior of the tank will be covered with a low-emittance surface.

The 8'-diameter cryoshroud was designed to operate with liquid hydrogen as a coolant to provide a low-temperature "black" heat sink for the shadow shield system. A system of four annular LH_2-cooled baffles which can be adjusted to line up with the shadow shields and payload simulator are provided to minimize the inter-reflections between shields. This requirement is brought about by the extremely small heat fluxes which can be attained in a shadow shield system. Radiation emanating from the room-temperature (or above) payload simulator is trapped by the cavity between the lowermost two baffles adjacent to the payload simulator and first shadow shield, thus preventing the room-temperature radiation from impinging on the second shadow shield, etc. All interior surfaces of the cryoshroud and the baffle surfaces were painted with "3M" Nextel Black Velvet (401 series)*.

As shown in Figure 4, the shield system is adjustable so that the tank-payload simulator and the number of shields can be varied. The maximum L/D (payload-tank spacing divided by the diameter of the payload is approximately 0.5.

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* Product of Minnesota Mining & Manufacturing Co.

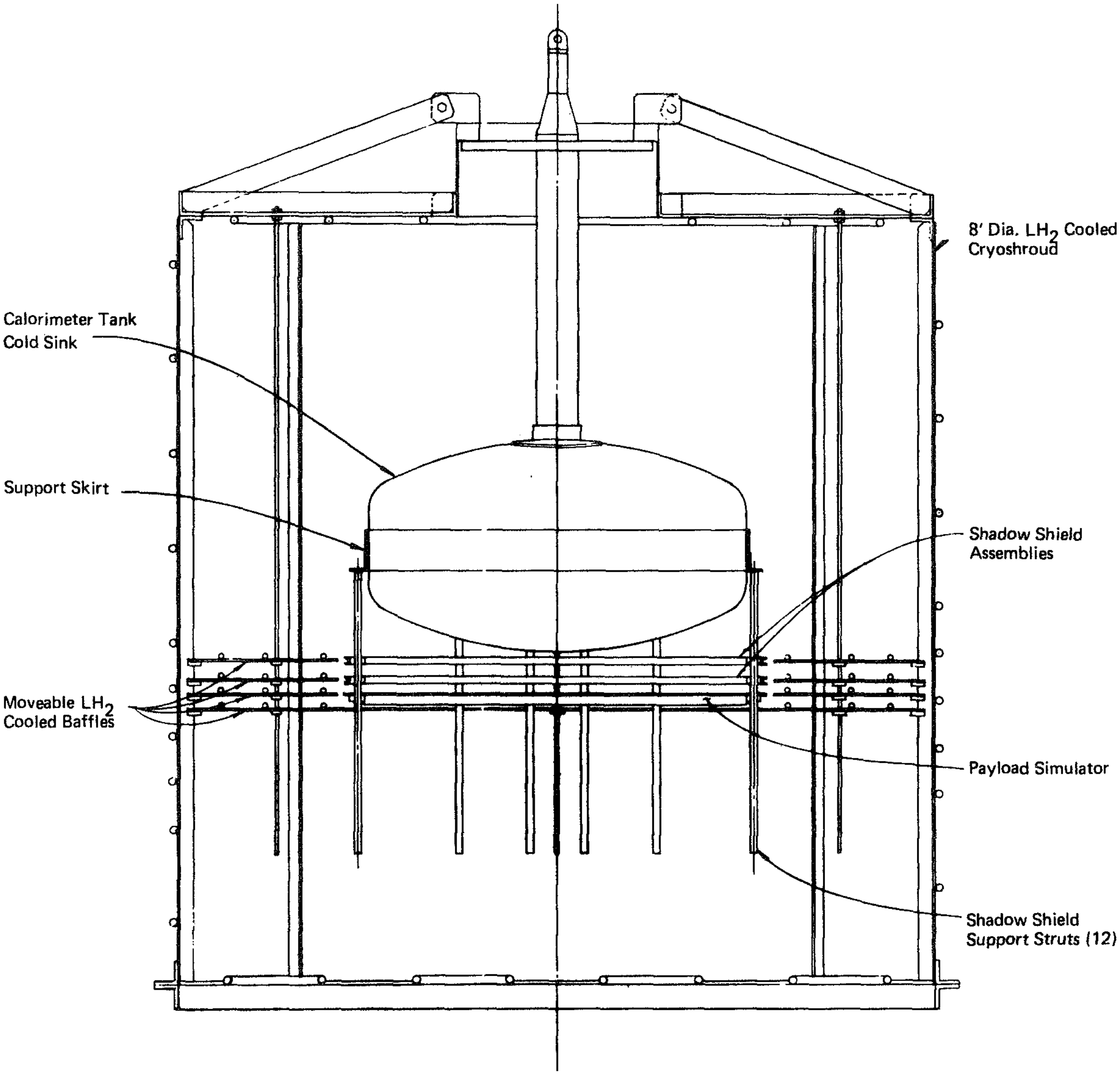

FIGURE 4 8' CRYOSHROUD AND SHADOW SHIELD ASSEMBLY

An assembly drawing (7005-004) which illustrates the details of the support skirt, structural tubes, payload simulator and heaters, and the attachment of the shadow shields is included in Appendix A.

4.2 Payload Simulator

The payload simulator (53 1/2" OD) is designed to provide a variable temperature source to simulate a payload operating between 520 and 750°R. The payload simulator is 1/8" thick, 6061-T6 aluminum which is polished to have a low-emittance (0.027) surface facing the shadow shields. A system of eight electrical resistance heaters is bonded to the back side of the stiffened plate. The details of the payload simulator are shown in Appendix A, (Dwg. 7005-006).

The details of the payload simulator heaters and strut attach points are shown in Figure 5. Two heaters, each of approximately equal area, are used in each 90° segment. This heater configuration was chosen so that radial temperature gradients in the payload simulator could be minimized by separately controlling the heater power. Each of the eight heater elements was designed to dissipate a maximum of approximately 500 watts which would provide a maximum payload simulator temperature of approximately 800°R with one side painted to have a high emittance. The details of the heater configuration are also presented in Appendix A (Dwg. 7005-020).

4.3 Shadow Shields

Five double-sheeted shadow shield assemblies were designed and fabricated. The shadow shield assembly (Appendix A, Dwg. 7005-005) consists of a 53 1/2" OD rolled aluminum channel ring (3/4 x 3/4 x 1/8") to which the twelve strut mounting blocks are attached. The channel, which is polished to have a low emittance, serves to support the shadow shield fabric and

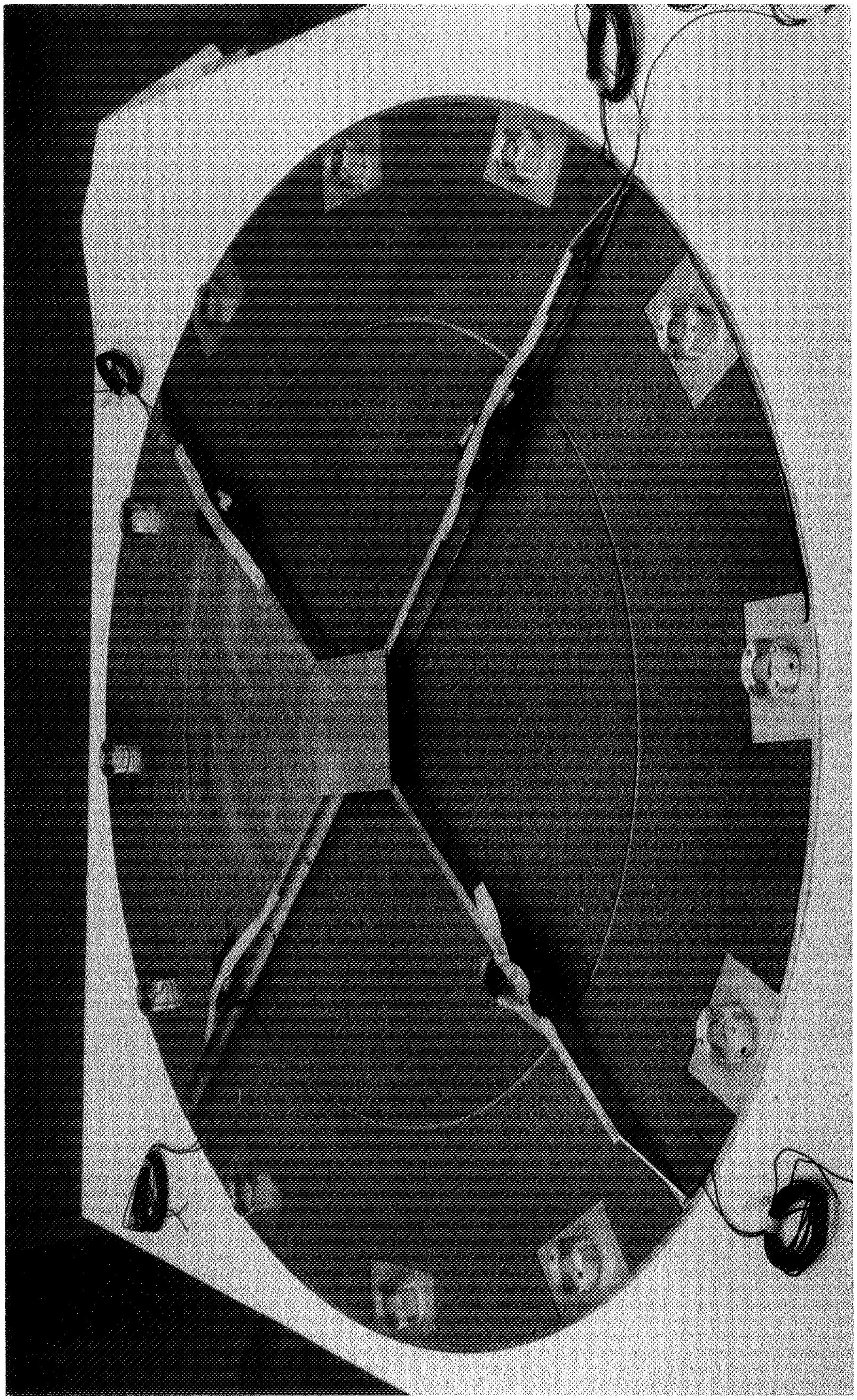

FIGURE 5 PAYLOAD SIMULATOR

position the strut mounting blocks so that each shield is interchangeable. (The aluminum channel was polished to have a low emittance for initial tests at NASA LeRC. Actually, the performance of a shadow shield system can be improved, i.e., the heat leak to the cryogen reduced, by utilizing a high-emittance surface on the shield supports. Future plans for testing at NASA LeRC include painting the channel to have a high emittance and comparing the system heat leak for the high and low-emittance surfaces.)

