STRESS CONCENTRATION FACTORS FOR CIRCULAR, REINFORCED PENETRATIONS IN PRESSURIZED CYLINDRICAL SHELLS

A Dissertation
Presented to
the Faculty of the School of Engineering and Applied Science
University of Virginia

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy (Civil Engineering)

By

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May 1975

(NASA-TM-X-68733) STRESS CONCENTRATION FACTORS FOR CIRCULAR, REINFORCED PENETRATIONS IN PRESSURIZED CYLINDRICAL SHELLS Ph.D. Thesis - Virginia Univ. (NASA) 205 p HC $7.25 CSCL 20K G3/39

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APPROVAL SHEET

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ACKNOWLEDGMENTS

The author wishes to gratefully acknowledge the following in making this dissertation possible:

The National Aeronautics and Space Administration for sponsoring this research;

Professor Furman W. Barton of the University of Virginia for his patience, encouragement, and constructive criticism throughout the preparation of this paper and my total Ph.D. program;

Dr. Ross L. Goble, Chief of Research Facilities Engineering Division, for his motivational push, moral support, and constructive criticism;

My management and fellow workers, especially Mr. John E. Doyle, for the opportunity to work and encouragement to finish;

Mr. Carl E. Gray, Jr. for helpful discussions, computer programming and figure preparation; Mr. Peter F. Jacobs, for programming; Mr. John T. Taylor for constructive ctiticism; and Miss Mary Morgan Cox and Mrs. Theresa C. Walker for help in preparing this manuscript.

And last, but certainly not least, the author also wishes to thank his wife, Jane, for her total encouragement and support before and during the course of the research and Jennifer, Todd, and Leslie - who make it all worthwhile.

ABSTRACT

The effect on stresses in a cylindrical shell with a circular penetration subject to internal pressure has been investigated. The research is limited to thin, shallow, linearly elastic cylindrical shells; however, some comparisons are made to thick shell experimental measurements. Results provide numerical predictions of peak stress concentration factors around nonreinforced and reinforced penetrations in pressurized cylindrical shells. Analytical results are correlated with published formulas, as well as theoretical and experimental results. An accuracy study is made of the finite element program for each of the configurations considered important in pressure vessel technology.

A formula is developed to predict the peak stress concentration factor (SCF) for analysis and/or design in conjunction with the ASME Boiler and Pressure Vessel Code, Section VIII, Divisions 1 and 2. The formula is rationally derived to include all of the parameters that are required to define the various penetration configurations used in pressure vessel analysis, design, and construction. The accuracy of the empirical formula is determined by comparing to numerical, theoretical, and experimental data. In most cases, it is shown that the ASME Pressure Vessel Code SCF of 3.3 is extremely conservative.

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A_j	multipoint constraint coefficient
A_{hole}, A_{pad}, $A_{reinf.}$	cross sectional areas
D	$ET^3/12\ (1 - \nu^2)$
E	modulus of elasticity
F	force vector
j	degree of freedom
K	stiffness matrix
M_y, M_{xy}, M_x	moments in plate element
P, p	pressure
R	cylindrical shell mid radius
t, t_p, T, TH	pipe, pad, shell, and shell or pipe thicknesses
u	system displacement vector
V_x, V_y	shears in plate element
w	radial shell deflection
X, Y, Z	rectangular coordinates
Z	longitudinal cylindrical coordinate
α	transformation matrix
β^4	$3(1 - \nu^2)/(16)R^2T^2$
β_1^4	$3(1 - \nu_p^2)/(16)R^2T^2$
Δ	deflection

δ	element displacement vector
λ	coefficient in force formula
ν_1, ν_p	Poisson's ratio of shell and pipe
ϕ	rotation angle to locate grid point
ρ	distance to locate grid point
ρ_a	hole radius
ρ_o	pipe mid radius
ρ_p	pad outside radius
σ_m	membrane stress
$\sigma_x, \sigma_y, \tau_{xy}$	stresses in plate element
θ	rotational cylindrical coordinate
Σ	summation symbol

CHAPTER I

INTRODUCTION

1.1 Statement of the Problem

In a cylindrical shell weakened by a hole, the stress distribution caused by an internal pressure load applied to the shell will differ considerably from that in an unweakened shell. The maximum stress will be much larger if there is a circular hole in the shell than in the case where there is no penetration. This conjecture is suggested immediately by the case of a flat plate weakened by a hole with the plate stretched per unit length in one direction and with one-half of this stretch per unit length in the other direction. The maximum stress is 2.5 times the maximum stress in the solid plate. This factor (2.5) is known as the stress concentration factor (SCF). There is no reason to expect that the SCF is 2.5 for the shell. It depends on the geometry of the shell and the penetration: the curvature parameter of the shell, $\frac{\rho_a^2}{RT}$ (ρ_a being the radius of the hole, which is a circle in the projected shell surface, R is the radius of the middle surface of the cylinder, and T, the shell wall thickness); the ratio of the diameter of the hole or pipe to the radius of the shell; and the ratio of the thickness of the pipe to that of the shell.(1) The most important feature of the stress state in the shell near the hole is that bending stresses occur, whereas in the unweakened shell only membrane stresses ($\frac{PR}{T}$ and $\frac{PR}{2T}$) are present.

The loaded hole boundary condition in a pressurized cylindrical shell with a membrane or diaphragm over the hole to contain pressure only has been investigated by many authors.(1,2,3,4,5,6) Another type of loaded hole boundary is the perpendicular intersection of two cylinders - shell and pipe. There are a few isolated numerical solutions (7,8,9,10) and some theoretical investigations. (1,2,11,12) There are many experimental results for both thin and thick shells containing nonreinforced penetrations (pipe only) (13 through 21) and very few for reinforced penetrations - pipe and pad (14,15,17,22,24) and pipe and pads. (23,24)

Also, the ASME Pressure Vessel Code(25) requires in a stress or fatigue analysis the stress concentration factor (SCF) to be not less than 3.3 for a "<u>well designed penetration</u>" in a cylindrical shell unless positive evidence is available to the contrary. This evidence usually means a separate analysis to confirm the peak SCF. This factor is primarily needed to obtain peak stresses to perform a fatigue analysis to predict the remaining life at a penetration in the shell or to assure that the peak stress around a penetration does not exceed allowable stresses. The need for a more refined and/or a more clearly defined stress concentration factor became apparent in validating the useful life of 91 penetrations in a cylindrical shell(38) located in a work/residential area of NASA - Langley Research Center. These penetrations in the shell range in size from 1-inch to 60-inches in diameter. There are a few formulas in the published literature(2,4,26,27) for a membrane over the hole or a very thin penetration (pipe), but none are applicable for reinforced penetrations in pressurized cylindrical shells.

The author and others were unsuccessful in obtaining any computer answers to an analytical finite element approach to the actual intersection curve of the shell, pipe, and pads boundaries. The compatibility equations for this actual curve, rather than a projected circular curve (uncovered during this study), were not acceptable to the computer program. Also, different coordinate systems for the shell and pipe input descriptions, solution vectors, and output notations were unsuccessful. Therefore, it was decided to abandon the analytical work and to magnetic particle examine and/or rework these penetrations rather than perform the analyses to obtain the refined stress concentration factors. This type of verification (field work in lieu of analysis) is not practical in all cases since this shell which contains 91 penetrations is one of 1,600 pressure vessels (6000 pressure components) for which the structural integrity must be verified or validated in a five-year program at NASA - Langley Research Center. Thus, there is a need for a positive and clear definition of a well designed penetration to allow use of the 3.3 SCF or to obtain the appropriate SCF. A "proven" formula to approximate the peak SCF and/or a finite element program to obtain a refined SCF would be invaluable in validating shells, pipes and/or pad(s) configurations.

1.2 Object and Scope

The objective of this study is to determine the effect on stresses in a cylindrical shell with a circular penetration subject to internal pressure. The research is limited to thin, shallow, linearly elastic cylindrical shells; however, some comparisons are made to thick shell experimental measurements. Results from this study provide numerical predictions of the peak stresses around nonreinforced and reinforced penetrations in cylindrical shells. Analytical results are correlated with published formulas, theoretical and experimental results.

The present research also investigates the convergence and accuracy of different finite elements and mesh sizes. Finally, an approximate formula is developed to predict the peak stress concentration factor for analysis and/or design in conjunction with the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1 and 2.(25) The formula is rationally derived to include all of the parameters that are required to define the penetrations used in pressure vessel technology. The accuracy of the empirical formula is determined by comparing to numerical, theoretical, and experimental data. Since limited data is available for reinforced penetrations, many different configurations are pursued to supplement the published data to provide the restrictions to the formula. These configurations are modeled utilizing finite elements where compatibility between the cylindrical shell and the pipe/pad(s) are introduced through enforced constraint equations. The configurations investigated are for force and/or pipe around both nonreinforced and reinforced circular penetrations in cylindrical shells subject to internal pressure. For the force case, the penetration is considered to be covered by a diaphragm or membrane that allows the hole edge to deflect and rotate. It also transmits the pressure force to the shell in the form of a uniform transverse shear stress at the hole edge. An automation computer program which punches cards for these configurations for input to a finite element computer program (NASA STRUCTURAL ANALYSIS PROGRAM - NASTRAN(28)) is utilized.

CHAPTER II

ANALYSIS

2.1 Matrix Analysis by Finite Element Methods

In the finite element method, it is necessary to obtain a characterization of the stiffness properties of each element in the structure and to relate end nodal displacements to the corresponding forces. This is expressed in the following form:

$$[K]\{u\} = \{F\} \qquad (1)$$

where: $[K]$ is the stiffness matrix

$\{u\}$ is the displacement vector

$\{F\}$ is the force vector

The process for generating a computer program of any structure that is composed of many finite elements is to first pick a set of local coordinates convenient for a typical element. The generalized element displacements are $\{\delta\}$ and forces are $\{F\}$. The displacements $\{\delta\}$ and stiffness matrix $[K]$ are partitioned corresponding to ends i and j:

$$\begin{bmatrix} K_{ii} & K_{ij} \\ K_{ji} & K_{jj} \end{bmatrix} \begin{Bmatrix} \delta_i \\ \delta_j \end{Bmatrix} = \begin{Bmatrix} F_i \\ F_j \end{Bmatrix} \qquad (2)$$

In the process of connecting elements, it is found that one element's local coordinates are not the same as those for another element. Therefore, a set of system coordinates is chosen that is convenient for a system of elements and the local coordinate points are numbered (points 1, 2, 3, ...).

A systematic numbering process for the node points and members is chosen. The stiffness K_{ij} for each element is calculated in local coordinates where i and j refer to the end points of each element.

If the system coordinates or displacements are called $\{u\}$, the transformation from an element's coordinates to a system's coordinates is accomplished by a transformation matrix, $[\alpha]$. That is:

$$\{\delta\} = [\alpha] \{u\} \tag{3}$$

The stiffness of the element is transformed to system coordinates by use of Equations (3), (2), and (1).

$$[\bar{K}] = [\alpha]^T [K] [\alpha] \tag{4}$$

Consider several elements that are connected. The next step is to generate the master stiffness matrix $[K_{ij}]_M$ by summing all member stiffnesses in system coordinates.(29)

The compatibility equations for required coordinate points are introduced through multipoint constraint (MPC) equations of the form:

$$\Sigma A_j u_j = 0 \tag{5}$$

where: A is the coefficient

u is the point

j is the degree of freedom

Thus, the stiffness matrix, force, and displacement vectors are modified by this degree of freedom link for each MPC Equation (5) at each grid point.(30)

After the compatibility equations are satisfied, the boundary conditions (displacements of the structure) are enforced through single-point constraints (SPC). Finally, the system applied external forces {F} are identified and the equation:

$$[K]_R \{u\}_R = \{F\}_R \tag{6}$$

is solved.

2.2 Formulation of the Problem

Consider a flat rectangular plate of thickness T containing a circular hole of radius ρ_a with its edges parallel to axes Y', Z' of the circular hole. A material point or finite element grid point within the plate may be located through cylindrical coordinates (ρ, ϕ, X) defined through

$$Y' = \rho \sin \phi, \; Z' = \rho \cos \phi \tag{7}$$

Suppose that the plane Y' Z' is now rolled into a circular cylindrical shell in such a way that the Z'-axis becomes a generator of the cylinder and Y' a circular arc denoted by Y (see Figure 2.2.1). If R is the radius of the middle surface of the shell and θ the angle in any normal cross section of the cylinder measured from the $Y=0$ plane in the positive direction of the Y-axis, then the following relationships are obtained to define the finite elements and grid points (see Figure 2.2.2):

$$\begin{aligned} Y' &= Y = R\theta \\ R &= R \\ \theta &= \text{Arc sin } \left(\frac{\rho \sin \phi}{R} \right) \\ Z' &= Z = \rho \cos \phi \end{aligned} \tag{8}$$

Consider that this same configuration - main (lower) shell (shown in Figure 2.2.1) with mid-surface radius R - is intersected by a branch (upper) shell with mid-surface radius ρ_0 and thickness t, ($\rho_0 = \rho_a + t/2$), see Figure 2.2.3. The axis of the branch shell is normal to the axis of the main shell. Both shells are considered to be infinite in length and capped at their ends. Finally, consider that these two circular cylindrical

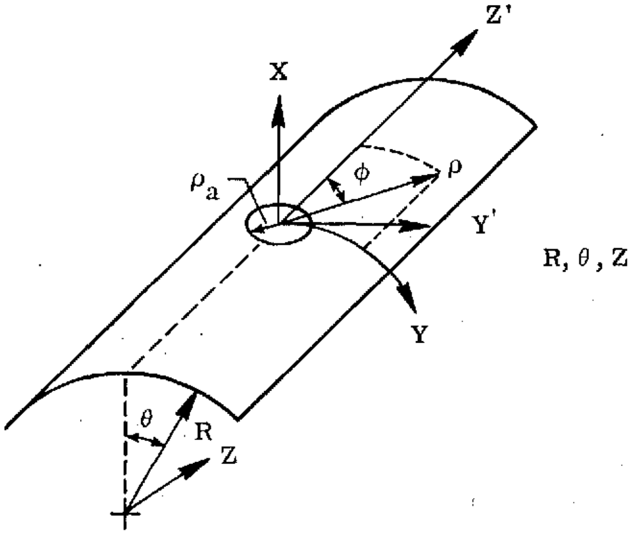
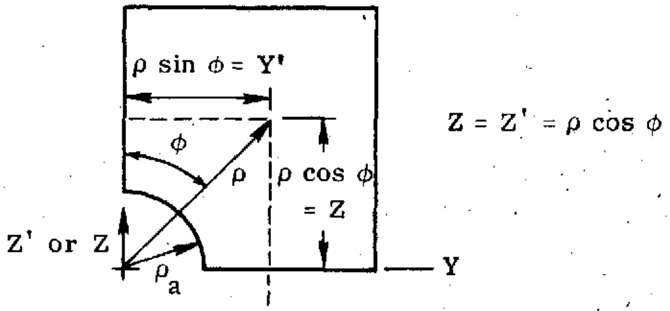
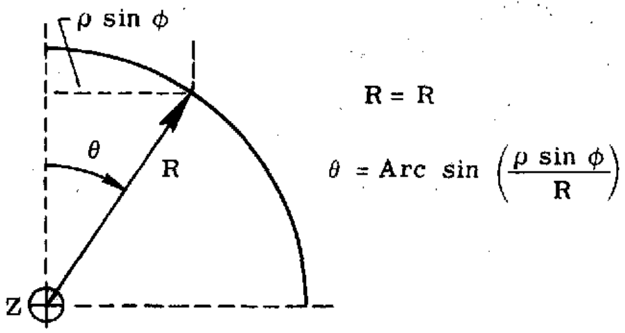


Figure 2.2.1.- Coordinate system for a cylindrical shell with hole.



(a) Plan view



(b) Elevation view

Figure 2.2.2.- Relationships used to define finite elements.

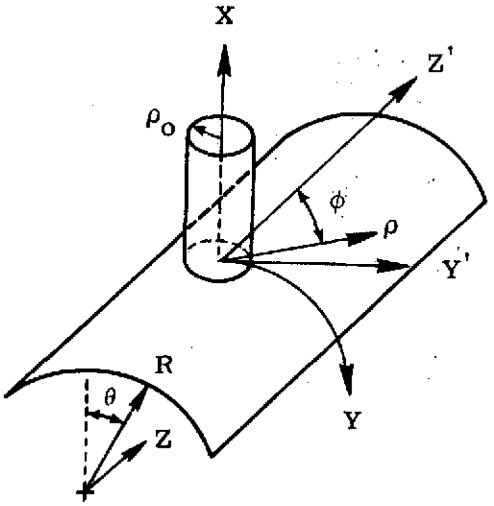


Figure 2.2.3.- Intersecting circular cylinders (pipe and shell).

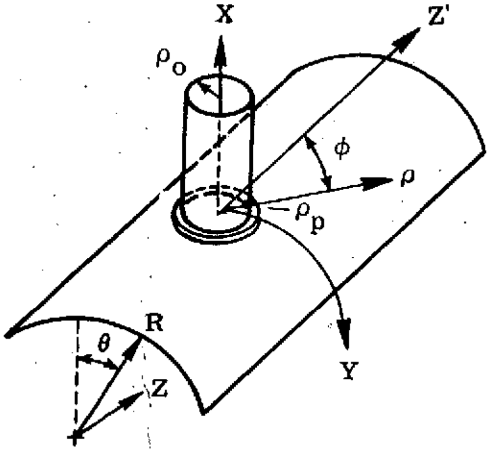


Figure 2.2.4.- Intersecting circular cylinders with reinforcing pad(s).

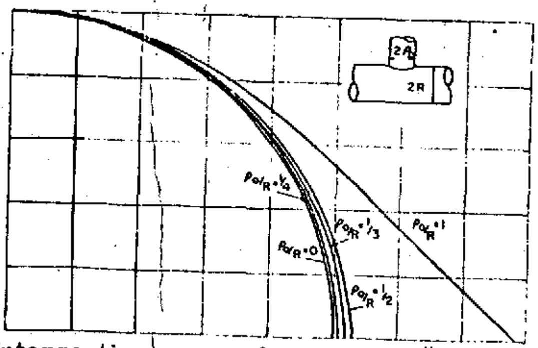


Figure 2.3.1.- Intersection curve of small cylinder with large cylinder when rolled out flat for various values of ρ_o/R.

shells with mid-surface radii ρ_o and R are complicated by the addition of one or two reinforcing pads with outside radius ρ_p and thickness t_p (see Figure 2.2.4). The location of the finite elements through grid points for a projected circular hole in a cylindrical shell with a pipe and pad(s) is governed by Equations (8).

2.3 Introduction of Compatibility Equations

The solution of these problems requires the matching of certain physical quantities (compatibility equations) along the intersection curve of the two shells and pad(s). When expressed in the cylindrical coordinate system, the intersection curve is of a very complex nature. Due to the difficulty of solving boundary value problems in which the boundaries are not situated on constant coordinate curves, the intersection curve can be approximated by ρ_a, ρ_o, and ρ_p equal to some constants, whenever ρ_o/R is small. Figure 2.3.1, indicates the error involved in this approximation when the lower shell surface is developed onto a plane.(11) It can be seen that the actual intersection curve does not differ appreciably from a circle, providing

$$\frac{\rho_o}{R} \leq 1/2 \quad . \tag{9}$$

Therefore, the actual hole boundary is assumed to be circular, identical to that of a projected view of the penetration.

The compatibility equations for a pipe and shell configuration (Figure 2.2.3) are introduced through MPC Equations (5). The six equations for each grid point for both the shell and the pipe at the pipe and shell juncture at ρ_o are as follows (Δ is deflection and θ is rotation):

$$
\begin{aligned}
&\Delta_R^{pipe} - \Delta_R^{shell} = 0 \\
&\Delta_\theta^{pipe} - \Delta_\theta^{shell} - \frac{T}{2}\,\theta_Z^{shell} = 0 \\
&\Delta_Z^{pipe} - \Delta_Z^{shell} - \frac{T}{2}\,(-\,\theta_\theta^{shell}) = 0 \\
&\theta_R^{pipe} - \theta_R^{shell} = 0 \\
&\theta_\theta^{pipe} - \theta_\theta^{shell} = 0 \\
&\theta_Z^{pipe} - \theta_Z^{shell} = 0
\end{aligned}
\tag{10}
$$

where the subscript is the degree of freedom of the grid point. For the finite element analysis, the independent degrees of freedom are those for the shell, and the dependent degrees of freedom are those for the pipe. The superscript in Equations (10) denotes whether the degree of freedom represents the pipe or shell.

The compatibility equations for a "pipe-shell-inner pad" configuration (Figure 2.2.4) are as follows:

1. Pipe-to-shell juncture (ρ_o): Equations (10)
2. Inner pad (ip) to shell junctures for each grid point at both ρ_a and ρ_p:

$$
\begin{aligned}
&\Delta_R^{ip} - \Delta_R^{shell} = 0 \\
&\Delta_\theta^{ip} - \Delta_\theta^{shell} - \frac{(T+t_{ip})}{2}(-\theta_Z^{shell}) = 0 \\
&\Delta_Z^{ip} - \Delta_Z^{shell} - \frac{(T+t_{ip})}{2}\,\theta_\theta^{shell} = 0 \\
&\theta_R^{ip} - \theta_R^{shell} = 0 \\
&\theta_\theta^{ip} - \theta_\theta^{shell} = 0 \\
&\theta_Z^{ip} - \theta_Z^{shell} = 0
\end{aligned}
\tag{11}
$$

The compatibility equations for a "pipe-shell-outer pad(op)" configuration for each grid point at locations ρ_o for the pipe and ρ_a and ρ_p for outer pad are as follows:

$$
\begin{aligned}
&\Delta_R^{pipe} - \Delta_R^{shell} = 0 \\
&\Delta_\theta^{pipe} - \Delta_\theta^{shell} - (\frac{T}{2} + t_{op})\,\theta_Z^{shell} = 0 \\
&\Delta_Z^{pipe} - \Delta_Z^{shell} + (\frac{T}{2} + t_{op})\,\theta_\theta^{shell} = 0
\end{aligned}
\tag{12a}
$$

$$\theta_R^{pipe} - \theta_R^{shell} = 0$$

$$\theta_\theta^{pipe} - \theta_\theta^{shell} = 0 \qquad (12a)$$

$$\theta_Z^{pipe} - \theta_Z^{shell} = 0$$

$$\Delta_R^{op} - \Delta_R^{shell} = 0$$

$$\Delta_\theta^{op} - \Delta_\theta^{shell} - (\frac{T+t_{op}}{2})\ \theta_Z^{shell} = 0$$

$$\Delta_Z^{op} - \Delta_Z^{shell} + (\frac{T+t_{op}}{2})\ \theta_\theta^{shell} = 0 \qquad (12b)$$

$$\theta_R^{op} - \theta_R^{shell} = 0$$

$$\theta_\theta^{op} - \theta_\theta^{shell} = 0$$

$$\theta_Z^{op} - \theta_Z^{shell} = 0$$

The compatibility equations for a "pipe-shell-outer and inner pads" configuration are identical to Equations (11) and (12). Each of these equations is provided as enforced constraints to every shell, pipe, and pad(s) connecting grid point.

2.4 Structural Analysis Computer Program

The finite element method is a modern, computer-oriented approach to the analysis of structures. One of its principal advantages is its complete generality. This versatility makes it possible to consider arbitrary geometries, support conditions, loadings, and variations of material properties within the structures. The principal limitation is the cost of operation. The cost is incurred both in the time required to prepare the input data describing the finite idealization of the structure and its loading, and in the computer time required to obtain the solution. The process for generating the complete finite element computer program is described in Chapter II, Section 2.1.

The finite element computer program utilized in this study is the latest NASA STRUCTURAL ANALYSIS (NASTRAN) version - level 15.5.1. Structural elements are provided for specific representation of more common types of construction including rods, beams, shear panels, and plates. The range of analyses that can be solved include static, elastic stability, and dynamic structural problems. NASTRAN has been specifically designed to treat large problems with many degrees of freedom. Computation procedures in NASTRAN were selected to provide the maximum obtainable efficiency for large problems. NASTRAN uses a finite element model, wherein the distributed physical properties of a structure are represented by the elements interconnecting at the grid points. Loads are applied either at grid points or on the elements for which displacements are calculated.(30)

The system displacements {u} in Equations (1), (3), (5), and (6) locate individual grid or node points which schematically represent the structure. The structure is approximated by connecting these grid points with the proper elements (rods, bars, beams, and plates) which best describe the individual shapes and the overall configuration to be analyzed. In the process of connecting the elements to the grids, material and geometrical properties (areas, moments of inertia, modulus of elasticity, Poisson's ratio) for each element can be identified. By organizing all of the grids, elements, and properties in the form acceptable to NASTRAN, or other general purpose finite element computer programs, the stiffness matrix [K] in Equations (1), (2), (4) and (6) can be generated in the computation process. The loads {F} that apply to each element and/or discrete grid points can be identified, and the cards generated.

Triangular and quadrilateral elements with both inplane and bending stiffness are used in this study. The NASTRAN (level 15) numerical results were calculated using Langley Research Center's CDC-6000 series computers. Also, HP-9810 programmable desk top calculator was used to assist in interpreting the data and to automate the empirical formula developed. The approximate number of degrees of freedom required to model the different configurations in this study are as follows: shell, 1500; pipe, 300; and pad, 300. Once the displacements {u}, Equation (6), are determined, internal element stresses are obtained. Finally, inside and outside surface stresses for each element in the structure are computed by NASTRAN from these internal stresses (membrane stress ± bending stress). A shell, pipe, and two pad configuration (modeled with 2400 degrees of freedom) is presented in Appendix A.

With regard to the cost of preparing the finite element program input data previously described, it is quite likely that this will exceed the cost of the computer operation in most cases. In any numerical computer method, the characterization process of a structure can be tedious and time-consuming. A major part of the cost of data preparation is spent in eliminating errors in the extensive tables of numbers required to describe the idealization. The extent of the input process can only be minimized by the use of automation. In order that the finite element method may be used effectively as a research, analysis, or design tool, it is essential that automatic mesh generation programs be developed which will define the idealizations of arbitrary shell geometries. Of similar importance to the practical use of such programs is automatic plotting to present the configuration and results in a readily usable format.

A computer program to "automatically" punch input cards in the format acceptable to NASTRAN was developed. This program generates the input for shell, pipe, and pads: grid, element, load, compatibility, and boundary condition cards. The cards punched from this program are input to NASTRAN for solving the inside and outside surface element stresses. Many configurations were solved (presented in Chapter V) in order to obtain trend data and comparative results. As a spin-off of the NASTRAN program, plots can be obtained for pictorial or presentation purposes and as a debugging tool. Sample plots are shown in Figures 2.4.1, 2.4.2, and 2.4.3.

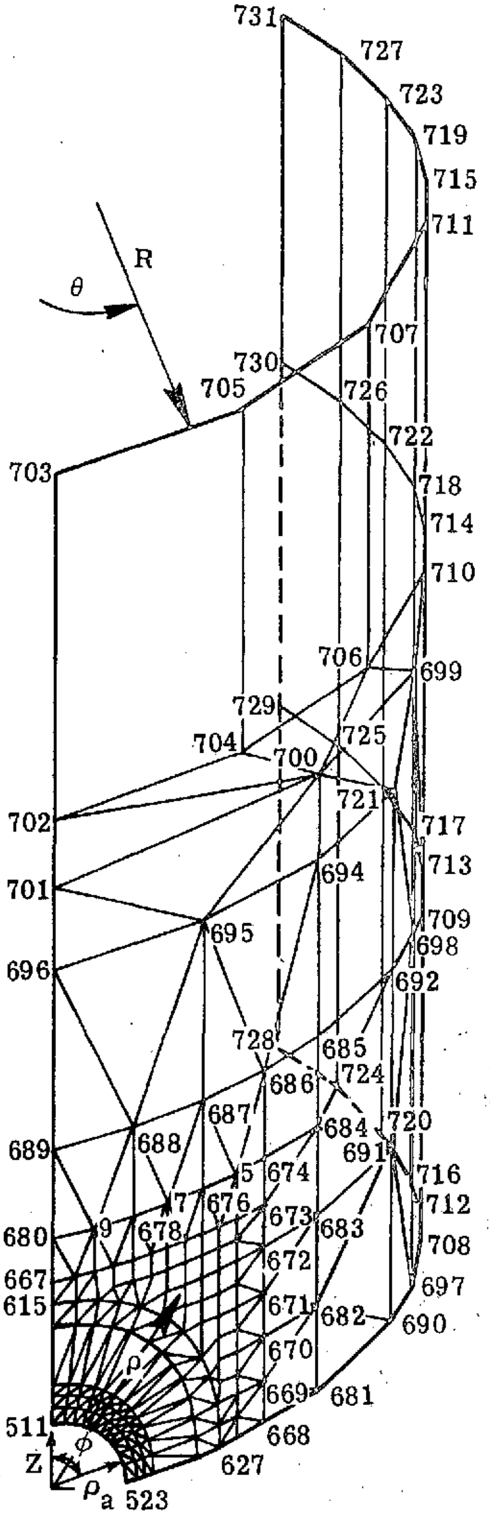


Figure 2.4.1.- Nonreinforced hole in cylindrical shell.

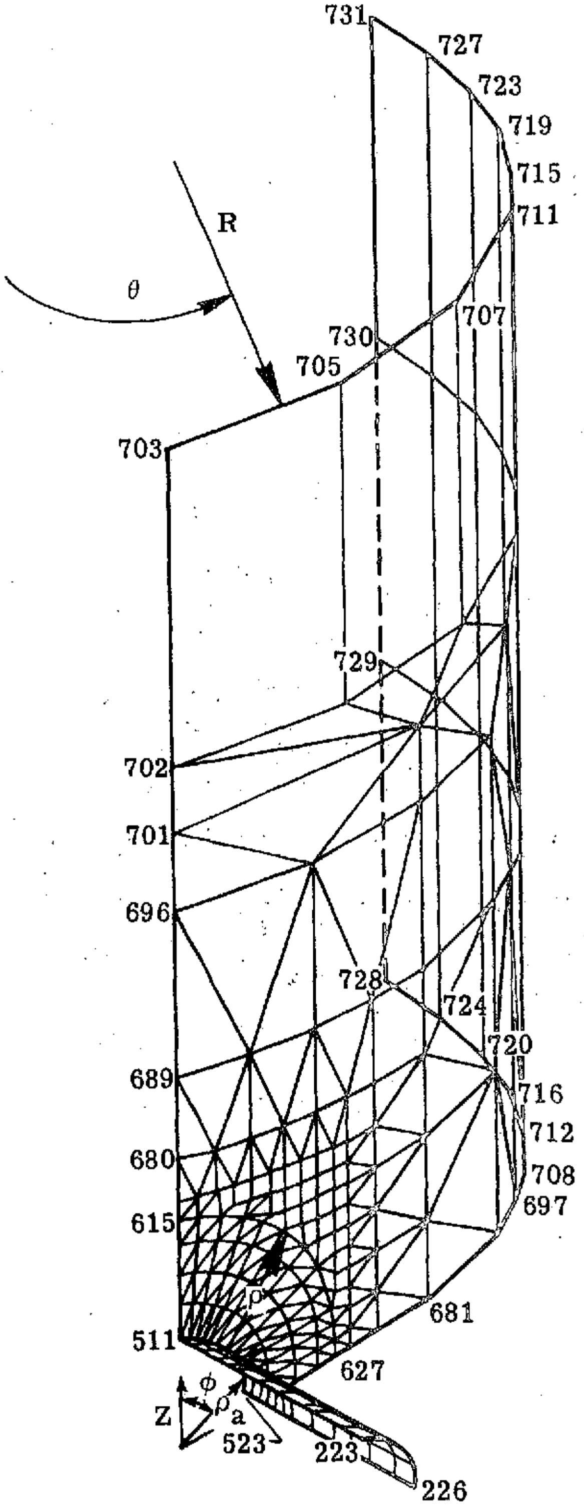


Figure 2.4.2.- Nonreinforced hole in cylindrical shells.

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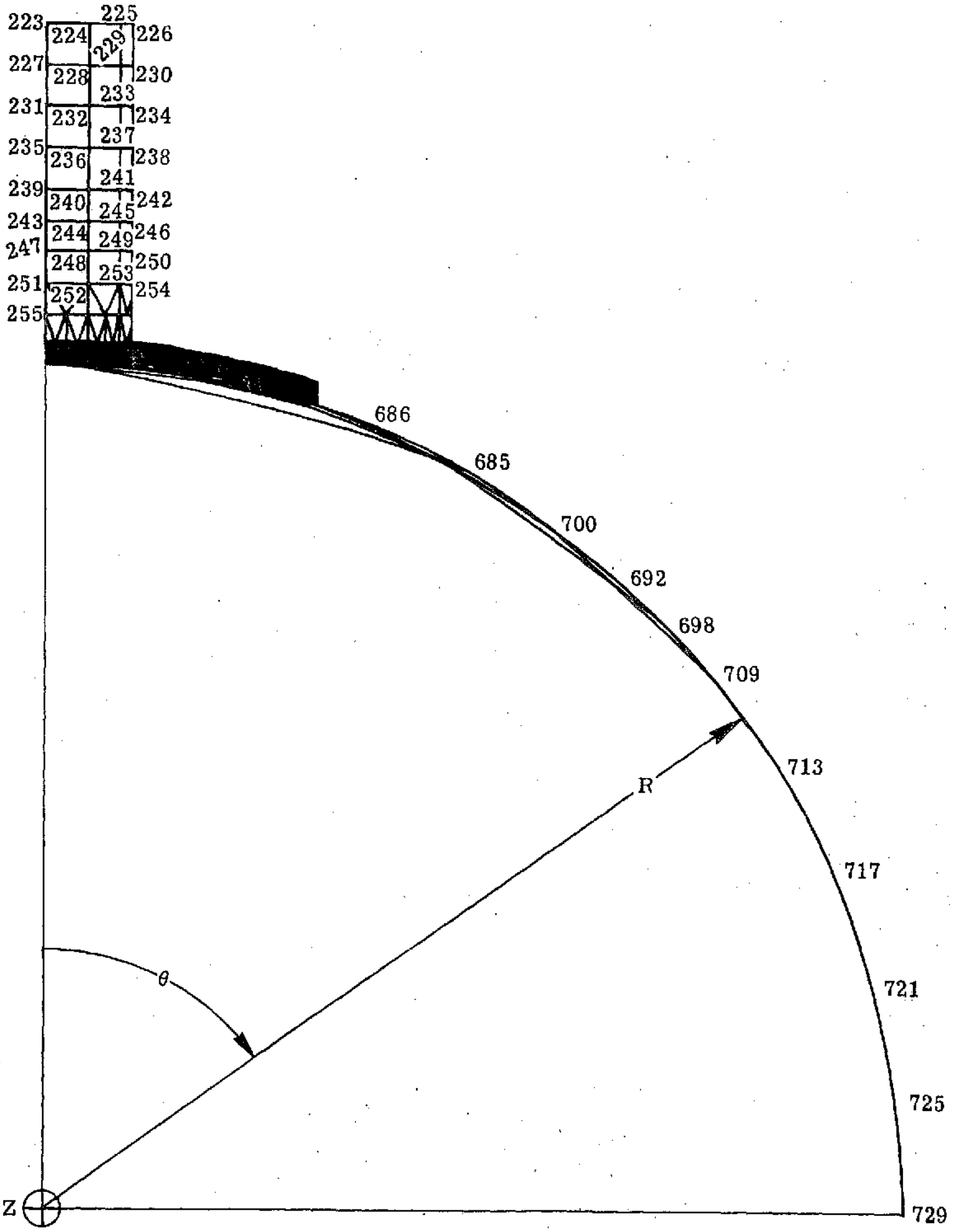

Figure 2.4.3.- Pipe and bottom pad reinforced hole in cylindrical shell.

CHAPTER III

ACCURACY STUDY

3.1 Introduction

In the finite element analysis of any structure, a first requirement is the idealization of the structure. For example, a shell surface (shown in Figure 3.1.1) is divided into a system of appropriately shaped pieces. The individual pieces must be standardized as simple shapes such as triangles, rectangles, or quadrilaterals in order that their stiffness properties may be defined. This requirement imposes a certain degree of approximation in idealizing the geometry of shells: a curved boundary will usually be represented as a series of straight line segments. In general, this boundary approximation is not severe, and it can be reduced to any desired error limit by reducing the size of the elements.

The most important approximation is in the shell behavior assumption itself. If the shell is treated as a two-dimensional surface rather than as a three-dimensional solid, this implies certain assumptions and limitations. For example, in the Kirchhoff theory, it is assumed that stresses in the direction normal to the shell surface are small compared to membrane stresses, and lines normal to the surface are assumed to remain normal and unstrained

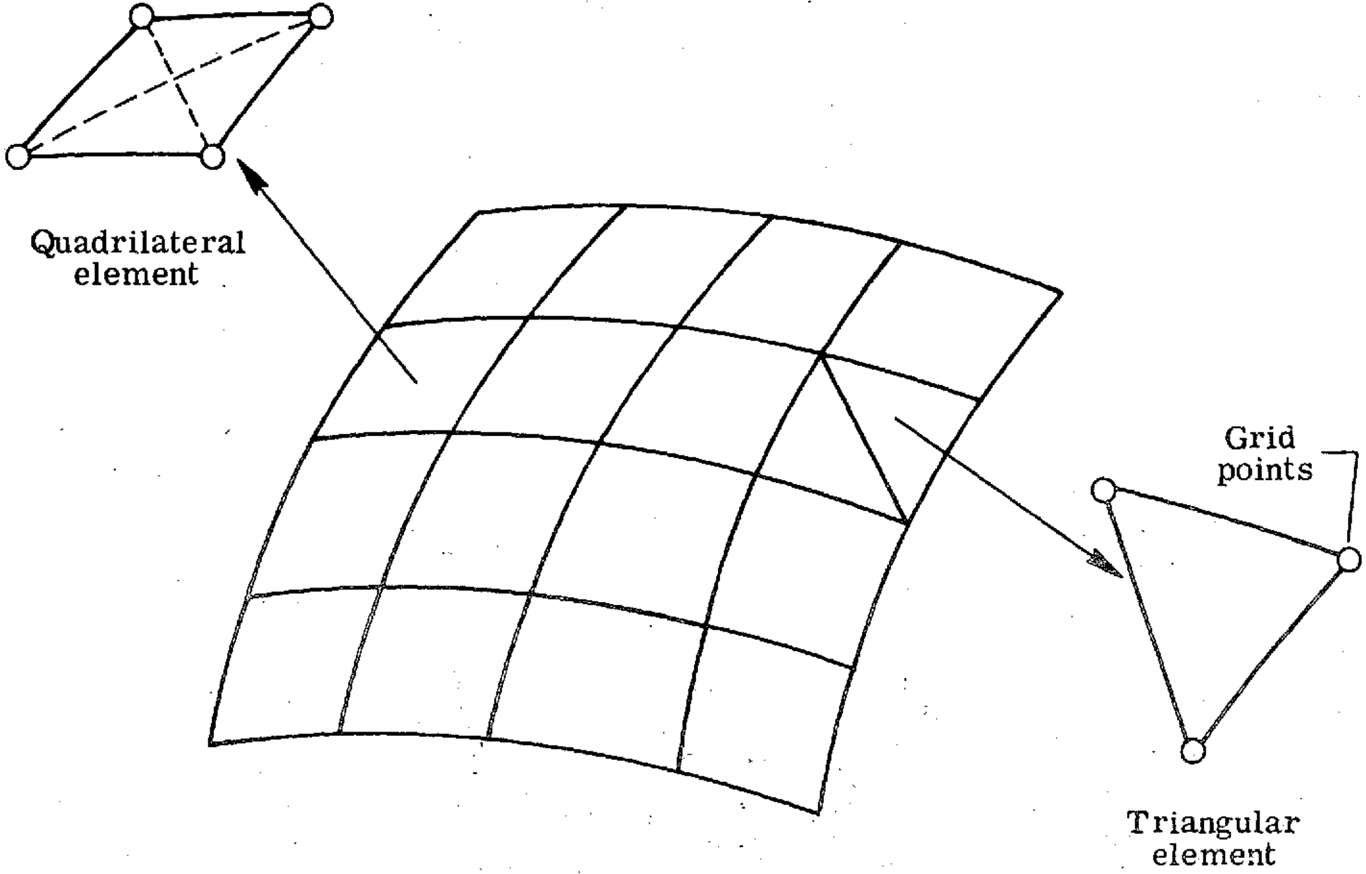

Figure 3.1.1.- Discretized shell.

during deformation. Approximations of this type are not a special feature of the finite element solution but are inherent in any shell theory. Another common approximation, in addition to the straight line segment representation of boundaries, is that the elements connecting grid points are flat surfaces or a group of several flat surfaces. The great advantage of this assumption is that the membrane and bending stiffness properties of the individual flat plates are uncoupled. The coupling, which is characteristic of shell behavior, is developed only in the assemblage of the flat plates into an approximation of the curved shell surface.(31)

3.2 Types of Finite Elements

The nature of the finite element approximation is such that the analytical results generally converge toward the true solution as the finite element mesh size is refined. Other factors in the convergence criteria are the number of grid points specified for each element, type of elements, and primarily, the number of degrees of freedom (DOF) at each grid. The Kirchhoff theory takes account of five DOF (3 translations and 2 rotations about axes tangent to the shell surface). Most shell elements make use of these same 5 DOF at each grid.

