ALSEP
CASK SUPPORT
DESIGN REVIEW
CCP 29
29 November 1967

ATM
725

Bendix Aerospace Systems Division

ALSEP CASK SUPPORT DESIGN REVIEW - CCP 29

29 November 1967

AGENDA

1.	Mechanical Design	W. Durrant
2.	Stress Analysis (Thermal and Static)	Dr. D. Dewhirst
3.	Dynamic Analysis	Dr. H. P. Lee
4.	Thermal Analysis	J. McNaughton
5.	Mechanical G & E	V. Jansen
6.	Astronaut Protection	A. Micocci

SECTION 1

MECHANICAL DESIGN

The Cask Support Assembly has been designed in accordance with the requirements laid down in the document CCP 29, (4 August 1967).

Briefly this refers to an interface with both the Grumman LM Structure (LID-360-22809) and the G.E. cask (IC 314121 and ICD 2334552). The specifications used by Bendix are:

1. The weight of the cask and support structure shall not exceed 60 lbs. (The cask/fuel capsule weight was to be 40 lbs nominally, although at the date of design commencement it was around 45 lbs. Bendix used a weight target of 20lbs for the design of the support structure.)

2. Equipment used by the astronaut during fuel transfer operations shall not exceed 250°F.

3. Tools required by the astronaut for fuel transfer - apart from the fuel handling tool which is G.F.E. - will be designed and manufactured. The weight for such tools will not be included in the 60 lbs. Stowage for such tools would not be part of this exercise but will be considered later.

4. The physical properties of the graphite were those stated in the CCP 29 document (and G.E. meeting minutes of 13 July 1967)

5. The maximum temperature on the surface of the cask shall be 800°F and circumferential gradients around the cask will not exceed 150°F.

6. The principal dimensions of the cask shall be in accordance with ICD 2334552 and internal details will be as on G.E. drawing SK-012067-19D dated 21 April 1967. The provisions of IC 314121 shall apply. The center of gravity of the cask will be 12 inches from the lower end of the cask and will be on the "x" axis.

7. The maximum torque and force that the astronaut can apply are 20 in lbs and 20 lbs, respectively.

8. The quasi-steady-state design load factor, in all three principal axes, is 60 g.

Fuel Cask Support Assembly (Fig. #1.1)

The material principally used for the design of the Cask Support Assembly is titanium. A small amount of stainless steel is used, primarily to avoid the engagement of similar material at points in the design where vacuum welding could occur.

Titanium was selected for three main reasons:

1. Low density - (.16 lbs/cu. in. compared with .29 lbs/cu. in. for steel), yet with an ultimate tensile strength about the same as the 300 series stainless steels.

2. Low coefficient of thermal expansion which is particularly desirable in the band arrangement for the cask.

3. Adequate strength at elevated temperature ($800^{\circ}F$)

Titanium was considered the most suitable material for use in the cask band arrangement where it is used as an elastic material which is pretensioned at room temperature so that adequate frictional loading remains on the cask when the temperature of $700-800^{\circ}F$ is reached.

Structure (Fig. #1.2)

This is a system of 2 "U" members which are attached to the LM interface points and stabilized by vertical and diagonal members. The lower "U" cradle is supported, when the cask is rotated for unloading, by two small links attached to the diagonal members.

On the lower cradle, trunnion attachment points for the cask are articulated to ensure that axial loads in the cask are only reacted by the support structure at the upper cradle. This loading requirement for the support of the cask was requested by G.E. and adds complication and weight to the support structure due to the condition which exists when the cask is rotated, and supported only by the lower cradle.

FUEL CASK SUPPORT ASSEMBLY

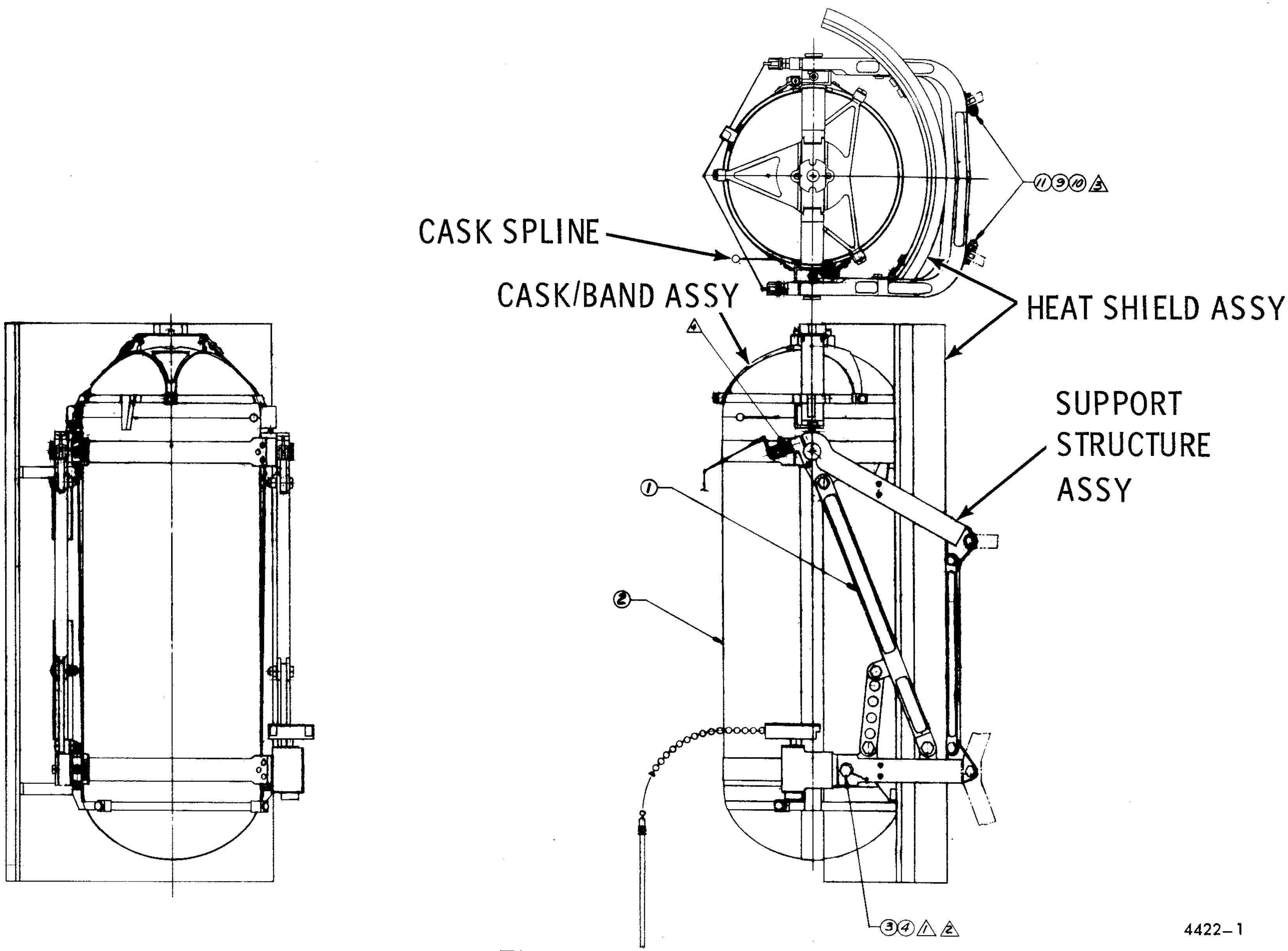

Figure 1.1

STRUCTURE ASSY. FUEL CASK

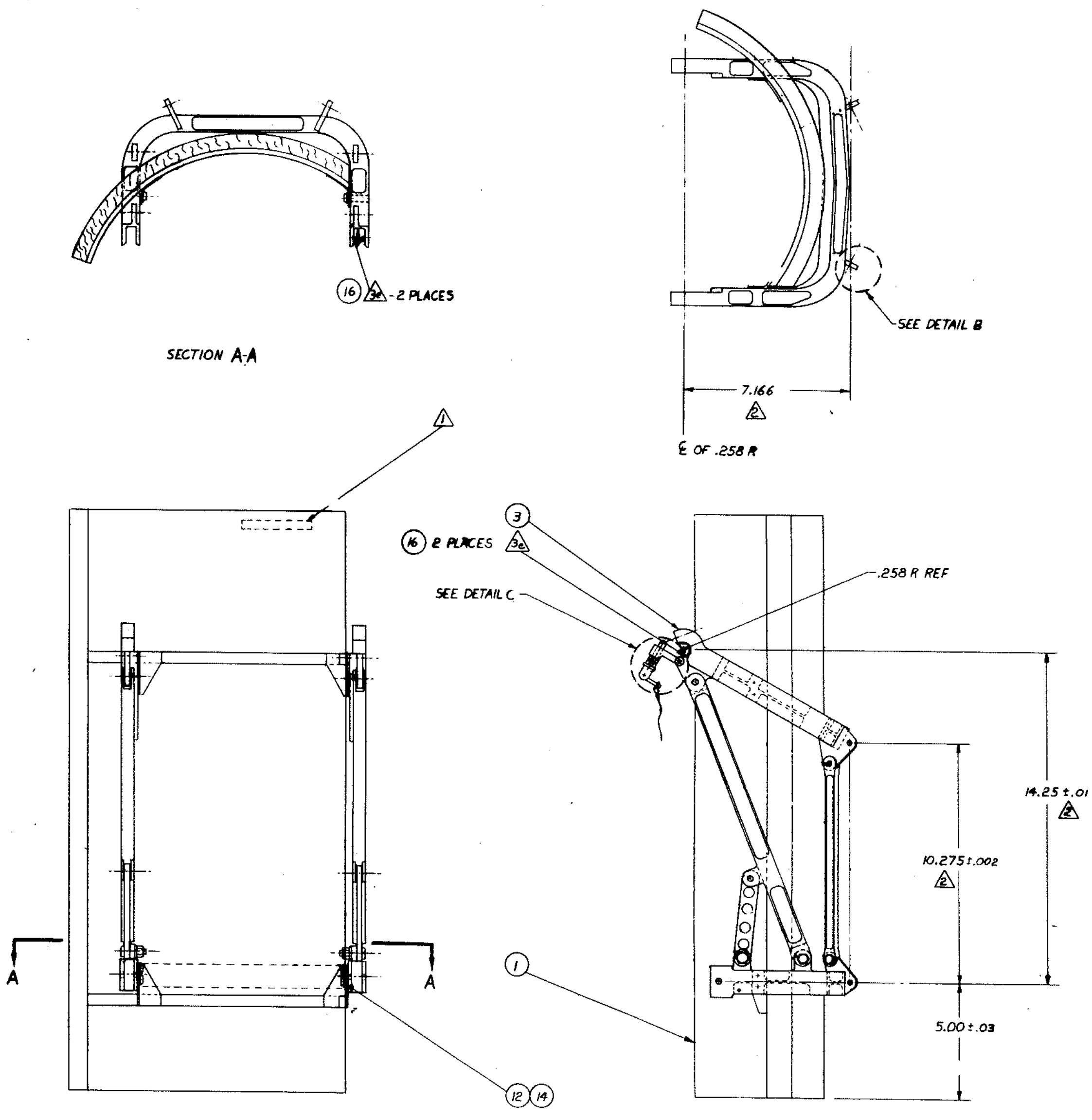

Figure 1.2

The upper cradle carries the trunnion release mechanism (Fig. #1.3) - consisting of 2 levers which close over the two upper trunnions. The levers are each secured by a ball-lock type pin which can be pretensioned to the flight "g" load by an adjuster nut which is then secured by a locknut. Release of the levers, prior to cask rotation is obtained by means of a lanyard attached to the pins - pulling the lanyard unlocks the ball pins and the pretension in the pins and levers ejects the lever assemblies which rotate about their pivot points.

The astronaut will need to exert a pull of 15 lbs maximum to release each lever. The levers may be released one after the other if necessary. This mechanism has yet to be proved under representative environmental conditions. Dissimilar materials for the components of this device have been used to minimize the possibility of vacuum welding occuring. In addition, a dry lubricant, ALPHA Molykote # 3 2 1, will be deposited on the interfacing components to increase protection from this complication.

The dry lubricant is also applied to the articulated links at the outer ends of the lower cradle and the Tilt Gear Box components.

Tilt Gear Box (Fig. #1.4)

The gear box replaces a more simple device for rotating the cask and locking it in the position for the operations to be performed on the cask. The astronaut must rotate the cask and choose a position for it which is dependent on the final attitude of the LM vehicle on the lunar surface and the height of his line of sight. It is therefore impossible to determine in advance a suitable attitude for the cask.

The earlier device enabled the astronaut to rotate the cask by means of a tool which was an extension of the rotating trunnion. The redesign of the LM door, which now opens to a position which prevents access to this trunnion, made it necessary for the astronaut to rotate the cask from a position in front of the assembly.

A level gear box would make this possible but the worm gear arrangement which has been chosen provides, in addition, the automatic locking of the cask in any position selected by the astronaut. A worm gear box suffers from considerable reduction in efficiency due to the high degree of friction inherent in its design if it is to be operable only from the worm

UPPERTRUNNION RELEASE MECHANISM

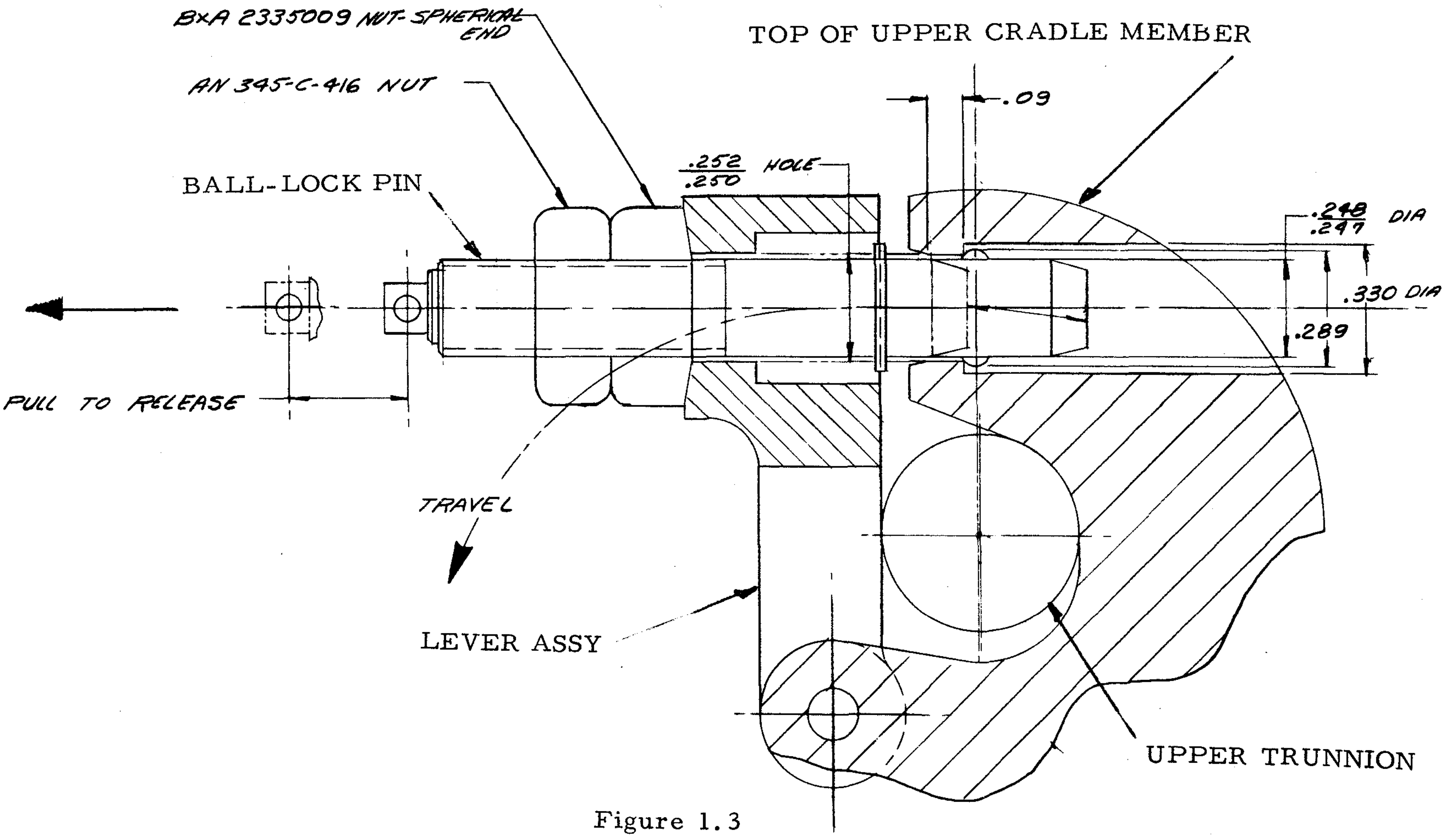

Figure 1.3

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CASK ROTATION DETAILS

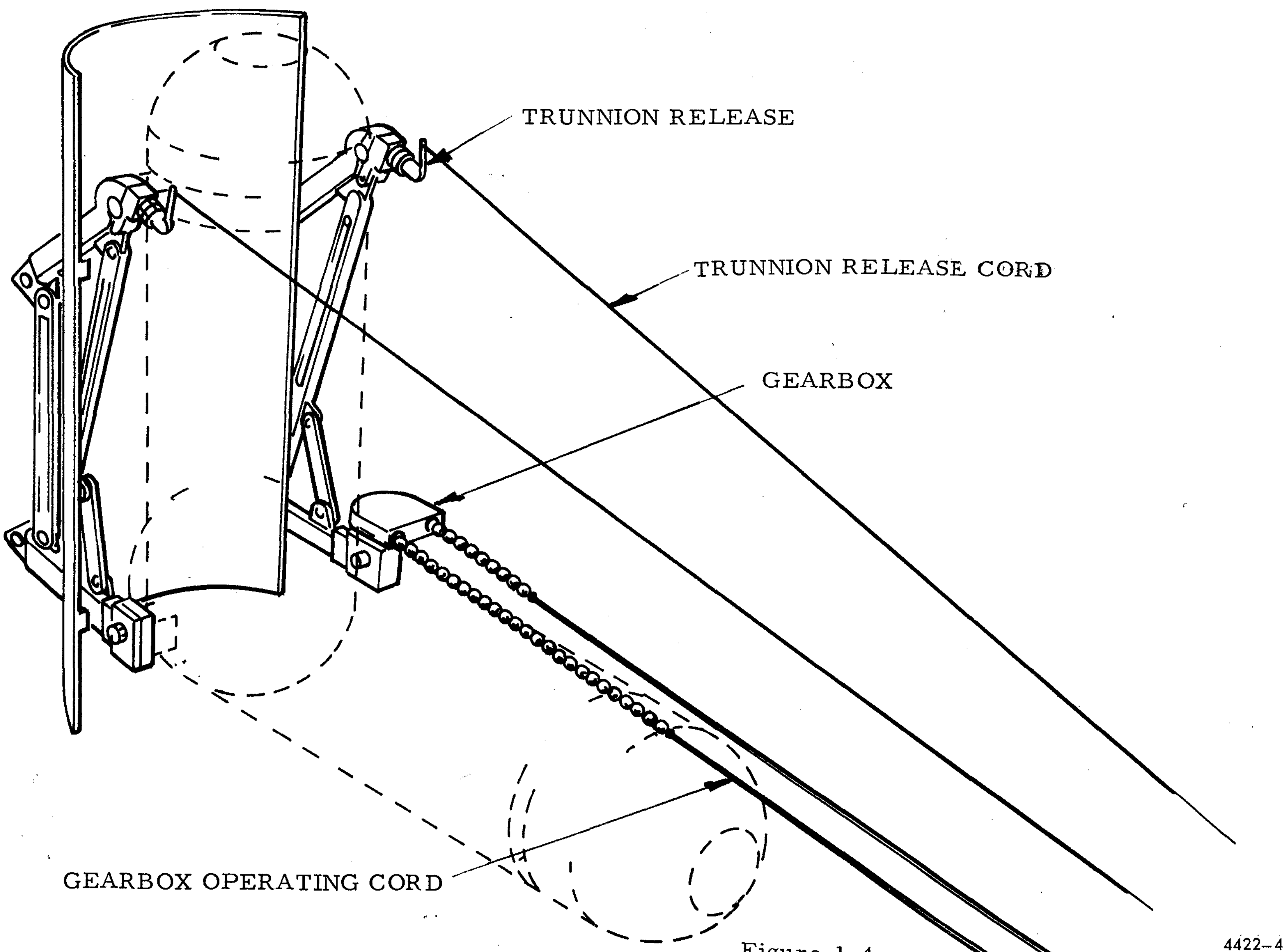

Figure 1.4

shaft, which, in this case, is necessary. The effort required from the astronaut to operate the gear box in the worst position under vacuum conditions must be finally determined by practical tests. Calculations indicate that the maximum effort required will be 12 lbs.

The gear box (Fig. #1.5) is operated by rotating a sprocket by means of a chain. The sprocket is attached to one end of the worm shaft whose worm is engaged by the worm wheel. The worm wheel is directly attached to the right hand trunnion, as seen by the astronaut. To minimize secondary friction the worm shaft runs in a pair of self-aligning ball bearings and both the lower cask trunnions also run in ball bearings. The worm is made from stainless steel and the worm wheel from titanium to avoid similar materials at this point of maximum friction. As has already been stated, the working faces of the gear box components are treated with the dry lubricant ALPHA Molykote #321.

To reduce weight, only that part of the pull cord, by which the astronaut operates the gear box, passing through the sprocket housing is metal - in fact, a bead chain - the section actually handled by the astronaut is of glass fiber.

<u>Band Arrangement (Fig. #1.6)</u>

The cask is secured to the Support Structure by an arrangement of 3 bands - one axial band and two circumferential bands. This method of support has been chosen because it is not possible to incorporate either adequate holes or protrusions on the outer face of the graphite cask - six 1/8 diameter holes have finally been inserted in the graphite outer face but are not suitable for support of the cask against high "g" loads.

This method of cask support is by no means ideal and imposes difficulties in tightening of the bands, determination of band pretension, alignment of trunnions and removal of the upper dome for capsule removal. However, under the circumstances it is difficult to envisage an alternative method of support which will also provide adequate radiative cooling for the cask.