Figures 6 and 7 illustrate the overall configuration of a shield assembly and the details of the method of lacing the shadow shield to the support ring. Each shadow shield assembly consists of two identical shields laced to the shield ring by a system of grommets and 0.010"-diameter stainless steel wire. Each shield is an aluminized Mylar--rip-stop nylon fabric--aluminized Mylar laminate.* The 1/2-mil, aluminized Mylar is applied to the 1.5 oz/yd^2 nylon fabric with the aluminized side facing outward. Thus, each shield assembly has two shields and four low-emittance surfaces.

The inside surface of one shield of each of the five shadow shield assemblies is equipped with six #40 3-mil copper-constantan thermocouples on radii of 10, 18, and 23 inches to measure the radial temperature gradients in the shields. The thermocouples were applied with a double-sided adhesive tape and covered with an aluminized tape to preserve the low-emittance shield surface. The thermocouple lead wires exit between the shield fabric and channel ring as shown in Figure 7. (The foam pads shown in Figure 7 are used to protect the small-diameter lead wires during shipment and will not be a part of the experimental apparatus.)

4.4 Support Struts

Twelve cylindrical support struts, each 35 5/8" long, are required to position the payload simulator and shields relative to the calorimeter tank. Two complete sets of tubular

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* Product of G. T. Schjeldahl Co.