The finite elements employed in the discretized shell in Figure 3.1.1 are both planar triangles and quadrilaterals assembled from 4 planar triangles. The forces and stresses on these elements are shown in Figure 3.2.1(30) The membrane stiffness of the triangular element is represented by the well-known constant strain triangle and shown in Figure 3.2.2. The components of displacement, u and v, are parallel to the local coordinate system (element X and Y axes). The bending property based on cubic displacement patterns is given by a fully compatible plate bending element, a Clough bending triangle.(32) This triangle is formed by subdividing it into three basic bending triangles as shown in Figure 3.2.3. The X-axis of each sub-triangle corresponds with an exterior edge, so that continuity of slope and deflection with surrounding Clough triangles is assured. The added grid point in the center is like the other grid points in that equilibrium of forces and compatibility of displacements are required at the center point. In addition, the rotations parallel to the internal boundaries at their midpoints, points 5, 6 and 7, are <u>constrained</u> to be continuous across the boundaries. The equations for slopes in the basic triangles contain quadratic and lower order terms, and since the normal slopes along interior boundaries are constrained to be equal at three points (both ends and the middle), it follows that slope continuity is satisfied along the whole boundary. Displacement continuity on all

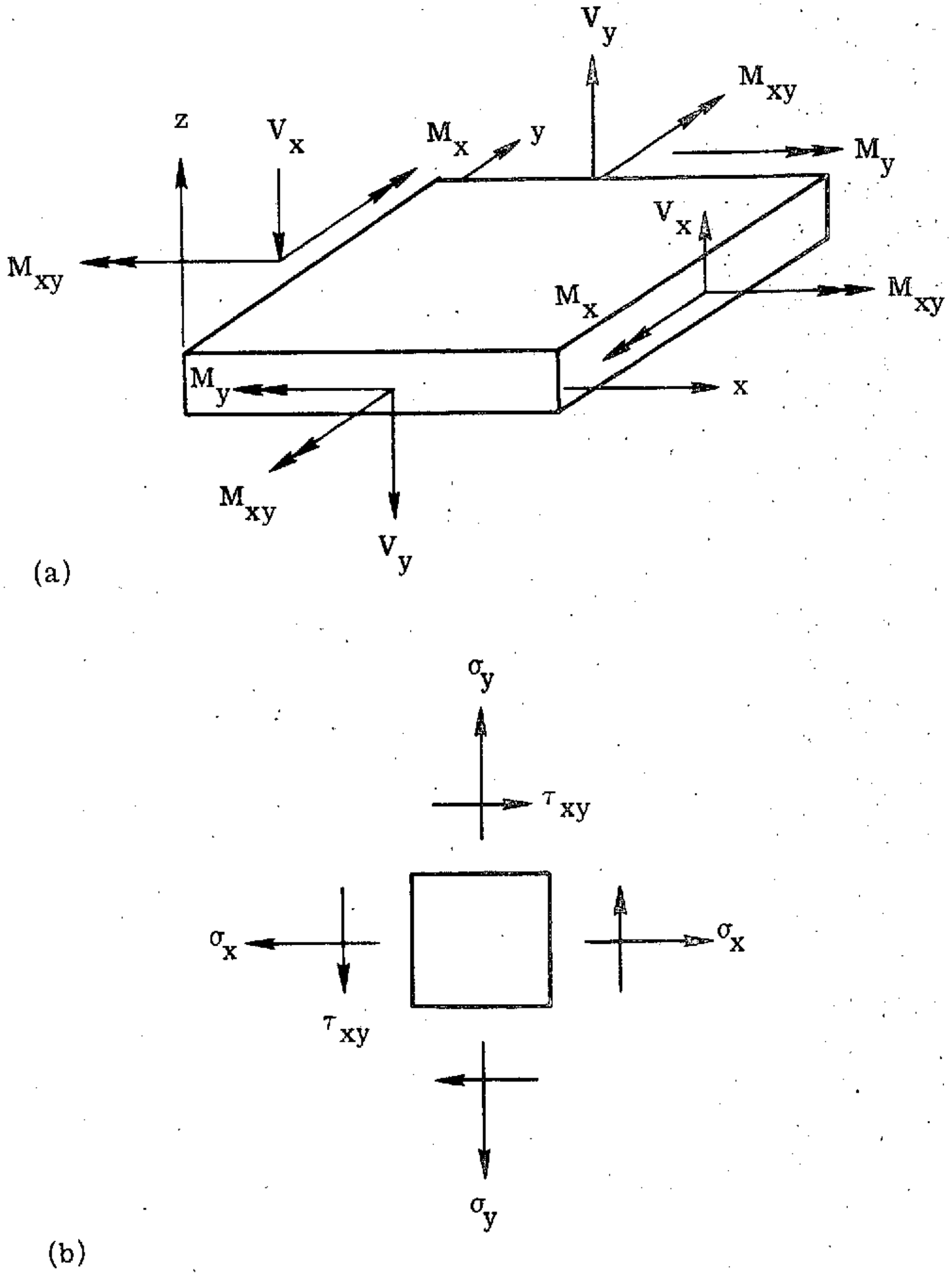

Figure 3.2.1.- Forces and stresses in plate elements.

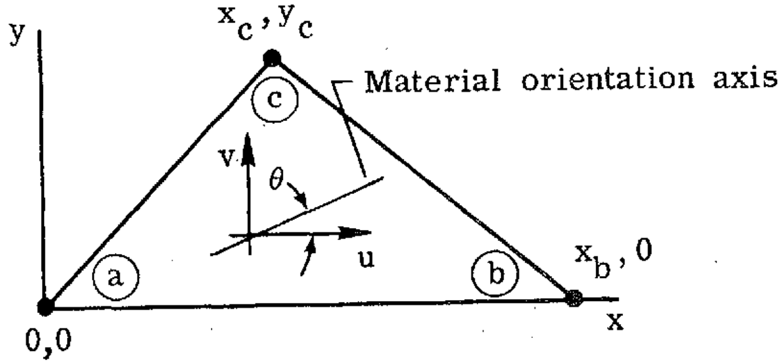

Figure 3.2.2.- Triangular membrane element.

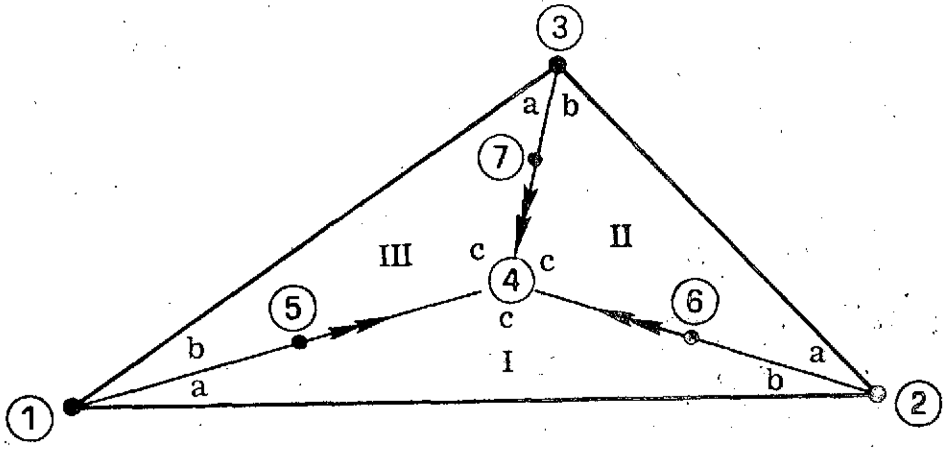

Figure 3.2.3.- Clough bending triangle.

boundaries is automatically satisfied when the displacement function contains only cubic and lower order terms. Thus, complete continuity of slope and displacement on all interior and exterior boundaries is assured for the Clough triangle.

The Clough triangle is superimposed with a membrane triangle to form triangular elements with both membrane and bending stiffness. Therefore, this triangular element has 5 DOF at each corner, 2 deriving from membrane displacements and 3 from the bending. The quadrilateral plate was developed to provide improved membrane strain behavior while retaining the basic 5 DOF per grid system. It is formed as 4 planar triangles as shown in Figure 3.2.4 plus 3.2.5, with the grids modeling the shell midsurface. Each triangle has one-half of the bending, stiffness or one-half of the thickness (membrane) assigned to the quadrilateral element. Since four points, in general, do not lie in a plane, care must be taken to ensure equilibrium and compatibility. Rather than try to define a warped surface, an averaging process is used on the noncoplanar membrane triangles. The bending element uses two sets of overlapping basic bending triangles. Since coupling between membrane stiffness and bending stiffness is not, at present, included in NASTRAN, quadrilateral elements with both membrane and bending properties are treated by simple superposition of their

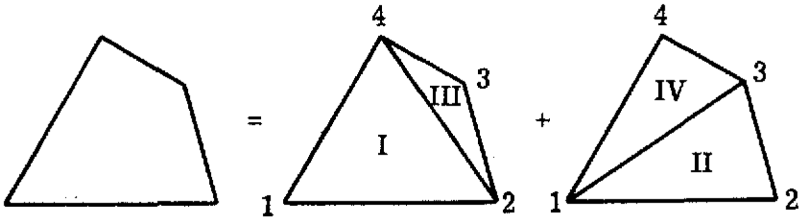

Figure 3.2.4.- Quadrilateral membrane element.

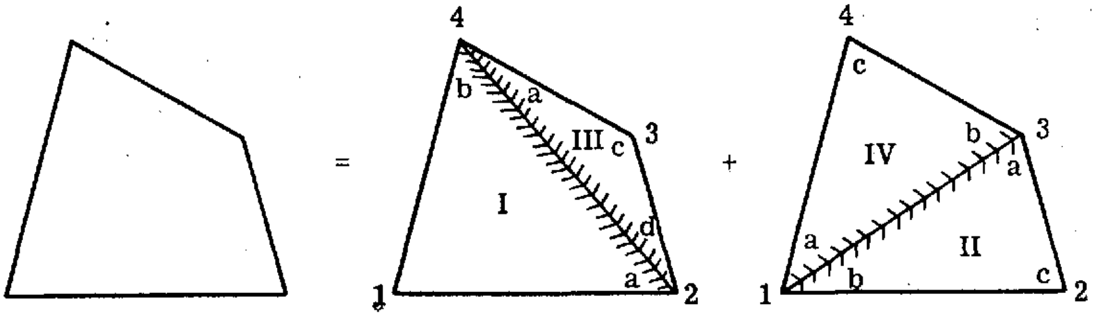

Figure 3.2.5.- Quadrilateral bending element.

membrane and bending stiffness matrices. The following NASTRAN elements are the ones used in this research:

1. TRIA 2 - The triangular element with both inplane and bending stiffness.
2. QUAD 2 - A quadrilateral element similar to TRIA 2.

3.3 Shell

In this section, consideration is given to the accuracy obtained with different mesh sizes and the two types of elements (TRIA 2 and QUAD 2) used to obtain the peak stress concentration factor for a pressurized cylindrical shell with a circular hole, Figure 2.2.1. A quarter of the shell is chosen as the model: shell radius, R; length, $\geq$ 2R; and the hole radius, ρ_a. A typical finite element model is shown in Figure 3.3.1. If the element size or general mesh geometry is too large at discontinuities (such as a penetration), the structure will be "too stiff". The finite element approximations to peak stress concentration factors will be below the correct answer. This model provides a gradual transition of large to small elements as the hole opening is approached. Since the "radial" section is the easiest to generate or modify, different mesh arrangements and elements will be used to compare the accuracy of peak stress concentration factors (SCF) to "exact" solutions.

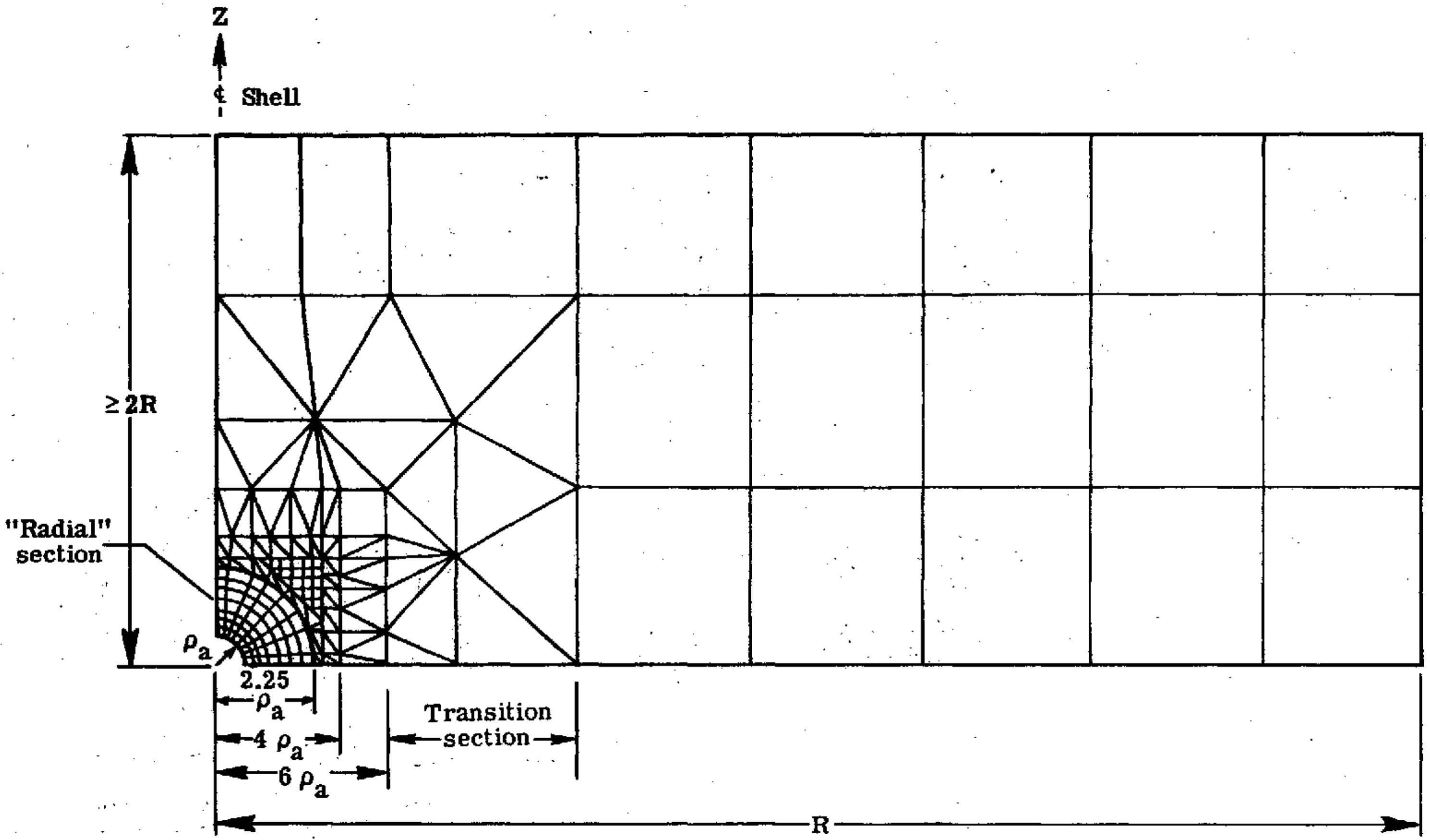

Figure 3.3.1.- Typical plan view of a finite element model of a cylindrical shell with a circular hole.

The rectangular arrangement of quadrilateral (RQ) elements of the "radial" section is shown to a larger scale in Figure 3.3.2. The right (RDT) and left (LDT) diagonal arrangements of triangular elements for the "radial" section are shown in Figures 3.3.3 and 3.3.4, respectively. A refined version (additional grid points) of left diagonal triangular (RLDT) elements is shown in Figure 3.3.5. The triangularizing of only the first element in the rectangular arrangement of quadrilateral (1TRQ) elements is shown in Figure 3.3.6. These code names for identifying the articulation arrangements are similar to those used by Melosh.(31) It should be noted that efforts were pursued in refining these configurations by grouping the same number of grid points very near the hole (see Figure 3.3.7) - all to no avail. Also, results for refining of the RLDT, regardless of the local transition, were in error. This idea of too much local refining is known.(31) When the elements were smaller than one-half of the shell thickness, the peak SCF oscillated about the "exact" solution.

A summary of the computer runs for peak stress concentration factors for a pressurized cylindrical shell with force around the hole is presented in Table 3.3.1. The units used in this table and throughout this study are in the English or American System (inches and pounds). The RQ radial section model approximates the peak inside SCF to within -11% (below) of the theoretical or "exact" solution obtained in Reference (3). The approximations for the triangular arrangements (RDT, 1TRQ, LDT) are converging to the theoretical solution without local refining (RLDT). Many authors have reported the mid-surface (average) SCF. (1,2,3) Since this is not the peak value, the largest SCF (inside) will be the gauge in the accuracy comparisons to determine the arrangement to use for all other shell/force problems. The LDT (which is much easier to generate) peak inside SCF is slightly more accurate (-1.05% difference) than the RLDT (+1.14% difference). Therefore, the LDT arrangement is the one chosen to obtain the peak SCF results for shell configurations with just a force around the hole.

Table 3.3.1 - Peak SCF For Finite Element Models For A Pressurized Cylindrical Shell With Force Around The Hole: ρ_a=13.0, R=112.0, ν=0.3.

RADIAL SECTION DESCRIPTION	T	Peak SCF @ $\phi = 0$ and ρ_a					
		INSIDE		OUTSIDE		AVG.	
		NASTRAN	% DIFF	NASTRAN	% DIFF	NASTRAN	% DIFF
RQ	1.25	4.997	-10.99	3.108	-16.83	4.053	-13.31
RDT	1.25	5.405	- 3.72	3.395	- 9.15	4.400	- 5.88
ITRQ	1.25	5.479	- 2.41	3.477	- 6.96	4.478	- 4.21
LDT	1.25	5.555	- 1.05	3.554	- 4.90	4.555	- 2.57
RLDT	1.25	5.678	+ 1.14	3.680	- 1.53	4.679	+ 0.09
		"EXACT" REF.(3)	5.614	"EXACT" REF.(3)	3.737	"EXACT" REFERENCES (1,2,3)	4.675

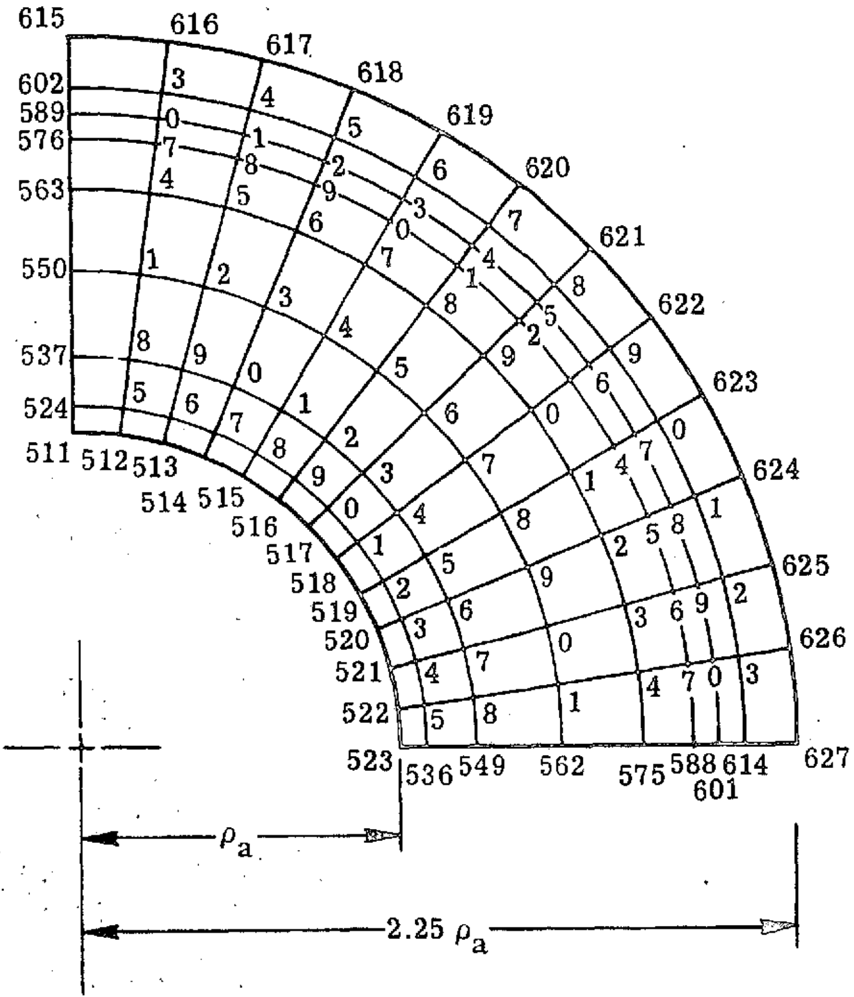

Figure 3.3.2.- Rectangular arrangement of quadrilateral (RQ) elements for "radial" section.

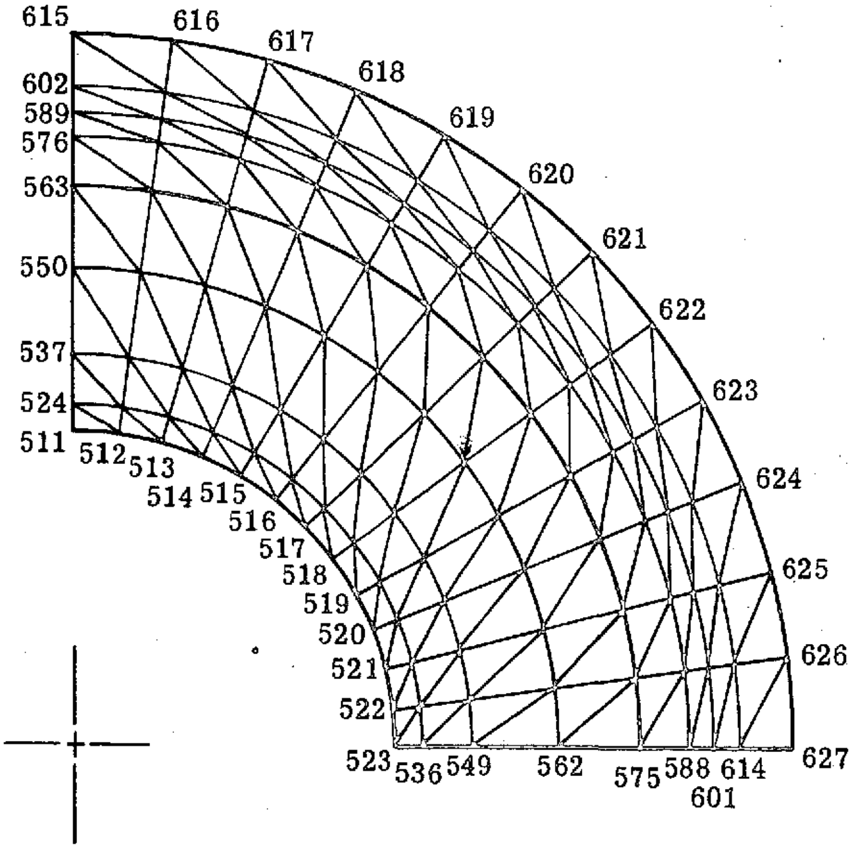

Figure 3.3.3.- Right diagonal arrangement of triangular (RDT) elements for "radial" section.

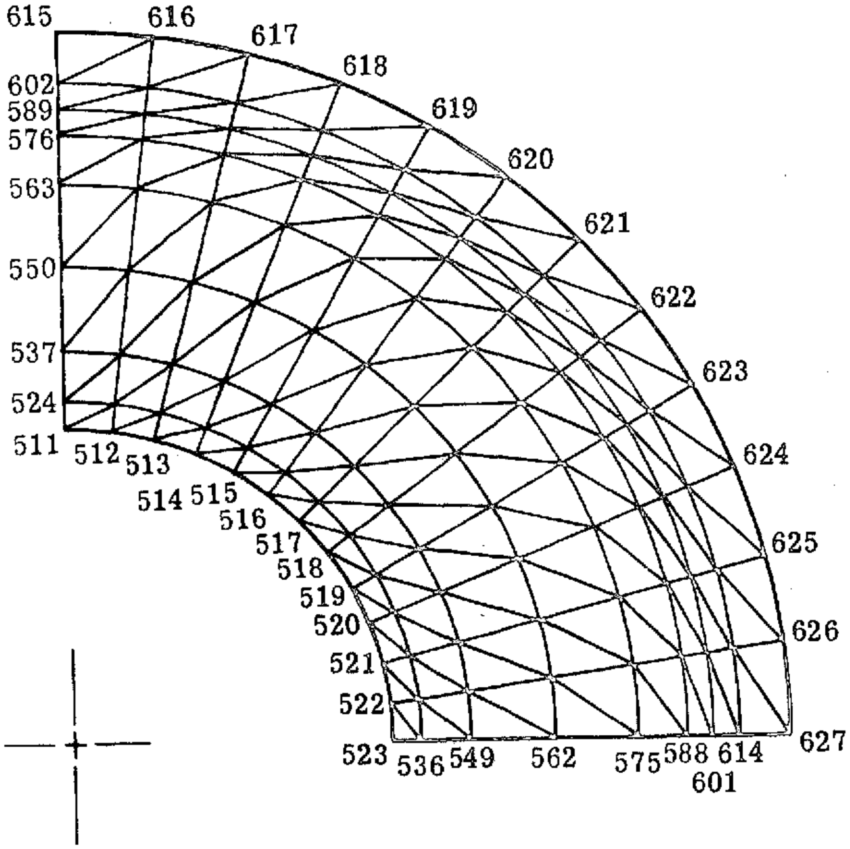

Figure 3.3.4.- Left diagonal arrangement of triangular (LDT) elements for "radial" section.

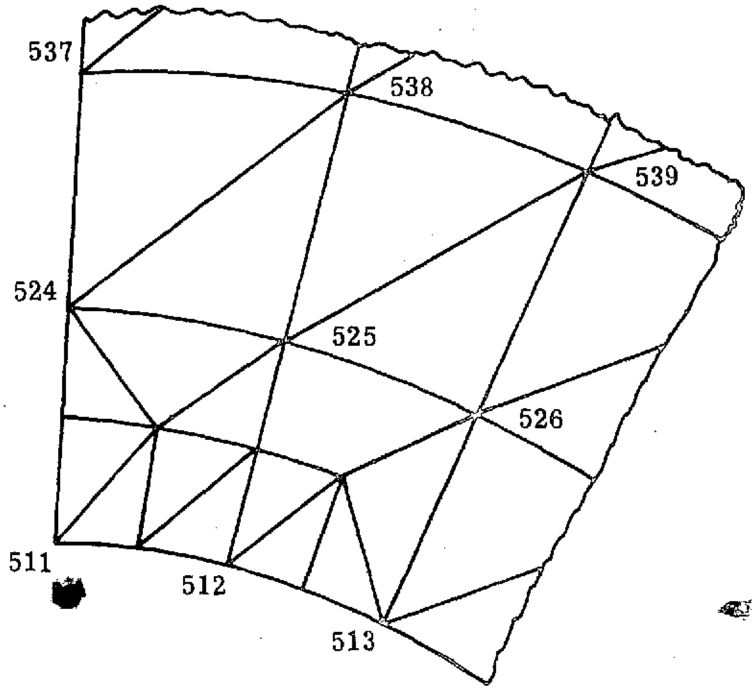

Figure 3.3.5.- Refined left diagonal arrangement of triangular (RLDT) elements.

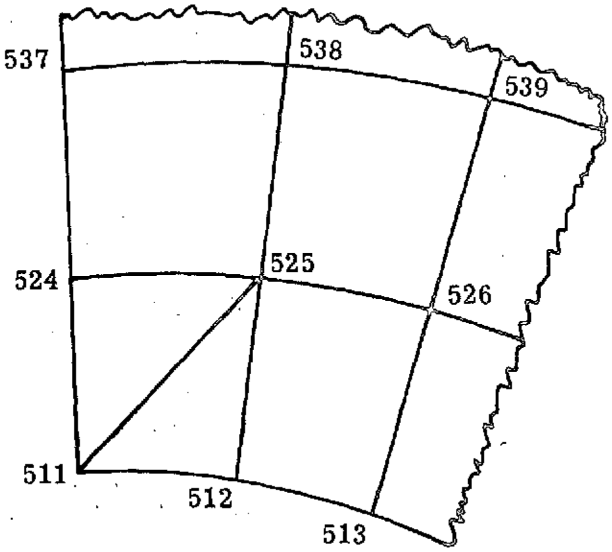

Figure 3.3.6.- First element triangularized in RQ arrangement (ITRQ).

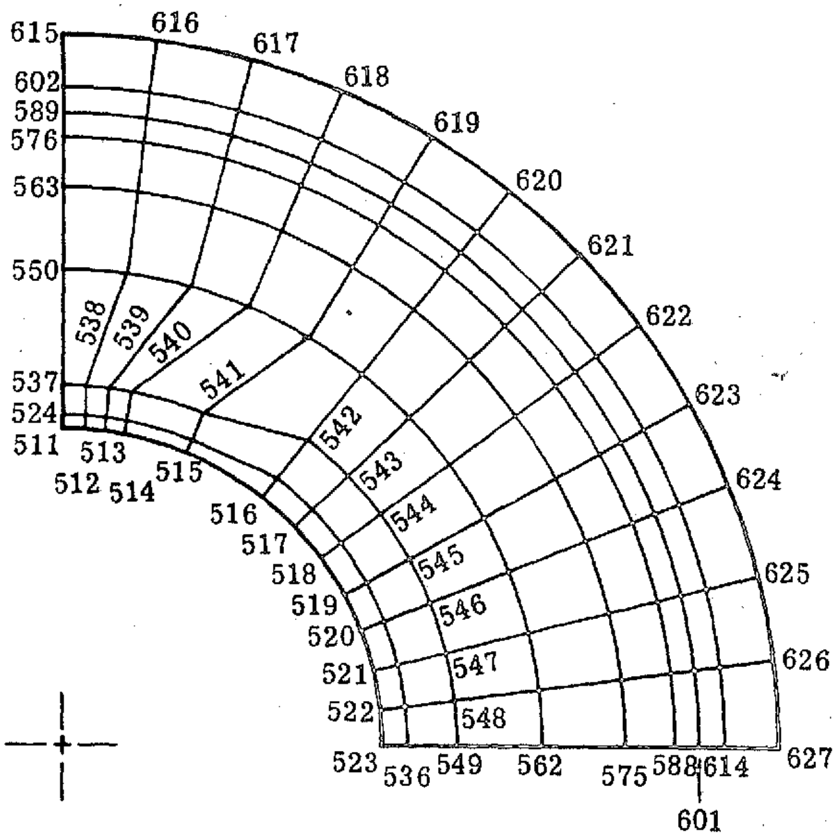

Figure 3.3.7.- Poor approach to refining of "radial" or pad(s) sections.

3.4 Shell and Pipe

The next configuration to be considered is two intersecting circular cylinders (shell and pipe) as shown in Figure 2.2.3. The same shell models in Section 3.3 are used; therefore, a quarter of the pipe is modeled: hole radius, ρ_a; pipe radius, ρ_o; pipe thickness, t; pipe length, $\geq 2\ \rho_a$, and all of the shell parameters previously described. Typical finite element models for a pipe are arranged and shown as follows: rectangular quadrilateral (RQ), Figure 3.4.1; right diagonal triangles (RDT), Figure 3.4.2; and left diagonal triangles (LDT), Figure 3.4.3. The successful implementation of the compatibility equations for the pipe/shell juncture was accomplished by using the following:

1. The θ relationship in Equations (8) and <u>not</u>

   $$\theta = 2 \text{ Arc sin } \left(\frac{\rho \sin \phi}{2R}\right) \quad \text{or}$$

   $$\theta = 2 \text{ Arc sin } \left(\frac{\rho_o \sin \phi}{2R}\right),$$

2. The same coordinate system for both the shell and the pipe, and
3. The same coordinate system for input, solution, and output.

A summary of the peak SCF computer solutions for shell and pipe is presented in Table 3.4.1. The finite element approximations are converging to the theoretical solutions.(1,3) For T = 1.084, the convergence is as good as the shell problem. For the same reasons, the left diagonal triangular shell and the right diagonal pipe is the configuration used in the numerical NASTRAN results. For comparison purposes, computer results for two other shell thicknesses (T = 1.25 and 2.167) for the "simplest" and the chosen configurations are also shown.

Figures 3.4.4 through 3.4.7 show the comparison of the NASTRAN results with experimental and analytical data. The difference between the chosen NASTRAN configuration and the experimental data from that in Cranch (14) is only 8.38%, see Figure 3.4.4. Another example of trend and accuracy is the nozzle-to-cylinder intersection model in Figure 3.4.5. The analysis was performed by Prince and the experimental investigation by the Oak Ridge National Laboratory.(7) Remarkable accuracy is achieved (-3.95% difference) with a direct trend comparison, see Figures 3.4.6 and 3.4.7. Other examples of experimental data and numerical/analytical findings are presented in the results, Chapter V.

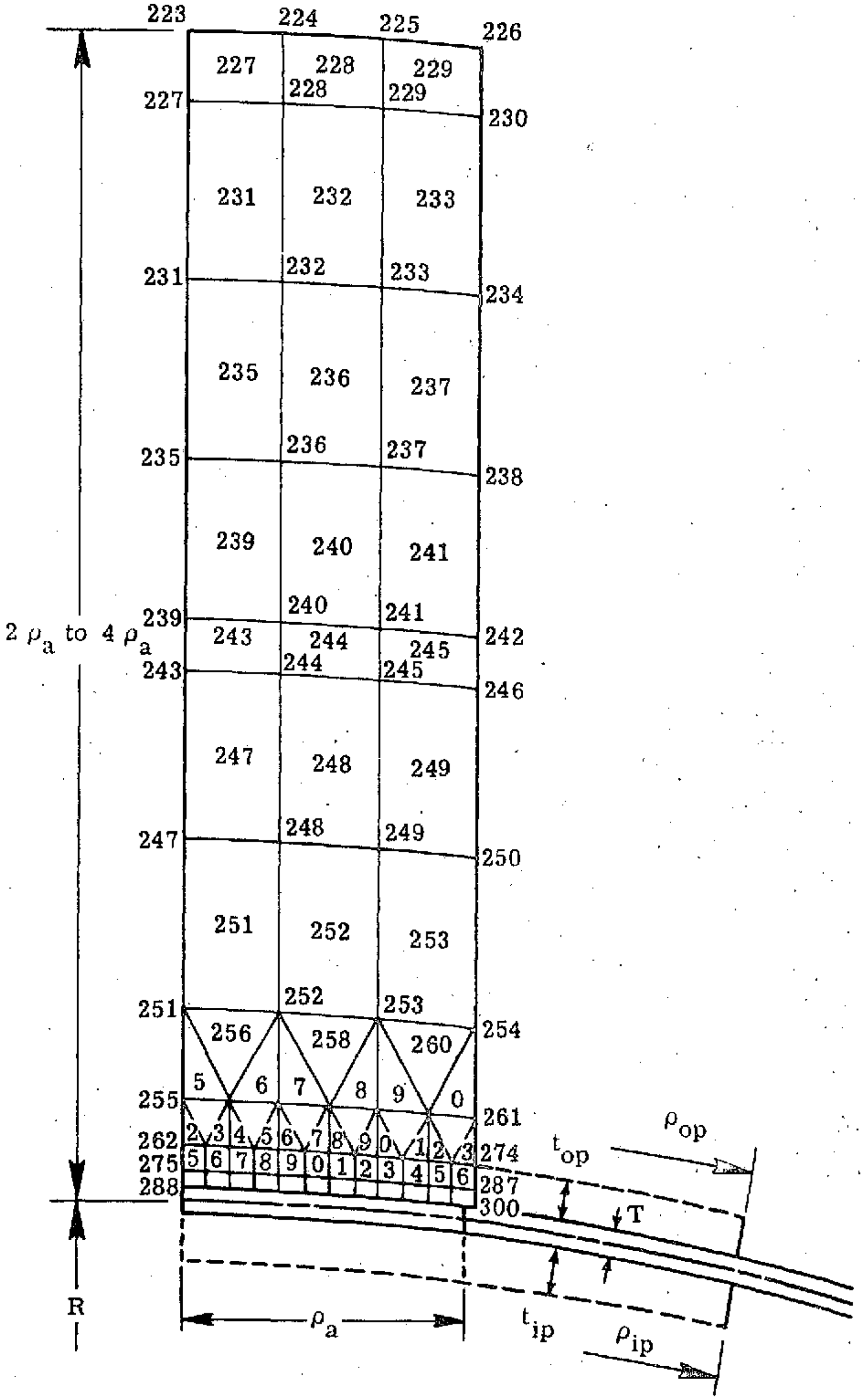

Figure 3.4.1.- Rectangular arrangement of quadrilateral (RQ) elements for pipe.

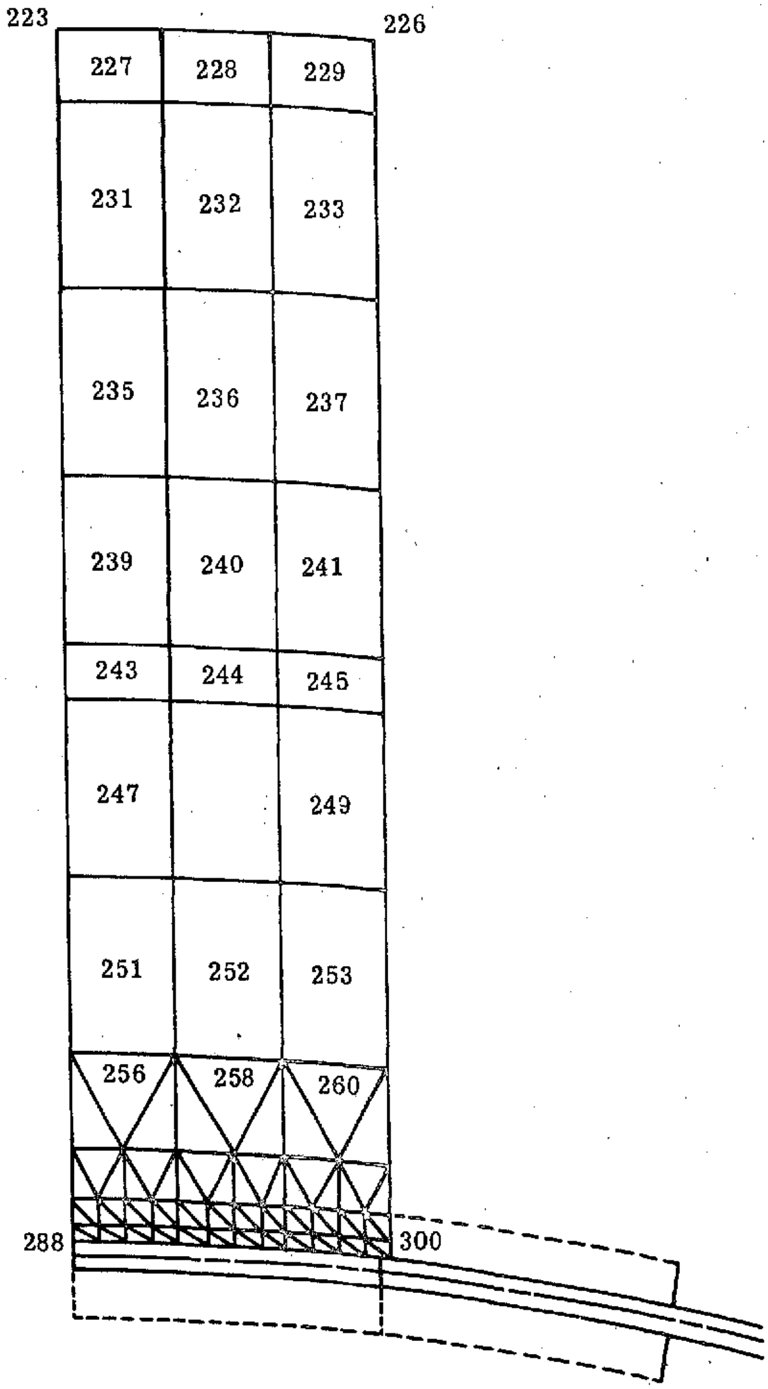

Figure 3.4.2.- Right diagonal arrangement of triangular (RDT) elements for pipe.

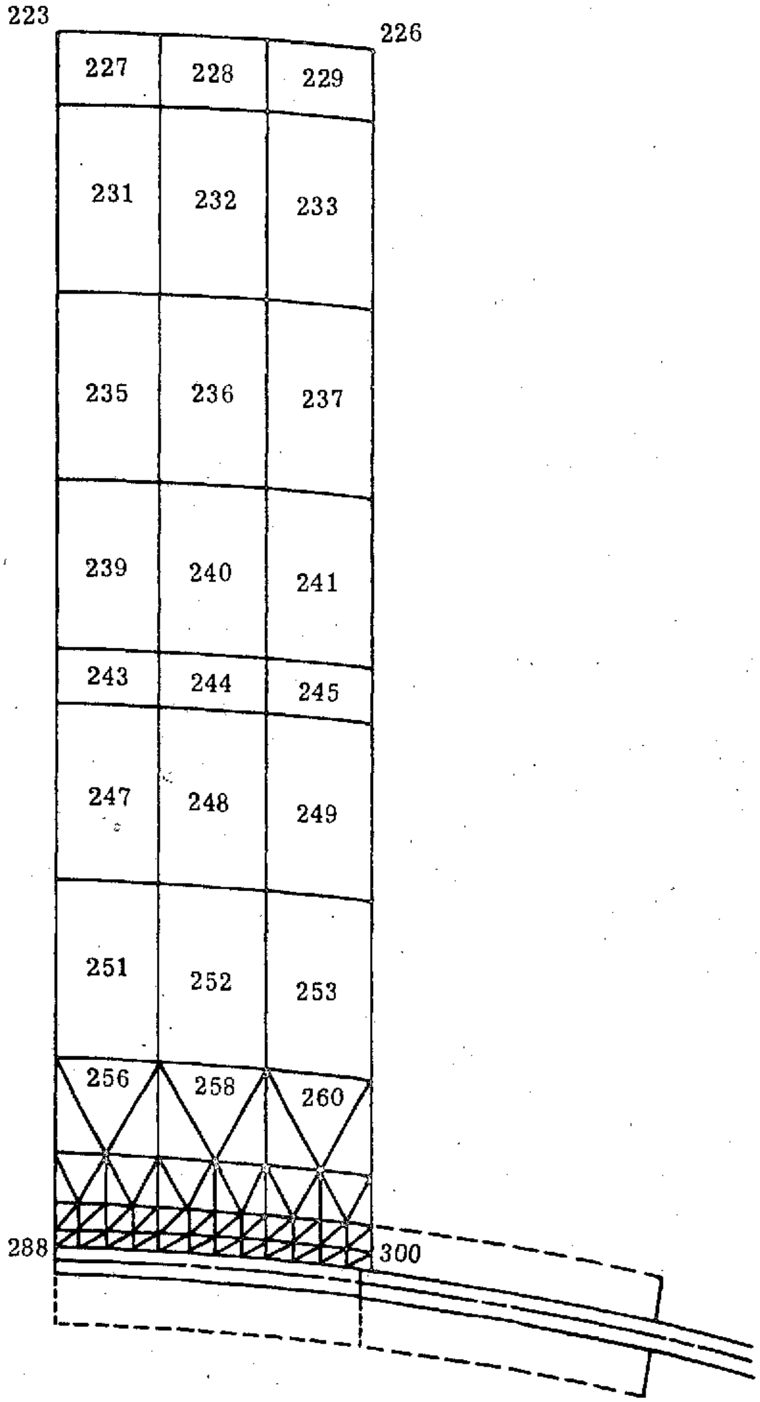

Figure 3.4.3.- Left diagonal arrangement of triangular (LDT) elements for pipe.

SHELL THICKNESS = 1.084			
		INSIDE SCF ON SHELL @ $\phi = 0$ & ρ_a	
SHELL RADIAL SECTION DESCRIPTION	PIPE DESCRIPTION	NASTRAN	% DIFFERENCE
LDT (First Row Removed)	LDT	2.189	-12.09
LDT (First Row Removed)	RDT	2.197	-11.77
RQ	RQ	2.227	-10.56
RDT	RDT	2.282	- 8.35
LDT	RQ	2.428	- 2.49
LDT	RDT	2.447	- 1.73
LDT T of First Row = T/2	RDT	2.462	- 1.12
RLDT T of First Row = T/2	RDT	2.524	+ 1.37
		"EXACT" Ref(1) →	2.490

	SHELL THICKNESS = 1.25		
RQ	RQ	2.213	-16.80
LDT T of First Row=T/2	RDT	2.563	- 3.65
		"EXACT" REF(1,3) →	2.660

	SHELL THICKNESS = 2.167		
RQ	RQ	2.513	-18.14
LDT	RDT	2.793	- 9.02
		"EXACT" REF(1) →	3.070

Table 3.4.1 - Peak SCF For Finite Element Models For a Cylindrical Shell With Pipe: $\rho_a = 13.0$, $R = 112.0$, $\nu = 0.3$, And $t = 1.3$.

