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LaRC DESIGN ANALYSIS REPORT

FOR

NATIONAL TRANSONIC FACILITY

FOR

304 STAINLESS STEEL TUNNEL SHELL

FINITE ELEMENT ANALYSIS OF CORNERS #3 AND #4

VOL. 2S

BY

JAMES W. RAMSEY, JR., JOHN T. TAYLOR, JOHN F. WILSON,
CARL E. GRAY, JR., ANNE D. LEATHERMAN, JAMES R. ROOKER,
AND JOHNNY W. ALLRED

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16. Abstract This report contains the results of extensive computer (finite element, finite difference and numerical integration), thermal, fatigue, and special analyses of critical portions of a large pressurized, cryogenic wind tunnel (National Transonic Facility). The computer models, loading and boundary conditions are described. Graphic capability was used to display model geometry, section properties, and stress results. A stress criteria is presented for evaluation of the results of the analyses. Thermal analyses were performed for major critical and typical areas. Fatigue analyses of the entire tunnel circuit is presented.

The major computer codes utilized are: SPAR - developed by Engineering Information Systems, Inc. under NASA Contracts NAS8-30536 and NAS1-13977; SALORS - developed by Langley Research Center and described in NASA TN D-7179; and SRA - developed by Structures Research Associates under NASA Contract NAS1-10091; "A General Transient Heat-Transfer Computer Program for Thermally Thick Walls" developed by Langley Research Center and described in NASA TM X-2058.

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NATIONAL TRANSONIC FACILITY

TUNNEL SHELL

NASA - LaRC

FINITE ELEMENT ANALYSIS
OF
CORNERS #3 AND #4

304 STAINLESS STEEL

SEPTEMBER 1976

VOLUME 2S

LaRC CALCULATIONS

FOR THE

NATIONAL TRANSONIC FACILITY

TUNNEL SHELL

DATE: SEPTEMBER, 1976

APPROVED:

DR. JAMES W. RAMSEY, JR., HEAD
STRUCTURAL ENGINEERING SECTION

ANALYSTS:

JOHN T. TAYLOR
HEAD SHELL ANALYST

JOHN F. WILSON, SHELL WORK
PACKAGE & CONSTRUCTION MANAGER

CARL E. GRAY, JR.
SHELL ANALYST

ANNE D. LEATHERMAN
SHELL PROGRAMMER

JAMES R. ROOKER
SHELL/THERMAL ANALYST

JOHNNY W. ALLRED
SHELL/THERMAL ANALYST

This report is one volume of a Design Analysis Report prepared by LaRC on portions of the pressure shell for the National Transonic Facility. This report is to be used in conjunction with reports prepared under NASA Contract NAS1-13535(c) by the Ralph M. Parsons Company (Job Number 5409-3 dated September 1976) and Fluidyne Engineering Corporation (Job Number 1060 dated September 1976). The volumes prepared by LaRC are listed below:

1. Finite Difference Analysis of Cone/Cylinder Junction (304 S.S.) Vol. 1, NASA TM X-73957-1.

2. Finite Element Analysis of Corners #3 and #4 (304 S.S.), Vol. 2S, NASA TM X-73957-2.

3. Finite Element Analysis of Plenum Region Including Side Access Reinforcement, Side Access Door and Angle of Attack Penetration (304 S.S.), Vol. 3S, NASA TM X73957-3.

4. Thermal Analysis (304 S.S.) Vol. 4S, NASA TM X73957-4.

5. Finite Element and Numerical Integration Analyses of the Bulkhead Region (304 S.S.), Vol. 5S, NASA TM X73957-5.

6. Fatigue Analysis (304 S.S.), Vol. 6S, NASA TM X73957-6.

7. Special Studies (304 S.S.), Vol. 7S, NASA TM X73957-7.

NTF DESIGN CRITERIA
FOR 304 STAINLESS STEEL

GENERAL

THE DESIGN OF THE PRESSURE SHELL REFLECTED IN THIS REPORT SATISFIES THE DESIGN REQUIREMENTS OF THE ASME BOILER AND PRESSURE VESSEL CODE, SECTION VIII, DIVISION 1. SINCE DIVISION 1 DOES NOT CONTAIN RULES TO COVER ALL DETAILS OF DESIGN, ADDITIONAL ANALYSES WERE PERFORMED IN AREAS HAVING COMPLEX CONFIGURATIONS SUCH AS THE CONE CYLINDER JUNCTIONS, THE GATE VALVE BULKHEADS, THE BULKHEAD-SHELL ATTACHMENTS, THE PLENUM ACCESS DOORS AND REINFORCEMENT AREAS, THE ELLIPTICAL CORNER SECTIONS, AND THE FIXED REGION (RING S8) OF THE TUNNEL. THE DIVISION 1 DESIGN CALCULATIONS, THE ADDITIONAL ANALYSES AND THE CRITERIA FOR EVALUATION OF THE RESULTS OF THE ADDITIONAL ANALYSES TO ENSURE COMPLIANCE WITH THE INTENT OF DIVISION 1 REQUIREMENTS ARE CONTAINED IN THE TEXT OF THIS REPORT. THE DESIGN ANALYSES AND ASSOCIATED CRITERIA CONSIDERED BOTH THE OPERATING AND HYDROSTATIC TEST CONDITIONS.

IN CONJUNCTION WITH THE DESIGN, A DETAILED FATIGUE ANALYSIS OF THE PRESSURE SHELL WAS ALSO PERFORMED UTILIZING THE METHODS OF THE ASME CODE, SECTION VIII, DIVISION 2.

MATERIAL

THE PRESSURE SHELL MATERIAL SHALL BE ASME, SA-240, GRADE 304 FOR PLATE AND SA-182, GRADE F304 FOR FORGINGS. THE MATERIAL PROPERTIES AT TEMPERATURES EQUAL TO OR BELOW 150°F ARE AS FOLLOWS:

(A) PLATE

YIELD = 30.0 KSI
ULTIMATE = 75.0 KSI

(B) WELDS (AUTOMATIC, SEMIAUTOMATIC, OR "STICK")

YIELD = 30.0 KSI
ULTIMATE = 75.0 KSI

OPERATING, DESIGN AND TEST CONDITIONS

THE OPERATING, DESIGN AND TEST CONDITIONS FOR THE TUNNEL PRESSURE SHELL AND ASSOCIATED SYSTEMS AND ELEMENTS ARE SUMMARIZED BELOW:

1. OPERATING MEDIUM

ANY MIXTURE OF AIR AND NITROGEN

2. DESIGN TEMPERATURE RANGE

MINUS 320 DEGREES FAHRENHEIT TO PLUS 150 DEGREES FAHRENHEIT, EXCEPT IN THE REGION OF THE PLENUM BULKHEADS AND GATE VALVES INSIDE A 23-FOOT, 4-INCH DIAMETER, FOR WHICH THE TEMPERATURE RANGE IS MINUS 320 DEGREES FAHRENHEIT TO PLUS 200 DEGREES FAHRENHEIT.

3. PRESSURE RANGE

	TUNNEL CONFIGURATION	OPERATING PRESSURE RANGE, PSIA	DESIGN PRESSURES PSID
A.	CONDITION I - PLENUM ISOLATION GATES OPEN AND TUNNEL OPERATING:		
	TUNNEL CIRCUIT EXCEPT PLENUM	8.3 to 130	A. 8 EXTERNAL B. 119 INTERNAL
	PLENUM (PLENUM PRESSURE IS LIMITED TO .4 TO 1 TIMES THE REMAINDER OF THE TUNNEL CIRCUIT	3.3 to 130	A. 15 EXTERNAL B. 119 INTERNAL
	BULKHEAD		56 (EXTERNAL TO PLENUM)
B.	CONDITION II - PLENUM ISOLATION GATES OPEN AND TUNNEL SHUTDOWN:		
	ENTIRE TUNNEL CIRCUIT	8.3 to 130	A. 8 EXTERNAL B. 119 INTERNAL
	BULKHEAD		0
C.	CONDITION III - PLENUM ISOLATION GATES AND ACCESS DOORS CLOSED:		
	TUNNEL CIRCUIT EXCEPT PLENUM	8.3 to 130	A. 8 EXTERNAL B. 119 INTERNAL

PLENUM (PLENUM OPERATING PRESSURE CAN EXCEED THE PRESSURE IN THE REMAINDER OF THE TUNNEL CIRCUIT BY 24 PSI, BUT DOES NOT EXCEED THE 130 PSIA MAXIMUM OPERATING PRESSURE)	0 to 130	A. 15 EXTERNAL B. 119 INTERNAL
BULKHEAD		A. 25 (INTERNAL TO PLENUM) B. 119 (EXTERNAL TO PLENUM) FOR MINUS 320 DEGREES FAHRENHEIT TO PLUS 150 DEGREES FAHRENHEIT *C. 115.7 (EXTERNAL TO PLENUM) FOR PLUS 151 DEGREES FAHRENHEIT TO PLUS 200 DEGREES FAHRENHEIT

*OPERATING PROCEDURES LIMIT PRESSURES TO THAT SHOWN.

D. CONDITION IV - PLENUM ISOLATION GATES CLOSED AND ACCESS DOORS OPEN:

TUNNEL CIRCUIT EXCEPT PLENUM	8.3 to 130	A. 8 EXTERNAL B. 119 INTERNAL
PLENUM	14.7	0
BULKHEAD		A. 119 (EXTERNAL TO PLENUM) FOR MINUS 320 DEGREES FAHRENHEIT TO PLUS 150 DEGREES FAHRENHEIT *B. 115.7 (EXTERNAL TO PLENUM) FOR PLUS 151 DEGREES FAHRENHEIT TO PLUS 200 DEGREES FAHRENHEIT.

*OPERATING PROCEDURES LIMIT PRESSURES TO THAT SHOWN.

4. HYDROSTATIC TEST DESIGN CONDITIONS

THE PRESSURE SHELL WAS DESIGNED FOR HYDROSTATIC TEST IN ACCORDANCE WITH THE REQUIREMENTS OF THE ASME CODE, SECTION VIII, DIVISION 1. THE TEST PRESSURES SHALL BE AS FOLLOWS. PRESSURE SHELL TEMPERATURE SHALL BE EQUAL TO OR BELOW 100°F DURING HYDROSTATIC TESTS.

CONDITION (1) - MAXIMUM INTERNAL PRESSURE CONDITION FOR THE ENTIRE TUNNEL CIRCUIT

$$PH_1 = 1.5\ (119)\ \left(\frac{18.7}{18.2}\right) + \text{HYDROSTATIC HEAD}$$

$$= 183.4 \text{ PSI} + \text{HYDROSTATIC HEAD}$$

CONDITION (2) - MAXIMUM DIFFERENTIAL PRESSURE CONDITION ACROSS THE PLENUM BULKHEADS

$$PH_2 = 1.5\ \left(\frac{18.7}{18.2}\right)\ (119) + \text{HYDROSTATIC HEAD}$$

$$= 183.4 + \text{HYDROSTATIC HEAD}$$

$$PH_2{}^* = 1.5\ (115.7)\ \left(\frac{18.7}{17.7}\right) + \text{HYDROSTATIC HEAD}$$

$$= 183.4 + \text{HYDROSTATIC HEAD}$$

*TUNNEL OPERATION LIMITATIONS PRECLUDE PRESSURE DIFFERENTIALS ACROSS BULKHEADS IN EXCESS OF 115.7 PSI FOR BULKHEAD AND GATE TEMPERATURES IN EXCESS OF 150°F.

CONDITION (3) - MAXIMUM REVERSE DIFFERENTIAL PRESSURE CONDITION ACROSS THE PLENUM BULKHEADS

$$PH_3 = 1.5\ \left(\frac{18.7}{18.2}\right)\ (25) = 38.5 \text{ PSI}$$

THE PRESSURE SHELL EXCEPT FOR THE PLENUM SHALL BE PRESSURIZED TO 144.9 PSIG. THE PLENUM SHALL BE PRESSURIZED TO 183.4 PSIG.

PRESSURE SHELL STRESS EVALUATION CRITERIA

THIS CRITERIA ESTABLISHES THE BASIS FOR ANALYSIS AND DESIGN OF THE PRESSURE SHELL SO IT WILL MEET OR EXCEED ALL OF THE REQUIREMENTS OF SECTION VIII, DIVISION 1 OF THE ASME BOILER AND PRESSURE VESSEL CODE AND CAN BE STAMPED WITH A DIVISION 1 "U" STAMP.

1. SECTION VIII, DIVISION 1, DIRECT APPLICATION

(A) THE MAXIMUM ALLOWABLE STRESS (S)

S = 18.2 KSI (-320°F TO +150°F)

S = 17.7 KSI (-320°F TO +200°F)

(B) PRIMARY BENDING PLUS PRIMARY MEMBRANE STRESSES

THE LOCAL MEMBRANE STRESSES ARE NOT GENERALLY CONSIDERED IN SECTION VIII, DIVISION 1 DESIGNS. HOWEVER, FOR THE PURPOSE OF DESIGNING LOCAL REINFORCEMENT AT BRACKETS, RINGS OR PENETRATIONS NOT COVERED BY DESIGN BASED ON STRESS ANALYSIS, THE LOCAL SHELL MEMBRANE STRESS SHALL BE:

$$P_b + P_m \leq 1.5\ SE$$

NOTE: E IS JOINT EFFICIENCY

2. IN REGIONS OF THE PRESSURE SHELL WHERE DIVISION 1 DOES NOT CONTAIN RULES TO COVER ALL DETAILS OF DESIGN (REF. U-2(g)), ADDITIONAL ANALYSES WERE PERFORMED UTILIZING THE GUIDELINES OF THE ASME CODE, SECTION VIII, DIVISION 2, APPENDIX 4, "DESIGN BASED ON STRESS ANALYSIS." THE BASIC STRESS CRITERIA FOR DIVISION 2 IS REPRESENTED IN FIGURE 4-130.1 AND RESTATED BELOW INDICATING ANY MODIFICATIONS OR EXCESS REQUIREMENTS APPLIED TO IT TO REMAIN WITHIN THE INTENT OF DIVISION 1 AND TO OBTAIN A DIVISION 1 STAMP.

A. GENERAL PRINCIPAL MEMBRANE STRESS

MAXIMUM ALLOWABLE STRESS

S = 18.2 KSI (-320°F TO +150°F)

S = 17.7 KSI (-320°F TO +200°F)

MAXIMUM ALLOWABLE STRESS INTENSITY

S_m = 20.0 KSI (-320°F TO +300°F)

B. PRIMARY GENERAL MEMBRANE STRESS INTENSITY

$$P_m \leq S_m$$

AND IN ORDER TO COMPLY WITH DIVISION 1, THE MAXIMUM PRINCIPAL MEMBRANE STRESS MUST BE:

$$P_m^* \leq S$$

NOTE: THE * IS USED TO DENOTE THAT MAXIMUM PRINCIPAL STRESSES ARE TO BE COMPUTED FOR THE GIVEN LOADING CONDITION. THE INTENT IS TO DETERMINE THE STRESSES WHICH REPRESENT THE HOOP STRESSES AND MERIDIONAL STRESSES WHICH ARE THE STRESSES USED IN DIVISION 1 COMPUTATIONS.

C. DESIGN LOADS, PRIMARY LOCAL MEMBRANE STRESS INTENSITY

$$P_L \leq 1.5\ S_m$$

NOTE: LOCAL MEMBRANE STRESS INTENSITY IS DEFINED IN ACCORDANCE WITH DIVISION 2, APPENDIX 4-112(i). THE TOTAL MERIDIONAL LENGTH IS CONSIDERED TO BE $1.0\ \sqrt{RT}$.

D. DESIGN LOADS, PRIMARY LOCAL MEMBRANE PLUS PRIMARY BENDING STRESS INTENSITY

$$P_L + P_b \leq 1.5\ S_m$$

E. OPERATING LOADS, PRIMARY PLUS SECONDARY STRESS INTENSITY

$$P_L + P_b + Q \leq 3\ S_m$$

3. A FATIGUE ANALYSIS WAS CONDUCTED IN ACCORDANCE WITH SECTION VIII, DIVISION 2 WITHOUT MODIFICATION.

4. HYDROSTATIC TEST CONDITION DESIGN CONSIDERATIONS

A. PRESSURE SHELL

IN ACCORDANCE WITH DIVISION 1 OF THE ASME CODE, DESIGN ANALYSIS OF THE PRESSURE SHELL FOR THE HYDROSTATIC TEST CONDITION IS NOT REQUIRED. HOWEVER, IN ORDER TO PROVIDE A SATISFACTORY ENGINEERING DESIGN FOR THE PRESSURE SHELL SPECIAL EMPHASIS WAS GIVEN, AS PROMPTED BY NOTE (1) OF SECTION VIII, DIVISION 1 OF THE ASME CODE, TO FLANGES OF GASKETED JOINTS OR OTHER APPLICATIONS WHERE SLIGHT AMOUNTS OF DISTORTION CAN CAUSE LEAKAGE OR MALFUNCTION. EXAMPLES OF THESE AREAS ARE THE PLENUM, PLENUM ACCESS DOORS, PLENUM ACCESS DOOR REINFORCEMENT, THE BULKHEADS, AND BULKHEAD FLANGES.

B. SUPPORT RINGS

DESIGN OF THE PRESSURE SHELL SUPPORT RINGS, INCLUDING

THE CORNER RINGS, FOR THE HYDROSTATIC TEST CONDITION, COMPLIES WITH THE FOLLOWING:

(A) THE COMBINED VALUE OF THE SHELL CIRCUMFERENTIAL PRESSURE STRESS, S_1 AND SHELL

BENDING STRESS S_2, RESULTING FROM ACTION OF A

PORTION OF THE SHELL AS AN INNER FLANGE OF THE RING, SHALL NOT EXCEED 0.8 WELD YIELD STRESS:

$$S_1 + S_2 \leq 0.8 \text{ WELD YIELD STRESS},$$

WHERE, FOR SUPPORT RINGS NOT ANALYZED BY FINITE ELEMENT TECHNIQUES,

$S_1 = P_H \left(\frac{R}{T}\right) + .6\ P_H$; P_H INCLUDES HYDROSTATIC HEAD CORRECTION, AND

S_2 = RING BENDING STRESS AT INNER FLANGE, BASED ON AN EFFECTIVE WIDTH OF THE PRESSURE SHELL ACTING AS AN INNER FLANGE OF THE RING OF 1.1 MULTIPLIED BY THE SQUARE ROOT OF D_0 T.

(B) THE BENDING STRESS, S_{2E} ON THE OUTSIDE FLANGE

SHALL NOT EXCEED .9 WELD YIELD STRESS. (IN THE COMPUTER ANALYSIS ALL LOADING CONDITIONS ARE LIMITED TO .9 S_Y ON THE OUTER FLANGE.)

(C) BRACKETS AND SUPPORT PAD WELDMENTS

THE DESIGN FOR ALL LOADING CONDITIONS INCLUDING THE HYDROSTATIC TEST CONDITION OF THOSE PORTIONS OF BRACKETS AND SUPPORT PAD WELDMENTS WHICH ARE ATTACHED TO THE PRESSURE SHELL BUT NOT ON THE SURFACE OF THE SHELL SHALL COMPLY WITH THE REQUIREMENTS OF THE AISC CODE, I.E. MAXIMUM STRESS IN TENSION EQUALS .6 S_Y, ETC.

BY _____ DATE _____ SUBJECT _____ SHEET NO. _____ OF _____
CHKD. BY _____ DATE _____ JOB NO. _____

Vol. 2S

Finite Element Analyses of Corners
No. 3 and No 4
304 S.S.

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CHKD. BY _____ DATE _____ Finite Element Analyses of Corner # 4 JOB NO. _____

Reference Drawing No's. LE-944383-S
LE-944389-S
LE-944390-S

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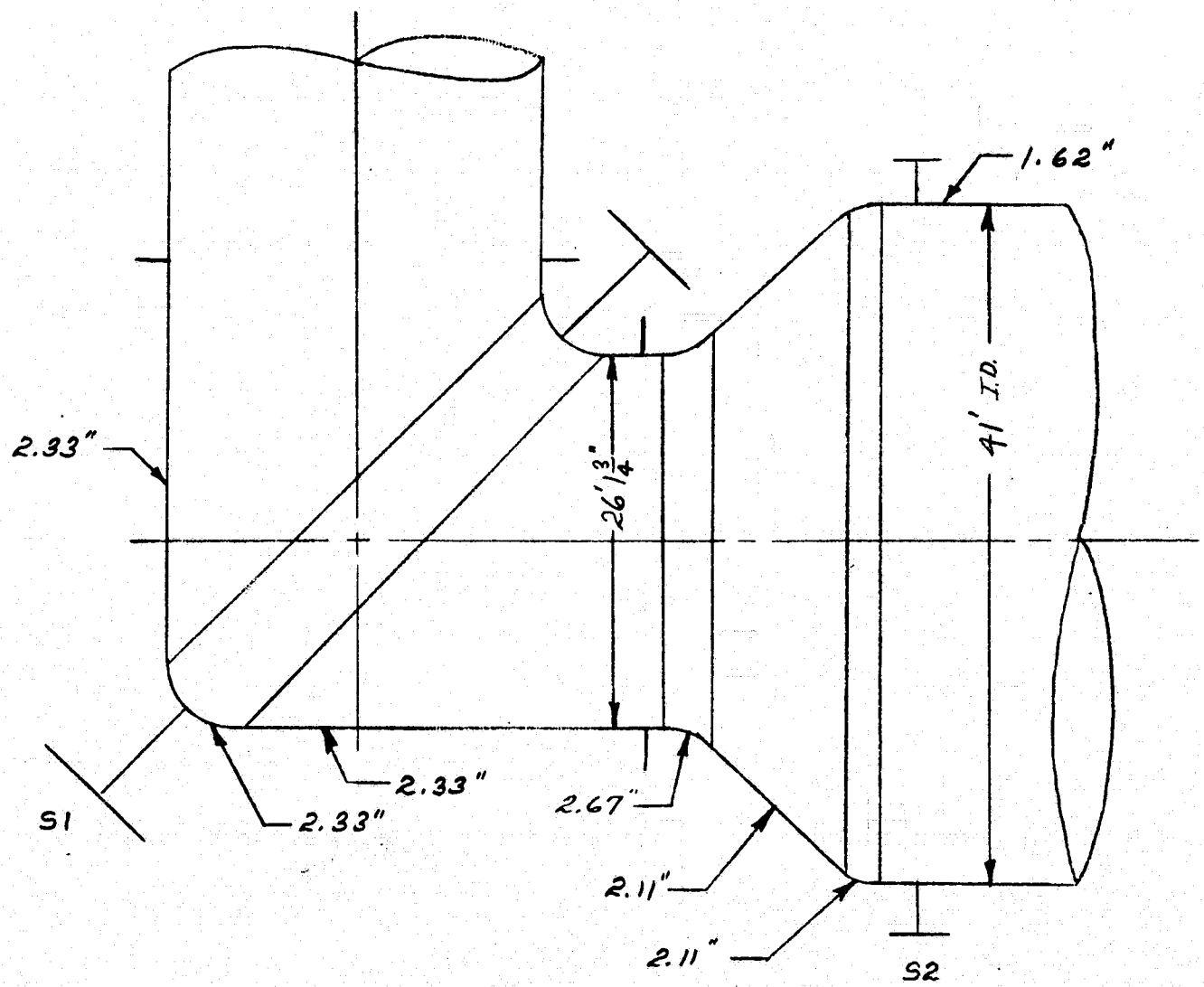


SPAR (a finite element computer code developed and maintained by Engineering Information System, Inc. under NASA Contracts NAS 8-30536 and NAS 1-13977) was used to analyze this region of the tunnel. The region was modeled using, triangular and quadrilateral, membrane plus bending flat aeolotropic elements.