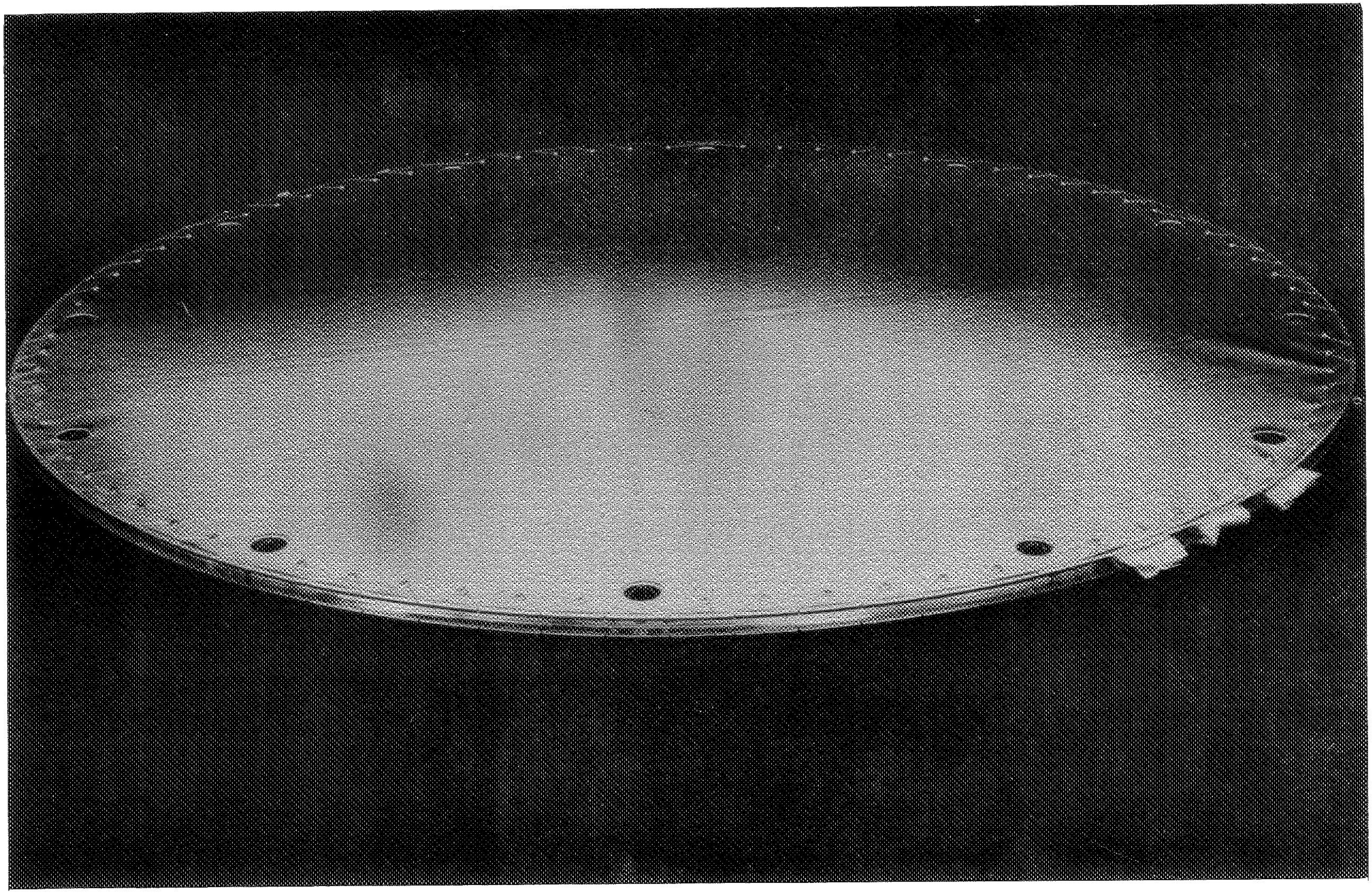


FIGURE 6 SHADOW SHIELD

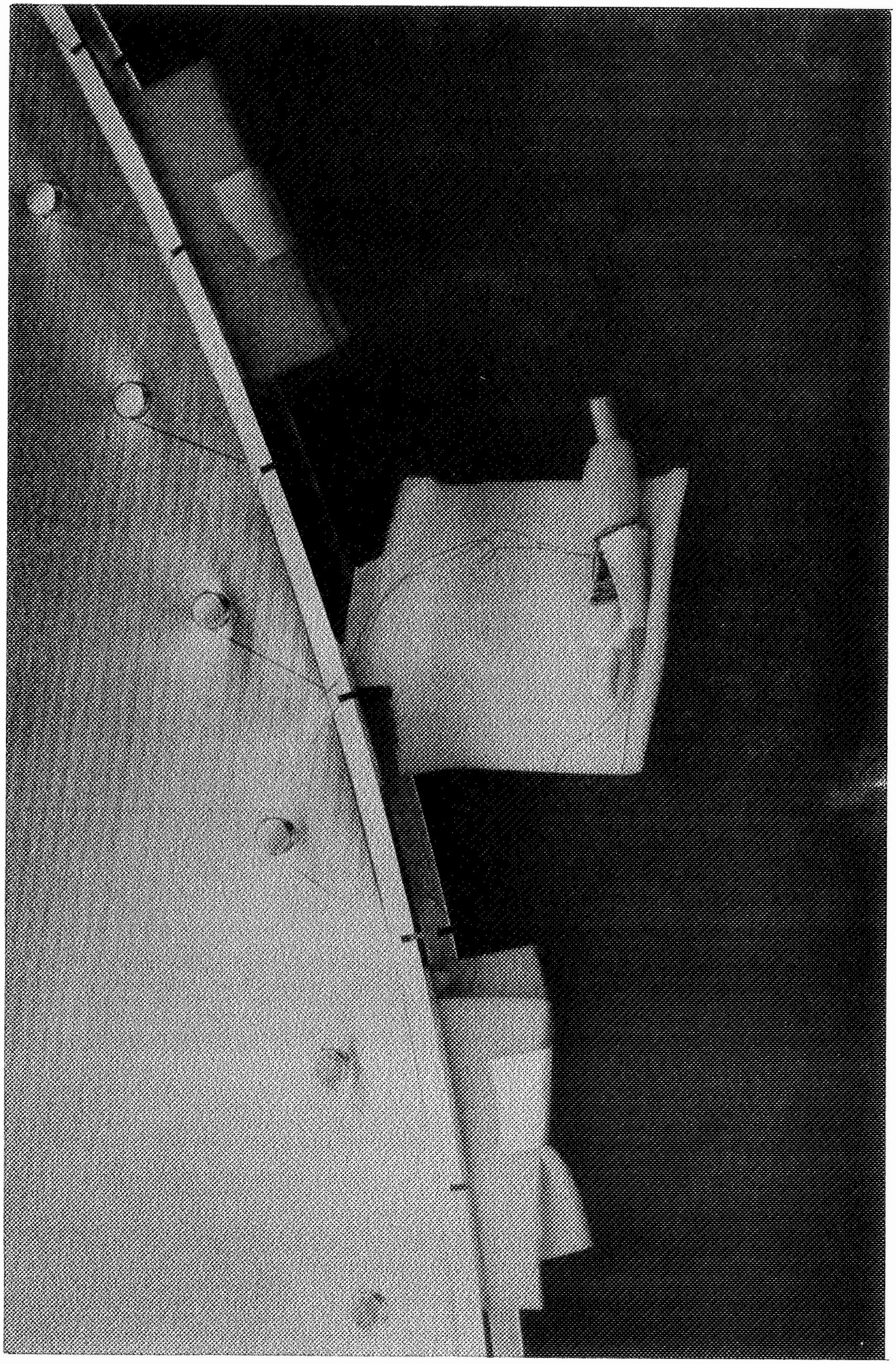


FIGURE 7 ATTACHMENT OF SHADOW SHIELDS TO SHIELD RING

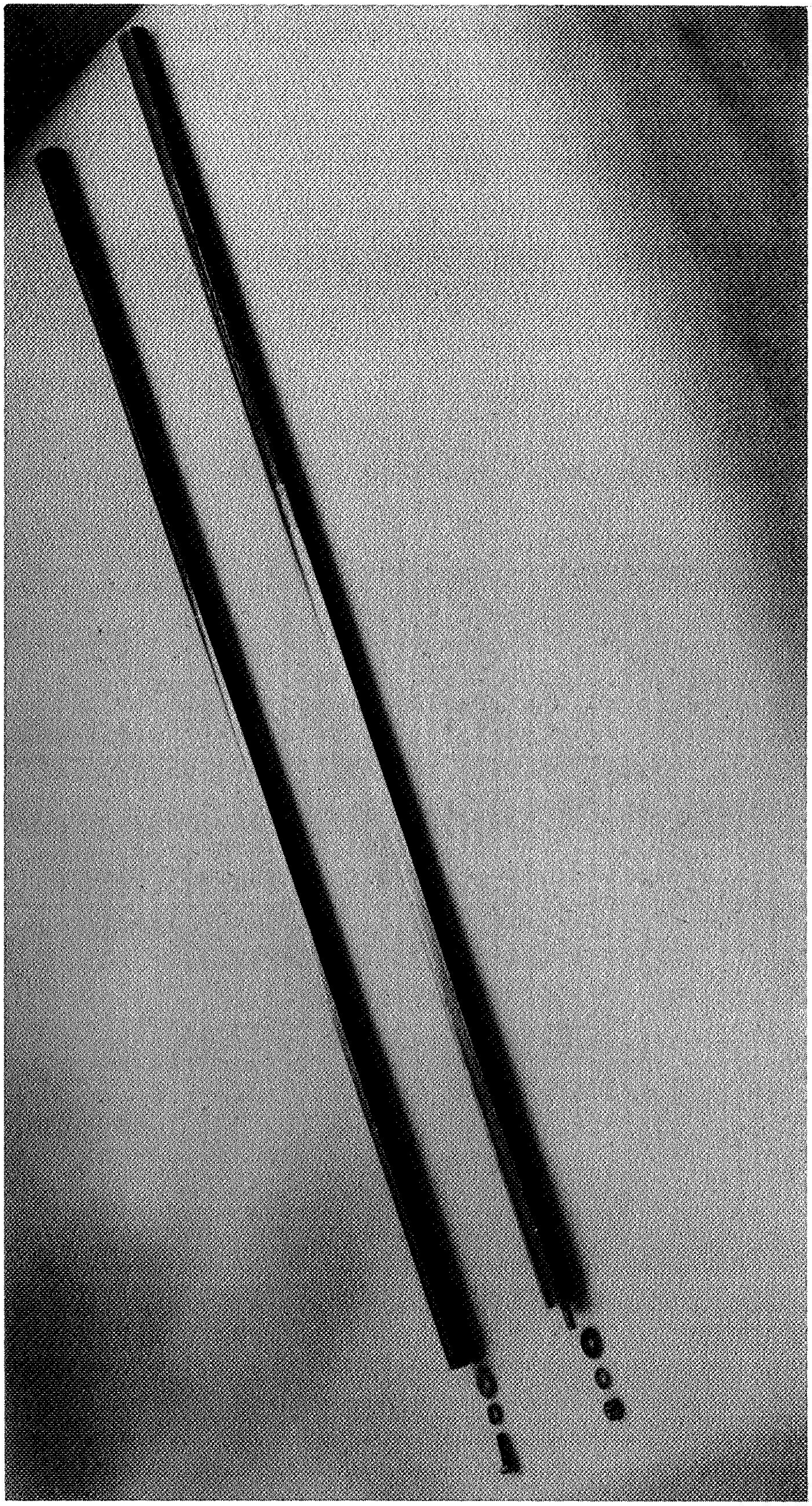


FIGURE 8 SUPPORT STRUTS

support struts of similar dimensions (7/8 OD x 0.015 W.T) were fabricated. One set was Nema G-10 fiber-glass; the other was 6Al-4V titanium (Appendix A, Dwgs. 7005-009, 7005-010).

A photograph of the two types of support struts is shown in Figure 8. The fiber-glass strut was equipped with a threaded stud for attachment to the support ring and the titanium support strut was equipped with a threaded plug.

Each strut was covered over 180° of the tube circumference with aluminized Mylar (aluminum side out) and painted with 3M Nextel Black Velvet over the remaining 180°. A low emittance over half the circumference which faces radially inward (i.e., toward the centerline between the payload simulator and cold sink) and a high emittance over the remaining portion which faces deep-space results in radiative cooling of the support structure thereby reducing the conductive heat leak from the payload to the cryogenic tank. It also minimizes the shield-strut radiative interaction.

To minimize the axial heat flow in the support struts by radiation without materially affecting the axial conduction, each tube was filled with a 2 lb/ft^3 foam.

For purposes of varying the thermal conductance between the support struts and the shadow shield rings, two sets of inserts for each shield assembly were fabricated. The inserts are cylindrical (1.12 OD x 0.25 W.T x 0.69 long) and fit between the outside diameter of the support tube and the inside diameter of the support blocks attached to the shadow shield rims (Appendix A, Dwg. 7005-011). One set was fabricated from 6061-aluminum, the other from micarta.

4.5 Support Skirt

The aluminum support skirt used to join the twelve support tubes to the cylindrical portion of the cold-sink calorimeter tank is shown in Figure 9 (for details see Appendix A, Dwg. 7005-007). The support skirt is made from 0.020"-thick 3003 aluminum and is designed to clamp around the periphery of

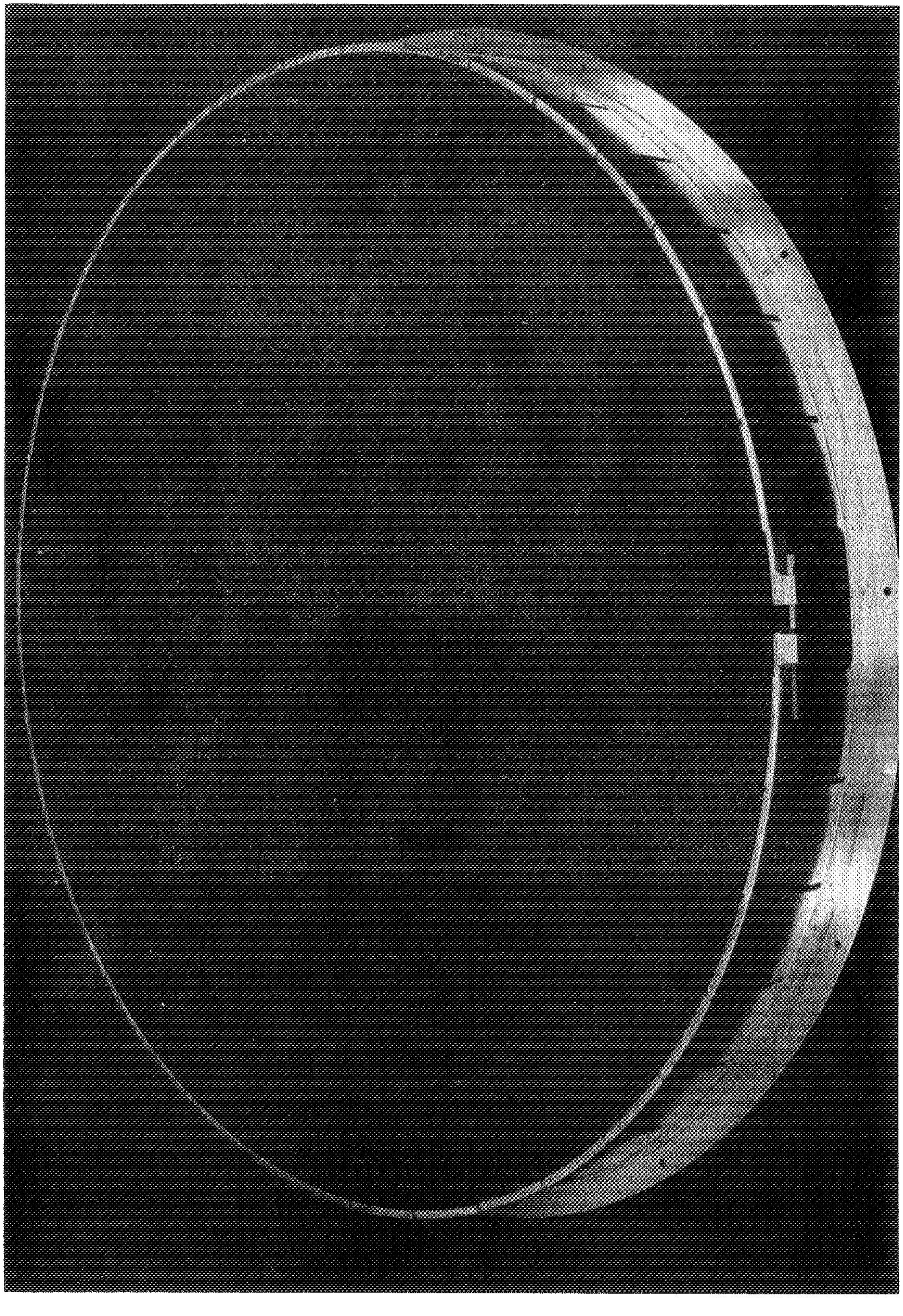


FIGURE 9 SUPPORT SKIRT

the copper cold sink. A 1 1/4" 6063 aluminum angle riveted to the 0.020"-thick skirt is used as an attachment member for the twelve support struts. The entire assembly is polished to have a low emittance. The overall length of the support skirt is 5 1/4 inches.

5.0 THERMAL PROPERTIES

5.1 Support Strut Conductivity

The following data relate the thermal conductivity to temperature for the fiber-glass and titanium struts over the temperature range of +68 to -400°F.

Type:	glass fabric reinforced epoxy resin
Grade:	Nema G-10
Designation:	Formica Corp. FF 89
Resin:	Amine-cured epoxy, 36% by weight
Glass:	Style 1674 glass fabric (2.6 oz/yd^2) 40-44 warp x 32-40 fill thread count, 64% by weight glass

Temperature (F)	$k^*_{\text{perpendicular}}$	k^*_{parallel}
+ 68	2.8	2.1
-100	2.5	1.95
-200	2.2	1.75
-300	1.85	1.30
-400	0.90	0.8

Type:	titanium
Alloy Designation:	4Al-6V

Temperature (F)	k(Btu-in/hr-ft^2-F)
+ 68	62
-100	45
-200	40
-300	33
-400	20

5.2 Measured Emittances

Table 2 lists the emittances of the various materials used in the shadow shield system. The data were obtained from emissometer measurements using the apparatus described in Ref. 5. The values quoted are total hemispherical emittances (integrated over all wavelengths) at room temperature.

---

* Conductivity units are Btu-in/hr-ft^2-F and are given perpendicular and parallel to the thickness.