The circumferential bands are made in two halves which are each attached at one end by rivets to a trunnion block. The other end of each halfband is attached to the trunnion by a bolt in a swivel and yoke arrangement. This permits adjustment of the trunnions in each band to obtain

TILT GEARBOX ASSEMBLY

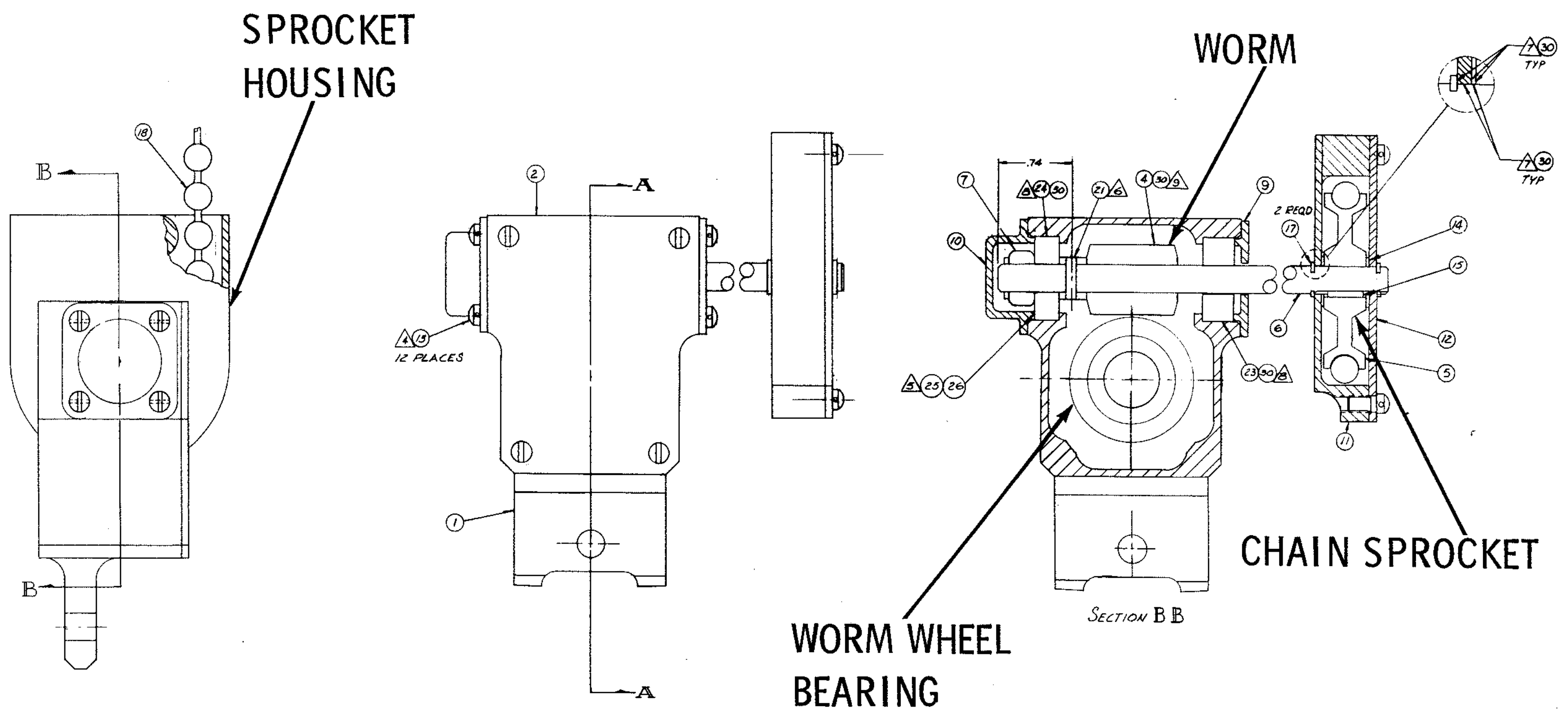

Figure 1.5

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CASK/BAND ASSY

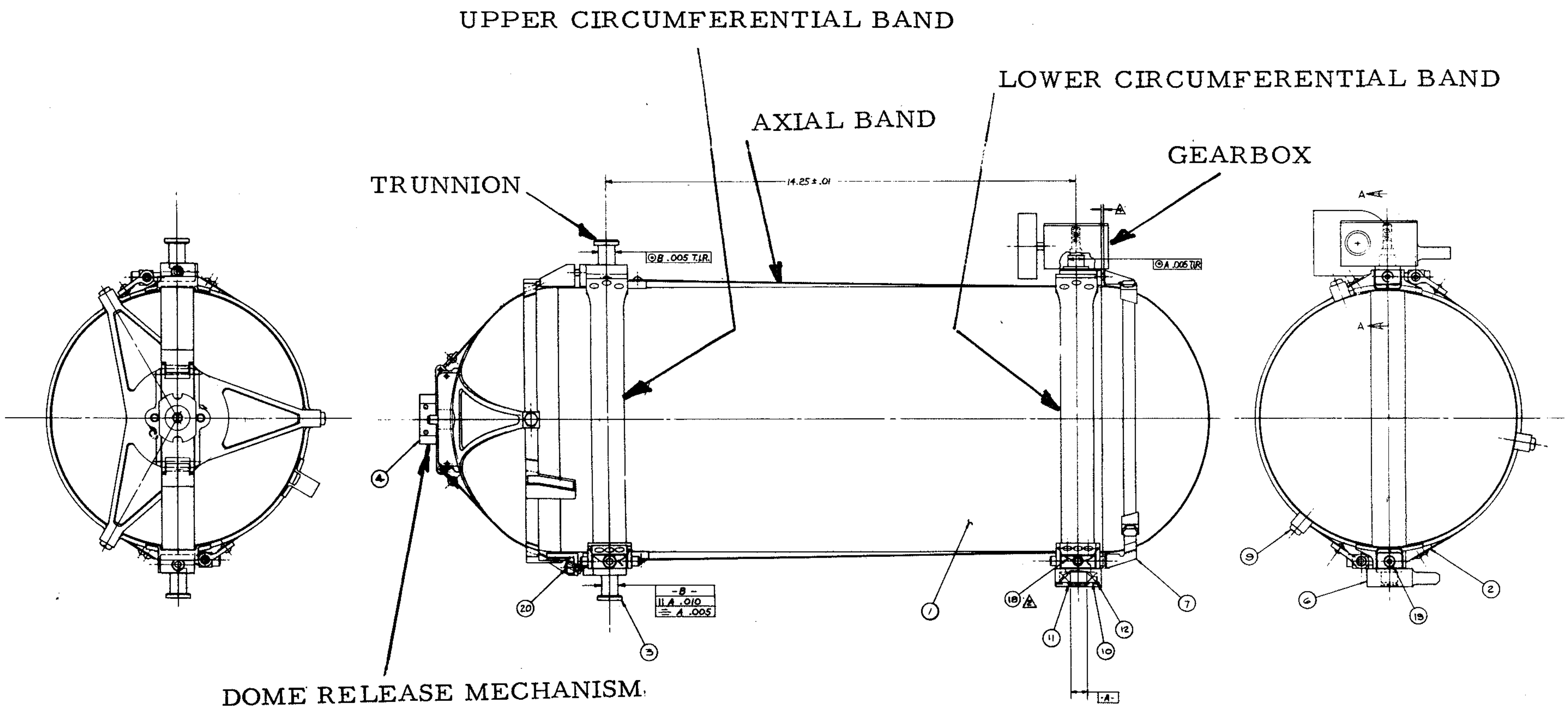


Figure 1.6

4422-3

co-axial alignment and also to obtain the correct amount of pretension in the bands. It is calculated that bolts will be torqued to a figure of 8 inch-lbs. to produce the required pretension in the bands. This figure must be checked by means of strain gauges during the test program.

The amount of pretension in the circumferential bands is most important - it must ensure that the graphite cask is not overstressed at room temperature, when the adjustment is made, and it must also ensure that when the cask has reached final working temperature there is still sufficient residual tension in the bands to secure the cask against the dome unlocking torque, etc. and to prevent axial motion of the cask when the axial band sections are separated for dome removal.

The axial band is attached to the upper circumferential band at the trunnions. There is no connection between the axial band and the lower circumferential band. For this reason axial loads can only be transmitted by friction on the lower band. This is eliminated by the articulated outer sections of the Lower "U" member. It therefore follows that all axial loads on the cask are reacted at the upper band trunnions. Loads in the "y" and "z" planes are reacted at both the upper and the lower circumferential bands.

To permit removal of the cask dome for access to the fuel capsule it is necessary to incorporate two joints in the axial band. The joints may be separated by the rotary motion applied to the cask dome release mechanism, required to eliminate the pretension in axial band. The torque required to do this is nominally 3 lbs. ins. at a cask temperature of 700°F.

<u>Band Release Mechanism (Fig. #1.7)</u>

This device consists of a pair of small levers attached to the upper ends of the shorter sections of the axial bands, which are held in the pretension position by a flange on a rotatable locking piece (Body, Release). To release the pretension in the band sections, it is necessary to depress a pair of locking plungers and then rotate the body release 90° at which point the two levers are free to move under the tension applied by the sections of the axial band. The locking plungers will re-engage the body release in this position to prevent over-travel.

DOME RELEASE DETAILS

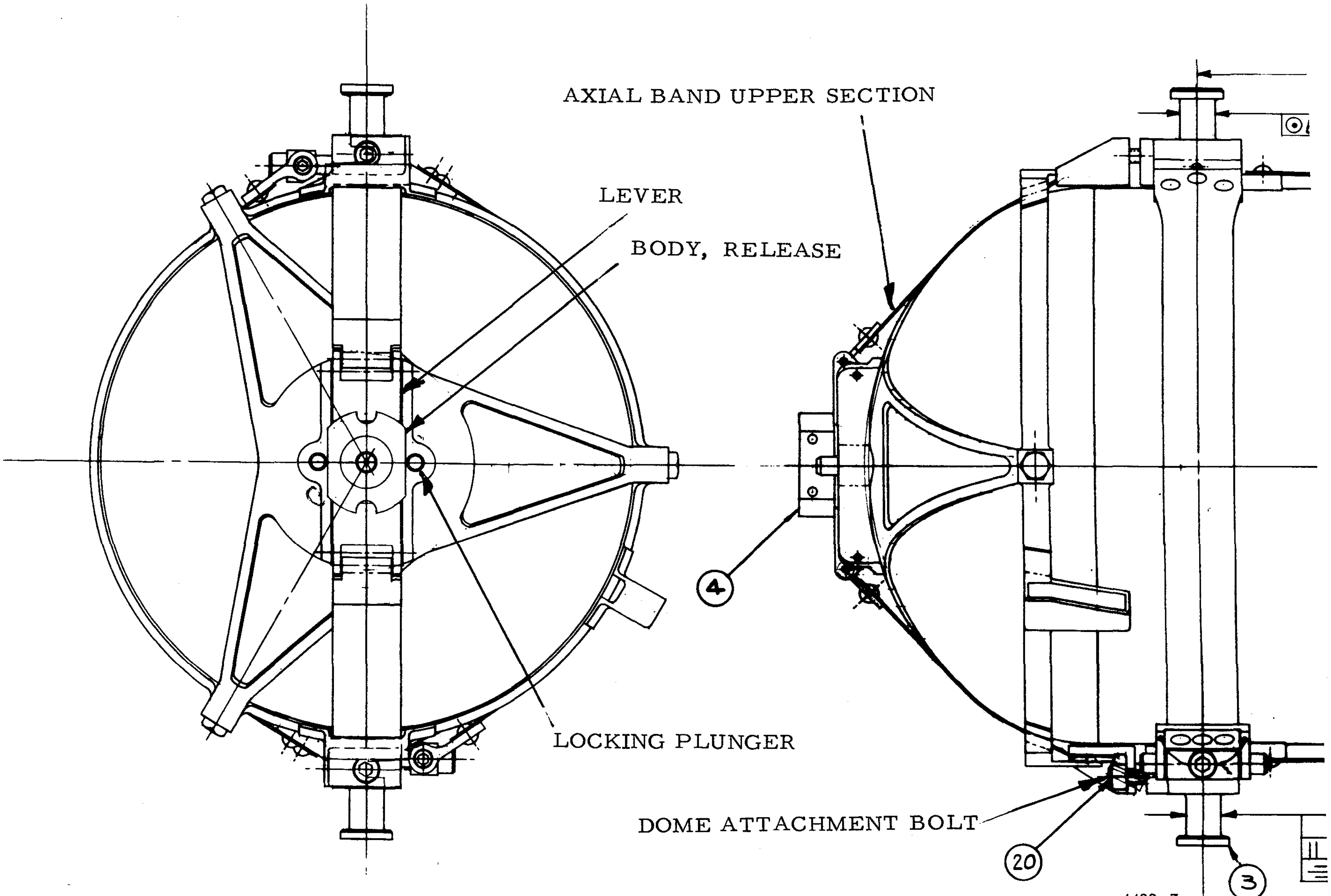


Figure 1.7

The pretension in the band is applied by torquing a pair of socket headed bolts which secure the lower ends of the axial band upper sections to the trunnion blocks on the upper circumferential bands. The band release mechanism is intended for use primarily by the astronaut and also for emergency release of the cask dome during "on pad" operations. During normal "ground" operations - installation, removal, etc. - the dome will be released by unscrewing the two tensioning bolts securing the axial band upper sections to the upper trunnion blocks.

The cask dome is removed by means of the dome removal tool which is locked into the release mechanism for the sequence of operations. The cask dome is attached to the release mechanism assembly by means of three special bolts attached to the lower band and engaging in 1/8 diameter holes in the dome. Since these holes also appear in the bottom cask dome they have been used to provide additional anchorage for the main body of the cask against movement during the lunar unloading operations - the cask should be secured under normal condition by the residual tension in the lower circumferential band.

The Dome Removal Tool, (Fig. #1.8) already mentioned, is approximately 21 1/2 inches long and performs three main functions:

1. Removal of dome locking spline

2. Release of axial band tension, unlocking (rotating) of dome from cask body, and removal of dome from cask.

3. It is finally used to carry the dome to a safe distance from the scene of operations where it is discarded.

The spline removal operation is performed by engaging the spring-load claw at one side of the lower end of the tool with the end of the spline which protrudes from the cask at the joint between dome and body. The claw is opened by the astronaut who operates a sliding bar at the upper end of the tool.

It should be possible to extract the spline by a straight pull in the plane at 90° to the x axis of the cask. If difficulty is experienced, the tool may be rotated thus winding up the spline and employing a mechanical advantage of approximately 5:1. The extracted spline may be discarded

DOME REMOVAL TOOL

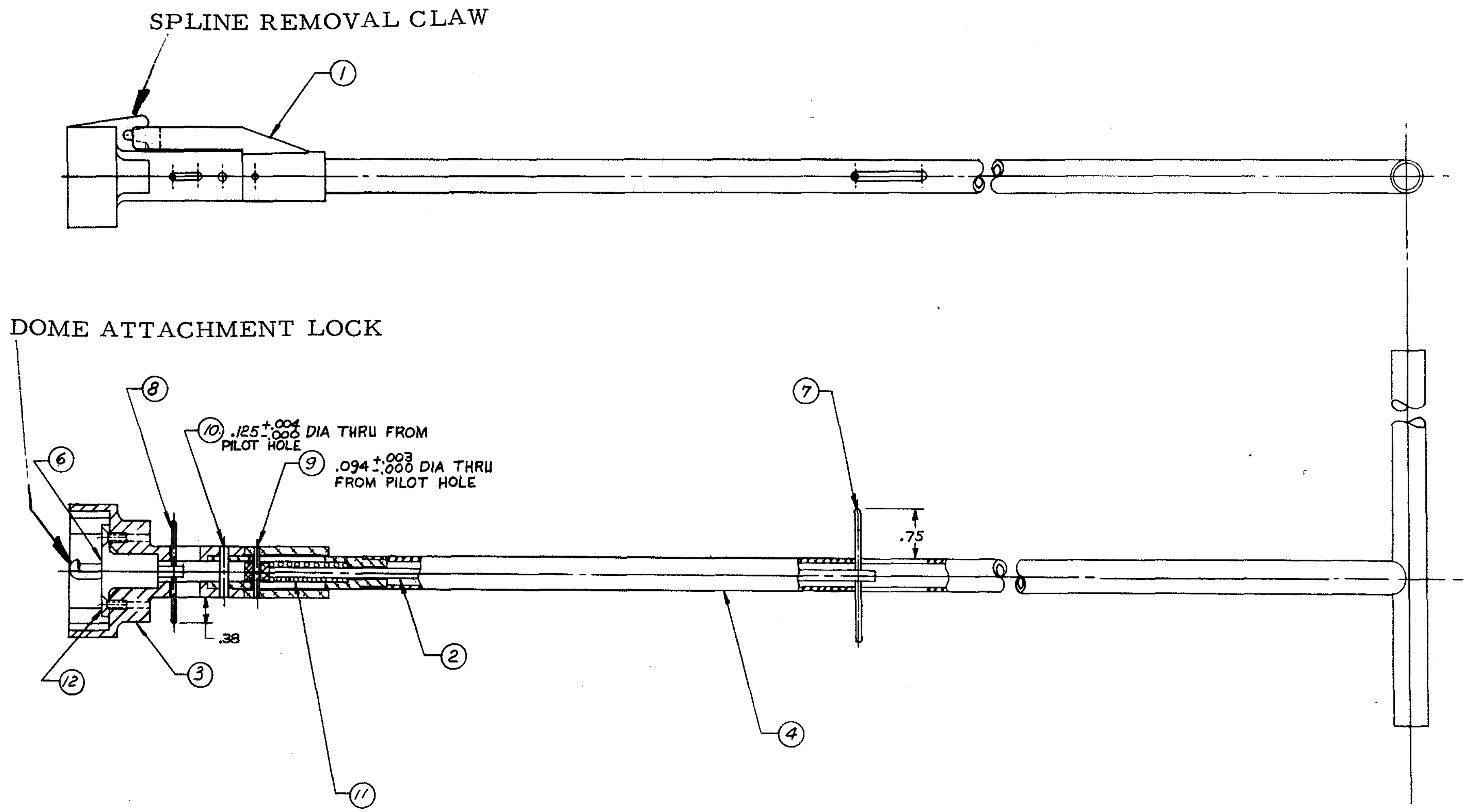


Figure 1.8

4422-8

or retained in the claw - this will be determined during the development program for the hardware.

Once engaged by the astronaut the tool cannot be removed from the dome release mechanism. The overall length of 21 1/2 inches is intended to enable the astronaut to operate the mechanism at a safe distance for the hot cask.

G.S.E.

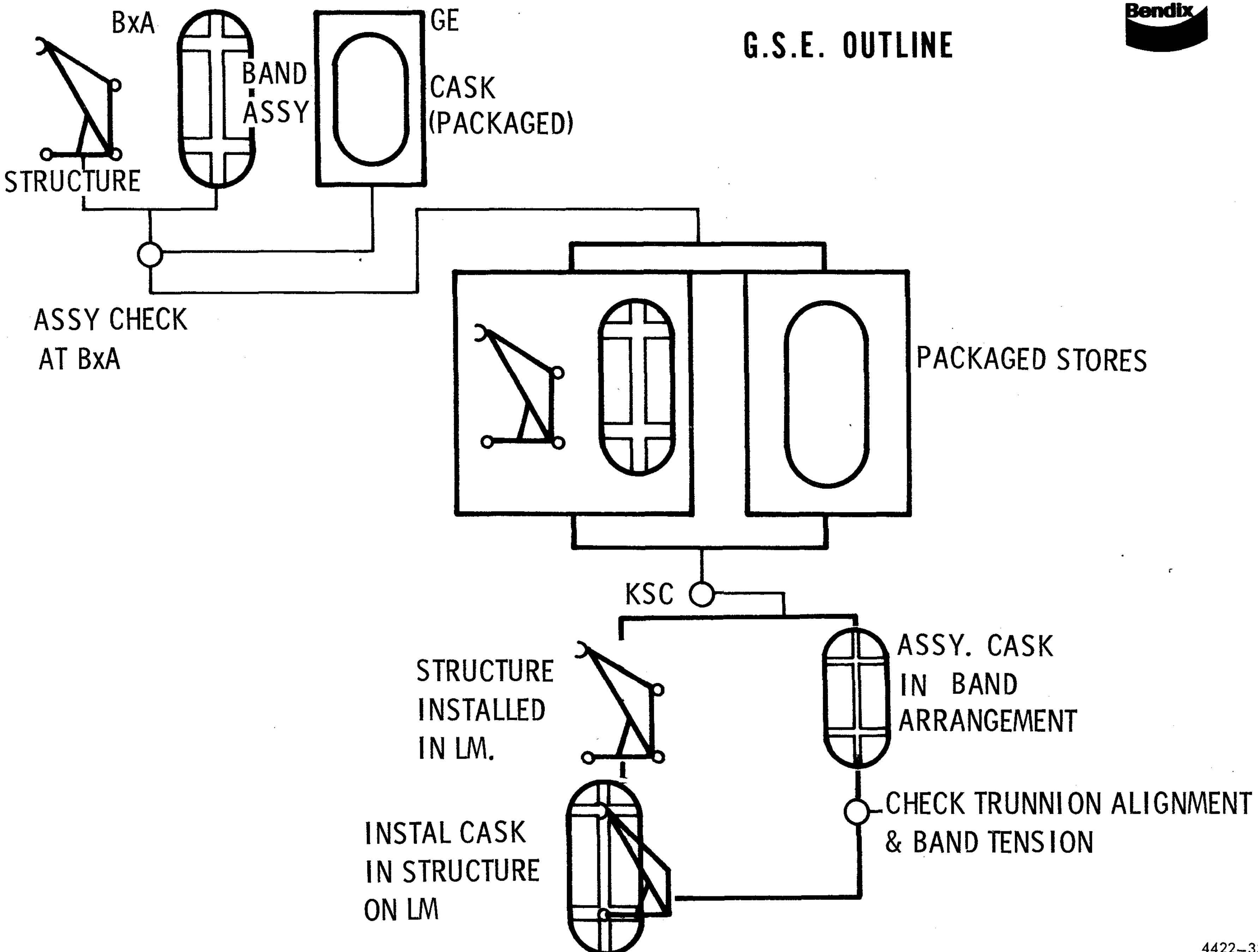
The G.S.E. aspects will be dealt with in more detail later in the presentation. As these have some impact on the design, mention is made at this point.

The basis for the G.S.E. philosophy is shown on Figure #1.9.

Because the complete support structure and cask cannot be installed inside the SLA to the LM structure easily, the support Structure is attached first and then, after checking, the cask and Band Arrangement are added to it.

For this reason a connection between the cask band assembly and the support structure which can be quickly and easily made and separated is desirable. This connection occurs at the four trunnion points on the band arrangement. The design of the upper trunnion release mechanism already provides a simple and quick release for the upper trunnions. The articulating links at the outer ends of the lower "U" cradle are used as the separation points for the lower trunnions. The two bolts on which the links pivot are threaded into the inner sides of the forks on the cradle member and wire-locked against vibration. To remove the cask/band assembly it is therefore only necessary to undo two bolts and unlatch the upper trunnion release mechanisms, while supporting the assembly - which will be hot for an "abort" removal - in the appropriate handling/installation fixture.

G.S.E. OUTLINE



4422-33

Figure 1.9

SECTION 2

STRESS ANALYSIS (THERMAL AND STATIC)

Figure 10 summarizes peak stresses and temperatures which occur throughout the titanium support structure. These stresses are obtained by the addition of direct stresses to bending stresses which result from a 60 g loading and a 45 lb. cask. Because the support structure analysis is so straight forward, the remainder of this discussion will center on the band-trunnion mechanism which directly supports the cask.

Figure 11 shows the evolution of the band cross section from that of a channel to that of a simple flat band with neglibible bending stiffness. The advantages and disadvantages of the flat cross section are listed in the figure. The most significant advantage is the reduction in thermal (pretension) stress. The most significant disadvantage is the possible need for strain gage apparatus to monitor the pretension operation.

Three sources of stress in the bands are listed in Figure 12. These stress sources are discussed in the following.

Figure 13 shows the clamping load required for cask retention for the conditions specified in the figure. Friction forces are normally greater in vacuum than they are in atmosphere. Therefore a friction coefficient of .2 or greater is presumed a conservative estimate of the cask-band surface combination. Accordingly, a line load requirement of 3 lb/in is chosen as a design goal for the band line load on the lunar surface. This 3 lb/in figure will again be referred to in Figure 16.

Figure 14 shows the equation used to compute the direct tensile load (P) in a circumferential band. The line load on the cask is equal to this load divided by the cask radius (P/R). In order to minimize band load due to temperature fluctuation, it is desirable to

1. Minimize the difference in thermal expansion coefficients between the cask material and the band material

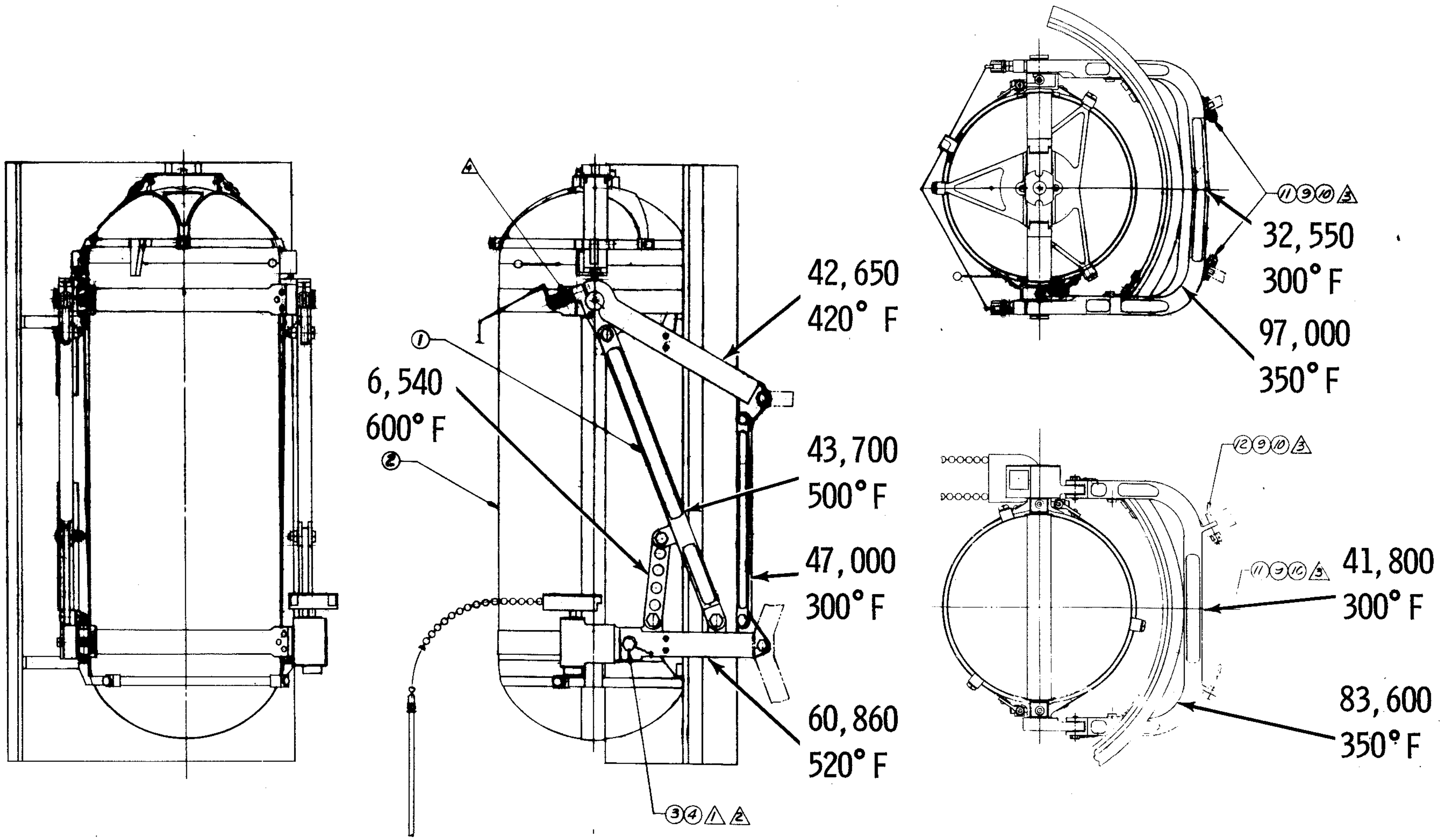
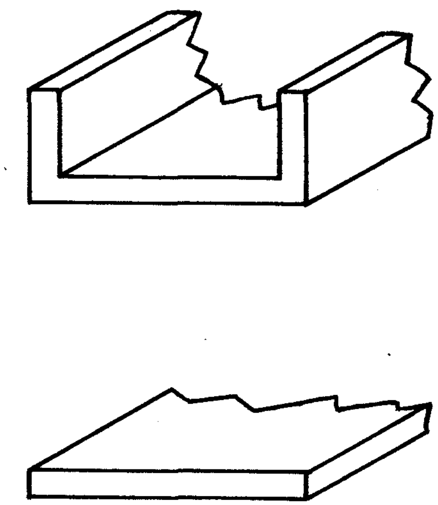

42,650
420° F
6,540
600° F
43,700
500° F
47,000
300° F
60,860
520° F
32,550
300° F
97,000
350° F
41,800
300° F
83,600
350° F

Figure 10

FLEXIBLE BANDS

ADVANTAGES

- MINIMUM THERMAL STRESS
- MINIMUM TOLERANCE PROBLEMS
- LOW WEIGHT
- LOW COST



DISADVANTAGE

- DIFFICULTY OF ACCURATELY PRETENSIONING BANDS.