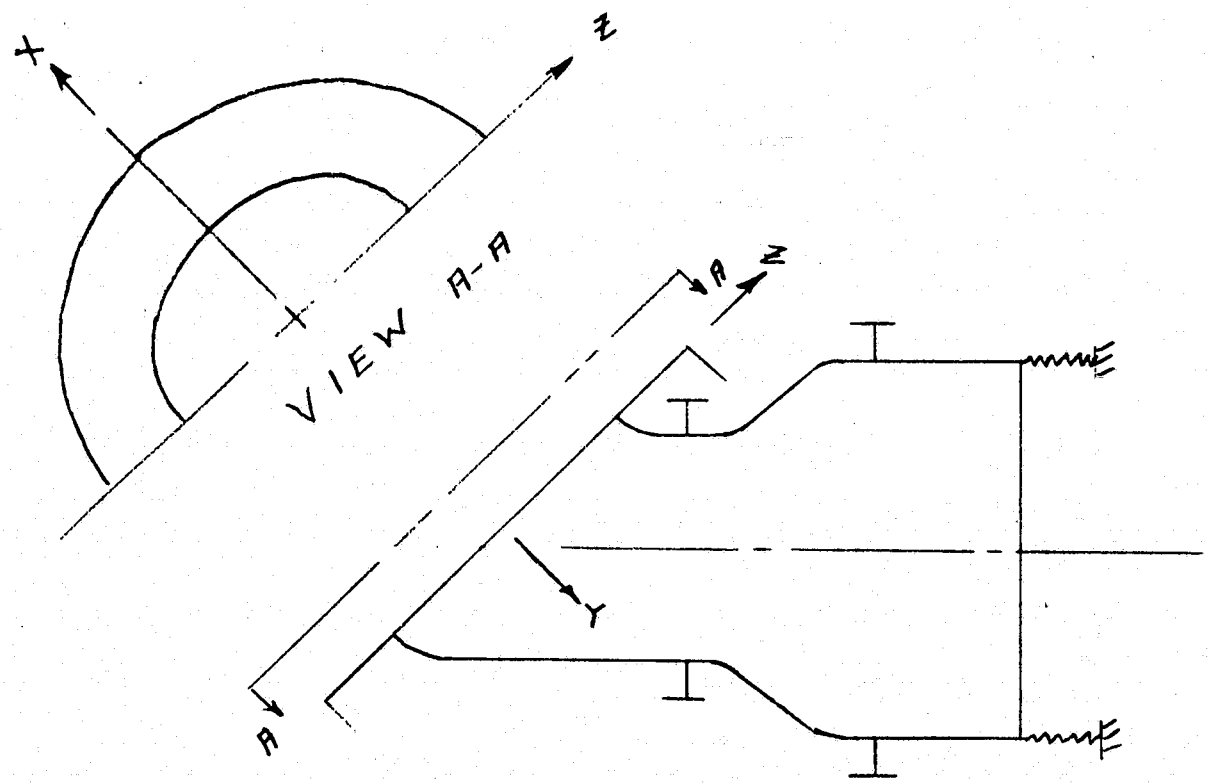
A 180° segment of the pressure shell was modeled from the center of the elliptical ring (S1) to beyond the ring (S2) on the 41' Diameter section. A plane thru the center of the elliptical ring perpendicular to the axis of rotation is a plane of symmetry. A plane thru the major axis of the ellipse is also a plane of symmetry

Computer plots of the model are shown in figs. 1 thru 4. The model consists of 1488 joints with 6 DOF at each joint except where boundary conditions are applied and rotation about an axis ⊥ to a plate element was restricted as required. The joint numbers are shown on figures 5 thru 16.

Shell section properties (plate thickness) are shown on figures 17 thru 22. The section properties and thicknesses are listed below

Shell Section Property	Thickness
1	1.625
2	1.95
3	2.33
4	2.33
5	2.33
6	1.62
7	1.612
8	2.11
9	2.67
10	1.62

Boundary Conditions



XZ plane is a plane of symmetry
YZ plane is a plane of symmetry
Boundary of cylinder restricts rotation about θ and Z axes (cyl. coordinates)

Boundary forces were developed by attaching linear springs (in the axial direction) to the end of the cylinder. The model was allowed to reach equilibrium and hence develop the axial forces. The spring constant was selected to approximately represent the spring constant of the cylindrical shell. However, it was found that the value of the spring constant had negligible effect on the stresses.

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Loadings

An internal pressure of 119 psig (design pressure) was applied as nodal pressure to the joints of the pressure surface.

Results

Nodal stresses are presented in Figures 23 thru 58.
The max. principal stress (PS1) or min. principal stress (PS2) are given for the mid-surface (surface 0), the inside surface (surface 1), and the outside surface (surface 2).

The stresses are plotted for joint 1 of the element. As an example (reference Fig. 5), for the element defined by joints 125 126 157 156, joint 1 for that element is 125.

Nodal stresses for one joint are given from 4 elements (for quadrilateral elements). If any discrepancies exist in the stresses for a joint, the largest value is used in the intrepretation of the results.

Membrane Stress Intensity

To evaluate the membrane stress intensity, the membrane stress intensity vs. meridional distance was plotted along the horizontal ℄ (ie the region of highest membrane stress)

From group 1 Joint 1

$\sigma_1 = 16.53$ KSI

$\sigma_2 = 3.24$ KSI

$\sigma_3 = -\frac{.119}{2} = -.06$ KSI

$S_{12} = 16.53 - 3.24 = 13.29$ KSI

$S_{23} = 3.24 - (-.06) = 3.30$ KSI

$S_{31} = -0.06 - 16.53 = -16.59$ KSI

$S = |-16.59| = 16.59$ KSI

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Table 1

Group/Ind	JOINT NO.	Meridional Length	S P = 119psig
1/1	1	1.533	16.59
2/1	125	6.133	16.68
3/1	156	10.733	17.13
4/1	218	15.333	17.27
5/1	249	19.933	16.50
7/1	311	23.800	14.40
2/1	342	25.40	12.56
2/31	373	26.65	12.26
2/61	404	27.89	12.05
2/91	435	29.14	11.95
3/1	466	30.38	11.95
3/31	621	36.38	13.58
6/1	652	46.80	19.13
6/61	683	51.046	21.51
6/121	714	55.293	23.26
6/181	745	59.540	24.10
6/241	776	63.787	23.90
4/1	807	66.62	22.60
4/31	838	75.00	20.10

P= 119 psi

The membrane stress intensity exceeds the allowable Sm (20.0 KSI) in the region of the knuckle at the small dia. of the cone.

$$S = 24.10 \text{ KSI}$$

$$P_L \leq 1.5 \, S_m$$

$$24.10 < 1.5 \, (20) = 30 \text{ KSI} \quad \text{O.K.}$$

The stress intensity exceeds 1.1 Sm (1.1 X 20 = 22 KSI) for a merdional distance of 13.5"

$$13.5'' < \sqrt{RT} = \sqrt{(156.875)(2.67)} = 20.46''$$

∴ This stress intensity is a local stress intensity

The principal membrane stresses, except for the region of local stress in the knuckle at the small dia of of the cone, do not exceed 18.2 KSI. This knuckle region is an area of local stress.

∴ The general principal membrane stress does not exceed the allowable of 18.2 KSI.

The primary general membrane stress intensity do not exceed the allowable stress intensity S_m = 20.0 KSI.

∴ The membrane stress (intensity) meets the stress evaluation criteria.

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P= 119 psi

Primary Plus Secondary Stress Intensity

Knuckle under the elliptical Ring

The max. stress intensity occured on the inside surface of the shell under the elliptical ring. See fig .

Inside Surface
1 / 22 11

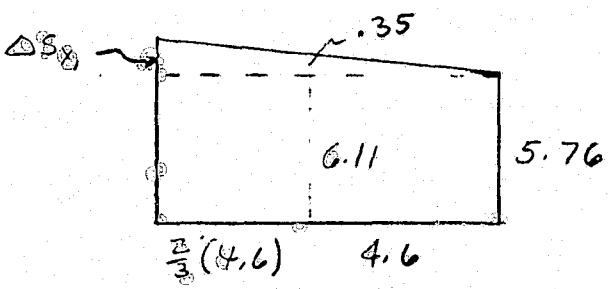
$\sigma_1 =$ 43.99 KSI

$\sigma_2 =$ 14.19 KSI

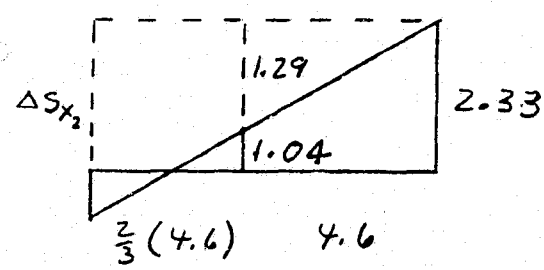
$\sigma_3 =$ .119 KSI

The membrane stress at the nodes of triangular elements are actually the stress at the centroid of the element. Therefore interpretation is required to find the actual membrane stress at the node.

PS 1



PS 2



$$\frac{.35}{4.6} = \frac{\Delta S_{x_1}}{\frac{2}{3}(4.6)+4.6}$$

$$\Delta S_{x_1} = .58$$

$$\frac{1.29}{4.6} = \frac{\Delta S_{x_2}}{\frac{2}{3}(4.6)+4.6}$$

$$\Delta S_2 = 2.15$$

To correct the stress at the node add (.58 − .35 =) .23 KSI to max principle (PS1) and (1.29 − 2.15 =) −.86 KSI to MIN. principle stress to find the corrected nodal stress

$\sigma_1 = 43.99 + .23 = 44.22$ KSI

$\sigma_2 = 14.19 - .86 = 13.33$ KSI

$\sigma_3 = -.12$ KSI

$S_{12} = 44.22 - 13.33 = 30.89$ KSI

$S_{23} = 13.33 - (-.12) = 13.45$ KSI

$S_{31} = -.12 - 44.22 = -44.34$ KSI

$S = |-44.34| = 44.34$ KSI

$P_L + P_b + Q \leq 3 S_m$

$44.34 \leq 3(20.0) = 60.0$ KSI

Outside Surface

$\sigma_1 = -12.29$ KSI

$\sigma_2 = -33.73$ KSI

$\sigma_3 = 0$

Since the max. outside stress occurs at approx. the same location as the max. inside stress, the correction for membrane stress at the node will be approximately same as for the outside surface.

$\sigma_1 = -12.29 + .23 = -12.05$ KSI

$\sigma_2 = -33.73 + (-.86) = -34.59$ KSI

$\sigma_3 = 0$

$S_{12} = -12.05 - (-34.59) = -22.54$ KSI

$S_{23} = -34.59 - (0) = -34.59$ KSI

$S_{31} = 0 - (-34.59) = 34.59$ KSI

$S = |34.59| = 34.59$ KSI

$P_L + P_b + Q \leq 3 S_m$

$34.59 < 3 \times 20 = 60$ KSI

$\therefore$ The primary plus Secondary Stress intensity for this region meets the stress evaluation criteria

Primary Plus Secondary Stress Intensity

Knuckle at small dia. of cone

Outside Surface

$\sigma_1 = 29.44$ KSI

$\sigma_2 = 21.49$ KSI

$\sigma_3 = 0$

$S_{12} = 29.44 - 21.49 = 7.95$ KSI

$S_{23} = 21.49 - 0 = 21.49$ KSI

$S_{31} = 0 - 29.44 = -29.44$ KSI

$S = |-29.44| = 29.44$ KSI

$P_L + P_b + Q \leq 3 S_m$

$29.44 < 3(20) = 60$ KSI O.K.

Inside Surface

$\sigma_1 = 19.04$ KSI

$\sigma_2 = -10.42$ KSI

$\sigma_3 = -\frac{.119}{2} = -.06$ KSI

$S_{12} = 19.04 - (-10.42) = 29.46$ KSI

$S_{23} = -10.42 - (-.06) = 10.36$ KSI

$S_{31} = -0.06 - 19.04 = -19.10$ KSI

$S = |29.46| = 29.46$ KSI

$P_L + P_b + Q \leq 3 S_m$

$29.46 < 3(20) = 60$ KSI O.K.

∴ The primary plus Secondary stress intensity for this region meets the stress evaluation criteria.

BY_____ DATE_____ SUBJECT_____ SHEET NO. 20 OF_____
CHKD. BY_____ DATE_____ JOB NO._____

Knuckle region at the large dia of cone

See Vol. 1S Finite Element Analysis of Cone/Cylinder Junctions (R1 to S2) for evaluation of this region

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Model checks

To verify that the elements were small enough (30 elements around 180° of the circumference) to produce peak stresses, a fine element models (100 element around 180° of circumference) was developed for the knuckle region under in elliptical "T". For the fine model, boundary conditions were from the course model.

Note: The thicknesses for the check models were different than the thicknesses present in this analysis.

Shell under the elliptical

Peak bending Principal stress

"30 element model"	"100 element" model
61.5 KSI	61.89 KSI

Stress on 41' dia Section.

$$\sigma_1 = \frac{Pr}{t} = \frac{(119)(20.5 \times 12 + .81)}{1.62} = 18.13 \text{ KSI}$$

$$\sigma_2 = \frac{Pr}{2t} = \frac{(119)(20.5 \times 12 + .81)}{2(1.62)} = 9.06 \text{ KSI}$$

From Computer model

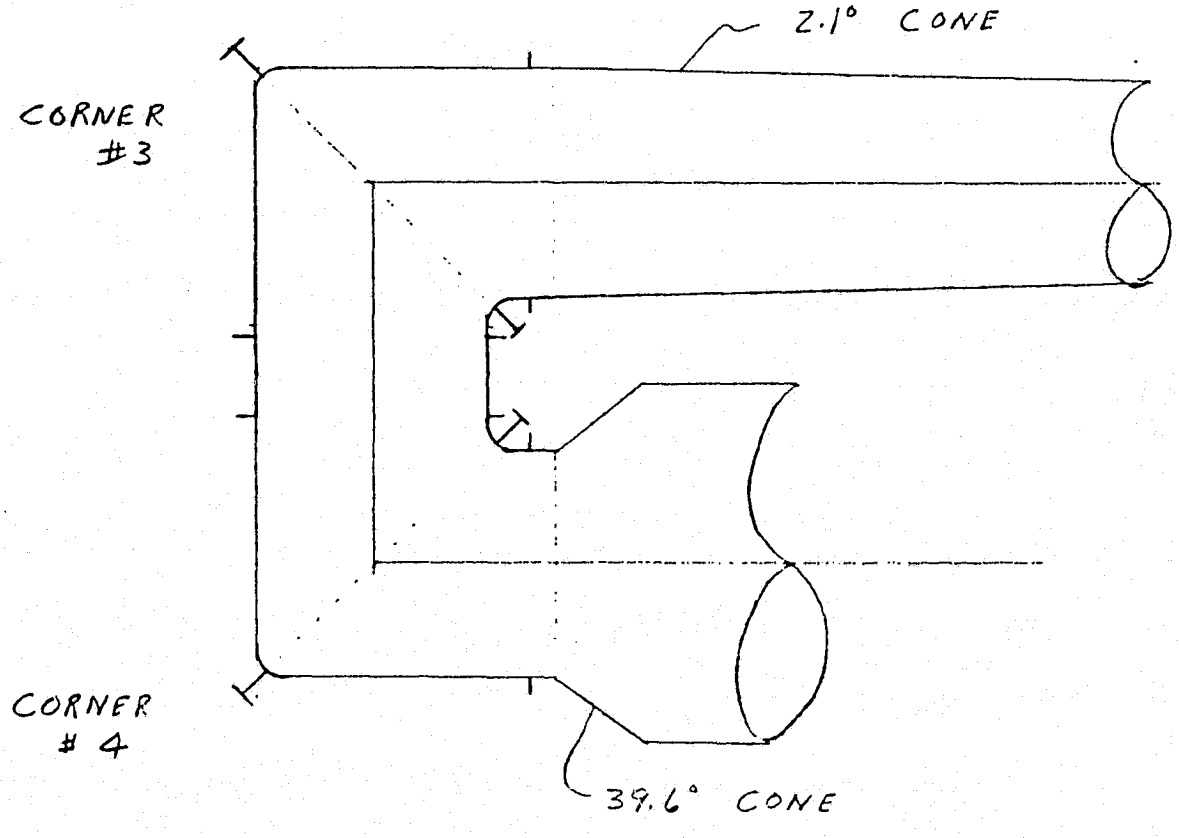
$\sigma_1 =$ 19.02 KSI

$\sigma_2 =$ 9.03 KSI

σ_1 is slightly high due to the effects of the "T" ring. The longitudional stress is generated correctly (9.06 vs 9.03 KSI)

∴ Model boundary conditions are O.K.

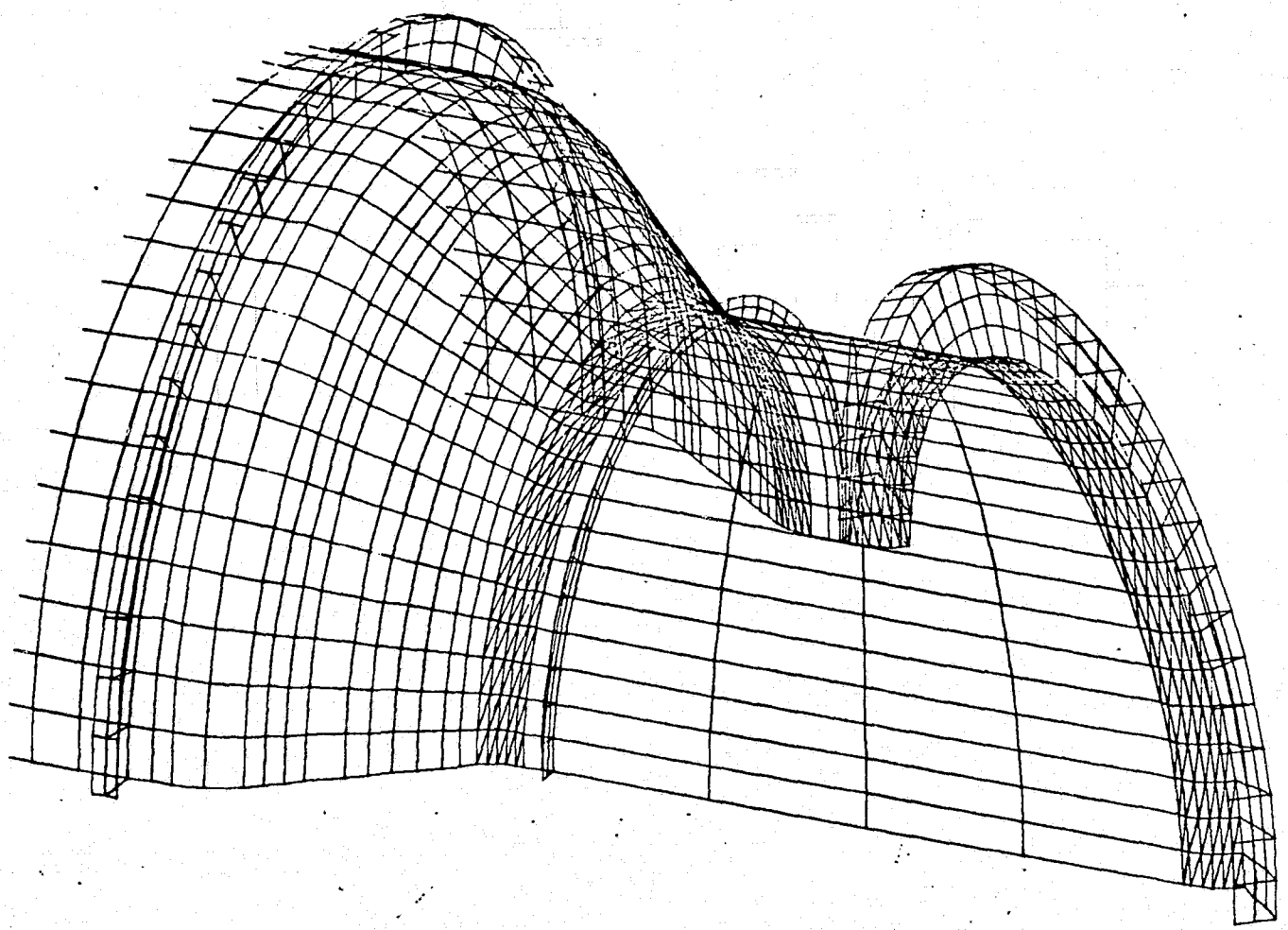
CORNER # 3



Corners No. 3 + 4 are the same except for the connecting cones. The discotinuity stresses produced by the junction of a shallow cone / cylinder are very small. (ref. Vol 1S FIG 12, 13 + 14) The approximate influence from the corner was considered in the evaluation of the stresses

in the region between R6 and R9 and between R10 and R12. These stresses meet the evaluation criteria.