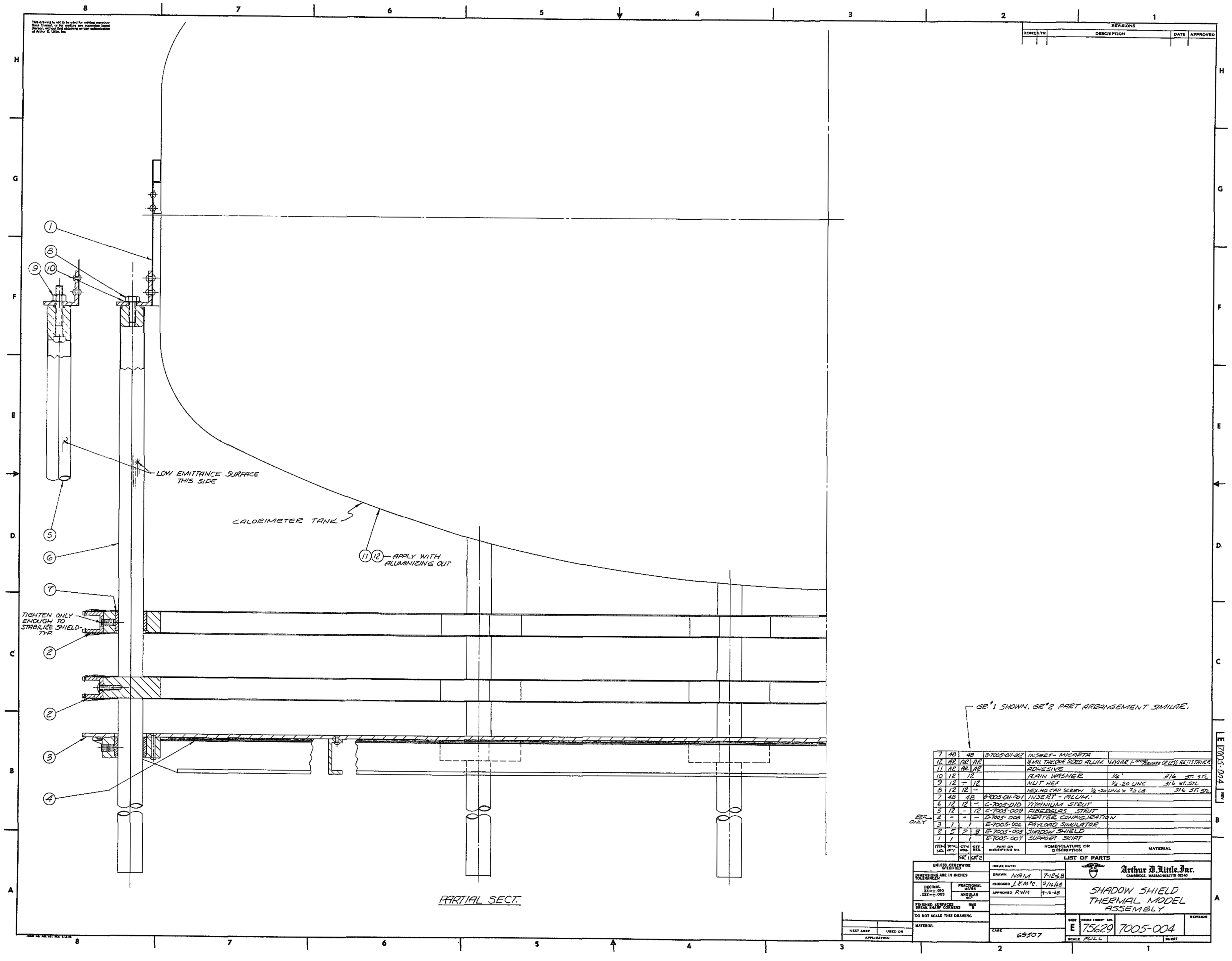
TABLE 2

SUMMARY OF EMITTANCE MEASUREMENTS

	Sample Description	"ε"
1)	Support Skirt Sample (6061-T6 aluminum, buffed and "bright-dipped")	0.024
2)	Payload Simulator Surface Sample (Polished 6061-T6)	0.027
3)	Support Strut Covering (1/4-mil aluminized Mylar)	
	Sample "A"	0.023
	Sample "B"	0.020
4)	Painted Surface of Support Struts (2 coats "3M"-101-C10 Optical Black Velvet - no primer)	0.88
5)	Shadow Shield Fabric (Aluminized Mylar bonded to nylon fabric - aluminized side measured)	
	Sample 868	0.0219
	866	0.0217
	862	0.0215
	861	0.0180
	860	0.0196
	859	0.0197

APPENDIX A

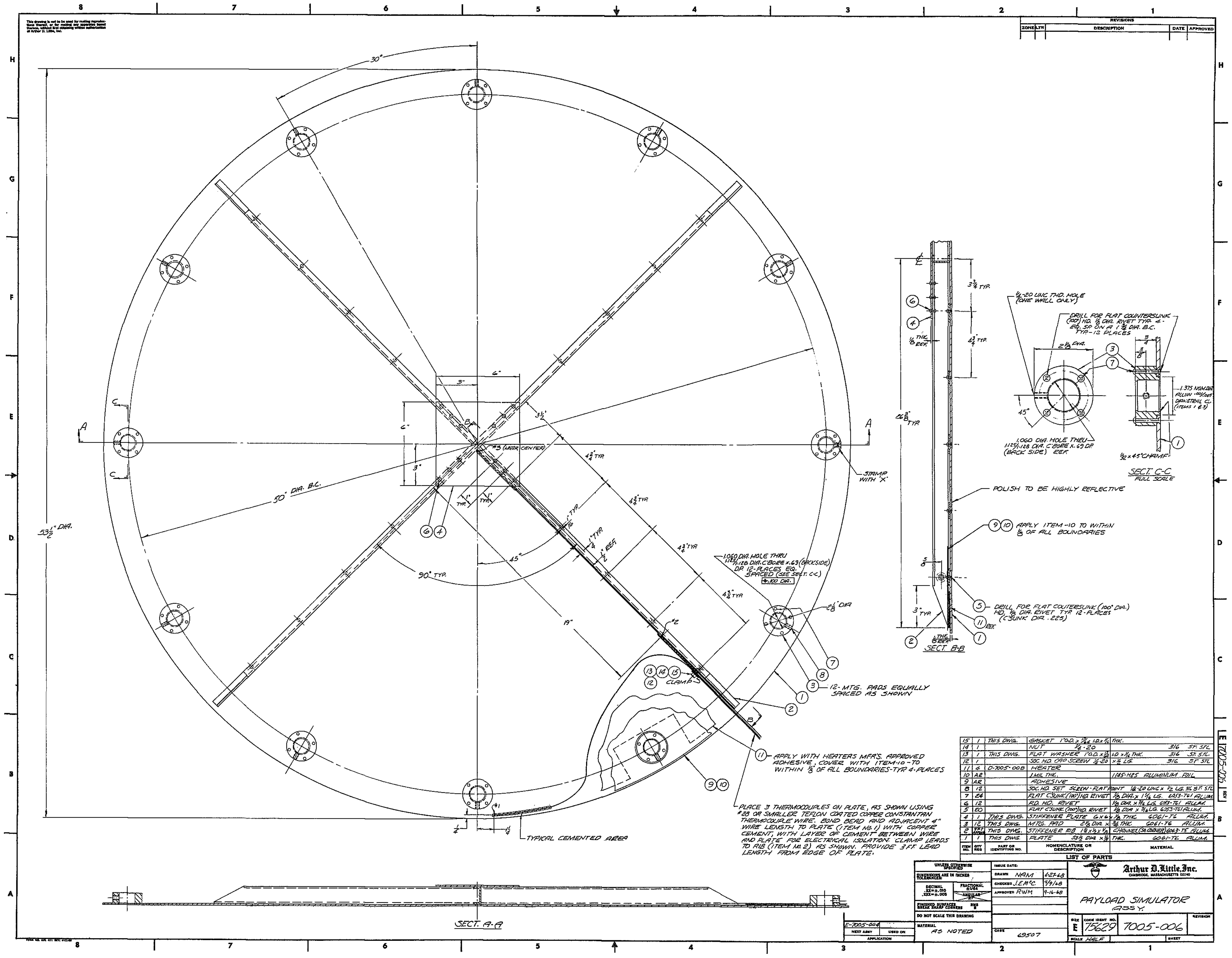
SHADOW SHIELD SYSTEM DRAWINGS



ITEM NO.	TOTAL QTY	QTY. REQ. GR#1	QTY. REQ. GR#2	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL
7	48	48		B-7005-011-002	INSERT- MICARTA	
12	AR	AR	AR		¼ MIL THK. ONE SIDED ALUM.	MYLAR, 1-OHM/SQUARE OR LESS RESISTANCE
11	AR	AR	AR		ADHESIVE	
10	12	12			PLAIN WASHER	¼" 316 ST. STL.
9	12	–	12		NUT HEX	¼-20 UNC 316 ST. STL.
8	12	12	–		HEX. HD. CAP SCREW ¼-20 UNC × ¾ LG.	316 ST. STL.
7	48	48		B-7005-011-001	INSERT - ALUM.	
6	12	12	–	C-7005-010	TITANIUM STRUT	
5	12	–	12	C-7005-009	FIBERGLAS STRUT	
4	–	–	–	D-7005-008	HEATER CONFIGURATION	
3	1	1		E-7005-006	PAYLOAD SIMULATOR	
2	5	2	3	E-7005-005	SHADOW SHIELD	
1	1	1		E-7005-007	SUPPORT SKIRT	