Figure 11

Bendix

SOURCES OF STRESS IN BANDS:

- PRETENSION REQUIREMENTS
- g LOADING
- MISALIGNMENT OR TOLERANCE PROBLEMS.

Figure 12

4422-14

2. Minimize the temperature change involved

3. Minimize the tensile stiffness (AE) of the band. A is inversely proportional to band strength while E is the Young's modules for the band material.

The materials which were considered for the bands are listed in Figure 5.

Using the line load criterion of Figure 13, the band load equation of Figure 14 and the E and α listed for titanium in Figure 15, we determine the line load requirement of 147 lb/in at room temperature shown in Figure 16. The corresponding band stress in the 1 in. wide by .017 in. thick titanium band is 34,600 psi. More significant is the band stress of 12,200 psi which occurs in combination with the max g loading at a temperature of 550°F. Note that the line load and band stress decreases with increasing temperature, because the bands expand more rapidly than the cask.

Calculation of band stresses due to g loading is illustrated by the free body diagrams of Figure 17.

Figure 18 illustrates the elastic stress induced in the flat band by the action of bending the normally flat metal strip around the 2.5 inch radius. The outside surface of the band must elongate while the inside surface must compress. This type of stress which is induced in the fabrication process is easily overlooked. In fact for the axial band illustrated in the figure, this stress is not of great significance since some yielding of this band is permissible. However, because the circumferential bands must retain a compressive line load on the cask, yielding cannot be permitted and this stress source must be accounted for. The bending stress illustrated in Figure 18 could be removed by a stress relief anneal. However any tolerance buildup between the band perimeter and the cask perimeter and/or any stretch of the band due to g loading would cause the 54,500 psi stress to occur at the intersection of the flat and the radius. Therefore the prestress procedure illustrated in Figure 19 is adopted. The flat band is wound around a small diameter mandrel and allowed to spring back to a radius intermediate between the radii shown in Figure 18. This produces a residual compressive stress in the outside fiber of 21,600 psi. Bending the prestressed band back to the flat configuration

REQUIRED CLAMPING LOAD FOR CASK RETENTION VS FRICTION COEFFICIENT

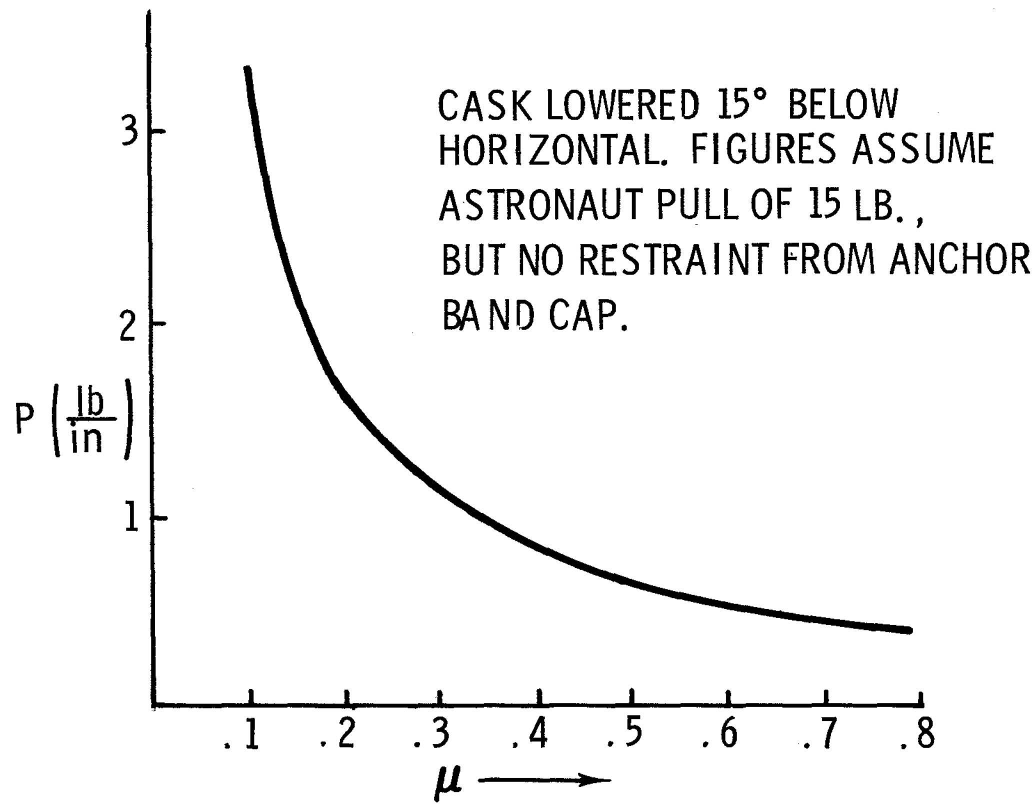


Figure 13

4422-15

BAND LOAD DUE TO TEMPERATURE FLUCTUATION

$$P = \frac{(\alpha_G - \alpha_M)\,\Delta T}{\left(\frac{1}{A_M E_M} + \frac{1}{A_G E_G}\right)}$$

- T ~ TEMPERATURE
- α ~ COEFFICIENT OF THERMAL EXPANSION
- A ~ CROSS SECTIONAL AREA
- E ~ MODULUS OF ELASTICITY
- G ~ GRAPHITE
- M ~ METAL

DESIRE TO MINIMIZE:

- $(\alpha_G - \alpha_M)$
- ΔT
- A E

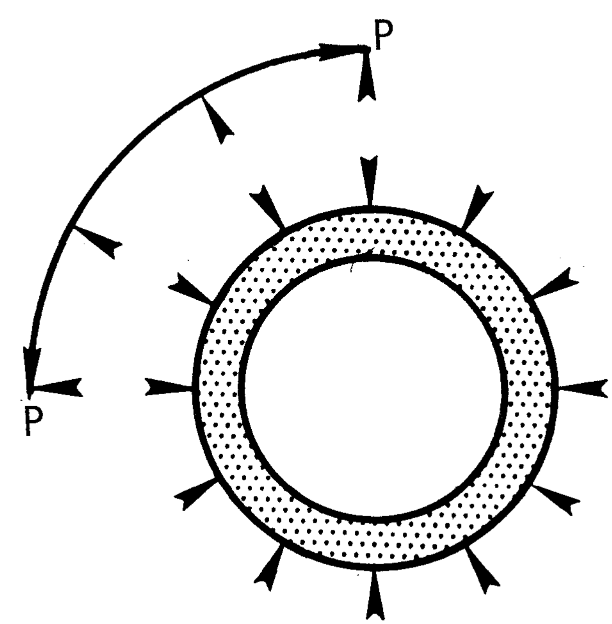


Figure 14

4422–13

BAND MATERIALS CONSIDERED

MATERIAL	$EX10^{-6}$	$\alpha X10^{6}$	DUCTILITY	F_{tu}KSI
GRAPHITE	1.5	1.775	0	5.22
TANTALUM	27	3.6	95 %	60
TUNGSTEN	59	2.5	0	220
TZM	46	2.7	55 %	125
S GLASS	10.5	1.6	0	665
TITANIUM 6A14V	16	5.3	10 %	160
STAINLESS STEEL 17-7PH (H1050)	29	6.3	9 %	200

Figure 15

4422–10

PRETENSION REQUIREMENTS

TOP BAND:

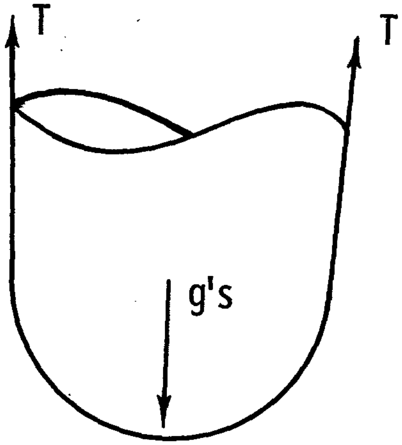
	LINE LOAD ON CASK lb/in.	STRESS IN BAND PSI
70° F, ROOM TEMPERATURE	147	34,600
550° F, MAX VIBRATION	52	12,200
800° F, LUNAR OPERATIONAL	3	705

Figure 16

4422-16

g LOADING

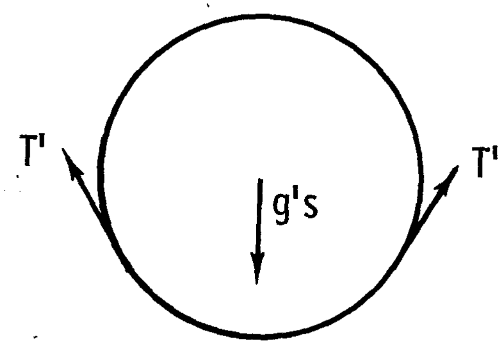
AXIAL BAND



$$2T = 45\ (60)$$

$$T = 1350$$

TOP BAND



$$2T' \cos 30^\circ = \frac{8.56}{14.25}\ (45)\ (60)$$

$$T' = 935$$

Figure 17

4422-17

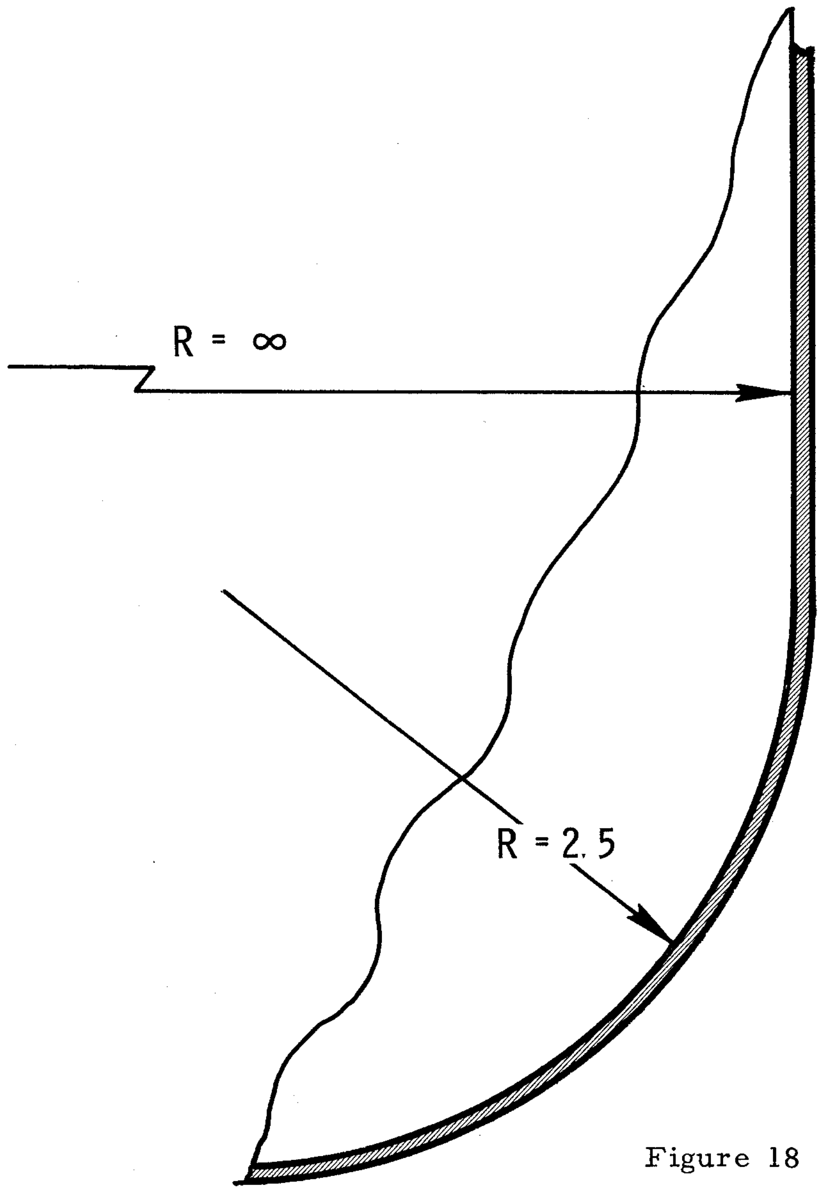


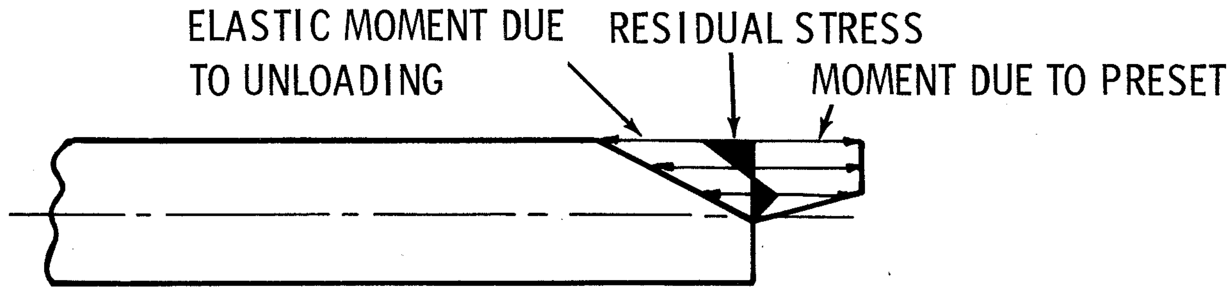
Figure 18

$$\epsilon = \frac{t}{2R} = \frac{.017}{5}$$

$$\sigma = E\epsilon = 16 \times 10^6 \ \frac{.017}{5}$$

$$= 54{,}500 \text{ PSI}$$

4422-19



FOR SPRINGBACK RADIUS = 16 in., RESIDUAL STRESS = 21,600 PSI.

ON FLAT SURFACE, TOTAL = 21,600 + 8,500 = 30,100 PSI { COMP OUT / TENSION IN

ON CURVED SURFACE, TOTAL = 46,000 - 21,600 = 24,400 PSI { TENS OUT / COMP IN

54,500 PSI

Figure 19

4422-20

results in an additional 8,500 psi compressive stress. The portion of the band which falls on the 2.5 inch curvature has a tensile stress of 46,000 psi from which the original 21,600 psi residual stress is subtracted. As seen in Figure 19, the prestressing process effectively divides the maximum bending stress into 2 smaller components.

A summary of the various band stresses is presented in the top half of Figure 20. The total stress in the top circumferential band is higher than that of the bottom circumferential band because of the greater cask thickness at the top, and because the C.G. is closer to top. Comparing the top band stress total of 79,385 with the strength of the annealed Ti 6Al 4V at 550°F, we obtain a margin of safety equal to .028, based on yielding.

The stresses in the axial band cannot be added in the same way since the assumption of elastic behavior does not apply. Yielding occurs in the axial band thereby relieving a portion of the bending and pretension stresses. Comparing the stress developed by the "g" loading to the ultimate strength of the titanium at 550°F, we obtain a margin of safety of .14 based on fracture.

Figure 21 illustrates a typical trunnion block which bears directly against the cask. The critical cask stresses due to trunnion bearing occur at the lower band position where the cask thickness is smallest. The worst tolerance condition is a .0025 in. mismatch between the trunnion radius and the cask radius.

The local bending loads due to the trunnion action on the cask are given in Figure 22. The 16° degree minimum spread between the trunnion hard points prevents the superposition of local bending stresses from the two loads labeled P in Figure 22.

Figure 23 shows the Mohrs circles associated with the stresses of Figure 22. These circles represent the complete states of stress at the inner and outer elements of the graphite cask which are illustrated. The planes of zero shear stress are the planes parallel to the cask surface, which planes are weak in shear. The critical surface is the inner radial surface which supports a tensile stress due to local bending of 3220 psi. To this stress another 480 psi is added due to the pretension load in the bands. The graphite tensile allowable is 5220 psi per CCP 29. These figures result in a margin of safety of .41 for the graphite cask.

STRESS SOURCE	PSI AXIAL BAND	PSI TOP BAND	BOTTOM BAND
1. PRETENSION	12,290	12,290	10,000
2. "g" LOADING	79,500	55,000	43,000
3. BENDING	30,100	21,145	21,145
TOTAL	121,890	79,385	77,095

BAND STRESS TOTALS

MIL HdbK 5 Ti 6 Al 4V	F_{ty} KSI ANNEALED	F_{ty} (B) KSI STA
RT	120	148 KSI
550° F	.68 (120) = 81 6	.70(148) = 103.7
800° F	.62 (120) = 74.5	.61(148) = 90.4

YIELD STRENGTH OF TITANIUM

Figure 20

4422-12

DETERMINE STRESSES ON CASK:
CRITICAL SECTION IS .35 IN THICKNESS AT LOWER BAND LOCATION:

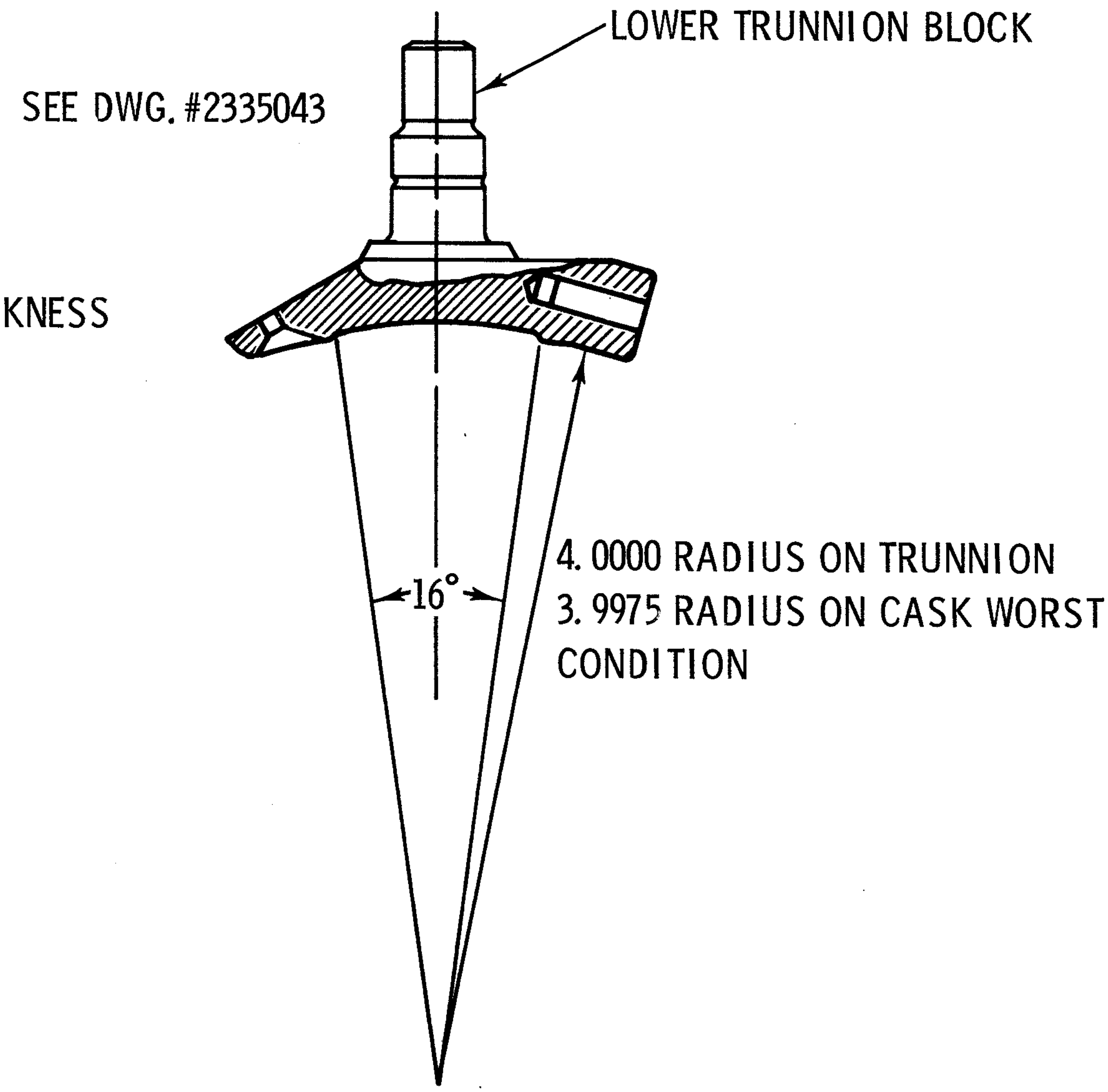


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Figure 21

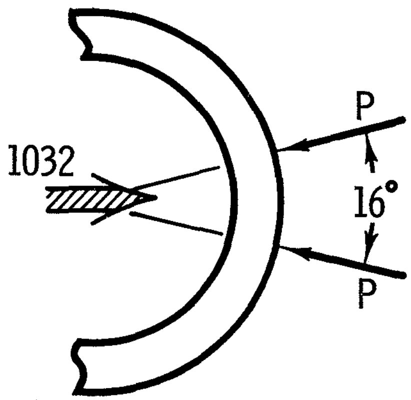


Figure 22

WORST C.G. LOCATION
WORST CLEARANCE ON TRUNNIONS
60 g's 45 lb.

$$2P \cos 8^\circ = 1032$$
$$P = 544$$

MAX CIRCUMFERENTIAL BENDING STRESS:

$$S\frac{1}{2} = \frac{P}{t^2}\left[.42 \ln \frac{.215R}{b} + \frac{6}{4\pi}\right]$$

$$= 3220 \text{ PSI}$$

MAX CONTACT STRESS:

$$S_c = .798 \sqrt{\frac{P \frac{D_1 - D_2}{D_1 D_2}}{\left[\frac{1 - V_1^2}{E} + \frac{1 - V_2^2}{E}\right]}}$$

$$= 201 \text{ PSI}$$

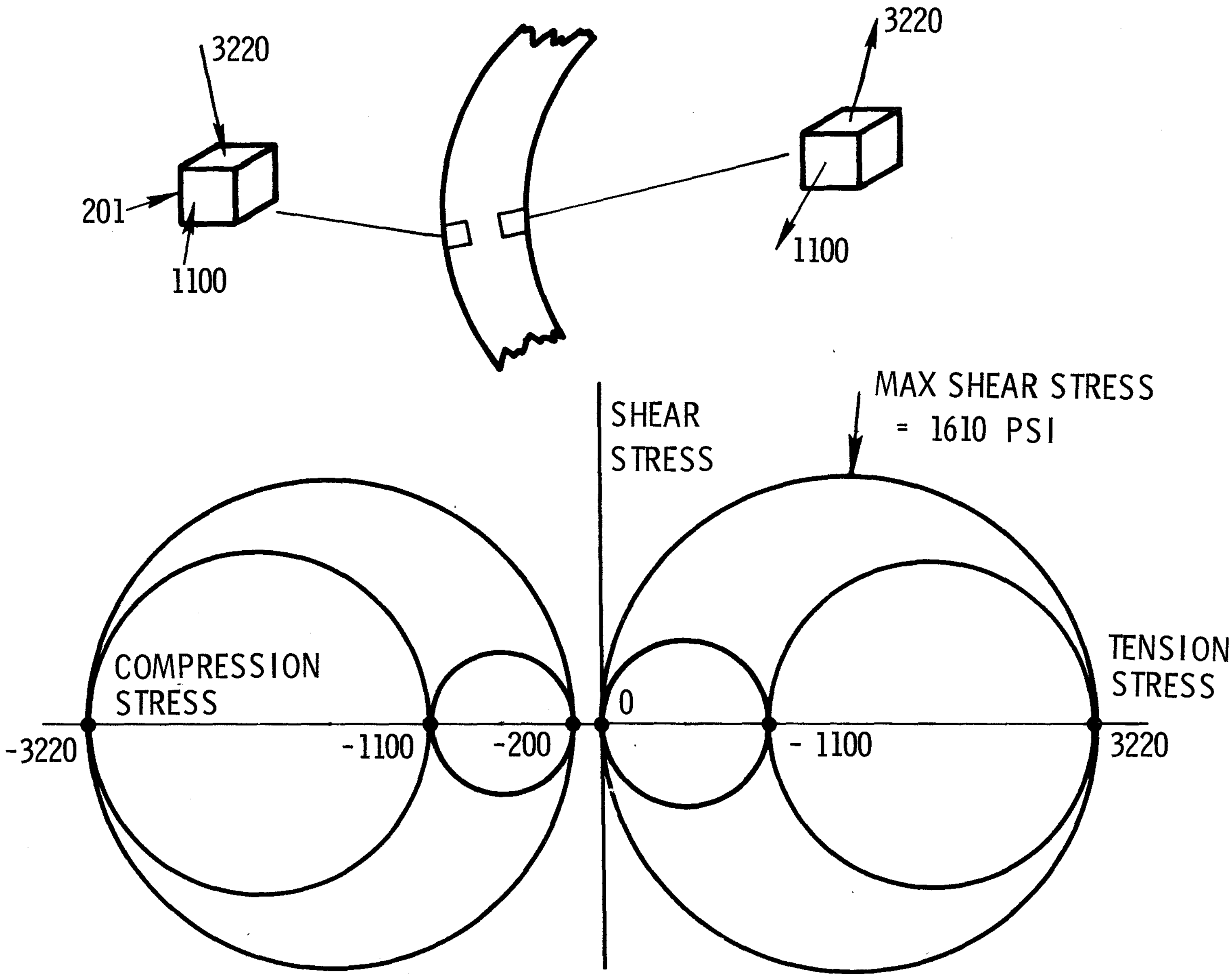
MAX LONGITUDINAL BENDING STRESS:

$$S\frac{1}{1} = \frac{P}{t^2}\left[.42 \ln \frac{.215R}{b} + \frac{6V}{4\pi}\right] = 1100 \text{ PSI}$$

4422-35

MOHR'S CIRCLE REPRESENTING STATES OF STRESS BENEATH TRUNNION

Figure 23



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SECTION 3

DYNAMIC ANALYSIS

The purpose of the dynamic analysis of the ALSEP-cask unit was to determine the vibrational characteristics of the structure. The essential information which may be derived are: the natural frequencies, the mode shapes, transmissibilities, etc. The ultimate goal was to assess the results of the vibrational responses of the system which was subjected to a given input level either sinusoidal or random.