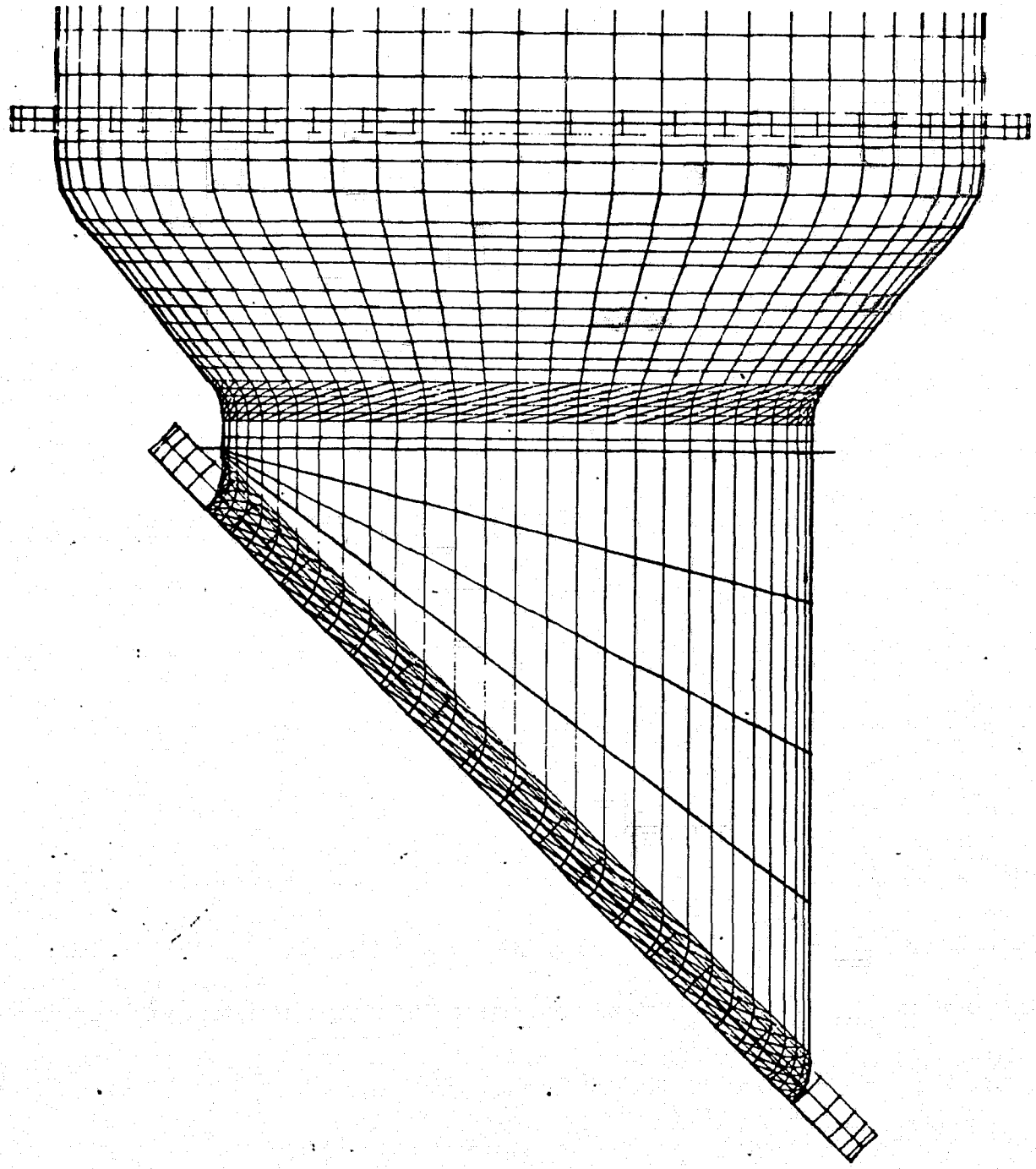
Since the junction at corner no. 3 will be less severe due to shallow cone angle, this area was not analyzed in detail.



SPEC 8.1 NTF ELLIP RING CONNECTED TO 41 FT CYL
.... PROJECTED VIEW....

0 88
SCALE

FIGURE 1

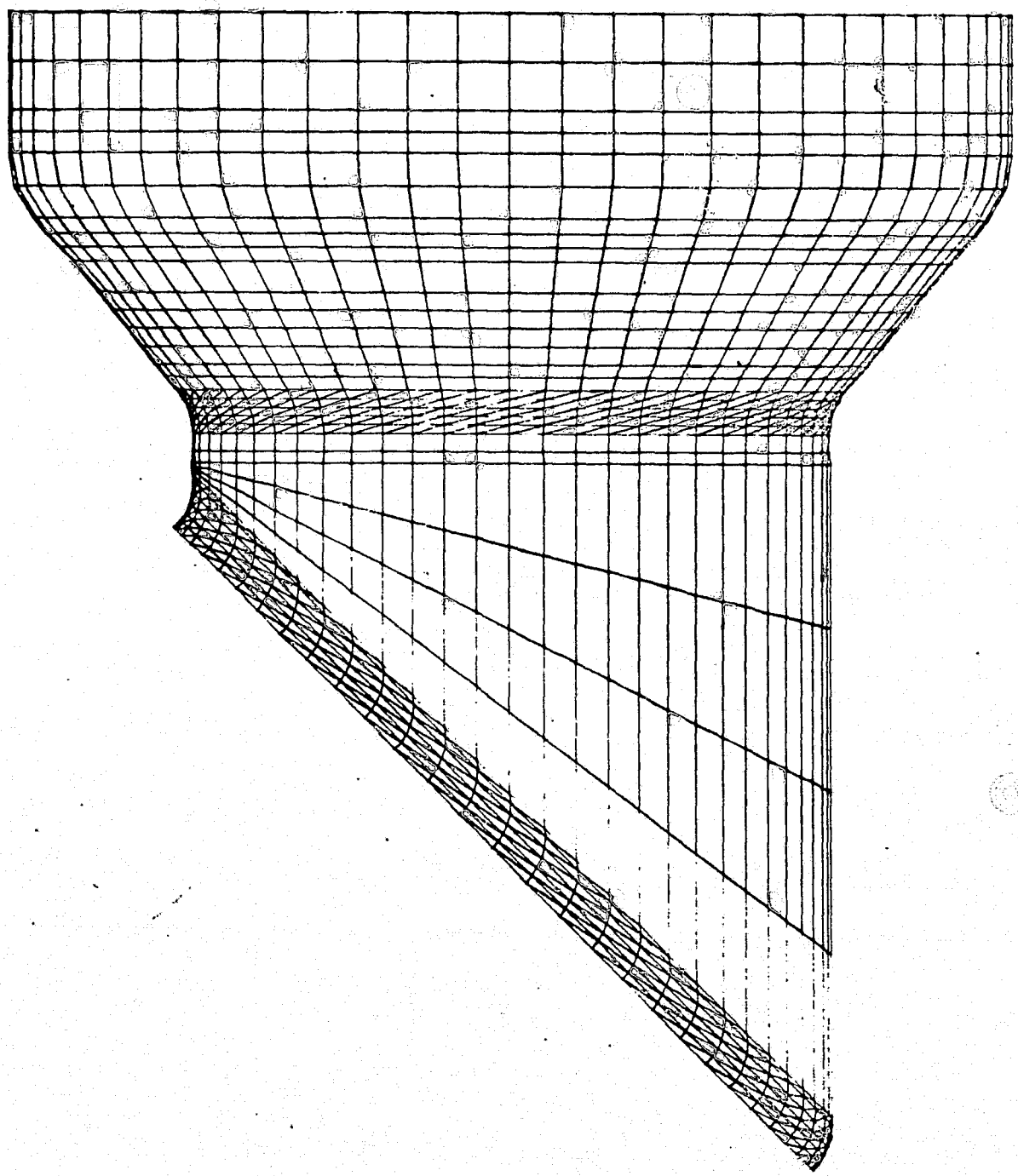


SPEC
13.1

NTF ELLIP RING CONNECTED TO 41 FT CYL
PLAN VIEW

0 93
SCALE

FIGURE 2

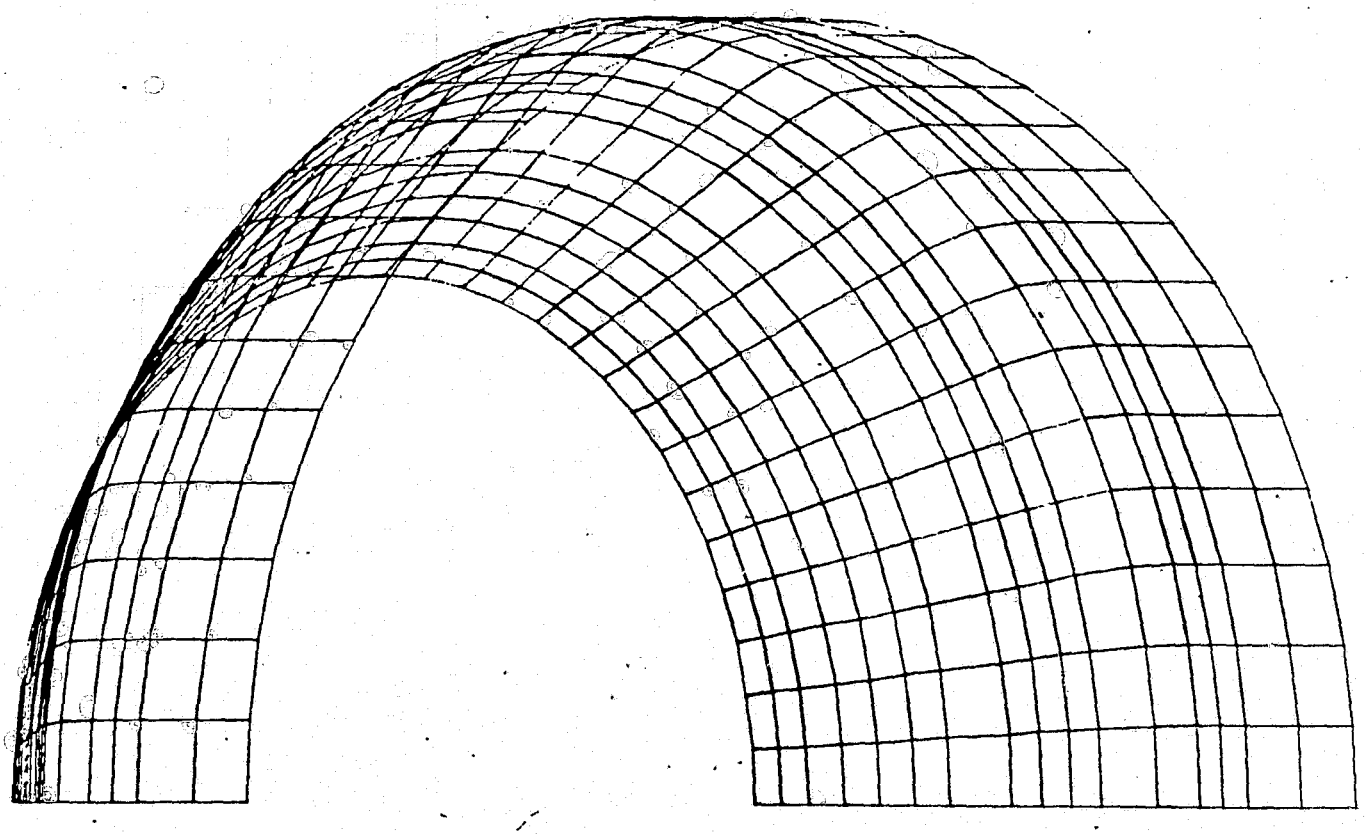


SPEC 2.1

NTF ELLIP RING CONNECTED TO 41 FT CYL
PRESSURE SURFACE WITH TEE

0 86
SCALE

FIGURE 3



SPEC 7.1

NTF ELLIP RING CONNECTED TO 41 FT CYL CONE WITH SPRING B.C.

0 64
SCALE

FIGURE 4

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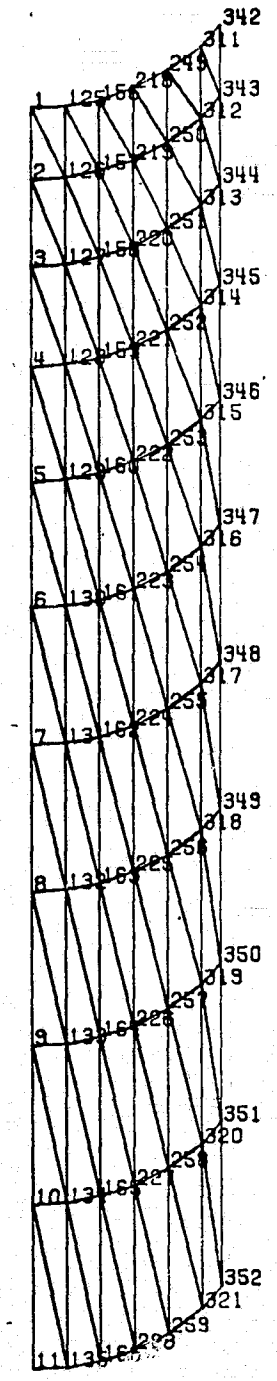
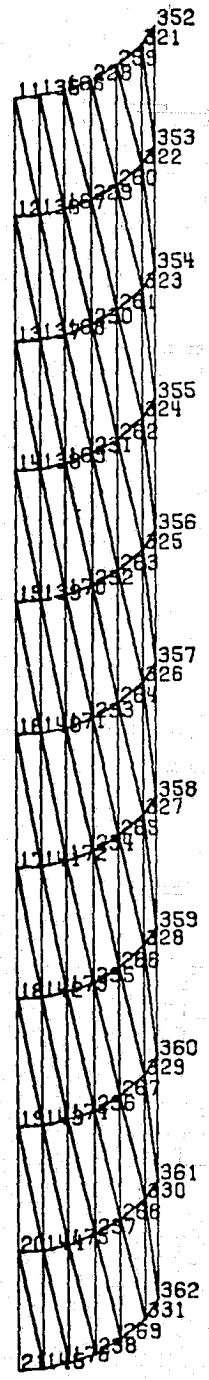


SPEC 1.1

NTF ELLIP RING CONNECTED TO 41 FT CYL
KNUCKLE SECT. AT ELLIP. RING(INS. CORNE

0 27
SCALE

FIGURE 5

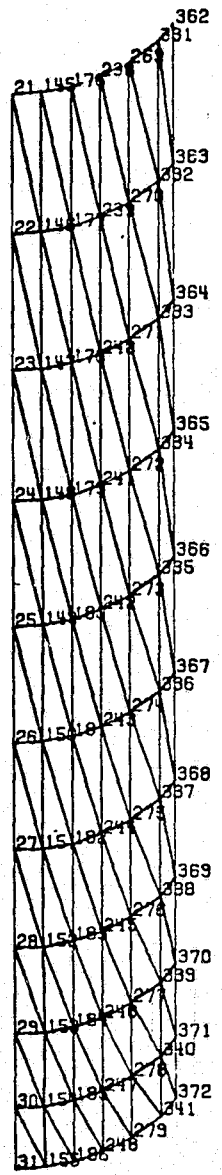


SPEC 2.1

NTF ELLIP RING CONNECTED TO 41 FT CYL
KNUCKLE SECT AT ELLIP RING (MIDDLE)

0 36
SCALE

FIGURE 6

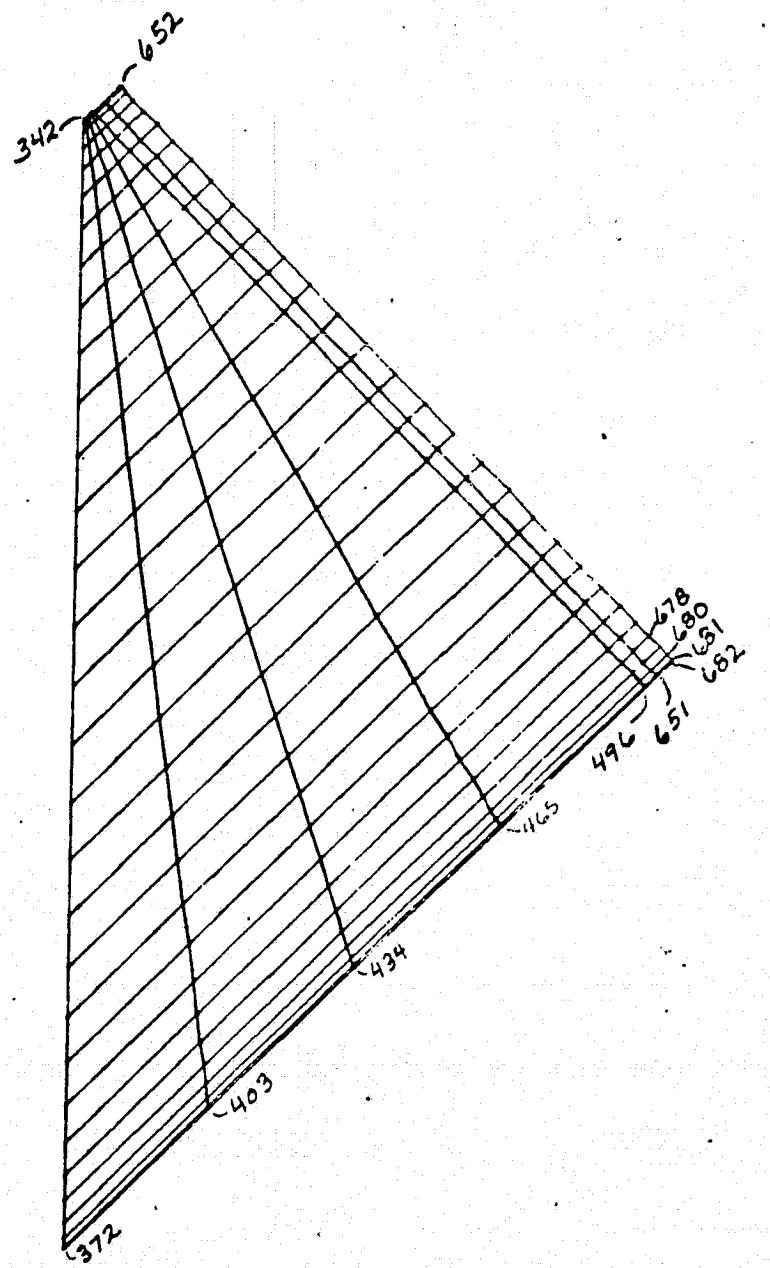


SPEC 3.1

NTF ELLIP RING CONNECTED TO 41 FT CYL
KNUCK SECT AT ELLIP RING (OUTSIDE)

0 27
SCALE

FIGURE 7

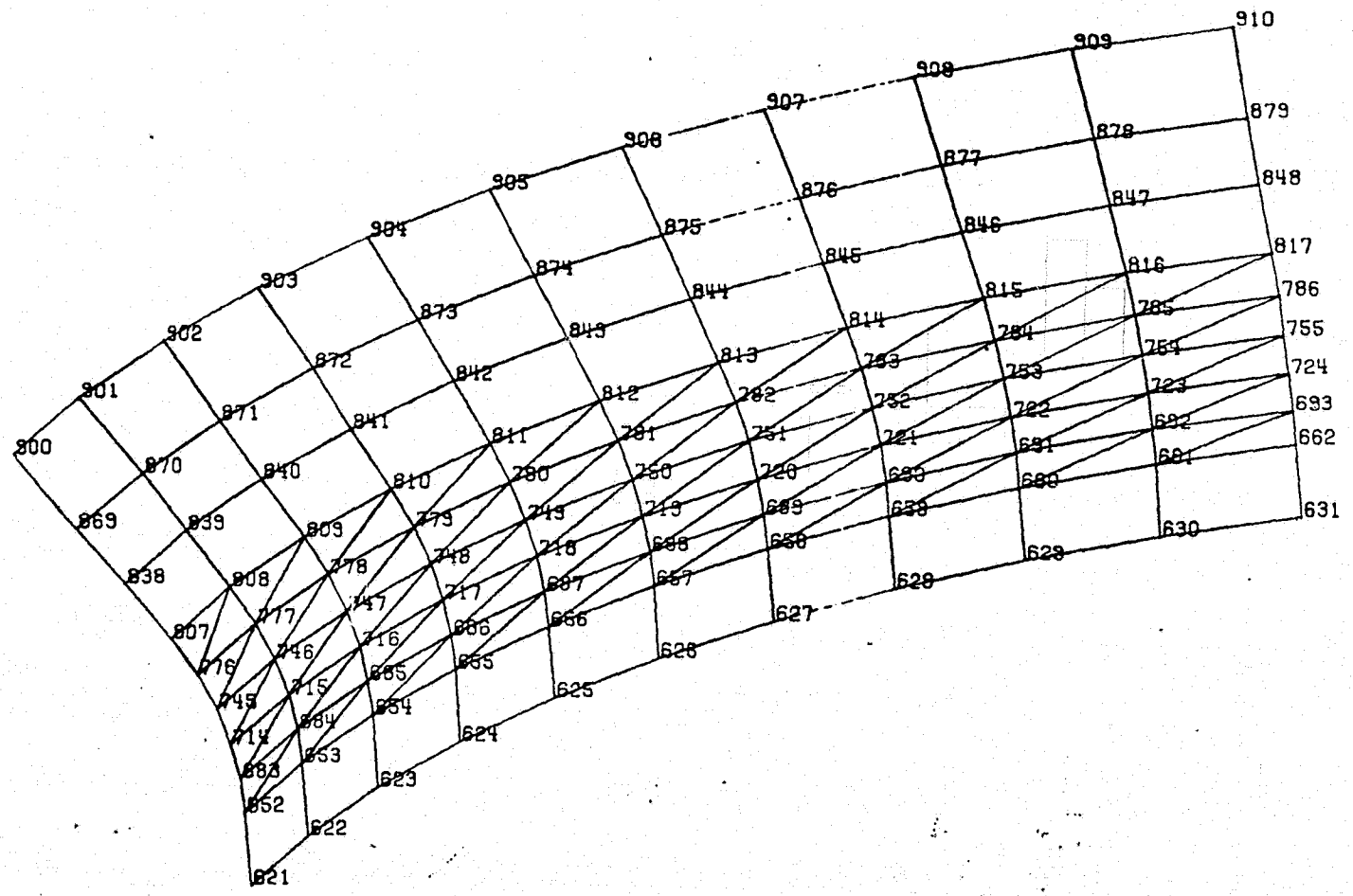


SPEC
17.1

CYL SHELL BETWEEN ELLIP KNUCK - CONE

0 70
SCALE

FIGURE 8

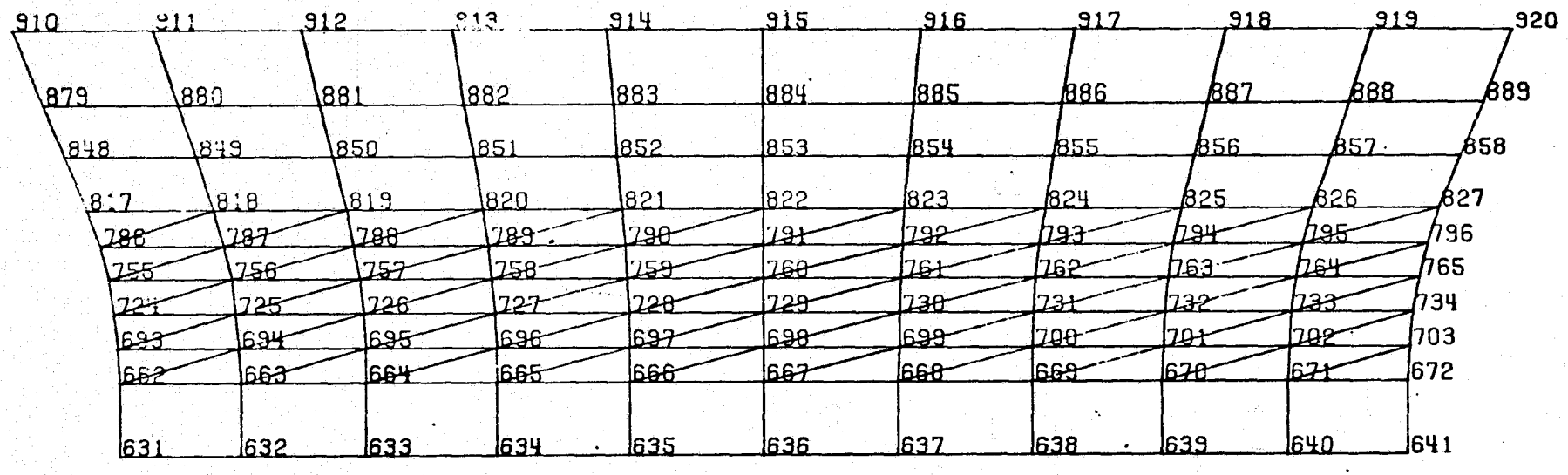


SPEC 4.1

NTF ELLIP RING CONNECTED TO 41 FT CYL
CONE KNUCKLE SECTION (INSIDE CORNER)