LIST OF PARTS

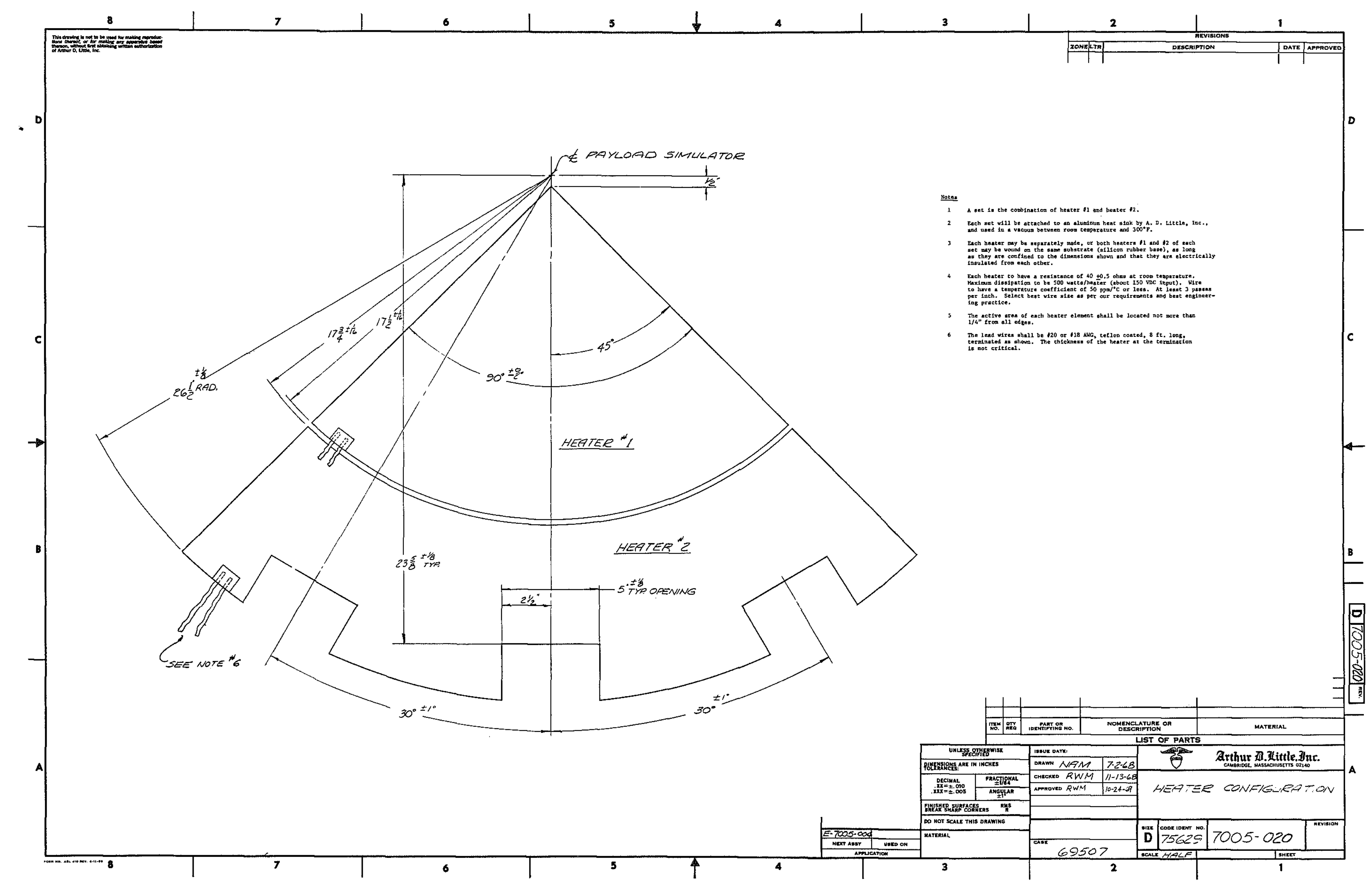
FIGURE A–1



15	1	THIS DWG.	GASKET 1" O.D. x 17/64 I.D. x 1/16	THK.
14	1		NUT ¼-20	316 ST. STL.
13	1	THIS DWG.	FLAT WASHER 1" O.D. x 17/32	I.D. x 1/16 THK. 316 ST. STL.
12	1		SOC. HD. CAP SCREW ¼-20	x ½ LG. 316 ST. STL.
11	4	D-7005-008	HEATER	
10	AR		1 MIL THK.	1145-H25 ALUMINUM FOIL
9	AR		ADHESIVE	
8	12		SOC. HD. SET SCREW-FLAT POINT	¼-20 UNC x ½ LG. 316 ST. STL.
7	24		FLAT C'SUNK (100°) HD. RIVET	⅛ DIA. x 1 1/16 LG. 6053-T61 ALUM.
6	12		RD. HD. RIVET	⅛ DIA. x 3/16 LG. 6053-T61 ALUM.
5	20		FLAT C'SUNK (100°) HD. RIVET	⅛ DIA. x 7/16 LG. 6053-T61 ALUM.
4	1	THIS DWG.	STIFFENER PLATE 6 x 6 x ⅛	THK. 6061-T6 ALUM.
3	12	THIS DWG.	MTG. PAD 2⅛ DIA. x	¾ THK. 6061-T6 ALUM.
2	9 FT APPROX	THIS DWG.	STIFFENER RIB 1½ x ½ x ⅛	CHANNEL (SQ. CORNER) 6063-T5 ALUM.
1	1	THIS DWG.	PLATE 53½ DIA. x ⅛	THK. 6061-T6 ALUM.
ITEM NO.	QTY REQ	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL

LIST OF PARTS

FIGURE A–2



Notes

1 A set is the combination of heater #1 and heater #2.

2 Each set will be attached to an aluminum heat sink by A. D. Little, Inc., and used in a vacuum between room temperature and 300°F.

3 Each heater may be separately made, or both heaters #1 and #2 of each set may be wound on the same substrate (silicon rubber base), as long as they are confined to the dimensions shown and that they are electrically insulated from each other.

4 Each heater to have a resistance of 40 ±0.5 ohms at room temperature. Maximum dissipation to be 500 watts/heater (about 150 VDC input). Wire to have a temperature coefficient of 50 ppm/°C or less. At least 3 passes per inch. Select best wire size as per our requirements and best engineering practice.

5 The active area of each heater element shall be located not more than 1/4" from all edges.

6 The lead wires shall be #20 or #18 AWG, teflon coated, 8 ft. long, terminated as shown. The thickness of the heater at the termination is not critical.

ITEM NO.	QTY REQ	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL

LIST OF PARTS

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES:
DECIMAL .XX = ±.010 .XXX = ±.005
FRACTIONAL ±1/64
ANGULAR ±1°
FINISHED SURFACES RMS
BREAK SHARP CORNERS R
DO NOT SCALE THIS DRAWING
MATERIAL

E-7005-006
NEXT ASSY
USED ON
APPLICATION

ISSUE DATE:
DRAWN NAM 7-2-68
CHECKED RWM 11-13-68
APPROVED RWM 10-24-68
CASE 69507

Arthur D. Little, Inc.
CAMBRIDGE, MASSACHUSETTS 02140

HEATER CONFIGURATION

SIZE D
CODE IDENT NO. 75625
7005-020
REVISION
SCALE HALF
SHEET

FIGURE A–3

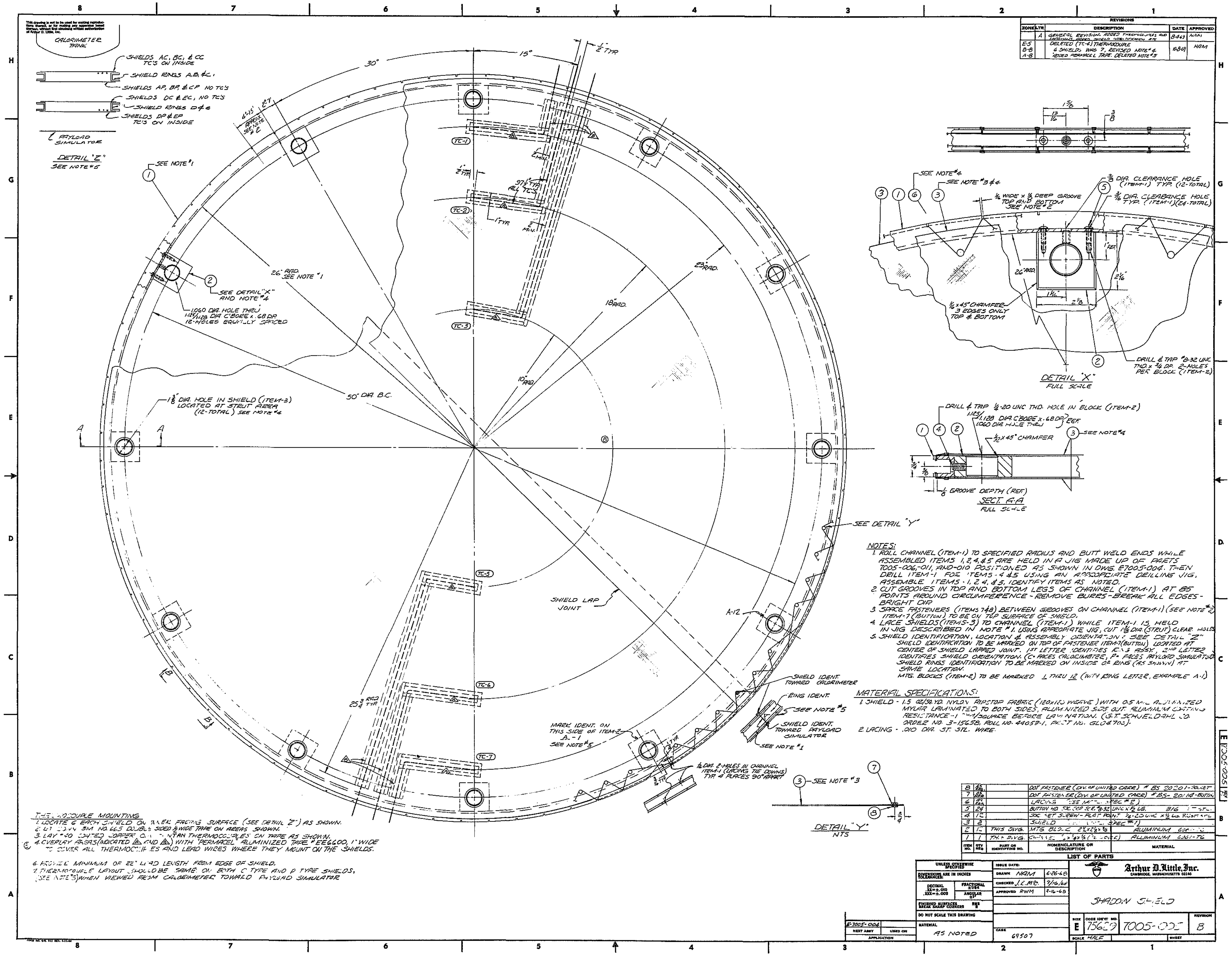
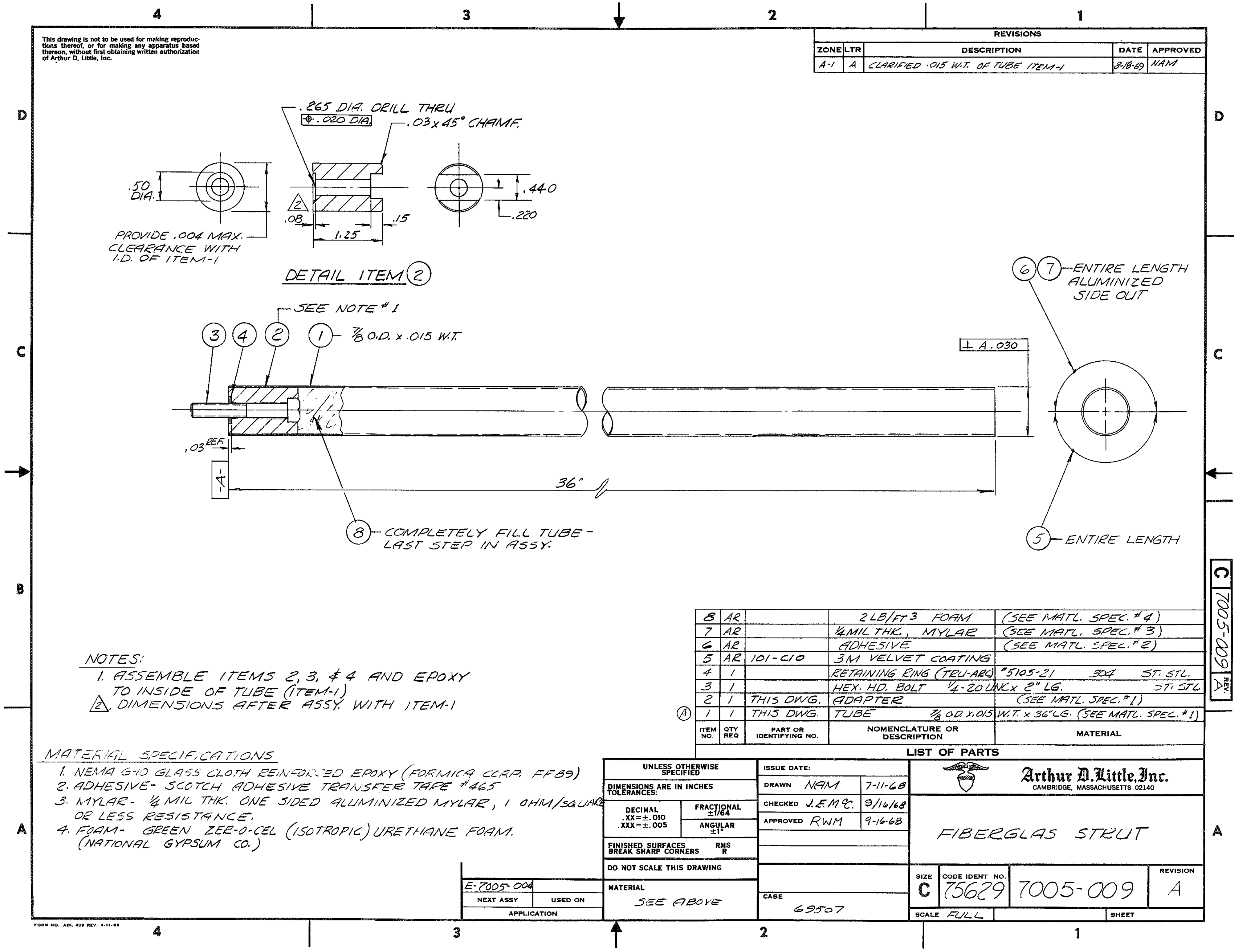