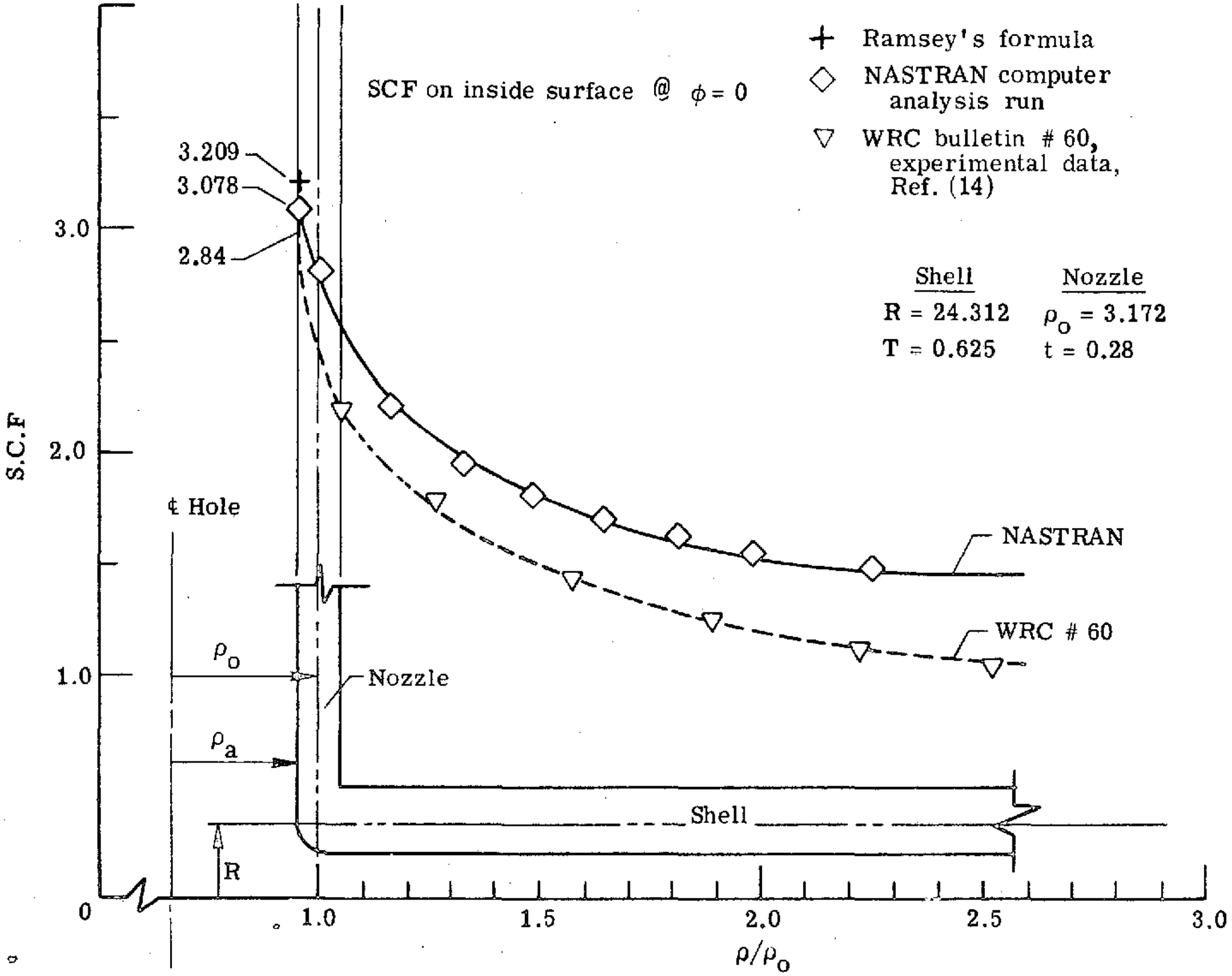

Figure 3.4.4.- Comparison of NASTRAN results with experimental data for shell and pipe.

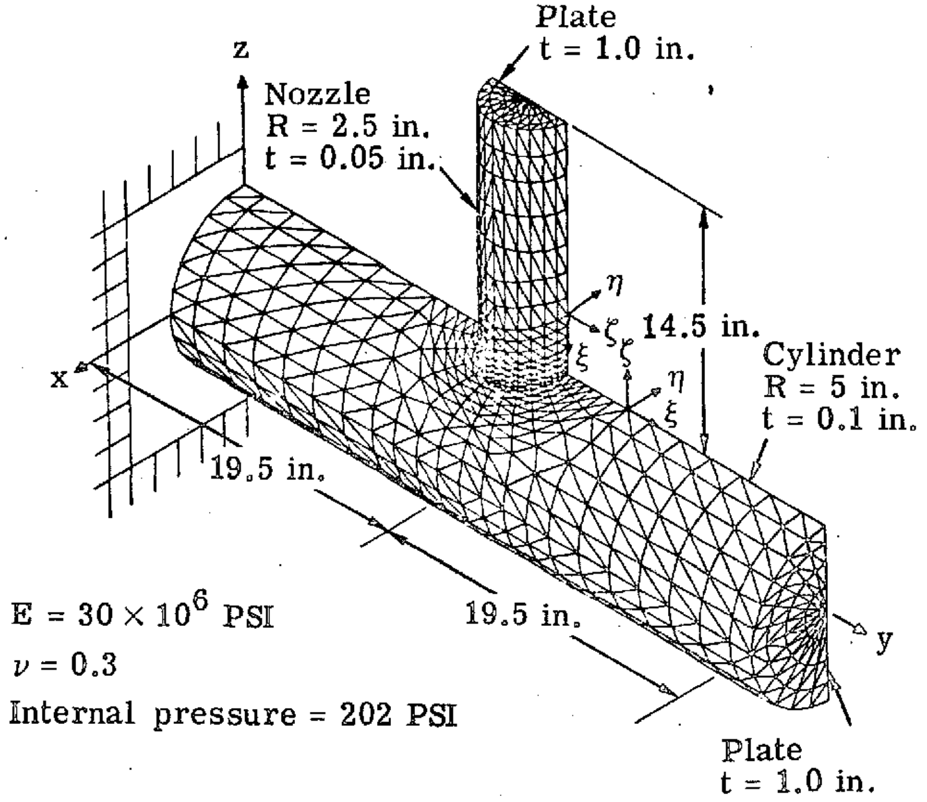

Figure 3.4.5.- Nozzle (pipe)-to-cylinder (shell) intersection model from Prince.(7)

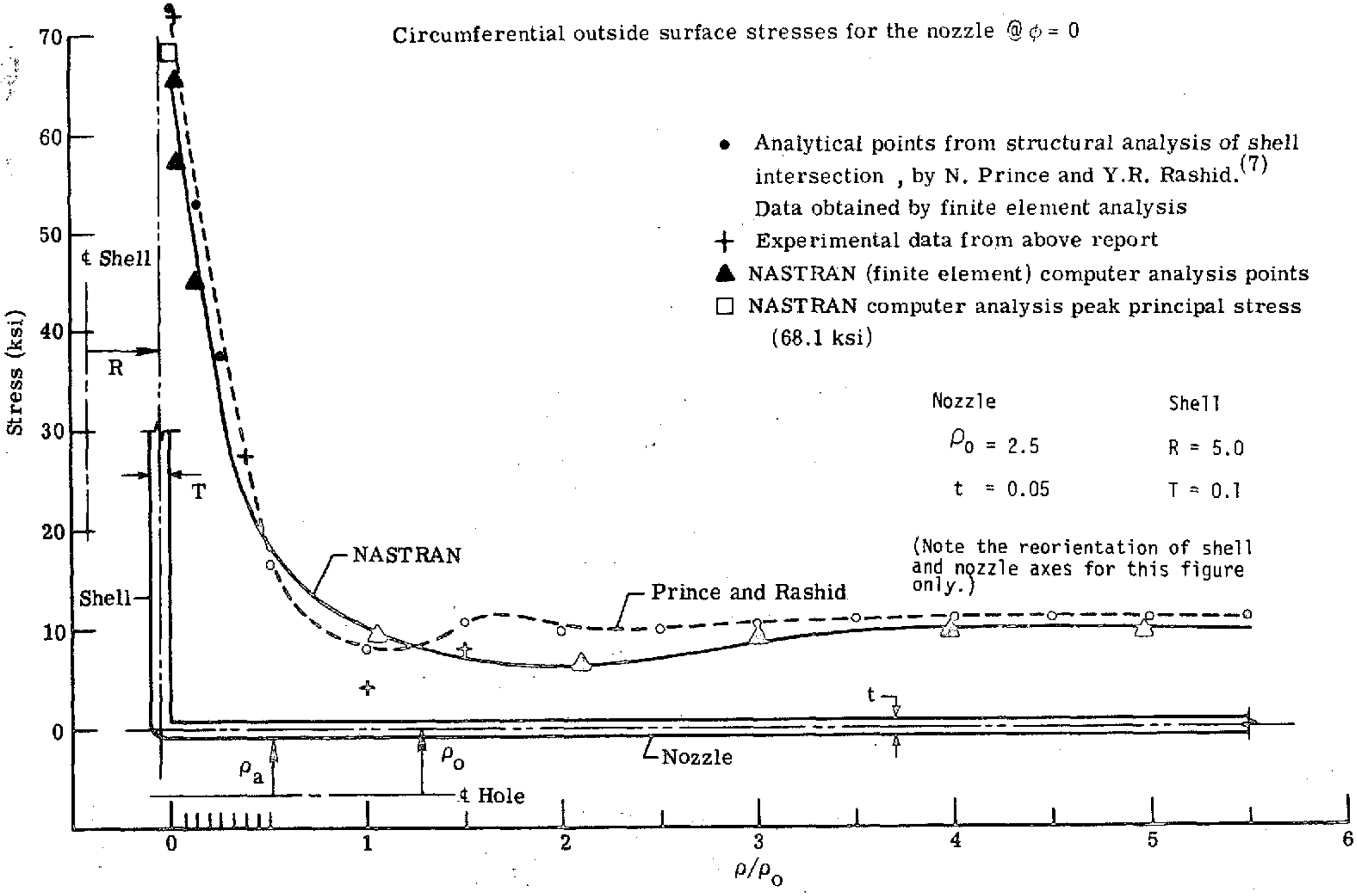

Figure 3.4.6.- Comparison of NASTRAN results with analytical and experimental data for shell and pipe.

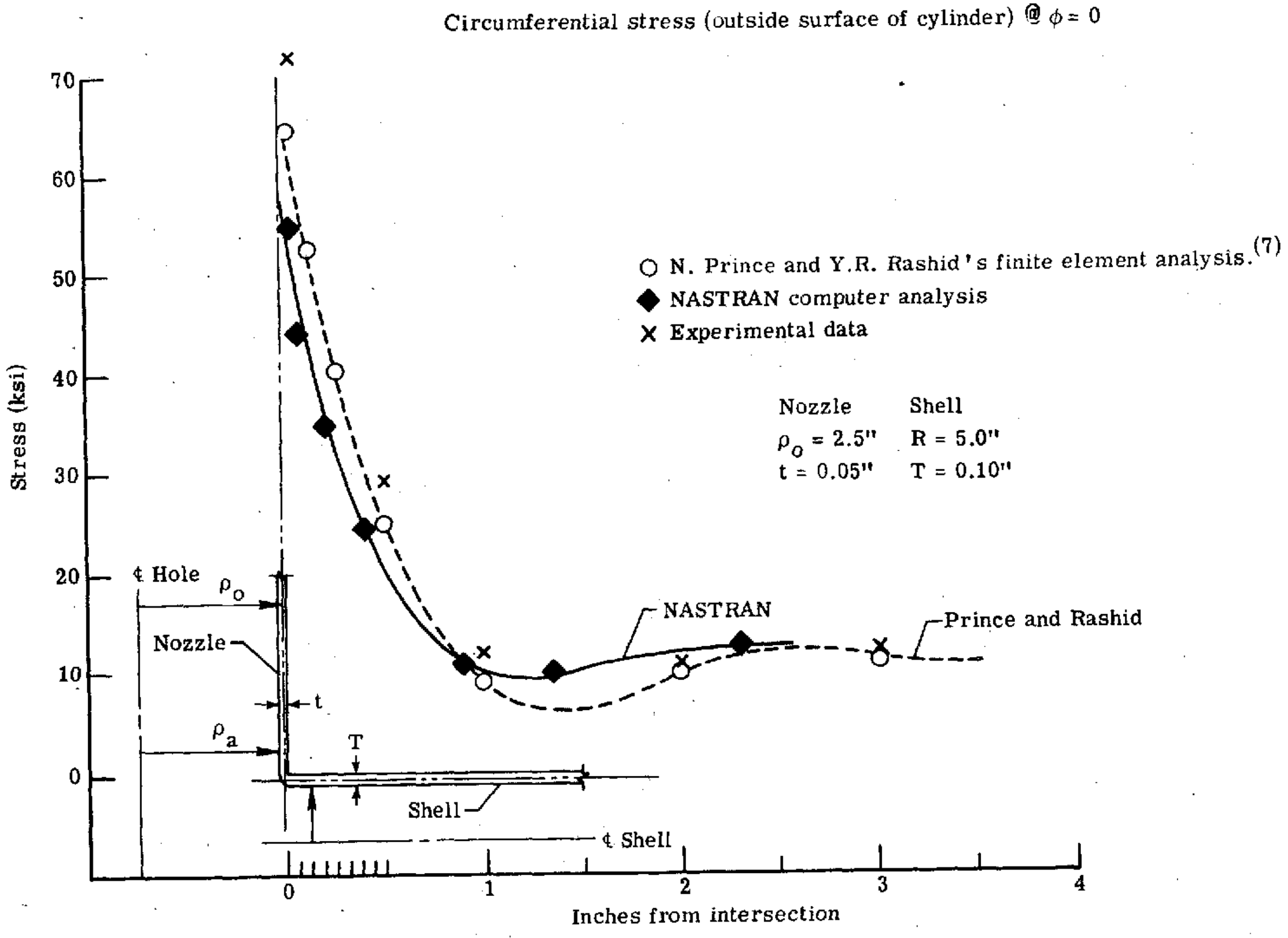

Figure 3.4.7.- Comparison of NASTRAN results with analystical and experimental data for shell and pipe.

3.5 Shell, Pipe, and Pad

The preceding sections provided comparisons of the accuracy of a variety of finite element solutions to theoretical, numerical, and experimental results. Results for this specific case (shell, pipe, and pad) are limited; however, a configuration was chosen to test the MPC cards. This configuration is two intersecting circular cylinders reinforced with a pad. The same shell and pipe models in Sections 3.3 and 3.4 are used; consequently, a quarter of the pad is modeled: outside pad radius, ρ_p; and pad thickness, t_p; and all of the shell and pad parameters previously described. Typical finite element models for a pad are similar to those of the shell "radial" section, see Figures 3.5.1 through 3.5.3. A summary of the peak SCF computer solutions for a shell/pipe/pad configuration is presented in Table 3.5.1.

There have been six shell/pipe/pad configurations experimentally investigated.(14,15,17,22,24) The NASTRAN result as compared to first set of data(14) is shown in Figure 3.5.4. The dashed line is the author's extension of the available experimental curve. The descriptions of the two models to show convergence is presented in Table 3.5.2. The second comparison(15) is shown in Figure 3.5.5 and presented in Table 3.5.3. This trend comparison is outstanding. The accuracies of the two, -3.85% and -4.42%, is remarkable. The convergence of these NASTRAN models for the two experimental cases lends authenticity to the first numerical case for which there is no comparison. Therefore, the LDT shell, RDT pipe, and LDT pad will be used as the finite element model for other numerical NASTRAN results. The other four experimental results will be presented in Chapter V (for comparison to the formula developed in Chapter IV).

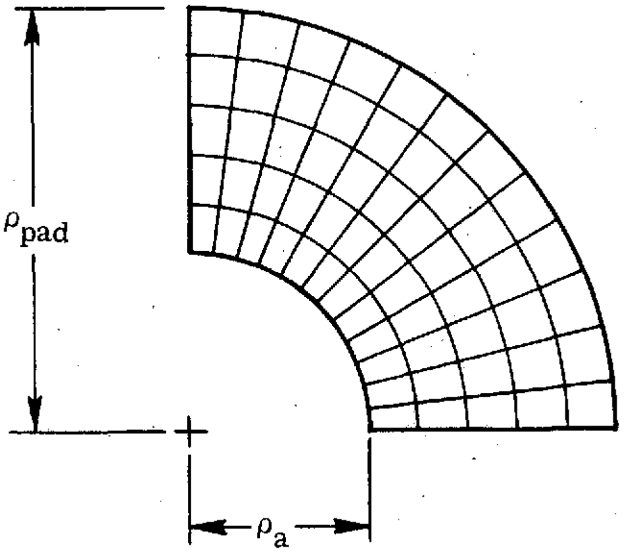

Figure 3.5.1.- RQ elements for pad(s).

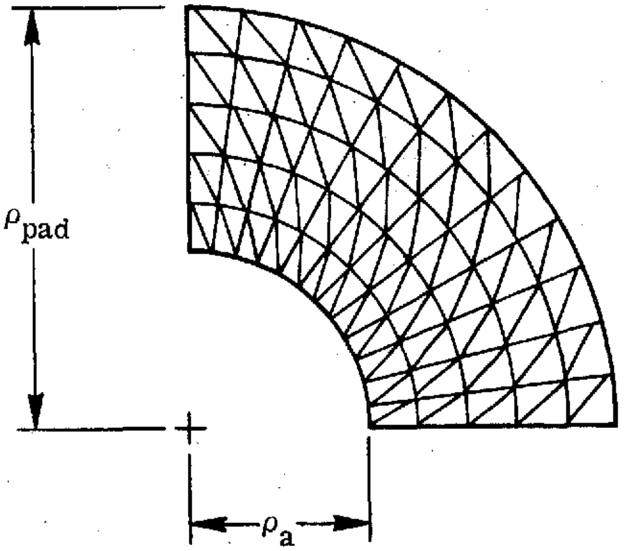

Figure 3.5.2.- RDT elements for pad.

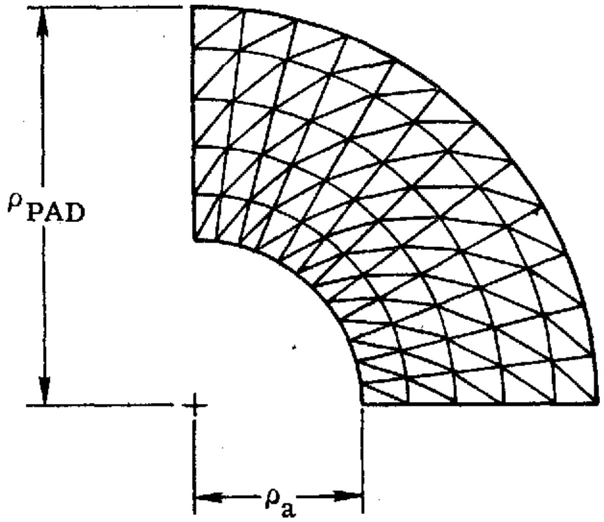

Figure 3.5.3.- LDT elements for pad(s).

SHELL RADIAL SECTION DESCRIPTION	PIPE DESCRIPTION	TOP PAD DESCRIPTION	SHELL SCF (INSIDE) $\phi = 0$ & ρ_a
RQ	RDT	RQ	1.711
RDT	RDT	RQ	1.808
RDT	RDT	RDT	1.831
LDT	RDT	LDT	1.868

Table 3.5.1 - Peak SCF For Finite Element Models for Cylindrical Shells With Pipe and Pad: $\rho_a = 13.0$, $T = 1.25$ $R = 112.0$, $\nu = 0.3$, $t = 1.3$, $t_p = 1.5$, & $\rho_p = 25.0$

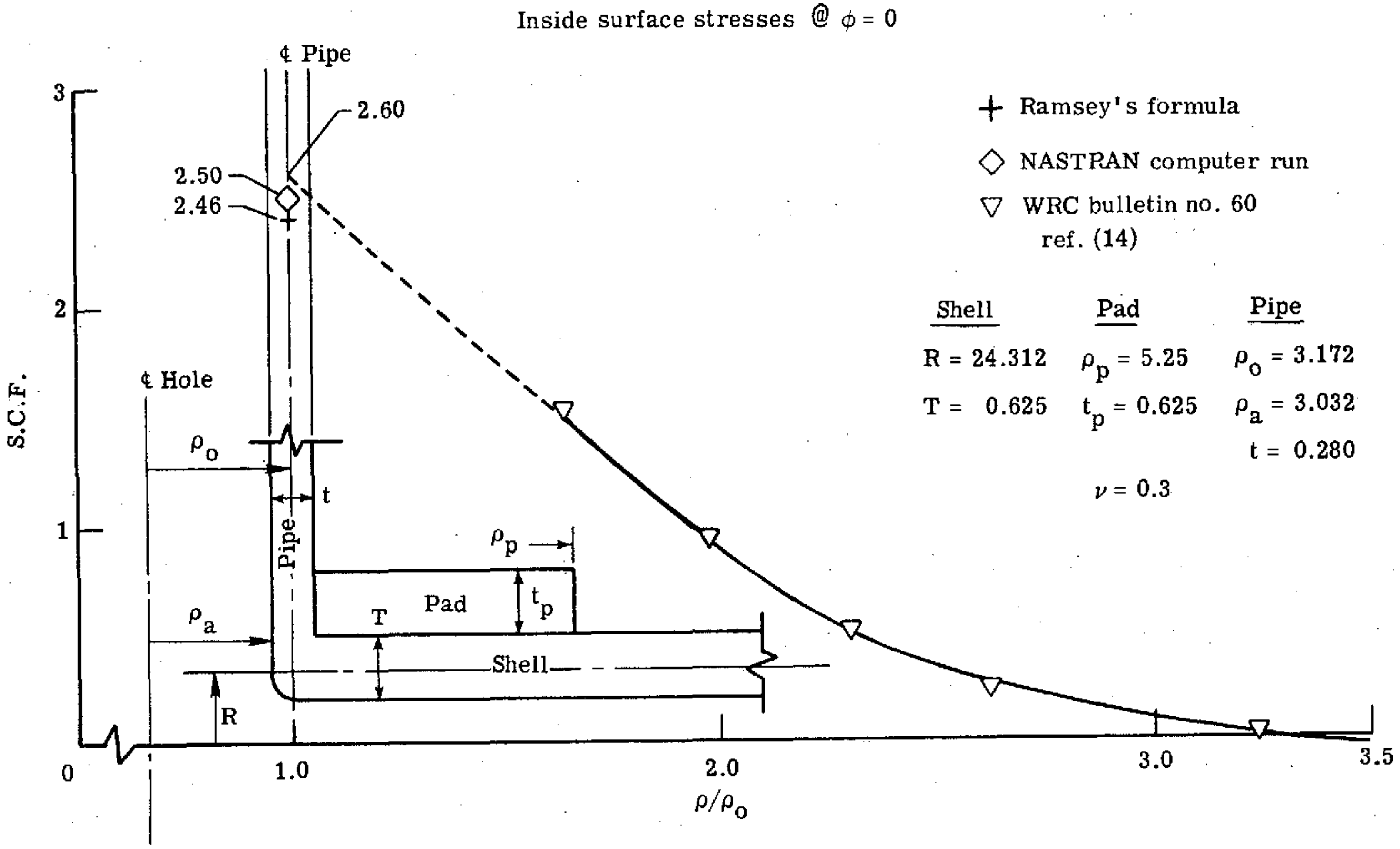

Figure 3.5.4.- Comparison of NASTRAN results with experimental data for shell, pipe and pad.

SHELL RADIAL SECTION DESCRIPTION	PIPE DESCRIPTION	PAD DESCRIPTION	SHELL PEAK SCF (I/S)	
			$\phi = 0$ & ρ_o NASTRAN	% DIFF
RQ	RDT	RQ	2.116	-18.62
LDT	RDT	LDT	2.498	-3.85

"EXACT" → $\boxed{2.60}$

REF (14)

TABLE 3.5.2 - PEAK SCF FOR FINITE ELEMENT MODELS FOR A PRESSURIZED CYLINDRICAL SHELL WITH PIPE AND PAD: $\rho_o = 3.172$, $t = 0.280$, $R = 24.312$, $T = 0.625$, $\rho_p = 5.25$, $t_p = 0.625$, AND $\nu = 0.3$.

SHELL RADIAL SECTION DESCRIPTION	PIPE DESCRIPTION	PAD DESCRIPTION	SHELL PEAK SCF (I/S)	
			$\phi = 0$ & ρ_o NASTRAN	% DIFF
RQ	RDT	RQ	2.362	-5.90
LDT	RDT	LDT	2.399	-4.42

"EXACT" → $\boxed{2.51}$

REF (15)

TABLE 3.5.3 - PEAK SCF FOR THE FINITE ELEMENT MODELS FOR A CYLINDRICAL SHELL WITH PIPE AND PAD: $\rho_o = 5.0785$, $t = 0.593$, $R = 19.0$, $T = 2.0$, $\rho_p = 9.482$, $t_p = 2.0$,

3.6 Shell, Pipe, and Pads

The shell, pipe, and pads configuration is often used in the design and construction of pressure vessels. One experimental investigation for this configuration was located through a paper by Kitching and Perkins.(23) The experimental results were for two intersecting circular cylinders (pipe and shell) reinforced with two pads (inside and outside of the shell) as shown in Figure 3.6.1. The experimental result was obtained during an investigation by the British Welding Research Association (BWRA).(24) The same shell, pipe, and pad models in previous sections are used; moreover, a quarter of the second pad is modeled identical to Figures 3.5.1 and 3.5.3. A summary of the peak SCF computer solutions, for the simplest and most accurate type (from previous sections) finite element configurations, is shown in Table 3.6.1. This is the only shell/pipe/pads experimental or numerical result available and the LDT type model has a difference of 9% above the exact answer. "However, the actual maximum value (SCF) would be slightly higher than the one measured in the test since it is impossible to measure immediately at a point of discontinuity."(23) The discontinuity point would be at the NASTRAN peak SCF location - inside shell surface at $\phi = 0$ and ρ_a. The difference would be < 9%, which is within engineering requirements. Therefore, the LDT shell, RDT pipe, and LDT pad(s) will be used in modeling all other numerical NASTRAN results.

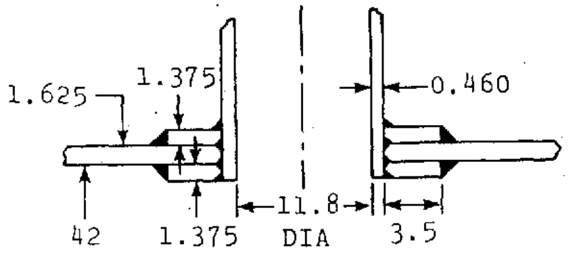

FIGURE 3.6.1 - DETAILS OF NOZZLE (PIPE) IN A SHELL REINFORCED WITH TWO PADS IN BWRA STUDIES.(24)

SHELL "RADIAL" SECTION DESCRIPTION	PIPE DESCRIPTION	TOP PAD DESCRIPTION	BOT. PAD DESCRIPTION	SCF	
				NASTRON	% DIFF
RQ	RDT	RQ	RQ	1.662	-7.67
LDT	RDT	LDT	LDT	1.964	9.11
				"EXACT"	1.80
				REF (24)	

TABLE 3.6.1 - PEAK SCF FOR FINITE ELEMENT MODELS FOR A PRESSURIZED CYLINDER WITH PIPE AND PADS: $\rho_o = 6.13$, $t = 0.46$, $R = 21.8125$, $T = 1.625$, $\rho_{OP} = 9.86$, $t_{OP} = 1.375$, $\rho_{ip} = 9.86$, $t_{ip} = 1.375$, AND $\nu = 0.3$.

CHAPTER IV

FORMULA

4.1 Introduction

In practical applications one frequently encounters problems in which a circular cylindrical shell is submitted to the action of forces distributed symmetrically with respect to the axis of the cylinder. The stress distribution in wind tunnels, cylindrical containers, and circular pipes under uniform internal pressure are examples of such problems.(34)

For the case of circular cylindrical shells arbitrarily loaded, two first approximation theories are of prime importance - (1) Love's first approximation theory and (2) its simplified version due to Donnell. The simplified version led to three partial differential equations in three displacement components. These three equations contain terms which higher approximation theories have shown to be negligible. It is therefore permissible to simplify the equations by omitting such terms.(9) If these terms are omitted (only pressure is considered) and the thickness of the shell is constant, these Donnell equations lead to a single fourth order equation in w, the radial deflection, for the case of axisymmetrically loaded circular cylindrical shells. This equation obtained by a number of authors(9,34-36) is

$$\frac{d^4 w}{dZ^4} + \frac{ETw}{R^2 D} = \frac{p}{D} \tag{13}$$

with

$$D = \frac{ET^3}{12(1 - \nu^2)}$$

where w is the radial deflection

E is Young's Modulus of the shell

R is the shell mid radius

T is the shell thickness

p is the internal pressure

ν is the Poisson's ratio of the shell.

For the case of unsymmetrically loaded circular cylinders, the linear shallow, thin shell equations may be readily combined into two differential equations involving only the membrane stress function F and the normal displacement w. The compatibility and equilibrium equations are

$$\begin{aligned} \nabla^4 F &= \frac{ET}{R} \frac{\partial^2 w}{\partial z^2} \\ \nabla^4 w + \frac{1}{RD} \frac{\partial F}{\partial z^2} &= \frac{p}{D} \end{aligned} \tag{14}$$

where $$\nabla^4 = \frac{\partial}{\partial Z^4} + \frac{2\partial}{\partial Z^2 \partial y^2} + \frac{\partial}{\partial y^4} \quad .$$

Elimination of the function F between the two equations above yields an eighth order partial differential equation in w of the form

$$\nabla^8 w + \frac{Et}{DR^2} \frac{\partial^4 w}{\partial Z^4} = \frac{p}{D} \tag{15a}$$

or

$$\nabla^8 w + 64\beta^4 \frac{\partial^4 w}{\partial Z^4} = \frac{p}{D} \tag{15b}$$

where

$$\beta^4 \equiv \frac{ET}{16R^2 D} = \frac{3(1 - \nu^2)}{16R^2 T^2} \quad .$$

Equations (15) are known as Donnell's linear theory.(1-3, 9-11)

4.2 Force Around Hole

The result of a perturbation solution to Equation (15b), modified to include a circular hole covered by a membrane (Figure 4.2.1), through terms of order $(\beta\rho_a)^2$ is a stress concentration factor at the hole-shell boundary.(2)

$$SCF = \frac{3}{2} + \cos 2\phi + \pi(\beta\rho_a)^2(1 + \frac{5}{4}\cos 2\phi) + \ldots \tag{16}$$

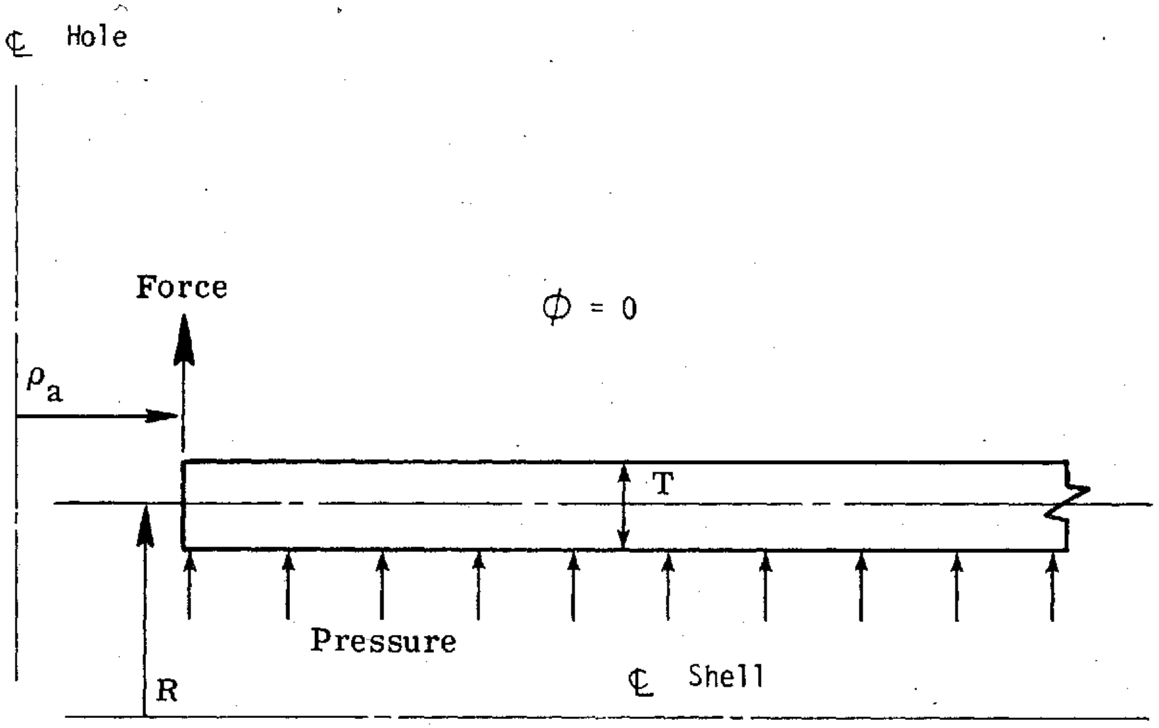

Figure 4.2.1.- Penetration (radius ρ_a) in a pressurized cylindrical shell (mid radius R, thickness T, and Poisson's ratio ν) covered by a membrane.

For the case of $\phi = 0$, Equation (16) becomes

$$SCF = 2.5 + \frac{9}{4} \pi \ (\beta \rho_a)^2 \qquad (17)$$

where ρ_a is the hole radius.

Savin's formula$^{(4)}$ for the same problem is

$$SCF = 2.5 + \frac{2.3}{RT} \rho_a^2 \quad . \qquad (18)$$

Lind's equation$^{(26)}$ is

$$SCF = 1 + 4 \ \beta \rho_a \ (1 \pm \frac{T}{2R}) \quad . \qquad (19)$$

Mershon$^{(27)}$ obtained for the same problem but with a pipe intersecting the shell hole

$$SCF = 2.5 + \frac{\rho_o}{R} \left(\frac{2R}{T}\right)^{1/2} = 2.5 + \left(\frac{2}{RT}\right)^{1/2} \rho_o \qquad (20)$$

where ρ_o is the pipe mid radius.

Mershon's Equation (20) is restricted to $t/T \simeq 0$ (force around hole only) or t/T small - where t is pipe thickness.

For $\nu = 0.3$, these Equations (16 through 20) reduce to

$$SCF_{\text{Van Dyke}} = 2.5 + \frac{2.92 \ \rho_a{}^2}{RT} \qquad (21a)$$

$$SCF_{Savin} = 2.5 + 2.3 \frac{\rho_a^{\,2}}{RT} \qquad (21b)$$

$$SCF_{Lind} = 1 + 2.585 \frac{\rho_a}{(RT)^{1/2}} \qquad (21c)$$

$$SCF_{Mershon} = 2.5 + \frac{1.414 \rho_o}{(RT)^{1/2}} \qquad (21d)$$

The first attempt at a rational analysis of a long pressurized cylindrical shell having a small circular hole and closed at its ends is due to Lur'e.(6) Due to errors introduced in the boundary conditions, his results are incorrect. The terms in Equation (16) of order $(\beta\rho_a)^2$ were one-half the values obtained originally by Lur'e. This error was also confirmed by Eringen(8) and Lekkerkerker(1). Eringen, Naghdi, and Thiel(3) presented a study using the exact solution of partial differential equations of thin, shallow, cylindrical shell theory. The boundary conditions were satisfied by use of Fourier series and the least square error technique through the aid of extensive numerical calculations of the force only around a circular hole in a cylindrical shell. A comparison of the results from this "exact" approach with Equation (21) is shown in Figure 4.2.2.

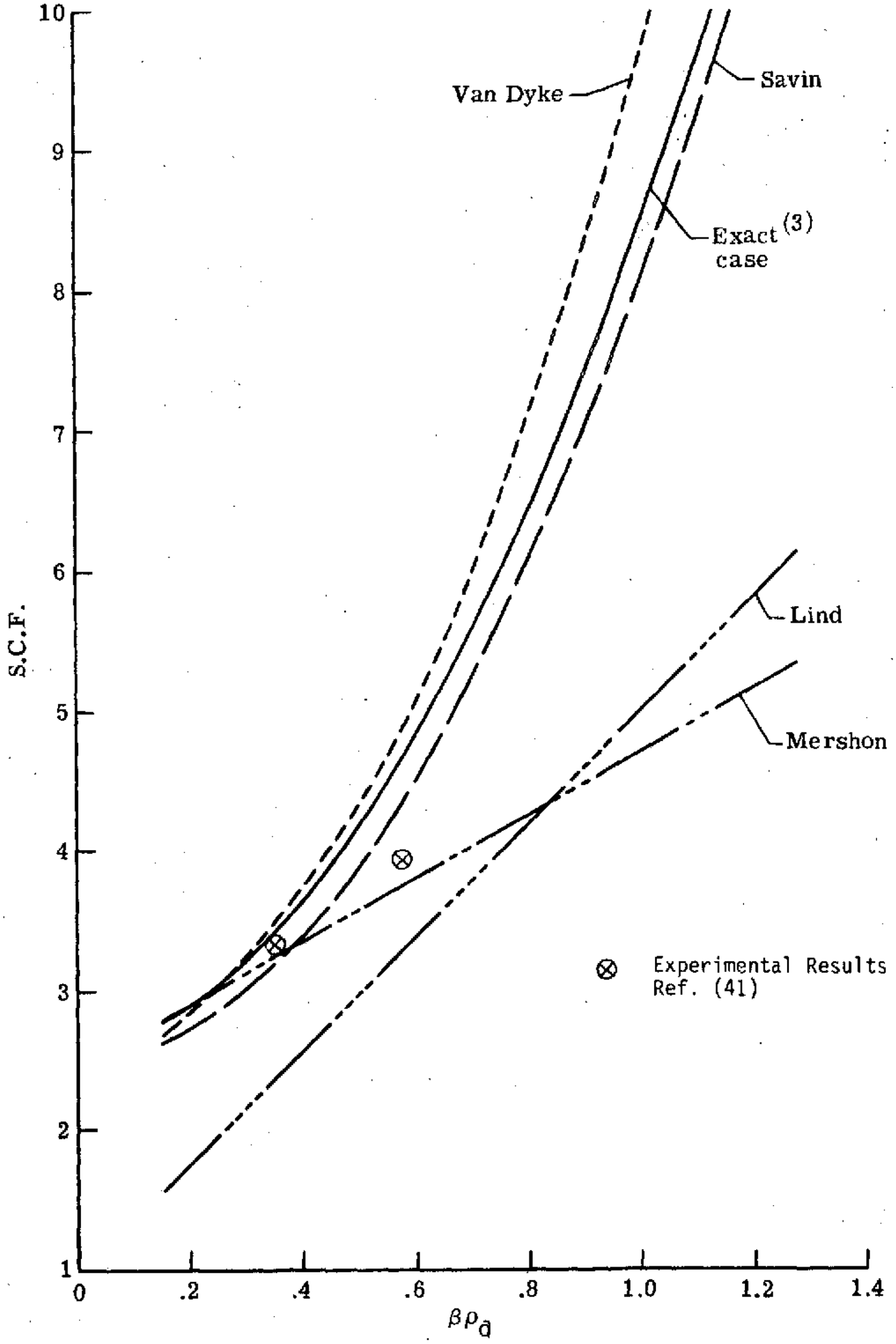

Figure 4.2.2.- Comparison of formulas with exact results.

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The two experimental results are those of Houghtan and Rothwell.(41) In both of these experiments, only the membrane stresses were measured. The stress concentration factors correspond to the ratio of the maximum membrane stress at the hole to the membrane stress in the shell far from the hole. Excellent agreement is shown for the first data point $(\beta\rho_a = 0.35)$. The experimental membrane covering the hole consisted of a very flexible, thin metal plug. This may have introduced slight restraints on the freedom of the hole edge. By measuring only the membrane stress and, perhaps, introducing the slight restraint, the peak SCF for the second experiment would be higher due to the larger size hole $(\beta\rho_a = 0.58)$.

The Van Dyke Equation (21a) is the only conservative equation in comparison with the "exact" results(3) and the first experimental case. Van Dyke's starting series for small $\beta\rho_a$, given by Equation (16), is generally accurate to a $\beta\rho_a$ of about 0.3.(2) The required engineering accuracy is exceeded for $\beta\rho_a > 0.6$; therefore, this equation is the one chosen to improve on in the following format for the force around the hole

$$SCF_{Force} = 2.5 + \lambda \frac{\rho_a^2}{RT} \tag{22}$$

where 2.5 is the stress concentration factor for a flat plate weakened by a circular hole with the plate stretched per unit length in one direction and with one-half of this stretch per unit length in the other direction,

and

$\frac{\rho_a^2}{RT}$ is a function to increase the stress due to shell curvature and thickness, and hole size,

with λ for values of $\frac{\rho_a}{(RT)^{1/2}}$ shown in Figure 4.2.3.

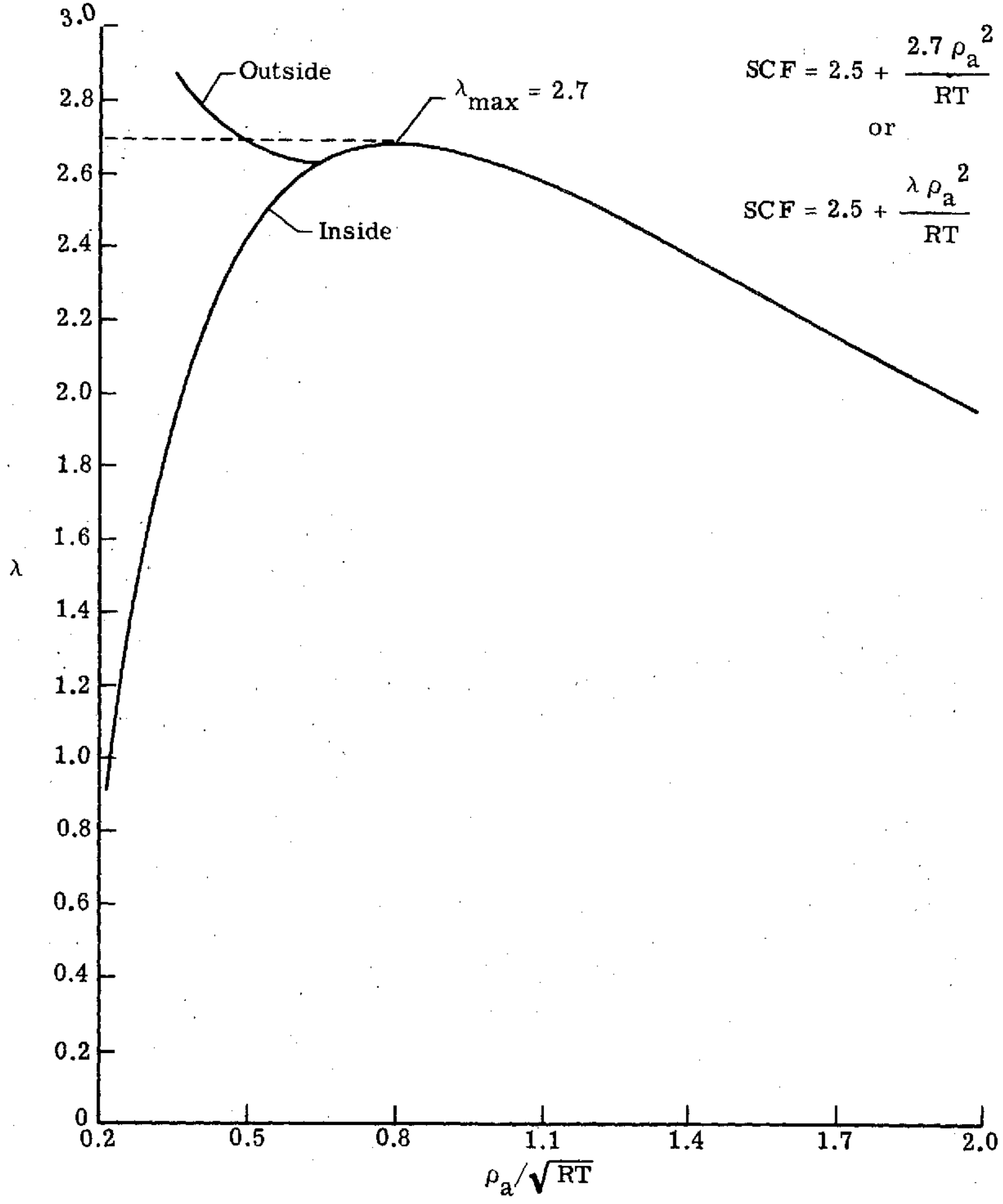
The values of λ to go in Equation (22) can be taken from this curve (Figure 4.2.3) or the maximum value of $\lambda = 2.7$ could be used. This value is used in Equation (22) in this report. For $\nu = 0.3$ the result is

$$SCF_{Force} = 2.5 + 2.7 \frac{\rho_a^2}{RT} \qquad (23a)$$

or for any ν

$$SCF_{Force} = 2.5 + 6.537\ (\beta\rho_a)^2 \qquad (23b)$$

where $\beta\rho_a = \frac{(3(1-\nu^2))^{1/4}}{2} \quad \frac{\rho_a}{(RT)^{1/2}}$.