0 23
SCALE

FIGURE 9

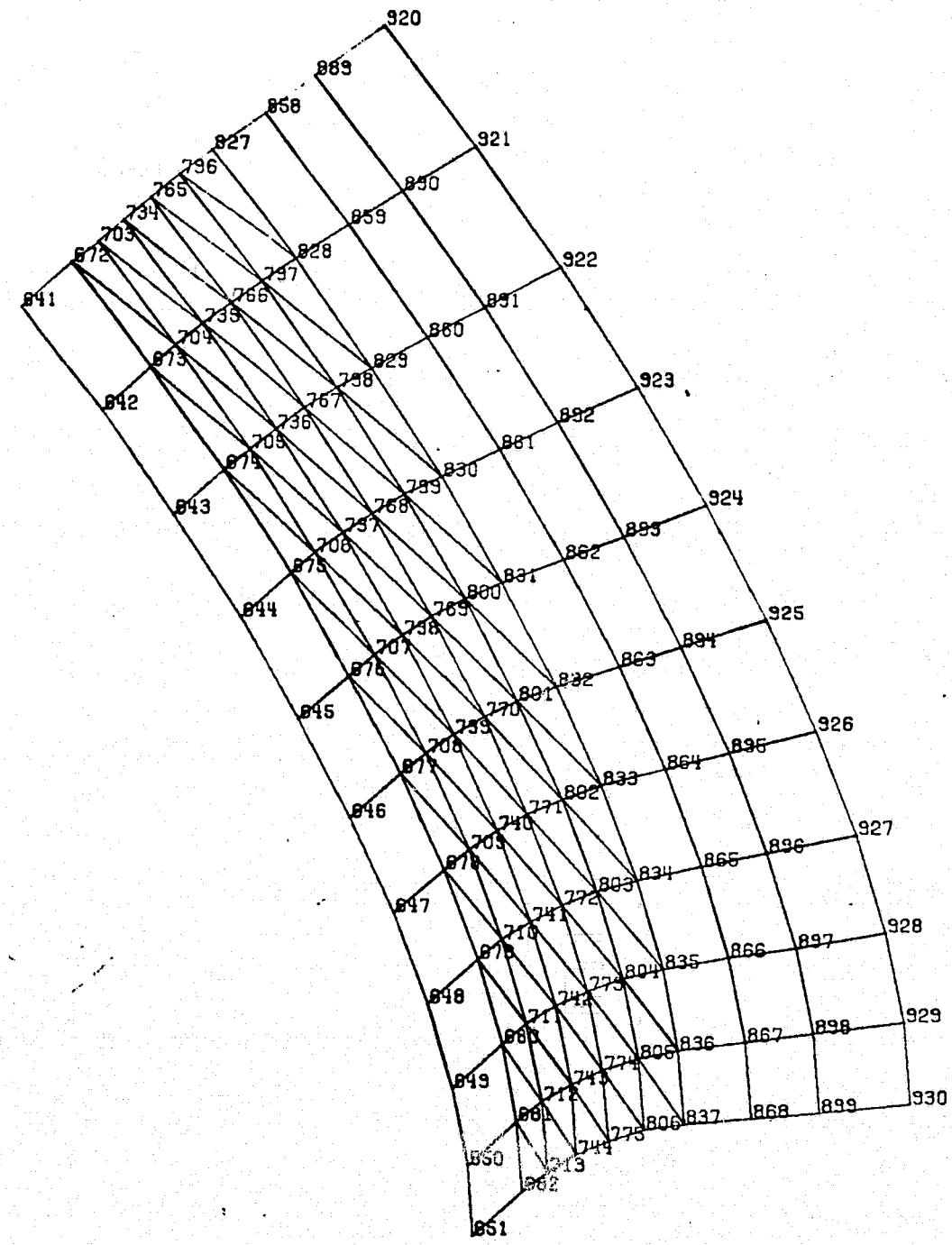


SPEC 5.1

NTF ELLIP RING CONNECTED TO 41 FT CYL
CONE KNUCKLE SECT (MIDDLE)

0 28
SCALE

FIGURE 10



SPEC 6.1

NTF ELLIP RING CONNECTED TO 41 FT CYL
CONE KNUC. SECT. (OUTSIDE CORNER)

0 23
SCALE

FIGURE 11

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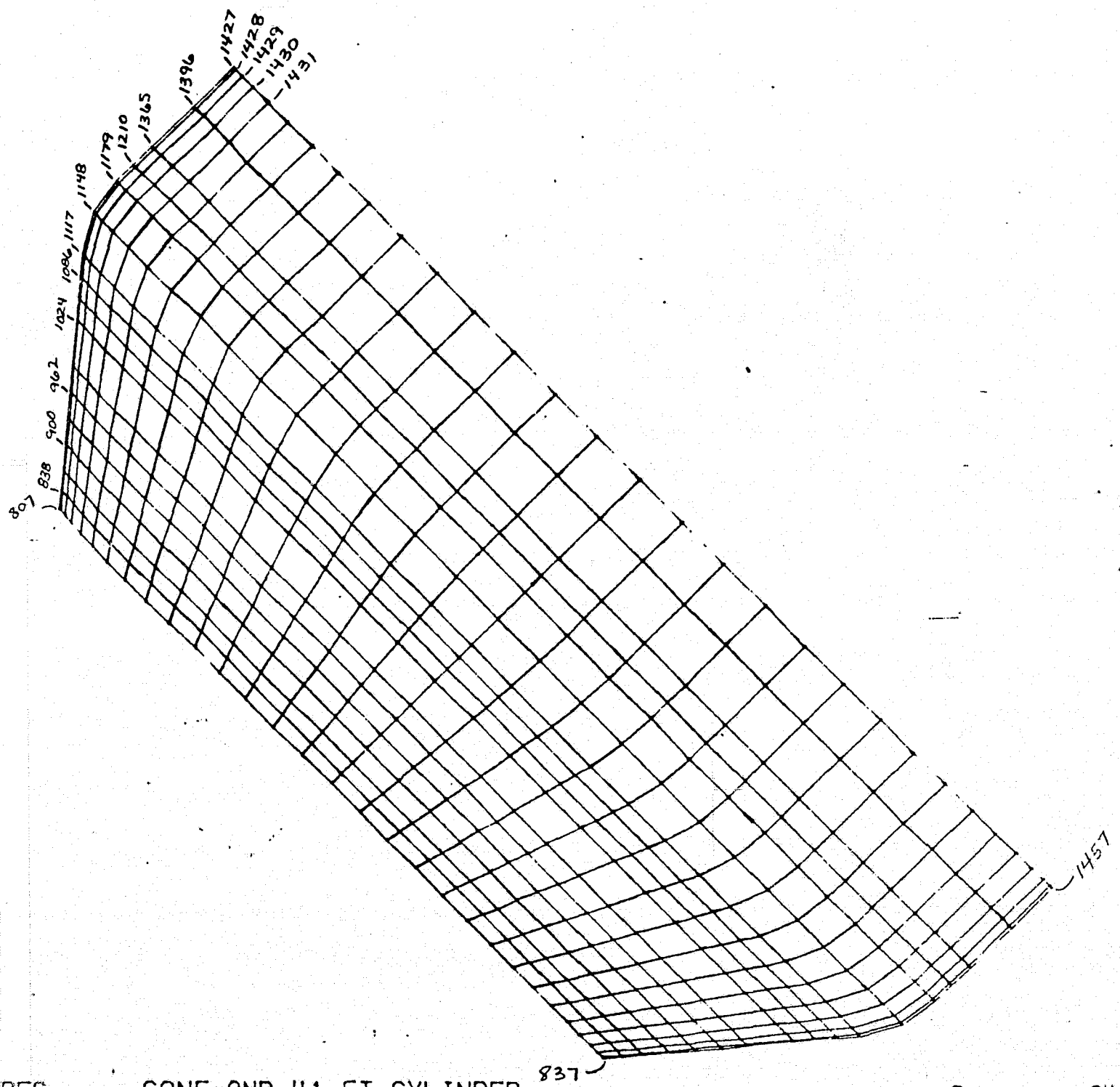
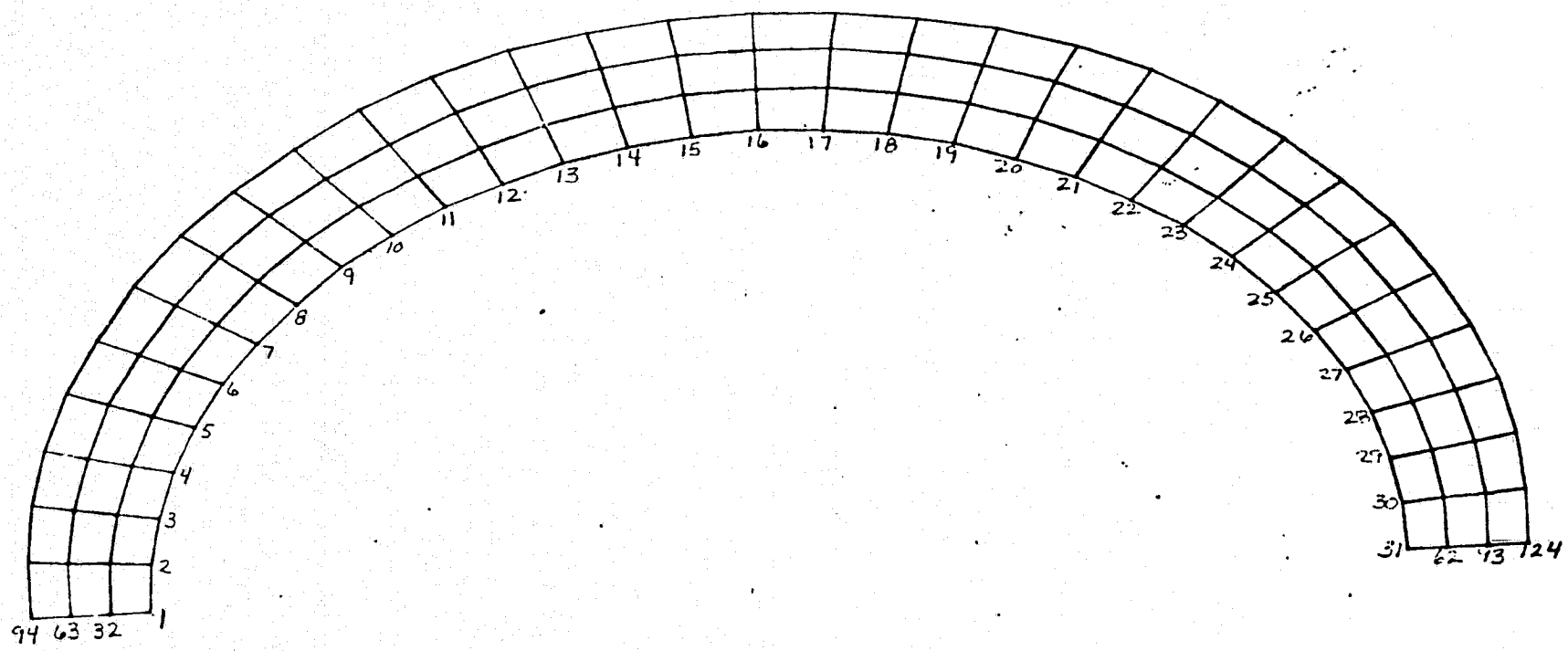


SPEC 18.1

CONE AND 41 FT CYLINDER

0 64
SCALE

FIGURE 12



0 81
SCALE

SPEC
14.1

ELLIPTICAL TEE

FIGURE 13

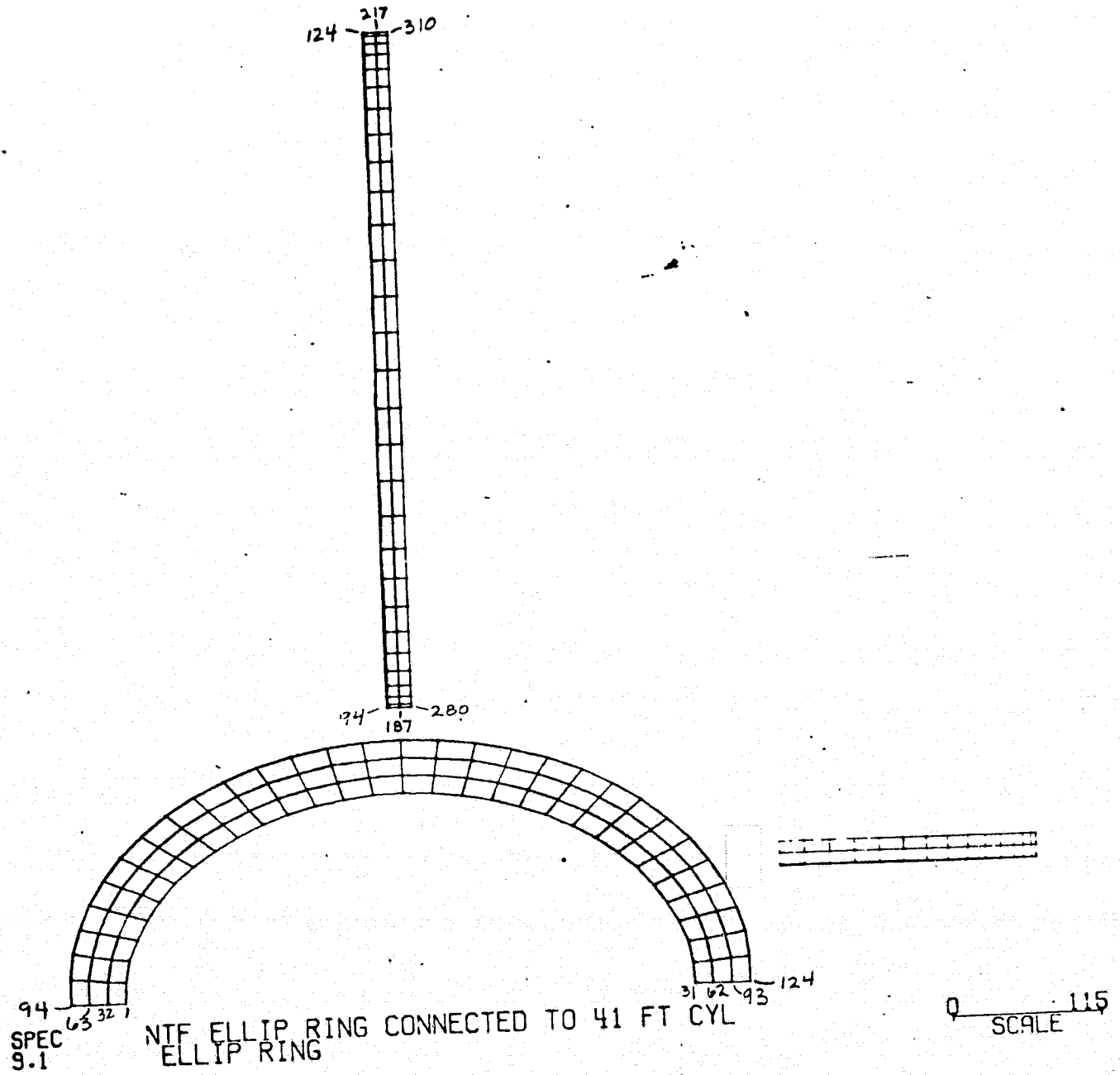
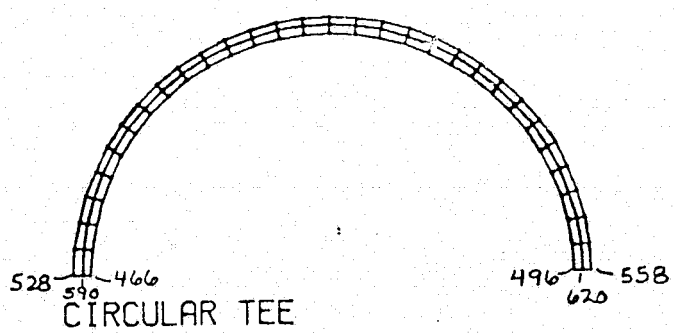

124
217
310
94
187
280
94
63
32
1
31
62
93
124
0
115
SCALE
SPEC
9.1
NTF ELLIP RING CONNECTED TO 41 FT CYL
ELLIP RING

FIGURE 14

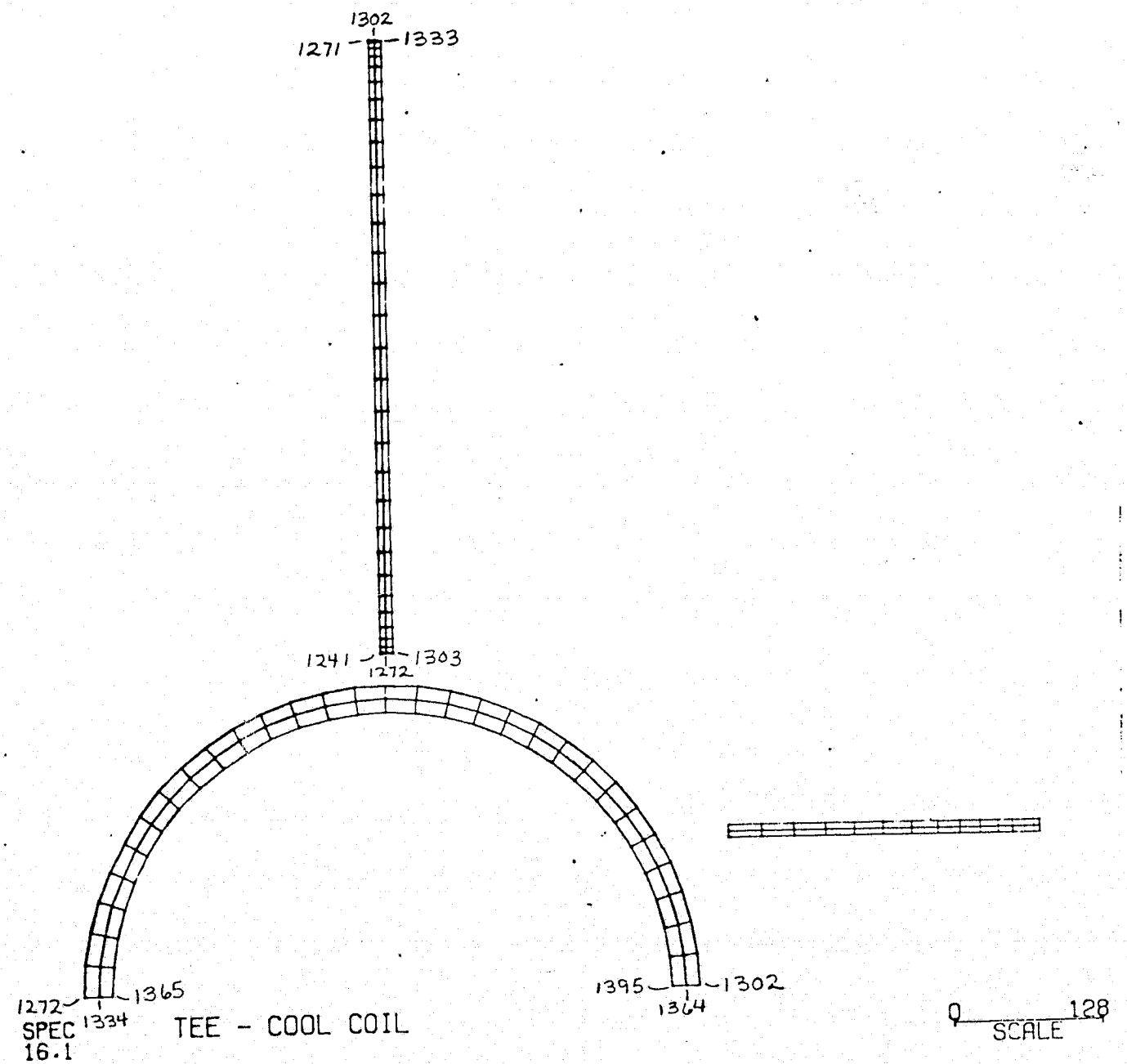


SPEC
15.1

CIRCULAR TEE

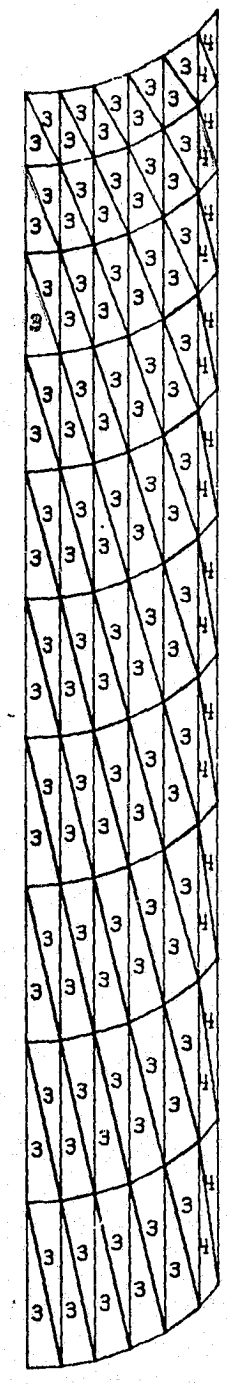
0 116
SCALE

FIGURE 15



SPEC 16.1 TEE - COOL COIL

FIGURE 16

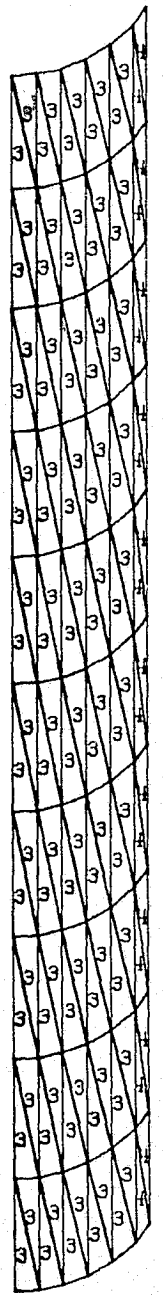


ELEMENT SECTION PROPERTY GROUPS

SPEC 1.1 NTF ELLIP RING CONNECTED TO 41 FT CYL KNUCKLE SECT. AT ELLIP. RING(INS. CORNE

0 27
SCALE

FIGURE 17

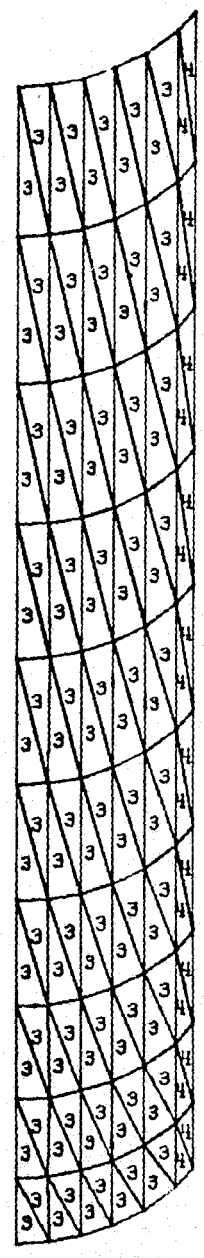


SPEC 2.1 NTF ELLIP RING CONNECTED TO 41 FT CYL KNUCKLE SECT AT ELLIP RING (MIDDLE)