These results reveal the critical frequencies. In the case of the random response levels, the mean square responses which render the equivalent sinusoidal g-loadings may be determined. Moreover, the vibrational responses at various locations, for example, at the supporting points, may be obtained, and the data may subsequently be used to specify the input levels for the test program.

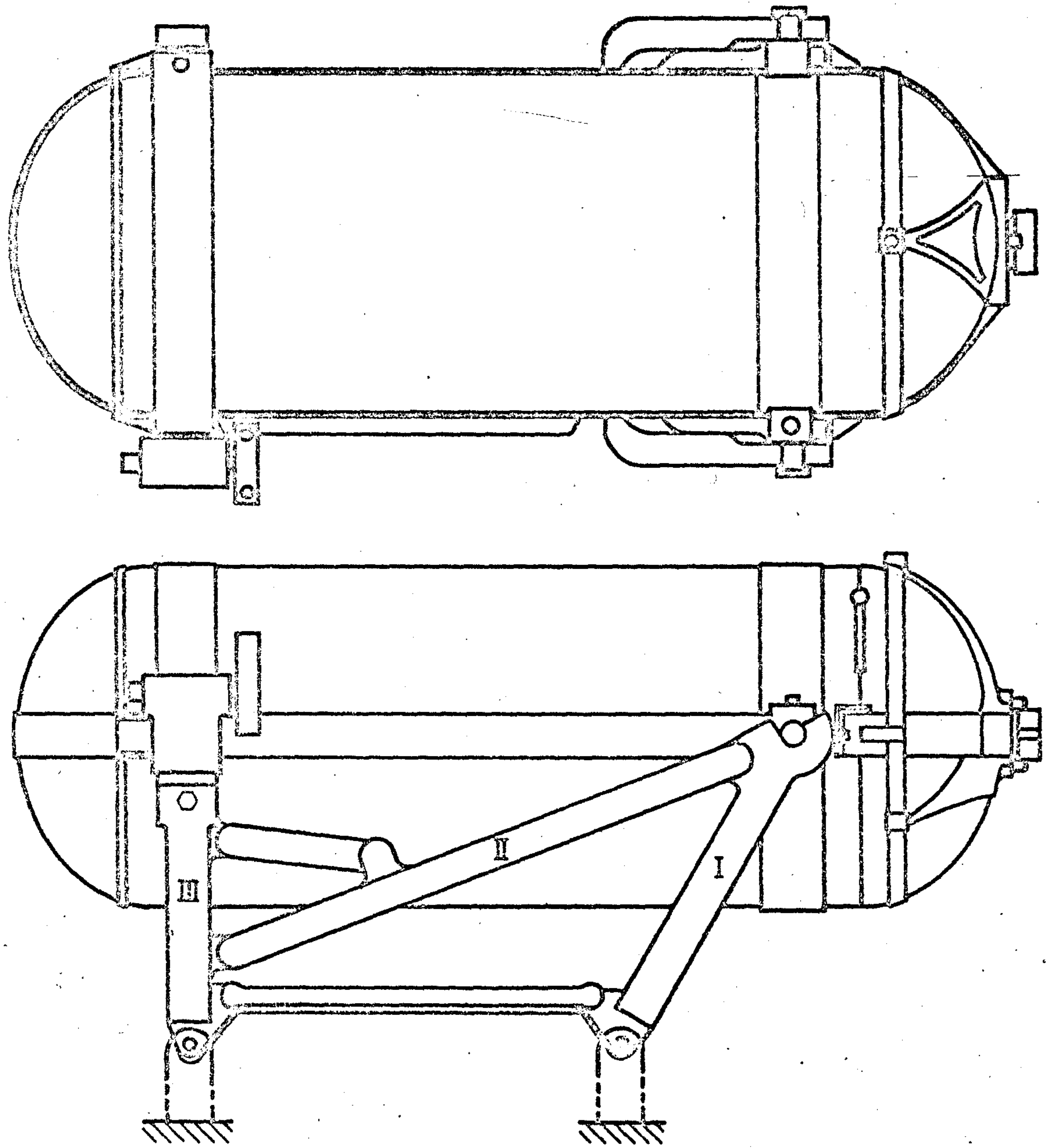
The physical model of the cask unit involved in the dynamic studies is shown in Figure 1. It consists of the cask shell, the fuel cask assembly, the bands, the gear box unit, and the mounting structure. A simplified model as shown in Figure 2 was used for the two-dimensional analysis. In conjunction with the mathematical formulation, the following assumptions and constraints were made:

1. The fuel cask assembly is rigid, and it is axial symmetric.

2. The mounting assembly supports at LEM are rigid.

3. The mounting structure was simplified to a three-member truss as shown in Figure 2. The two supporting points of the mounting structure to the cask shell at 1 and 2 have translational motions in x and z axes, and rotation ϕ about the origin.

4. The truss members were treated as massless springs which would contribute only to the stiffness.



4422-23

FIGURE 1 PHYSICAL MODEL OF THE CASK ASSEMBLY AND THE MOUNTING STRUCTURE

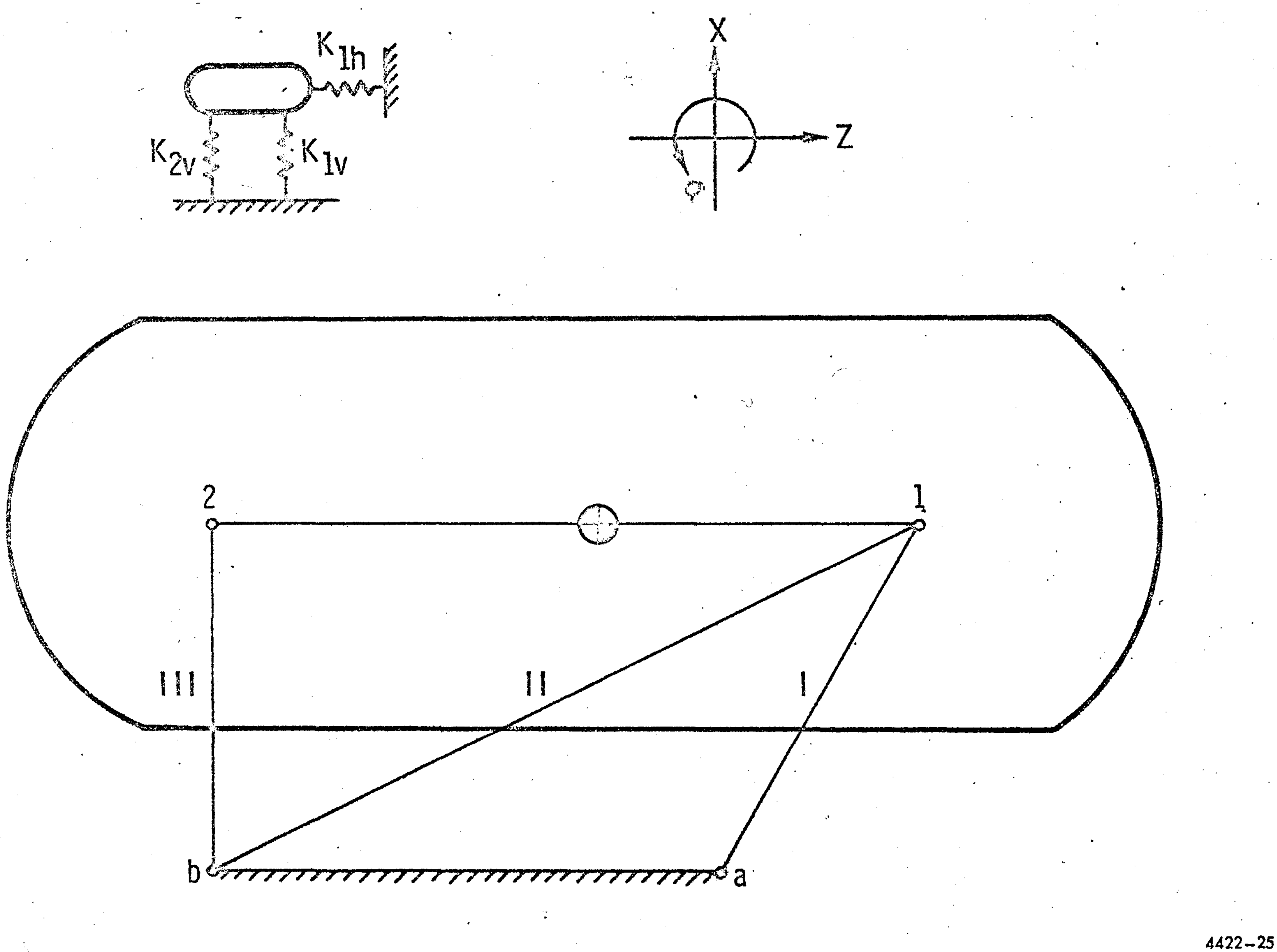


FIGURE 2 TWO-DIMENSIONAL MODEL AND THE COORDINATE SYSTEM

5. The hinged joints were assumed between any two truss members.

6. A damping constant of 5 percent of the value for critical viscous damping was used in the numerical calculations.

7. The responses at the two supporting points 1 and 2 were assumed as such that the motions in z-axis at 1 and 2 are identical, i.e., $w_1 = w_2$; but the motions in x-axis at 1 and 2 are different as being denoted by u_1 and u_2 respectively. This vibrational system, therefore, has three-degrees of freedom.

The analytical procedure involved was to form the three governing matrices, namely the mass matrix $[M]$, the stiffness matrix $[K]$, and the forcing matrix $[Q]$. They must be transformed appropriately from the c.g. of the cask to the points where the results were sought.

With the known weights of the constituent components and the mass moments of inertia of the cask unit, the weights which were lumped at the c.g. of the cask assembly are shown in Table 1.

The computer results yielded three natural frequencies at 246, 837, and 1002 cps.

The transmissibility vs. frequency curves at those two supporting points 1 and 2 are presented in Figures 3-8.

The response to a random excitation was calculated on the basis of the root mean square response* which yields the equivalent sinusoidal g-loading. The results are summarized in Table 2.

Using the two input levels based on the raw test data LTA-3-DR for the sinusoidal and random excitations which are shown in Figures 9 and 10, respectively, the responses at these supporting points were computed according to the following formulas:

1. Response to the sinusoidal excitation:

$$\ddot{x}_r(f) = T(f)\ \ddot{x}_o(f)$$

---

* See pp. 397-405 "Dynamics of Structures" by W. C. Hurty and M. F. Rubinstein, Prentice-Hall, Inc. 1964.

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FIGURE 3 TRANSMISSIBILITY

LOCATION : 1 (u_1) x -AXIS EXCITATION

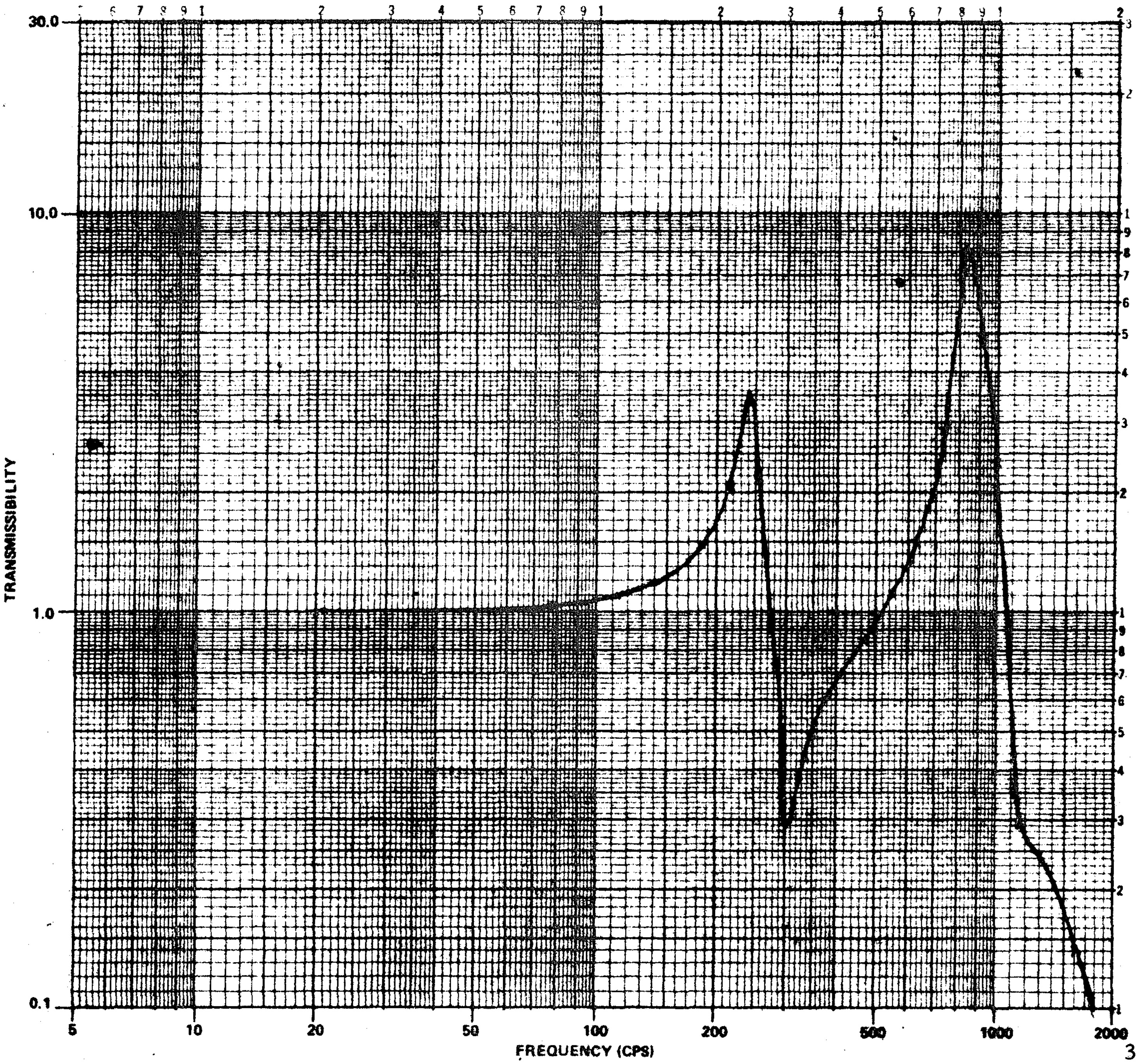

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FIGURE 4 TRANSMISSIBILITY

LOCATION : 2 (u_2) X -AXIS EXCITATION

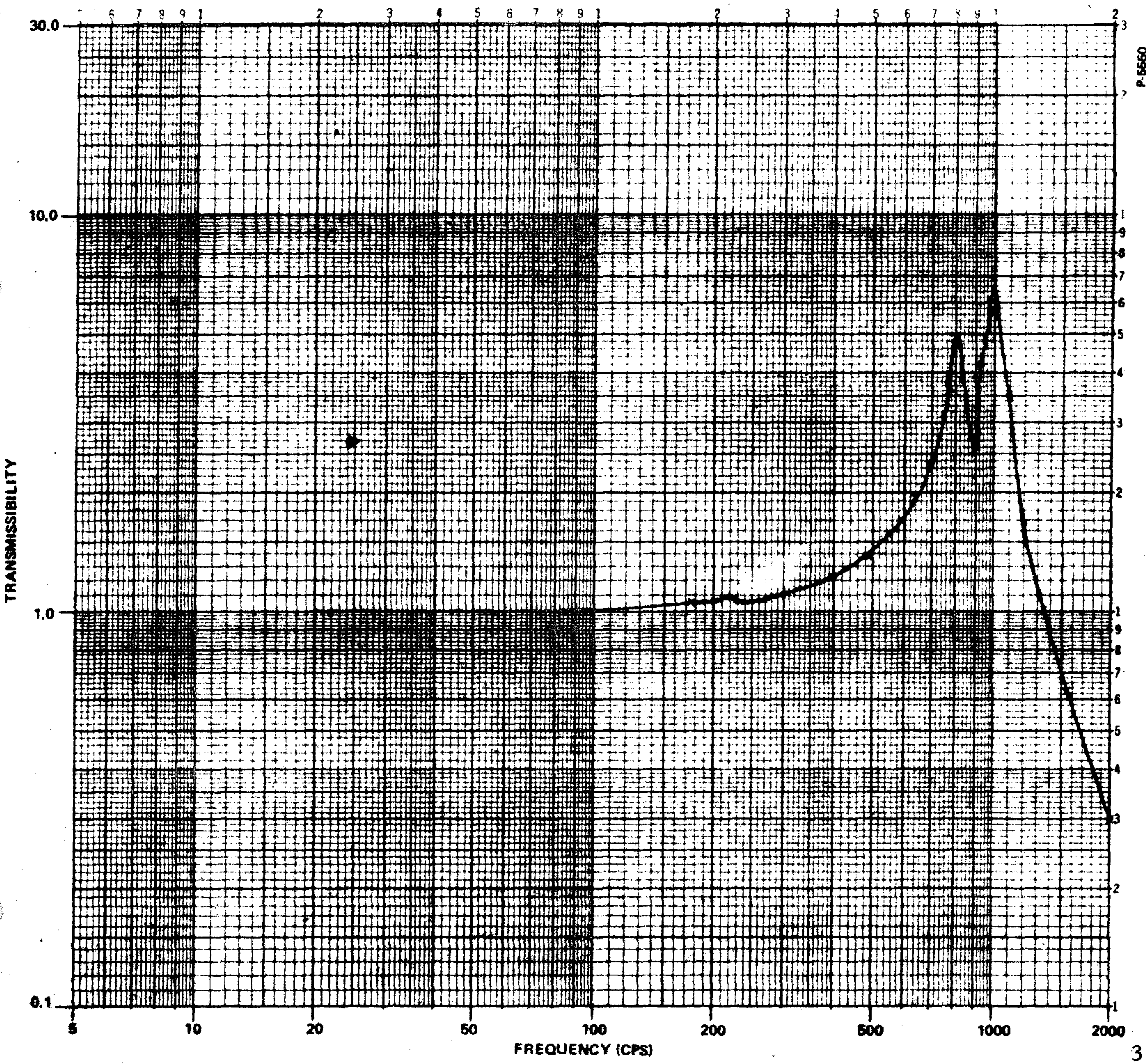

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FIGURE 5 TRANSMISSIBILITY

LOCATION : 3 (w_1)