Either use

$$SCF = 2.5 + \frac{2.7\,\rho_a^{\,2}}{RT}$$

or

$$SCF = 2.5 + \frac{\lambda\,\rho_a^{\,2}}{RT}$$

Figure 4.2.3.- Values of λ in shell with force equation.

4.3 Pipe Around Hole

The installation (physically or analytically) of a pipe into a cylindrical shell (Figure 4.3.1) reduces the peak stress concentration factor at the shell-pipe juncture. A function or reduction factor is needed to decrease this stress due to a small amount of reinforcement from the pipe. The reduction is dependent on the amount of pipe reinforcement (opening and pipe thickness) not needed to withstand the pressure. Thus, the following form is assumed

$$SCF_{Pipe} = SCF_{Force} \text{ (reduction factor)}. \qquad (24)$$

The usual pressurization of cylindrical vessels (wind tunnels) is analogous to a suddenly applied load.(37) The dynamic response of a structure due to this type load is a dynamic load factor of "one minus some term." Therefore, the above reduction factor takes the form

$$1 - (\beta\rho_o)^2 \text{ (pipe to shell thickness ratio)} \qquad (25)$$

where ρ_o is mid surface radius of the pipe and β is modified to include Poisson's ratio of the pipe. The pipe to shell thickness ratio (to be of the same order as β) will be taken as $(t/T)^{1/4}$. Equation (24) becomes

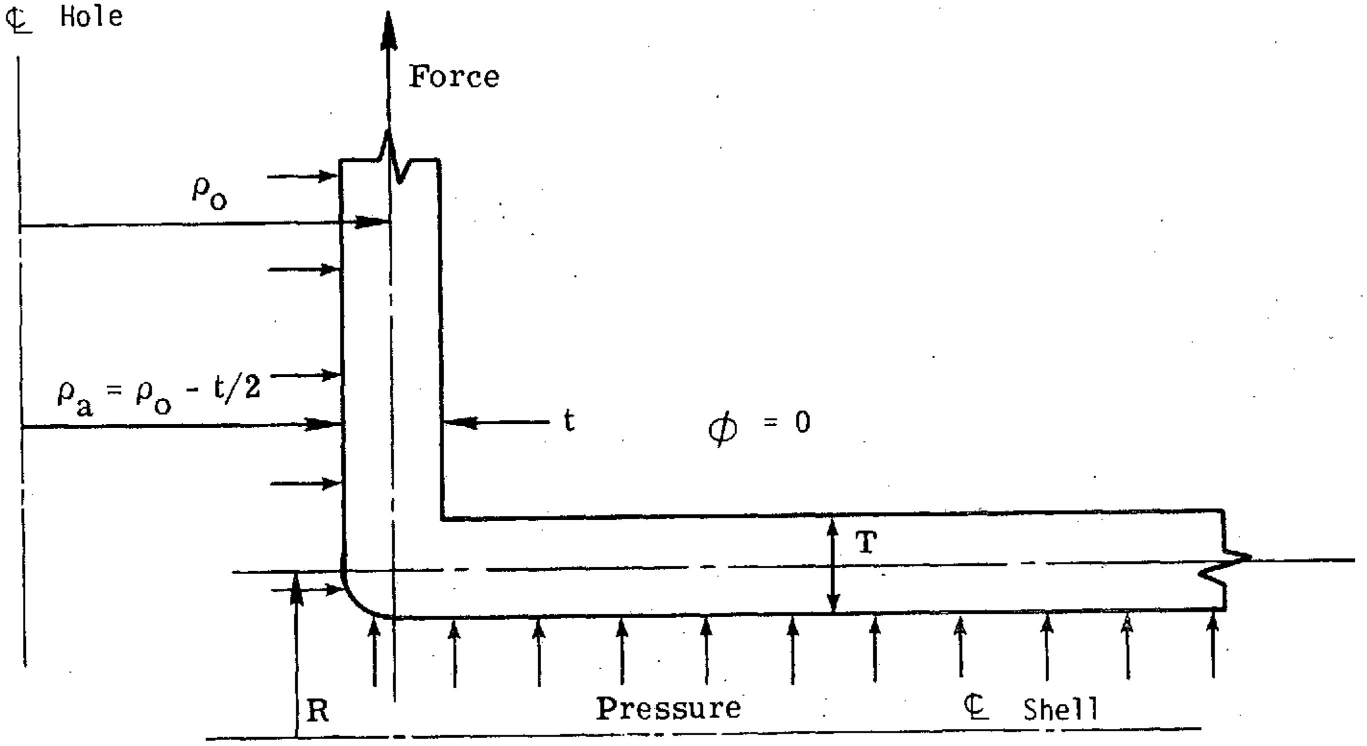


Figure 4.3.1.- Pipe (mid radius ρ_o, thickness t, and Poission's ratio ν_p) in a pressurized cylindrical shell (mid radius R, thickness T and Poission's ratio ν).

$$SCF_{pipe} = SCF_{force} \left|1 - (\beta_1\rho_o)^2(\frac{t}{T})^{1/4} \right| . \quad (26)$$

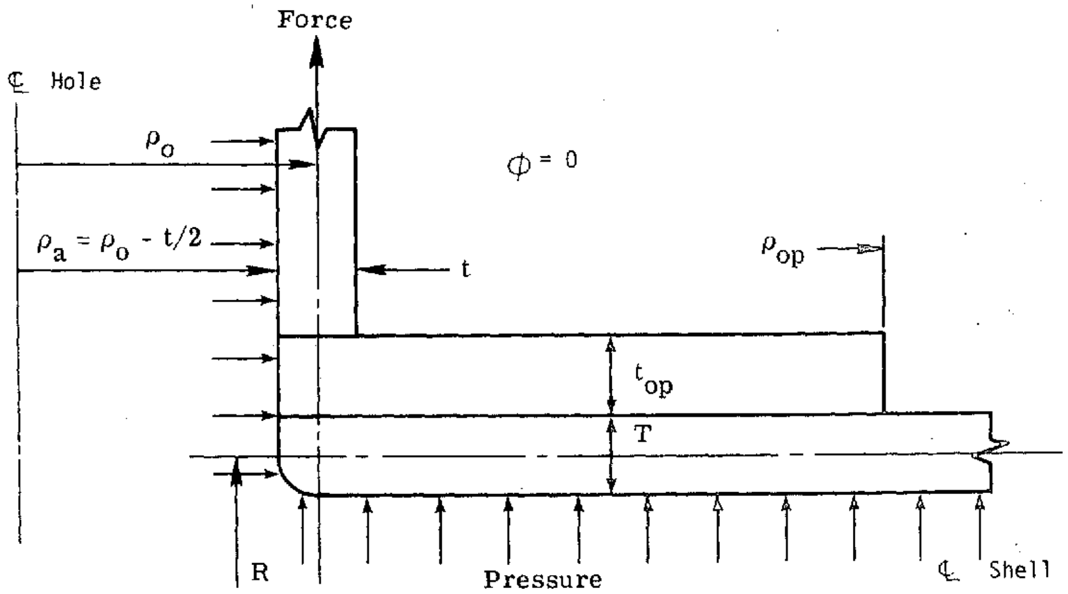
The total equation (23 and 26) developed thus far is

$$SCF_{pipe} = (2.5 + 6.537 (\beta\rho_a)^2)\left|1-(\beta_1\rho_o)^2(\frac{t}{T})^{1/4}\right| . \quad (27)$$

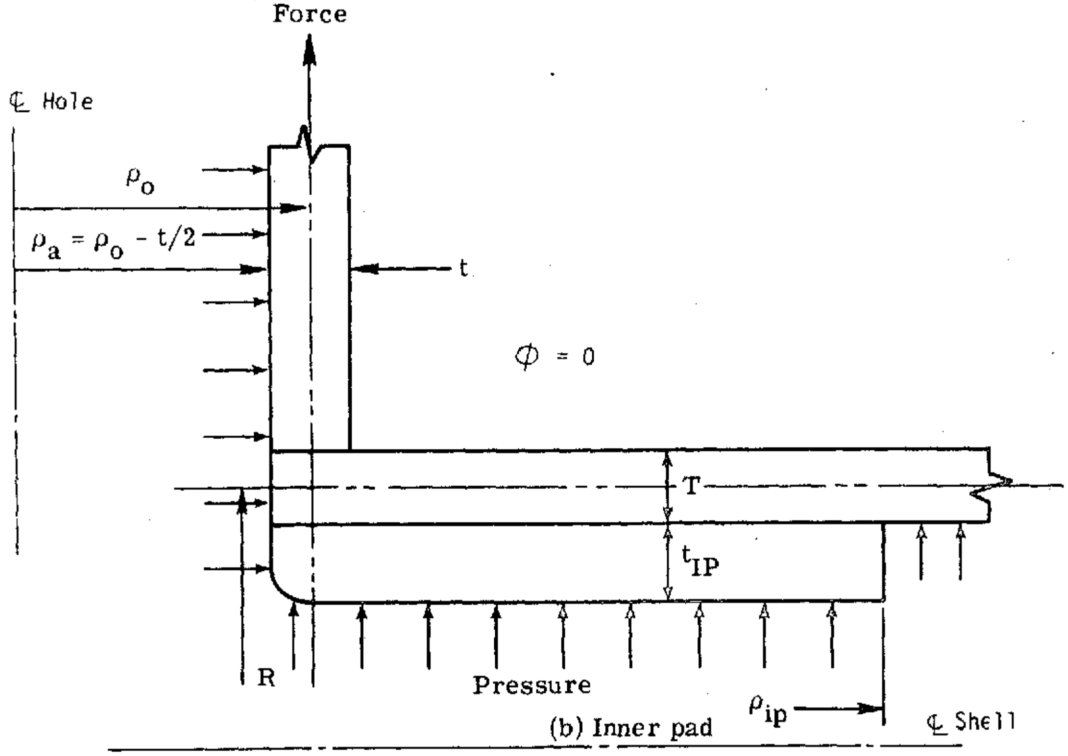
4.4 Pipe and Reinforcing Pad Around Hole

The addition of an inner or outer reinforcing pad to a pipe in a cylindrical shell is shown in Figure 4.4.1. The two new parameters introduced with this configuration are the outside radius (ρ_p) and the thickness (t_p) of the inner or outer pad. The major parameters from Equation (27) that contribute to this configuration's influence on the SCF are the mid radius (R), the thickness (T) of the shell and the inside radius (ρ_a), the thickness (t) of the pipe. Thus, a function to decrease the stress due to a reinforcing pad around the pipe or hole should contain ρ_p, R, ρ_a, t_p, and t or T. This function should be similar to $\beta\rho$ and multiplied times a pad to shell or pipe thickness ratio to some power. Note that

$$\beta\rho = \frac{(3(1 - \nu^2))^{1/4}}{2} \frac{\rho}{(RT)^{1/2}} \propto \frac{\rho_p}{(R \rho_a)^{1/2}} . \quad (28)$$



(a) Outer pad



(b) Inner pad

Figure 4.4.1.- Pipe (mid radius ρ_o, thickness t, and Poisson's ratio ν_p) in a pressurized cylindrical shell (mid radius R, thickness T and Poisson's ratio ν) reinforced with an inner or outer pad (outside radius ρ_p and thickness t_p).

The pad to shell or pipe thickness ratio (to be of the same order as β) will be taken as $(t_p/TH)^{1/4}$.

Therefore, the reduction in peak stress concentration factor due to an inner or outer reinforcing pad to a pipe in a cylindrical shell is

$$\frac{\rho_p}{(R\ \rho_a)^{1/2}} \quad (\frac{t_p}{TH})^{1/4} \tag{29}$$

where $TH = \begin{cases} t & \text{for case of a thin, thin shell where pipe thickness is more important than the shell} \\ T & \text{for approaching case of a thick shell where shell thickness is more important than the pipe.} \end{cases}$

The limits as to when each thickness should be used ($TH=t$ for $\frac{R}{T} > 33$ and $TH=T$ for $\frac{R}{T} \leqslant 33$) are discussed in Chapters V and VI under the presentation and discussion of results. The SCF equation becomes

$$SCF_{pad} = SCF_{pipe} - \frac{\rho_p}{(R\ \rho a)^{1/2}} (\frac{t_p}{TH})^{1/4} \cdot \tag{30}$$

The total equation (27 and 30) developed thus far is

$$SCF_{pad} = (2.5 + 6.537(\beta\rho_a)^2)|1 - (\beta_1\rho_o)^2(\frac{t}{T})^{1/4}|$$
$$- \frac{\rho_p}{(R\ \rho_a)^{1/2}} \quad (\frac{t_p}{TH})^{1/4} \tag{31}$$

where ρ_p is outer or inner outside pad radius and t_p is outer or inner pad thickness.

4.5 Pipe and Reinforcing Pads Around Hole

The addition of inner and outer reinforcing pads to a pipe in a cylindrical shell is shown in Figure 4.5.1. The only new parameters introduced with this configuration are the outside radius and thickness of the second reinforcing pad. Therefore, the same type of term as Equation (29) will apply as a reduction to Equation (31) to obtain the peak stress concentration factor for two pads. The general SCF equation becomes

$$\begin{aligned} SCF = (2.5 + 6.537(\beta\rho_a)^2)|1 - (\beta_1\rho_o)^2(\frac{t}{T})^{1/4}| \\ - \frac{\rho_{op}}{(R\ \rho_a)}\ 1/2\ \ (\frac{t_{op}}{TH})^{1/4} - \frac{\rho_{ip}}{(R\ \rho_a)}\ 1/2\ (\frac{t_{ip}}{TH})^{1/4} \end{aligned} \qquad (32)$$

where subscripts o and i are for the outer and inner pads, respectively.

One can obtain the peak SCF for any of the previously developed five cases (force, pipe, outer pad, inner pad, and outer and inner pads) by merely substituting the appropriate parameters in Equation (32). For example, the pipe problem would be solved with $\rho_{op} = \rho_{ip} = t_{op} = t_{ip} = 0$, which would result in Equation (27). The practical approach

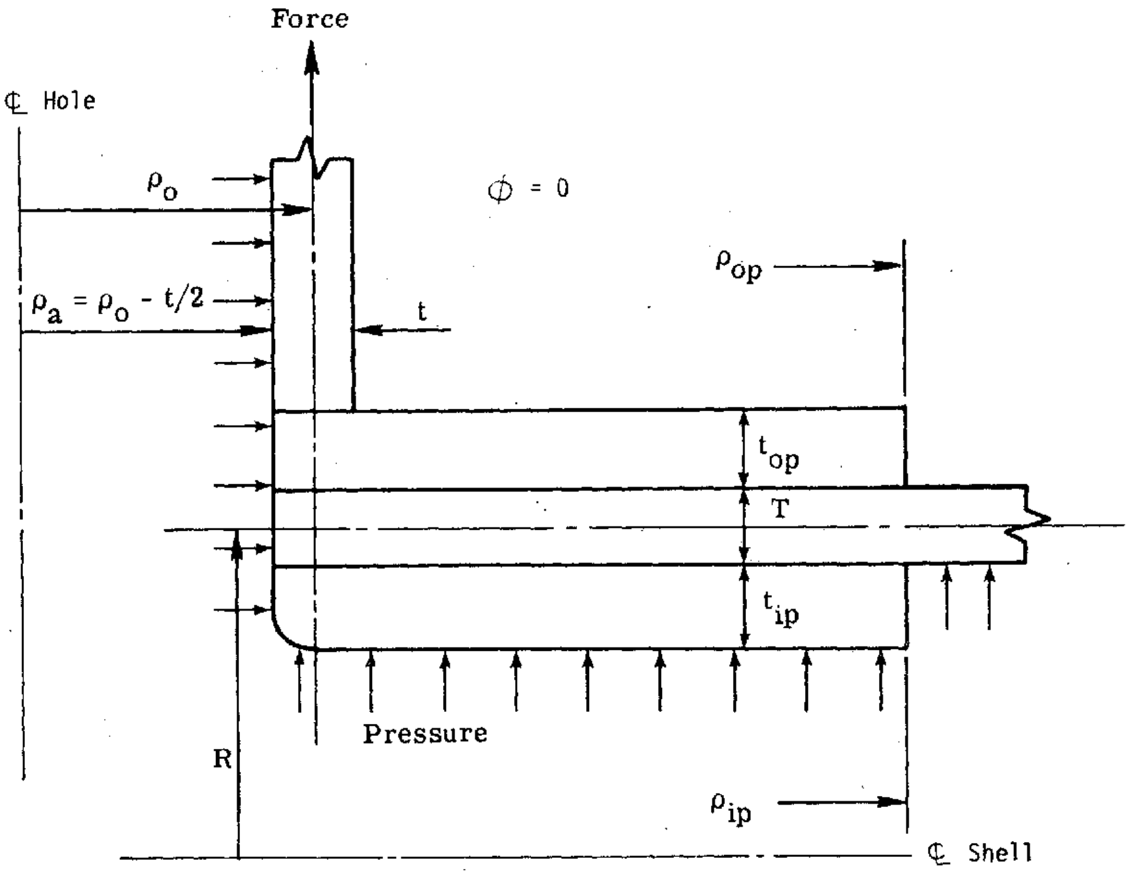


Figure 4.5.1.- Pipe and shell reinforced with inner and outer pads.

in the construction of cylindrical shells is to generally reinforce around pipes; therefore, these five configurations are the major thrust of this research. Another combination of cases can be addressed, i.e. force (t = 0) and pad(s). The physical significance of force, no pipe, and pad(s) could be (1) a cap welded to a reinforcing pad to close off an opening and (2) glass ports for observing the inside of cylindrical pressure vessels (test sections).

The accuracy of the formula is determined by comparing to available and applicable published numerical, theoretical, and experimental data and to the analytical (NASTRAN) results. Many different cases and examples of this formula were pursued in order to uncover the restrictions in the formula. The accuracy, results, and applications are presented and discussed in Chapters V and VI.

Since the formula is compared to theoretical (Shell theory) and to the author's computer (NASTRAN) results, the reliability of the answers from shell theory and NASTRAN in this study is needed. An analogy to the cylindrical shell problem is the example of pure bending of an infinite plate with a circular hole. Reissner(42) addresses this problem by including the effect of transverse shear deformations. It is assumed in Shell theory and NASTRAN that the stresses vary linearly across the thickness. Reissner obtained a factor 6/5 (in lieu of 1.0) in front of the transverse shear deformation terms in the stress-strain equations for two-dimensional plate theory. The significance of this difference is presented by comparing to an exact (three-dimensional elasticity theory) analysis of the plate with a circular hole subject to pure bending. The effect of transverse shear on the peak stress concentration factor is negligible provided ρ_a/T is greater than about 3.0. Therefore, even though Reissner's paper is concerned with a flat plate, the effect of transverse shear on this study will be negligible as long as $\rho_a/T > 3.0$ and $R/T > 25.0$.

It is permitted in NASTRAN to use any shear factor in front of the transverse shear deformation terms.(43,44) The factor used in this study is 1.0. Therefore, a slightly different SCF than the exact answer will be obtained. All of the theoretical and NASTRAN results presented in this study have a ρ_a/T ratio greater than 4.0, except the NASTRAN configurations where the shell thickness equals 8.96 ($\rho_a/T = 1.2$ and $R/T = 13$). It will be shown in Chapter V that for experimental results for $\rho_a/T < 0.6$ and $R/T < 15$, the transverse shear effects are not negligible.

CHAPTER V

PRESENTATION OF NUMERICAL RESULTS

5.1 Introduction

The finite element technique described in Section 2.1 has been used to complete numerical analyses for the configurations previously described (Section 2.2, Chapters III and IV): shell with force around hole, shell and pipe, and shell/pipe/pad(s). The units used throughout this study are in the English or American System (inches and pounds). Except where noted in these results, Poisson's ratio is taken as 0.3 and Young's modulus as 29 x 10^6 psi. The membrane stress of a cylindrical shell is well known.

$$\sigma_m = P \frac{R}{T} \tag{33}$$

The ratio of the largest principal stress at a point in question to that which would occur at that point if the shell were not penetrated will be called a stress concentration factor (SCF). This is defined by

$$\text{SCF} = \frac{\text{Max. stress}}{\sigma_m} \tag{34}$$

where σ_m is defined by Equation (33).

The numerical (NASTRAN) results were calculated using Langley Research Center's CDC-6000 series computers. All of the NASTRAN models are composed of triangular and quadrilateral elements with both inplane and bending stiffness. The pressurized cylindrical shell with a circular penetration is modeled as follows:

1. General shell, Figure 3.3.1
2. Radial shell section, Figure 3.3.4
3. Pipe, Figure 3.4.2
4. Pad(s), Figure 3.5.3.

For all of the tabulated results, the peak SCF at the shell/hole or pipe/pad(s) juncture is given. Appendix A contains a representative NASTRAN run. The detail computer printouts of the numerous cases fill a volume of 7 cubic feet; therefore, for brevity, Appendix B contains typical one page summaries of the NASTRAN runs presented in this section and Chapter III. These summaries for shell thicknesses 0.896 and 2.215 are organized in the following configurations: force, pipe, pipe and pad, pipe and pads, force and pad, and force and pads.

The one page summary defines parameters used to model thatconfiguration: shell mid radius (R) and thickness (T); hole radius (ρ_a); pipe mid radius (ρ_o) and thickness (t); outer pad outside radius (ρ_{op}) and thickness (t_{op}); inner pad outside radius (ρ_{ip}) and thickness (t_{ip}); and Poisson's radio of shell (ν), pipe (ν_p), and pad(s) (ν_{PAD}). The location of each SCF is determined by (1) the angle (ϕ, see Figures 2.2.1 and 2.2.2); (2) inside surface (I/s) or outside surface (0/s) of shell, pipe, and pad(s); and (3) ratio of the grid point location (ρ, see Figures 2.2.1 and 2.2.2) divided by the pipe mid radius (ρ_o). The peak SCF used as the design criterion is the largest of all SCF values computed for a configuration.

The accuracy of the NASTRAN results is determined by comparing to theoretical and experimental data. Since limited data are available for reinforced penetrations, many different configurations were modeled to supplement the published "exact" data to provide the accuracy and restrictions to the formula.

5.2 Formula Restrictions and Conditions

The accuracy of the formula presented in Chapter IV was improved by imposing certain restrictions and conditions based on the results in this chapter. These results were from experimental, theoretical, published numerical, and the NASTRAN analytical results. The general restrictions inherent in any shell theory or finite element solution are as follows:

1. $\frac{\rho_o}{R} \leq \frac{1}{2}$ (Equation (9))

2. $\left.\begin{array}{l} \dfrac{\rho_o}{t} > 10 \\ \\ \end{array}\right\}$ (thin shell theory)

3. $\dfrac{R}{T} > 10$

4. $\rho_a/T \geq 1.2$ (Transverse shear effect).

There are other conditions that the author has used to improve the accuracy of the formula. These conditions are

1. $\frac{t}{T} < 0.4$; use $SCF_{pipe} = SCF_{force}$,

   but retain the calculated SCF_{pipe} for $SCF_{pad(s)}$.

2. $TH = \left\{\begin{array}{ll} t & \text{for } \frac{R}{T} > 33 \\ T & \text{for } \frac{R}{T} \leq 33 \end{array}\right\}$ in Equation (32).

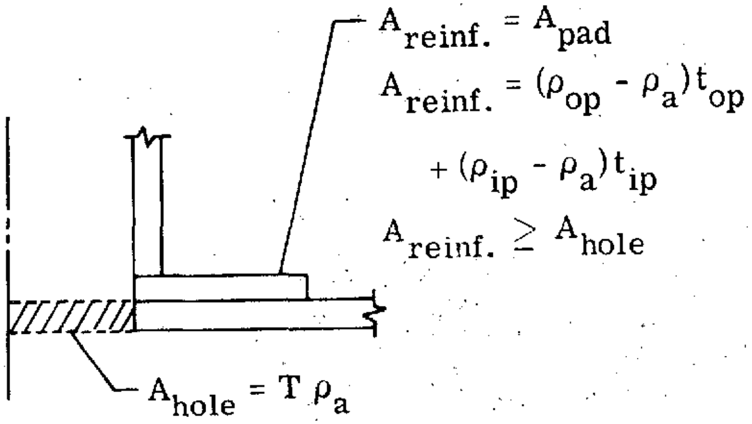
3. If ASME "coded" top or bottom pad[(39)] (approximately $A_{hole} \leq A_{reinf.}$), see Figure 5.2.1, and $\dfrac{\rho_o}{t} > 10$, then treat as a two pad problem with $\frac{1}{2}\ t_p$ on top and $\frac{1}{2}\ t_p$ on bottom.

4. $(\beta_1\ \rho_o)^2\ (\frac{t}{T})^{1/4} \leq 1.9$ or pipe is "ill-conditioned."

5. If $(\beta_1\ \rho_o)^2\ (\frac{t}{T})^{1/4} > 1.0$, treat as "coded" pad - condition 3.

6. If $0.9 < (\beta_1\ \rho_o)^2\ (\frac{t}{T})^{1/4} < 1.3$, use

   $e^{-(\beta_1\ \rho_o)^2\ (\frac{t}{T})^{1/4}}$ in Equation (32) in place of Equation (25).



$$A_{reinf.} = A_{pad}$$

$$A_{reinf.} = (\rho_{op} - \rho_a)t_{op} + (\rho_{ip} - \rho_a)t_{ip}$$

$$A_{reinf.} \geq A_{hole}$$

$$A_{hole} = T\,\rho_a$$

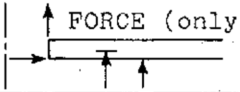
Figure 5.2.1.- Illustration of "reinforcement" required for ASME coded top or bottom pad. (38)

7. If $t = 0$ and configuration is pad(s) reinforced, then $\rho_p \equiv 2\ \rho_p$, $TH = T$, and treat as "coded" pad.
8. SCF from Equations (31) and (32) is always ≥ 1.0.

All the formula stress concentration factors are obtained from a computer program which is based on Equation (32) and these restrictions and conditions.

5.3 Force, Pipe, and Pipe/Pad(s)

Several calculations were obtained for the configuration of Figure 4.2.1, force around the hole. These results were computed to compare with theoretical ("exact") results(1,2,3) as well as to provide check points for the formula presented in Chapter IV, Equation (32). Throughout this chapter, the formula answers will be referred to as SCF Ramsey. The comparisons between NASTRAN/"exact" (N-E), Ramsey/NASTRAN (R-N), and Ramsey/"exact" (R-E) for different shell and force configurations are presented in Table 5.3.1. The second result in this table for $\frac{R}{T} = 156.5$ will arbitrarily be defined as the only membrane result. All other results in this table are in the thin shell theory realm, $\frac{R}{T} > 10$. The overall differences of the comparisons of the results are as follows: N-E, 17.4% and -8.9%; R-N, 8.6% and -12.8%; and R-E, approximately ±5%. The minus sign in this study always indicates less than and the plus sign greater than.



PEAK SCF @ $\phi = 0$ & ρ_a ON INSIDE SURFACE

$\nu_S = 0.3 \quad \frac{R}{T} > 10$

ρ_a	R	T	SCF NASTRAN	SCF "EXACT"	SCF RAMSEY	% DIFF	
						N-E/R-N	R-E
2.42	25	0.2	6.497	5.534	5.663	17.40 -12.84	2.33
7.09	50	0.32	9.603	10.4	10.983	- 7.66 14.37	5.61
4.84	50	0.40	6.199	5.534	5.663	+12.02 - 8.65	2.33
8.712	90	0.72	5.746	5.534	5.663	3.83 - 1.44	2.33
10.842	112	0.896	5.406	5.534	5.663	- 2.31 4.75	2.33
13.0	112	1.084	5.907	6.027	6.259	- 1.99 5.95	3.85
14.52	150	1.2	5.404	5.534	5.663	- 2.35 4.79	2.33
13.309	112	1.25	5.643	5.746	5.916	- 1.79 4.84	2.96
13.0	112	1.25	5.555	5.614	5.760	- 1.05 3.69	2.60
12.285	112	1.25	5.374	5.319	5.411	1.03 0.69	1.73
12.25	50	2.0	6.033	6.257	6.552	- 3.58 8.60	4.71
13.309	112	2.1667	4.478	4.457	4.471	0.47 - 0.16	0.31
10.7667	112	2.1667	3.884	3.774	3.790	2.92 - 2.42	0.42
13.0	112	2.1667	4.464	4.371	4.380	2.13 - 1.88	0.21
12.285	112	2.1667	4.331	4.170	4.179	+ 3.86 - 3.51	0.22
13.2	72	2.215	5.233	5.353	5.450	- 2.24 4.15	1.81
12.01	112	2.9867	3.836	3.639	3.664	5.41 - 4.48	.69
10.752	112	8.96	2.694	2.958	2.811	- 8.93 4.34	-4.97

Table 5.3.1 - NASTRAN, EXACT(1, 2, 3), and Formula Comparisons for Different Shell and Force Configurations.

the "exact" value. In Figure 5.3.1 all three curves (NASTRAN, "exact" and formula) are approaching the flat plate ($\beta = 0$) value at 2.5. For $\beta\rho_a < 0.6$ the three curves concide. For $\beta\rho_a > 0.6$ the NASTRAN curve is below (as expected) the "exact", and the formula curve is above (as desired).

The shell and pipe configurations (Figure 4.3.1) are presented in Tables 5.3.2 through 5.3.6 for different types of comparisons for various categories. The types of comparisons are as follows: NASTRAN/exact/Ramsey, Table 5.3.2; analytical/Ramsey, Table 5.3.4; and experimental/Ramsey, Tables 5.3.3, 5.3.5 and 5.3.6. The categories are defined as the following: thin shell, $\frac{R}{T} \geq 10$; and thick shell, $\frac{R}{T} < 10$; thin pipe, $\frac{\rho_o}{t} \geq 10$; and thick pipe, $\frac{\rho_o}{t} < 10$. Several NASTRAN thin shell and thin pipe configurations were modeled to compare to theoretical$^{(1,11)}$, numerical$^{(7)}$, and experimental$^{(7,14,17,20,24)}$ results (see Table 5.3.2(a) and 5.3.3(a). The overall differences of the thin shell and pipe NASTRAN results from the "exact" are -14.0% to 8.9%. The formula differences between NASTRAN and "exact"$^{(1,7,11,14,17,20,24)}$ are approximately ±14%. Note the configuration where $\nu_p = 0.3$ and 0.5. The accuracy of the formula as compared to both NASTRAN solutions is approximately 3%.

The thin shell and thick pipe results are shown in Tables 5.3.2(b) and 5.3.3(b). Those in Table 5.3.2(b) are

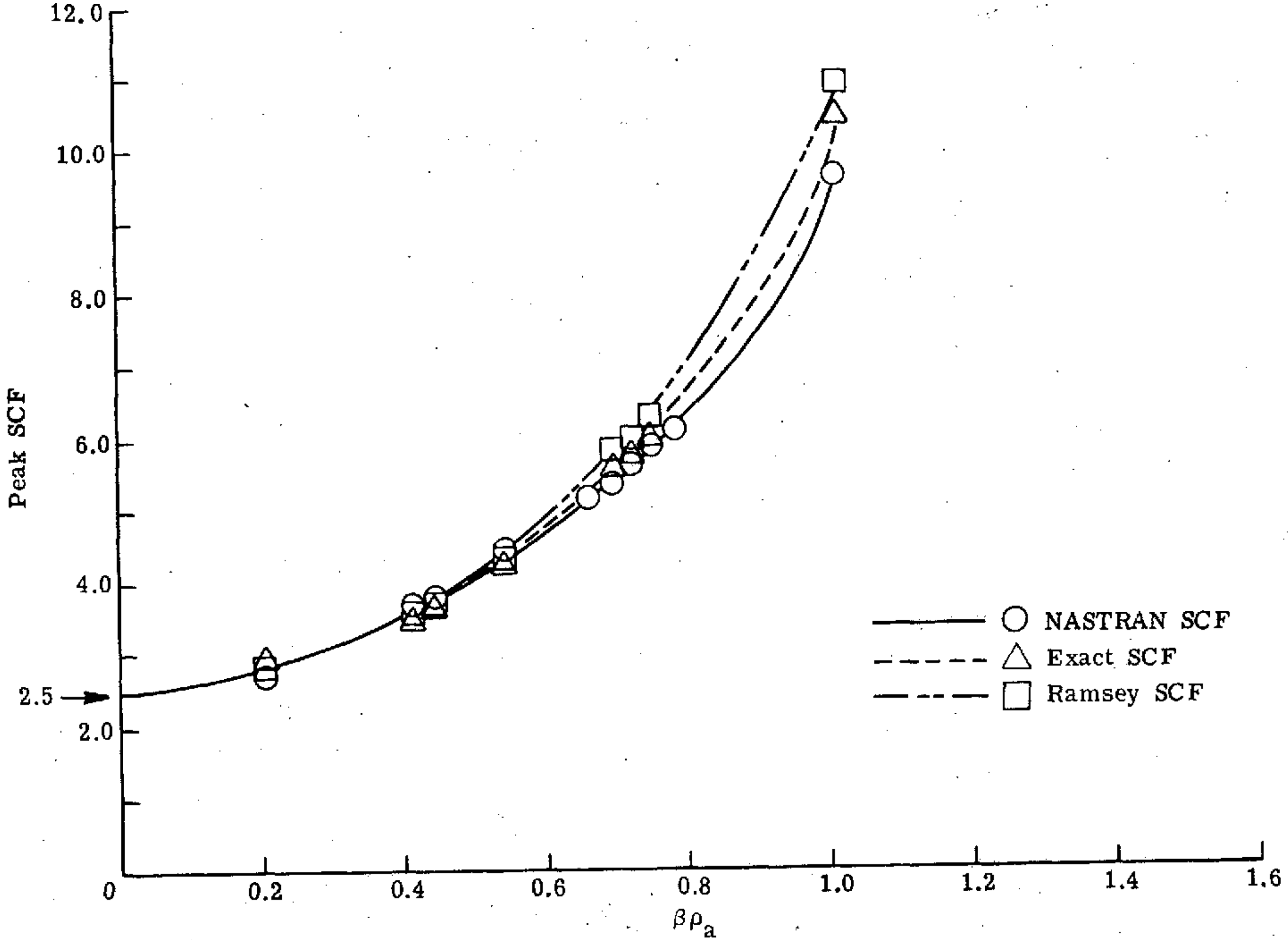


Figure 5.3.1.- Effect of shell thickness and curvature, and hole size ($\beta\rho_a$) on peak SCF for shell and force (t = 0) configurations.

Table 5.3.2 - NASTRAN, EXACT, and Formula Comparisons for Different Thin Shell and Thick/Thin Pipe Configurations: $\nu = 0.3$, $\nu_p = 0.3$; except as noted.

ρ_a	R	T	t	SCF NASTRAN	SCF "EXACT" Ref.(1, 11)	SCF RAMSEY	% DIFF	
							N-E/R-N	R-E
2.42	25	0.2	0.16	2.812	2.856	2.898	- 1.54 3.06	1.47
7.09	50	0.32	0.32	3.139	-	3.921	24.91	
4.84	50	0.40	0.34	2.776	2.856	2.844	- 2.80 2.44	- 0.42
8.712	90	0.72	0.576	2.760	2.856	2.898	- 3.36 5.00	1.47
10.842	112	0.896	0.717	2.812	-	2.897	3.02	
10.842	112	0.896	0.717(ν_p = 0.5)	3.061	-	3.152	2.97	
13.0	112	1.084	1.3	2.462	2.490	2.107	- 1.12 -14.42	-15.38
14.52	150	1.2	0.96	2.721	2.856	2.898	- 4.73 6.51	1.47
13.309	112	1.25	0.6825	3.544	3.420	3.120	3.63 -11.96	- 8.77
13.0	112	1.25	1.3	2.563	2.660	2.562	- 3.65 - 0.04	- 3.68
12.25	50	2.00	0.5	4.728	4.94	-	- 4.29	
13.309	112	2.1667	0.682	4.211	4.459	4.471	- 5.56 6.17	0.27
10.7667	112	2.1667	0.86668	2.992	3.157	3.146	-5.23 5.15	-0.35
13.0	112	2.1667	1.3	2.793	3.07	3.158	- 9.02 13.07	2.87
13.2	72	2.215	1.1	2.809	3.268	3.210	-14.04 14.28	1.77
10.752	112	8.96	0.896	2.770	2.790	2.811	- 0.72 1.48	0.75

(a) Thin Pipe $\frac{\rho_o}{t} \geq 10$

TABLE 5.3.2 - (concluded)

ρ_a	R	T	t	SCF NASTRAN	SCF "EXACT" Ref. ( )	SCF RAMSEY	% DIFF.	
							N-E/R-N	R-E
3.032 6.0	24.312 21.8125	0.625 1.625	0.28 1.625	3.078 -	2.84 (14) 2.60 (24)	3.209 2,407	8.38 4.26	12.99 -7.42
2.475 6.0	5.0 21.8125	0.1 1.625	.05 1.000	6.743 -	7.129 (7) 3.000 (24)	- 2.956	-5.42	-1.47

(a) Thin Pipe $\frac{\rho o}{t} \geq 10$

ρ_a	R	T	t	Ref.	SCF NASTRAN	SCF "EXACT"	SCF RAMSEY	% DIFF.	
								N-E/R-N	R-E
12.285	112	2.1667	2.73	(1,11)	2.347	(2.580)	2.775	$\frac{-4.03}{18.24}$	7.56
12.285	112	1.25	2.73	(1,11)	1.867	-	1.795	- 3.9	-
12.01	112	2.9867	4.48	(1,11)	2.332	2.345	2.647	$\frac{-0.55}{13.51}$	12.88
4.125	22.6725	4.845	0.938	(24)	-	3.3	2.918		-11.576
4.125	22.6725	4.845	0.938	(24)	-	2.7	2.918		8.074
5.9375	22.6725	4.845	1.438	(24)	-	3.3	3.367		2.03

(b) Thick Pipe ($\rho_o/t < 10$)

Table 5.3.3 - Experimental and Formula Comparisons for Thin Shell ($R/T \geq 10$) and Thin/Thick Pipe Configurations.

ρ_a	R	T	t	Reference	SCF "EXACT"	SCF RAMSEY	% DIFF
3.06	11.860	0.281	0.25	(17)	3.050	2.975	- 2.46
0.98	7.659	0.153	0.021	(20)	4.750	4.713	- 0.78
6.00	21.813	1.625	0.380	(17)	5.000	5.242	4.84

(a) THIN PIPE ($\rho_o/t \geq 10$)

0.97	24.844	1.688	0.730	(17)	3.120	2.524	-19.10
0.97	24.844	1.688	0.218	↓	3.060	2.561	-16.31
1.91	24.844	1.688	1.095	↓	2.980	2.589	-13.12
1.91	24.844	1.688	0.729	↓	2.980	2.622	-12.01
6.00	21.813	1.625	1.625	↓	2.700	2.407	-10.85
3.72	24.844	1.688	1.593	↓	2.910	2.719	- 6.56
6.00	21.813	1.625	1.000	↓	3.100	2.956	- 4.65

(b) THICK PIPE ($\frac{\rho_o}{t} < 10$)

slightly more accurate than the thin pipe results for both the formula (±12%) and NASTRAN (-4%) as compared to the "exact"(1,11;24) results. For the same category, it is shown in Table 5.3.3(b) that the formula comparisons are below the experimental(17) by 19%. The first four configurations in Table 5.3.3(b) and the last three in Table 5.3.2(b) have $\rho_a/T \leq 1.1$. At the end of Chapter IV, it was stated that transverse shear effects would be negligible provided $\rho_a/T > 3.0$ and $R/T \geq 25.0$. Both of these requirements are violated. Therefore, the low SCF from the formula is to be expected since the hole is too small and/or the shell too thick. Therefore, the overall accuracy of the formula for a thin shell and thick pipe is approximately ±12% by not including the configurations where $\rho_a/T < 1.1$ and $\frac{R}{T} < 14.7$.

The theoretical comparison of Eringen's(11) analytical results to the formula for the shell and pipe configurations is presented in Table 5.3.4. The accuracy between the two of ±8% is remarkable. The cases are tabulated by per cent difference from lowest to highest. These are the only valid cases from this report. The others violated all four of <u>his</u> theoretical requirements:

$R/T > 10$, $\rho_o/t > 10$, $\beta\rho_o < 0.5$, and $\rho_o/R \leq 1/3$.

Tables 5.3.5 and 5.3.6 present numerous experimental(8,11,16,17,19,21,22,135) configurations for thick

Table 5.3.4 - Formula and Analytical(11)Comparison for Shell and Pipe Configurations.