0 SCALE 3

ELEMENT SECTION PROPERTY GROUPS

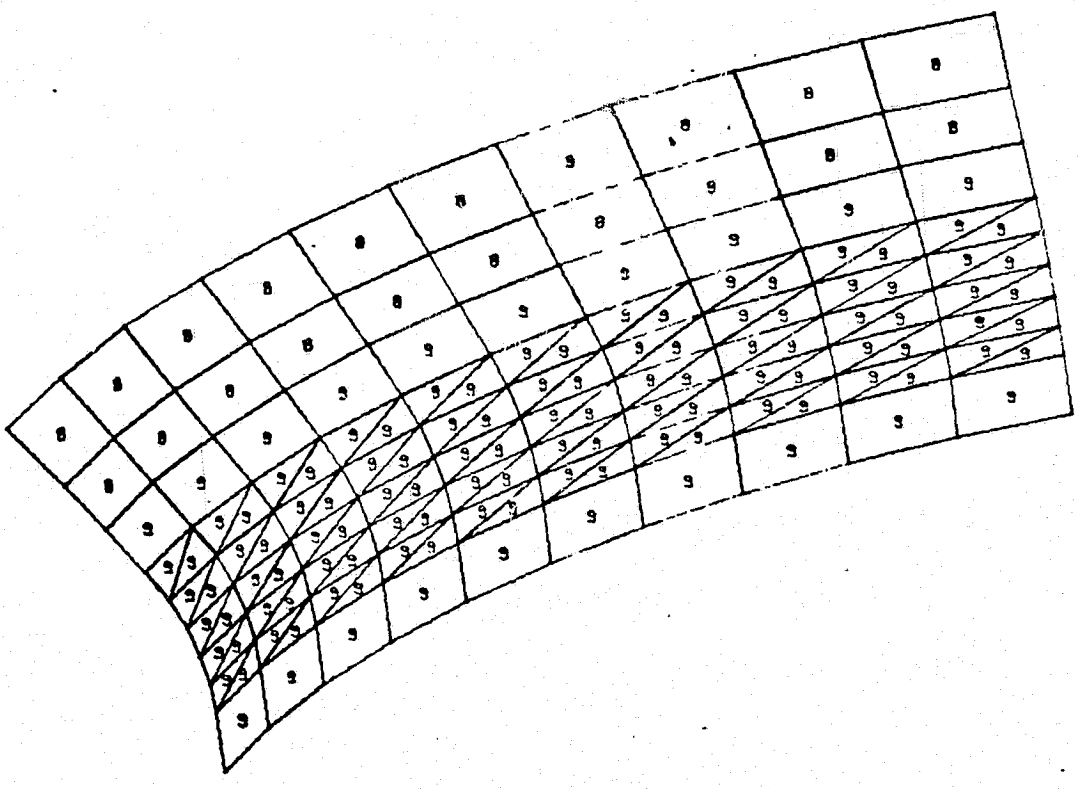
FIGURE 18



SPEC 3.1 NTF ELLIP RING CONNECTED TO 41 FT CYL KNUCK SECT AT ELLIP RING (OUTSIDE).

0 27
SCALE

FIGURE 19

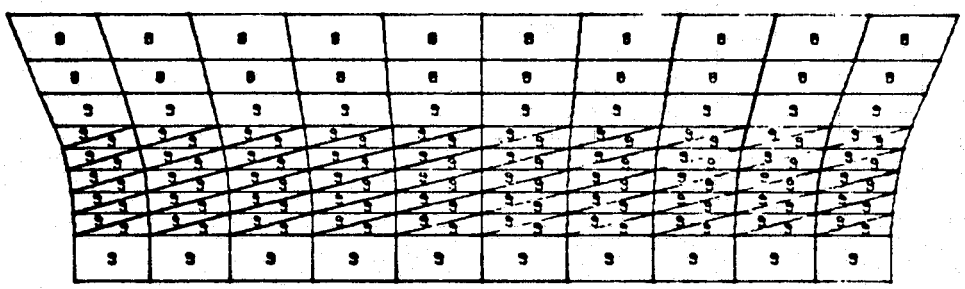


SPEC
4.1

NTF ELLIP RING CONNECTED TO 41 FT CYL
CONE KNUCKLE SECTION (INSIDE CORNER)

0 SCALE 23

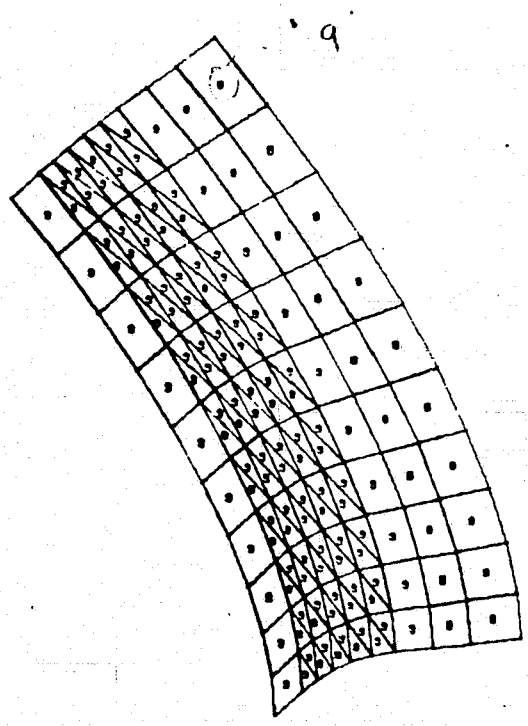
FIGURE 20



SPEC 6.1 NTF ELLIP RING CONNECTED TO 41 FT CYL CONE KNUCKLE SECT (MIDDLE)

0 SCALE 28

FIGURE 21



SPEC 8.1 NTE ELLIP RING CONNECTED TO 41 FT CYL CONE KNUC. SECT. (OUTSIDE CORNER)

0 SCALE 23

FIGURE 22

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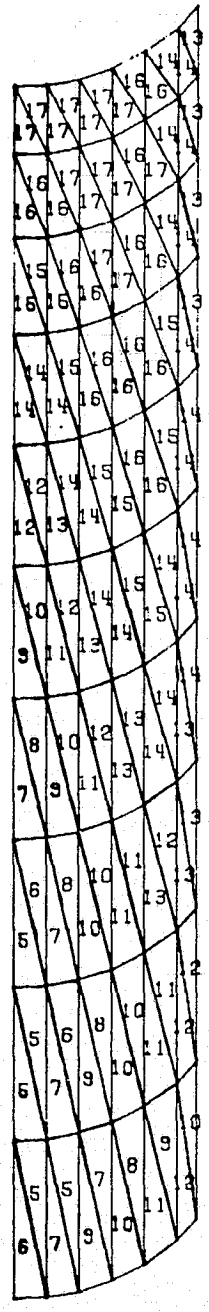
1/1/1



SPEC
1.1

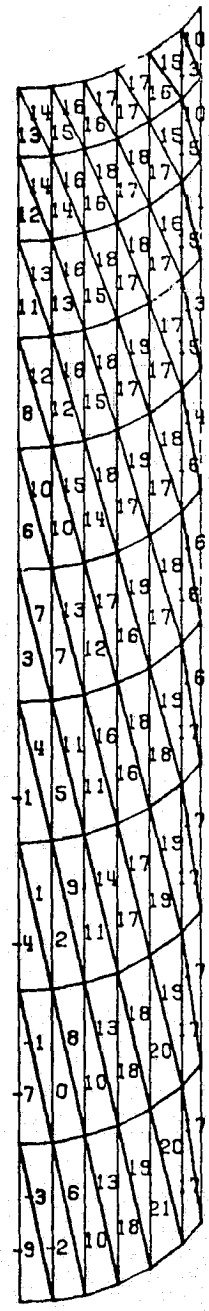
NTF ELLIP RING CONNECTED TO 41 FT CYL
KNUCKLE SECT. AT ELLIP. RING(INS. CORNE

0 27
SCALE

FIGURE 23

DISPLAY= PS1 /1000 , NODE= 1, SURFACE= 1

1/1/1



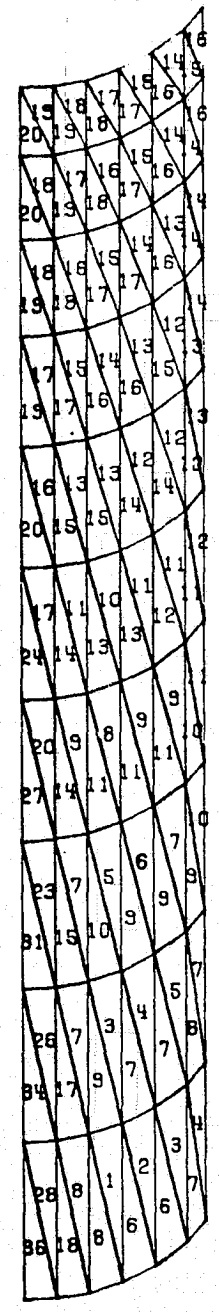
SPEC 1.1 NTF ELLIP RING CONNECTED TO 41 FT CYL KNUCKLE SECT. AT ELLIP. RING INS. CORNE

0 27
SCALE

FIGURE 24

DISPLAY= PS1 /1000 , NODE= 1 , SURFACE= 2

1/1/1



SPEC
1.1

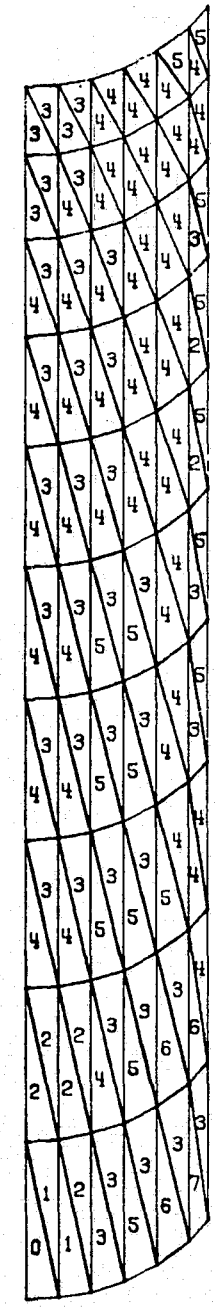
NTF ELLIP RING CONNECTED TO 41 FT CYL
KNUCKLE SECT. AT ELLIP. RING(INS. CORNE

0 27
SCALE

FIGURE 25

DISPLAY= PS2 /1000 , NODE= 1 , SURFACE= 0

1/1/1



SPEC
1.1

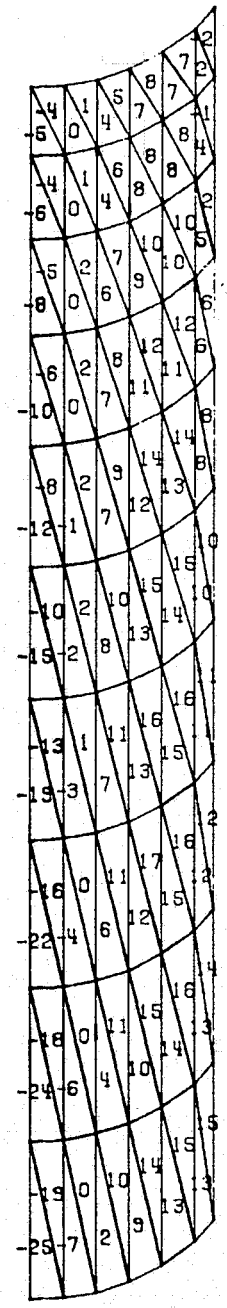
NTF ELLIP RING CONNECTED TO 41 FT CYL
KNUCKLE SECT. AT ELLIP. RING(INS. CORNE

0 27
SCALE

FIGURE 26

DISPLAY= PS2 /1000 , NODE= 1 , SURFACE= 1

1/1/1



SPEC 1.1

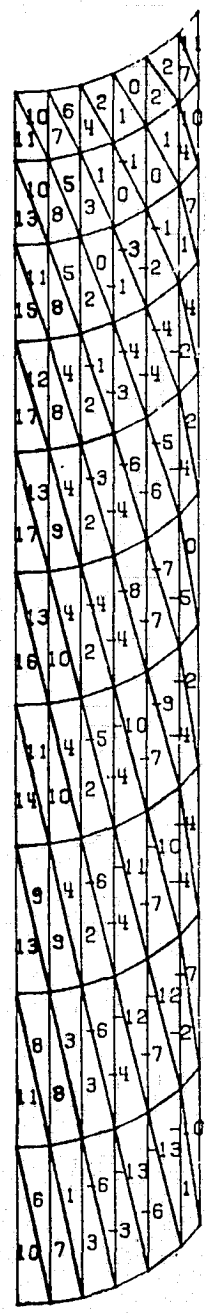
NTF ELLIP RING CONNECTED TO 41 FT CYL
KNUCKLE SECT. AT ELLIP. RING(INS. CORNE

0 27
SCALE

FIGURE 27

DISPLAY= PS2 /1000 , NODE= 1, SURFACE= 2

1/1/1



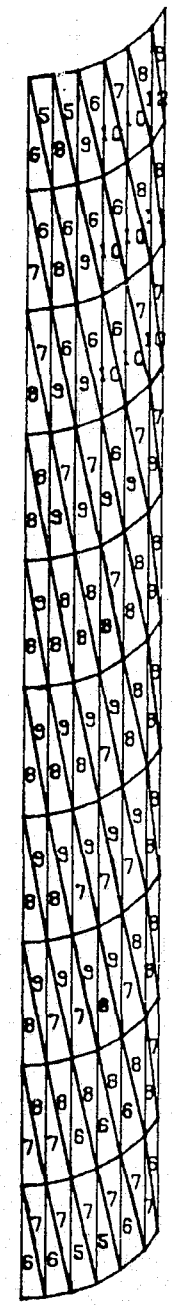
SPEC 1.1 NTF ELLIP RING CONNECTED TO 41 FT CYL KNUCKLE SECT. AT ELLIP. RING(INS. CORNE

0 27
SCALE

FIGURE 28

DISPLAY= PS1 /1000 , NODE= 1, SURFACE= 0

1/1/1



SPEC 2.1

NTF ELLIP RING CONNECTED TO 41 FT CYL
KNUCKLE SECT AT ELLIP RING (MIDDLE)

0 36
SCALE

FIGURE 29

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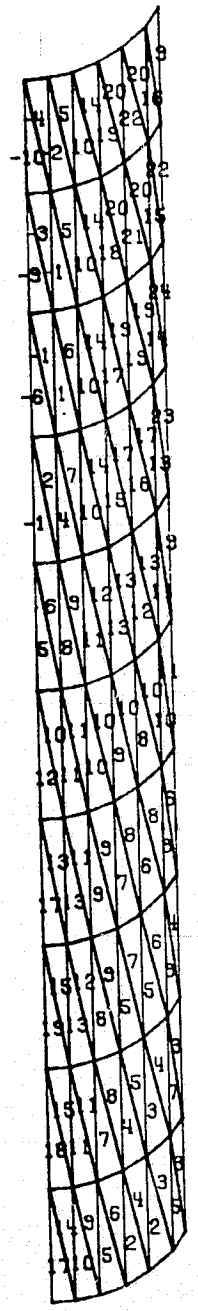
1/1/1

DISPLAY= PS1 /1000 , NODE= 1 , SURFACE= 1



SPEC
2.1

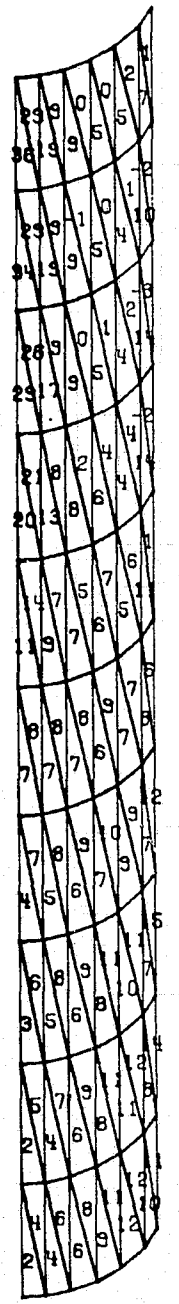
NTF ELLIP RING CONNECTED TO 41 FT CYL
KNUCKLE SECT AT ELLIP RING (MIDDLE)

0 36
SCALE

FIGURE 30

DISPLAY= PS1 /1000 , NODE= 1 , SURFACE= 2

1/1/1



SPEC 2.1

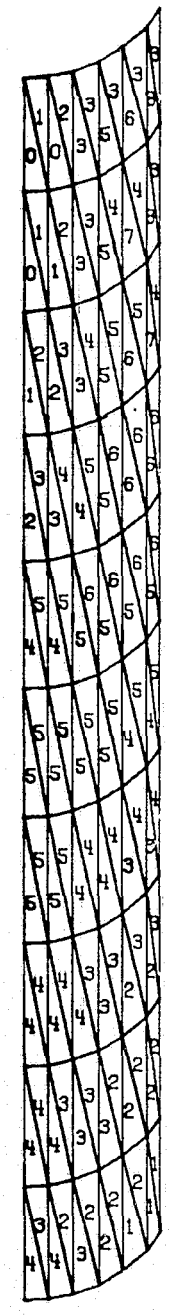
NTF ELLIP RING CONNECTED TO 41 FT CYL
KNUCKLE SECT AT ELLIP RING (MIDDLE)

0 36
SCALE

FIGURE 31

DISPLAY= . PSC /1000 , NODE= 1 , SURFACE= 0

1/1/1



SPEC
2.1

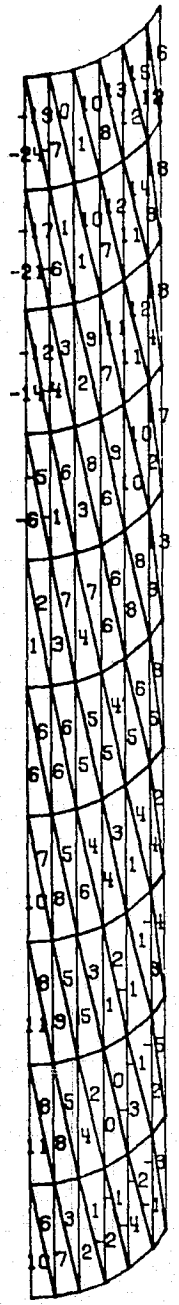
NTF ELLIP RING CONNECTED TO 41 FT CYL
KNUCKLE SECT AT ELLIP RING (MIDDLE)

0 36
SCALE

FIGURE 32

DISPLAY= PS2 /1000 , NODE= 1 , SURFACE= 1

1/1/1



SPEC 2.1

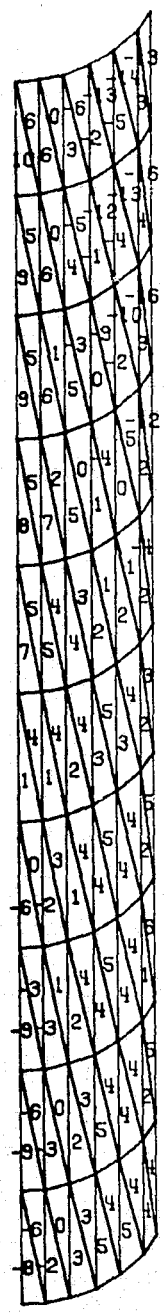
NTF ELLIP RING CONNECTED TO 41 FT CYL
KNUCKLE SECT AT ELLIP RING (MIDDLE)

0 36
SCALE

FIGURE 33

DISPLAY= PS2 /1000 , NODE= 1 , SURFACE= 2

1/1/1



SPEC 2.1

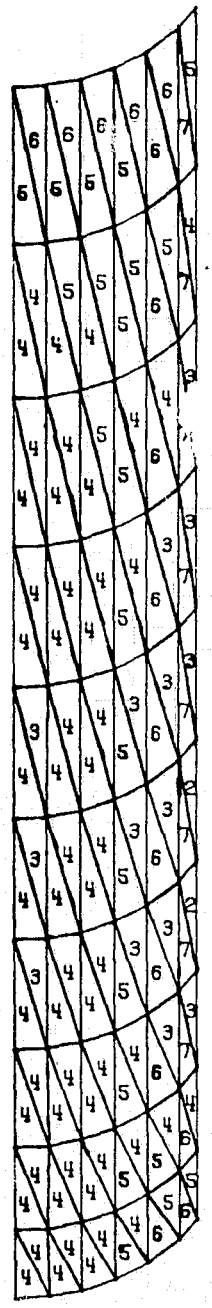
NTF ELLIP RING CONNECTED TO 41 FT CYL
KNUCKLE SECT AT ELLIP RING (MIDDLE)

0 36
SCALE

FIGURE 34

DISPLAY= PS1 /1000 , NODE= 1 , SURFACE= 0

1/1/1



SPEC
3.1

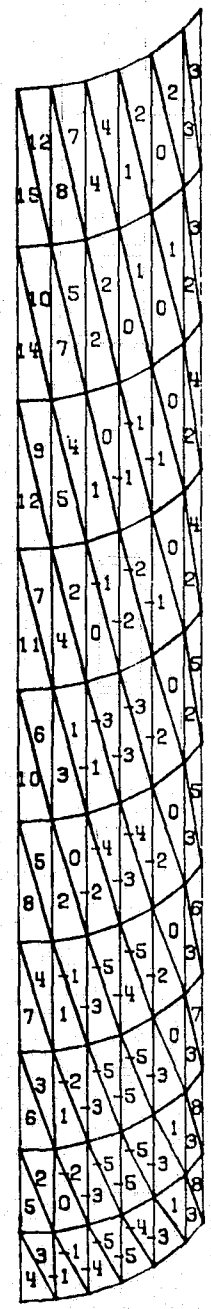
NTF ELLIP RING CONNECTED TO 41 FT CYL
KNUCK SECT AT ELLIP RING (OUTSIDE)