x –AXIS EXCITATION

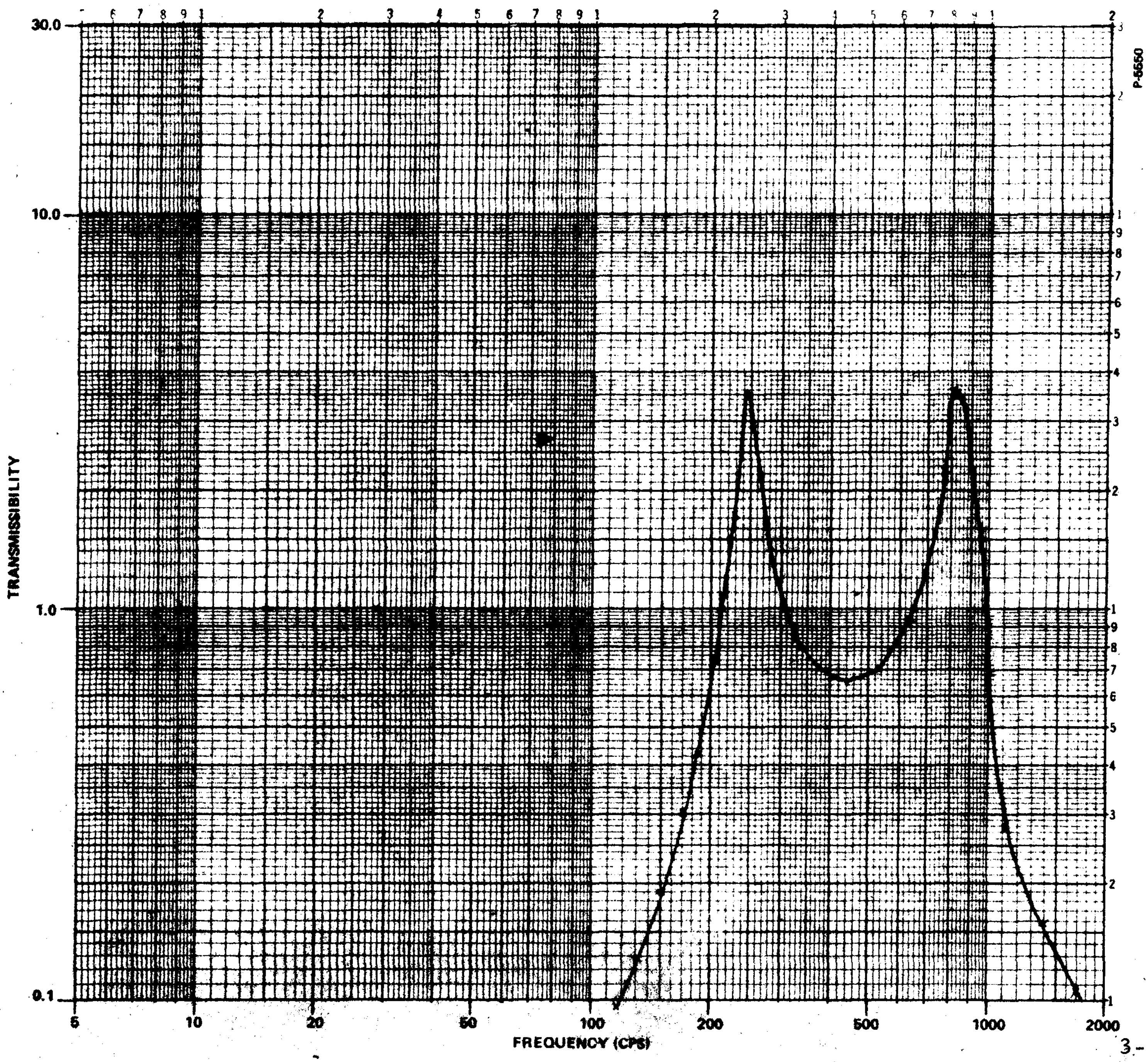

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FIGURE 6 TRANSMISSIBILITY

LOCATION: 1 (u_1) z –AXIS EXCITATION

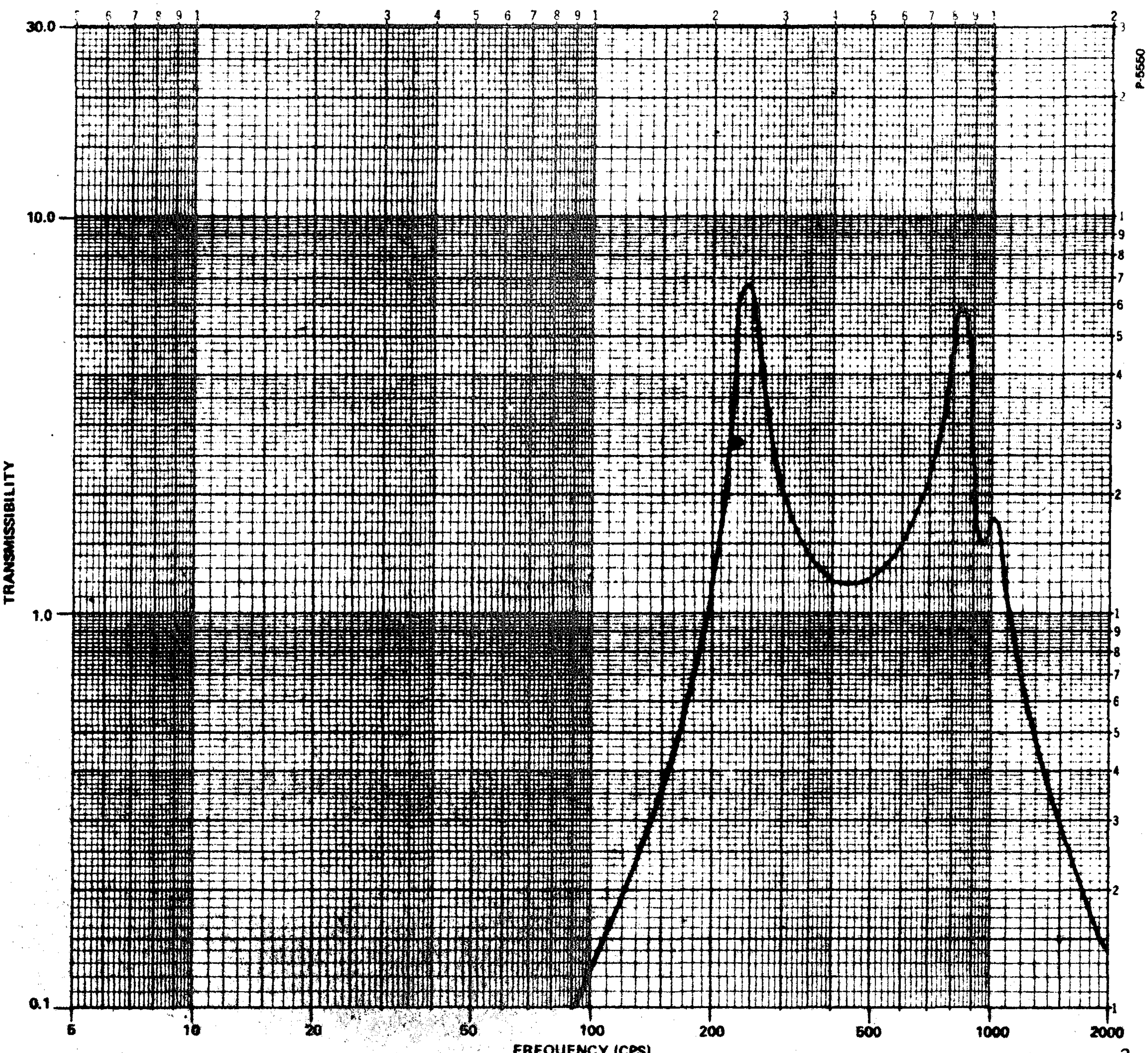

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FIGURE 7 TRANSMISSIBILITY

LOCATION : 2 (u_2) z -AXIS EXCITATION

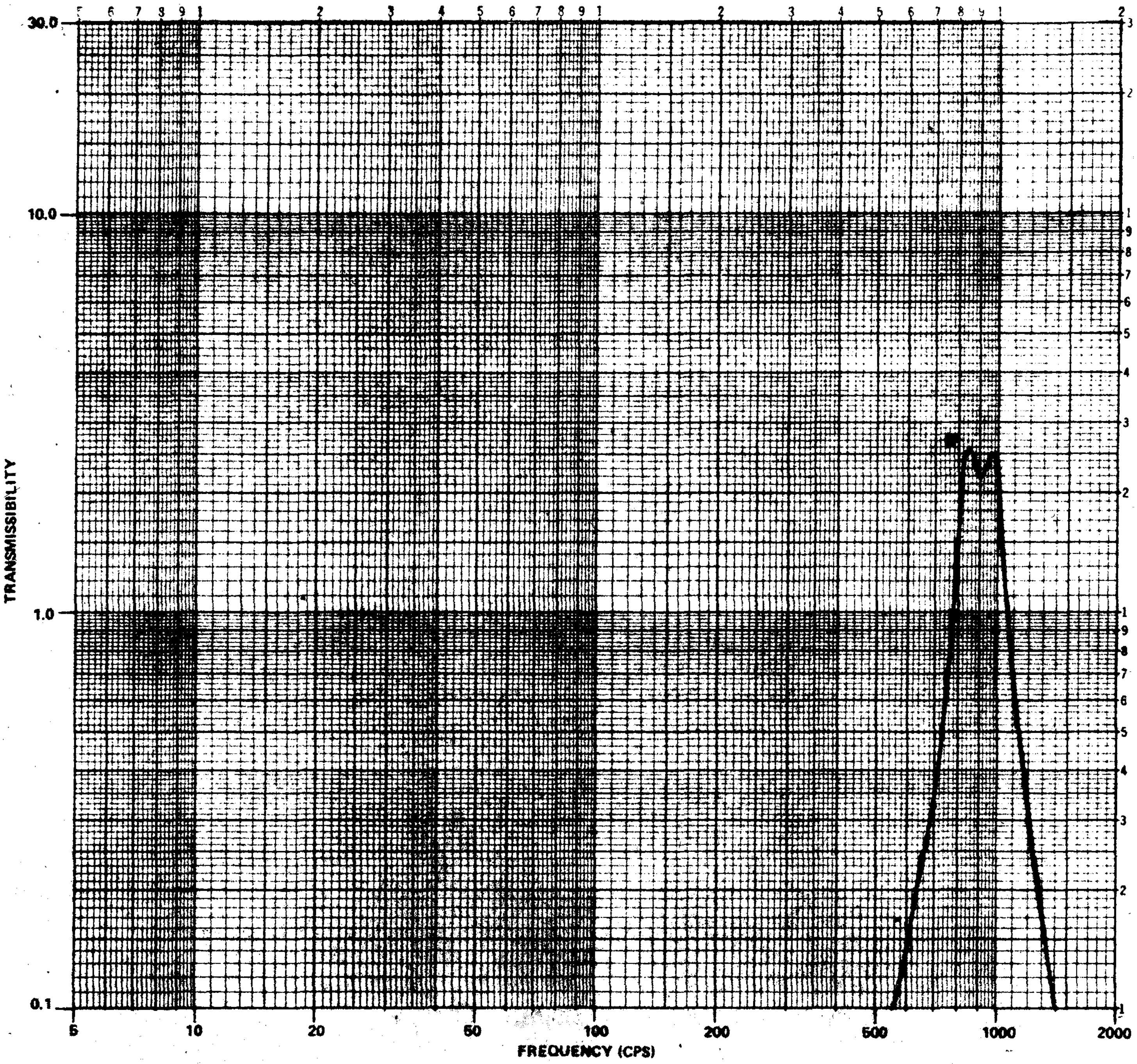
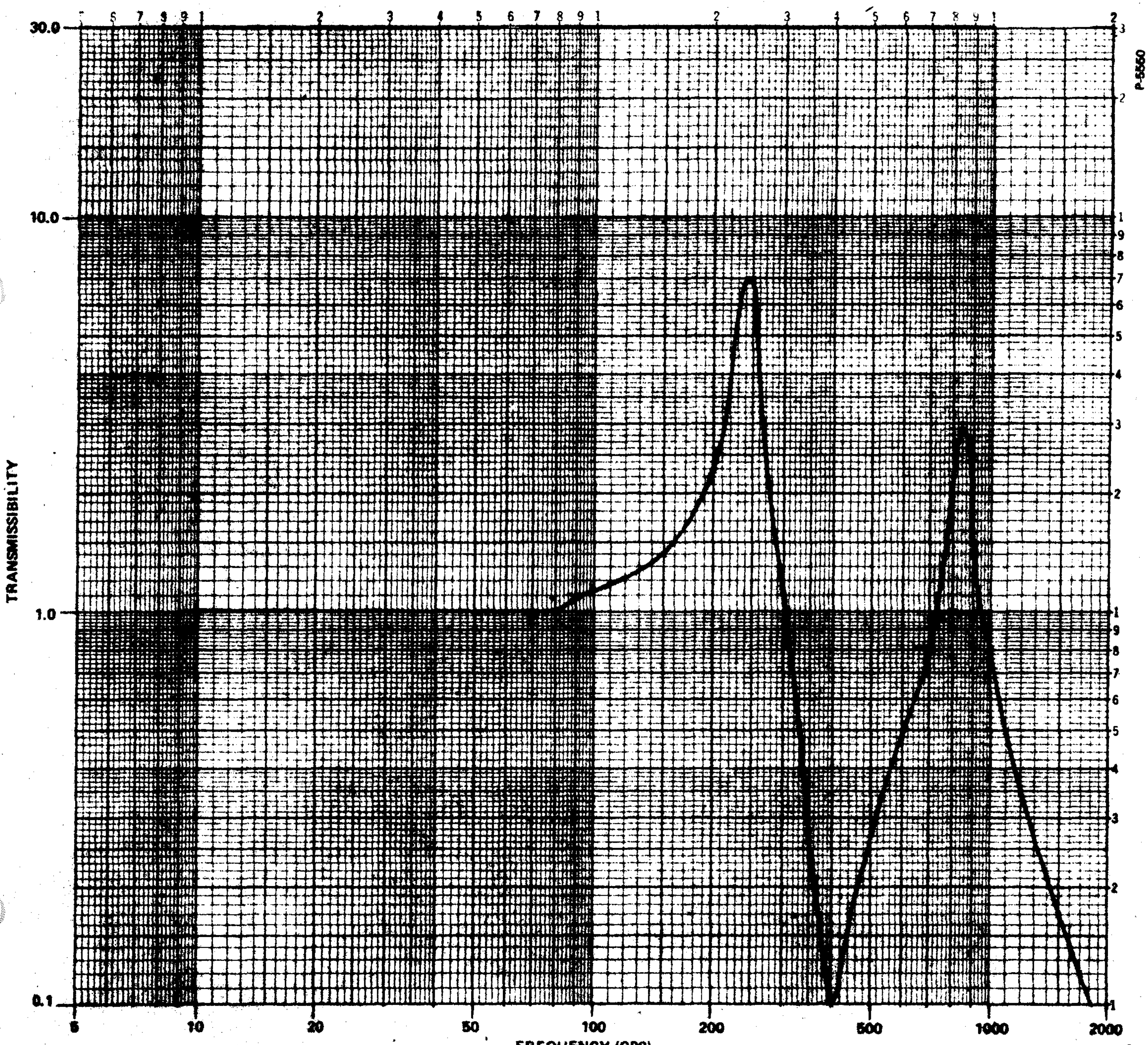


FIGURE 8 TRANSMISSIBILITY

LOCATION: 3 (W_1) Z -AXIS EXCITATION



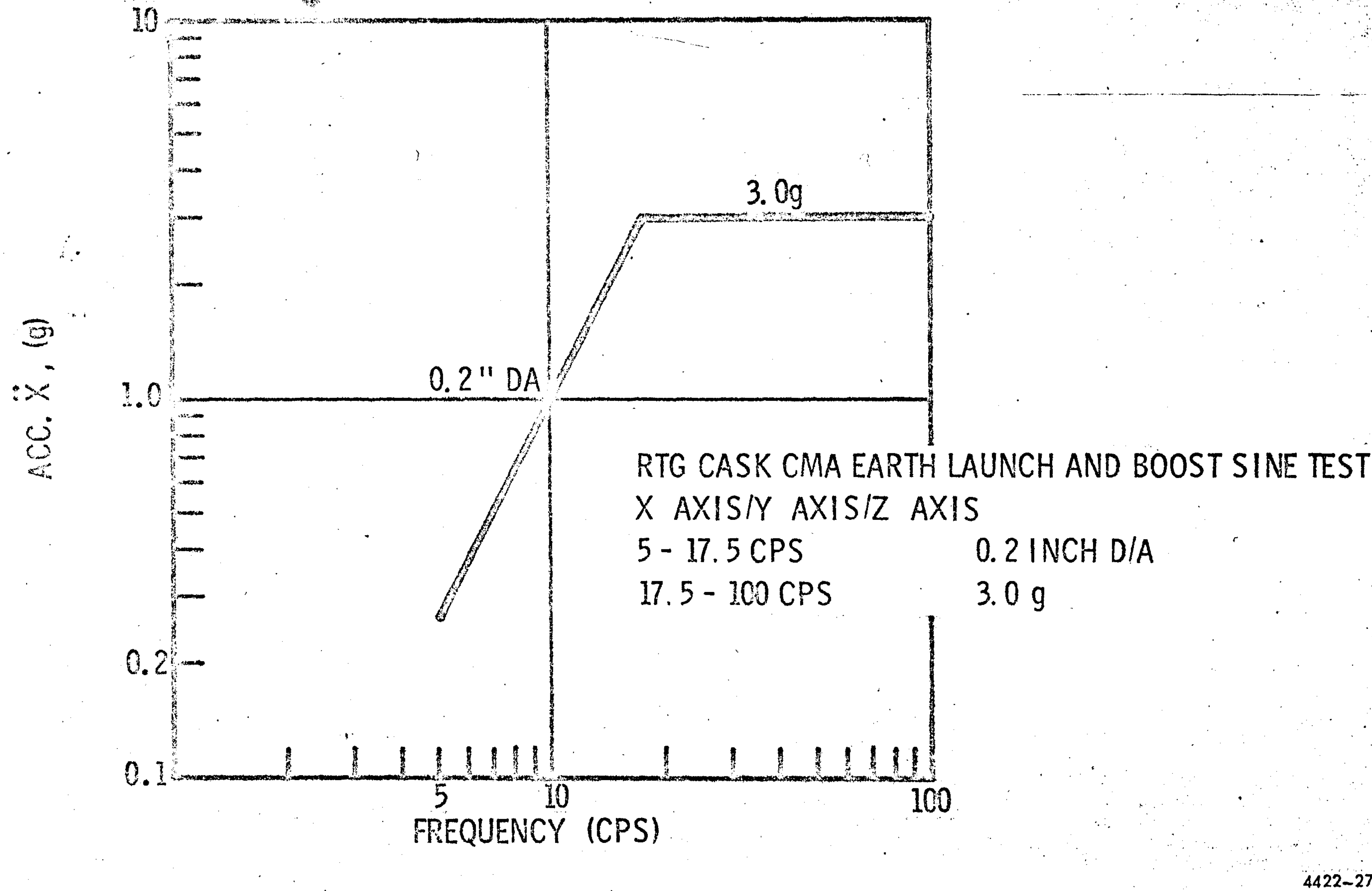


FIGURE 9 ALSEP-CASK SINUSOIDAL VIBRATION LEVEL (BASED ON LTA-3-D/R TEST DATA)

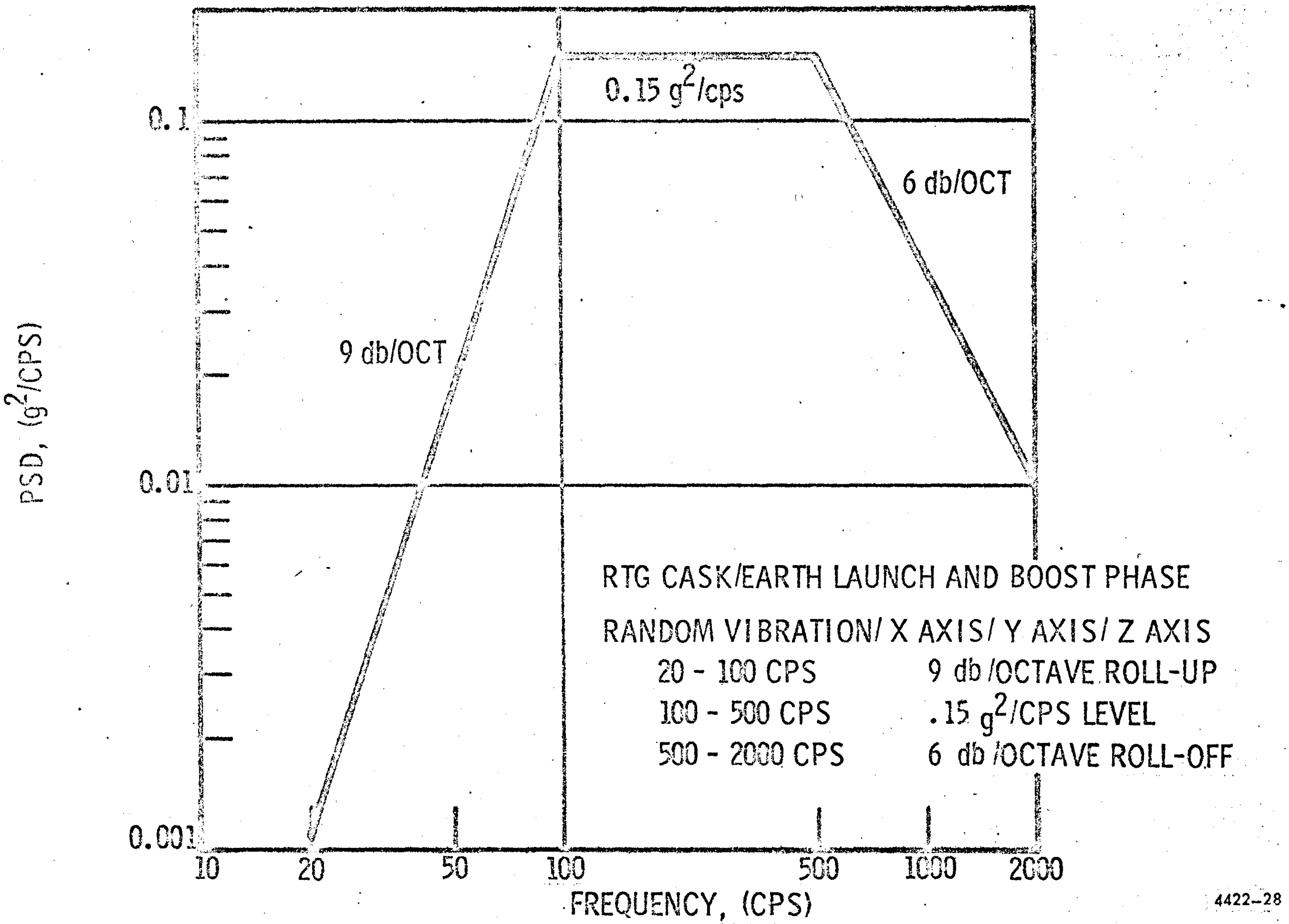


FIGURE 10 ALSEP-CASK RANDOM VIBRATION LEVEL (BASED ON LTA-3-D/R TEST DATA)

2. Response to the random excitation:

$$PSD_r(f) = T^2(f)\ PSD_o(f)$$

where T(f) is the transmissibility being a function of the operating frequency f(cps) in a given axis; $\ddot{x}$ is the acceleration (g); and PSD is the power spectral density (g^2/cps). The subscript o denotes input, and r denotes response.

The PSD_r vs. frequency curves are presented in Figures 11-16. While the range of interest of the sinusoidal inputs is from 5 to 100 cps, the corresponding values of the transmissibility are generally low (T has the magnitude of 1 or lower), thus the x_r vs f curves are not presented.