CASE NO.	2R/T	ρo/R	$\beta\rho_o$	t/T	SCF-LIT (Ref.(11)	SCF RAMSEY	% DIFF
131	250.00	.050	.35900	.1000	3.63	3.330	-8.26
104	100.00	.100	.45400	.1000	4.11	3.823	-6.98
102	100.00	.100	.45400	.4000	3.31	3.130	-5.43
125	250.00	.025	.18000	.0250	2.86	2.709	-5.27
132	250.00	.050	.35900	.0500	3.52	3.337	-5.20
124	250.00	.025	.18000	.0500	2.85	2.708	-5.00
126	250.00	.025	.18000	.0125	2.85	2.710	-4.91
127	250.00	.025	.18000	.0062	2.85	2.711	-4.89
64	50.00	.050	.16100	.0125	2.80	2.667	-4.75
130	250.00	.050	.35900	.2000	3.48	3.317	-4.68
20	10.00	.250	.35900	.1250	3.42	3.261	-4.63
63	50.00	.050	.16100	.0250	2.79	2.665	-4.47
16	10.00	.100	.14400	.0250	2.75	2.628	-4.42
97	100.00	.050	.22700	.0500	2.96	2.831	-4.37
98	100.00	.050	.22700	.0250	2.96	2.834	-4.25
99	100.00	.050	.22700	.0125	2.96	2.836	-4.20
21	10.00	.250	.35900	.0625	3.44	3.302	-4.01
32	25.00	.050	.11400	.0125	2.69	2.583	-3.99
91	100.00	.025	.11400	.0125	2.69	2.584	-3.96
92	100.00	.025	.11400	.0062	2.69	2.584	-3.94
18	10.00	.250	.35900	.5000	2.82	2.711	-3.88
38	25.00	.100	.22700	.0250	2.94	2.831	-3.71
103	100.00	.100	.45400	.2000	3.94	3.797	-3.64
39	25.00	.250	.56800	2.0000	2.22	2.142	-3.51
123	250.00	.025	.18000	.1000	2.80	2.704	-3.42
31	25.00	.050	.11400	.0250	2.67	2.581	-3.33
90	100.00	.025	.11400	.0250	2.67	2.583	-3.27
62	50.00	.050	.16100	.0500	2.75	2.662	-3.20
129	250.00	.050	.35900	.4000	3.05	2.953	-3.17
37	25.00	.100	.22700	.0500	2.91	2.824	-2.95
96	100.00	.050	.22700	.1000	2.91	2.824	-2.95
15	10.00	.100	.14400	.0500	2.70	2.662	-2.89
19	10.00	.250	.35900	.2500	3.27	3.183	-2.65
56	50.00	.025	.08000	.0125	2.61	2.541	-2.63
57	50.00	.025	.0800	.0062	2.61	2.542	-2.61
119	250.00	.010	.07200	.0050	2.60	2.534	-2.55
120	250.00	.010	.07200	.0025	2.60	2.534	-2.55
105	100.00	.100	.45400	.0500	3.93	3.837	-2.38
11	10.00	.050	.07200	.0125	2.59	2.582	-2.24
118	250.00	.010	.07200	.0100	2.59	2.533	-2.18
55	50.00	.025	.08000	.0250	2.59	2.541	-1.91
89	100.00	.025	.11400	.0500	2.63	2.581	-1.86
117	250.00	.010	.07200	.0200	2.58	2.533	-1.81
30	25.00	.050	.11400	.0500	2.62	2.578	-1.61
10	10.00	.050	.07200	.0250	2.57	2.530	-1.54

Table 5.3.4 (Continued)

CASE NO.	2R/T	ρo/R	$\beta\rho_o$	t/T	SCF-LIT Ref.(11)	SCF RAMSEY	% DIFF
134	250.00	.050	.35900	.0125	3.38	3.342	-1.12
116	250.00	.010	.07200	.0400	2.55	2.533	-0.68
71	50.00	.100	.32100	.0250	3.19	3.168	-0.68
69	50.00	.100	.32100	.1000	3.16	3.148	-0.37
133	250.00	.050	.35900	.0250	3.35	3.340	-0.29
70	50.00	.100	.32100	.0500	3.17	3.162	-0.27
54	50.00	.025	.08000	.0500	2.54	2.539	-0.04
9	10.00	.050	.07200	.0500	2.52	2.527	0.29
36	25.00	.100	.22700	.1000	2.79	2.811	0.75
61	50.00	.050	.16100	.1000	2.63	2.656	0.97
6	13.13	.129	.21300	.1335	2.72	2.750	1.11
114	250.00	.010	.07200	.1600	2.49	2.530	1.59
14	10.00	.100	.14400	.1000	2.56	2.609	1.93
106	100.00	.100	.45400	.0250	3.77	3.843	1.94
115	250.00	.010	.07200	.0800	2.48	2.532	2.08
43	25.00	.250	.56800	.1250	4.42	4.526	2.39
35	25.00	.100	.22700	.2000	2.72	2.786	2.41
87	100.00	.025	.11400	.2000	2.51	2.571	2.45
34	25.00	.100	.22700	.4000	2.56	2.626	2.58
88	100.00	.025	.11400	.1000	2.51	2.578	2.70
60	50.00	.050	.16100	.2000	2.56	2.643	3.24
29	25.00	.050	.11400	.1000	2.49	2.571	3.27
41	25.00	.250	.56800	.5000	3.02	3.123	3.40
53	50.00	.025	.08000	.1000	2.45	2.536	3.50
122	250.00	.025	.18000	.2000	2.60	2.698	3.76
86	100.00	.025	.11400	.4000	2.43	2.533	4.24
59	50.00	.050	.16100	.4000	2.46	2.565	4.27
95	100.00	.050	.22700	.2000	2.69	2.811	4.50
68	50.00	.100	.32100	.2000	2.97	3.122	5.12
8	10.00	.050	.07200	.1000	2.39	2.522	5.51
52	50.00	.025	.08000	.2000	2.39	2.530	5.85
28	25.00	.050	.11400	.2000	2.41	2.560	6.20
137	250.00	.100	.71800	.4000	3.20	3.403	6.35
44	25.00	.250	.56800	.0625	4.28	4.567	6.71
67	50.00	.100	.32100	.4000	2.64	2.820	6.80
121	250.00	.025	.18000	.4000	2.44	2.616	7.20
94	100.00	.050	.22700	.4000	2.49	2.672	7.29
13	10.00	.100	.14400	.2000	2.41	2.586	7.32
128	250.00	.050	.35900	.8000	2.65	2.844	7.34
101	100.00	.100	.45400	.8000	2.72	2.933	7.82

Table 5.3. 5 - Experimental and Formula Comparisons for Different Thick Shell and Pipe (R/T and $\rho_o/t < 10$) Configurations.

ρ_a	R	T	t	Reference	SCF "EXACT"	SCF RAMSEY	% DIFF. R-E
1.41	3.67	0.590	0.445	(21)	3.070	2.620	-14.66
0.91	3.652	0.553	0.281		3.360	2.920	-13.10
0.91	3.653	0.555	0.285		3.320	2.915	-12.20
0.56	3.286	1.011	0.093		3.090	2.755	-10.84
0.91	3.656	0.563	0.279		3.280	2.921	-10.95
1.00	19.000	2.000	0.188		2.780	2.571	- 7.52
1.41	3.670	0.590	0.400		2.840	2.745	- 3.35
0.44	3.694	0.568	0.073	(8,11,21)	2.800	2.749	- 1.82
1.09	3.578	0.377	0.434	(21)	2.280	2.235	- 1.97
1.41	3.315	1.009	0.236		4.110	4.105	- 0.12
0.68	3.658	0.565	0.112		3.040	3.104	2.11
0.91	3.653	0.565	0.227		2.900	2.985	2.93
0.17	3.516	0.565	0.027		2.450	2.539	3.63
0.51	3.670	0.490	0.218	(16)	2.520	2.683	6.47

Table 5.3.6 - Formula and Experimental Comparison for Thick Shell and Thick Pipe Configurations.

ρ_a	R	T	t	Reference	SCF "EXACT"	SCF RAMSEY	% DIFF.
4.78	19.00	2.0	2.405	(17)	3.140	2.444	-22.17
2.88	9.50	1.0	0.432	(22)	3.779	3.216	-14.90
0.91	3.652	0.553	0.281	(21)	3.360	2.920	-13.10
0.92	3.648	0.546	0.280	(17)	3.360	2.928	-12.86
0.91	3.653	0.550	0.285		3.320	2.915	-12.20
4.13	22.673	4.845	0.94		3.300	2.919	-11.55
0.95	3.653	0.555	0.285	(21)	3.320	2.940	-11.45
0.56	3.286	1.011	0.092	(17)	3.090	2.755	-10.84
0.91	3.656	0.563	0.279	(17, 21)	3.280	2.921	-10.95
3.72	24.844	4.188	0.593	(17)	3.100	2.859	- 7.77
1.45	19.0	2.0	1.144	(17)	2.750	2.547	- 7.38
1.0	19.0	2.0	0.188	(17, 135)	2.760	2.571	- 6.85
0.92	3.650	0.565	0.277	(19)	2.900	2.931	1.07
5.94	22.673	4.845	1.440	(17)	3.300	3.367	2.03
0.91	3.658	0.565	0.227	(17, 21)	2.900	2.985	2.93
0.68	3.658	0.565	0.112	(17, 21)	3.000	3.104	3.47
0.17	3.658	0.565	0.027		2.450	2.538	3.59
0.51	3.620	0.490	0.369		2.220	2.593	16.80

shells and pipes. The comparison between the formula and these experiments are presented to illustrate the need to impose the restrictions presented in Section 5.2. The differences between the formula and thick shell and pipe experimental results are -22% to +17%.

The shell/pipe/pad (top and bottom) configurations (Figure 4.4.1) are listed in Tables 5.3.7 through 5.3.9. The same categories as shell and pipe are maintained for the shell/pipe/pad comparisons. The comparisons are for NASTRAN, formula, and six experimental results. The thin shell and pipe ($\frac{R}{T}$ and $\frac{\rho_o}{t} \geq 10$) cylinders with a top pad are presented in Table 5.3.7. The differences of the formula as compared to NASTRAN for the top pad are -15.9% to 11.4%. The thin shell and pipe with a bottom pad are listed in Table 5.3.8. The formula differences for the bottom pad as compared to NASTRAN and the one experimental result(24) are -16.1% to +3.2%. The thick pipe ($\frac{\rho_o}{t} < 10$), thin/thick shell, and pad results are shown in Table 5.3.9.

The last three configurations in Table 5.3.7 and first three in Table 5.3.9 have only one difference - Poisson's ratio. There are 0.8% (Table 5.3.7) and 1.0% (Table 5.3.9) differences between the NASTRAN SCF for all ν's = 0.3 and for $\nu = 0.3$, $\nu_p = \nu_{pad} = 0.5$. Based on these six examples, the formula only provides a different Poisson's ratio for

Table 5.3.7 - NASTRAN, EXPERIMENTAL, and Formula Comparison for Thin Shell, Thin Pipe, and Top Pad Configurations.

ρ_a/ρ_o	R	T	t	ρ_{op}	t_{op}	SCF NASTRAN	SCF RAMSEY	% Diff.
2.42 2.50	25	0.2	0.16	4.25	0.125	2.403	2.384	- 0.79
7.09 7.25	50	0.32	0.32	11.25	0.25	2.889	2.976	3.01
4.84 5.01	50	0.4	0.34	8.5	0.25	2.369	2.338	- 1.31
8.712 9.00	90	0.72	0.576	14.75	0.50	2.303	2.389	3.73
10.842 11.2	112	0.896	0.7168	19.85935	0.50	2.403	2.377	- 1.08
10.842 11.2	112	0.896	0.7168	20.0	1.00	1.945	1.848	- 4.99
14.52 15.00	150	1.200	0.96	23.0	1.00	2.154	2.400	11.42
13.309 13.65	112	1.25	0.6825	24.999	1.50	2.134	1.795	-15.89
13.0 13.65	112	1.25	1.3	24.999	1.50	1.868	1.883	0.80
12.031 12.50	125	1.25	0.938	21.5	1.50	1.924	2.030	5.51
12.25 12.50	50	2.00	0.50	21.0	1.50	2.908	2.772	- 4.68
13.309 13.65	112	2.1667	0.6825	24.999	1.50	2.421	2.620	8.22
10.7667 11.2	112	2.1667	0.86668	18.5625	1.50	2.396	2.533	5.72
13.0 13.65	112	2.1667	1.3	24.999	1.50	2.259	2.479	9.74

TABLE 5.3.7 - (Concluded)

ρ_a/ρ_o	R	T	t	ρ_{op}	t_{op}	SCF NASTRAN	SCF RAMSEY	% Diff.	SCF "Exact" or Notes
13.2 13.75	72	2.215	1.10	23.0	1.50	2.783	2.533	- 8.98	
10.752 11.2	112	8.96	0.896	20.64	5.00	2.316	2.215	- 4.36	
3.032 3.172	24.312	0.625	0.28	5.25	0.625	2.498	2.461	- 3.85 - 1.48 - 5.35	Ref. (14) 2.60 ν =0.3
3.032 3.172	24.312	0.625	0.28	5.25	0.625	2.484	2.546	2.50	ν =0.3 ν_p=0.5 ν_{pad}=0.3
3.032 3.172	24.312	0.625	0.28	5.25	0.625	2.476	2.546	2.83	ν =0.3 ν_p=0.5 ν_{pad}=0.5

Table 5.3.8 - NASTRAN and Formula Comparison for Thin Shell, Thin Pipe, and Bottom Pad Configurations.

ρ_a/ρ_o	R	T	t	ρ_{ip}	t_{ip}	SCF NASTRAN	SCF RAMSEY	% DIFF.	SCF "Exact" Ref. (24)
10.842 11.2	112	0.896	0.7168	20.25	1.00	1.779	1.835	3.15	—
13.0 13.65	112	1.25	1.30	25.0	1.50	1.824	1.883	3.23	—
13.2 13.75	72	2.215	1.10	23.0	1.50	3.019	2.533	-16.10	—
5.9 6.135	21.813	1.625	0.469	9.869	2.75		1.827	-3.84	1.900

Table 5.3.9 - NASTRAN, Experimental, and Formula Comparison for Thick/Thin Shell, Thick Pipe, and Top Pad Configurations.

ρ_a/ρ_o	R	T	t	ρ_{op}	t_{op}	NOTES	SCF NASTRAN	SCF "EXACT"	SCF RAMSEY	% DIFF	
										N-E/R-N	R-E
4.782 5.0785	19	2.0	0.593	9.482	2.0		2.399	(15) 2.51	2.277	-4.42 -5.09	-9.28
4.782 5.0785	19	2.0	0.593	9.482	2.0	ν_p=0.5	2.349		2.355	0.26	
4.782 5.0785	19	2.0	0.593	9.482	2.0	ν_p=ν_{PA}=0.5	2.372		2.355	-0.72	
2.88 3.095	9.5	1.0	0.43	4.858	2.0			(17) 2.07	2.105		+1.7
2.88 3.095	9.5	1.0	0.43	5.437	1.125			(17) 2.22	2.149		-3.2
2.8815 3.0975	9.5	1.0	0.432	5.4375	1.125			(22) 2.295	2.145		-6.5

(a) Thick Shell.

Table 5.3.9 (Continued)

ρ_a/ρ_o	R	T	t	ρ_{op}	t_{op}	SCF NASTRAN	SCF RAMSEY	% DIFF.
12.285 13.65	112	2.1667	2.73	24.999	1.50	1.914	2.195	14.68
12.01 14.25	112	2.9867	4.48	18.0	2.00	2.212	2.246	1.54
12.285 13.65	112	1.25	2.73	24.999	1.50	1.379	1.215	-11.89

(b) Thin Shell

the shell and pipe. The overall differences between NASTRAN and the formula for the shell/pipe/and pad (top and bottom) are -16.1% to 11.4%. The comparisons between experiments and the formula are -9.3% to 1.7% differences.

The NASTRAN/formula comparisons for shell, pipe, and pads configurations (see Figure 4.5.1) are presented in Table 5.3.10. All of these results are for thin shell and pipe except the three thick pipe configurations denoted by an asterisk (*) in the "exact" column. The "two pad" experimental investigation presented in Chapter III is also included. The configuration that is presented in Appendix A as a representative NASTRAN program is indicated by "Appendix A" in the "exact" column. Most of the SCF values obtained are for configurations that represent current pressure vessel analysis, design, and construction - i.e. identical inner and outer pad thicknesses and outside radii. The fifth through the seventh configurations in Table 5.3.10 have different geometries for the two pads. The accuracy of the formula for these examples is approximately ±6%. The overall accuracy is -8.91% to +14.65% difference.

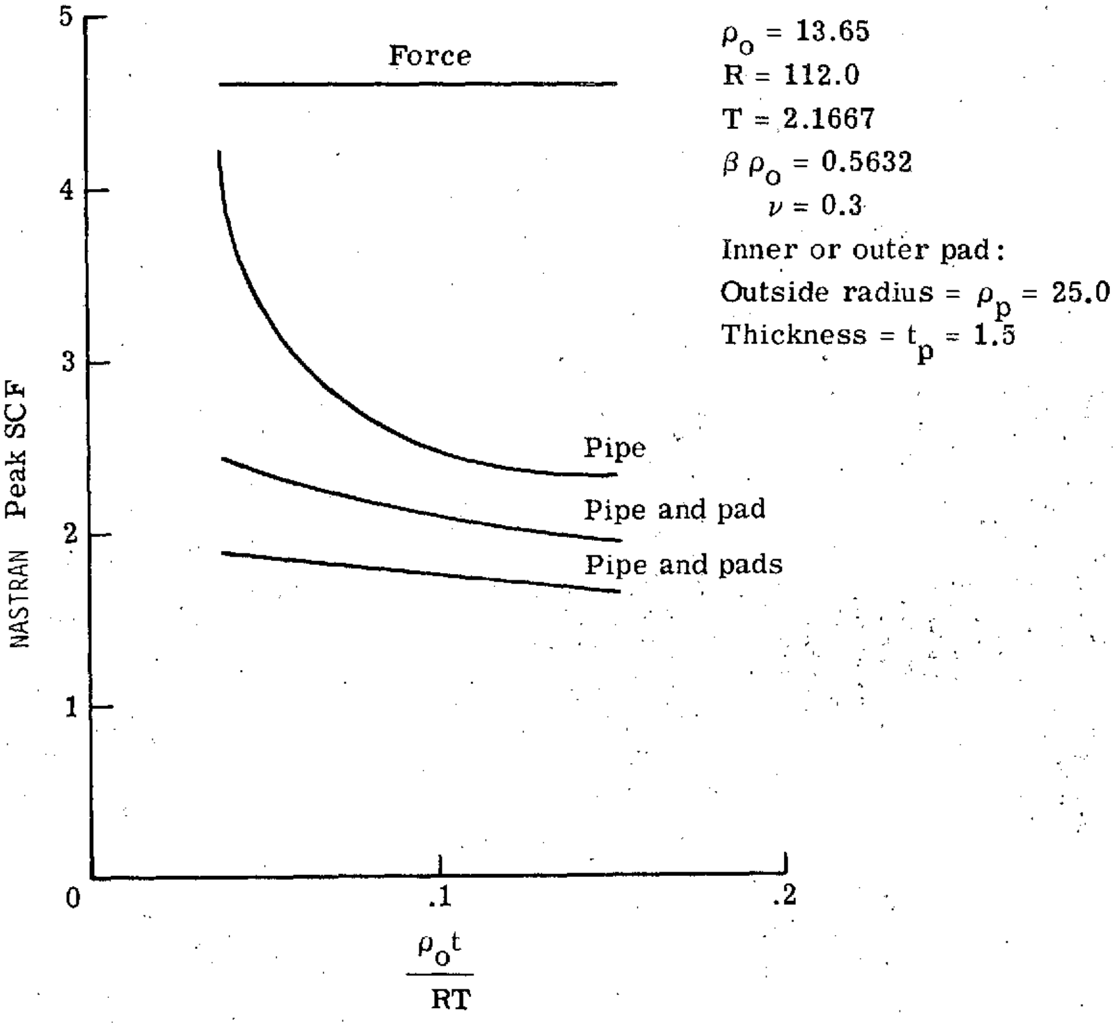
Figures 5.3.2 and 5.3.3 are representative of the manner in which peak stress concentration factors (SCF) for a pressurized cylindrical shell are affected by (1) thickness and curvature of shell and hole size ($\beta\rho_a$), and (2) reinforcement configurations (pipe and pipe/pad(s)).

Table 5.3.10 - NASTRAN, Experimental and Formula Comparison for Thin Shell, Thin Pipe, and Pads Configuration.

ρ_a & ρ_o	R	T	t	ρ_{oP}	t_{oP}	ρ_{iP}	t_{iP}	SCF NASTRAN	SCF "EXACT"	SCF RAMSEY	% DIFF.
2.42 2.50	25	0.2	0.16	4.25	0.125	4.25	0.125	1.871	-	1.870	0.05
7.09 7.25	50	0.32	0.32	11.25	0.25	11.25	0.25	1.940	**	2.032	4.74
4.84 5.01	50	0.4	0.34	8.5	0.25	8.5	0.25	1.846		1.832	- 0.76
8.712 9.000	90	0.72	0.576	14.75	0.50	14.75	0.50	1.735		1.881	8.42
10.842 11.2	112	0.896	0.7168	19.85935	0.50	19.85935	0.50	1.967		1.856	- 5.64
10.842 11.2	112	0.896	0.7168	19.85935	0.50	17.43	0.75	1.855		1.871	0.86
10.842 11.2	112	0.896	0.7168	19.85935	0.50	19.85935	1.00	1.656		1.757	6.10
14.52 15.00	150	1.200	0.960	23.0	1.00	23.0	1.00	1.659		1.902	14.65
13.309 13.65	112	1.25	0.6825	24.999	1.50	24.999	1.50	1.383		1.544	11.64
13.0 13.65	112	1.25	1.3	24.999	1.50	24.999	1.50	1.295		1.204	- 7.03
12.285 13.65	112	1.25	2.73	24.999	1.50	24.999	1.50	1.032	*	1.000	- 3.10
12.25 12.50	50	2.00	0.50	21.0	1.50	21.0	1.50	2.177		1.983	- 8.91
13.309 13.65	112	2.1667	0.6825	24.999	1.50	24.999	1.50	1.904		1.832	- 3.78
10.7667 11.2	112	2.1667	0.86668	18.5625	1.50	18.5625	1.50	1.876		1.920	2.35

TABLE 5.3.10 - (Concluded)

ρ_a & ρ_o	R	T	t	ρ_{oP}	t_{oP}	ρ_{iP}	t_{iP}	SCF NASTRAN	SCF "EXACT"	SCF RAMSEY	% DIFF.
13.0 13.65	112	2.1667	1.3	24.999	1.50	24.999	1.50	1.820		1.800	-1.10
12.285 13.65	112	2.1667	2.73	24.999	1.50	24.999	1.50	1.626	*	1.615	-0.68
13.2 13.75	72	2.215	1.10	23.0	1.50	23.0	1.50	1.957	APPENDIX A	1.856	-5.1
12.01 14.25	112	2.9867	4.48	18.0	2.00	18.0	2.00	1.935	*	1.845	-4.65
10.752 11.2	112	8.96	0.896	20.64	5.00	20.64	5.00	1.527		1.701	11.40
5.90 6.13	21.813	1.625	0.460	9.86	1.38	9.86	1.38	1.964	Ref.(23&24) 1.80	1.838	9.11 -6.42 2.11



$\rho_o = 13.65$
$R = 112.0$
$T = 2.1667$
$\beta \rho_o = 0.5632$
$\nu = 0.3$
Inner or outer pad:
Outside radius = $\rho_p = 25.0$
Thickness = $t_p = 1.5$

Figure 5.3.2.- Effect of reinforcement (pipe and pipe/pad(s) configurations) on peak SCF for a pressurized cylindrical shell ($\beta \rho_o = 0.5632$).

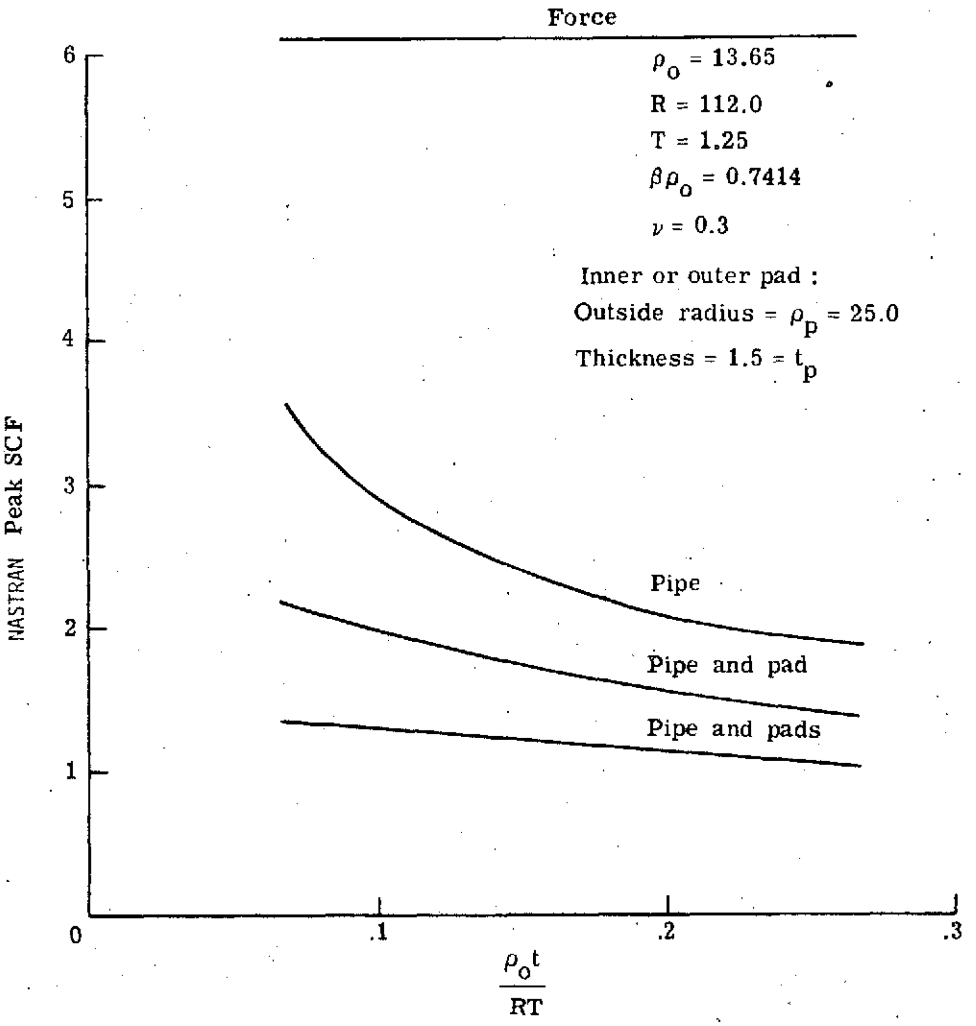


Figure 5.3.3.- Effect of reinforcement (pipe and pipe/pad(s) configurations) on peak SCF for a pressurized cylindrical shell ($\beta\rho_o$ = .7414).

The force value in each figure was obtained from Figure 5.3.1. For both $\beta\rho_o = 0.5632$ and $\beta\rho_o = 0.7414$, the largest reduction in SCF is due to the reinforcement either offered from a "thick" pipe or from a "thin" pipe and one pad. This was typical of all results obtained. The SCF reduction due to a second pad was always minor in comparison to that obtained from a thick pipe or pipe/pad configuration. Although more pronounced for the smaller $\beta\rho_o$ (analogons to smaller hole), the peak stress concentration factors for the shell and pipe rapidly increase as $\frac{\rho_o t}{RT}$ decreases. This is indicative of the transverse shear effects (small ρ_o/T). Extension of the pipe and pad(s) curves to the peak SCF ordinate at $t = 0$ yields the answer for the shell/force/pad(s) configurations.

5.4 Force and Pad(s)

It was stressed in Chapter IV that the primary thrust of the analysis would be for the cases previously presented. Another type of configuration can be solved by the formula. This is for $t = 0$ and the hole reinforced by one or two pads. Table 5.4.1 contains comparisons of formula to NASTRAN results for thin, pressurized, cylindrical shells with pad(s) reinforcing a hole covered with a membrane (force only). This type of configuration is identical to Figure 4.2.1 plus one or two reinforcing pads. The formula results for

Table 5.4.1 - Comparison of Formula to NASTRAN Results for Thin Shell with Pad(s) Reinforcing a Hole.

ρ_a	R	T	ρ_p	t_p	TOP or BOT.	SCF NASTRAN	SCF RAMSEY	% DIFF
4.84	50	0.4	8.5	0.25	TOP	5.158	4.691	- 9.05
4.84	50	0.4	8.5	0.25	BOT.	3.589	4.029	12.26
10.842	112	0.896	19.86	0.50	TOP	5.174	4.678	- 9.59
10.842	112	0.896	19.86	0.50	BOT.	3.810	4.006	5.14
12.031	125	1.25	21.50	1.50	BOT.	3.656	3.840	5.03
13.2	72	2.215	23.0	1.50	TOP	3.912	4.097	4.73
11.0	72	1.44	20.0	1.875	TOP	3.766	4.133	9.75
11.0	72	1.44	20.0	1.875	BOT.	3.654	4.133	13.11

(a) Force and Pad

ρ_a	R	T	ρ_{op}	t_{op}	ρ_{ip}	t_{ip}	SCF NASTRAN	SCF RAMSEY	% DIFF
4.84	50	0.4	8.5	0.25	8.5	0.25	3.197	3.057	- 4.38
8.172	90	0.72	14.75	0.50	14.75	0.50	2.655	2.620	- 1.32
10.842	112	0.896	19.86	0.50	19.86	0.50	3.364	3.021	-10.20
11.0	72	1.44	20.0	1.875	20.0	1.875	1.668	1.580	- 5.28

(b) Force and Pads

the top pad configuration have an accuracy of approximately ±9.7%, whereas all of bottom pad stress concentration factors were 5% to 13% above the NASTRAN results. All of the force and pads formula results were below the NASTRAN answers. The difference range is -10.2% to -1.3%.

CHAPTER VI

DISCUSSION OF RESULTS

This study provides numerical predictions of peak stress concentration factors around nonreinforced and reinforced penetrations. Numerical results have been correlated with published formulas, as well as theoretical and experimental results. Most of the configurations have been for thin shells, and all are based on linear elastic structures. Some thick shell NASTRAN and published results were obtained. An accuracy study was made of the finite element program for each of the configurations considered important in pressure vessel technology. A formula was developed to predict the peak stress concentration factor for analysis and/or design in conjunction with the ASME Pressure Vessel Code. The accuracy of the empirical formula is determined by comparing to numerical, theoretical, and experimental data.

The peak stress concentration factors (SCF) presented in Chapter V have confirmed that the 3.3 limit imposed by the ASME Code is indeed conservative for the vast majority of cases. The peak SCF results due to reinforcement (pipe or pad(s)) around a circular penetration in cylindrical, pressurized shells suggest a different number. If fact, 78.5% (124 out of 158) of the shell and pipe configurations were less than 3.3. Using the procedure for a well designed penetration presented in Ref. (25) and shown approximately in Figure 5.2.1, the one pad problems (32) were checked for ASME Code reinforcement requirements. The six "coded" pad configurations are as follows: Table 5.3.7, first two t = 1.25 configurations (SCF = 2.134 and 1.868); Table 5.3.8, second and fourth configurations (SCF = 1.824 and 1.827); and Table 5.3.9, first T = 1.0 and T = 1.25 configurations (SCF = 2.07 and 1.379). All of the other 26 one pad configurations were not "coded" and yet had peak SCF results equal to or below 3.0. The two pad problems were mostly "coded" (by choice). The seven configurations in Table 5.3.10 which are not "coded" are the first five examples and those with T = 1.2 and T = 4.48. For the two pad configuration only one of the twenty problems had a peak SCF outside of the range of 1.0 to 2.0. This was a "coded" pads configuration (T = 2.0 and R/T = 25) with a peak SCF = 2.177. Based on these results, a "thick" pipe (Figure 5.3.3), "coded" pad, or two pad configuration would have a peak SCF of about 2.2 (2/3 of the 3.3 limit), whereas the shell and pipe configuration could achieve the "well designed penetration" (SCF = 3.3) definition.

All of the peak SCF results are summarized in Table 6.1 according to thick, thin, or membrane shell definitions. The NASTRAN results compared to published values, +17.4% to

TABLE 6.1

SCF % DIFFERENCE SUMMARY

CASES	THIN SHELL & PIPE			THIN SHELL & THICK PIPE			MEM. SHELL & THIN PIPE			THICK SHELL & PIPE		
	NASTRAN TO EXACT	RAMSEY TO NASTRAN	RAMSEY TO EXACT	NASTRAN TO EXACT	RAMSEY TO NASTRAN	RAMSEY TO EXACT	NASTRAN TO EXACT	RAMSEY TO NASTRAN	RAMSEY TO EXACT	NASTRAN TO EXACT	RAMSEY TO NASTRAN	RAMSEY TO EXACT
FORCE	- 8.93 TO 17.40	-12.84 TO 8.60	- 4.97 TO 4.71	-	-	-	-7.66	14.37	5.61	-	-	-
PIPE	-14.04 TO + 8.88	-14.42 TO 14.28	-15.38 TO 12.99	-4.03 TO -0.55	- 3.90 TO 18.24	-10.85 TO 12.88	-	24.91	-	-	-	-22.17 TO 16.80
PIPE & PAD	- 3.85	-16.10 TO 11.42	-5.35 TO -3.84	-	-11.89 TO 14.68	-	-	3.01	-	-4.42	-5.09 TO -0.72	-9.28 TO +1.70
PIPE & PADS	9.11	- 8.91 TO 14.65	2.11	-	- 4.65 TO - 0.68	-	-	4.74	-	-	-	-
FORCE & TOP PAD	-	- 9.59 TO 9.75	-	-	-	-	-	-	-	-	-	-
FORCE & BOT PAD	-	+ 5.03 +13.11	-	-	-	-	-	-	-	-	-	-
FORCE & PADS	-	-10.20 TO - 1.32	-	-	-	-	-	-	-	-	-	-

-8.9%, are high, as expected, when the membrane category is approached and low for an almost thick shell. This same general trend is true for the shell and pipe examples. The thin shell and pipe NASTRAN accuracy is +8.8% to -14.0%. There is not enough data to determine any trend for the pipe and pad(s) NASTRAN results.

The formula results compare favorably with NASTRAN and the published "experimental, theoretical, and numerical" data. The results for individual comparisons to NASTRAN and "exact" are shown in Table 6.1 by categories. The thin shell approximate percent difference results are as follows: force, ±4.8%; pipe, ±14.4%; pipe and pad, ±13.7%; pipe and pads, ±11.7%; force and top pad, ±9,7%; force and bottom pad, 13%; and force and pads, -10%.

One application of this formula is to an ASME Code "hillside" (elliptical hole) penetration. The amplification factor by the code for this penetration is $1 + 2 \sin^2$ (the angle the axis of the pipe makes with the normal to the shell wall). Two experimental results were obtained.(15,38) This amplification factor was multiplied times the (circular) peak SCF from the formula to obtain the following comparisons:

1. "Exact" SCF = 1.840(15) vs formula SCF = 1.826 (-0.8% difference) for $\rho_a = 4.782$, $R = 19.0$, $T = 1.0$, $t = 0.593$, $\rho_{op} = 7.438$, $t_{op} = 11.625$ $\nu = 0.3$, and the angle = 20°.

2. "Exact SCF = 2.897$^{(38)}$ vs formula SCF = 2.897 (-9.9% difference) for ρ_a = 11.94, R = 69.185, T = 1.995, ν = 0.3, and the angle = 45°.

CHAPTER VII

SUMMARY

The effect on stresses in a cylindrical shell with a circular penetration subject to internal pressure has been investigated. A general purpose finite element (NASTRAN) computer program was utilized to supplement the limited data for reinforced penetrations. A mesh generation computer program was developed to "automatically" punch input cards in the format acceptable to NASTRAN. This program is readily adaptable to solving a general finite element shell problem. The NASTRAN compatibility equations for a shell/pipe or a shell/pipe/pad(s) configuration were successfully implemented. This provides a quick access to a detail SCF for a reinforced nozzle in a pressure vessel. The accuracy of the finite element model has been investigated. Moreover, for an immediate, approximate solution to this complex problem, the formula may be utilized.

The formula is (1) more accurate than the published nonreinforced penetration formulas and, (2) believed to be the only formula applicable for reinforced penetrations in pressurized cylindrical shells. The accuracy of the formula was determined by comparing to the numerical, theoretical, and experimental data. It has been shown that the shell and pipe configuration can easily achieve the "well designed penetration" (SCF = 3.3) definition. A reinforced penetration (thick pipe, coded pad, or two pads) would have a peak SCF of about 2.2 (2/3 of the 3.3 limit).

This formula can be used to obtain the peak stress concentration factor for reinforced or nonreinforced penetrations in pressurized cylindrical shells. Thus, in the analysis and design of a new pressure vessel, the formula could save (1) the time to perform a detail analysis; (2) the time to construct the reinforcing pad(s) which are not always required; and (3) the extra cost of materials, fabrication, and weld examination. Also, fatigue analyses can be performed to obtain the remaining life in the penetration welds of cylindrical shells. If the remaining life is small or exhausted, then a nondestructive examination (NDE, i.e. magnetic particle, ultrasonic, or radiographic) and/or repair of these penetrations would be performed.

This type of verification (analyses and partial field work) of structural integrity of welds is invaluable since it is not practical to examine and/or repair every weld in all pressure vessels. The economics and feasibility of a validation program (6000 pressure components at Langley Research Center within the next five years) would be impractical without this formula. There have been six tunnels (pressure vessels) for which this procedure (formula and NDE) has been followed. For example, the world's first known "cryogenic" tunnel utilizing nitrogen as the working medium(40) incorporated this formula in obtaining the expected life of this facility.

REFERENCES

LIST OF REFERENCES

1. Lekkerkerker, J. G.: On the Stress Distribution in Cylindrical Shells Weakened by a Circular Hole. Ph.D. Dissertation, February 1965.

2. Van Dyke, P.: Stresses About a Circular Hole in a Cylindrical Shell. Journal, AIAA, Vol. 3, No. 9, September 1965, pp. 1733-1742.

3. Eringen, A. C.; Naghdi, A. K.; and Thiel, C. C.: State of Stress in a Circular Cylindrical Shell with a Circular Hole. Welding Research Council Bulletin, No. 102, January 1965.

4. Savin, G. N.: Stress Concentration Around Holes. Pergamon Press, New York, 1961, pp. 114-116.

5. Durelli, A. J.; del Rio, C. J.; Parks, V. J.; Feng, H.: Stresses in a Pressurized Cylinder with a Hole. Proceedings, ASCE, Vol. 93, No. ST5, October 1967, pp. 383-399.

6. Lur'e, A. I.: Statics of Thin-Walled Elastic Shells. Moscow, 1947, TRANSL. AEC - TR - 3798, 1959, pp. 147-200.

7. Prince, N.; and Rashid, Y. R.: Structural Analysis of Shell Intersections. First International Conference on Pressure Vessel Technology, ASME, Design and Analysis, September 29 - October 2, 1969, pp. 245-254.

8. Eringen, A. C.; Naghdi, A. K.; Mahmood, S. S.; Thiel, C. C.; and Ariman, T.: Analysis of Stress and Deformation in Two Normally Intersecting Cylindrical Shells Subject to Internal Pressure. General Technology Corp., Tech. Report, No. 3-8, December 1965.

9. Baker, E. H.; Capperi, A. P.; Kovalevsky, L.; Rish, F. L.; and Verette, R. M.: Shell Analysis Manual. NASA CR-912, April 1968, pp. 77-79.

10. Savin, G. N.: Stress Distribution Around Holes. NASA TT F-607, November 1970.

11. Eringen, A. C.; Naghdi, A. K.; Mahmood, S. S.; Theil, C. C.; and Ariman, T.: Stress Concentrations in Two Normally Intersecting Cylindrical Shells Subject to Internal Pressure. Welding Research Council Bulletin, No. 139, April 1969.

12. Hansberry, J. W.; and Jones, N.: A Theoretical Study of the Elastic Behavior of Two Normally Intersecting Cylindrical Shells. Journal of Engineering for Industry, Transactions, ASME, August 1969, pp. 563-572.

13. Leckie, F. A.; and Penny, R. K.: Stress Concentration Factors for the Stresses at Nozzle Intersections in Pressure Vessels, Welding Research Council Bulletin, No. 90, September 1963, pp. 19-26.

14. Cranch, E. T.: An Experimental Investigation of Stresses in the Neighborhood of Attachments to a Cylindrical Shell. Welding Research Council Bulletin, No. 60, May 1960.

15. Pickett, A. G.; and Grigory, S. C.: Cylic Pressure Tests of Full-Size Pressure Vessels. Welding Research Council Bulletin, No. 135, November 1968.

16. Leven, M. M.: Photoelastic Determination of the Stresses in Reinforced Openings in Pressure Vessels. Welding Research Council Bulletin, No. 113, April 1966, pp. 25-52.

17. Mershon, J. L.: PVRC Research on Reinforcement of Openings in Pressure Vessels. Welding Research Council Bulletin, No. 77, May 1962.

18. Riley, W. F.: Experimental Determination of Stress Distributions in Thin-Walled Cylindrical and Spherical Pressure Vessels with Circular Nozzles. Welding Research Council Bulletin, No. 108, September 1965, pp. 1-10.

19. Mershon, J. L.: Preliminary Evaluation of PVRC Photoelastic Test Data on Reinforced Openings in Pressure Vessels. Welding Research Council Bulletin, No. 113, April 1966, pp. 53-70.

20. Leven, M. M.: Photoelastic Determination of Stresses at an Opening in a Thin Walled Cylindrical Pressure Vessel. Pressure Vessel Research Committee, Report 67-9D7-PHOTO-R1, August 1967.

21. Taylor, C. E.; and Lind, N. C.: Photoelastic Study of the Stresses Near Openings in Pressure Vessels. Welding Research Council Bulletin, No. 113, April 1966, pp. 1-24.

22. Hardenbergh, D. E.; Zamrik, S. Y.; and Edmondson, A. J.: Experimental Investigation of Stresses in Nozzles in Cylindrical Pressure Vessels. Welding Research Council Bulletin, No. 89, July 1963.

23. Kitching, R.; and Perkins, J.: Stress Analysis of Rim and Ring Reinforced Openings in Pressure Vessels. Journal of Nuclear Engineering, June 1963, pp. 192-194.

24. Wells, A. A,; et al: Stress Analysis of Nozzles in Cylindrical Pressure Vessels. Institution of Mechanical Engineers, Proceedings of Pressure Vessel Research Towards Better Design, January 1961.

25. ASME Boiler and Pressure Vessel Code. Section VII, Divisions 1 and 2, 1974 Edition.

26. Lind, N. C.: Stress Concentration of Holes in Pressurized Cylindrical Shells. AIAA Journal, Vol. 6, No. 7, 1969, pp. 1397-1938.

27. Mershon, J. L.: Reinforcement of Openings Under Internal Pressure. Welding Research Council Bulletin, No. 95, April 1964.

28. McCormick, C. W.: The NASTRAN's User's Manual. NASA SP-222(01), June 1972.

29. Ramsey, J. W., Jr.: Finite Element Analysis for Buckling of Semirigid Space Frames, Master's Thesis, University of Virginia, June 1968, pp. 3-18.

30. MacNeal, R. H.: The Theoretical Manual. NASA SP-221, September 1970.

31. Clough R. W.; and Johnson, C. P.: Finite Element Analysis of Arbitrary Thin Shells. American Concrete Institute, SP-28, 1971, pp. 333-364.

32. Clough, R. W. and Tocher, J. L.: Finite Element Stiffness Matrices for Analysis of Plate Bending. Proc. of Conference on Matrix Methods in Structural Mechanics, Air Force Flight Dynamics Laboratory Report AFFDL-TR-66-80. December 1965.

33. Melosh, R. J.: The Optimum Approach to Analysis of Elastic Continua. Proceedings, Computer Oriented Analysis of Shell Structures, AFFDL-TR-71-79, June 1971, pp. 862-898.

34. Timoshenko, S.; and Wolnowsky - Krieger, S.: Theory of Plates and Shells. McGraw-Hill Book Company, Inc., New York, 1959, pp. 466-532.

35. Billington, D. P.: Thin Shell Concrete Structures. McGraw-Hill Book Company, Inc., New York, 1965, pp. 1-35.

36. Langhaar, H. L.: Energy Methods in Applied Mechanics. John Wiley and Sons, Inc., New York, 1962, pp. 177-200.

37. Norris, C. H.; et al: Structural Design for Dynamic Loads. McGraw-Hill Book Company, Inc., New York, 1959, pp. 61-72.

38. Taylor, J. T.; Lewis, P. E.; and Ramsey, J. W., Jr.: A Procedure for Verifying the Structural Integrity of an Existing Pressurized Wind Tunnel. ASME National Pressure Vessel Conference, June 1974; and ASME JEMT, October 1974, pp. 283-291.

39. Wilson, J. F.; and Taylor, J. T.: An Automated Program for Reinforcement Requirements for Openings in Cylindrical Pressure Vessels. NASA TMX 72648, January 1975.

40. Wilson, J. F.; Ware, G. D.; and Ramsey, J. W., Jr.: Pilot Cryo Tunnel: Attachments, Seals, and Insulation. ASCE National Structural Conference, No. 2239, April 1974.

41. Houghton, D. S.; Rothwell, A.: The Effect of Curvature on the Stress Concentrations Around Holes in Shells. The College of Aeronautics, Cranfield, England, No. 156, May 1962.

42. Reissner, E.: On Transverse Bending of Plates, Including the Effect of Transverse Shear Deformation. Int. J. Soilds Structures, Vol. 11, 1975, pp. 569-573.

43. Narayanaswami, R.; and Adelman, H. M.: Inclusion of Transverse Shear Deformation in Finite Element Displacement Formulations. AIAA Journal, Vol. 12, No. 11, November 1974, pp. 1613-1614.

44. Narayanaswami, R.: New Triangular Plate-Bending Finite Element with Transverse Shear Flexibility. AIAA Journal, Vol. 12, No. 12, December 1974, pp. 1761-1763.

APPENDICES

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NASTRAN EXECUTIVE CONTROL DECK ECHO


ID RAMSEY,CUTOUT1
APP DISPLACEMENT
SOL 1,0
TIME  333
CEND
```

APPENDIX A

SAMPLE NASTRAN COMPUTER PROGRAM

SHELL, PIPE, AND PADS

$\rho_a = 13.2$; $R = 72$, $T = 2.215$; $t = 1.10$; $\rho_{op} = 23.0$; $t_{op} = 1.50$;
$\rho_{ip} = 23.0$; $t_{ip} = 1.50$.