0 27
SCALE

FIGURE 35

DISPLAY= PS1 /1000 , NODE= 1 , SURFACE= 1

1/1/1



SPEC 3.1

NTF ELLIP RING CONNECTED TO 41 FT CYL
KNUCK SECT AT ELLIP RING (OUTSIDE)

0 27
SCALE

FIGURE 36

REPRODUCIBILITY OF THE
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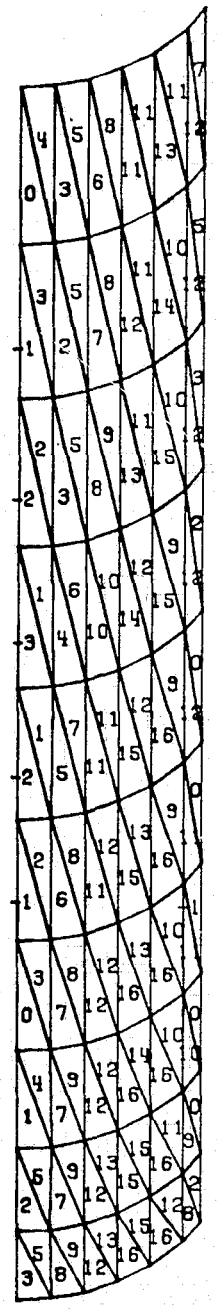
DISPLAY= PS1 /1000 , NODE= 1 , SURFACE= 2

1/1/1



SPEC 3.1

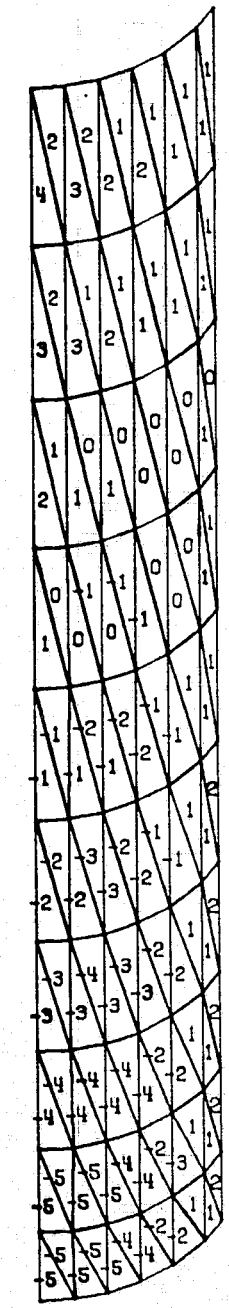
NTF ELLIP RING CONNECTED TO 41 FT CYL
KNUCK SECT AT ELLIP RING (OUTSIDE)

0 27
SCALE

FIGURE 37

DISPLAY= PS2 /1000 , NODE= 1 , SURFACE= 0

1/1/1



SPEC 3.1

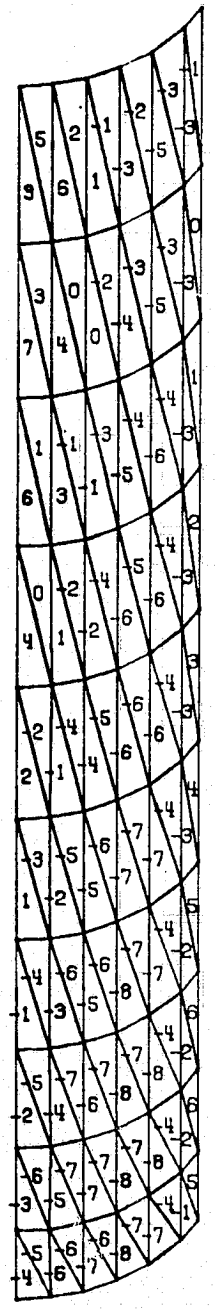
NTF ELLIP RING CONNECTED TO 41 FT CYL
KNUCK SECT AT ELLIP RING (OUTSIDE)

0 27
SCALE

FIGURE 38

DISPLAY= PS2 /1000 , NODE= 1 , SURFACE= 1

1/1/1



SPEC 3.1

NTF ELLIP RING CONNECTED TO 41 FT CYL
KNUCK SECT AT ELLIP RING (OUTSIDE)

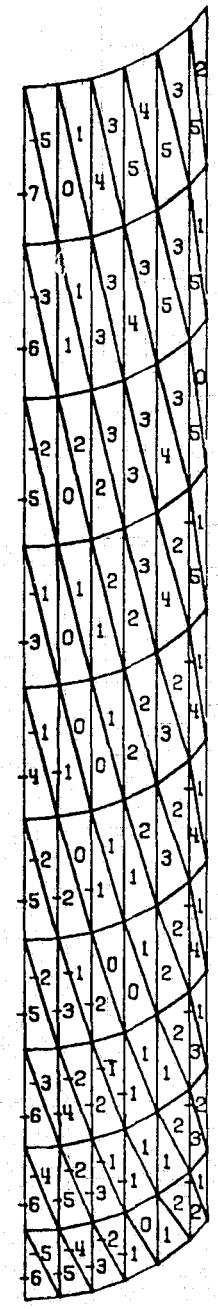
0 27
SCALE

FIGURE 39

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

DISPLAY= PS2 /1000 , NODE= 1 , SURFACE= 2

1/1/1



SPEC
3.1

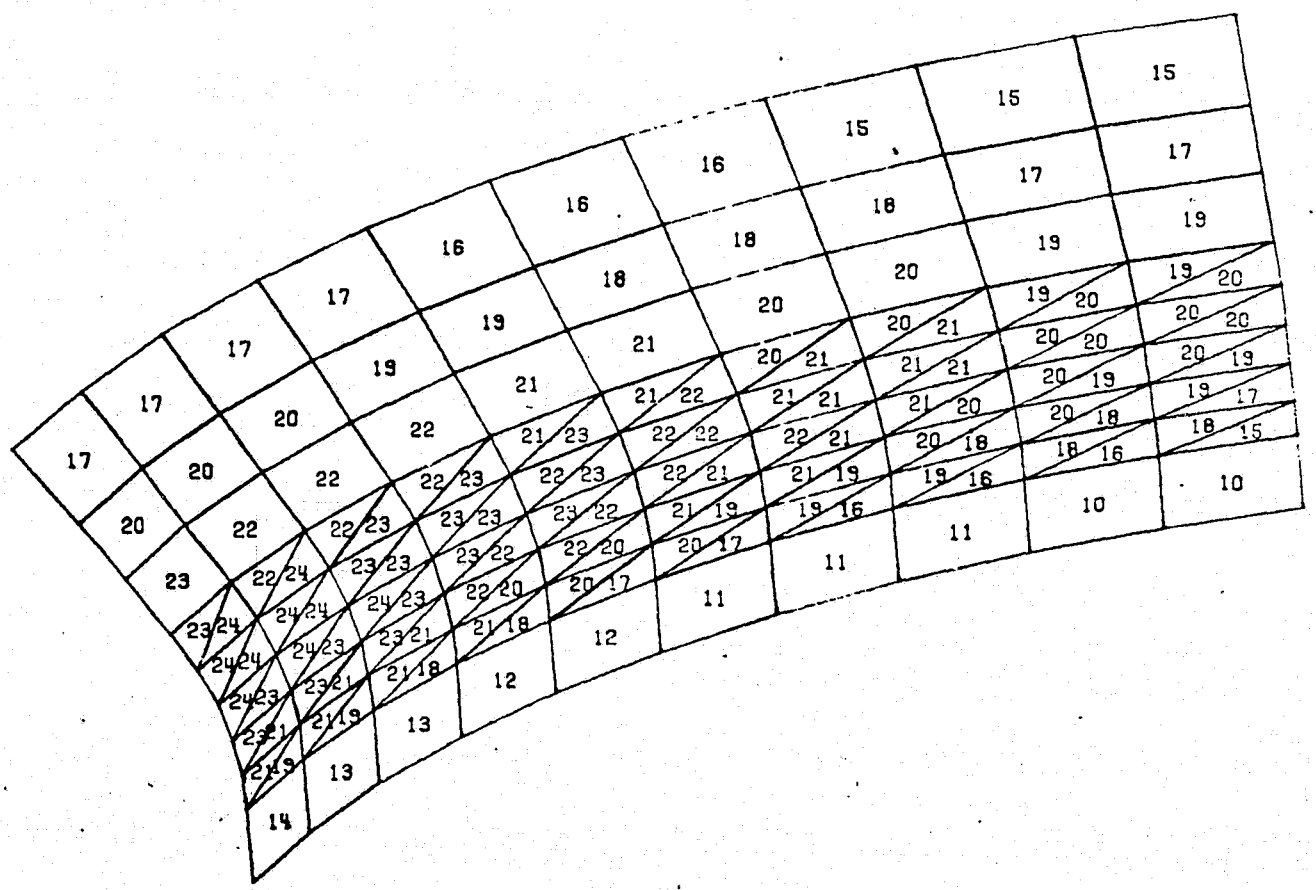
NTF ELLIP RING CONNECTED TO 41 FT CYL
KNUCK SECT AT ELLIP RING (OUTSIDE)

0 27
SCALE

FIGURE 40

DISPLAY= PS1 /1000 , NODE= 1 , SURFACE= 0

1/1/1



SPEC 4.1

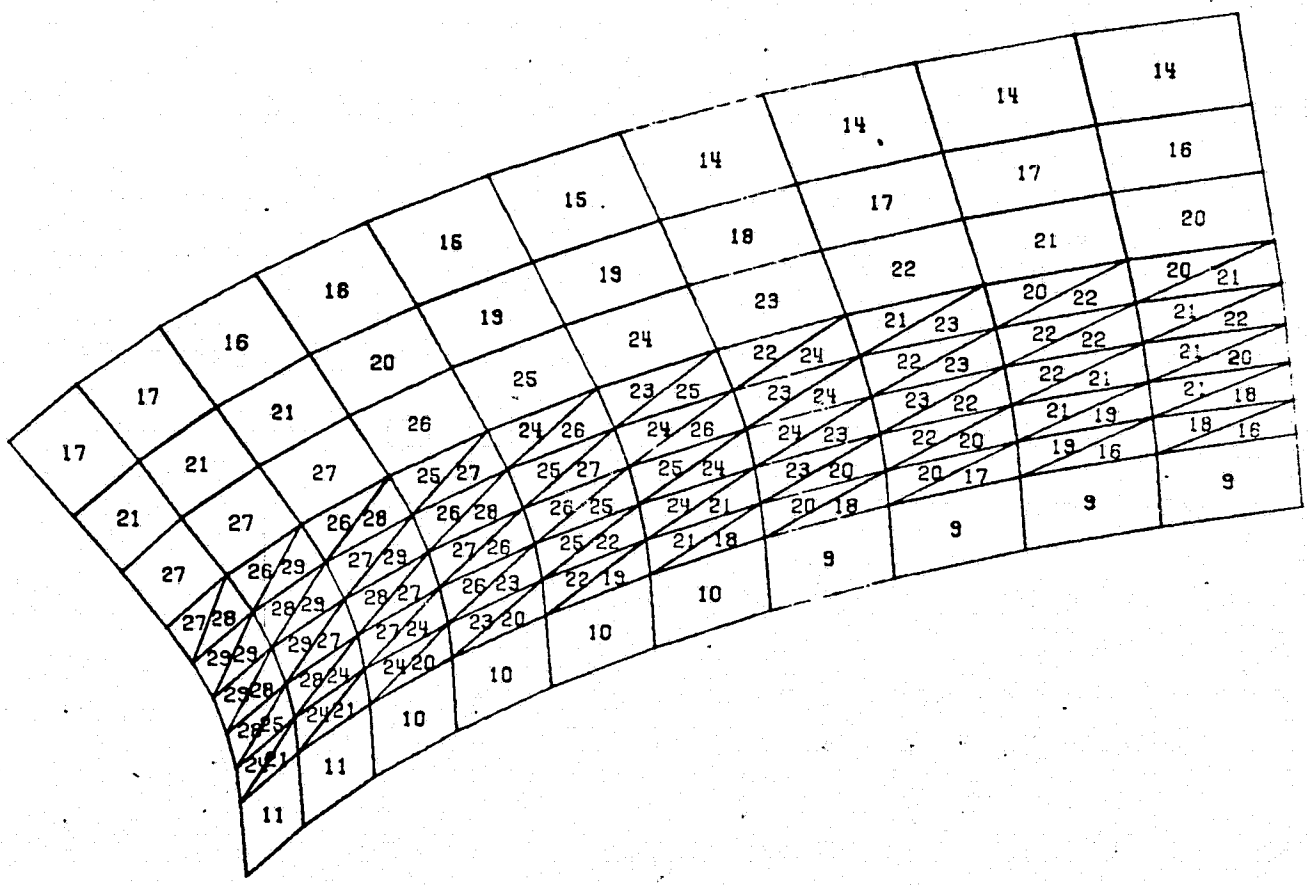
NTF ELLIP RING CONNECTED TO 41 FT CYL CONE KNUCKLE SECTION (INSIDE CORNER)

0 23
SCALE

FIGURE 41

DISPLAY= PS1 /1000 , NODE= 1 , SURFACE= 1

1/1/1



SPEC 4.1

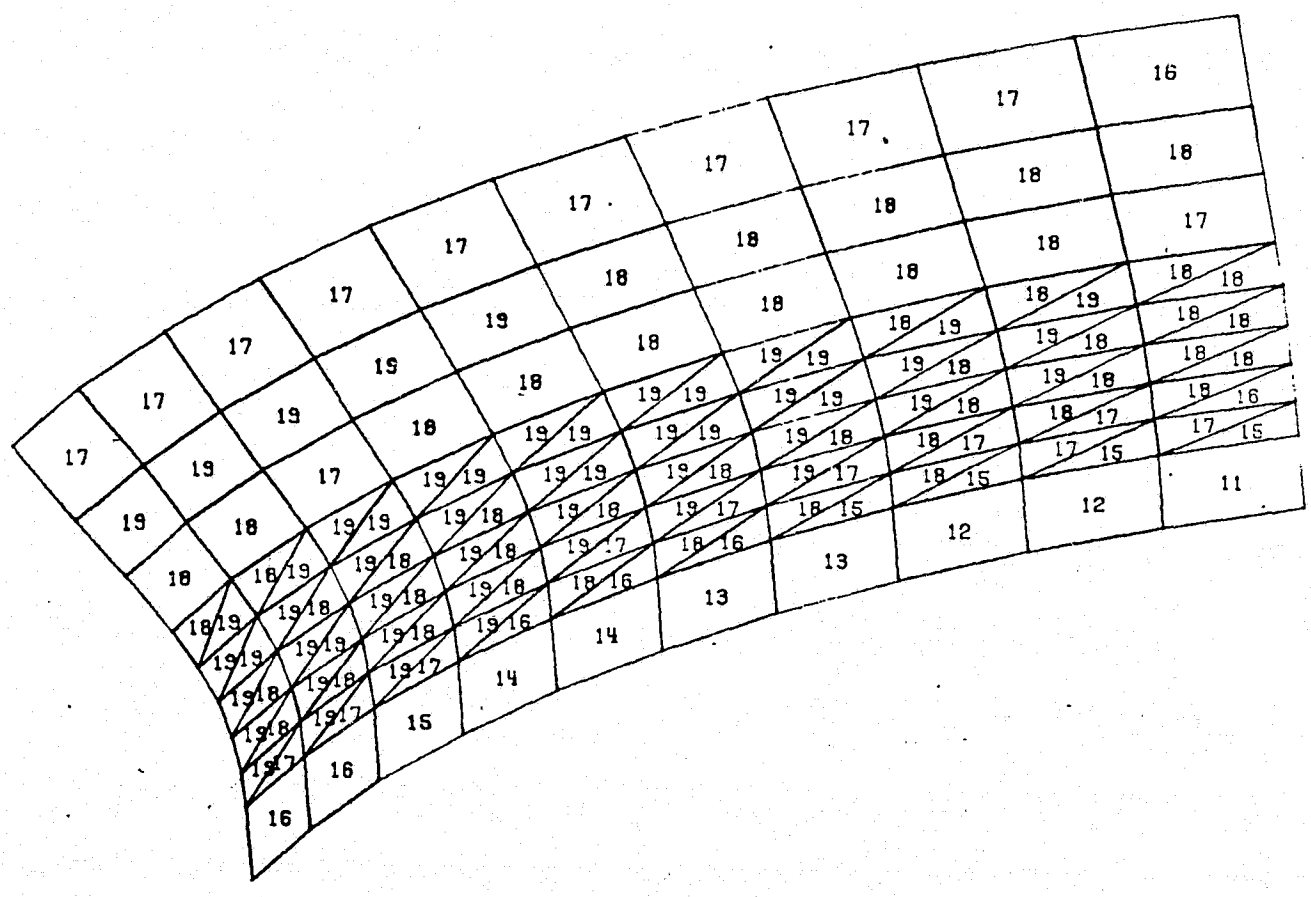
NTF ELLIP RING CONNECTED TO 41 FT CYL
CONE KNUCKLE SECTION (INSIDE CORNER)

0 23
SCALE

FIGURE 42

DISPLAY= PS1 /1000 , NODE= 1, SURFACE= 2

1/1/1



SPEC 4.1

NTF ELLIP RING CONNECTED TO 41 FT CYL
CONE KNUCKLE SECTION (INSIDE CORNER)

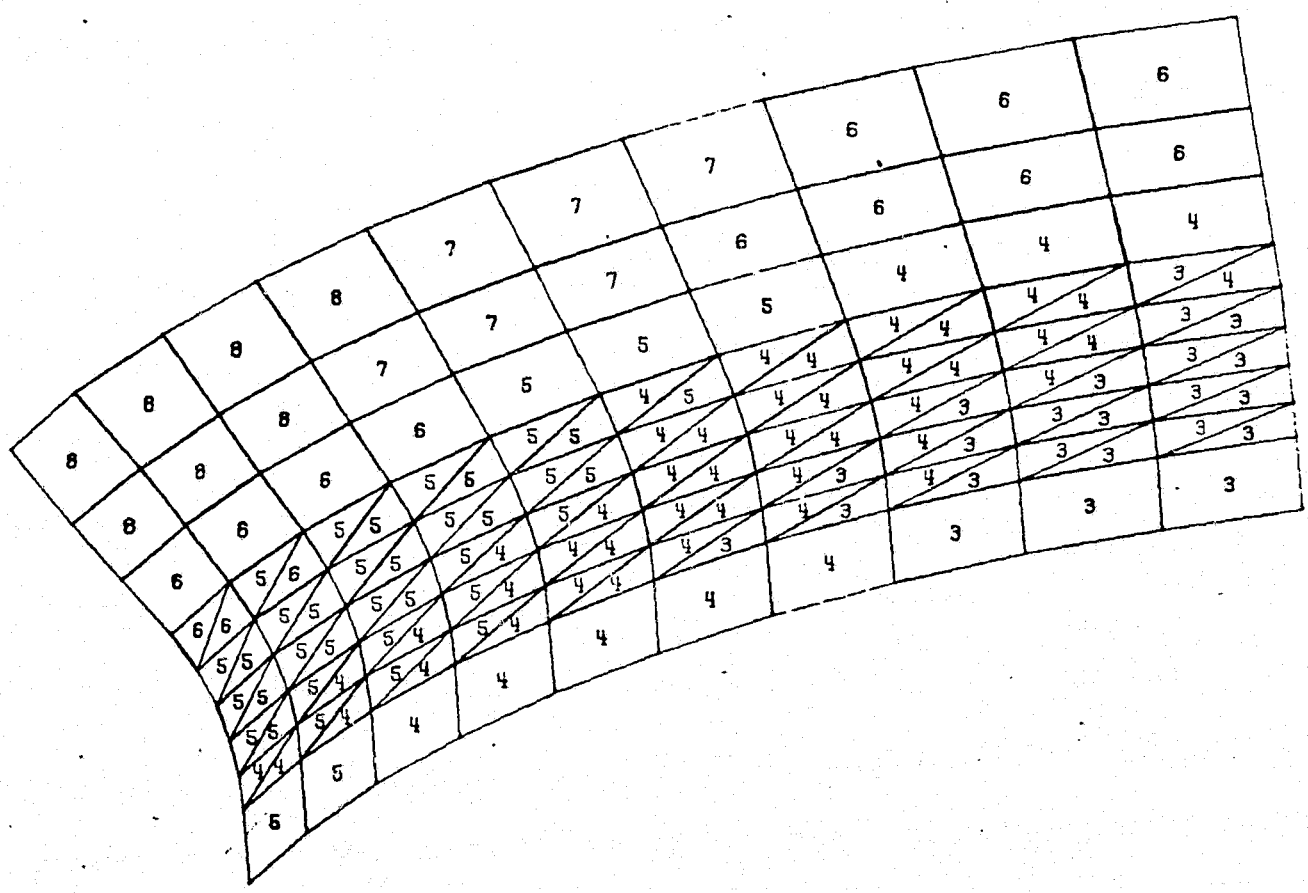
0 23
SCALE

FIGURE 43

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

DISPLAY= PS2 /1000 , NODE= 1 , SURFACE= 0

1/1/1



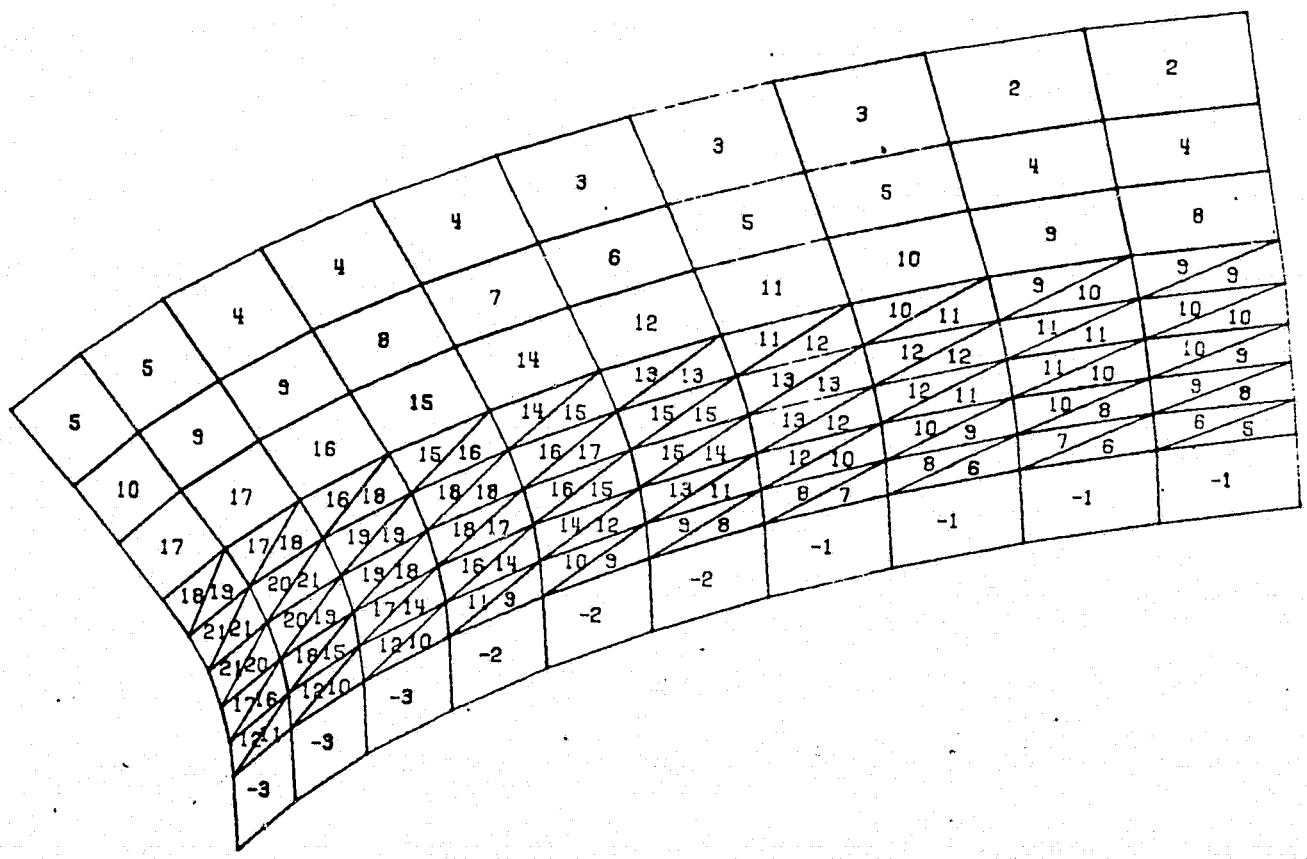
SPEC 4.1

NTF ELLIP RING CONNECTED TO 41 FT CYL CONE KNUCKLE SECTION (INSIDE CORNER)