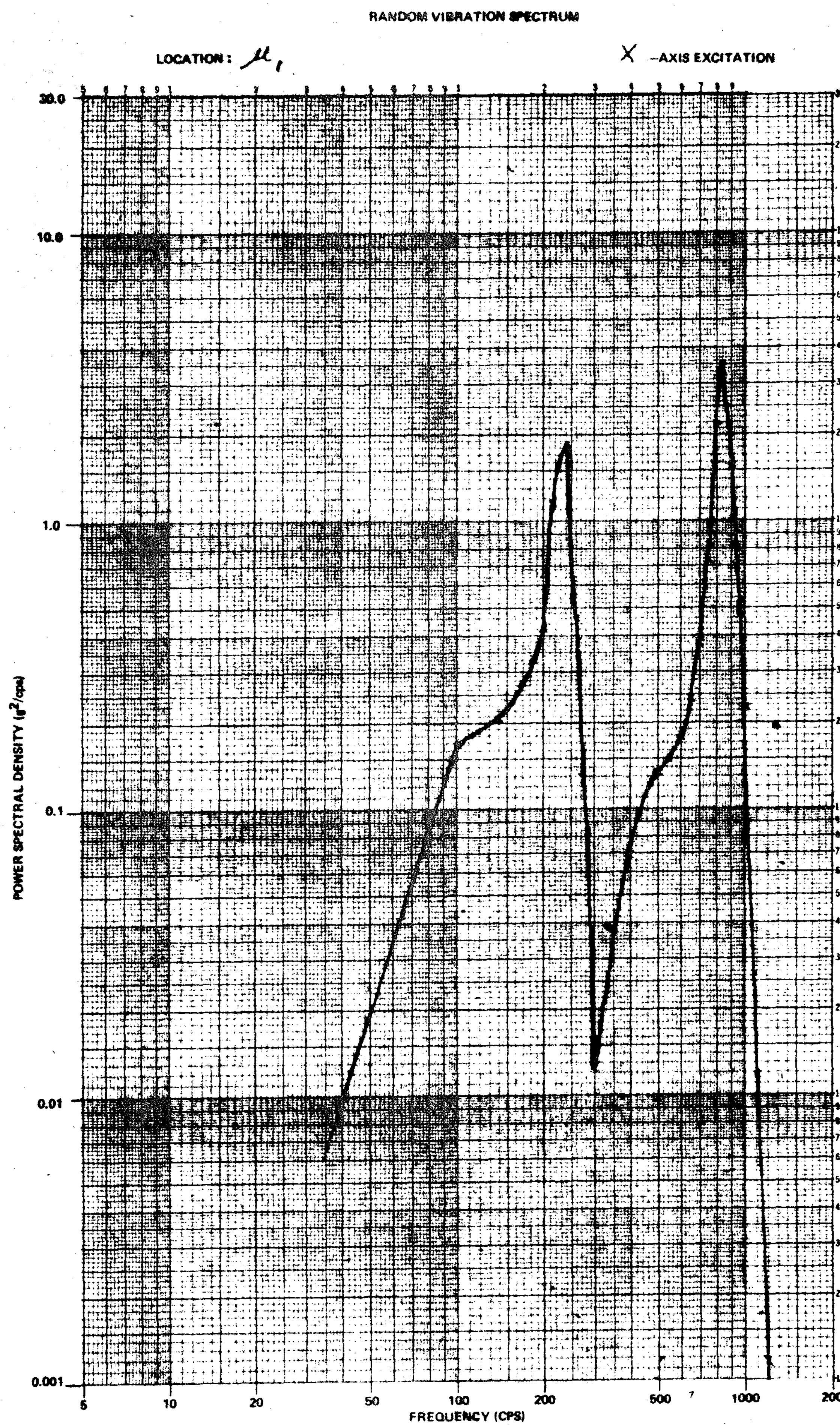


Figure 11 Random Vibration Spectrum at 1 (u_1) Due to x-axis Excitation

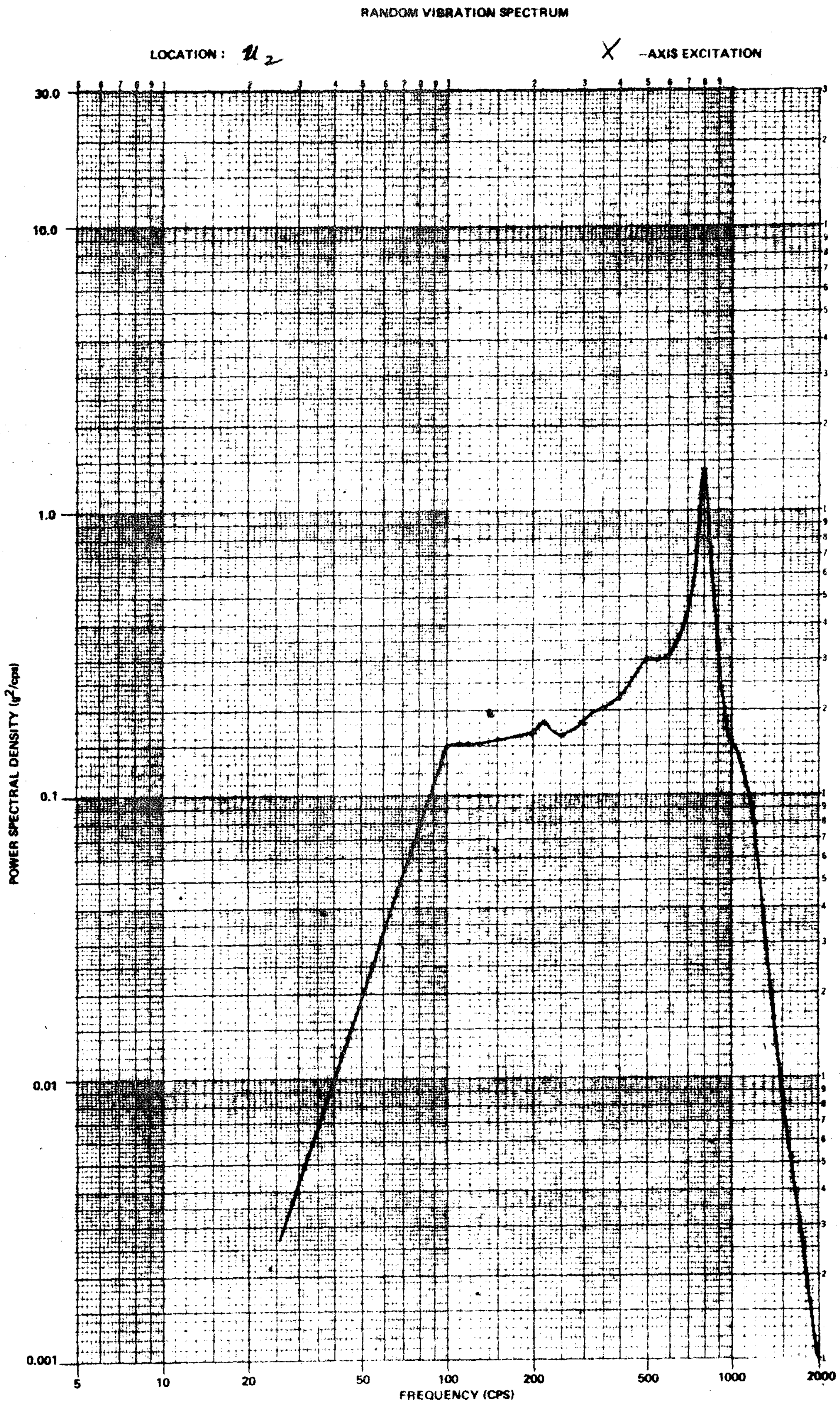


Figure 12 Random Vibration Spectrum at 2 (u_2) Due to x-axis Excitation

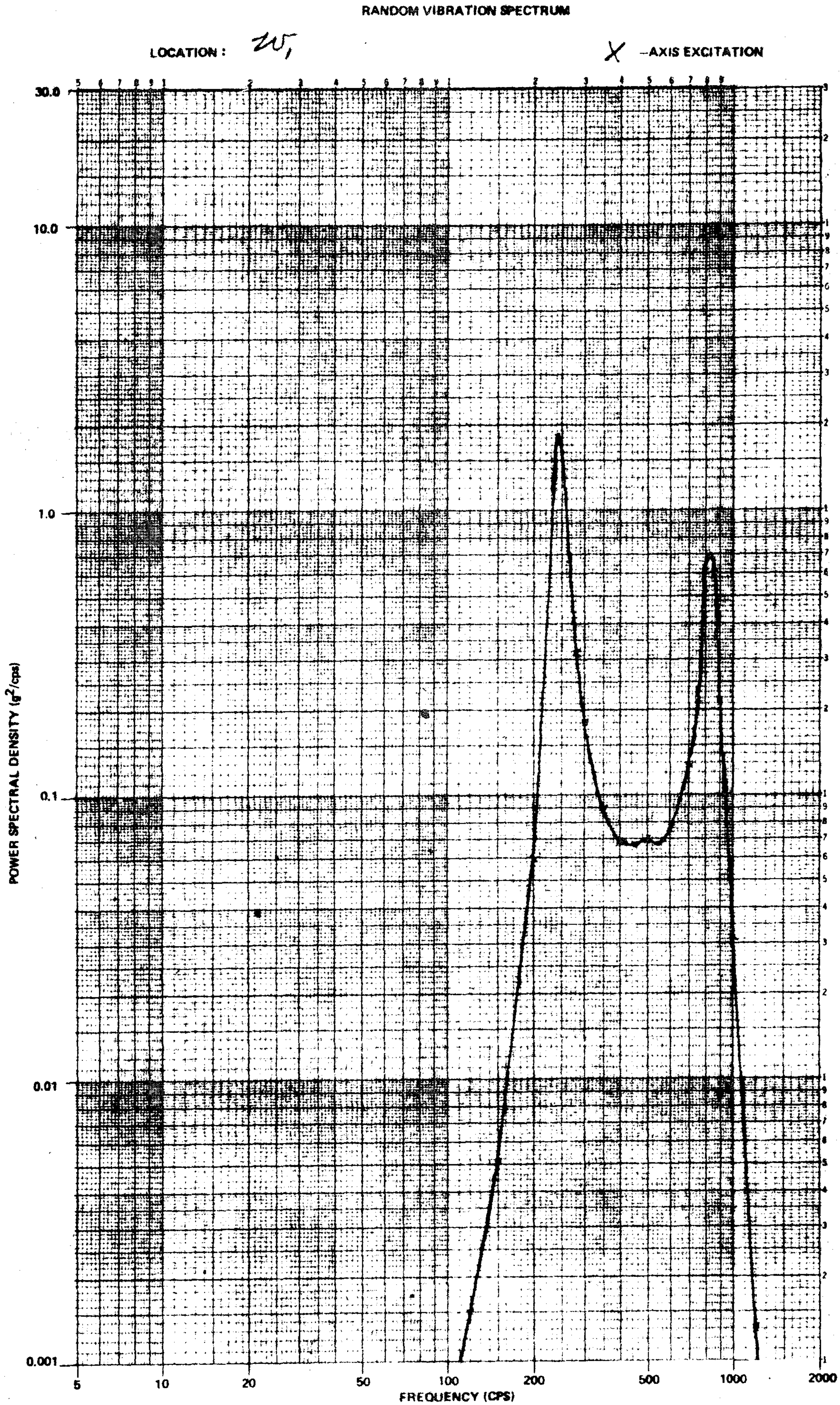


Figure 13 Random Vibration Spectrum at 3 (W_1) Due to x-axis Excitation

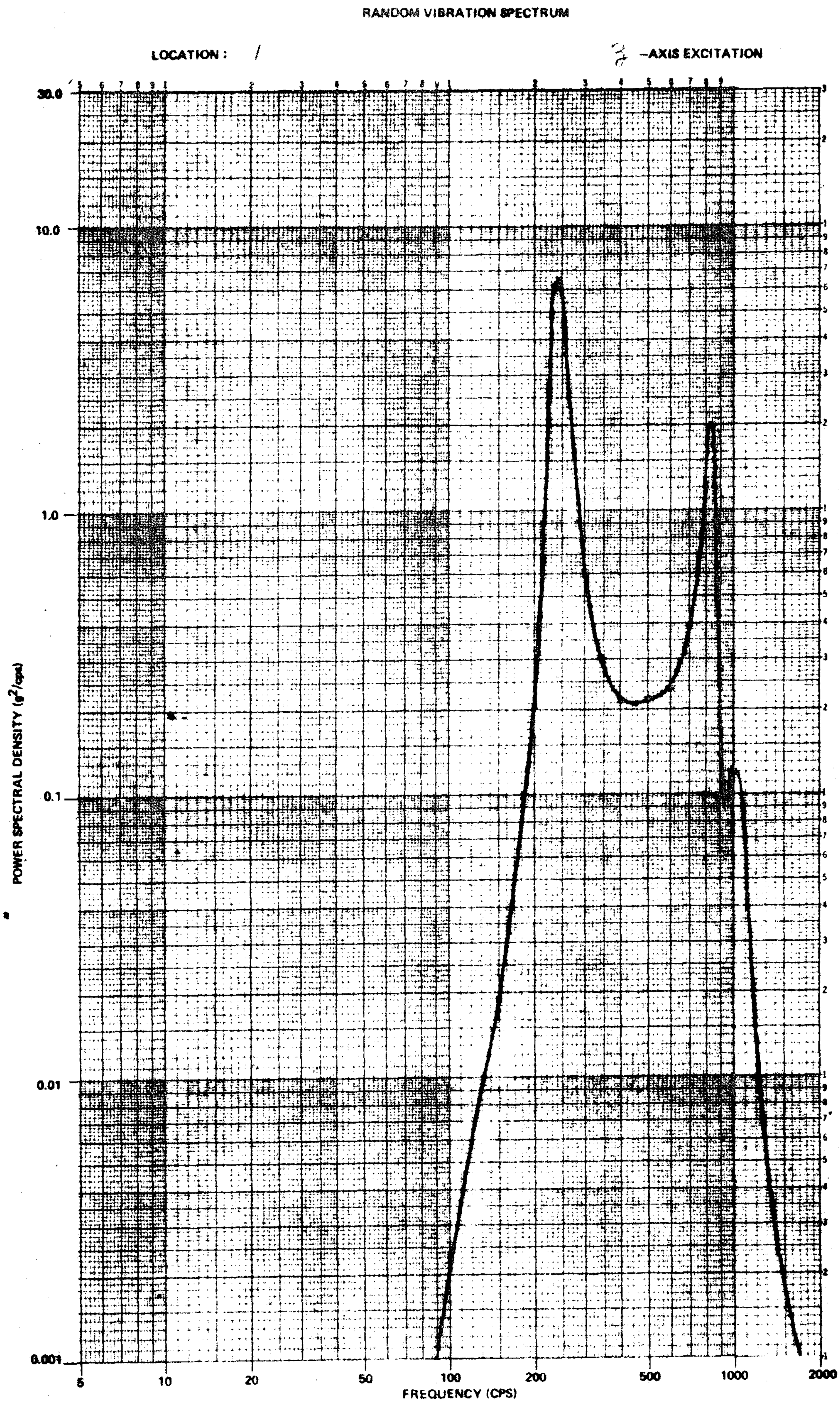


Figure 14 Random Vibration Spectrum at 1 (u_1) Due to z-axis Excitation

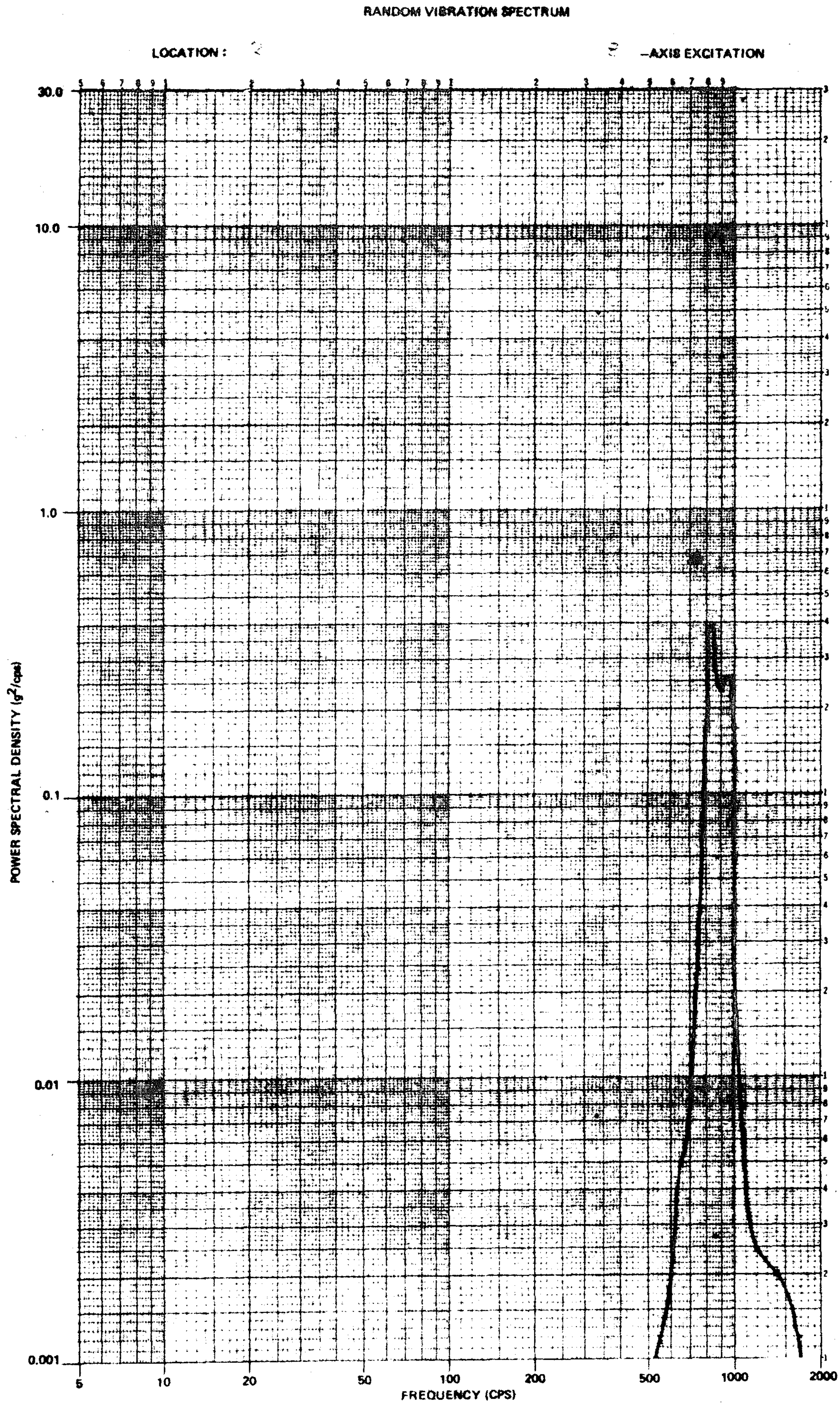


Figure 15 Random Vibration Spectrum at 2 (u_2) Due to z-axis Excitation

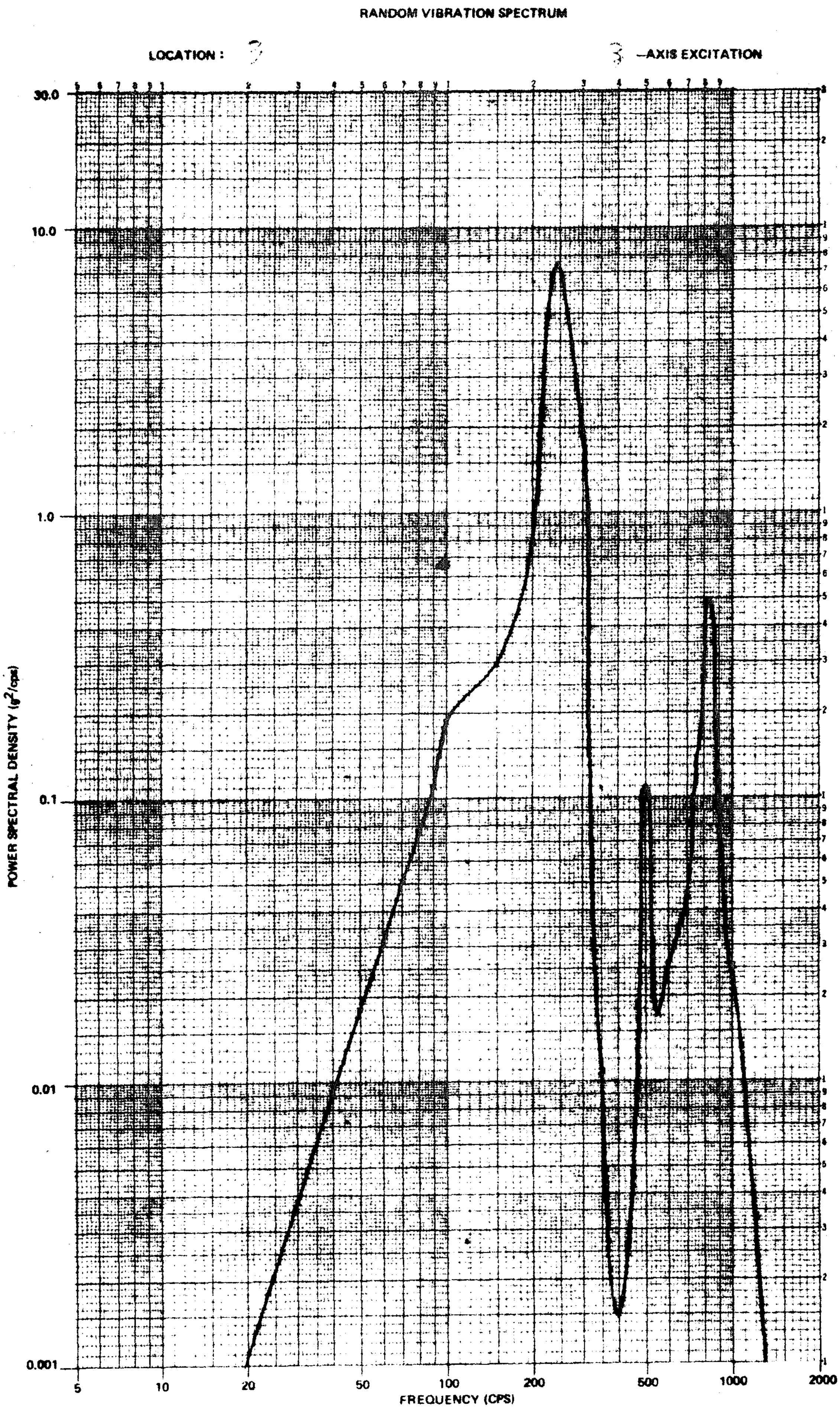


Figure 16 Random Vibration Spectrum at 3 (W_1) Due to z-axis Excitation

SECTION 4

THERMAL ANALYSIS

The thermal integration of the graphite fuel cask with the LM Descent Stage vehicle has been conducted for the several operational phases of the LM mission from prelaunch to lunar deployment. Figure 4-1 lists the interface and design requirements used for the input criteria to the BxA thermal model of the ALSEP/cask/LM interface configuration. Inputs from five organizations including MSC, NAA, GAEC, GE and BxA have been utilized to establish the overall assumptions and input criteria required for the BxA digital computer model of the cask interface. The thermal analyses has been conducted on the BxA prototype design using the -19D graphite cask and material properties defined by the ground rules established in CCP #29.

Figure 4-2 describes the BxA digital computer programs used for the thermal analyses of ALSEP/cask/LM configuration. The thermal integration of the graphite cask required four basic computer programs in order to determine (1) temperature levels and gradients on the cask, support structure, LM and SLA, and (2) radiation and conduction heat leak into the LM for the specific vehicle flight phases. A fifth program has been written to investigate the pressure and flow distributions inside the Saturn SIVB Instrumentation Unit (I. U.) manifold to support the BxA on pad cask cooling study. Two additional programs have been written to investigate in detail the circumferencial internal and external surface temperatures of the graphite cask barrel and end domes. The results of both of these detailed programs are reflected in the 15 node, 3 dimensional thermal model of the ALSEP/cask/LM interface temperatures shown in Figure 4-3.

Figure 4-3 shows the results of the 15 node thermal model of the ALSEP/cask/LM interface for on pad, earth orbit, translunar and lunar mission phases. The temperatures are the same basic thermal results presented at the cask integration meetings held at BxA on 8 June 1967 and at MSC on August 10 and 11, 1967. As shown in the Figure 4-3 cask surface temperatures are predicted to be approximately 725 $\pm 50^{o}$ for all flight and lunar phases.

. **Bendix**

1. Prototype structural design configuration
2. Prototype thermal shield design

   A. Circumferencial angle of shield with cask is 135^{o}
   B. Total hemispherical emittance $\leq .10$

3. 800^{o}F maximum temperature with 150^{o}F circumferencial gradient around cask

. **G. E.**

1. -19D cask design configuration
2. Material properties per CCP #29
3. Graphite coatings for total emittance ≥ 0.80 per -19D and CCP #29
4. 1530 watts maximum power
5. Fuel Capsule design per ICS 314119

. **GAEC**

1. 100 Btu/hr maximum heat leak into LM due to direct cask radiation and conduction
2. 270^{o}F maximum temperature on LM (not including new astronaut thermal door)
3. Mechanical interface per LID 360-22809
4. Environmental interface per ICS LIS 360-22402 and LED 520-F

. **MSC**

1. NAA SLA internal and external thermal coatings per MSC transmittal dated June 1966
2. LM vehicle thermal coatings per LM-3 and on report by J. Smith, of MSC, dated January 1967
3. LM vehicle mission profile per MSC June 1966 transmittal and LED 520-F
4. Apollo Program environment specification per M-DE 8020.008B dated April 1965
5. BxA/MSC contract 9-5829, Exhibit B

Figure 4-1 Interface and Design Requirements Used for Input Criteria for BxA Thermal Model of ALSEP/Cask/LM Interface Configuration

- 15 node, 3 dimensional thermal model for ALSEP/cask/LM configuration defined by CCP #29, reference Figure 4-3

- 25 node, 3 dimensional thermal model of ALSEP/LM vehicle interface to evaluated GAEC temperatures on thermal door and landing gear, reference Figure 4-4

- 22 node, 3 dimensional thermal model of BxA/GAEC support structure interface for conduction heat leak evaluation

- 20 node, 3 dimensional thermal model of ALSEP/cask interface to evaluate axial and circumferencial gradients for on pad cooling temperature and thermal stresses

- 35 node, 2 dimensional model of Saturn SIVB Instrumentation Unit (I. U.) manifold to determine flow distribution and pressure gradients in I. U. manifold for on pad cooling requirements

Figure 4-2 Description of BxA Digital Computer Programs Utilized for Thermal Analysis of ALSEP/Cask/LM Interface

		Ambient Temperatures, °F	Translunar Temperatures, °F			Lunar Surface Temperatures, °F	
	Surface Description	On Pad $h_c = 1.0$	SLA On, Sun Orientated	SLA Off, Sun Orientated	SLA Off, Sun Orientated	Sun-Orientated	Space-Orientated
1	Cask Barrel Surface	588-622	689-740	689-726	661-713	707-743	684-733
2	Cask Ends	348	428	417	413	429	433-445
3	Fuel Capsule	1346	1372	1370	1363	1376	1370
4	Thermal Shield - Front	156	474	441	427	467	458
5	Thermal Shield - Rear	92	233	53	22	125	105
6	LM	95, $\epsilon = 36$	183	106	-206	153	0.6
7	SLA/Space	92	250	-459	-459	(Lur) 85 (Sp) -459	(Lur) 85 (Sp) -459

*Results based on -19D cask design using HITCO material properties

Figure 4-3 Preliminary Results of BxA Thermal Analysis of ALSEP/Graphite Cask/LM Interface*

Figure 4-4 summarizes the LM Compartment 1 thermal door and undeployed landing gear maximum temperatures for LM earth orbit, SLA on case. Maximum temperature on the LM thermal door are shown to be less than 350° with the SLA attached and a 90° sun angle to the SLA. Maximum landing gear temperatures for the same case are less than 225°F.

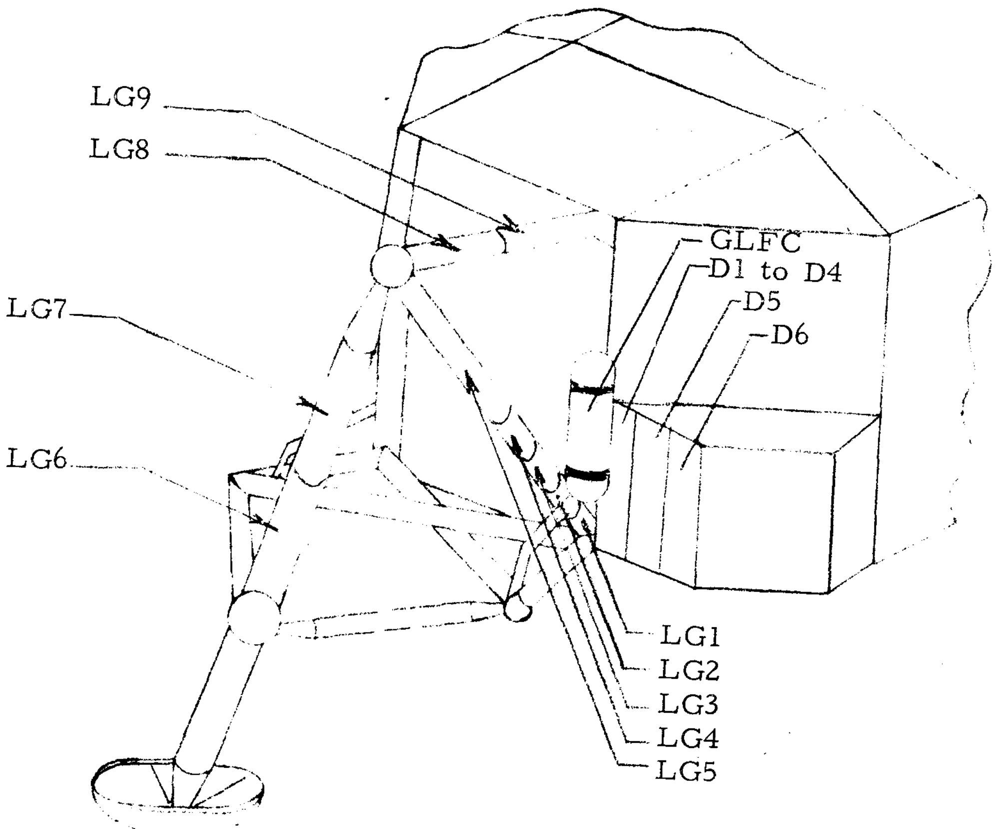
Figure 4-5 summarizes the test results versus pre-test predictions for the free convection cooling case obtained as part of the BxA On Pad Cask Cooling Test Program. For this ambient baseline test without active cooling the maximum cask surface temperature recorded was 576°F with a 1080°F maximum EFCS temperature. The average cask and capsule surface temperatures obtained from this cask cooling baseline test are estimated to be approximately 50°F for the cask and 300°F for the capsule lower than the present flight cask due to the hybrid cask configuration tested. The test configuration consisted of simulated prototype hardware including the cask support structure, the BxA thermal shield, the LM support struts and vehicle mounting panel, the M5 electric fuel capsule simulator (EFCS) and a pyrolytic graphite cask by Super Temp. Due to the unavailability of hardware, the graphite cask did not include the following GE internal cask parts:

1. Capsule back plate
2. Cask latch fitting
3. Capsule lower support assembly
4. Cask re-entry radiation shield

Differences in material thermal properties between the Super Temp and Hitco casks are also predicted to provide increased temperature gradients for the flights cask internal and external surfaces.