```
    PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                          JUNE  28, 1974   NASTRAN  2/
  A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750

   LTPT

                                                        C A S E   C O N T R O L   D E C K   E C H O
                    CARD
                    COUNT
                     1        LABEL= LTPT
                     2        TITLE=   PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL
                     3        SUBTITLE=A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750
                     4        LOAD=6
                     5        MPC=36
                     6        SPC=5
                     7        STRESS=ALL
                     8        LINE=35
                     9        BEGIN BULK


 *** USER INFORMATION MESSAGE 207, BULK DATA NOT SORTED,XSORT WILL RE-ORDER DECK.
```

```
   PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                JUNE 28, 1974  NASTRAN  2/
A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750

  LTPT

                                          S O R T E D   B U L K   D A T A   E C H O
                 CARD
                 COUNT           .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10
                    1-         CORD2C  40              0.0     0.0     0.0     0.0     0.0     +100.0  +Z
                    2-         +Z      +100.0  0.0     +100.0
                    3-         CQUAD2  227     51      227     228     224     223
                    4-         CQUAD2  228     51      228     229     225     224
                    5-         CQUAD2  229     51      229     230     226     225
                    6-         CQUAD2  231     51      231     232     228     227
                    7-         CQUAD2  232     51      232     233     229     228
                    8-         CQUAD2  233     51      233     234     230     229
                    9-         CQUAD2  235     51      235     236     232     231
                   10-         CQUAD2  236     51      236     237     233     232
                   11-         CQUAD2  237     51      237     238     234     233
                   12-         CQUAD2  239     51      239     240     236     235
                   13-         CQUAD2  240     51      240     241     237     236
                   14-         CQUAD2  241     51      241     242     238     237
                   15-         CQUAD2  243     51      243     244     240     239
                   16-         CQUAD2  244     51      244     245     241     240
                   17-         CQUAD2  245     51      245     246     242     241
                   18-         CQUAD2  247     51      247     248     244     243
                   19-         CQUAD2  248     51      248     249     245     244
                   20-         CQUAD2  249     51      249     250     246     245
                   21-         CQUAD2  251     51      251     252     248     247
                   22-         CQUAD2  252     51      252     253     249     248
                   23-         CQUAD2  253     51      253     254     250     249
                   24-         CQUAD2  628     41      628     632     633     631
                   25-         CQUAD2  629     41      629     631     642     643
                   26-         CQUAD2  630     41      630     637     638     632
                   27-         CQUAD2  631     41      631     633     641     642
                   28-         CQUAD2  632     41      632     638     639     633
                   29-         CQUAD2  633     41      633     639     640     641
                   30-         CQUAD2  634     41      634     650     651     635
                   31-         CQUAD2  635     41      635     651     652     636
                   32-         CQUAD2  636     41      636     652     653     637
                   33-         CQUAD2  637     41      637     653     654     638
                   34-         CQUAD2  638     41      638     654     655     639
                   35-         CQUAD2  639     41      639     655     656     640
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  PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                    JUNE 28, 1974   NASTRAN  2/
A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750

 LTPT

                                                    S O R T E D   B U L K   D A T A   E C H O

                     CARD
                     COUNT          .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10
                        36-         COQUAD2 640     41      640     656     657     658
                        37-         CQUAD2  641     41      641     640     658     659
                        38-         CQUAD2  642     41      642     641     659     660
                        39-         CQUAD2  643     41      643     642     660     661
                        40-         CQUAD2  644     41      644     643     661     662
                        41-         CQUAD2  645     41      645     644     662     663
                        42-         CQUAD2  646     41      646     645     663     664
                        43-         CQUAD2  657     41      673     674     675     657
                        44-         CQUAD2  674     41      684     685     686     674
                        45-         CQUAD2  685     41      692     693     694     685
                        46-         CQUAD2  702     41      702     704     705     703
                        47-         CQUAD2  704     41      704     706     707     705
                        48-         CQUAD2  706     41      706     710     711     707
                        49-         CQUAD2  708     41      708     712     713     709
                        50-         CQUAD2  709     41      709     713     714     710
                        51-         CQUAD2  710     41      710     714     715     711
                        52-         CQUAD2  712     41      712     716     717     713
                        53-         CQUAD2  713     41      713     717     718     714
                        54-         CQUAD2  714     41      714     718     719     715
                        55-         CQUAD2  716     41      716     720     721     717
                        56-         CQUAD2  717     41      717     721     722     718
                        57-         CQUAD2  718     41      718     722     723     719
                        58-         CQUAD2  720     41      720     724     725     721
                        59-         CQUAD2  721     41      721     725     726     722
                        60-         CQUAD2  722     41      722     726     727     723
                        61-         CQUAD2  724     41      724     728     729     725
                        62-         CQUAD2  725     41      725     729     730     726
                        63-         CQUAD2  726     41      726     730     731     727
                        64-         CTRIA2  255     51      255     256     251
                        65-         CTRIA2  256     51      256     257     252
                        66-         CTRIA2  257     51      257     258     252
                        67-         CTRIA2  258     51      258     259     253
                        68-         CTRIA2  259     51      259     260     253
                        69-         CTRIA2  260     51      260     261     254
                        70-         CTRIA2  262     51      262     263     255
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    PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                    JUNE  28, 1974   NASTRAN  2/
  A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 P0=13.750

   LIPT

                                             S O R T E D   B U L K   D A T A   E C H O
                  CARD
                  COUNT         .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10
                   71-          CTRIA2  263     51      263     264     256
                   72-          CTRIA2  264     51      264     265     256
                   73-          CTRIA2  265     51      265     266     257
                   74-          CTRIA2  266     51      266     267     257
                   75-          CTRIA2  267     51      267     268     258
                   76-          CTRIA2  268     51      268     269     258
                   77-          CTRIA2  269     51      269     270     259
                   78-          CTRIA2  270     51      270     271     259
                   79-          CTRIA2  271     51      271     272     260
                   80-          CTRIA2  272     51      272     273     260
                   81-          CTRIA2  273     51      273     274     261
                   82-          CTRIA2  311     75      311     312     325
                   83-          CTRIA2  312     75      312     313     326
                   84-          CTRIA2  313     75      313     314     327
                   85-          CTRIA2  314     75      314     315     328
                   86-          CTRIA2  315     75      315     316     329
                   87-          CTRIA2  316     75      316     317     330
                   88-          CTRIA2  317     75      317     318     331
                   89-          CTRIA2  318     75      318     319     332
                   90-          CTRIA2  319     75      319     320     333
                   91-          CTRIA2  320     75      320     321     334
                   92-          CTRIA2  321     75      321     322     335
                   93-          CTRIA2  322     75      322     323     336
                   94-          CTRIA2  324     44      324     325     338
                   95-          CTRIA2  325     44      325     326     339
                   96-          CTRIA2  326     44      326     327     340
                   97-          CTRIA2  327     44      327     328     341
                   98-          CTRIA2  328     44      328     329     342
                   99-          CTRIA2  329     44      329     330     343
                  100-          CTRIA2  330     44      330     331     344
                  101-          CTRIA2  331     44      331     332     345
                  102-          CTRIA2  332     44      332     333     346
                  103-          CTRIA2  333     44      333     334     347
                  104-          CTRIA2  334     44      334     335     348
                  105-          CTRIA2  335     44      335     336     349
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    PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                    JUNE 28, 1974   NASTRAN  2/
  A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750

    LTPT

                                                       S O R T E D   B U L K   D A T A   E C H O
                  CARD
                  COUNT         .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10
                   141-         CTRIA2  374     44      374     375     388
                   142-         CTRIA2  411     43      411     412     425
                   143-         CTRIA2  412     43      412     413     426
                   144-         CTRIA2  413     43      413     414     427
                   145-         CTRIA2  414     43      414     415     428
                   146-         CTRIA2  415     43      415     416     429
                   147-         CTRIA2  416     43      416     417     430
                   148-         CTRIA2  417     43      417     418     431
                   149-         CTRIA2  418     43      418     419     432
                   150-         CTRIA2  419     43      419     420     433
                   151-         CTRIA2  420     43      420     421     434
                   152-         CTRIA2  421     43      421     422     435
                   153-         CTRIA2  422     43      422     423     436
                   154-         CTRIA2  424     43      424     425     438
                   155-         CTRIA2  425     43      425     426     439
                   156-         CTRIA2  426     43      426     427     440
                   157-         CTRIA2  427     43      427     428     441
                   158-         CTRIA2  428     43      428     429     442
                   159-         CTRIA2  429     43      429     430     443
                   160-         CTRIA2  430     43      430     431     444
                   161-         CTRIA2  431     43      431     432     445
                   162-         CTRIA2  432     43      432     433     446
                   163-         CTRIA2  433     43      433     434     447
                   164-         CTRIA2  434     43      434     435     448
                   165-         CTRIA2  435     43      435     436     449
                   166-         CTRIA2  437     43      437     438     451
                   167-         CTRIA2  438     43      438     439     452
                   168-         CTRIA2  439     43      439     440     453
                   169-         CTRIA2  440     43      440     441     454
                   170-         CTRIA2  441     43      441     442     455
                   171-         CTRIA2  442     43      442     443     456
                   172-         CTRIA2  443     43      443     444     457
                   173-         CTRIA2  444     43      444     445     458
                   174-         CTRIA2  445     43      445     446     459
                   175-         CTRIA2  446     43      446     447     460
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  PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                  JUNE 28, 1974   NASTRAN  2/
A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750

 1TPT

                                               S O R T E D   B U L K   D A T A   E C H O
                    CARD
                    COUNT        .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10
                    106-         CTRIA2  337     44      337     338     351
                    107-         CTRIA2  338     44      338     339     352
                    108-         CTRIA2  339     44      339     340     353
                    109-         CTRIA2  340     44      340     341     354
                    110-         CTRIA2  341     44      341     342     355
                    111-         CTRIA2  342     44      342     343     356
                    112-         CTRIA2  343     44      343     344     357
                    113-         CTRIA2  344     44      344     345     358
                    114-         CTRIA2  345     44      345     346     359
                    115-         CTRIA2  346     44      346     347     360
                    116-         CTRIA2  347     44      347     348     361
                    117-         CTRIA2  348     44      348     349     362
                    118-         CTRIA2  350     44      350     351     364
                    119-         CTRIA2  351     44      351     352     365
                    120-         CTRIA2  352     44      352     353     366
                    121-         CTRIA2  353     44      353     354     367
                    122-         CTRIA2  354     44      354     355     368
                    123-         CTRIA2  355     44      355     356     369
                    124-         CTRIA2  356     44      356     357     370
                    125-         CTRIA2  357     44      357     358     371
                    126-         CTRIA2  358     44      358     359     372
                    127-         CTRIA2  359     44      359     360     373
                    128-         CTRIA2  360     44      360     361     374
                    129-         CTRIA2  361     44      361     362     375
                    130-         CTRIA2  363     44      363     364     377
                    131-         CTRIA2  364     44      364     365     378
                    132-         CTRIA2  365     44      365     366     379
                    133-         CTRIA2  366     44      366     367     380
                    134-         CTRIA2  367     44      367     368     381
                    135-         CTRIA2  368     44      368     369     382
                    136-         CTRIA2  369     44      369     370     383
                    137-         CTRIA2  370     44      370     371     384
                    138-         CTRIA2  371     44      371     372     385
                    139-         CTRIA2  372     44      372     373     386
                    140-         CTRIA2  373     44      373     374     387
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  PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                    JUNE 28, 1974   NASTRAN  2/
A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750

 LTPT

                                             S O R T E D   B U L K   D A T A   E C H O

                  CARD
                  COUNT        .   1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10  .
                   176-        CTRIA2  447     43      447     448     461
                   177-        CTRIA2  448     43      448     449     462
                   178-        CTRIA2  450     43      450     451     464
                   179-        CTRIA2  451     43      451     452     465
                   180-        CTRIA2  452     43      452     453     466
                   181-        CTRIA2  453     43      453     454     467
                   182-        CTRIA2  454     43      454     455     468
                   183-        CTRIA2  455     43      455     456     469
                   184-        CTRIA2  456     43      456     457     470
                   185-        CTRIA2  457     43      457     458     471
                   186-        CTRIA2  458     43      458     459     472
                   187-        CTRIA2  459     43      459     460     473
                   188-        CTRIA2  460     43      460     461     474
                   189-        CTRIA2  461     43      461     462     475
                   190-        CTRIA2  463     43      463     464     477
                   191-        CTRIA2  464     43      464     465     478
                   192-        CTRIA2  465     43      465     466     479
                   193-        CTRIA2  466     43      466     467     480
                   194-        CTRIA2  467     43      467     468     481
                   195-        CTRIA2  468     43      468     469     482
                   196-        CTRIA2  469     43      469     470     483
                   197-        CTRIA2  470     43      470     471     484
                   198-        CTRIA2  471     43      471     472     485
                   199-        CTRIA2  472     43      472     473     486
                   200-        CTRIA2  473     43      473     474     487
                   201-        CTRIA2  474     43      474     475     488
                   202-        CTRIA2  511     41      511     512     525
                   203-        CTRIA2  512     41      512     513     526
                   204-        CTRIA2  513     41      513     514     527
                   205-        CTRIA2  514     41      514     515     528
                   206-        CTRIA2  515     41      515     516     529
                   207-        CTRIA2  516     41      516     517     530
                   208-        CTRIA2  517     41      517     518     531
                   209-        CTRIA2  518     41      518     519     532
                   210-        CTRIA2  519     41      519     520     533
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   PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                        JUNE  28, 1974   NASTRAN  2/
A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 P0=13.750

  LTPT
                                                     S O R T E D   B U L K   D A T A   E C H O
                   CARD
                   COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                    211-        CTRIA2  520     41      520     521     534
                    212-        CTRIA2  521     41      521     522     535
                    213-        CTRIA2  522     41      522     523     536
                    214-        CTRIA2  524     41      524     525     538
                    215-        CTRIA2  525     41      525     526     539
                    216-        CTRIA2  526     41      526     527     540
                    217-        CTRIA2  527     41      527     528     541
                    218-        CTRIA2  528     41      528     529     542
                    219-        CTRIA2  529     41      529     530     543
                    220-        CTRIA2  530     41      530     531     544
                    221-        CTRIA2  531     41      531     532     545
                    222-        CTRIA2  532     41      532     533     546
                    223-        CTRIA2  533     41      533     534     547
                    224-        CTRIA2  534     41      534     535     548
                    225-        CTRIA2  535     41      535     536     549
                    226-        CTRIA2  537     41      537     538     551
                    227-        CTRIA2  538     41      538     539     552
                    228-        CTRIA2  539     41      539     540     553
                    229-        CTRIA2  540     41      540     541     554
                    230-        CTRIA2  541     41      541     542     555
                    231-        CTRIA2  542     41      542     543     556
                    232-        CTRIA2  543     41      543     544     557
                    233-        CTRIA2  544     41      544     545     558
                    234-        CTRIA2  545     41      545     546     559
                    235-        CTRIA2  546     41      546     547     560
                    236-        CTRIA2  547     41      547     548     561
                    237-        CTRIA2  548     41      548     549     562
                    238-        CTRIA2  550     41      550     551     564
                    239-        CTRIA2  551     41      551     552     565
                    240-        CTRIA2  552     41      552     553     566
                    241-        CTRIA2  553     41      553     554     567
                    242-        CTRIA2  554     41      554     555     568
                    243-        CTRIA2  555     41      555     556     569
                    244-        CTRIA2  556     41      556     557     570
                    245-        CTRIA2  557     41      557     558     571
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     PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                    JUNE 28, 1974   NASTRAN  2/
  A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 P0=13.750

   LTPT

                                                S O R T E D   B U L K   D A T A   E C H O
                   CARD
                   COUNT        .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10  .
                    246-        CTRIA2  558     41      558     559     572
                    247-        CTRIA2  559     41      559     560     573
                    248-        CTRIA2  560     41      560     561     574
                    249-        CTRIA2  561     41      561     562     575
                    250-        CTRIA2  563     41      563     564     577
                    251-        CTRIA2  564     41      564     565     578
                    252-        CTRIA2  565     41      565     566     579
                    253-        CTRIA2  566     41      566     567     580
                    254-        CTRIA2  567     41      567     568     581
                    255-        CTRIA2  568     41      568     569     582
                    256-        CTRIA2  569     41      569     570     583
                    257-        CTRIA2  570     41      570     571     584
                    258-        CTRIA2  571     41      571     572     585
                    259-        CTRIA2  572     41      572     573     586
                    260-        CTRIA2  573     41      573     574     587
                    261-        CTRIA2  574     41      574     575     588
                    262-        CTRIA2  576     41      576     577     590
                    263-        CTRIA2  577     41      577     578     591
                    264-        CTRIA2  578     41      578     579     592
                    265-        CTRIA2  579     41      579     580     593
                    266-        CTRIA2  580     41      580     581     594
                    267-        CTRIA2  581     41      581     582     595
                    268-        CTRIA2  582     41      582     583     596
                    269-        CTRIA2  583     41      583     584     597
                    270-        CTRIA2  584     41      584     585     598
                    271-        CTRIA2  585     41      585     586     599
                    272-        CTRIA2  586     41      586     587     600
                    273-        CTRIA2  587     41      587     588     601
                    274-        CTRIA2  589     41      589     590     603
                    275-        CTRIA2  590     41      590     591     604
                    276-        CTRIA2  591     41      591     592     605
                    277-        CTRIA2  592     41      592     593     606
                    278-        CTRIA2  593     41      593     594     607
                    279-        CTRIA2  594     41      594     595     608
                    280-        CTRIA2  595     41      595     596     609
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    PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                      JUNE  28, 1974   NASTRAN  2
 A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 P0=13.750

   LTPT

                                                  S O R T E D   B U L K   D A T A   E C H O
                 CARD
                 COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                  281-        CTRIA2  596     41      596     597     610
                  282-        CTRIA2  597     41      597     598     611
                  283-        CTRIA2  598     41      598     599     612
                  284-        CTRIA2  599     41      599     600     613
                  285-        CTRIA2  600     41      600     601     614
                  286-        CTRIA2  602     41      602     603     616
                  287-        CTRIA2  603     41      603     604     617
                  288-        CTRIA2  604     41      604     605     618
                  289-        CTRIA2  605     41      605     606     619
                  290-        CTRIA2  606     41      606     607     620
                  291-        CTRIA2  607     41      607     608     621
                  292-        CTRIA2  608     41      608     609     622
                  293-        CTRIA2  609     41      609     610     623
                  294-        CTRIA2  610     41      610     611     624
                  295-        CTRIA2  611     41      611     612     625
                  296-        CTRIA2  612     41      612     613     626
                  297-        CTRIA2  613     41      613     614     627
                  298-        CTRIA2  615     41      616     666     615
                  299-        CTRIA2  616     41      617     665     616
                  300-        CTRIA2  617     41      618     646     617
                  301-        CTRIA2  618     41      619     645     618
                  302-        CTRIA2  619     41      620     629     619
                  303-        CTRIA2  620     41      621     628     620
                  304-        CTRIA2  621     41      622     628     621
                  305-        CTRIA2  622     41      623     630     622
                  306-        CTRIA2  623     41      624     635     623
                  307-        CTRIA2  624     41      625     634     624
                  308-        CTRIA2  625     41      626     649     625
                  309-        CTRIA2  626     41      627     648     626
                  310-        CTRIA2  627     41      627     647     648
                  311-        CTRIA2  647     41      668     648     647
                  312-        CTRIA2  648     41      668     669     648
                  313-        CTRIA2  649     41      669     650     649
                  314-        CTRIA2  650     41      669     670     650
                  315-        CTRIA2  651     41      670     652     651
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     PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                    JUNE 28, 1974  NASTRAN  27
  A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750

   LTPT

                                                 S O R T E D   B U L K   D A T A   E C H O
                     CARD
                     COUNT          .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10
                      316-          CTRIA2  652     41      670     671     652
                      317-          CTRIA2  653     41      671     654     653
                      318-          CTRIA2  654     41      671     672     654
                      319-          CTRIA2  655     41      672     656     655
                      320-          CTRIA2  656     41      672     673     656
                      321-          CTRIA2  658     41      675     676     658
                      322-          CTRIA2  659     41      676     660     659
                      323-          CTRIA2  660     41      676     677     660
                      324-          CTRIA2  661     41      677     662     661
                      325-          CTRIA2  662     41      677     678     662
                      326-          CTRIA2  663     41      678     664     663
                      327-          CTRIA2  664     41      678     679     664
                      328-          CTRIA2  665     41      679     666     665
                      329-          CTRIA2  666     41      679     680     666
                      330-          CTRIA2  668     41      681     669     668
                      331-          CTRIA2  669     41      681     682     669
                      332-          CTRIA2  670     41      682     671     670
                      333-          CTRIA2  671     41      682     683     671
                      334-          CTRIA2  672     41      683     673     672
                      335-          CTRIA2  673     41      683     684     673
                      336-          CTRIA2  675     41      686     687     675
                      337-          CTRIA2  676     41      687     677     676
                      338-          CTRIA2  677     41      687     688     677
                      339-          CTRIA2  678     41      688     679     678
                      340-          CTRIA2  679     41      688     689     679
                      341-          CTRIA2  681     41      690     682     681
                      342-          CTRIA2  682     41      690     691     682
                      343-          CTRIA2  683     41      691     684     683
                      344-          CTRIA2  684     41      691     692     684
                      345-          CTRIA2  686     41      694     695     686
                      346-          CTRIA2  687     41      686     695     687
                      347-          CTRIA2  688     41      695     696     688
                      348-          CTRIA2  689     41      688     696     689
                      349-          CTRIA2  690     41      690     697     691
                      350-          CTRIA2  691     41      691     697     698
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     PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                   JUNE 28, 1974   NASTRAN  27
  A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750

    LIPT

                                                       S O R T E D   B U L K   D A T A   E C H O
                      CARD
                      COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                       351-        CTRIA2  692     41      692     698     693
                       352-        CTRIA2  693     41      693     698     699
                       353-        CTRIA2  694     41      694     693     700
                       354-        CTRIA2  695     41      695     694     700
                       355-        CTRIA2  696     41      696     695     701
                       356-        CTRIA2  697     41      697     708     698
                       357-        CTRIA2  698     41      698     708     709
                       358-        CTRIA2  699     41      699     709     710
                       359-        CTRIA2  700     41      700     699     706
                       360-        CTRIA2  701     41      701     700     702
                       361-        CTRIA2  1256    51      256     252     251
                       362-        CTRIA2  1258    51      258     253     252
                       363-        CTRIA2  1260    51      260     254     253
                       364-        CTRIA2  1263    51      263     256     255
                       365-        CTRIA2  1265    51      265     257     256
                       366-        CTRIA2  1267    51      267     258     257
                       367-        CTRIA2  1269    51      269     259     258
                       368-        CTRIA2  1271    51      271     260     259
                       369-        CTRIA2  1273    51      273     261     260
                       370-        CTRIA2  1615    41      615     666     667
                       371-        CTRIA2  1616    41      616     665     666
                       372-        CTRIA2  1618    41      618     645     646
                       373-        CTRIA2  1619    41      619     644     645
                       374-        CTRIA2  1620    41      620     628     629
                       375-        CTRIA2  1622    41      622     630     628
                       376-        CTRIA2  1623    41      623     635     636
                       377-        CTRIA2  1624    41      624     634     635
                       378-        CTRIA2  1625    41      625     649     634
                       379-        CTRIA2  1626    41      626     648     649
                       380-        CTRIA2  1627    41      617     646     665
                       381-        CTRIA2  1629    41      629     643     644
                       382-        CTRIA2  1630    41      636     637     630
                       383-        CTRIA2  1648    41      648     669     649
                       384-        CTRIA2  1650    41      650     670     651
                       385-        CTRIA2  1652    41      652     671     653
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    PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                 JUNE  28, 1974   NASTRAN  27
 A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750

    LIPT

                                              S O R T E D   B U L K   D A T A   E C H O
                   CARD
                   COUNT         .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10  .
                    386-         CTRIA2  1654    41      654     672     655
                    387-         CTRIA2  1656    41      656     673     657
                    388-         CTRIA2  1657    41      675     658     657
                    389-         CTRIA2  1658    41      658     676     659
                    390-         CTRIA2  1660    41      660     677     661
                    391-         CTRIA2  1662    41      662     678     663
                    392-         CTRIA2  1664    41      664     679     665
                    393-         CTRIA2  1666    41      666     680     667
                    394-         CTRIA2  1669    41      669     682     670
                    395-         CTRIA2  1671    41      671     683     672
                    396-         CTRIA2  1673    41      673     684     674
                    397-         CTRIA2  1674    41      686     675     674
                    398-         CTRIA2  1675    41      675     687     676
                    399-         CTRIA2  1677    41      677     688     678
                    400-         CTRIA2  1679    41      679     689     680
                    401-         CTRIA2  1682    41      682     691     683
                    402-         CTRIA2  1684    41      684     692     685
                    403-         CTRIA2  1685    41      694     686     685
                    404-         CTRIA2  1687    41      695     688     687
                    405-         CTRIA2  1691    41      691     698     692
                    406-         CTRIA2  1693    41      693     699     700
                    407-         CTRIA2  1695    41      695     700     701
                    408-         CTRIA2  1698    41      698     709     699
                    409-         CTRIA2  1699    41      699     710     706
                    410-         CTRIA2  1700    41      700     704     702
                    411-         CTRIA2  2619    41      619     629     644
                    412-         CTRIA2  2623    41      623     636     630
                    413-         CTRIA2  2625    41      649     650     634
                    414-         CTRIA2  2627    41      646     664     665
                    415-         CTRIA2  2629    41      628     631     629
                    416-         CTRIA2  2630    41      630     632     628
                    417-         CTRIA2  2700    41      700     706     704
                    418-         CTRIA2  3311    75      311     325     324
                    419-         CTRIA2  3312    75      312     326     325
                    420-         CTRIA2  3313    75      313     327     326
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  PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                    JUNE  28, 1974   NASTRAN   2
A=13.200 BR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 P0=13.750

 LTPT

                                                  S O R T E D   B U L K   D A T A   E C H O
                CARD
                COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                 421-        CTRIA2  3314    75      314     328     327
                 422-        CTRIA2  3315    75      315     329     328
                 423-        CTRIA2  3316    75      316     330     329
                 424-        CTRIA2  3317    75      317     331     330
                 425-        CTRIA2  3318    75      318     332     331
                 426-        CTRIA2  3319    75      319     333     332
                 427-        CTRIA2  3320    75      320     334     333
                 428-        CTRIA2  3321    75      321     335     334
                 429-        CTRIA2  3322    75      322     336     335
                 430-        CTRIA2  3324    44      324     338     337
                 431-        CTRIA2  3325    44      325     339     338
                 432-        CTRIA2  3326    44      326     340     339
                 433-        CTRIA2  3327    44      327     341     340
                 434-        CTRIA2  3328    44      328     342     341
                 435-        CTRIA2  3329    44      329     343     342
                 436-        CTRIA2  3330    44      330     344     343
                 437-        CTRIA2  3331    44      331     345     344
                 438-        CTRIA2  3332    44      332     346     345
                 439-        CTRIA2  3333    44      333     347     346
                 440-        CTRIA2  3334    44      334     348     347
                 441-        CTRIA2  3335    44      335     349     348
                 442-        CTRIA2  3337    44      337     351     350
                 443-        CTRIA2  3338    44      338     352     351
                 444-        CTRIA2  3339    44      339     353     352
                 445-        CTRIA2  3340    44      340     354     353
                 446-        CTRIA2  3341    44      341     355     354
                 447-        CTRIA2  3342    44      342     356     355
                 448-        CTRIA2  3343    44      343     357     356
                 449-        CTRIA2  3344    44      344     358     357
                 450-        CTRIA2  3345    44      345     359     358
                 451-        CTRIA2  3346    44      346     360     359
                 452-        CTRIA2  3347    44      347     361     360
                 453-        CTRIA2  3348    44      348     362     361
                 454-        CTRIA2  3350    44      350     364     363
                 455-        CTRIA2  3351    44      351     365     364
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   PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                          JUNE  28, 1974  NASTRAN  2/
 A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PD=13.750

  1TPT

                                                 S O R T E D   B U L K   D A T A   E C H O
                CARD
                COUNT        .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10  .
                 456-        CTRIA2  3352    44      352     366     365
                 457-        CTRIA2  3353    44      353     367     366
                 458-        CTRIA2  3354    44      354     368     367
                 459-        CTRIA2  3355    44      355     369     368
                 460-        CTRIA2  3356    44      356     370     369
                 461-        CTRIA2  3357    44      357     371     370
                 462-        CTRIA2  3358    44      358     372     371
                 463-        CTRIA2  3359    44      359     373     372
                 464-        CTRIA2  3360    44      360     374     373
                 465-        CTRIA2  3361    44      361     375     374
                 466-        CTRIA2  3363    44      363     377     376
                 467-        CTRIA2  3364    44      364     378     377
                 468-        CTRIA2  3365    44      365     379     378
                 469-        CTRIA2  3366    44      366     380     379
                 470-        CTRIA2  3367    44      367     381     380
                 471-        CTRIA2  3368    44      368     382     381
                 472-        CTRIA2  3369    44      369     383     382
                 473-        CTRIA2  3370    44      370     384     383
                 474-        CTRIA2  3371    44      371     385     384
                 475-        CTRIA2  3372    44      372     386     385
                 476-        CTRIA2  3373    44      373     387     386
                 477-        CTRIA2  3374    44      374     388     387
                 478-        CTRIA2  3411    43      411     425     424
                 479-        CTRIA2  3412    43      412     426     425
                 480-        CTRIA2  3413    43      413     427     426
                 481-        CTRIA2  3414    43      414     428     427
                 482-        CTRIA2  3415    43      415     429     428
                 483-        CTRIA2  3416    43      416     430     429
                 484-        CTRIA2  3417    43      417     431     430
                 485-        CTRIA2  3418    43      418     432     431
                 486-        CTRIA2  3419    43      419     433     432
                 487-        CTRIA2  3420    43      420     434     433
                 488-        CTRIA2  3421    43      421     435     434
                 489-        CTRIA2  3422    43      422     436     435
                 490-        CTRIA2  3424    43      424     438     437
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   PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                    JUNE  28, 1974   NASTRAN  2/
 A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750

  LTPT

                                             S O R T E D   B U L K   D A T A   E C H O
                   CARD
                   COUNT         .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10
                    491-         CTRIA2  3425    43      425     439     438
                    492-         CTRIA2  3426    43      426     440     439
                    493-         CTRIA2  3427    43      427     441     440
                    494-         CTRIA2  3428    43      428     442     441
                    495-         CTRIA2  3429    43      429     443     442
                    496-         CTRIA2  3430    43      430     444     443
                    497-         CTRIA2  3431    43      431     445     444
                    498-         CTRIA2  3432    43      432     446     445
                    499-         CTRIA2  3433    43      433     447     446
                    500-         CTRIA2  3434    43      434     448     447
                    501-         CTRIA2  3435    43      435     449     448
                    502-         CTRIA2  3437    43      437     451     450
                    503-         CTRIA2  3438    43      438     452     451
                    504-         CTRIA2  3439    43      439     453     452
                    505-         CTRIA2  3440    43      440     454     453
                    506-         CTRIA2  3441    43      441     455     454
                    507-         CTRIA2  3442    43      442     456     455
                    508-         CTRIA2  3443    43      443     457     456
                    509-         CTRIA2  3444    43      444     458     457
                    510-         CTRIA2  3445    43      445     459     458
                    511-         CTRIA2  3446    43      446     460     459
                    512-         CTRIA2  3447    43      447     461     460
                    513-         CTRIA2  3448    43      448     462     461
                    514-         CTRIA2  3450    43      450     464     463
                    515-         CTRIA2  3451    43      451     465     464
                    516-         CTRIA2  3452    43      452     466     465
                    517-         CTRIA2  3453    43      453     467     466
                    518-         CTRIA2  3454    43      454     468     467
                    519-         CTRIA2  3455    43      455     469     468
                    520-         CTRIA2  3456    43      456     470     469
                    521-         CTRIA2  3457    43      457     471     470
                    522-         CTRIA2  3458    43      458     472     471
                    523-         CTRIA2  3459    43      459     473     472
                    524-         CTRIA2  3460    43      460     474     473
                    525-         CTRIA2  3461    43      461     475     474
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  PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                   JUNE  28, 1974   NASTRAN  2/
 A=13.200 BR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 P0=13.750

  1TPT
                                                     S O R T E D   B U L K   D A T A   E C H O
                 CARD
                 COUNT           .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10  .
                  526-           CTRIA2  3463    43         463     477     476
                  527-           CTRIA2  3464    43         464     478     477
                  528-           CTRIA2  3465    43         465     479     478
                  529-           CTRIA2  3466    43         466     480     479
                  530-           CTRIA2  3467    43         467     481     480
                  531-           CTRIA2  3468    43         468     482     481
                  532-           CTRIA2  3469    43         469     483     482
                  533-           CTRIA2  3470    43         470     484     483
                  534-           CTRIA2  3471    43         471     485     484
                  535-           CTRIA2  3472    43         472     486     485
                  536-           CTRIA2  3473    43         473     487     486
                  537-           CTRIA2  3474    43         474     488     487
                  538-           CTRIA2  3511    41         511     525     524
                  539-           CTRIA2  3512    41         512     526     525
                  540-           CTRIA2  3513    41         513     527     526
                  541-           CTRIA2  3514    41         514     528     527
                  542-           CTRIA2  3515    41         515     529     528
                  543-           CTRIA2  3516    41         516     530     529
                  544-           CTRIA2  3517    41         517     531     530
                  545-           CTRIA2  3518    41         518     532     531
                  546-           CTRIA2  3519    41         519     533     532
                  547-           CTRIA2  3520    41         520     534     533
                  548-           CTRIA2  3521    41         521     535     534
                  549-           CTRIA2  3522    41         522     536     535
                  550-           CTRIA2  3524    41         524     538     537
                  551-           CTRIA2  3525    41         525     539     538
                  552-           CTRIA2  3526    41         526     540     539
                  553-           CTRIA2  3527    41         527     541     540
                  554-           CTRIA2  3528    41         528     542     541
                  555-           CTRIA2  3529    41         529     543     542
                  556-           CTRIA2  3530    41         530     544     543
                  557-           CTRIA2  3531    41         531     545     544
                  558-           CTRIA2  3532    41         532     546     545
                  559-           CTRIA2  3533    41         533     547     546
                  560-           CTRIA2  3534    41         534     548     547
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    PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                 JUNE 28, 1974   NASTRAN 2/
  A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 P0=13.750

    LTPT

                                                   S O R T E D   B U L K   D A T A   E C H O

                    CARD
                    COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10
                     561-        CTRIA2  3535    41      535     549     548
                     562-        CTRIA2  3537    41      537     551     550
                     563-        CTRIA2  3538    41      538     552     551
                     564-        CTRIA2  3539    41      539     553     552
                     565-        CTRIA2  3540    41      540     554     553
                     566-        CTRIA2  3541    41      541     555     554
                     567-        CTRIA2  3542    41      542     556     555
                     568-        CTRIA2  3543    41      543     557     556
                     569-        CTRIA2  3544    41      544     558     557
                     570-        CTRIA2  3545    41      545     559     558
                     571-        CTRIA2  3546    41      546     560     559
                     572-        CTRIA2  3547    41      547     561     560
                     573-        CTRIA2  3548    41      548     562     561
                     574-        CTRIA2  3550    41      550     564     563
                     575-        CTRIA2  3551    41      551     565     564
                     576-        CTRIA2  3552    41      552     566     565
                     577-        CTRIA2  3553    41      553     567     566
                     578-        CTRIA2  3554    41      554     568     567
                     579-        CTRIA2  3555    41      555     569     568
                     580-        CTRIA2  3556    41      556     570     569
                     581-        CTRIA2  3557    41      557     571     570
                     582-        CTRIA2  3558    41      558     572     571
                     583-        CTRIA2  3559    41      559     573     572
                     584-        CTRIA2  3560    41      560     574     573
                     585-        CTRIA2  3561    41      561     575     574
                     586-        CTRIA2  3563    41      563     577     576
                     587-        CTRIA2  3564    41      564     578     577
                     588-        CTRIA2  3565    41      565     579     578
                     589-        CTRIA2  3566    41      566     580     579
                     590-        CTRIA2  3567    41      567     581     580
                     591-        CTRIA2  3568    41      568     582     581
                     592-        CTRIA2  3569    41      569     583     582
                     593-        CTRIA2  3570    41      570     584     583
                     594-        CTRIA2  3571    41      571     585     584
                     595-        CTRIA2  3572    41      572     586     585
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     PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                JUNE 28, 1974   NASTRAN  2/
  A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750

     LIPT

                                                   S O R T E D   B U L K   D A T A   E C H O
                 CARD
                 COUNT        .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10  .
                  596-        CTRIA2  3573    41      573     587     586
                  597-        CTRIA2  3574    41      574     588     587
                  598-        CTRIA2  3576    41      576     590     589
                  599-        CTRIA2  3577    41      577     591     590
                  600-        CTRIA2  3578    41      578     592     591
                  601-        CTRIA2  3579    41      579     593     592
                  602-        CTRIA2  3580    41      580     594     593
                  603-        CTRIA2  3581    41      581     595     594
                  604-        CTRIA2  3582    41      582     596     595
                  605-        CTRIA2  3583    41      583     597     596
                  606-        CTRIA2  3584    41      584     598     597
                  607-        CTRIA2  3585    41      585     599     598
                  608-        CTRIA2  3586    41      586     600     599
                  609-        CTRIA2  3587    41      587     601     600
                  610-        CTRIA2  3589    41      589     603     602
                  611-        CTRIA2  3590    41      590     604     603
                  612-        CTRIA2  3591    41      591     605     604
                  613-        CTRIA2  3592    41      592     606     605
                  614-        CTRIA2  3593    41      593     607     606
                  615-        CTRIA2  3594    41      594     608     607
                  616-        CTRIA2  3595    41      595     609     608
                  617-        CTRIA2  3596    41      596     610     609
                  618-        CTRIA2  3597    41      597     611     610
                  619-        CTRIA2  3598    41      598     612     611
                  620-        CTRIA2  3599    41      599     613     612
                  621-        CTRIA2  3600    41      600     614     613
                  622-        CTRIA2  3602    41      602     616     615
                  623-        CTRIA2  3603    41      603     617     616
                  624-        CTRIA2  3604    41      604     618     617
                  625-        CTRIA2  3605    41      605     619     618
                  626-        CTRIA2  3606    41      606     620     619
                  627-        CTRIA2  3607    41      607     621     620
                  628-        CTRIA2  3608    41      608     622     621
                  629-        CTRIA2  3609    41      609     623     622
                  630-        CTRIA2  3610    41      610     624     623
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  PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                    JUNE 28, 1974   NASTRAN  2/
A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 P0=13.750

 LTPT

                                          S O R T E D   B U L K   D A T A   E C H O

                 CARD
                 COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                  631-        CTRIA2  3611    41      611     625     624
                  632-        CTRIA2  3612    41      612     626     625
                  633-        CTRIA2  3613    41      613     627     626
                  634-        FORCE   6       703     40      38571.4 .0      .0      1.0
                  635-        FORCE   6       705     40      77142.8 .0      .0      1.0
                  636-        FORCE   6       707     40      77142.8 .0      .0      1.0
                  637-        FORCE   6       711     40      55928.5 .0      .0      1.0
                  638-        FORCE   6       715     40      34714.3 .0      .0      1.0
                  639-        FORCE   6       719     40      34714.3 .0      .0      1.0
                  640-        FORCE   6       723     40      34714.3 .0      .0      1.0
                  641-        FORCE   6       727     40      35789.5 .0      .0      1.0
                  642-        FORCE   6       731     40      18432.4 .0      .0      1.0
                  643-        FORCE1  6       223     2280.80 227     223
                  644-        FORCE1  6       224     4561.59 228     224
                  645-        FORCE1  6       225     4561.59 229     225
                  646-        FORCE1  6       226     2280.80 230     226
                  647-        GRDSET          40                              40      4
                  648-        GRID    223             124.800 .00000  13.7500
                  649-        GRID    224             124.800 3.15792 11.9078
                  650-        GRID    225             124.800 5.47523 6.8750
                  651-        GRID    226             124.800 6.32548 .0000
                  652-        GRID    227             118.200 .00000  13.7500
                  653-        GRID    228             118.200 3.33444 11.9078
                  654-        GRID    229             118.200 5.78197 6.8750
                  655-        GRID    230             118.200 6.68024 .0000
                  656-        GRID    231             111.600 .00000  13.7500
                  657-        GRID    232             111.600 3.53188 11.9078
                  658-        GRID    233             111.600 6.12519 6.8750
                  659-        GRID    234             111.600 7.07728 .0000
                  660-        GRID    235             105.000 .00000  13.7500
                  661-        GRID    236             105.000 3.75420 11.9078
                  662-        GRID    237             105.000 6.51181 6.8750
                  663-        GRID    238             105.000 7.52463 .0000
                  664-        GRID    239             98.400  .00000  13.7500
                  665-        GRID    240             98.400  4.00640 11.9078
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  PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                JUNE  28, 1974   NASTRAN  2/
A=13.200 RP=  72.0 TS=2.215 TP=1.100 TPAD=1.500 P0=13.750

 1TPT

                                         S O R T E D   B U L K   D A T A   E C H O

             CARD
             COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
              666-        GRID    241             98.400  6.95067 6.8750
              667-        GRID    242             98.400  8.03256 .0000
              668-        GRID    243             93.642  .00000  13.7500
              669-        GRID    244             93.642  4.21035 11.9078
              670-        GRID    245             93.642  7.30575 6.8750
              671-        GRID    246             93.642  8.44364 .0000
              672-        GRID    247             88.883  .00000  13.7500
              673-        GRID    248             88.883  4.43619 11.9078
              674-        GRID    249             88.883  7.69918 6.8750
              675-        GRID    250             88.883  8.89926 .0000
              676-        GRID    251             84.125  .00000  13.7500
              677-        GRID    252             84.125  4.68767 11.9078
              678-        GRID    253             84.125  8.13756 6.8750
              679-        GRID    254             84.125  9.40709 .0000
              680-        GRID    255             79.366  .00000  13.7500
              681-        GRID    256             79.366  2.56999 13.2815
              682-        GRID    257             79.366  4.96941 11.9078
              683-        GRID    258             79.366  7.03667 9.7227
              684-        GRID    259             79.366  8.62906 6.8750
              685-        GRID    260             79.366  9.63345 3.5588
              686-        GRID    261             79.366  9.97670 .0000
              687-        GRID    262             74.608  .00000  13.7500
              688-        GRID    263             74.608  1.37842 13.6324
              689-        GRID    264             74.608  2.73403 13.2815
              690-        GRID    265             74.608  4.04429 12.7033
              691-        GRID    266             74.608  5.28723 11.9078
              692-        GRID    267             74.608  6.44175 10.9086
              693-        GRID    268             74.608  7.48796 9.7227
              694-        GRID    269             74.608  8.40752 8.3705
              695-        GRID    270             74.608  9.18404 6.8750
              696-        GRID    271             74.608  9.80343 5.2619
              697-        GRID    272             74.608  10.254313.5588
              698-        GRID    273             74.608  10.528271.7947
              699-        GRID    274             74.608  10.62017.0000
              700-        GRID    311             70.142  .00000  13.2000
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   PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                    JUNE  28, 1974   NASTRAN  2/
 A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750