CALORIMETER TANK
SHIELDS AC, BC, & CC TC'S ON INSIDE
SHIELD RINGS A,B, & C
SHIELDS AP, BP, & CP NO TC'S
SHIELDS DC & EC, NO TC'S
SHIELD RINGS D & E
SHIELDS DP & EP TC'S ON INSIDE
℄ PAYLOAD SIMULATOR
DETAIL "Z"
SEE NOTE #5
SEE NOTE #1
26" RAD. SEE NOTE #1
SEE DETAIL "X" AND NOTE #4
1.060 DIA. HOLE THRU 1.125/1.128 DIA C'BORE x .68 DP 12-HOLES EQUALLY SPACED
1⅛" DIA. HOLE IN SHIELD (ITEM-3) LOCATED AT STRUT AREA (12-TOTAL) SEE NOTE #4
50" DIA B.C.
30°
15°
25⅝" RAD.
18" RAD.
10" RAD.
TC-1
TC-2
TC-3
TC-5
TC-6
TC-7
SHIELD LAP JOINT
MARK IDENT. ON THIS SIDE OF ITEM-2 A-1 SEE NOTE #5
SHIELD IDENT. TOWARD CALORIMETER
RING IDENT.
SEE NOTE #5
SHIELD IDENT. TOWARD PAYLOAD SIMULATOR
SEE NOTE #1
¼ DIA. 2-HOLES IN CHANNEL ITEM-1 (LACING TIE DOWNS) TYP 4 PLACES 90° APART
A-12
SEE DETAIL "Y"
SEE NOTE #3
DETAIL "Y"
NTS
SEE NOTE #4
SEE NOTE #3 & 4
⅜ DIA. CLEARANCE HOLE (ITEM-1) TYP. (12-TOTAL)
¼ WIDE x ⅛ DEEP GROOVE TOP AND BOTTOM SEE NOTE #2
3/16 DIA. CLEARANCE HOLE TYP. (ITEM-1) (24-TOTAL)
1/16 x 45° CHAMFER 3 EDGES ONLY TOP & BOTTOM
DRILL & TAP #8-32 UNC THD. x ⅜ DP. 2-HOLES PER BLOCK (ITEM-2)
DETAIL "X"
FULL SCALE
DRILL & TAP ¼-20 UNC THD. HOLE IN BLOCK (ITEM-2)
1.125/1.128 DIA C'BORE x .68 DP REF.
1.060 DIA HOLE THRU
1/32 x 45° CHAMFER
SEE NOTE #4
⅛ GROOVE DEPTH (REF)
SECT. A-A
FULL SCALE
NOTES:
1. ROLL CHANNEL (ITEM-1) TO SPECIFIED RADIUS AND BUTT WELD ENDS WHILE ASSEMBLED ITEMS 1, 2, 4, & 5 ARE HELD IN A JIG MADE UP OF PARTS 7005-006, -011, AND -010 POSITIONED AS SHOWN IN DWG. E7005-004. THEN DRILL ITEM-1 FOR ITEMS-4 & 5 USING AN APPROPRIATE DRILLING JIG. ASSEMBLE ITEMS-1, 2, 4, & 5, IDENTIFY ITEMS AS NOTED.
2. CUT GROOVES IN TOP AND BOTTOM LEGS OF CHANNEL (ITEM-1) AT 85 POINTS AROUND CIRCUMFERENCE - REMOVE BURRS - BREAK ALL EDGES - BRIGHT DIP
3. SPACE FASTENERS (ITEMS 7 & 8) BETWEEN GROOVES ON CHANNEL (ITEM-1) (SEE NOTE #2) ITEM-7 (BUTTON) TO BE ON TOP SURFACE OF SHIELD.
4. LACE SHIELDS (ITEMS-3) TO CHANNEL (ITEM-1) WHILE ITEM-1 IS HELD IN JIG DESCRIBED IN NOTE #1. USING APPROPIATE JIG, CUT 1⅛ DIA. (STRUT) CLEAR HOLES
5. SHIELD IDENTIFICATION, LOCATION & ASSEMBLY ORIENTATION: SEE DETAIL "Z" SHIELD IDENTIFICATION TO BE MARKED ON TOP OF FASTENER ITEM-7 (BUTTON) LOCATED AT CENTER OF SHIELD LAPPED JOINT. 1ST LETTER IDENTIFIES RING ASSY., 2ND LETTER IDENTIFIES SHIELD ORIENTATION. (C = FACES CALORIMETER, P = FACES PAYLOAD SIMULATOR) SHIELD RINGS IDENTIFICATION TO BE MARKED ON INSIDE OF RING (AS SHOWN) AT SAME LOCATION. MTG. BLOCKS (ITEM-2) TO BE MARKED 1 THRU 12 (WITH RING LETTER, EXAMPLE A-1)
MATERIAL SPECIFICATIONS:
1. SHIELD - 1.5 OZ/SQ.YD. NYLON RIPSTOP FABRIC (120x120 WEAVE) WITH 0.5 MIL ALUMINIZED MYLAR LAMINATED TO BOTH SIDES, ALUMINIZED SIDE OUT. ALUMINUM COATING RESISTANCE - 1 OHM/SQUARE BEFORE LAMINATION. (G.T. SCHJELDAHL CO. ORDER NO. 3-15658, ROLL NO. 44053-1, PART NO. GL04702).
2. LACING - .010 DIA. ST. STL. WIRE.
THERMOCOUPLE MOUNTING
1. LOCATE 6 EACH SHIELD ON INNER FACING SURFACE (SEE DETAIL "Z") AS SHOWN.
2. LAY DOWN 3M NO. 665 DOUBLE SIDED ½ WIDE TAPE ON AREAS SHOWN.
3. LAY #40 COATED COPPER CONSTANTAN THERMOCOUPLES ON TAPE AS SHOWN.
4. OVERLAY AREAS (INDICATED A AND B) WITH "PERMACEL" ALUMINIZED TAPE #EE6600, 1" WIDE TO COVER ALL THERMOCOUPLES AND LEAD WIRES WHERE THEY MOUNT ON THE SHIELDS.
6. PROVIDE MINIMUM OF 22" LEAD LENGTH FROM EDGE OF SHIELD.
7. THERMOCOUPLE LAYOUT SHOULD BE SAME ON BOTH C TYPE AND P TYPE SHIELDS, (SEE NOTE #5) WHEN VIEWED FROM CALORIMETER TOWARD PAYLOAD SIMULATOR
REVISIONS
A GENERAL REVISION. ADDED THERMOCOUPLES
DELETED (TC-4) THERMOCOUPLE
6 SHIELDS, WAS 7, REVISED NOTE #4
ADDED PERMACEL TAPE. DELETED NOTE #5
8 AS REQ. DOT FASTENER (DIV. OF UNITED CARR) # BS 20201-SOCKET
7 AS REQ. DOT FASTENER (DIV. OF UNITED CARR) #BS-20114-BUTTON
6 AS REQ. LACING (SEE MATL. SPEC #2)
5 24 BUTTON HD. SOC. CAP SCR. #8-32 UNC x ½ LG. 316 ST. STL.
4 12 SOC. SET SCREW - FLAT POINT ¼-20 UNC x ½ LG. 316 ST. STL.
3 2 SHIELD (SEE MATL. SPEC #1)
2 12 THIS DWG. MTG. BLOCK 2¼x2⅛x¾ ALUMINUM 6061-T6
1 1 THIS DWG. CHANNEL ALUMINUM 6061-T6
ITEM NO. / QTY REQ / PART OR IDENTIFYING NO. / NOMENCLATURE OR DESCRIPTION / MATERIAL
LIST OF PARTS
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES TOLERANCES:
DECIMAL .XX=±.010 .XXX=±.005
FRACTIONAL ±1/64
ANGULAR ±1°
FINISHED SURFACES BREAK SHARP CORNERS
DO NOT SCALE THIS DRAWING
MATERIAL AS NOTED
DRAWN NAM 6-26-68
CHECKED J.E.MC. 9/16/68
APPROVED RWM 9-16-68
CASE 69507
Arthur D. Little, Inc.
CAMBRIDGE, MASSACHUSETTS 02140
SHADOW SHIELD
SIZE E
CODE IDENT NO. 75629
7005-005
REVISION B
SCALE HALF
E-7005-004
NEXT ASSY
USED ON
APPLICATION
E 7005-005

FIGURE A–4



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REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED
A-1	A	CLARIFIED .015 W.T. OF TUBE ITEM-1	8-18-69	NAM

NOTES:
1. ASSEMBLE ITEMS 2, 3, & 4 AND EPOXY TO INSIDE OF TUBE (ITEM-1)
2. DIMENSIONS AFTER ASSY. WITH ITEM-1

MATERIAL SPECIFICATIONS
1. NEMA G-10 GLASS CLOTH REINFORCED EPOXY (FORMICA CORP. FF89)
2. ADHESIVE- SCOTCH ADHESIVE TRANSFER TAPE #465
3. MYLAR- 1/4 MIL THK. ONE SIDED ALUMINIZED MYLAR, 1 OHM/SQUARE OR LESS RESISTANCE.
4. FOAM- GREEN ZER-O-CEL (ISOTROPIC) URETHANE FOAM. (NATIONAL GYPSUM CO.)