0 23
SCALE

FIGURE 44

DISPLAY= PS2 /1000 , NODE= 1 , SURFACE= 1 1/1/1



SPEC 4.1

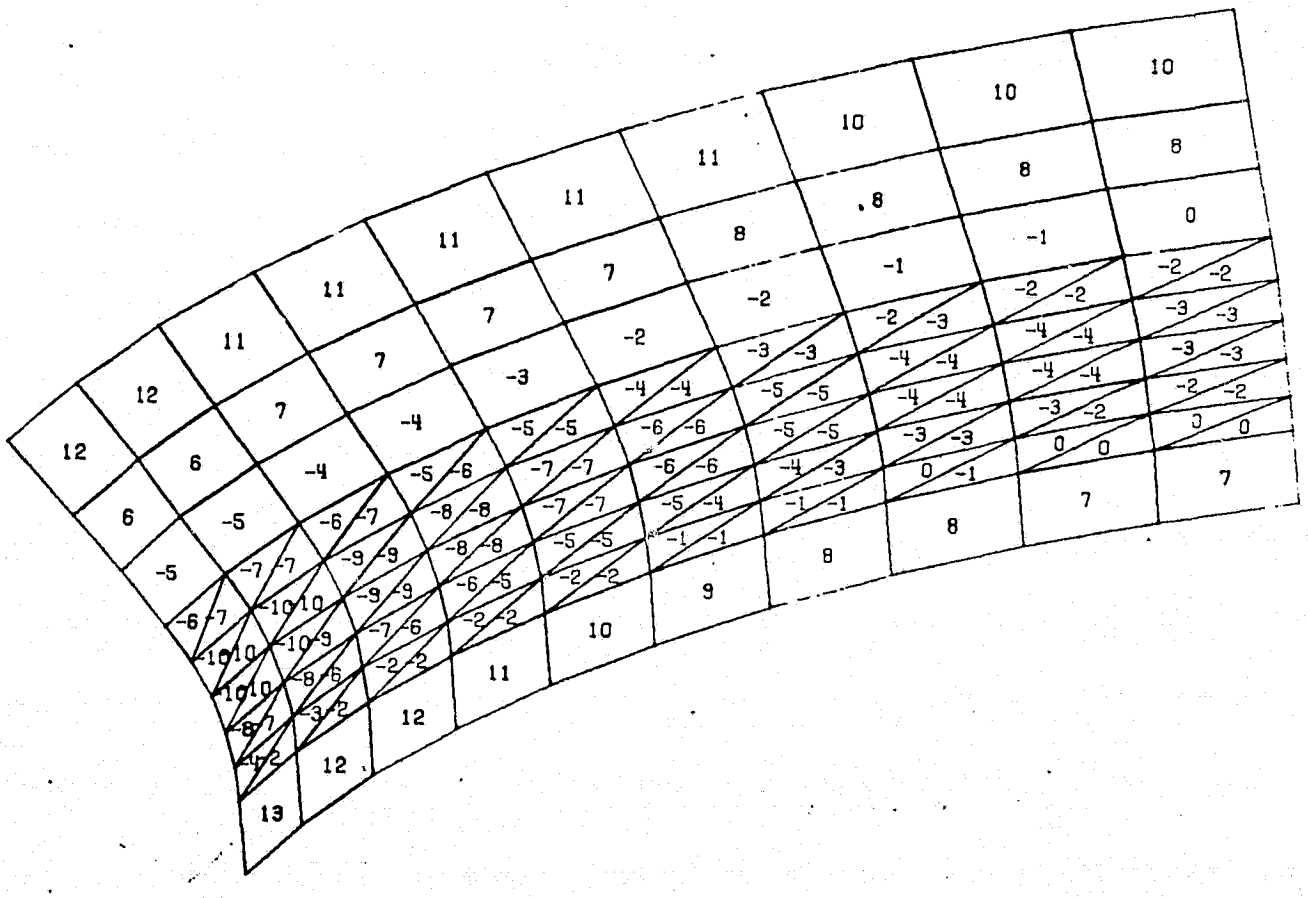
NTF ELLIP RING CONNECTED TO 41 FT CYL
CONE KNUCKLE SECTION (INSIDE CORNER)

0 23
SCALE

FIGURE 45

DISPLAY= PS2 /1000 , NODE= 1 , SURFACE= 2

1/1/1



SPEC 4.1

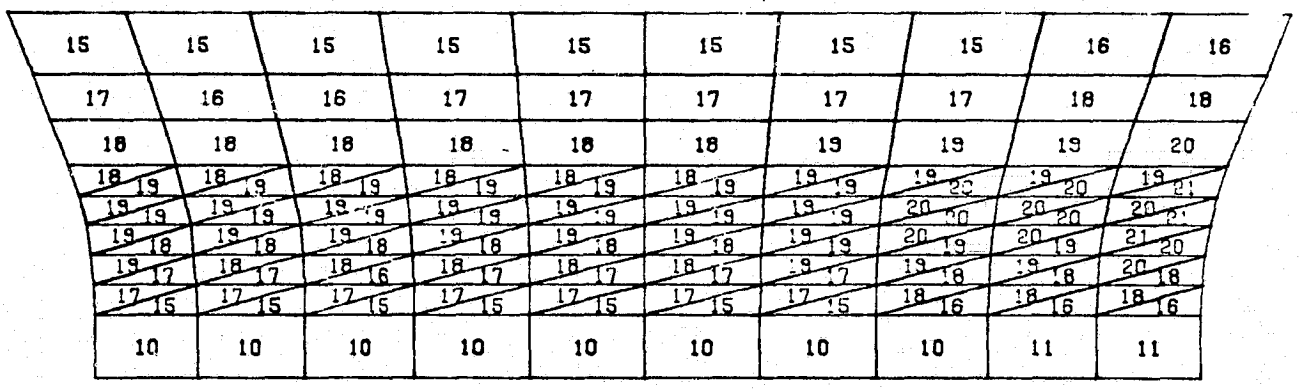
NTF ELLIP RING CONNECTED TO 41 FT CYL
CONE KNUCKLE SECTION (INSIDE CORNER)

0 23
SCALE

FIGURE 46

DISPLAY= PS1 /1000 , NODE= 1 , SURFACE= 0

1/1/1



SPEC 5.1

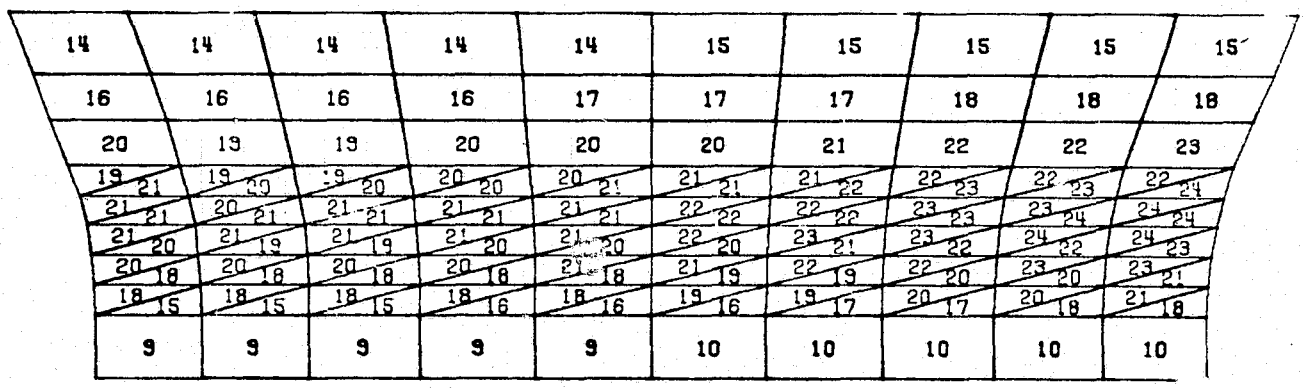
NTF ELLIP RING CONNECTED TO 41 FT CYL
CONE KNUCKLE SECT (MIDDLE)

0 28
SCALE

FIGURE 47

DISPLAY= PS1 /1000 , NODE= 1 , SURFACE= 1

1/1/1



SPEC 5.1

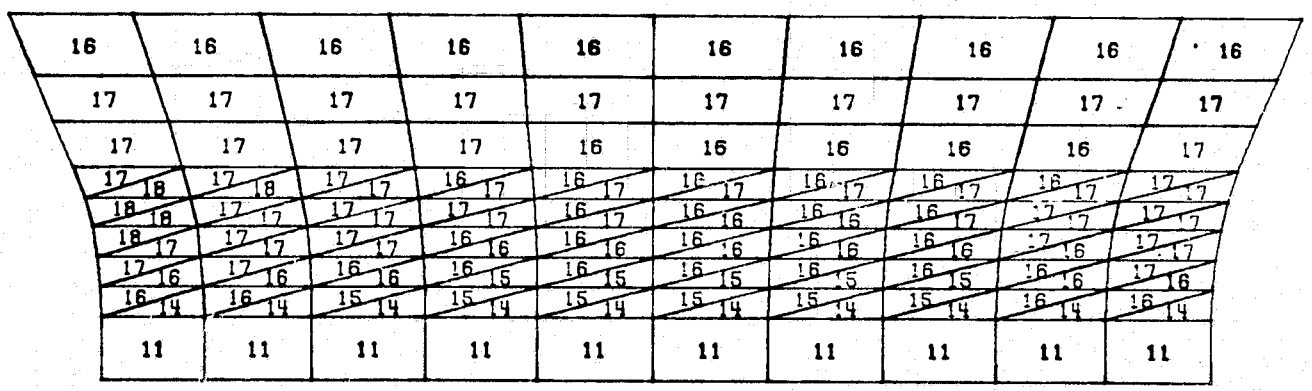
NTF ELLIP RING CONNECTED TO 41 FT CYL CONE KNUCKLE SECT (MIDDLE)

0 28
SCALE

FIGURE 48

DISPLAY= PS1 /1000 , NODE= 1, SURFACE= 2

1/1/1



SPEC 5.1

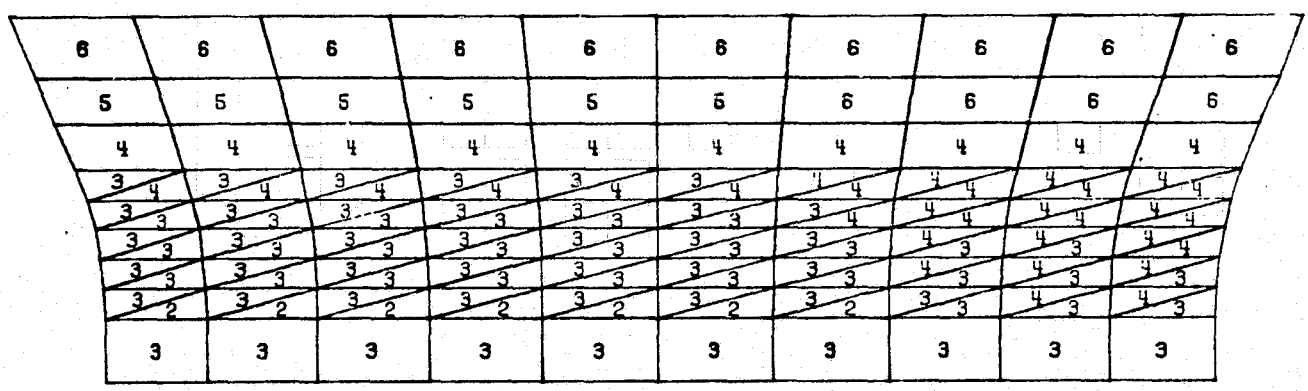
NTF ELLIP RING CONNECTED TO 41 FT CYL
CONE KNUCKLE SECT (MIDDLE)

0 28
SCALE

FIGURE 49

DISPLAY= PS2 /1000 , NODE= 1, SURFACE= 0

1/1/1



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AL PAGE IS POOR

SPEC 5.1

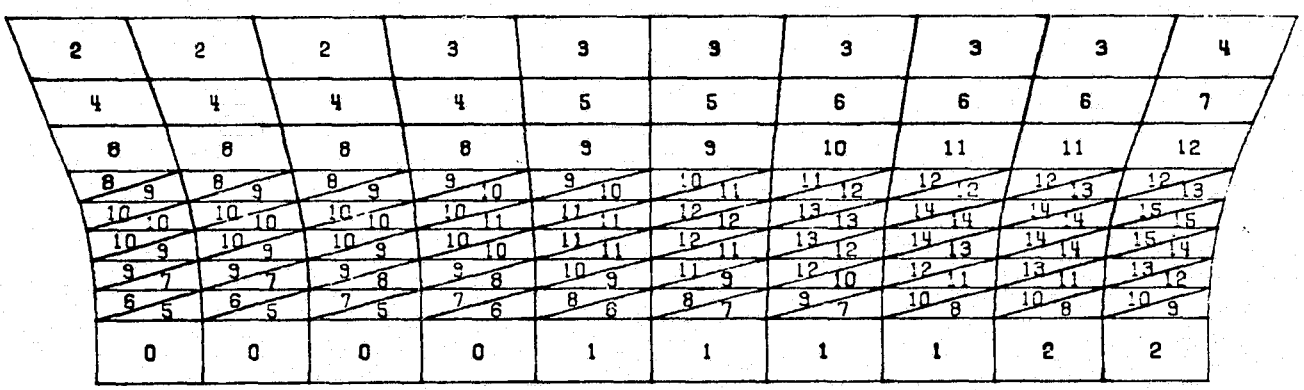
NTF ELLIP RING CONNECTED TO 41 FT CYL
CONE KNUCKLE SECT. (MIDDLE)

0 28
SCALE

FIGURE 5D

DISPLAY= . PS2 /1000 , NODE= 1, SURFACE= 1

1/1/1



SPEC 5.1

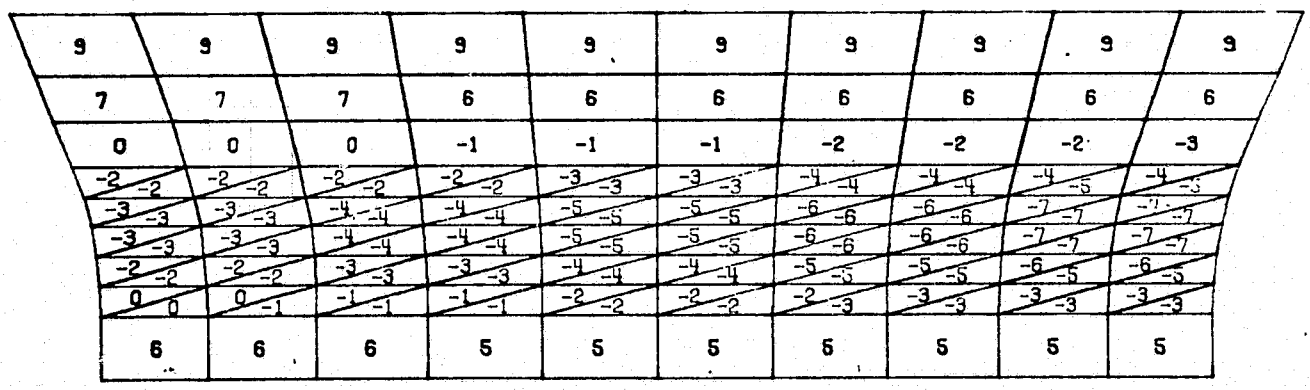
NTF ELLIP RING CONNECTED TO 41 FT CYL
CONE KNUCKLE SECT (MIDDLE)

0 28
SCALE

FIGURE 51

DISPLAY= PS2 /1000 , NODE= 1 , SURFACE= 2

1/1/1



SPEC 5.1

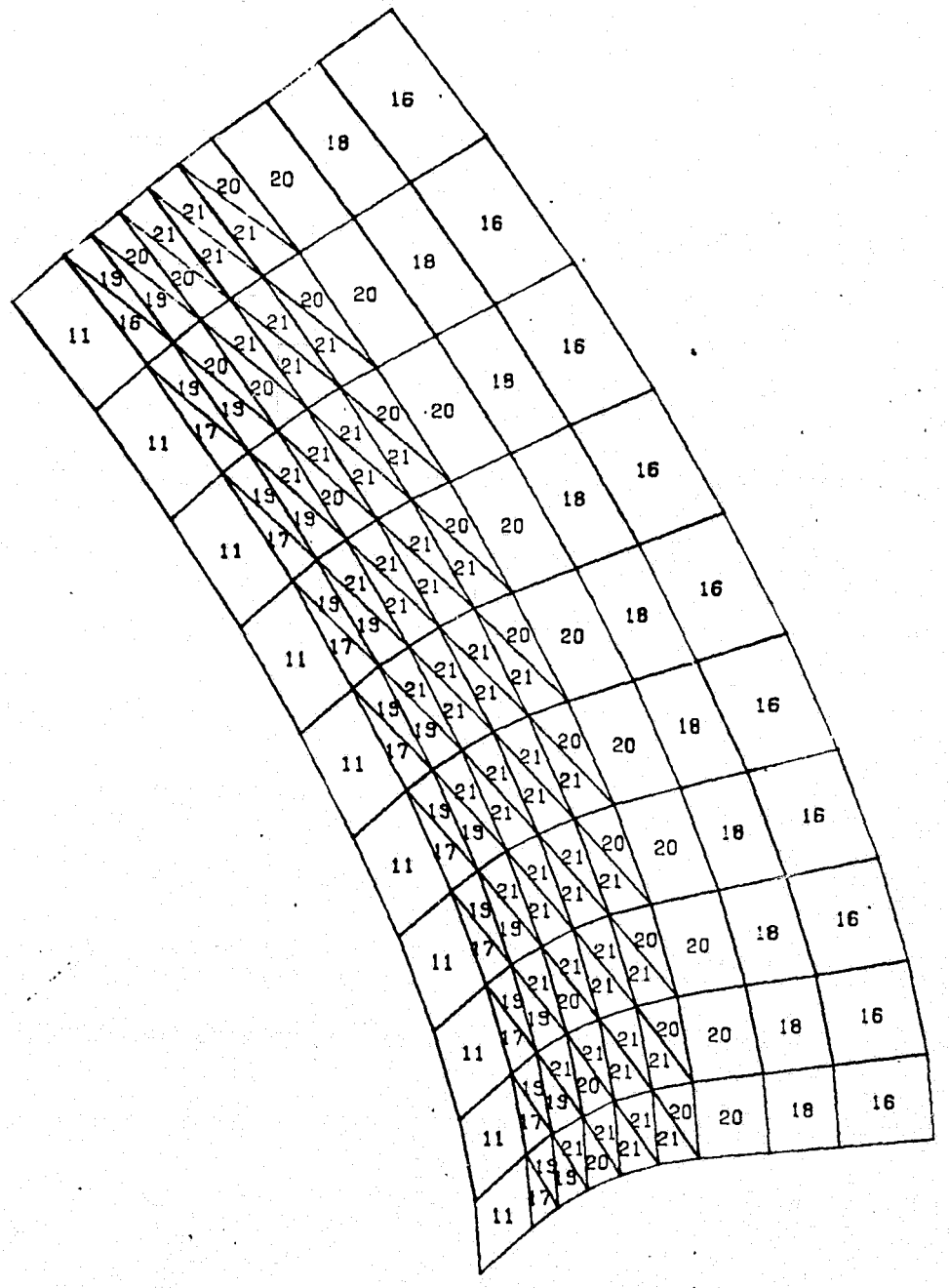
NTF ELLIP RING CONNECTED TO 41 FT CYL CONE KNUCKLE SECT (MIDDLE)