As shown in Figure 4-5, the post test correlation of the temperature data from the ambient air test and the pretest thermal predictions were within very close agreement. Cask surface temperatures from analysis were predicted to vary between 533°F to 599°F and actual cask temperatures obtained ranged from 507°F to 594°F. The BxA thermal shield temperatures for the ambient test ranged from 79°F to 127°F as compared to predicted values of 91°F to 128°F. This close agreement of the BxA thermal

SUMMARY OF LM COMPARTMENT I THERMAL DOOR AND UNDEPLOYED LANDING GEAR MAXIMUM TEMPERATURES FOR EARTH ORBIT, SLA ON CASE

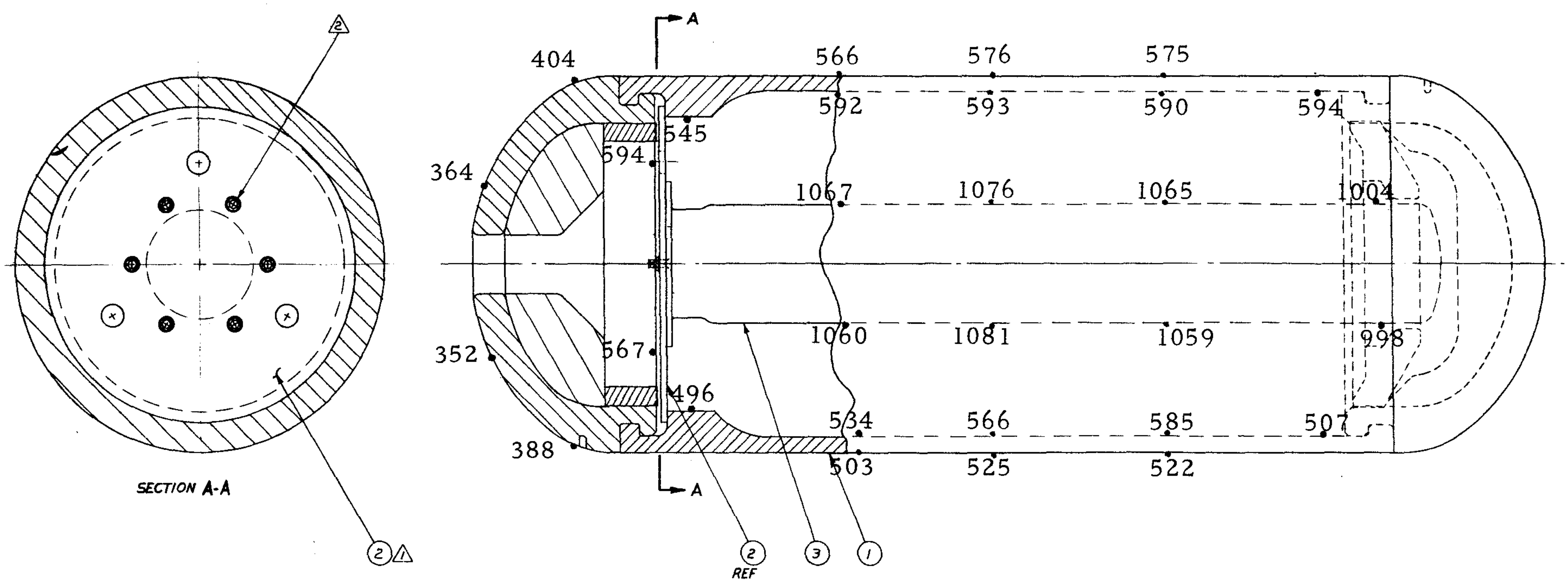


Node No	Temperature, °F	Node No.	Temperature, °F
D1	259	LG1	192
D2	299	LG2	192
D3	320	LG3	192
D4	326	LG4	192
D5	292	LG5	218
D6	236	LG6	219
LM (ave.)	220	LG7	219
SLA	250	LG8	211
GLFC	690	LG9	212
		GLFC	690

Figure 4.4

Figure 4.5

TEST RESULTS VERSUS PRE-TEST PREDICTIONS FOR FUEL CAPSULE AND CASK ASSEMBLY FOR ON PAD COOLING TEST WITHOUT PURGE (FREE CONVECTION CASE)



Surface Description	Test Results, °F	Pre-test Predictions, °F
1. Capsule Surface	998 to 1081	1050
2. Cask Internal Surface	507 to 594	533 to 599
3. Cask External Surface	503 to 576	516 to 586
4. Cask Domes	352 to 364	347
5. Thermal Shield	79 to 127	91 to 128
6. LM Panel	78 to 92	73 to 88

model with the ambient test results for the ALSEP/cask/LM interface indicates that temperature predictions for subsequent phases of the LM mission including lunar operations should also be valid.

Figure 4-6 lists the additional areas of the BxA thermal design and analysis required to support prototype design and testing. The major areas that require updating include:

1. Update BxA/GE ICS and ICD

2. Update CCP #29

3. Incorporate cask cooling requirements per CCP #76

4. Provide for new proposal and design of flight cask cooling

5. Re-analyze the ALSEP/cask/LM interface for transient and steady state temperature levels and distributions for new cask design and material properties

6. Update of the LM vehicle thermal cannister to current GAEC interface for prototype T/V testing scheduled for February 1968 at BxA.

The updating of the BxA thermal model of the BxA/GE/GAEC cask interface is required to provide meaningful thermal pre-test prediction for prototype cask T/V testing, i.e., temperature gradients and resulting thermal stresses both internally and externally on the graphite cask and support band and structure, transient temperature histories of the prototype configuration versus time, and vehicle heat loading due to the revised cask and LM design.

- Update BxA/GE ICS 314121 dated 4/29/67 and ICD 2334552 dated 4/26/67

- Update BxA CCP #29 to include:

  1. -19XX design from -19D dated 21 April 1967
  2. Hitco material thermal properties
  3. Graphite thermal coating properties at temperature
  4. Redesigned GAEC interface

- Incorporate On Pad Cask Cooling Requirements per CCP #76

  1. Preliminary report 11/29/67
  2. Preliminary thermal and structural requirements for BxA, MSC, MSFC, KSC and GAEC during 12/67
  3. BxA final thermal report for onpad cooling system 12/22/67

- New proposal for On Pad Cooling Flight Design

  1. Thermal/Structural design of flight configuration
  2. Provide flight instrumentation for prelaunch cask temperature monitoring

- Re-analyze ALSEP/cask/LM configuration for both transient and steady state temperature and thermal stress gradients to include above referenced items for technical requirements into ALSEP Prototype tests

- Update LM vehicle cannister for thermal/vacuum testing at BxA to include:

  1. New astronaut thermal door design
  2. Revised GAEC thermal coatings for LM
  3. New LM support struts
  4. On pad cooling configuration to evaluated velocity and pressure effects on LM structure and landing gear super insulation design

Figure 4-6 Additional Items Required for BxA Thermal Design and Analysis to Support Prototype Design and Test

SECTION 5

1.0 Mechanical Ground Support Equipment (M.G.S.E.)

The M.G.S.E. will be designed to implement the functional requirements consistent with the design of the fuel cask support assembly and KSC operations. The design of the MGSE is in the preliminary phase.

The MGSE comprises the fixtures, handling devices, and special tools required to effect assembly and handling functions and also shipment of relevant hardware.

The functional flow diagram shown in Figure 5.1 specifies functional requirements along the mainstream, with the required MGSE feeding into each functional block. The purpose of this flow diagram is to present functional requirements only and not to define an operational sequence.

The MGSE required for the fuel cask support assembly is as follows:

Shipping Container, Fuel Cask Support Assy.

Handling Cart Assy., Fuel Cask

Holding Fixture, Trunnion Alignment/Band Calibration

Cask Band Prestress Measuring Means

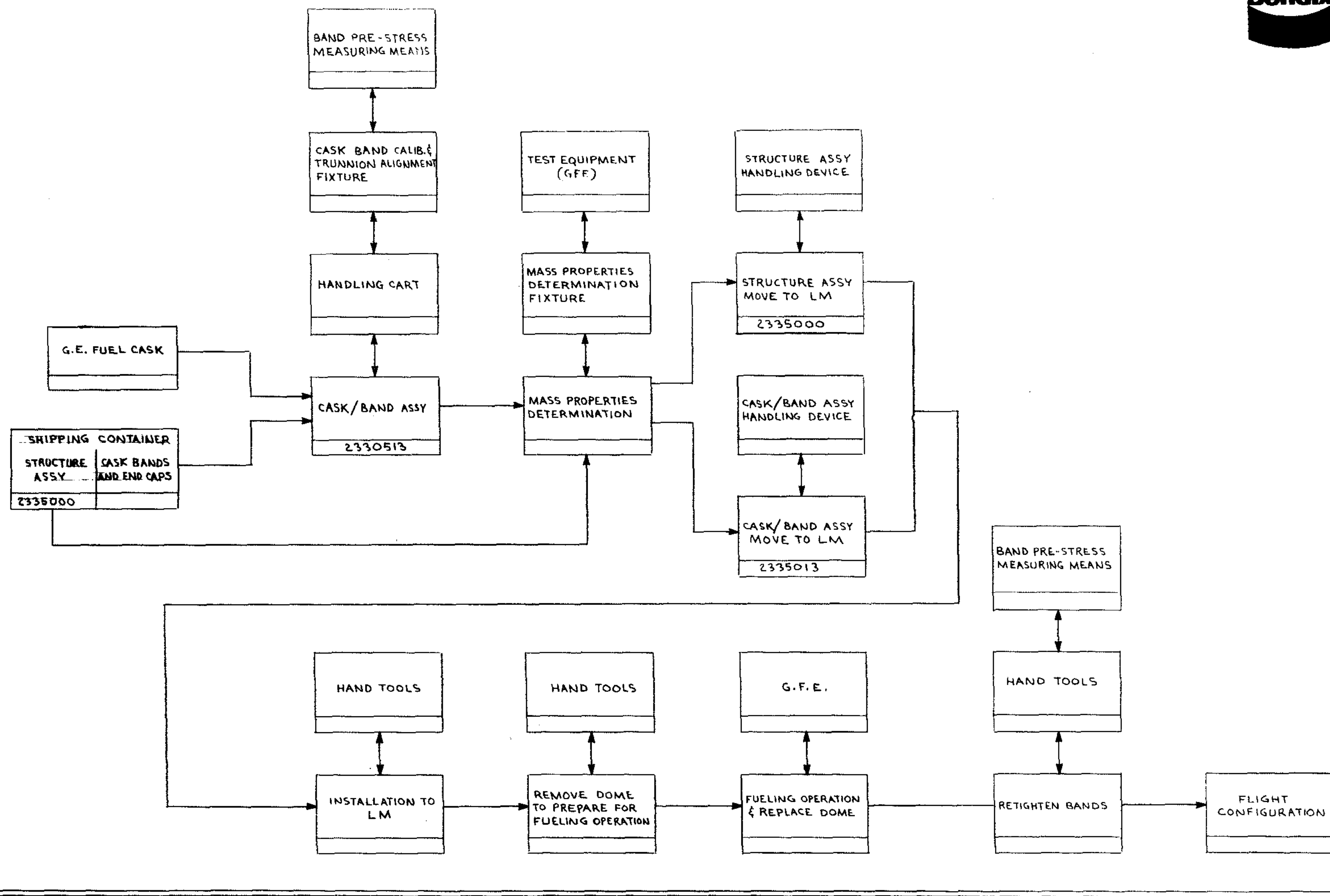
Holding Fixture, Mass Properties Determination, Fuel Cask

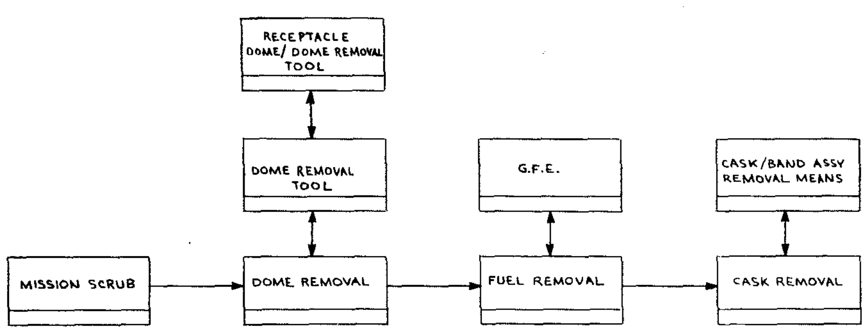
Handling Device, Cask/Band Assy.

Handling Device, Structure Assy.

1.1 Shipping Container

The shipping container is designed to accept the structure assembly, assembled to a support plate that simulates the LM interface, and also the fuel cask bands and end caps assembled to a dummy fuel cask.





ASSEMBLY, ALIGNMENT AND INSTALLATION FLOW DIAGRAM OF FUEL CASK AND SUPPORT ASSY

Figure 5.1

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1.2 Cask/Band Assy Function

The following MGSE is used to effect the cask/band assembly.

Handling Cart Assy, Fuel Cask, Fig. #5.2 and 5.3

Holding Fixture, Trunnion Alignment/Band Calibration

Cask Band Pre-stress Measuring Means

The handling cart provides a means for attachment of the holding fixture and also provides a work surface for related equipment.

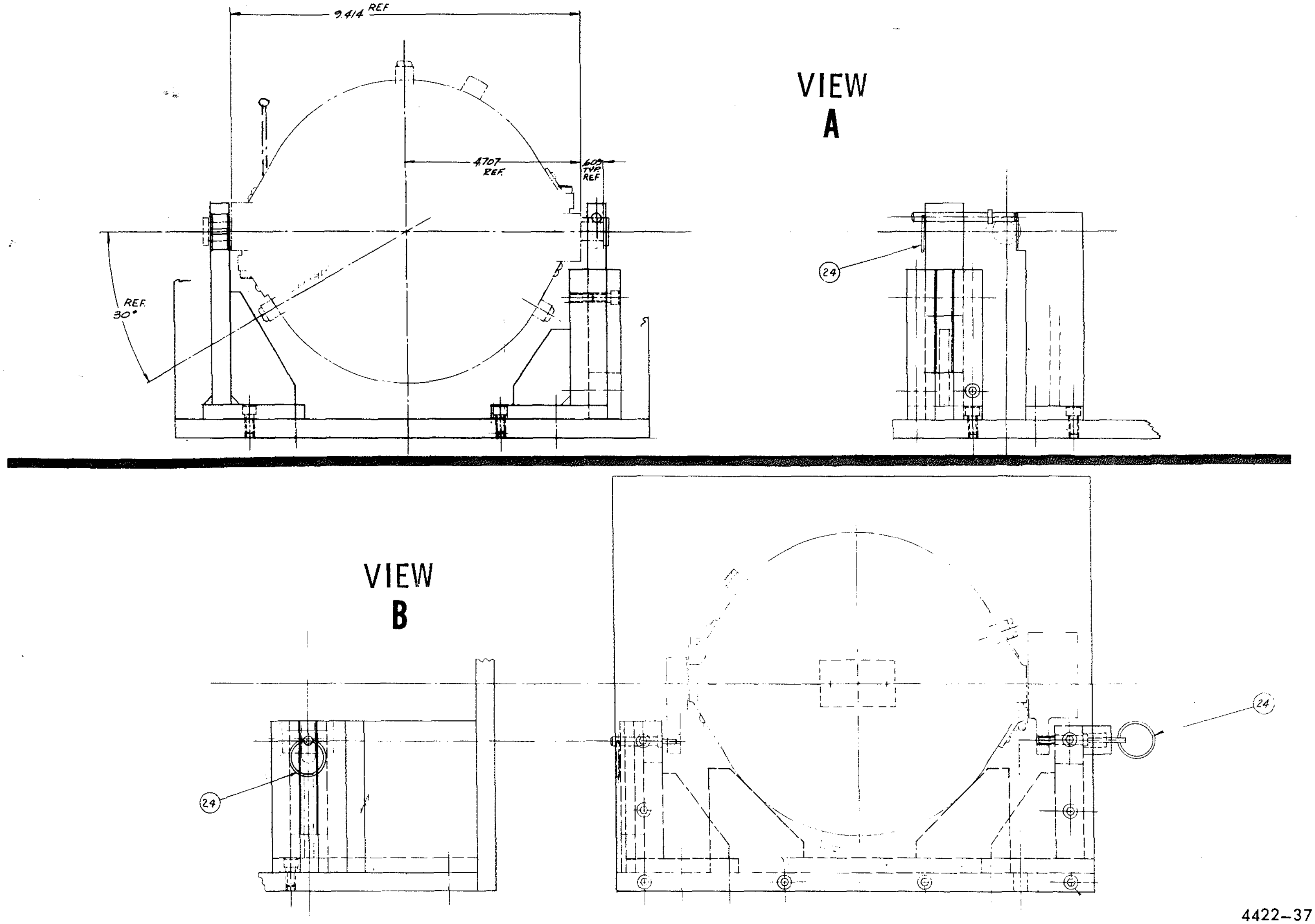
The cask bands and end caps are assembled to the fuel cask and pre-stressed as follows:

- Loosely assembly bands and end caps to fuel cask.
- Place assembly in holding fixture and orient cask spline lock to proper position.
- Align and lock upper trunnion in Vee block.
- Align upper trunnion in plane normal to axial center-line of cask.
- Adjust axial bands to attain proper pre-stress.
- Adjust upper band to attain proper pre-stress and simultaneously align the upper trunnions in a plane parallel to the axial center line of the cask.
- Adjust lower bands to attain proper pre-stress and simultaneously align the lower trunnion and attachment point in a plane parallel to the axial center line of the cask.

1.3 Mass Properties Determination

Determination of specific mass properties is accomplished by use of the Holding Fixture, Mass Properties Determination, (Fig. #5.4) in conjunction with a weighing device.

Figure 5.2



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HOLDING FIXTURE TRUNNION ALIGNMENT/ BAND CALIBRATION

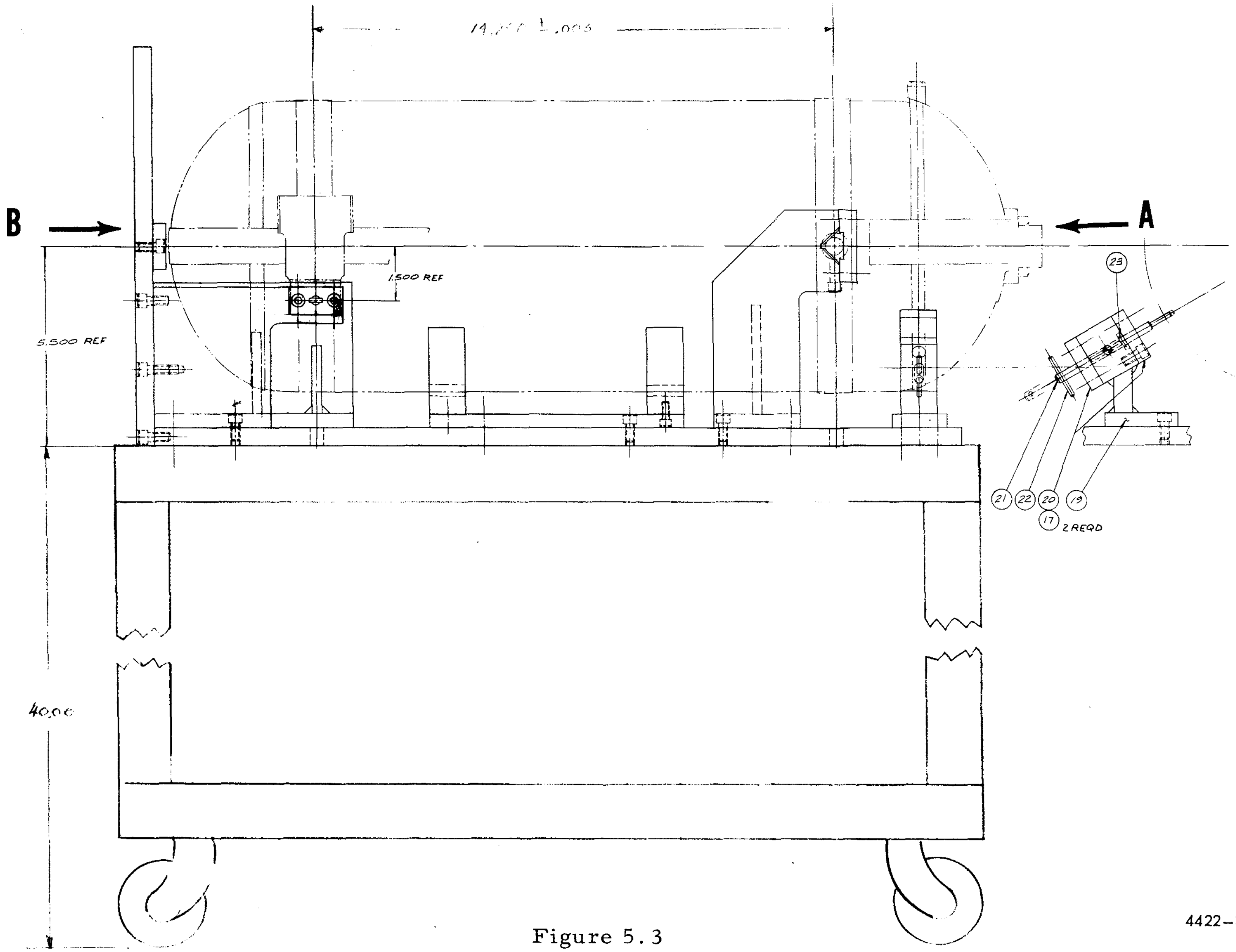

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Figure 5.3

HOLDING FIXTURE, MASS PROPERTIES DETERMINATION

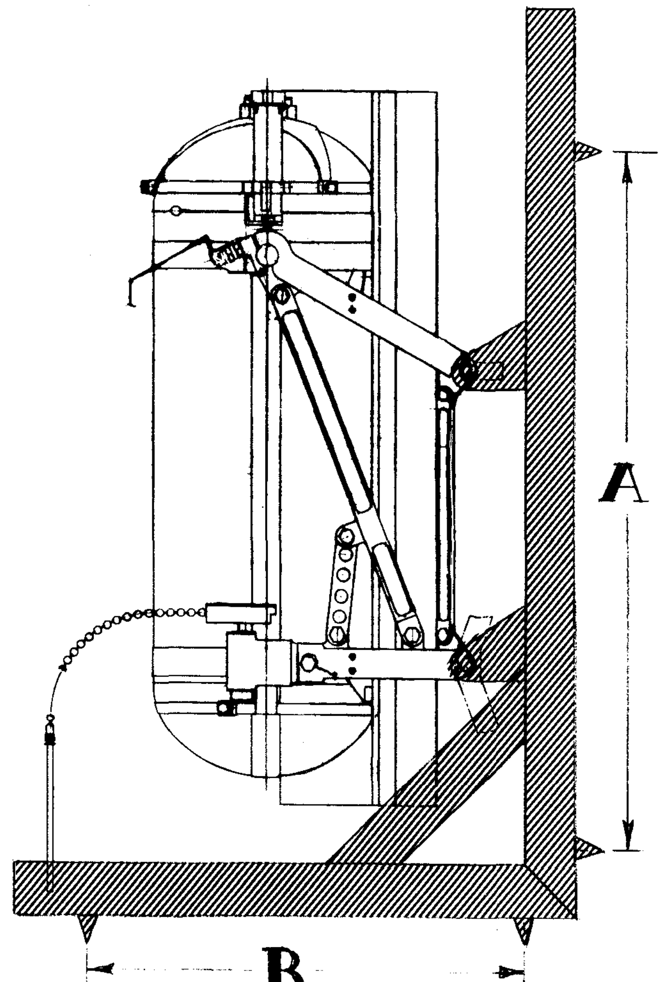

Figure 5.4

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The holding fixture is designed to simulate the LM hardpoints and also to provide pins, to interface with a fixed surface and/or a weighing device as required to determine total weight or center of gravity.