   LTPT

                                                   S O R T E D   B U L K   D A T A   E C H O

                   CARD
                   COUNT        .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10  .
                    701-        GRID    312             70.142  1.40753 13.0871
                    702-        GRID    313             70.142  2.79181 12.7502
                    703-        GRID    314             70.142  4.12984 12.1952
                    704-        GRID    315             70.142  5.39921 11.4315
                    705-        GRID    316             70.142  6.57838 10.4723
                    706-        GRID    317             70.142  7.64702 9.3338
                    707-        GRID    318             70.142  8.58639 8.0356
                    708-        GRID    319             70.142  9.37971 6.6000
                    709-        GRID    320             70.142  10.012565.0514
                    710-        GRID    321             70.142  10.473263.4164
                    711-        GRID    322             70.142  10.753201.7229
                    712-        GRID    323             70.142  10.84711.0000
                    713-        GRID    324             70.142  .00000  13.7500
                    714-        GRID    325             70.142  1.46619 13.6324
                    715-        GRID    326             70.142  2.90823 13.2815
                    716-        GRID    327             70.142  4.30223 12.7033
                    717-        GRID    328             70.142  5.62489 11.9078
                    718-        GRID    329             70.142  6.85377 10.9086
                    719-        GRID    330             70.142  7.96768 9.7227
                    720-        GRID    331             70.142  8.94703 8.3704
                    721-        GRID    332             70.142  9.77429 6.8750
                    722-        GRID    333             70.142  10.434325.2619
                    723-        GRID    334             70.142  10.914893.5587
                    724-        GRID    335             70.142  11.206931.7947
                    725-        GRID    336             70.142  11.30490.0000
                    726-        GRID    337             70.142  .00000  14.8500
                    727-        GRID    338             70.142  1.58352 14.7230
                    728-        GRID    339             70.142  3.14111 14.3440
                    729-        GRID    340             70.142  4.64714 13.7196
                    730-        GRID    341             70.142  6.07651 12.8605
                    731-        GRID    342             70.142  7.40503 11.7813
                    732-        GRID    343             70.142  8.60975 10.5005
                    733-        GRID    344             70.142  9.66941 9.0401
                    734-        GRID    345             70.142  10.564877.4250
                    735-        GRID    346             70.142  11.279605.6828
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   PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL              JUNE 28, 1974  NASTRAN  2/
A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 RO=13.750

 LTPT

                                              S O R T E D   B U L K   D A T A   E C H O

                   CARD
                   COUNT       .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10
                    736-       GRID    347             70.142  11.800153.8434
                    737-       GRID    348             70.142  12.116571.9383
                    738-       GRID    349             70.142  12.22272.0000
                    739-       GRID    350             70.142  .00000  17.0000
                    740-       GRID    351             70.142  1.81285 16.8546
                    741-       GRID    352             70.142  3.59645 16.4207
                    742-       GRID    353             70.142  5.32178 15.7059
                    743-       GRID    354             70.142  6.96035 14.7224
                    744-       GRID    355             70.142  8.48453 13.4870
                    745-       GRID    356             70.142  9.86794 12.0208
                    746-       GRID    357             70.142  11.0859310.3489
                    747-       GRID    358             70.142  12.116148.5000
                    748-       GRID    359             70.142  12.939136.5056
                    749-       GRID    360             70.142  13.538944.3999
                    750-       GRID    361             70.142  13.903722.2189
                    751-       GRID    362             70.142  14.02613.0000
                    752-       GRID    363             70.142  .00000  20.5000
                    753-       GRID    364             70.142  2.18625 20.3246
                    754-       GRID    365             70.142  4.33819 19.8015
                    755-       GRID    366             70.142  6.42165 18.9395
                    756-       GRID    367             70.142  8.40282 17.7535
                    757-       GRID    368             70.142  10.2485616.2637
                    758-       GRID    369             70.142  11.9267814.4957
                    759-       GRID    370             70.142  13.4070812.4796
                    760-       GRID    371             70.142  14.6614810.2500
                    761-       GRID    372             70.142  15.665227.8450
                    762-       GRID    373             70.142  16.397805.3057
                    763-       GRID    374             70.142  16.843752.6757
                    764-       GRID    375             70.142  16.99349.0000
                    765-       GRID    376             70.142  .00000  23.0000
                    766-       GRID    377             70.142  2.45302 22.8032
                    767-       GRID    378             70.142  4.86845 22.2163
                    768-       GRID    379             70.142  7.20871 21.2492
                    769-       GRID    380             70.142  9.43640 19.9186
                    770-       GRID    381             70.142  11.5145218.2471
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PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL *            JUNE  28, 1974   NASTRAN  2/
A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750

LTPT

                                              S O R T E D   B U L K   D A T A   E C H O
                  CARD
                  COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10
                   771-        GRID    382             70.142  13.4068516.2634
                   772-        GRID    383             70.142  15.0786514.0015
                   773-        GRID    384             70.142  16.4975511.5000
                   774-        GRID    385             70.142  17.634578.8017
                   775-        GRID    386             70.142  18.465405.9528
                   776-        GRID    387             70.142  18.971613.0020
                   777-        GRID    388             70.142  19.14165.0000
                   778-        GRID    411             73.858  .00000  13.2000
                   779-        GRID    412             73.858  1.33672 13.0871
                   780-        GRID    413             73.858  2.65126 12.7502
                   781-        GRID    414             73.858  3.92176 12.1952
                   782-        GRID    415             73.858  5.12686 11.4315
                   783-        GRID    416             73.858  6.24611 10.4723
                   784-        GRID    417             73.858  7.26021 9.3338
                   785-        GRID    418             73.858  8.15144 8.0356
                   786-        GRID    419             73.858  8.90393 6.6000
                   787-        GRID    420             73.858  9.50408 5.0514
                   788-        GRID    421             73.858  9.94091 3.4164
                   789-        GRID    422             73.858  10.206311.7229
                   790-        GRID    423             73.858  10.29533.0000
                   791-        GRID    424             73.858  .00000  13.7500
                   792-        GRID    425             73.858  1.39242 13.6324
                   793-        GRID    426             73.858  2.76182 13.2815
                   794-        GRID    427             73.858  4.08544 12.7033
                   795-        GRID    428             73.858  5.34109 11.9078
                   796-        GRID    429             73.858  6.50746 10.9086
                   797-        GRID    430             73.858  7.56446 9.7227
                   798-        GRID    431             73.858  8.49354 8.3704
                   799-        GRID    432             73.858  9.27813 6.8750
                   800-        GRID    433             73.858  9.90399 5.2619
                   801-        GRID    434             73.858  10.359593.5587
                   802-        GRID    435             73.858  10.636431.7947
                   803-        GRID    436             73.858  10.72929.0000
                   804-        GRID    437             73.858  .00000  14.8500
                   805-        GRID    438             73.858  1.50384 14.7230
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    PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                    JUNE 28, 1974   NASTRAN  2.
  A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750

    LTPT

                                                 S O R T E D   B U L K   D A T A   E C H O

                  CARD
                  COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10 .
                   806-        GRID     439              73.858  2.98296 14.3440
                   807-        GRID     440              73.858  4.41289 13.7196
                   808-        GRID     441              73.858  5.76977 12.8605
                   809-        GRID     442              73.858  7.03059 11.7813
                   810-        GRID     443              73.858  8.17360 10.5005
                   811-        GRID     444              73.858  9.17867 9.0401
                   812-        GRID     445              73.858  10.027767.4250
                   813-        GRID     446              73.858  10.705305.6828
                   814-        GRID     447              73.858  11.198663.8434
                   815-        GRID     448              73.858  11.498501.9383
                   816-        GRID     449              73.859  11.59909.0000
                   817-        GRID     450              73.858  .00000  17.0000
                   818-        GRID     451              73.858  1.72163 16.8546
                   819-        GRID     452              73.858  3.41531 16.4207
                   820-        GRID     453              73.858  5.05335 15.7059
                   821-        GRID     454              73.858  6.60861 14.7224
                   822-        GRID     455              73.858  8.05481 13.4870
                   823-        GRID     456              73.858  9.36694 12.0208
                   824-        GRID     457              73.858  10.5217210.3489
                   825-        GRID     458              73.858  11.498108.5000
                   826-        GRID     459              73.858  12.277806.5056
                   827-        GRID     460              73.858  12.845904.3999
                   828-        GRID     461              73.858  13.191322.2189
                   829-        GRID     462              73.858  13.30722.0000
                   830-        GRID     463              73.858  .00000  20.5000
                   831-        GRID     464              73.858  2.07623 20.3246
                   832-        GRID     465              73.858  4.11957 19.8015
                   833-        GRID     466              73.858  6.09735 18.9395
                   834-        GRID     467              73.858  7.97730 17.7535
                   835-        GRID     468              73.858  9.72786 16.2637
                   836-        GRID     469              73.858  11.3186614.4957
                   837-        GRID     470              73.858  12.7210212.4796
                   838-        GRID     471              73.858  13.9086810.2500
                   839-        GRID     472              73.858  14.858527.8450
                   840-        GRID     473              73.858  15.551445.3057
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     PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL              JUNE 28, 1974   NASTRAN  2/
   A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 RO=13.750

     LIPT

                                                  S O R T E D   B U L K   D A T A   E C H O

                    CARD
                    COUNT      .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                     841-        GRID    474                  73.858  15.973122.6757
                     842-        GRID    475                  73.858  16.11468.0000
                     843-        GRID    476                  73.858  .00000  23.0000
                     844-        GRID    477                  73.858  2.32956 22.8032
                     845-        GRID    478                  73.858  4.62299 22.2163
                     846-        GRID    479                  73.858  6.84430 21.2492
                     847-        GRID    480                  73.858  8.95770 19.9186
                     848-        GRID    481                  73.858  10.9279618.2471
                     849-        GRID    482                  73.858  12.7208016.2634
                     850-        GRID    483                  73.858  14.3035114.0015
                     851-        GRID    484                  73.858  15.6457711.5000
                     852-        GRID    485                  73.858  16.720638.8017
                     853-        GRID    486                  73.858  17.505595.9528
                     854-        GRID    487                  73.858  17.983653.0020
                     855-        GRID    488                  73.858  18.14421.0000
                     856-        GRID    511                  72.000  .00000  13.2000
                     857-        GRID    512                  72.000  1.37121 13.0871
                     858-        GRID    513                  72.000  2.71972 12.7502
                     859-        GRID    514                  72.000  4.02311 12.1952
                     860-        GRID    515                  72.000  5.25951 11.4315
                     861-        GRID    516                  72.000  6.40793 10.4723
                     862-        GRID    517                  72.000  7.44859 9.3338
                     863-        GRID    518                  72.000  8.36324 8.0356
                     864-        GRID    519                  72.000  9.13560 6.6000
                     865-        GRID    520                  72.000  9.75166 5.0514
                     866-        GRID    521                  72.000  10.200113.4164
                     867-        GRID    522                  72.000  10.472581.7229
                     868-        GRID    523                  72.000  10.56398.0000
                     869-        GRID    524                  72.000  .00000  13.7500
                     870-        GRID    525                  72.000  1.42836 13.6324
                     871-        GRID    526                  72.000  2.83313 13.2815
                     872-        GRID    527                  72.000  4.19103 12.7033
                     873-        GRID    528                  72.000  5.47931 11.9078
                     874-        GRID    529                  72.000  6.67612 10.9066
                     875-        GRID    530                  72.000  7.76082 9.7227
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   PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                    JUNE  28, 1974   NASTRAN  2
 A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750

  LTPT

                                                   S O R T E D   B U L K   D A T A   E C H O
                      CARD
                      COUNT       .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10 .
                       876-       GRID    531                 72.000  8.71437 8.3704
                       877-       GRID    532                 72.000  9.51972 6.8750
                       878-       GRID    533                 72.000  10.162215.2619
                       879-       GRID    534                 72.000  10.629953.5587
                       880-       GRID    535                 72.000  10.914181.7947
                       881-       GRID    536                 72.000  11.00953.0000
                       882-       GRID    537                 72.000  .00000  14.8500
                       883-       GRID    538                 72.000  1.54265 14.7230
                       884-       GRID    539                 72.000  3.05999 14.3440
                       885-       GRID    540                 72.000  4.52699 13.7196
                       886-       GRID    541                 72.000  5.91916 12.8605
                       887-       GRID    542                 72.000  7.21294 11.7813
                       888-       GRID    543                 72.000  8.36599 10.5005
                       889-       GRID    544                 72.000  9.41762 9.0401
                       890-       GRID    545                 72.000  10.289277.4250
                       891-       GRID    546                 72.000  10.984905.6828
                       892-       GRID    547                 72.000  11.491493.8434
                       893-       GRID    548                 72.000  11.799391.9383
                       894-       GRID    549                 72.000  11.90268.0000
                       895-       GRID    550                 72.000  .00000  17.0000
                       896-       GRID    551                 72.000  1.76606 16.8546
                       897-       GRID    552                 72.000  3.50354 16.4207
                       898-       GRID    553                 72.000  5.18409 15.7059
                       899-       GRID    554                 72.000  6.77991 14.7224
                       900-       GRID    555                 72.000  8.26407 13.4870
                       901-       GRID    556                 72.000  9.61089 12.0208
                       902-       GRID    557                 72.000  10.7964110.3489
                       903-       GRID    558                 72.000  11.798978.5000
                       904-       GRID    559                 72.000  12.599726.5056
                       905-       GRID    560                 72.000  13.183244.3999
                       906-       GRID    561                 72.000  13.538062.2189
                       907-       GRID    562                 72.000  13.65713.0000
                       908-       GRID    563                 72.000  .00000  20.5000
                       909-       GRID    564                 72.000  2.12982 20.3246
                       910-       GRID    565                 72.000  4.22605 19.8015
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   PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRIC/L SHELL                    JUNE  28, 1974   NASTRAN  2/
 A=13.200 RP=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750

  LIPT

                                         S O R T E D   B U L K   D A T A   E C H O

                  CARD
                  COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10
                   911-        GRID    566             72.000  6.25529 18.9395
                   912-        GRID    567             72.000  8.18451 17.7535
                   913-        GRID    568             72.000  9.98139 16.2637
                   914-        GRID    569             72.000  11.6147114.4957
                   915-        GRID    570             72.000  13.0549712.4796
                   916-        GRID    571             72.000  14.2750510.2500
                   917-        GRID    572             72.000  15.251087.8450
                   918-        GRID    573             72.000  15.963255.3057
                   919-        GRID    574             72.000  16.396722.6757
                   920-        GRID    575             72.000  16.54225.0000
                   921-        GRID    576             72.000  .00000  23.0000
                   922-        GRID    577             72.000  2.38970 22.8032
                   923-        GRID    578             72.000  4.74254 22.2163
                   924-        GRID    579             72.000  7.02176 21.2492
                   925-        GRID    580             72.000  9.19079 19.9186
                   926-        GRID    581             72.000  11.2135218.2471
                   927-        GRID    582             72.000  13.0547316.2634
                   928-        GRID    583             72.000  14.6807414.0015
                   929-        GRID    584             72.000  16.0602111.5000
                   930-        GRID    585             72.000  17.165248.8017
                   931-        GRID    586             72.000  17.972465.9528
                   932-        GRID    587             72.000  18.464183.0020
                   933-        GRID    588             72.000  18.62933.0000
                   934-        GRID    589             72.000  .00000  25.0000
                   935-        GRID    590             72.000  2.59763 24.7861
                   936-        GRID    591             72.000  5.15601 24.1481
                   937-        GRID    592             72.000  7.63585 23.0970
                   938-        GRID    593             72.000  9.99786 21.6506
                   939-        GRID    594             72.000  12.2030019.8338
                   940-        GRID    595             72.000  14.2127817.6776
                   941-        GRID    596             72.000  15.9900515.2190
                   942-        GRID    597             72.000  17.4998712.4999
                   943-        GRID    598             72.000  18.710829.5670
                   944-        GRID    599             72.000  19.596336.4704
                   945-        GRID    600             72.000  20.136133.2631
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    PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                 JUNE  28, 1974   NASTRAN  2.
 A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 P0=13.750

  LTPT

                                          S O R T E D   B U L K   D A T A   E C H O
                 CARD
                 COUNT       .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                  946-       GRID    601             72.000  20.31751.0000
                  947-       GRID    602             72.000  .00000  27.0000
                  948-       GRID    603             72.000  2.80560 26.7690
                  949-       GRID    604             72.000  5.56975 26.0800
                  950-       GRID    605             72.000  8.25081 24.9447
                  951-       GRID    606             72.000  10.8069523.3827
                  952-       GRID    607             72.000  13.1961821.4205
                  953-       GRID    608             72.000  15.3767919.0918
                  954-       GRID    609             72.000  17.3079916.4365
                  955-       GRID    610             72.000  18.9510313.4999
                  956-       GRID    611             72.000  20.2706510.3324
                  957-       GRID    612             72.000  21.236756.9880
                  958-       GRID    613             72.000  21.826183.5241
                  959-       GRID    614             72.000  22.02431.0000
                  960-       GRID    615             72.000  .00000  29.7000
                  961-       GRID    616             72.000  3.08642 29.4459
                  962-       GRID    617             72.000  6.12876 28.6880
                  963-       GRID    618             72.000  9.08255 27.4392
                  964-       GRID    619             72.000  11.9027125.7209
                  965-       GRID    620             72.000  14.5434823.5626
                  966-       GRID    621             72.000  16.9586921.0010
                  967-       GRID    622             72.000  19.1024818.0802
                  968-       GRID    623             72.000  20.9305514.8499
                  969-       GRID    624             72.000  22.4018811.3656
                  970-       GRID    625             72.000  23.480997.6868
                  971-       GRID    626             72.000  24.140223.8765
                  972-       GRID    627             72.000  24.36198.0000
                  973-       GRID    628             72.000  18.3824023.1000
                  974-       GRID    629             72.000  15.7563426.4000
                  975-       GRID    630             72.000  21.0084519.8000
                  976-       GRID    631             72.000  18.3824026.4000
                  977-       GRID    632             72.000  21.0084523.1000
                  978-       GRID    633             72.000  21.0084526.4000
                  979-       GRID    634             72.000  23.634519.9000
                  980-       GRID    635             72.000  23.6345113.2000
```

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     PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                    JUNE 28, 1974  NASTRAN  2/
  A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750

     LIPT

                                                       S O R T E D   B U L K   D A T A   E C H O

                 CARD
                 COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                   981-        GRID    636             72.000  23.6345116.5000
                   982-        GRID    637             72.000  23.6345119.8000
                   983-        GRID    638             72.000  23.6345123.1000
                   984-        GRID    639             72.000  23.6345126.4000
                   985-        GRID    640             72.000  23.6345129.7000
                   986-        GRID    641             72.000  21.0084529.7000
                   987-        GRID    642             72.000  18.3824029.7000
                   988-        GRID    643             72.000  15.7563429.7000
                   989-        GRID    644             72.000  13.1302829.7000
                   990-        GRID    645             72.000  10.5042329.7000
                   991-        GRID    646             72.000  7.87817 29.7000
                   992-        GRID    647             72.000  26.26057.0000
                   993-        GRID    648             72.000  26.260573.3000
                   994-        GRID    649             72.000  26.260576.6000
                   995-        GRID    650             72.000  26.260579.9000
                   996-        GRID    651             72.000  26.2605713.2000
                   997-        GRID    652             72.000  26.2605716.5000
                   998-        GRID    653             72.000  26.2605719.8000
                   999-        GRID    654             72.000  26.2605723.1000
                  1000-        GRID    655             72.000  26.2605726.4000
                  1001-        GRID    656             72.000  26.2605729.7000
                  1002-        GRID    657             72.000  26.2605733.0000
                  1003-        GRID    658             72.000  23.6345133.0000
                  1004-        GRID    659             72.000  21.0084533.0000
                  1005-        GRID    660             72.000  18.3824033.0000
                  1006-        GRID    661             72.000  15.7563433.0000
                  1007-        GRID    662             72.000  13.1302833.0000
                  1008-        GRID    663             72.000  10.5042333.0000
                  1009-        GRID    664             72.000  7.87817 33.0000
                  1010-        GRID    665             72.000  5.25211 33.0000
                  1011-        GRID    666             72.000  2.62606 33.0000
                  1012-        GRID    667             72.000  .00000  33.0000
                  1013-        GRID    668             72.000  31.51268.0000
                  1014-        GRID    669             72.000  31.512686.6000
                  1015-        GRID    670             72.000  31.5126813.2000
```

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   PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                      JUNE  28, 1974   NASTRAN   2
A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 P0=13.750

 IIPT

                                                     S O R T E D   B U L K   D A T A   E C H O
                  CARD
                  COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10
                  1016-        GRID    671             72.000  31.5126819.8000
                  1017-        GRID    672             72.000  31.5126826.4000
                  1018-        GRID    673             72.000  31.5126833.0000
                  1019-        GRID    674             72.000  31.5126839.6000
                  1020-        GRID    675             72.000  26.2605739.6000
                  1021-        GRID    676             72.000  21.0084539.6000
                  1022-        GRID    677             72.000  15.7563439.6000
                  1023-        GRID    678             72.000  10.5042339.6000
                  1024-        GRID    679             72.000  5.25211 39.6000
                  1025-        GRID    680             72.000  .00000  39.6000
                  1026-        GRID    681             72.000  42.01690.0000
                  1027-        GRID    682             72.000  42.0169013.2000
                  1028-        GRID    683             72.000  42.0169026.4000
                  1029-        GRID    684             72.000  42.0169039.6000
                  1030-        GRID    685             72.000  42.0169052.8000
                  1031-        GRID    686             72.000  31.5126852.8000
                  1032-        GRID    687             72.000  21.0084552.8000
                  1033-        GRID    688             72.000  10.5042352.8000
                  1034-        GRID    689             72.000  .00000  52.8000
                  1035-        GRID    690             72.000  63.02536.0000
                  1036-        GRID    691             72.000  63.0253626.4000
                  1037-        GRID    692             72.000  63.0253652.8000
                  1038-        GRID    693             72.000  63.0253679.2000
                  1039-        GRID    694             72.000  42.0169079.2000
                  1040-        GRID    695             72.000  21.0084579.2000
                  1041-        GRID    696             72.000  .00000  79.2000
                  1042-        GRID    697             72.000  57.09113.0000
                  1043-        GRID    698             72.000  57.0911352.8000
                  1044-        GRID    699             72.000  57.0911389.6000
                  1045-        GRID    700             72.000  42.0169089.6000
                  1046-        GRID    701             72.000  .00000  89.6000
                  1047-        GRID    702             72.000  .00000  100.0000
                  1048-        GRID    703             72.000  .00000  150.0000
                  1049-        GRID    704             72.000  17.05230100.0000
                  1050-        GRID    705             72.000  17.05230150.0000
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     PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                      JUNE 28, 1974  NASTRAN 2/
  A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 P0=13.750

    LTPT

                                                 S O R T E D   B U L K   D A T A   E C H O
                 CARD
                 COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10
                 1051-        GRID    706             72.000  34.10460100.0000
                 1052-        GRID    707             72.000  34.10460150.0000
                 1053-        GRID    708             72.000  51.15690.0000
                 1054-        GRID    709             72.000  51.1569050.0000
                 1055-        GRID    710             72.000  51.15690100.0000
                 1056-        GRID    711             72.000  51.15690150.0000
                 1057-        GRID    712             72.000  58.83040.0000
                 1058-        GRID    713             72.000  58.8304050.0000
                 1059-        GRID    714             72.000  58.83040100.0000
                 1060-        GRID    715             72.000  58.83040150.0000
                 1061-        GRID    716             72.000  66.50390.0000
                 1062-        GRID    717             72.000  66.5039050.0000
                 1063-        GRID    718             72.000  66.50390100.0000
                 1064-        GRID    719             72.000  66.50390150.0000
                 1065-        GRID    720             72.000  74.17740.0000
                 1066-        GRID    721             72.000  74.1774050.0000
                 1067-        GRID    722             72.000  74.17740100.0000
                 1068-        GRID    723             72.000  74.17740150.0000
                 1069-        GRID    724             72.000  81.85090.0000
                 1070-        GRID    725             72.000  81.8509050.0000
                 1071-        GRID    726             72.000  81.85090100.0000
                 1072-        GRID    727             72.000  81.85090150.0000
                 1073-        GRID    728             72.000  90.00000.0000
                 1074-        GRID    729             72.000  90.0000050.0000
                 1075-        GRID    730             72.000  90.00000100.0000
                 1076-        GRID    731             72.000  90.00000150.0000
                 1077-        MAT1    47      29.0+6          .3
                 1078-        MPC     30      263     6       1.0     525     6       -1.0
                 1079-        MPC     30      264     6       1.0     526     6       -1.0
                 1080-        MPC     30      265     6       1.0     527     6       -1.0
                 1081-        MPC     30      266     6       1.0     528     6       -1.0
                 1082-        MPC     30      267     6       1.0     529     6       -1.0
                 1083-        MPC     30      268     6       1.0     530     6       -1.0
                 1084-        MPC     30      269     6       1.0     531     6       -1.0
                 1085-        MPC     30      270     6       1.0     532     6       -1.0
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    PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                    JUNE  28, 1974   NASTRAN  2/
   A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 P0=13.750

   LTPT

                                               S O R T E D   B U L K   D A T A   E C H O
                  CARD
                  COUNT       .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10
                  1086-       MPC     30      271     6       1.0     533     6       -1.0
                  1087-       MPC     30      272     6       1.0     534     6       -1.0
                  1088-       MPC     30      273     6       1.0     535     6       -1.0
                  1089-       MPC     31      263     5       1.0     525     5       -1.0
                  1090-       MPC     31      264     5       1.0     526     5       -1.0
                  1091-       MPC     31      265     5       1.0     527     5       -1.0
                  1092-       MPC     31      266     5       1.0     528     5       -1.0
                  1093-       MPC     31      267     5       1.0     529     5       -1.0
                  1094-       MPC     31      268     5       1.0     530     5       -1.0
                  1095-       MPC     31      269     5       1.0     531     5       -1.0
                  1096-       MPC     31      270     5       1.0     532     5       -1.0
                  1097-       MPC     31      271     5       1.0     533     5       -1.0
                  1098-       MPC     31      272     5       1.0     534     5       -1.0
                  1099-       MPC     31      273     5       1.0     535     5       -1.0
                  1100-       MPC     32      263     1       1.0     525     1       -1.0
                  1101-       MPC     32      264     1       1.0     526     1       -1.0
                  1102-       MPC     32      265     1       1.0     527     1       -1.0
                  1103-       MPC     32      266     1       1.0     528     1       -1.0
                  1104-       MPC     32      267     1       1.0     529     1       -1.0
                  1105-       MPC     32      268     1       1.0     530     1       -1.0
                  1106-       MPC     32      269     1       1.0     531     1       -1.0
                  1107-       MPC     32      270     1       1.0     532     1       -1.0
                  1108-       MPC     32      271     1       1.0     533     1       -1.0
                  1109-       MPC     32      272     1       1.0     534     1       -1.0
                  1110-       MPC     32      273     1       1.0     535     1       -1.0
                  1111-       MPC     34      263     2       1.0     525     2       -1.0            +JR1
                  1112-       +JR1            525     6       -2.6077
                  1113-       MPC     34      264     2       1.0     526     2       -1.0            +JR2
                  1114-       +JR2            526     6       -2.6077
                  1115-       MPC     34      265     2       1.0     527     2       -1.0            +JR3
                  1116-       +JR3            527     6       -2.6077
                  1117-       MPC     34      266     2       1.0     528     2       -1.0            +JR4
                  1118-       +JR4            528     6       -2.6077
                  1119-       MPC     34      267     2       1.0     529     2       -1.0            +JR5
                  1120-       +JR5            529     6       -2.6077
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    PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL          JUNE 28, 1974   NASTRAN  2.
  A=13.203 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750

   LTPT

                                         S O R T E D   B U L K   D A T A   E C H O
                   CARD
                   COUNT       .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10 .
                   1121-       MPC     34      268     2       1.0     530     2       -1.0    +JR6
                   1122-       +JR6            530     6       -2.6077
                   1123-       MPC     34      269     2       1.0     531     2       -1.0    +JR7
                   1124-       +JR7            531     6       -2.6077
                   1125-       MPC     34      270     2       1.0     532     2       -1.0    +JR8
                   1126-       +JR8            532     6       -2.6077
                   1127-       MPC     34      271     2       1.0     533     2       -1.0    +JR9
                   1128-       +JR9            533     6       -2.6077
                   1129-       MPC     34      272     2       1.0     534     2       -1.0    +JR10
                   1130-       +JR10           534     6       -2.6077
                   1131-       MPC     34      273     2       1.0     535     2       -1.0    +JR11
                   1132-       +JR11           535     6       -2.6077
                   1133-       MPC     35      263     3       1.0     525     3       -1.0    +JR12
                   1134-       +JR12           525     5       2.6077
                   1135-       MPC     35      264     3       1.0     526     3       -1.0    +JR13
                   1136-       +JR13           526     5       2.6077
                   1137-       MPC     35      265     3       1.0     527     3       -1.0    +JR14
                   1138-       +JR14           527     5       2.6077
                   1139-       MPC     35      266     3       1.0     528     3       -1.0    +JR15
                   1140-       +JR15           528     5       2.6077
                   1141-       MPC     35      267     3       1.0     529     3       -1.0    +JR16
                   1142-       +JR16           529     5       2.6077
                   1143-       MPC     35      268     3       1.0     530     3       -1.0    +JR17
                   1144-       +JR17           530     5       2.6077
                   1145-       MPC     35      269     3       1.0     531     3       -1.0    +JR18
                   1146-       +JR18           531     5       2.6077
                   1147-       MPC     35      270     3       1.0     532     3       -1.0    +JR19
                   1148-       +JR19           532     5       2.6077
                   1149-       MPC     35      271     3       1.0     533     3       -1.0    +JR20
                   1150-       +JR20           533     5       2.6077
                   1151-       MPC     35      272     3       1.0     534     3       -1.0    +JR21
                   1152-       +JR21           534     5       2.6077
                   1153-       MPC     35      273     3       1.0     535     3       -1.0    +JR22
                   1154-       +JR22           535     5       2.6077
                   1155-       MPC     37      262     1       1.0     524     1       -1.0
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  PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                    JUNE  28, 1974   NASTRAN  2/
A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750

  LIPT

                                              S O R T E D   B U L K   D A T A   E C H O

                   CARD
                   COUNT      .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                   1156-      MPC     37      262     3       1.0     524     3               -1.0            +JR23
                   1157-      +JR23           524     5               2.6077
                   1158-      MPC     37      262     5       1.0     524     5               -1.0
                   1159-      MPC     37      274     1       1.0     536     1               -1.0
                   1160-      MPC     37      274     2       1.0     536     2               -1.0            +JR24
                   1161-      +JR24           536     6               -2.6077
                   1162-      MPC     37      274     6       1.0     536     6               -1.0
                   1163-      MPC     60      312     1       1.0     512     1               -1.0
                   1164-      MPC     60      313     1       1.0     513     1               -1.0
                   1165-      MPC     60      314     1       1.0     514     1               -1.0
                   1166-      MPC     60      315     1       1.0     515     1               -1.0
                   1167-      MPC     60      316     1       1.0     516     1               -1.0
                   1168-      MPC     60      317     1       1.0     517     1               -1.0
                   1169-      MPC     60      318     1       1.0     518     1               -1.0
                   1170-      MPC     60      319     1       1.0     519     1               -1.0
                   1171-      MPC     60      320     1       1.0     520     1               -1.0
                   1172-      MPC     60      321     1       1.0     521     1               -1.0
                   1173-      MPC     60      322     1       1.0     522     1               -1.0
                   1174-      MPC     60      377     1       1.0     577     1               -1.0
                   1175-      MPC     60      378     1       1.0     578     1               -1.0
                   1176-      MPC     60      379     1       1.0     579     1               -1.0
                   1177-      MPC     60      380     1       1.0     580     1               -1.0
                   1178-      MPC     60      381     1       1.0     581     1               -1.0
                   1179-      MPC     60      382     1       1.0     582     1               -1.0
                   1180-      MPC     60      383     1       1.0     583     1               -1.0
                   1181-      MPC     60      384     1       1.0     584     1               -1.0
                   1182-      MPC     60      385     1       1.0     585     1               -1.0
                   1183-      MPC     60      386     1       1.0     586     1               -1.0
                   1184-      MPC     60      387     1       1.0     587     1               -1.0
                   1185-      MPC     60      412     1       1.0     512     1               -1.0
                   1186-      MPC     60      413     1       1.0     513     1               -1.0
                   1187-      MPC     60      414     1       1.0     514     1               -1.0
                   1188-      MPC     60      415     1       1.0     515     1               -1.0
                   1189-      MPC     60      416     1       1.0     516     1               -1.0
                   1190-      MPC     60      417     1       1.0     517     1               -1.0
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     PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                JUNE 28, 1974   NASTRAN   2
A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750

    LTPT

                                         S O R T E D   B U L K   D A T A   E C H O
                    CARD
                    COUNT         .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                    1191-         MPC     60      418     1       1.0     518     1               -1.0
                    1192-         MPC     60      419     1       1.0     519     1               -1.0
                    1193-         MPC     60      420     1       1.0     520     1               -1.0
                    1194-         MPC     60      421     1       1.0     521     1               -1.0
                    1195-         MPC     60      422     1       1.0     522     1               -1.0
                    1196-         MPC     60      477     1       1.0     577     1               -1.0
                    1197-         MPC     60      478     1       1.0     578     1               -1.0
                    1198-         MPC     60      479     1       1.0     579     1               -1.0
                    1199-         MPC     60      480     1       1.0     580     1               -1.0
                    1200-         MPC     60      481     1       1.0     581     1               -1.0
                    1201-         MPC     60      482     1       1.0     582     1               -1.0
                    1202-         MPC     60      483     1       1.0     583     1               -1.0
                    1203-         MPC     60      484     1       1.0     584     1               -1.0
                    1204-         MPC     60      485     1       1.0     585     1               -1.0
                    1205-         MPC     60      486     1       1.0     586     1               -1.0
                    1206-         MPC     60      487     1       1.0     587     1               -1.0
                    1207-         MPC     61      312     5       1.0     512     5               -1.0
                    1208-         MPC     61      313     5       1.0     513     5               -1.0
                    1209-         MPC     61      314     5       1.0     514     5               -1.0
                    1210-         MPC     61      315     5       1.0     515     5               -1.0
                    1211-         MPC     61      316     5       1.0     516     5               -1.0
                    1212-         MPC     61      317     5       1.0     517     5               -1.0
                    1213-         MPC     61      318     5       1.0     518     5               -1.0
                    1214-         MPC     61      319     5       1.0     519     5               -1.0
                    1215-         MPC     61      320     5       1.0     520     5               -1.0
                    1216-         MPC     61      321     5       1.0     521     5               -1.0
                    1217-         MPC     61      322     5       1.0     522     5               -1.0
                    1218-         MPC     61      377     5       1.0     577     5               -1.0
                    1219-         MPC     61      378     5       1.0     578     5               -1.0
                    1220-         MPC     61      379     5       1.0     579     5               -1.0
                    1221-         MPC     61      380     5       1.0     580     5               -1.0
                    1222-         MPC     61      381     5       1.0     581     5               -1.0
                    1223-         MPC     61      382     5       1.0     582     5               -1.0
                    1224-         MPC     61      383     5       1.0     583     5               -1.0
                    1225-         MPC     61      384     5       1.0     584     5               -1.0
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    PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                    JUNE  28, 1974   NASTRAN  2/
 A=13.200 RR=, 72.0 TS=2.215 TP=1.100 TPAD=1.500 P0=13.750

   LTPT
                                               S O R T E D   B U L K   D A T A   E C H O

                  CARD
                  COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10
                  1226-        MPC     61      385     5       1.0     585     5               -1.0
                  1227-        MPC     61      386     5       1.0     586     5               -1.0
                  1228-        MPC     61      387     5       1.0     587     5               -1.0
                  1229-        MPC     61      412     5       1.0     512     5               -1.0
                  1230-        MPC     61      413     5       1.0     513     5               -1.0
                  1231-        MPC     61      414     5       1.0     514     5               -1.0
                  1232-        MPC     61      415     5       1.0     515     5               -1.0
                  1233-        MPC     61      416     5       1.0     516     5               -1.0
                  1234-        MPC     61      417     5       1.0     517     5               -1.0
                  1235-        MPC     61      418     5       1.0     518     5               -1.0
                  1236-        MPC     61      419     5       1.0     519     5               -1.0
                  1237-        MPC     61      420     5       1.0     520     5               -1.0
                  1238-        MPC     61      421     5       1.0     521     5               -1.0
                  1239-        MPC     61      422     5       1.0     522     5               -1.0
                  1240-        MPC     61      477     5       1.0     577     5               -1.0
                  1241-        MPC     61      478     5       1.0     578     5               -1.0
                  1242-        MPC     61      479     5       1.0     579     5               -1.0
                  1243-        MPC     61      480     5       1.0     580     5               -1.0
                  1244-        MPC     61      481     5       1.0     581     5               -1.0
                  1245-        MPC     61      482     5       1.0     582     5               -1.0
                  1246-        MPC     61      483     5       1.0     583     5               -1.0
                  1247-        MPC     61      484     5       1.0     584     5               -1.0
                  1248-        MPC     61      485     5       1.0     585     5               -1.0
                  1249-        MPC     61      486     5       1.0     586     5               -1.0
                  1250-        MPC     61      487     5       1.0     587     5               -1.0
                  1251-        MPC     62      312     6       1.0     512     6               -1.0
                  1252-        MPC     62      313     6       1.0     513     6               -1.0
                  1253-        MPC     62      314     6       1.0     514     6               -1.0
                  1254-        MPC     62      315     6       1.0     515     6               -1.0
                  1255-        MPC     62      316     6       1.0     516     6               -1.0
                  1256-        MPC     62      317     6       1.0     517     6               -1.0
                  1257-        MPC     62      318     6       1.0     518     6               -1.0
                  1258-        MPC     62      319     6       1.0     519     6               -1.0
                  1259-        MPC     62      320     6       1.0     520     6               -1.0
                  1260-        MPC     62      321     6       1.0     521     6               -1.0
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     PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                    JUNE  28, 1974   NASTRAN  2
   A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750

    LTPT

                                           S O R T E D   B U L K   D A T A   E C H O
                     CARD
                     COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                     1261-        MPC     62      322     6       1.0     522     6       -1.0
                     1262-        MPC     62      377     6       1.0     577     6       -1.0
                     1263-        MPC     62      378     6       1.0     578     6       -1.0
                     1264-        MPC     62      379     6       1.0     579     6       -1.0
                     1265-        MPC     62      380     6       1.0     580     6       -1.0
                     1266-        MPC     62      381     6       1.0     581     6       -1.0
                     1267-        MPC     62      382     6       1.0     582     6       -1.0
                     1268-        MPC     62      383     6       1.0     583     6       -1.0
                     1269-        MPC     62      384     6       1.0     584     6       -1.0
                     1270-        MPC     62      385     6       1.0     585     6       -1.0
                     1271-        MPC     62      386     6       1.0     586     6       -1.0
                     1272-        MPC     62      387     6       1.0     587     6       -1.0
                     1273-        MPC     62      412     6       1.0     512     6       -1.0
                     1274-        MPC     62      413     6       1.0     513     6       -1.0
                     1275-        MPC     62      414     6       1.0     514     6       -1.0
                     1276-        MPC     62      415     6       1.0     515     6       -1.0
                     1277-        MPC     62      416     6       1.0     516     6       -1.0
                     1278-        MPC     62      417     6       1.0     517     6       -1.0
                     1279-        MPC     62      418     6       1.0     518     6       -1.0
                     1280-        MPC     62      419     6       1.0     519     6       -1.0
                     1281-        MPC     62      420     6       1.0     520     6       -1.0
                     1282-        MPC     62      421     6       1.0     521     6       -1.0
                     1283-        MPC     62      422     6       1.0     522     6       -1.0
                     1284-        MPC     62      477     6       1.0     577     6       -1.0
                     1285-        MPC     62      478     6       1.0     578     6       -1.0
                     1286-        MPC     62      479     6       1.0     579     6       -1.0
                     1287-        MPC     62      480     6       1.0     580     6       -1.0
                     1288-        MPC     62      481     6       1.0     581     6       -1.0
                     1289-        MPC     62      482     6       1.0     582     6       -1.0
                     1290-        MPC     62      483     6       1.0     583     6       -1.0
                     1291-        MPC     62      484     6       1.0     584     6       -1.0
                     1292-        MPC     62      485     6       1.0     585     6       -1.0
                     1293-        MPC     62      486     6       1.0     586     6       -1.0
                     1294-        MPC     62      487     6       1.0     587     6       -1.0
                     1295-        MPC     64      312     2       1.0     512     2       -1.0                    +R2
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  PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                JUNE 28, 1974   NASTRAN  2/
A=13.200 RP=   72.0 TS=2.215 TP=1.100 TPAD=1.500 P0=13.750

 LIPT

                                        S O R T E D   B U L K   D A T A   E C H O
                CARD
                COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                1296-        +R2                 512     6               1.8577
                1297-        MPC     64          313     2       1.0     513     2               -1.0            +R3
                1298-        +R3                 513     6               1.8577
                1299-        MPC     64          314     2       1.0     514     2               -1.0            +R4
                1300-        +R4                 514     6               1.8577
                1301-        MPC     64          315     2       1.0     515     2               -1.0            +R5
                1302-        +R5                 515     6               1.8577
                1303-        MPC     64          316     2       1.0     516     2               -1.0            +R6
                1304-        +R6                 516     6               1.8577
                1305-        MPC     64          317     2       1.0     517     2               -1.0            +R7
                1306-        +R7                 517     6               1.8577
                1307-        MPC     64          318     2       1.0     518     2               -1.0            +R8
                1308-        +R8                 518     6               1.8577
                1309-        MPC     64          319     2       1.0     519     2               -1.0            +R9
                1310-        +R9                 519     6               1.8577
                1311-        MPC     64          320     2       1.0     520     2               -1.0            +R10
                1312-        +R10                520     6               1.8577
                1313-        MPC     64          321     2       1.0     521     2               -1.0            +R11
                1314-        +R11                521     6               1.8577
                1315-        MPC     64          322     2       1.0     522     2               -1.0            +R12
                1316-        +R12                522     6               1.8577
                1317-        MPC     64          377     2       1.0     577     2               -1.0            +R24
                1318-        +R24                577     6               1.8577
                1319-        MPC     64          378     2       1.0     578     2               -1.0            +R25
                1320-        +R25                578     6               1.8577
                1321-        MPC     64          379     2       1.0     579     2               -1.0            +R26
                1322-        +R26                579     6               1.8577
                1323-        MPC     64          380     2       1.0     580     2               -1.0            +R27
                1324-        +R27                580     6               1.8577
                1325-        MPC     64          381     2       1.0     581     2               -1.0            +R28
                1326-        +R28                581     6               1.8577
                1327-        MPC     64          382     2       1.0     582     2               -1.0            +R29
                1328-        +R29                582     6               1.8577
                1329-        MPC     64          383     2       1.0     583     2               -1.0            +R30
                1330-        +R30                583     6               1.8577
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    PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                  JUNE 28, 1974   NASTRAN  2/
  A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 P0=13.750