0 28
SCALE

FIGURE 52

DISPLAY= PS1 /1000 , NODE= 1 , SURFACE= 0

1/1/1



SPEC 6.1

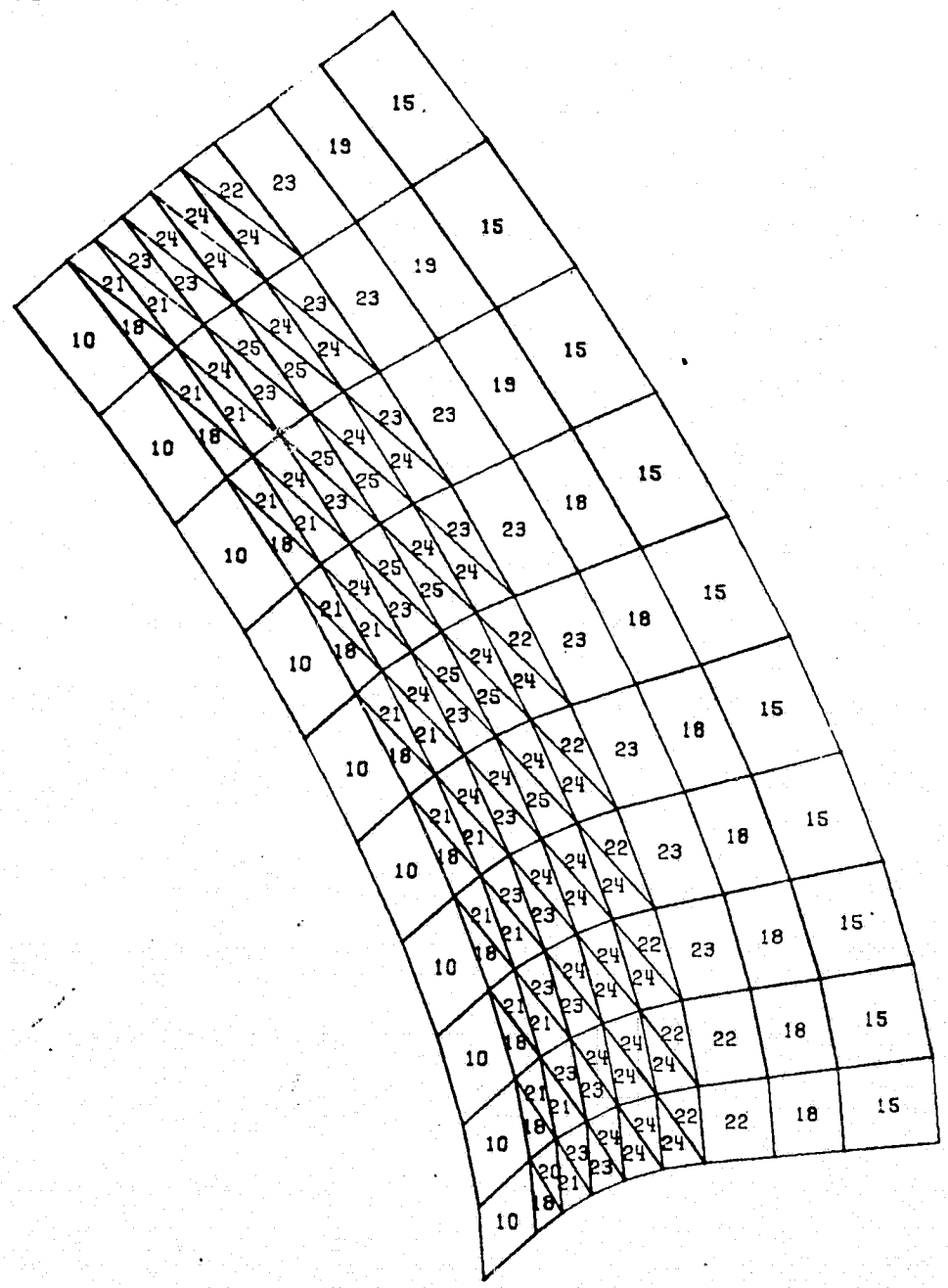
NTF ELLIP RING CONNECTED TO 41 FT CYL
CONE KNUC. SECT. (OUTSIDE CORNER)

0 23
SCALE

FIGURE 53

DISPLAY= PS1 /1000 , NODE= 1 , SURFACE= 1

1/1/1



SPEC 6.1

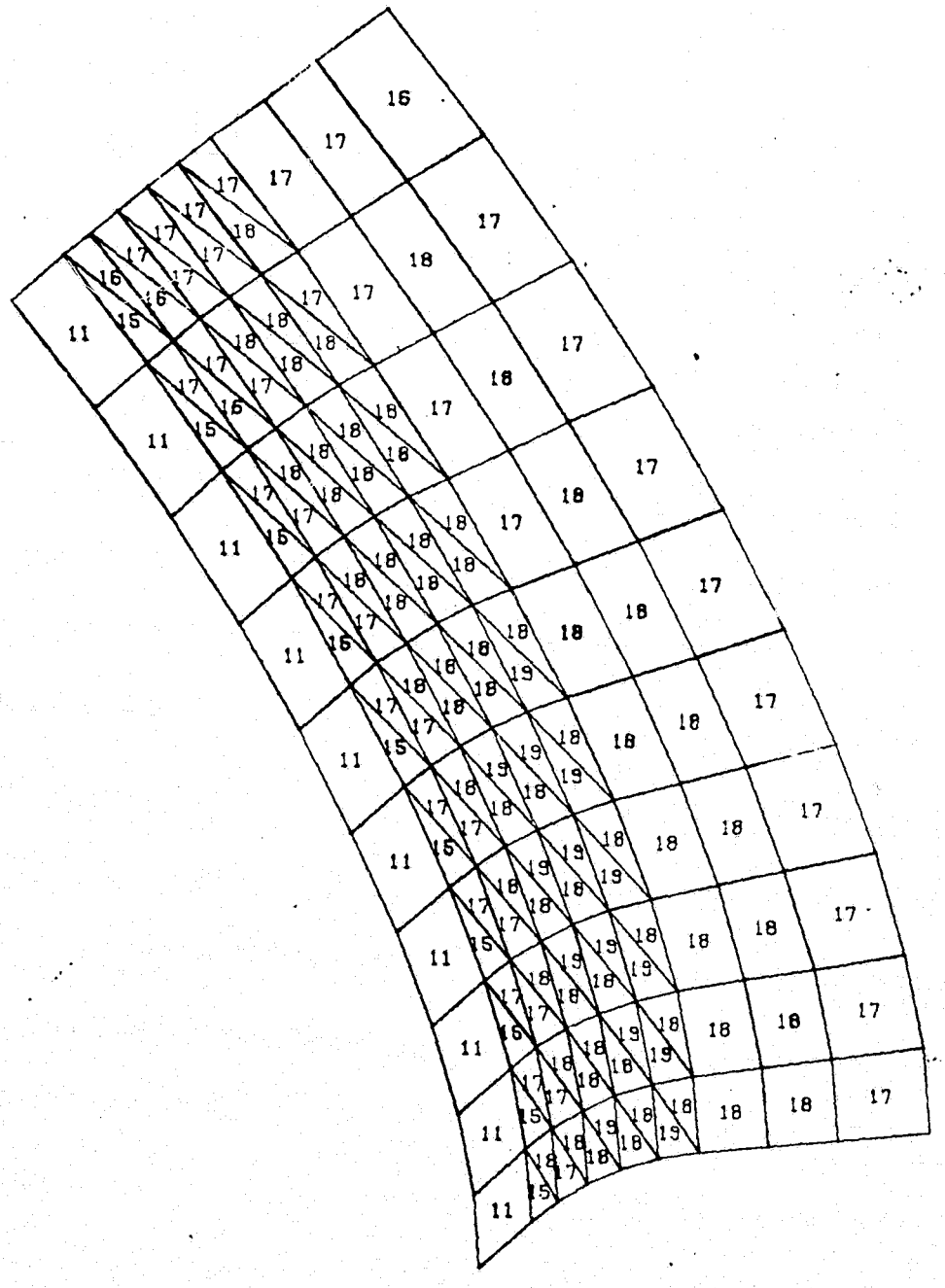
NTF ELLIP RING CONNECTED TO 41 FT CYL CONE KNUC. SECT. (OUTSIDE CORNER)

0 23 SCALE

FIGURE 5.4

DISPLAY= PS1 /1000 , NODE= 1 , SURFACE= 2

1/1/1



SPEC 6.1

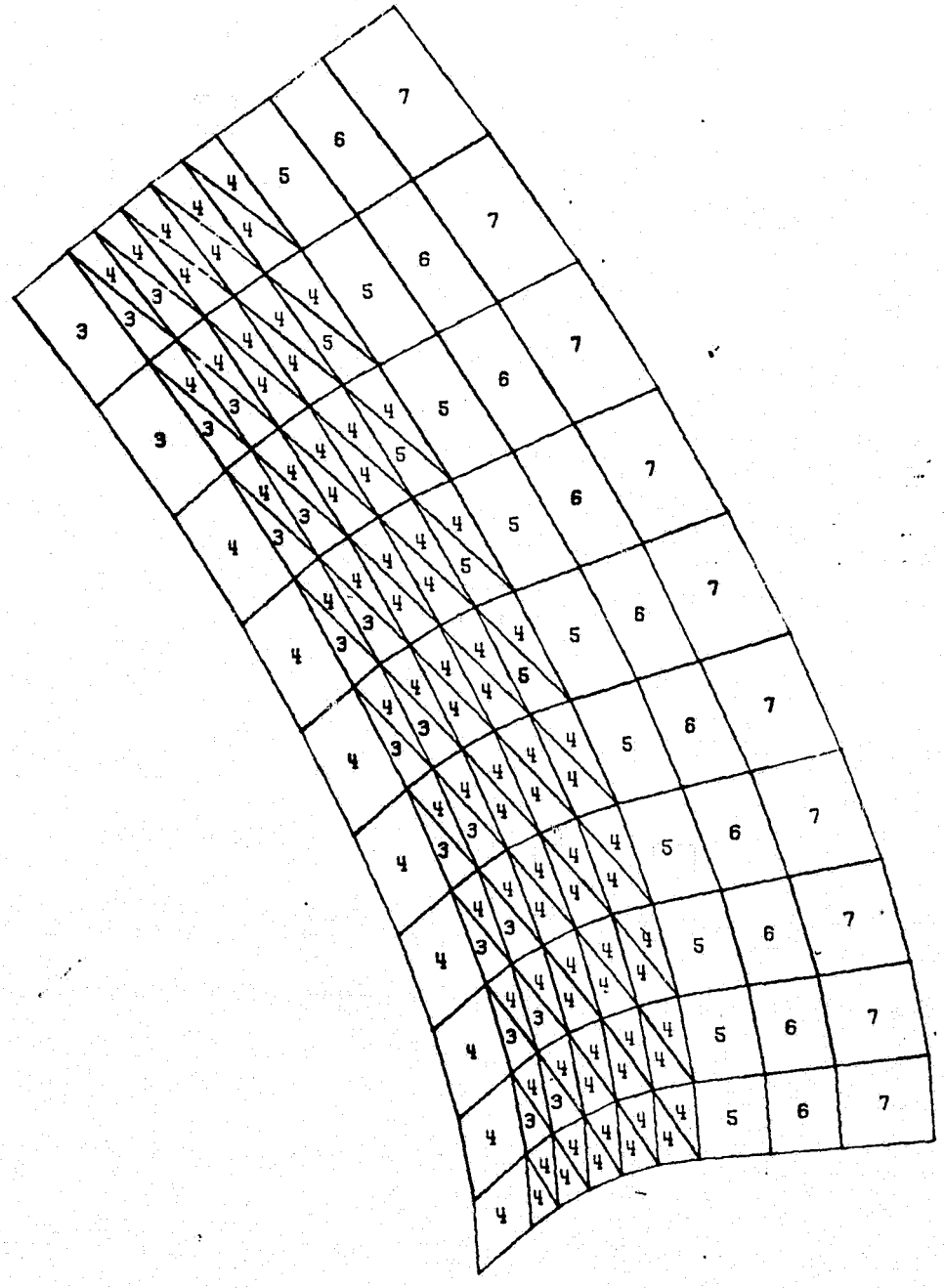
NTF ELLIP RING CONNECTED TO 41 FT CYL CONE KNUC. SECT. (OUTSIDE CORNER)

0 23 SCALE

FIGURE 55

DISPLAY= PS2 /1000 , NODE= 1, SURFACE= 0

1/1/1



SPEC 6.1

NTF ELLIP RING CONNECTED TO 41 FT CYL CONE KNUC. SECT. (OUTSIDE CORNER)

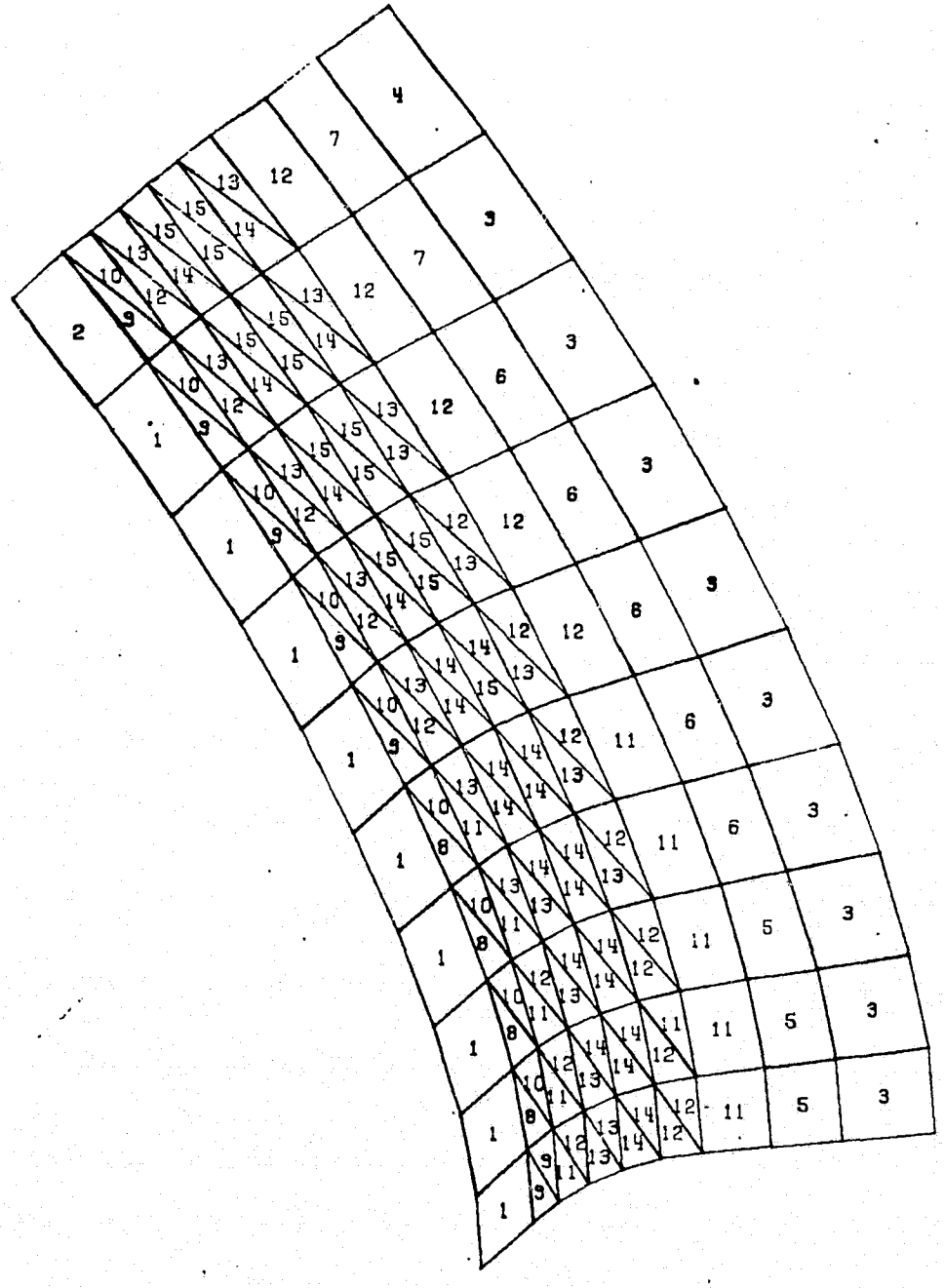
0 23
SCALE

FIGURE 56

UCIBILITY OF THE

DISPLAY= PS2 /1000 , NODE= 1 , SURFACE= 1

1/1/1



SPEC 6.1

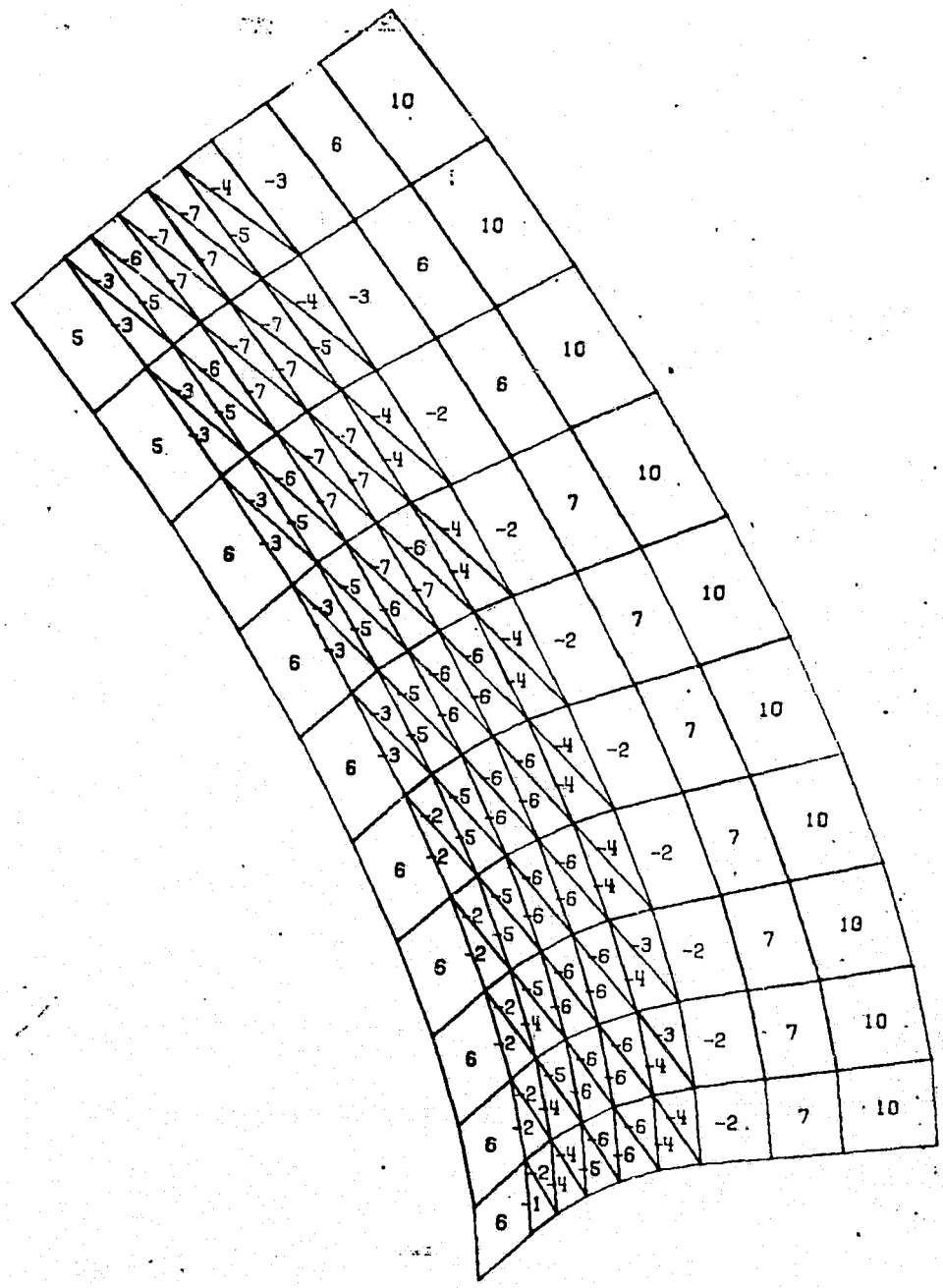
NTF ELLIP RING CONNECTED TO 41 FT CYL CONE KNUC. SECT. (OUTSIDE CORNER)

0 23
SCALE

FIGURE 57

DISPLAY= PS2 /1000 , NODE= 1, SURFACE= 2

1/1/1



SPEC 6.1

NTF ELLIP RING CONNECTED TO 41 FT CYL
CONE KNUC. SECT. (OUTSIDE CORNER)

0 23
SCALE

FIGURE 58

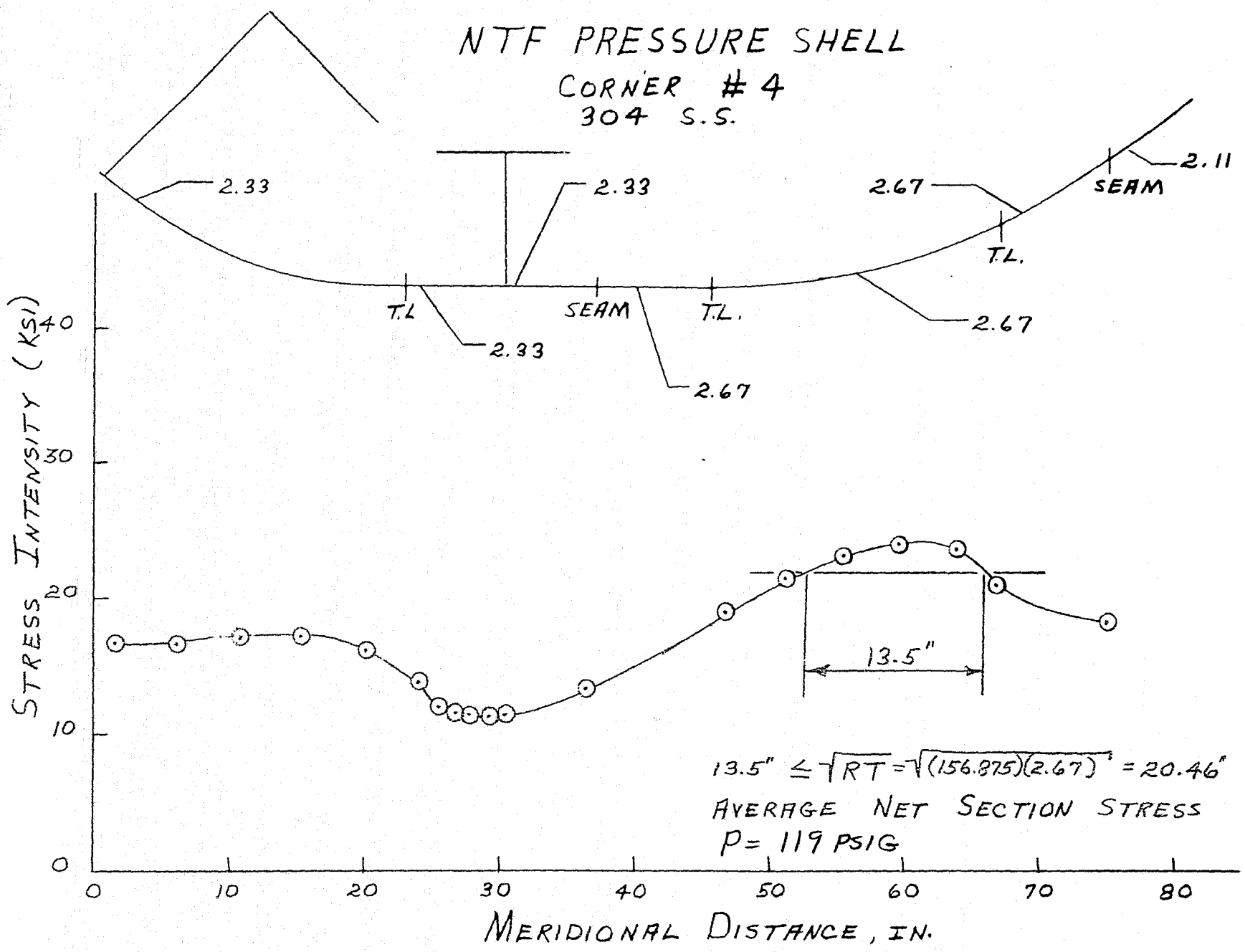


FIGURE 59

BY _____ DATE _____
CHKD. BY _____ DATE _____
SUBJECT Elliptical Ring Case 55
SHEET NO. _____ OF _____
JCB NO. _____