ITEM NO.	QTY REQ	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL
8	AR		2 LB/FT3 FOAM	(SEE MATL. SPEC. #4)
7	AR		1/4 MIL THK., MYLAR	(SEE MATL. SPEC. #3)
6	AR		ADHESIVE	(SEE MATL. SPEC. #2)
5	AR	101-C10	3M VELVET COATING	
4	1		RETAINING RING (TRU-ARC)	#5105-21 304 ST. STL.
3	1		HEX. HD. BOLT 1/4-20 UNC x 2" LG.	ST. STL.
2	1	THIS DWG.	ADAPTER	(SEE MATL. SPEC. #1)
Ⓐ 1	1	THIS DWG.	TUBE 7/8 O.D. x .015	W.T. x 36" LG. (SEE MATL. SPEC. #1)

LIST OF PARTS

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES:
DECIMAL .XX = ±.010 .XXX = ±.005
FRACTIONAL ±1/64
ANGULAR ±1°
FINISHED SURFACES RMS
BREAK SHARP CORNERS R
DO NOT SCALE THIS DRAWING
MATERIAL SEE ABOVE

E-7005-004
NEXT ASSY | USED ON
APPLICATION

ISSUE DATE:
DRAWN NAM 7-11-68
CHECKED J.E.McC. 9/16/68
APPROVED RWM 9-16-68
CASE 69507

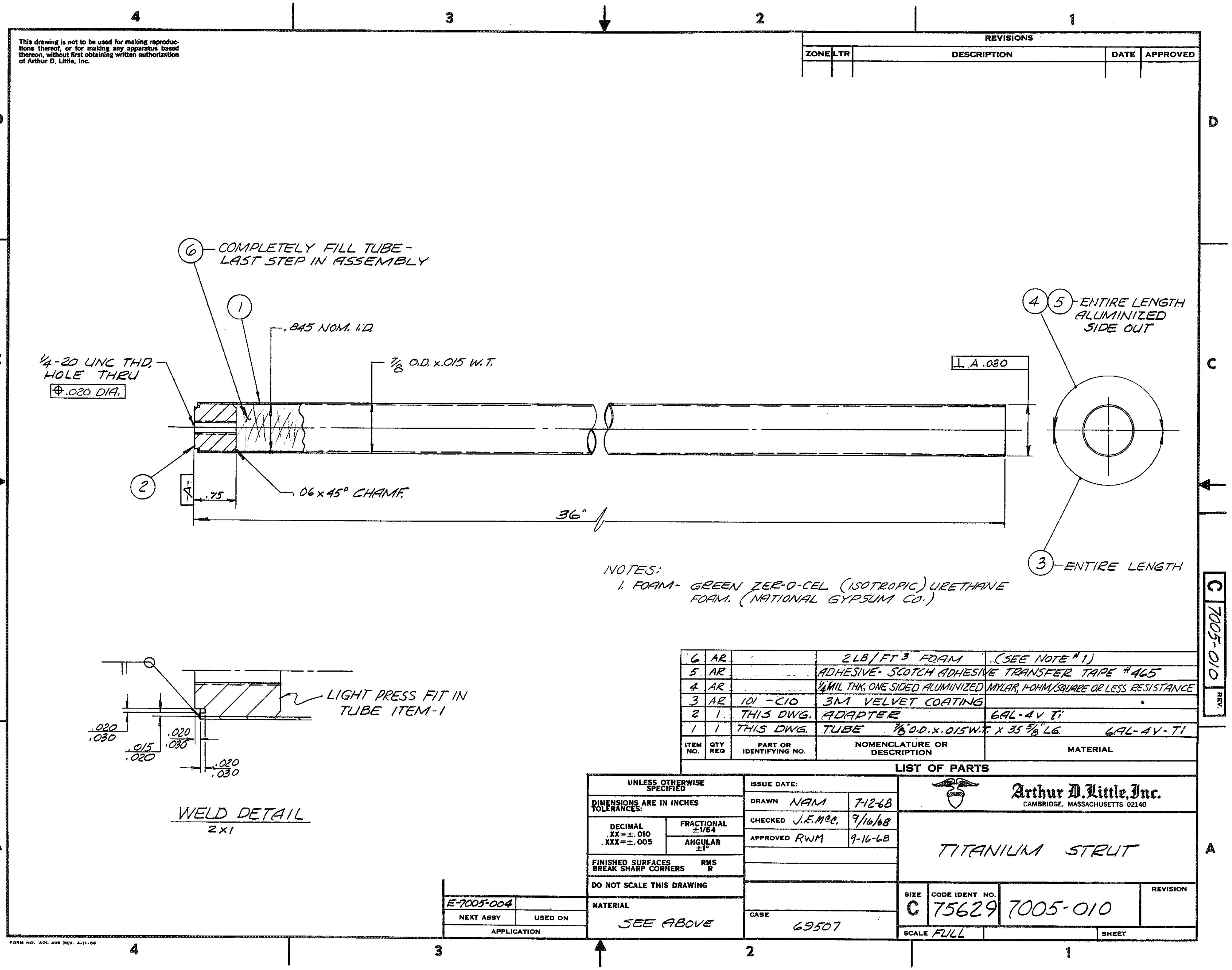
Arthur D. Little, Inc.
CAMBRIDGE, MASSACHUSETTS 02140

FIBERGLAS STRUT

SIZE C
CODE IDENT NO. 75629
7005-009
REVISION A
SCALE FULL
SHEET

FORM NO. ADL 409 REV. 4-11-66

FIGURE A–5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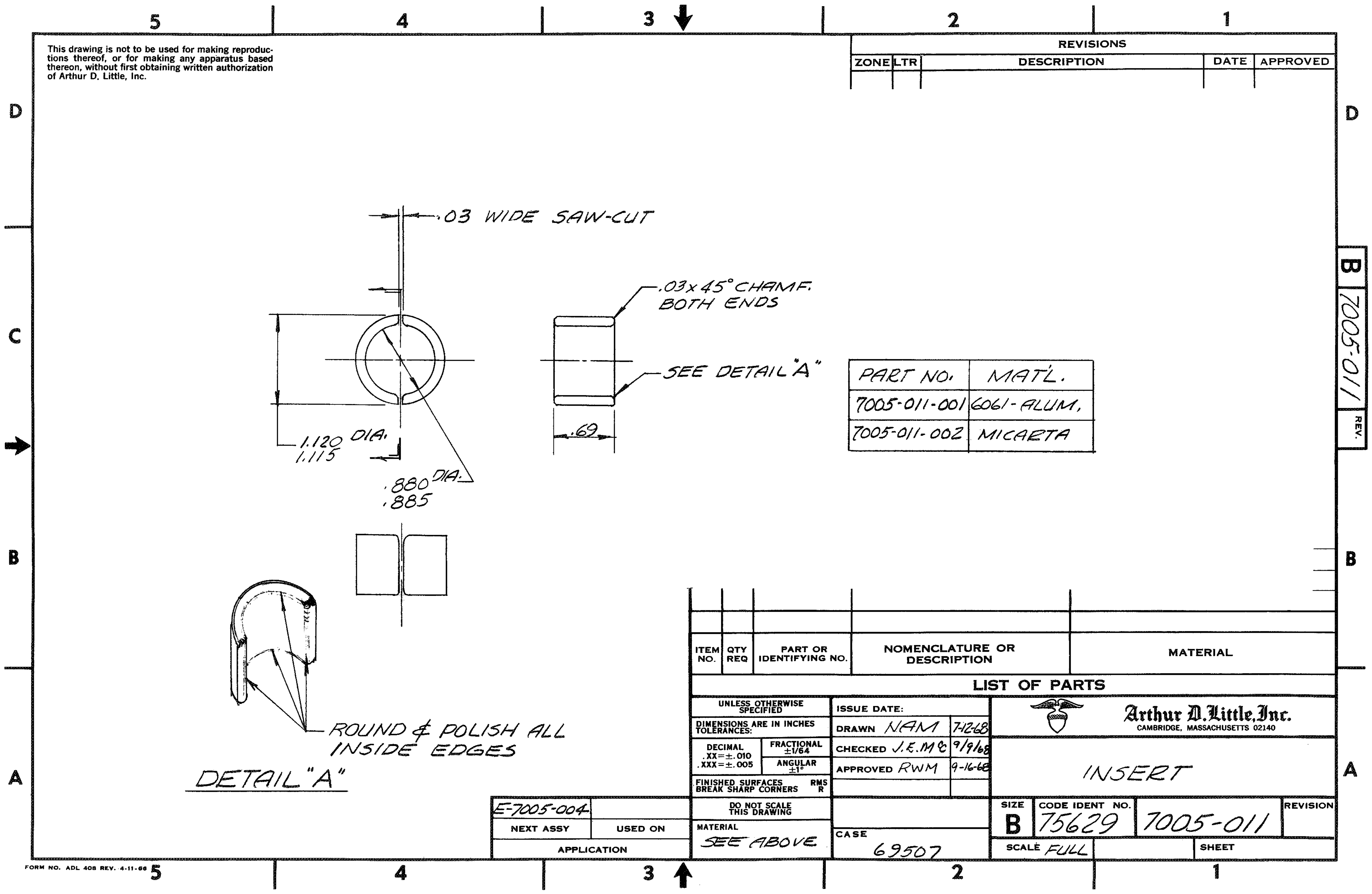
REVISIONS
ZONE LTR DESCRIPTION DATE APPROVED
6 — COMPLETELY FILL TUBE - LAST STEP IN ASSEMBLY
1
.845 NOM. I.D.
7/8 O.D. x .015 W.T.
1/4-20 UNC THD. HOLE THRU
⊕ .020 DIA.
2
A
.75
.06 x 45° CHAMF.
36"
⊥ A .030
4 5 — ENTIRE LENGTH ALUMINIZED SIDE OUT
3 — ENTIRE LENGTH
NOTES:
1. FOAM - GREEN ZER-O-CEL (ISOTROPIC) URETHANE FOAM. (NATIONAL GYPSUM CO.)
LIGHT PRESS FIT IN TUBE ITEM-1
.020 .030
.015 .020
.020 .030
.020 .030
WELD DETAIL
2x1
6 AR 2LB/FT3 FOAM (SEE NOTE #1)
5 AR ADHESIVE - SCOTCH ADHESIVE TRANSFER TAPE #465
4 AR 1/4 MIL THK, ONE SIDED ALUMINIZED MYLAR, 1-OHM/SQUARE OR LESS RESISTANCE
3 AR 101-C10 3M VELVET COATING
2 1 THIS DWG. ADAPTER 6AL-4V Ti
1 1 THIS DWG. TUBE 7/8" O.D. x .015 W.T. x 35 5/8" LG. 6AL-4V-Ti
ITEM NO. QTY REQ PART OR IDENTIFYING NO. NOMENCLATURE OR DESCRIPTION MATERIAL
LIST OF PARTS
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES:
DECIMAL .XX=±.010 .XXX=±.005
FRACTIONAL ±1/64
ANGULAR ±1°
FINISHED SURFACES RMS R
BREAK SHARP CORNERS
DO NOT SCALE THIS DRAWING
MATERIAL SEE ABOVE
ISSUE DATE:
DRAWN NAM 7-12-68
CHECKED J.E.McC. 9/16/68
APPROVED RWM 9-16-68
CASE 69507
Arthur D. Little, Inc.
CAMBRIDGE, MASSACHUSETTS 02140
TITANIUM STRUT
SIZE C
CODE IDENT NO. 75629
7005-010
REVISION
SCALE FULL
SHEET
E-7005-004
NEXT ASSY USED ON
APPLICATION
C 7005-010 REV.
FORM NO. ADL 409 REV. 4-11-68