The holding fixture may also be used to support the structure assembly to perform relevant fit checks of the fuel capsule.

1.4 Structural Assembly, Movement to LM (Fig. #5.5)

The structure assembly handling device is used to handle the structure assembly during movement to LM.

The handling device attaches to the structure assembly at the cask trunnion interface and allows access to the hardpoints that interface with LM.

Considerations for the handling device design are as follows:

- Provides protection for heat shield and structure.
- Provides handles at extreme ends of assembly to facilitate handling.
- Precludes contact with thermal control surface.
- Provides a base for rest in the assembly on a flat surface e.g. work platform.

The handling device is designed to be removed after the structure assembly is interfaced with LM.

1.5 Cask/Band Assy., Movement to LM (Fig. #5.6)

The Cask/Band Assy Handling Device is used to handle the cask/band assy. during movement to LM.

The handling device attaches to the cask band trunnions.

Considerations of the handling device design are as follows:

- Provides protection for cask/band assy.

HANDLING DEVICE, STRUCTURE ASSEMBLY

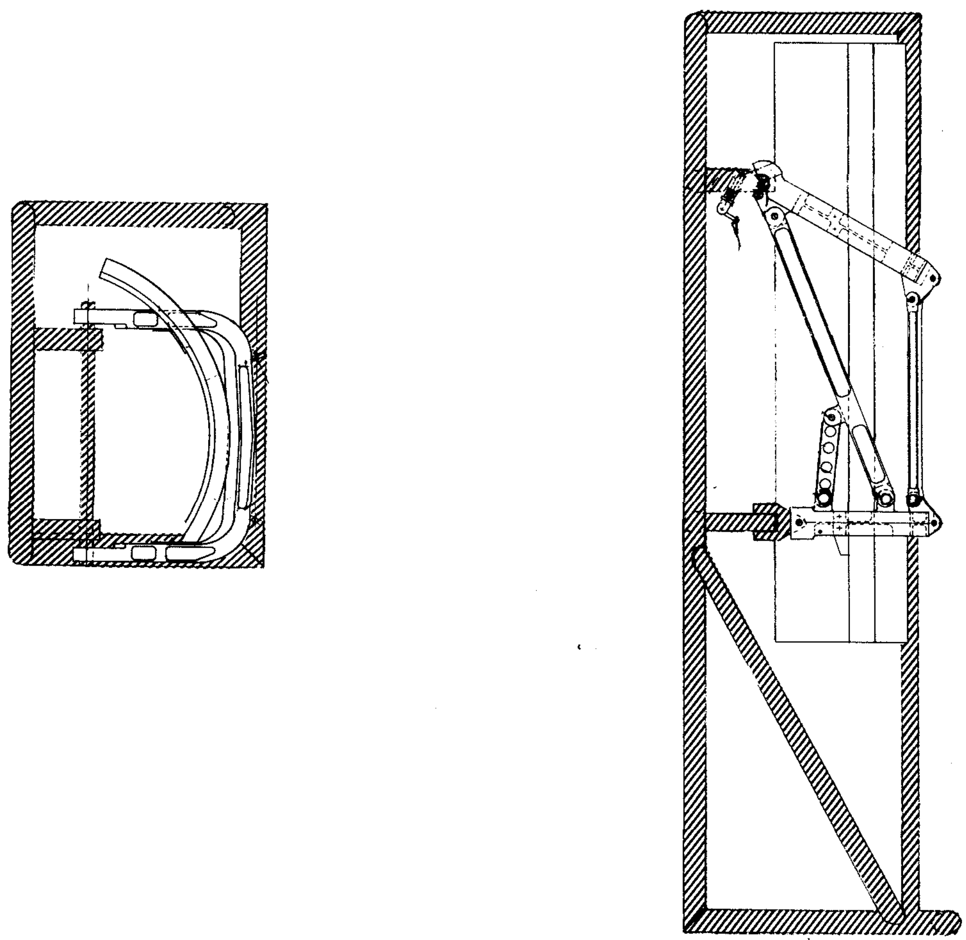

Figure 5.5

Handling Device Cask/Band Assy

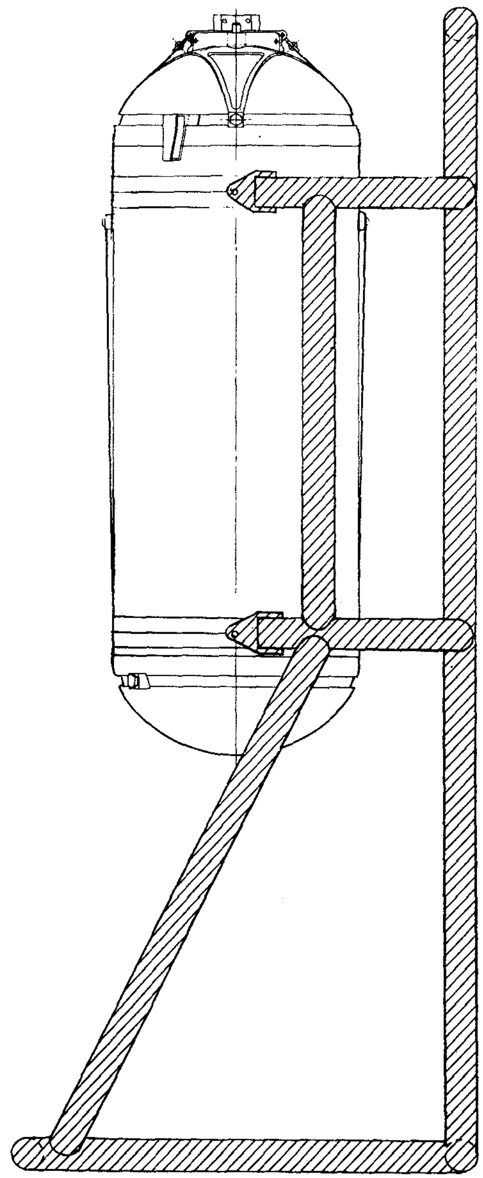

Figure 5.6

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- Provides handles at extreme ends of assy. to facilitate handling.
- Precludes necessary contact with thermal control surfaces.
- Provides a base for resting the assy on a flat surface e.g. work platform.

1.6 Installation to LM and Dome Removal

Hand tools are used to accomplish these functions.

1.7 Fueling Operation

The fueling operation is accomplished with G.F.E.

1.8 Retighten Cask Bands

Cask bands are retightened using hand tools and the band pre-stress measuring means. The fuel cask assy. is then in "flight" configuration (Fig. #5.7).

1.9 Mission Scrub

The following MGSE will be designed for use in the event that the mission is scrubbed and the fuel element and fuel cask is to be off loaded.

Cask Dome Removal Tool

Receptacle for carrying dome and dome removal tool.

Cask Band Assy removal means.

FUEL CASK SUPPORT ASSEMBLY

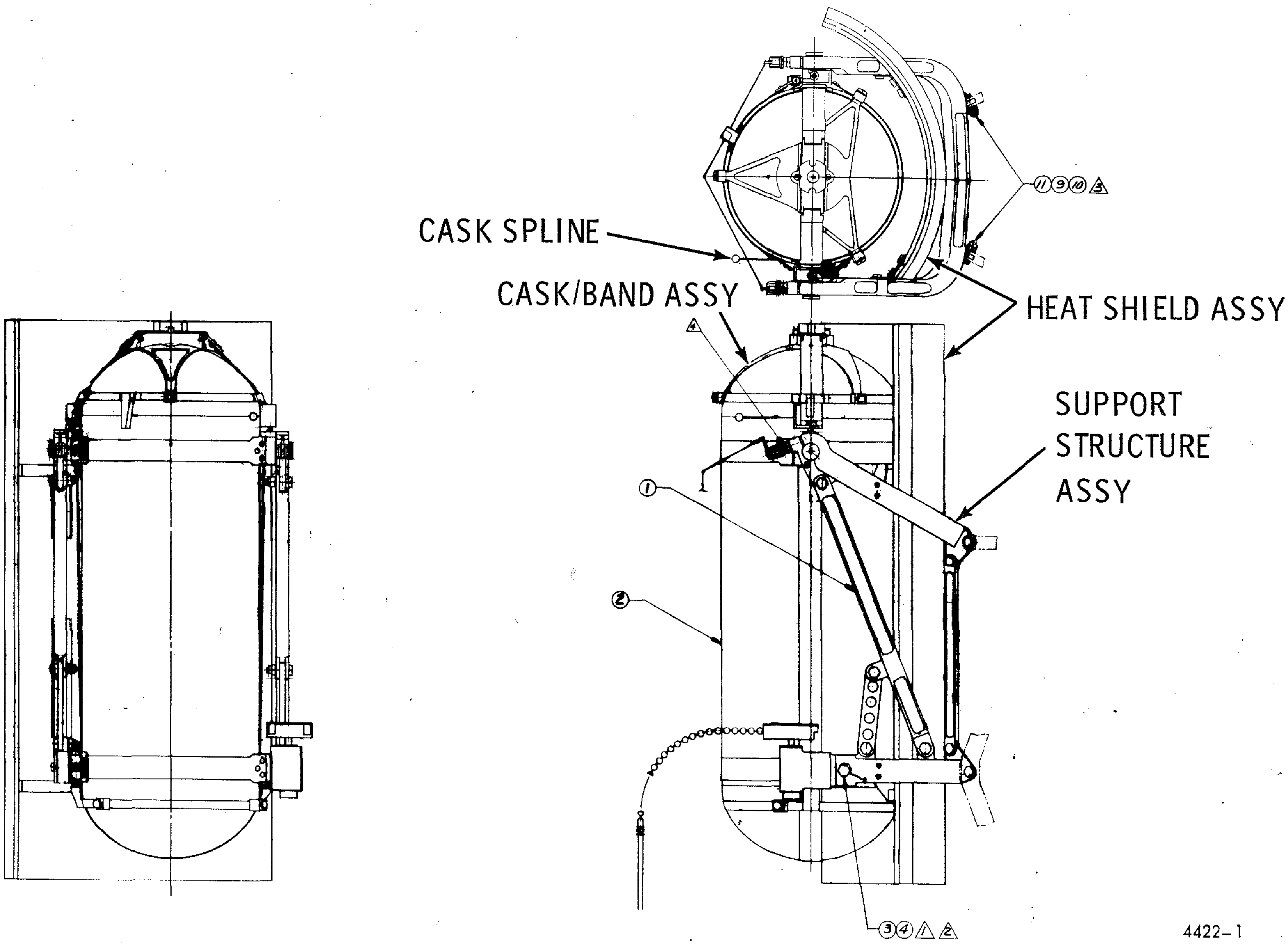

Figure 5.7

SECTION 6

ASTRONAUT PROTECTION

Introduction

During the ALSEP CDR, the Astronaut Office representatives submitted RFC #03-02 which required provision of additional protection to the astronaut while he performs his tasks in proximity to the hot fuel cask. This protective device must be capable of fending off the astronaut if he stumbles in the area of the tilted cask from a head-on approach. The protective door prevents the astronaut from contact on one side of the cask while the LM landing gear performs this function on the other side (see Figure #1). Therefore, the head-on approach presents the only condition under which the astronaut might come in contact with the fuel cask.

Further, the device must be installed on the lunar surface since any prelaunch installation would result in a situation wherein the device would exceed the suit thermal capabilities and defeat its purpose.

To provide this protection, a "bird cage" (Bendix terminology) or "catcher's mask" (astronaut terminology) assembly was sketched out (see Figure #2), a soft (feasibility) mockup fabricated and shirt sleeve tests performed by Bendix Crew Engineering. The concept appeared feasible; therefore, an improved, updated cage was constructed for further feasibility testing with the CCP #54 cask mechanism. It must be emphasized that Crew Engineering is still performing feasibility or conceptual testing on this device.

The current mockup of this device incorporates an interface arrangement with a previous tool. The possibility of the use of the dome removal tool will be investigated; however, this may not be feasible and one of the other tools may be required instead. This will be determined after sufficient testing takes place.

There is only one particular problem with this device -- stowage. There is no space available in the SEQ Bay at this time and a request has

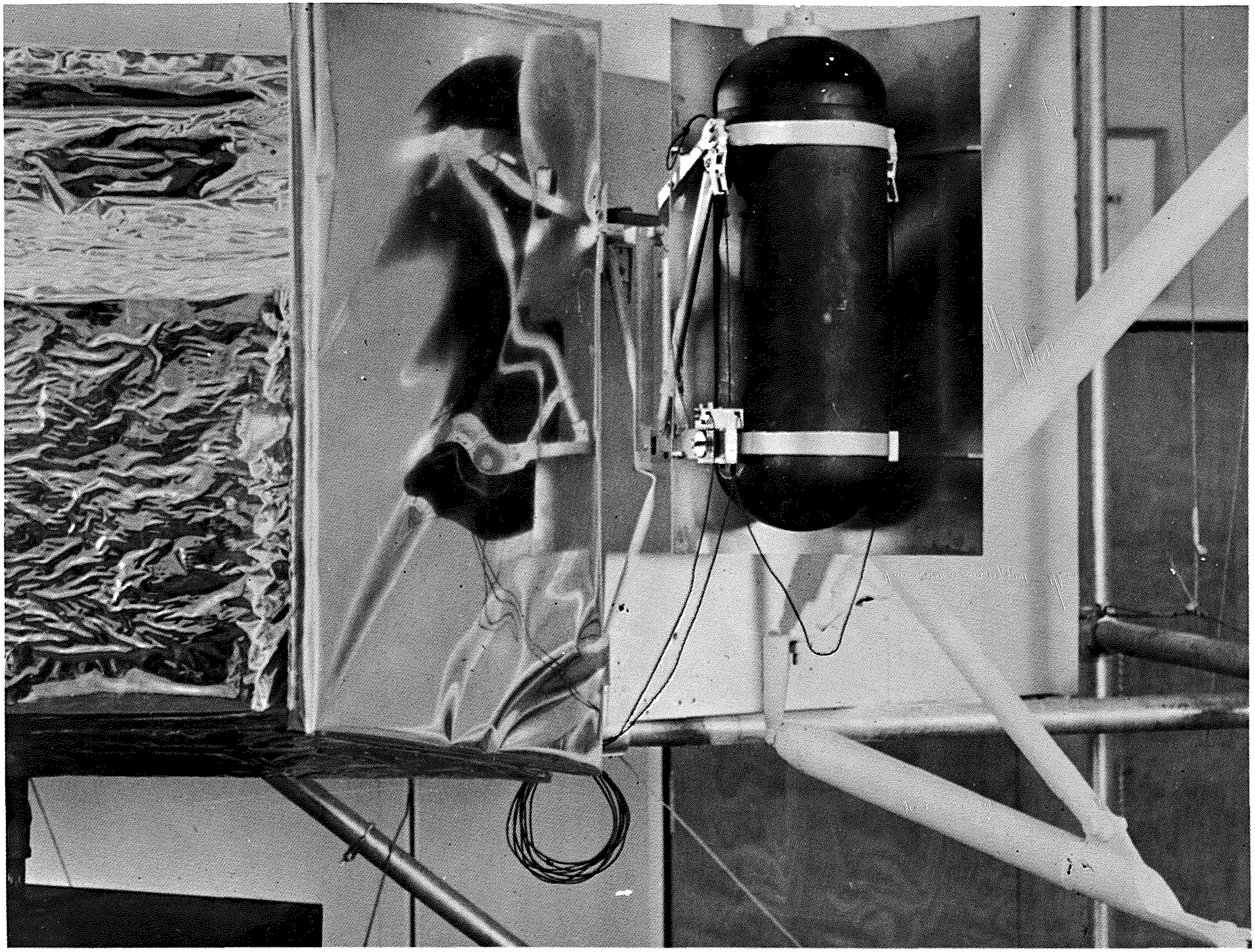

FIGURE #1 - PROTECTIVE DOOR/FUEL CASK/LM LANDING GEAR INTERFACES

SKETCH ASTRONAUT PROTECTIVE DEVICE - FUEL CASK OPERATIONS

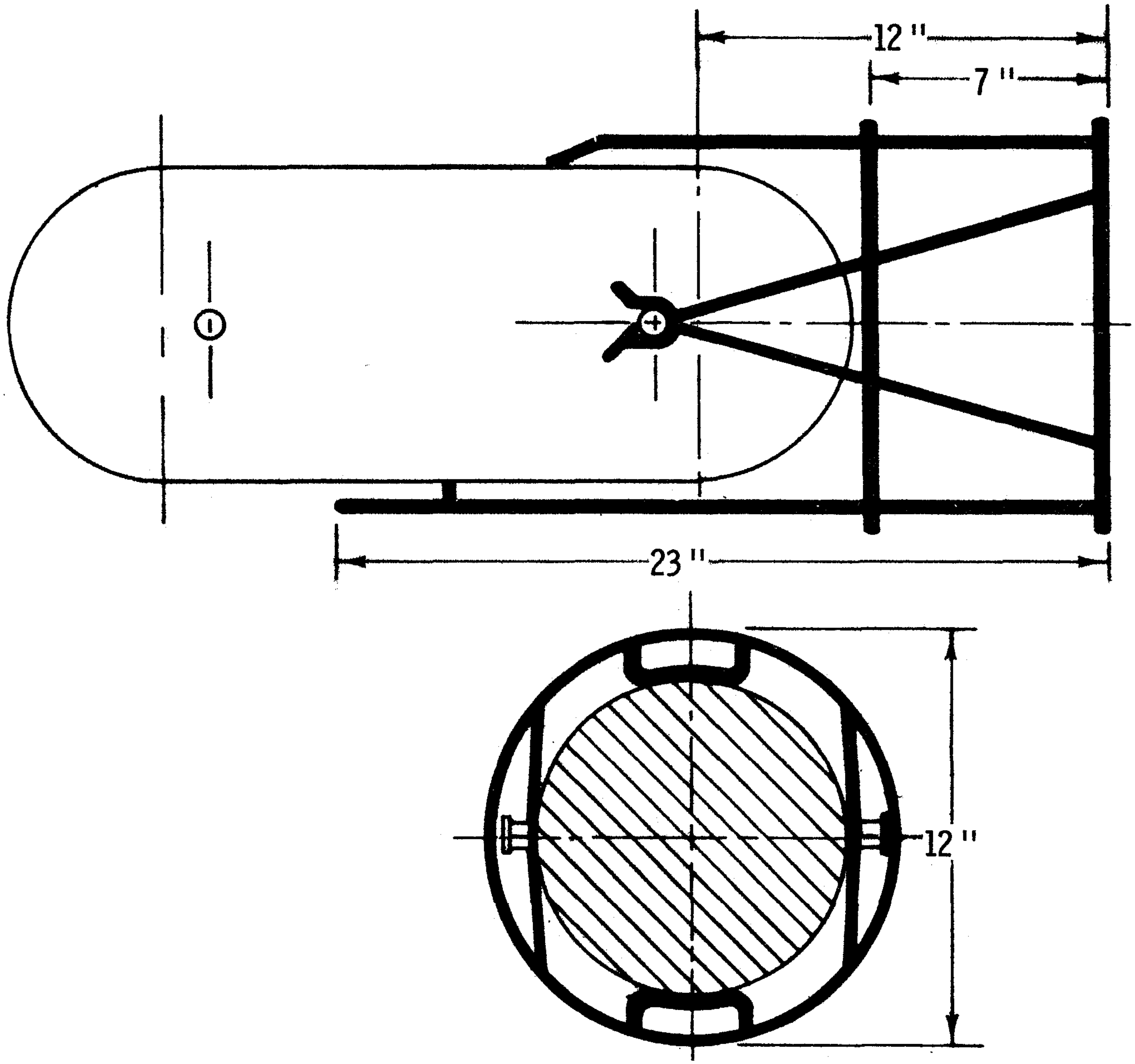

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FIGURE #2

been submitted to NASA/MSC for consideration of space allocation in the SRC stowage area. No reply has been received to date regarding this request.

Following is the expected or proposed sequence of events in the handling and deployment of the protective device.

Deployment Sequence - Protective Device

1. Retrieve protective device from in-flight stowage and stow temporarily near fuel cask area.

2. Tilt cask after releasing the latches and retrieving the tilt mechanism lanyard.

3. Retrieve protective device from temporary stowage and interconnect the tool to the device.

4. Install the device by manipulation of the tool such that the hair pin latches engage over the latching studs with the long arm on the cage on the bottom side of the cask.

5. Insure that the device is secure by pulling back slightly on the tool.

6. Retrieve the Dome Removal Tool and remove spline key.

7. Release and remove dome -- discard in the nearby LM landing gear dish.

8. Disengage the tool and prepare for fuel transfer using the established procedure.

Preliminary Test Results

The (bird cage) protective device was tested by a suited, pressurized subject performing the required tasks in the Bendix 1/6 G suspension harness. The subject inserted the tool through the ring provided on the circumference of the cage and mated the tool to the interface provided on the inner portion of the protective device. He then installed the cage over the fuel cask (see Figure #3) per the specified procedures and then removed the fuel cask dome and the fuel capsule.

Subjective response during and after the tests revealed that some problems exist which must be considered during detailed design of the cage and its relationship to the dome and fuel capsule removal tasks. Emplacement (deployment) of the protective device was an easily and rapidly performed task. However, because of the restricted mobility afforded in the suit, the fuel cask required being lowered more than usual such that there was not a normal view of the capsule head available for fuel transfer. The subject could not raise his arms sufficiently to maintain both hands on the tool to emplace the protective device while the cask is high enough to allow facile and fast removal of the dome and fuel capsule.

Another potential problem area discovered was interference between the dome stop mechanism which indicates that the dome has been rotated sufficiently to disengage the lock. This mechanism did not clear the cage used and resulted in momentary inability of the subject to complete dome removal. This was later solved by enlarging the cage in the area surrounding the stop mechanism; however, it will be a point of consideration during detailed design.

As a result of these tests, certain recommendations will be made to the design group. These are:

1. Retest of the cage/fuel cask/fuel retrieval and transfer tasks with the improved Apollo flight suits to determine if the increased mobility allowed by these suits is a favorable factor in task performance.

2. Larger flaring of the cage device to allow clearance between the dome stop mechanism and the cage.

3. Long enough lanyard on the dome spline lock to allow insertion of the cage prior to removal of the spline key. This will require extensive coordination and very fine control of the fabrication of the spline location and cage configuration to insure that the spline removal cord clears the cage and still allows easy retrieval and removal.

4. Color coding the tool/cage/cask interface points to allow the astronaut to have some visual access to the interconnection to be made.

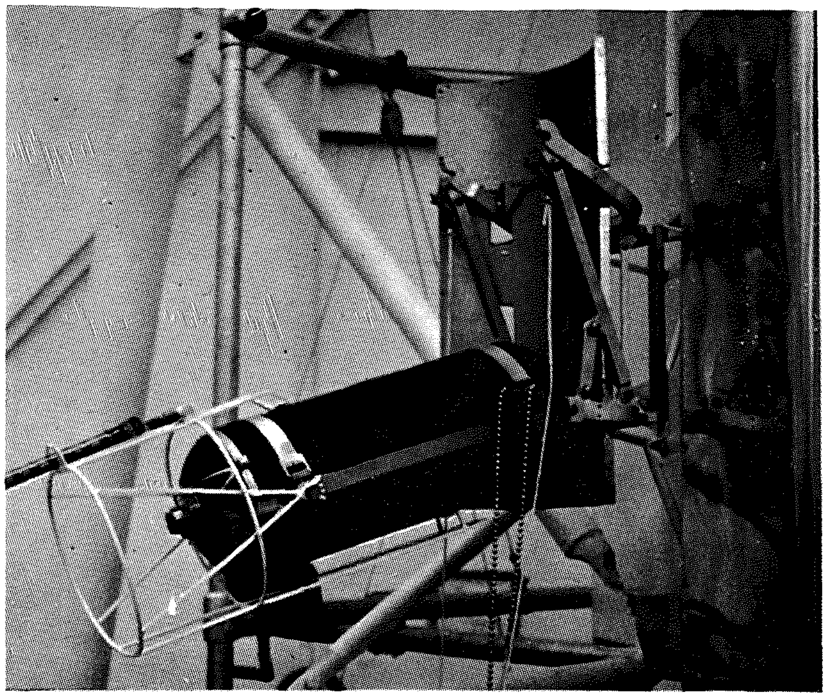

FIGURE #3 - PROTECTIVE DEVICE INSTALLED ON CASK UTILIZING PREVIOUS DOME REMOVAL TOOL

5. KC-135 flight testing of the mechanism <u>after</u> the above mentioned recommendations are made and tested extensively in the Bendix Crew Engineering Laboratory.