FIGURE A–6



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PART NO.	MAT'L.
7005-011-001	6061-ALUM.
7005-011-002	MICAETA

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES:
DECIMAL .XX = ±.010 .XXX = ±.005
FRACTIONAL ±1/64
ANGULAR ±1°
FINISHED SURFACES RMS R
BREAK SHARP CORNERS
DO NOT SCALE THIS DRAWING
MATERIAL SEE ABOVE

ISSUE DATE:
DRAWN NAM 7-12-68
CHECKED J.E.M.C. 9/9/68
APPROVED RWM 9-16-68
CASE 69507

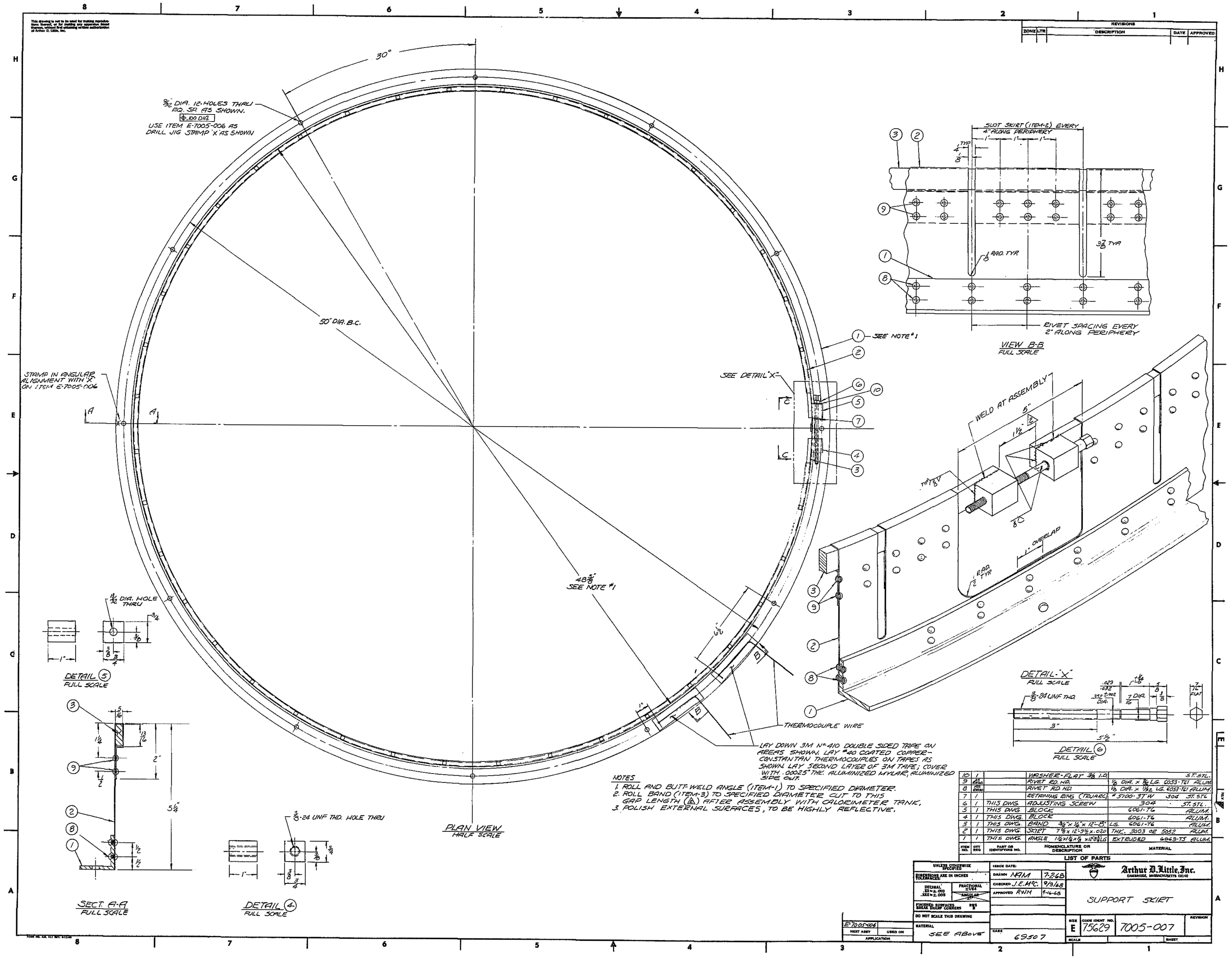
Arthur D. Little, Inc.
CAMBRIDGE, MASSACHUSETTS 02140

INSERT

SIZE B
CODE IDENT NO. 75629
7005-011
REVISION
SCALE FULL
SHEET

E-7005-004
NEXT ASSY
USED ON
APPLICATION

FIGURE A–7



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LAY DOWN 3M Nº 410 DOUBLE SIDED TAPE ON AREAS SHOWN. LAY #40 COATED COPPER-CONSTANTAN THERMOCOUPLES ON TAPES AS SHOWN. LAY SECOND LAYER OF 3M TAPE; COVER WITH .00025" THK. ALUMINIZED MYLAR, ALUMINIZED SIDE OUT.

NOTES

1. ROLL AND BUTT-WELD ANGLE (ITEM-1) TO SPECIFIED DIAMETER.
2. ROLL BAND (ITEM-3) TO SPECIFIED DIAMETER CUT TO THIS GAP LENGTH (Ⓐ) AFTER ASSEMBLY WITH CALORIMETER TANK,
3. POLISH EXTERNAL SURFACES, TO BE HIGHLY REFLECTIVE.

ITEM NO.	QTY REQ	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL
10	1		WASHER-FLAT 3/8 I.D.	ST. STL.
9	AS REQD		RIVET RD. HD.	1/8 DIA. × 7/32 LG. 6053-T61 ALUM.
8	AS REQD		RIVET RD. HD.	1/8 DIA. × 11/32 LG. 6053-T61 ALUM.
7	1		RETAINING RING (TRUARC)	#5100-37W 304 ST. STL.
6	1	THIS DWG.	ADJUSTING SCREW	304 ST. STL.
5	1	THIS DWG.	BLOCK	6061-T6 ALUM.
4	1	THIS DWG.	BLOCK	6061-T6 ALUM.
3	1	THIS DWG.	BAND 3/4" × 1/4" × 12'-8"	LG. 6061-T6 ALUM.
2	1	THIS DWG.	SKIRT 7 1/8 × 12'-9 1/2 × .020	THK. 3003 OR 5052 ALUM.
1	1	THIS DWG.	ANGLE 1 1/4 × 1 1/4 × 1/8 × 12'-8 1/2 LG	EXTRUDED 6063-T5 ALUM.

LIST OF PARTS

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES:
DECIMAL .XX = ±.010 .XXX = ±.005
FRACTIONAL ±1/64
ANGULAR ±1°
FINISHED SURFACES BREAK SHARP CORNERS RMS
DO NOT SCALE THIS DRAWING
MATERIAL SEE ABOVE
E-7005-004 NEXT ASSY
USED ON
APPLICATION
ISSUE DATE:
DRAWN NAM 7-2-68
CHECKED J.E.McC. 9/9/68
APPROVED RWM 9-16-68
CASE 69507
Arthur D. Little, Inc.
CAMBRIDGE, MASSACHUSETTS 02140
SUPPORT SKIRT
SIZE E
CODE IDENT NO. 75629
7005-007
REVISION
SCALE
SHEET

REVISIONS
ZONE | LTR | DESCRIPTION | DATE | APPROVED

FIGURE A–8

APPENDIX B

Distribution List for Final Report NASA CR-72595

"CONCEPTUAL DESIGN AND ANALYSIS OF SHADOW SHIELD SYSTEMS FOR THERMAL PROTECTION OF CRYOGENIC PROPELLANTS"

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Cambridge, Massachusetts 02140

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