   LTPT

                                                 S O R T E D   B U L K   D A T A   E C H O
                 CARD
                 COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                 1331-        MPC     64      384     2       1.0     584     2               -1.0            +R31
                 1332-        +R31            584     6       1.8577
                 1333-        MPC     64      385     2       1.0     585     2               -1.0            +R32
                 1334-        +R32            585     6       1.8577
                 1335-        MPC     64      386     2       1.0     586     2               -1.0            +R33
                 1336-        +R33            586     6       1.8577
                 1337-        MPC     64      387     2       1.0     587     2               -1.0            +R34
                 1338-        +R34            587     6       1.8577
                 1339-        MPC     64      412     2       1.0     512     2               -1.0            +R13
                 1340-        +R13            512     6       -1.8577
                 1341-        MPC     64      413     2       1.0     513     2               -1.0            +R14
                 1342-        +R14            513     6       -1.8577
                 1343-        MPC     64      414     2       1.0     514     2               -1.0            +R15
                 1344-        +R15            514     6       -1.8577
                 1345-        MPC     64      415     2       1.0     515     2               -1.0            +R16
                 1346-        +R16            515     6       -1.8577
                 1347-        MPC     64      416     2       1.0     516     2               -1.0            +R17
                 1348-        +R17            516     6       -1.8577
                 1349-        MPC     64      417     2       1.0     517     2               -1.0            +R18
                 1350-        +R18            517     6       -1.8577
                 1351-        MPC     64      418     2       1.0     518     2               -1.0            +R19
                 1352-        +R19            518     6       -1.8577
                 1353-        MPC     64      419     2       1.0     519     2               -1.0            +R20
                 1354-        +R20            519     6       -1.8577
                 1355-        MPC     64      421     2       1.0     520     2               -1.0            +R21
                 1356-        +R21            520     6       -1.8577
                 1357-        MPC     64      421     2       1.0     521     2               -1.0            +R22
                 1358-        +R22            521     6       -1.8577
                 1359-        MPC     64      422     2       1.0     522     2               -1.0            +R23
                 1360-        +R23            522     6       -1.8577
                 1361-        MPC     64      477     2       1.0     577     2               -1.0            +R35
                 1362-        +R35            577     6       -1.8577
                 1363-        MPC     64      478     2       1.0     578     2               -1.0            +R36
                 1364-        +R36            578     6       -1.8577
                 1365-        MPC     64      479     2       1.0     579     2               -1.0            +R37
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  PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                        JUNE  28, 1974   NASTRAN  2/
A=13.200 RP=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750

 LTPT

                                            S O R T E D   B U L K   D A T A   E C H O
                CARD
                COUNT         .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10
                1366-        +R37              579     6       -1.8577
                1367-        MPC      64       480     2      1.0      580      2        -1.0             +R38
                1368-        +R38              580     6       -1.8577
                1369-        MPC      64       481     2      1.0      581      2        -1.0             +R39
                1370-        +R39              581     6       -1.8577
                1371-        MPC      64       482     2      1.0      582      2        -1.0             +R40
                1372-        +R40              582     6       -1.8577
                1373-        MPC      64       483     2      1.0      583      2        -1.0             +R41
                1374-        +R41              583     6       -1.8577
                1375-        MPC      64       484     2      1.0      584      2        -1.0             +R42
                1376-        +R42              584     6       -1.8577
                1377-        MPC      64       485     2      1.0      585      2        -1.0             +R43
                1378-        +R43              585     6       -1.8577
                1379-        MPC      64       486     2      1.0      586      2        -1.0             +R44
                1380-        +R44              586     6       -1.8577
                1381-        MPC      64       487     2      1.0      587      2        -1.0             +R45
                1382-        +R45              587     6       -1.8577
                1383-        MPC      65       312     3      1.0      512      3        -1.0             +R46
                1384-        +R46              512     5       -1.8577
                1385-        MPC      65       313     3      1.0      513      3        -1.0             +R47
                1386-        +R47              513     5       -1.8577
                1387-        MPC      65       314     3      1.0      514      3        -1.0             +R48
                1388-        +R48              514     5       -1.8577
                1389-        MPC      65       315     3      1.0      515      3        -1.0             +R49
                1390-        +R49              515     5       -1.8577
                1391-        MPC      65       316     3      1.0      516      3        -1.0             +R50
                1392-        +R50              516     5       -1.8577
                1393-        MPC      65       317     3      1.0      517      3        -1.0             +R51
                1394-        +R51              517     5       -1.8577
                1395-        MPC      65       318     3      1.0      518      3        -1.0             +R52
                1396-        +R52              518     5       -1.8577
                1397-        MPC      65       319     3      1.0      519      3        -1.0             +R53
                1398-        +R53              519     5       -1.8577
                1399-        MPC      65       320     3      1.0      520      3        -1.0             +R54
                1400-        +R54              520     5       -1.8577
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OF POOR QUALITY

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      PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                    JUNE 28, 1974  NASTRAN 2/
   A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 P0=13.750

     LIPT

                                                S O R T E D   B U L K   D A T A   E C H O
                     CARD
                     COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10 .
                     1401-        MPC     65      321     3       1.0     521     3       -1.0            +R55
                     1402-        +R55            521     5       -1.8577
                     1403-        MPC     65      322     3       1.0     522     3       -1.0            +R56
                     1404-        +R56            522     5       -1.8577
                     1405-        MPC     65      377     3       1.0     577     3       -1.0            +R68
                     1406-        +R68            577     5       -1.8577
                     1407-        MPC     65      378     3       1.0     578     3       -1.0            +R69
                     1408-        +R69            578     5       -1.8577
                     1409-        MPC     65      379     3       1.0     579     3       -1.0            +R70
                     1410-        +R70            579     5       -1.8577
                     1411-        MPC     65      380     3       1.0     580     3       -1.0            +R71
                     1412-        +R71            580     5       -1.8577
                     1413-        MPC     65      381     3       1.0     581     3       -1.0            +R72
                     1414-        +R72            581     5       -1.8577
                     1415-        MPC     65      382     3       1.0     582     3       -1.0            +R73
                     1416-        +R73            582     5       -1.8577
                     1417-        MPC     65      383     3       1.0     583     3       -1.0            +R74
                     1418-        +R74            583     5       -1.8577
                     1419-        MPC     65      384     3       1.0     584     3       -1.0            +R75
                     1420-        +R75            584     5       -1.8577
                     1421-        MPC     65      385     3       1.0     585     3       -1.0            +R76
                     1422-        +R76            585     5       -1.8577
                     1423-        MPC     65      386     3       1.0     586     3       -1.0            +R77
                     1424-        +R77            586     5       -1.8577
                     1425-        MPC     65      387     3       1.0     587     3       -1.0            +R78
                     1426-        +R78            587     5       -1.8577
                     1427-        MPC     65      412     3       1.0     512     3       -1.0            +R57
                     1428-        +R57            512     5        1.8577
                     1429-        MPC     65      413     3       1.0     513     3       -1.0            +R58
                     1430-        +R58            513     5        1.8577
                     1431-        MPC     65      414     3       1.0     514     3       -1.0            +R59
                     1432-        +R59            514     5        1.8577
                     1433-        MPC     65      415     3       1.0     515     3       -1.0            +R60
                     1434-        +R60            515     5        1.8577
                     1435-        MPC     65      416     3       1.0     516     3       -1.0            +R61
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 PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                     JUNE 28, 1974   NASTRAN  2/
A=13.200 RB=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750

 1IPT

                                         S O R T E D   B U L K   D A T A   E C H O
              CARD
              COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
              1436-        +R61                516     5          1.8577
              1437-        MPC     65          417     3       1.0      517     3       -1.0              +R62
              1438-        +R62                517     5          1.8577
              1439-        MPC     65          418     3       1.0      518     3       -1.0              +R63
              1440-        +R63                518     5          1.8577
              1441-        MPC     65          419     3       1.0      519     3       -1.0              +R64
              1442-        +R64                519     5          1.8577
              1443-        MPC     65          420     3       1.0      520     3       -1.0              +R65
              1444-        +R65                520     5          1.8577
              1445-        MPC     65          421     3       1.0      521     3       -1.0              +R66
              1446-        +R66                521     5          1.8577
              1447-        MPC     65          422     3       1.0      522     3       -1.0              +R67
              1448-        +R67                522     5          1.8577
              1449-        MPC     65          477     3       1.0      577     3       -1.0              +R79
              1450-        +R79                577     5          1.8577
              1451-        MPC     65          478     3       1.0      578     3       -1.0              +R80
              1452-        +R80                578     5          1.8577
              1453-        MPC     65          479     3       1.0      579     3       -1.0              +R81
              1454-        +R81                579     5          1.8577
              1455-        MPC     65          480     3       1.0      580     3       -1.0              +R82
              1456-        +R82                580     5          1.8577
              1457-        MPC     65          481     3       1.0      581     3       -1.0              +R83
              1458-        +R83                581     5          1.8577
              1459-        MPC     65          482     3       1.0      582     3       -1.0              +R84
              1460-        +R84                582     5          1.8577
              1461-        MPC     65          483     3       1.0      583     3       -1.0              +R85
              1462-        +R85                583     5          1.8577
              1463-        MPC     65          484     3       1.0      584     3       -1.0              +R86
              1464-        +R86                584     5          1.8577
              1465-        MPC     65          485     3       1.0      585     3       -1.0              +R87
              1466-        +R87                585     5          1.8577
              1467-        MPC     65          486     3       1.0      586     3       -1.0              +R88
              1468-        +R88                586     5          1.8577
              1469-        MPC     65          487     3       1.0      587     3       -1.0              +R89
              1470-        +R89                587     5          1.8577
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     PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                  JUNE 28, 1974   NASTRAN  2
  A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750

     LTPT

                                           S O R T E D   B U L K   D A T A   E C H O

                   CARD
                   COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10
                   1471-        MPC     66      311     1       1.0     511     1               -1.0
                   1472-        MPC     66      311     3       1.0     511     3               -1.0            +R90
                   1473-        +R90            511     5         -1.8577
                   1474-        MPC     66      311     5       1.0     511     5               -1.0
                   1475-        MPC     66      323     1       1.0     523     1               -1.0
                   1476-        MPC     66      323     2       1.0     523     2               -1.0            +R94
                   1477-        +R94            523     6          1.8577
                   1478-        MPC     66      323     6       1.0     523     6               -1.0
                   1479-        MPC     66      376     1       1.0     576     1               -1.0
                   1480-        MPC     66      376     3       1.0     576     3               -1.0            +R92
                   1481-        +R92            576     5         -1.8577
                   1482-        MPC     66      376     5       1.0     576     5               -1.0
                   1483-        MPC     66      388     1       1.0     588     1               -1.0
                   1484-        MPC     66      388     2       1.0     588     2               -1.0            +R96
                   1485-        +R96            588     6          1.8577
                   1486-        MPC     66      388     6       1.0     588     6               -1.0
                   1487-        MPC     66      411     1       1.0     511     1               -1.0
                   1488-        MPC     66      411     3       1.0     511     3               -1.0            +R91
                   1489-        +R91            511     5          1.8577
                   1490-        MPC     66      411     5       1.0     511     5               -1.0
                   1491-        MPC     66      423     1       1.0     523     1               -1.0
                   1492-        MPC     66      423     2       1.0     523     2               -1.0            +R95
                   1493-        +R95            523     6         -1.8577
                   1494-        MPC     66      423     6       1.0     523     6               -1.0
                   1495-        MPC     66      476     1       1.0     576     1               -1.0
                   1496-        MPC     66      476     3       1.0     576     3               -1.0            +R93
                   1497-        +R93            576     5          1.8577
                   1498-        MPC     66      476     5       1.0     576     5               -1.0
                   1499-        MPC     66      488     1       1.0     588     1               -1.0
                   1500-        MPC     66      488     2       1.0     588     2               -1.0            +R97
                   1501-        +R97            588     6         -1.8577
                   1502-        MPC     66      488     6       1.0     588     6               -1.0
                   1503-        MPCADD  36      30      31      32      66      34      35      37              +R1
                   1504-        +R1     60      61      62      64      65
                   1505-        PLOAD2  6       100.    576     THRU    587
```

```
     PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                          JUNE 28, 1974   NASTRAN  2
   A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 P0=13.750

    LTPT

                                                S O R T E D   B U L K   D A T A   E C H O

                   CARD
                   COUNT          .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                   1506-          PLOAD2  6       100.    589     THRU    600
                   1507-          PLOAD2  6       100.    602     THRU    613
                   1508-          PLOAD2  6       100.    615     THRU    666
                   1509-          PLOAD2  6       100.    668     THRU    679
                   1510-          PLOAD2  6       100.    681     THRU    702
                   1511-          PLOAD2  6       100.    708     THRU    710
                   1512-          PLOAD2  6       100.    712     THRU    714
                   1513-          PLOAD2  6       100.    716     THRU    718
                   1514-          PLOAD2  6       100.    720     THRU    722
                   1515-          PLOAD2  6       100.    724     THRU    726
                   1516-          PLOAD2  6       100.    1615    1616    1618    1619    1620    1622
                   1517-          PLOAD2  6       100.    1623    1624    1625    1626    1627    1629
                   1518-          PLOAD2  6       100.    1630    1648    1650    1652    1654    1656
                   1519-          PLOAD2  6       100.    1657    1658    1660    1662    1664    1666
                   1520-          PLOAD2  6       100.    1669    1671    1673    1674    1675    1677
                   1521-          PLOAD2  6       100.    1679    1682    1684    1685    1687    1698
                   1522-          PLOAD2  6       100.    1693    1695
                   1523-          PLOAD2  6       100.    1699    1700    2619    2623    2625    2627
                   1524-          PLOAD2  6       100.    2629    2630    2700    704     706     1691
                   1525-          PLOAD2  6       100.0   311     THRU    322
                   1526-          PLOAD2  6       100.0   324     THRU    335
                   1527-          PLOAD2  6       100.0   337     THRU    348
                   1528-          PLOAD2  6       100.0   350     THRU    361
                   1529-          PLOAD2  6       100.0   363     THRU    374
                   1530-          PLOAD2  6       100.0   3311    THRU    3322
                   1531-          PLOAD2  6       100.0   3324    THRU    3335
                   1532-          PLOAD2  6       100.0   3337    THRU    3348
                   1533-          PLOAD2  6       100.0   3350    THRU    3361
                   1534-          PLOAD2  6       100.0   3363    THRU    3374
                   1535-          PLOAD2  6       100.0   3576    THRU    3587
                   1536-          PLOAD2  6       100.0   3589    THRU    3600
                   1537-          PLOAD2  6       100.0   3602    THRU    3613
                   1538-          PLOAD2  6       -100.0  227     THRU    229
                   1539-          PLOAD2  6       -100.0  231     THRU    233
                   1540-          PLOAD2  6       -100.0  235     THRU    237
```

ORIGINAL PAGE IS
OF POOR QUALITY

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   PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                      JUNE  28, 1974   NASTRAN  2/
A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 P0=13.750

 ITPT

                                         S O R T E D   B U L K   D A T A   E C H O

                CARD
                COUNT         .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                1541-         PLOAD2  6       -100.0  239     THRU    241
                1542-         PLOAD2  6       -100.0  243     THRU    245
                1543-         PLOAD2  6       -100.0  247     THRU    249
                1544-         PLOAD2  6       -100.0  251     THRU    253
                1545-         PLOAD2  6       -100.0  255     THRU    260
                1546-         PLOAD2  6       -100.0  262     THRU    273
                1547-         PLOAD2  6       -100.0  1256    1258    1260
                1548-         PLOAD2  6       -100.0  1263    1265    1267    1269    1271    1273
                1549-         PQUAD2  41      47      2.21538
                1550-         PQUAD2  43      47      1.50000
                1551-         PQUAD2  44      47      1.50000
                1552-         PQUAD2  51      47      1.10000
                1553-         PQUAD2  75      47      .75000
                1554-         PTRIA2  41      47      2.21538
                1555-         PTRIA2  43      47      1.50000
                1556-         PTRIA2  44      47      1.50000
                1557-         PTRIA2  51      47      1.10000
                1558-         PTRIA2  75      47      .75000
                1559-         SPC1    1       26      511     524     537     550     563     576     +K1
                1560-         +K1     589     602     615     667     680     689     696     701     +K2
                1561-         +K2     702     311     324     337     350     363     376     411     +K3
                1562-         +K3     424     437     450     463     476
                1563-         SPC1    2       35      523     536     549     562     575     588     +L1
                1564-         +L1     601     614     627     647     668     681     690     697     +L2
                1565-         +L2     708     712     716     720     724     323     336     349     +L3
                1566-         +L3     362     375     388     423     436     449     462     475     +L4
                1567-         +L4     488
                1568-         SPC1    3       5       705     707     711     715     719     723     +M1
                1569-         +M1     727
                1570-         SPC1    4       26      729     730
                1571-         SPC1    6       2356    728
                1572-         SPC1    8       256     703     731
                1573-         SPC1    9       246     223     227     231     235     239     243     +P1
                1574-         +P1     262     247     251     255
                1575-         SPC1    10      345     226     230     234     238     242     246     +P2
```

```
  PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                    JUNE 28, 1974   NASTRAN  2/
 A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 P0=13.750

  LTPT
                                         S O R T E D   B U L K   D A T A   E C H O
                 CARD
                 COUNT       .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10
                 1576-       +P2     274     250     254     261
                 1577-       SPCADD  5       1       2       3       4       6       8       9       +P3
                 1578-       +P3     10
                             ENDDATA



        **NO ERRORS FOUND - EXECUTE NASTRAN PROGRAM**
                                                 METHOD 2 NT,NBR PASSES =    1,EST. TIME =        14.6
                                                 METHOD 2 T ,NBR PASSES =    1,EST. TIME =         9.7
                                                 METHOD 2 T ,NBR PASSES =    1,EST. TIME =        38.0

*** USER INFORMATION MESSAGE 3023.          B =      71
                                            C =     183
                                            R =      70

*** USER INFORMATION MESSAGE 3027. SYMMETRIC REAL S.P. TIME ESTIMATE IS      640 SECONDS.
                                                 METHOD 2 T ,NBR PASSES =    1,EST. TIME =          .2
                                                 METHOD 2 NT,NBR PASSES =    1,EST. TIME =         1.1
                                                 METHOD 1 NT,NBR PASSES =    1,EST. TIME =         5.1

*** USER INFORMATION MESSAGE 3035

FOR LOAD     1 EPSILON SUB E =-23.2524127E-14
                                                 METHOD 2 NT,NBR PASSES =    1,EST. TIME =          .4
                                                 METHOD 1 T ,NBR PASSES =    1,EST. TIME =         1.6
                                                 METHOD 2 NT,NBR PASSES =    1,EST. TIME =          .2

*** SYSTEM WARNING MESSAGE 3022

    DATA BLOCK PLTPAR   IS REQUIRED AS INPUT AND IS NOT OUTPUT BY A PREVIOUS MODULE IN THE CURRENT DMAP ROU

*** SYSTEM WARNING MESSAGE 3022

    DATA BLOCK GPSETS   IS REQUIRED AS INPUT AND IS NOT OUTPUT BY A PREVIOUS MODULE IN THE CURRENT DMAP ROU
```

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    PIPE AND BOTH PADS REINFORCED HOLE IN CYLINDRICAL SHELL                      JUNE  28, 1974
  A=13.200 RR=  72.0 TS=2.215 TP=1.100 TPAD=1.500 PO=13.750

  LTPT

                   S T R E S S E S   I N   G E N E R A L   T R I A N G U L A R   E L E M E N T S
ELEMENT       FIBRE                    STRESSES IN ELEMENT COORD SYSTEM              PRINCIPAL STRESSES
  ID.          DISTANCE              NORMAL-X         NORMAL-Y       SHEAR-XY        ANGLE          MAJOR

    267  -55.000000E-02       36.626921E+02  15.282235E+02  16.874622E+01       4.4925    36.759504E+02
          55.000000E-02       27.996382E+02  79.493408E+00 -12.236078E+01      -2.5704    28.051313E+02

    268  -55.000000E-02       17.455225E+02  10.201016E+02 -31.448518E+00      -2.4777    17.468833E+02
          55.000000E-02       37.184511E+02  34.966212E+01  30.306191E+01       5.0999    37.454979E+02

    269  -55.000000E-02       28.478904E+02  10.733020E+02  21.705942E+01       6.8732    28.740544E+02
          55.000000E-02       19.551830E+02 -30.799750E+01 -63.394563E+00      -1.6033    19.569574E+02

    270  -55.000000E-02       12.970949E+02  64.832626E+01  17.810507E+00       1.5714    12.975834E+02
          55.000000E-02       26.851675E+02 -10.364289E+01  22.019174E+01       4.4868    27.024457E+02

    271  -55.000000E-02       21.905377E+02  64.843281E+01  82.812711E+00       3.0651    21.949721E+02
          55.000000E-02       13.357490E+02 -65.177969E+01  38.476868E+00       1.1086    13.364936E+02

    272  -55.000000E-02       13.067414E+02  37.872258E+01 -57.859562E+00      -3.5539    13.103348E+02
          55.000000E-02       17.634289E+02 -51.761951E+01  16.233038E+01       4.0502    17.749232E+02

    273  -55.000000E-02       16.595845E+02  40.629698E+01  47.376145E+00       2.1618    16.613728E+02
          55.000000E-02       12.291916E+02 -71.326576E+01 -27.871346E+00       -.8219    12.295915E+02
                                                                             Peak Stress Answer
    311  -37.500000E-02       63.524534E+02  69.873755E+01 -21.898232E+01      -2.2148   |63.609224E+02|
          37.500000E-02       59.054469E+02  44.554233E+01 -20.918724E+01      -2.1909    59.134498E+02

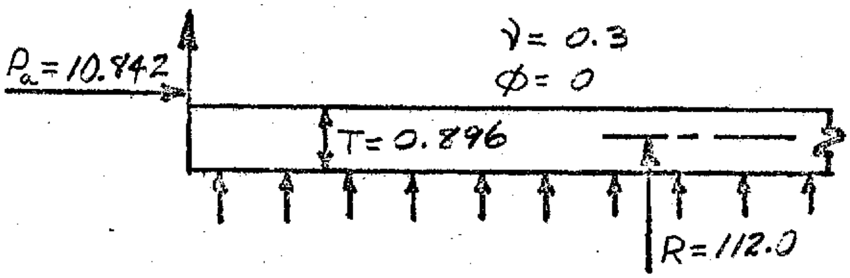
    312  -37.500000E-02       60.296639E+02  72.081228E+01 -23.693549E+01      -2.5500    60.402347E+02
          37.500000E-02       56.980266E+02  52.815005E+01 -23.783955E+01      -2.6285    57.089453E+02

    313  -37.500000E-02       58.169284E+02  74.174435E+01 -13.888619E+01      -1.5664    58.207263E+02
          37.500000E-02       52.382165E+02  28.458522E+01 -16.351277E+01      -1.8885    52.436080E+02

    314  -37.500000E-02       53.494800E+02  86.723580E+01 -89.961737E+00      -1.1493    53.512848E+02
          37.500000E-02       48.072939E+02  18.989494E+01 -13.207812E+01      -1.6371    48.110689E+02
```

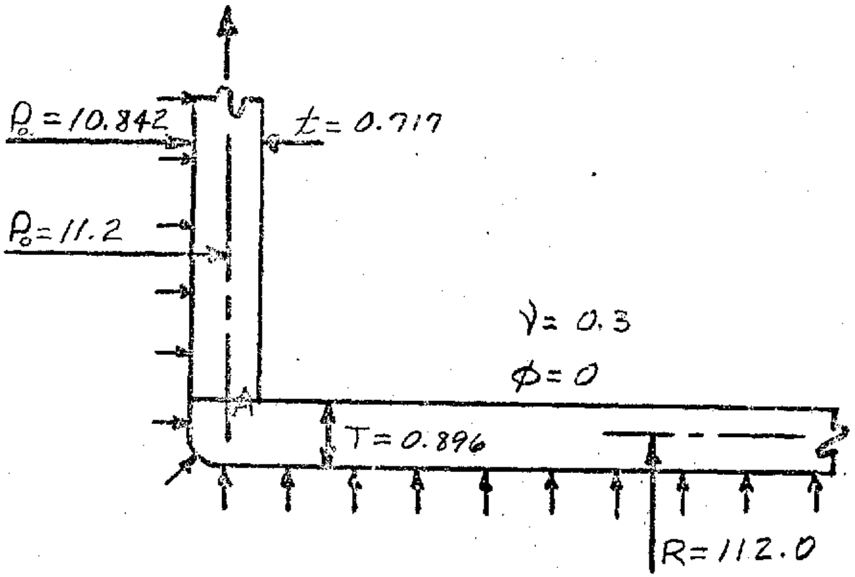
APPENDIX B

NASTRAN SUMMARY SHEETS



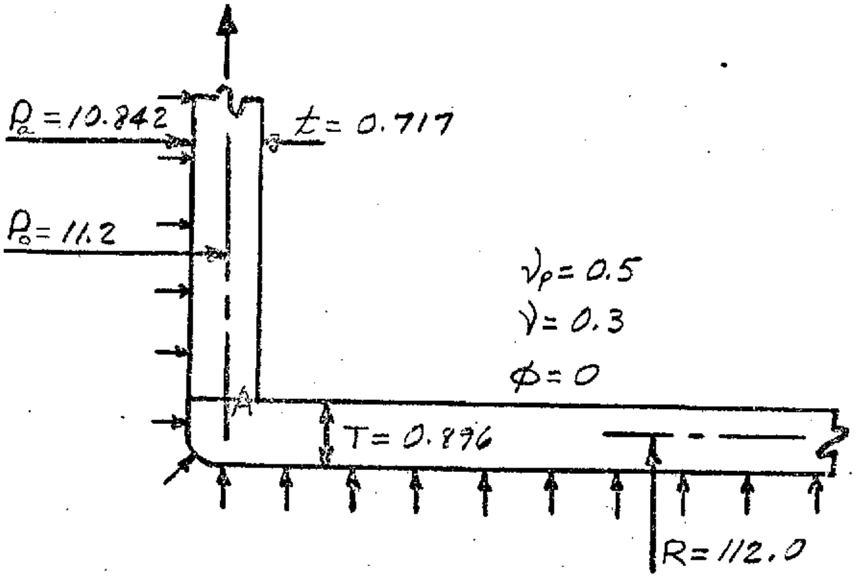
P/P_a	I/s SCF	O/s SCF
1.000	5.406	3.575
1.033	5.147	3.282
1.224	3.550	1.939
1.416	2.630	1.284
1.607	1.971	0.936
1.832	1.634	0.777
2.120	1.283	0.656
2.409	1.121	0.676

FORCE



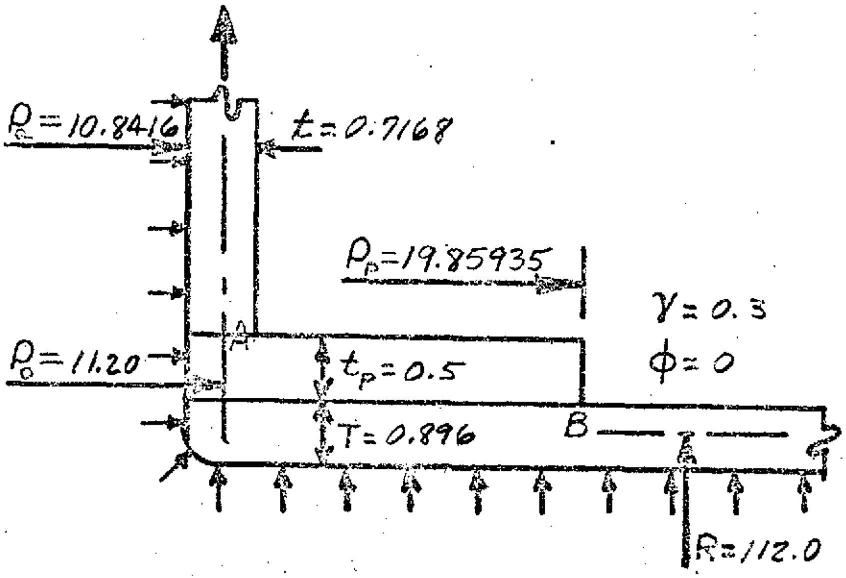
P/P_o	I/s SCF	O/s SCF
1.000 @ A	1.975	2.547
SHELL @ $\phi = 0$		
0.968	2.812	2.398
1.000	2.509	2.524
1.185	1.857	2.099
1.371	1.566	1.720
1.556	1.343	1.423
1.773	1.264	1.277
2.052	1.093	1.079
2.332	1.006	1.001

PIPE



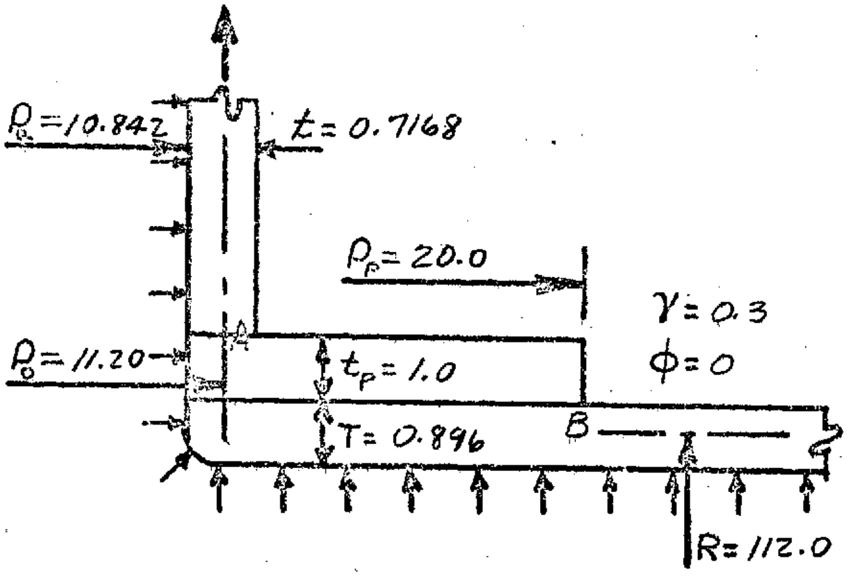
P/P_o	I/s SCF	O/s SCF
1.000 @ A	2.009	2.910
SHELL @ $\phi = 0$		
0.968	3.061	2.598
1.000	2.685	2.630
1.185	1.869	2.143
1.371	1.559	1.717
1.556	1.368	1.420
1.773	1.209	1.203
2.052	1.083	1.048
2.332	1.019	0.976

PIPE



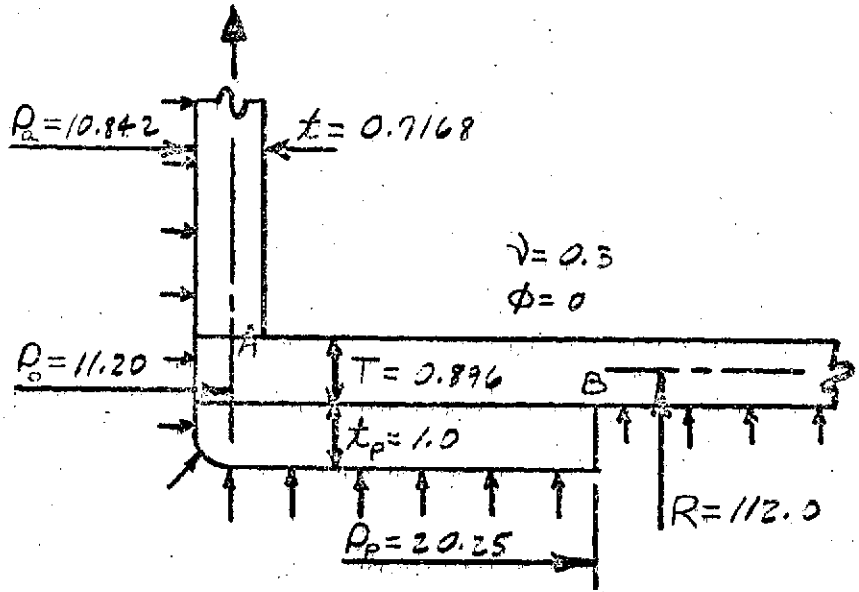
ρ/ρ_o	I/S SCF	O/S SCF
1.000 @ A	1.538	1.695
1.773 @ B	0.601	1.400
SHELL @ $\phi = 0$		
0.968	2.403	1.698
1.000	2.005	1.878
1.134	1.528	1.473
1.383	1.358	1.114
1.631	1.282	0.800
1.773	1.195	0.843
1.844	1.127	0.968
1.915	1.092	0.881

PIPE AND PAD



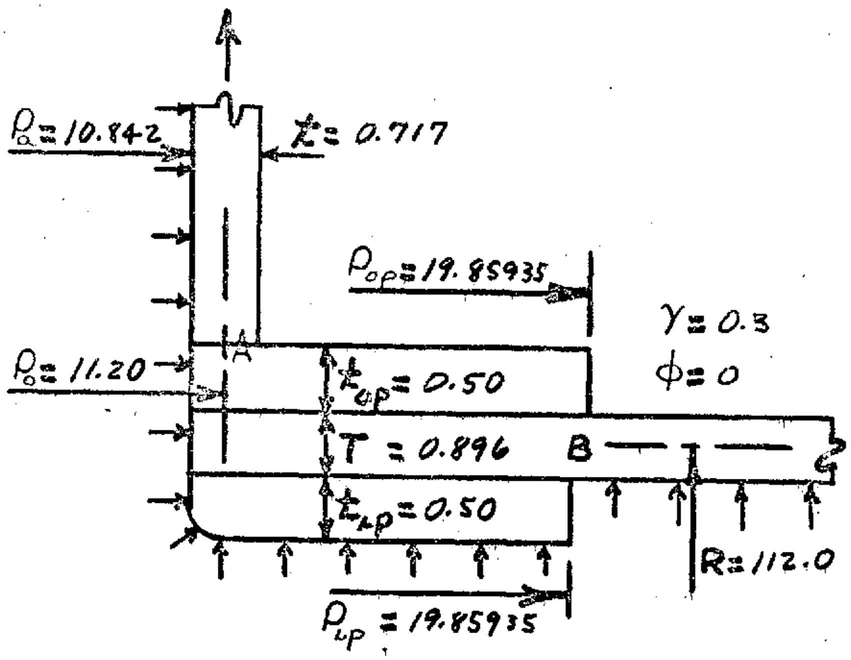
ρ/ρ_0	I/S SCF	O/S SCF
1.000 @ A	1.242	0.808
1.786 @ B	0.593	1.473
SHELL @ $\phi=0$		
0.968	1.945	1.494
1.000	1.648	1.552
1.071	1.546	1.382
1.250	1.382	1.072
1.518	1.305	0.726
1.786	1.173	0.713
2.052	1.160	0.811
2.332	1.129	0.848

PIPE AND PAD



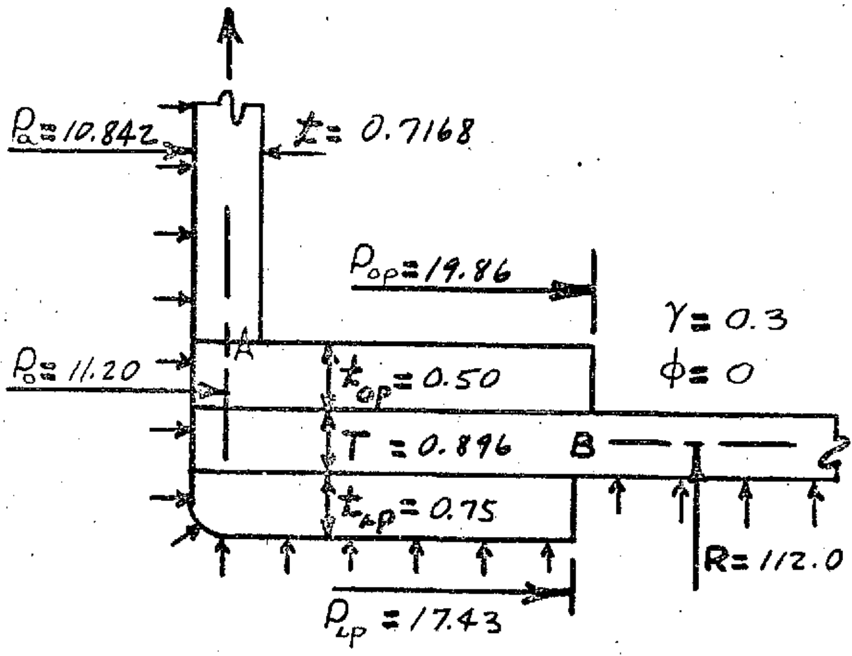
ρ / ρ_o	I/S SCF	O/S SCF
1.000 @ A	1.327	1.635
1.808 @ B	1.356	0.789
SHELL @ $\phi = 0$		
0.968	1.779	1.529
1.000	1.413	1.751
1.071	1.392	1.531
1.250	1.178	1.283
1.518	0.865	1.188
1.808	0.894	0.977
2.052	0.813	0.975
2.332	0.796	0.994

PIPE AND PAD



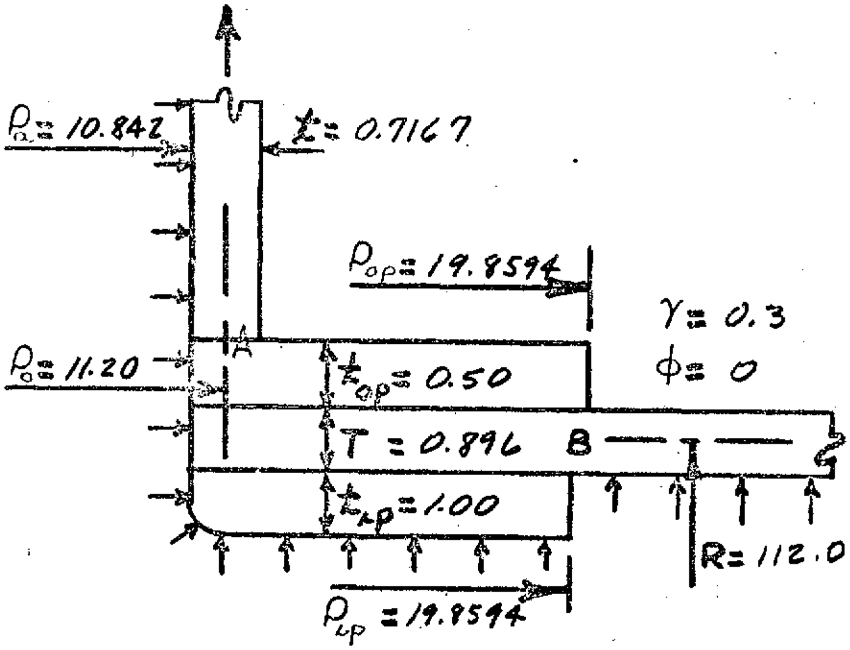
ρ/ρ_o	I/S SCF	O/S SCF
1.000 @ A	1.257	1.467
1.773 @ B	1.105	1.080
INNER PAD @ $\phi = 0$		
0.968	1.967	1.402
1.000	1.693	1.520
1.185	1.154	1.285
1.371	0.948	1.048
1.556	0.923	0.706
1.773	0.866	0.700
2.053	0.869	0.824
2.332	0.882	0.896

PIPE AND PADS



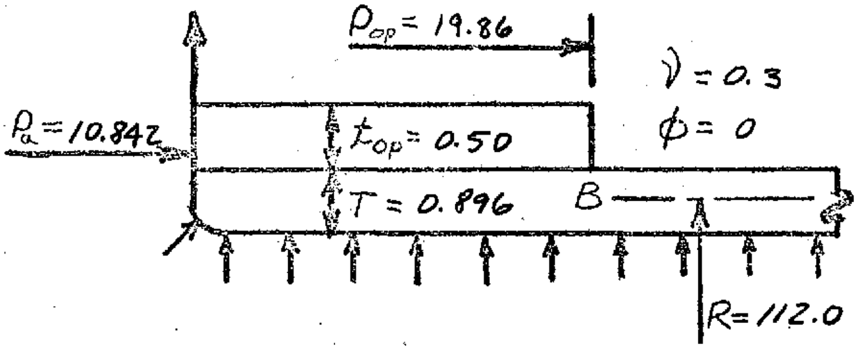
P/P_o	I/S SCF	O/S SCF
1.000 @ A	1.215	1.512
1.556 @ B	1.467	0.571
SHELL @ $\phi = 0$		
0.968	1.855	1.237
1.000	1.484	1.470
1.185	1.091	1.134
1.371	0.858	0.951
1.556	1.202	0.617
1.773	0.866	0.719
2.053	0.894	0.855
2.332	0.911	0.920

PIPE AND PADS



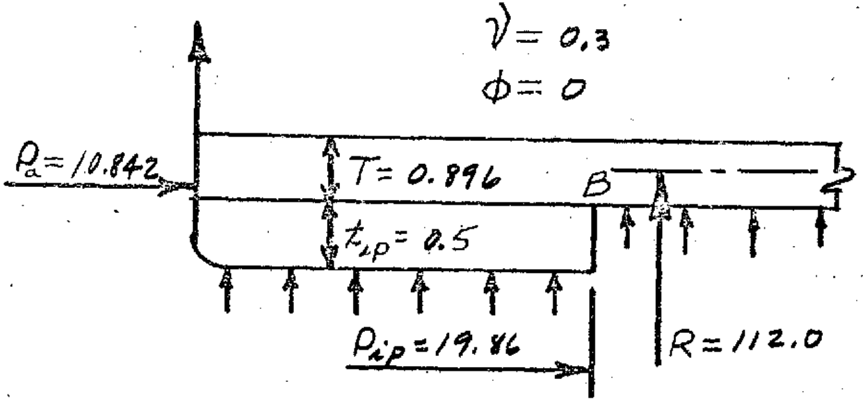
ρ/ρ_o	I/S SCF	O/S SCF
1.000 @ A	1.125	1.436
1.773 @ B	1.187	0.965
SHELL @ φ = 0		
0.968	1.653	1.098
1.000	1.315	1.322
1.185	0.992	0.986
1.371	0.809	0.802
1.556	0.640	0.735
1.773	0.939	0.641
2.052	0.772	0.781
2.332	0.799	0.879

PIPE AND PADS



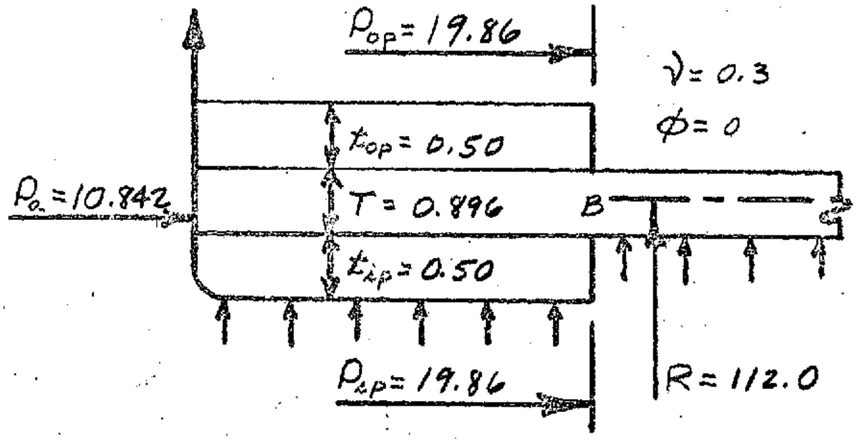
ρ/ρ_a	I/S SCF	O/S SCF
1.832 @ B	0.158	1.686
SHELL@ $\phi = 0$		
1.000	4.655	3.689
1.033	5.174	2.426
1.224	3.645	1.143
1.416	2.854	5.663
1.607	2.335	0.295
1.832	2.014	-0.005
2.120	1.752	0.060
2.409	1.625	0.160

FORCE AND PAD



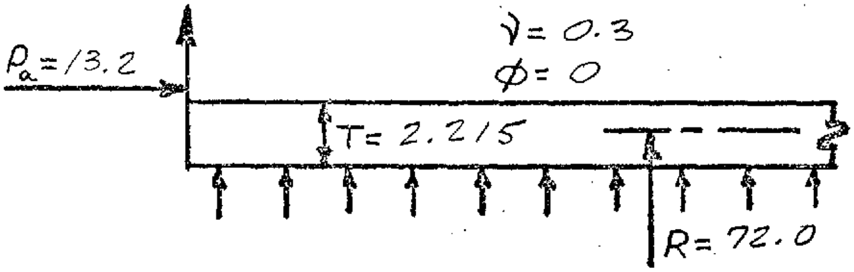
P/P_a	I/S SCF	O/S SCF
1.832 @ B	1.475	1.245
PAD @ $\phi = 0$		
1.000	3.810	3.221
1.033	3.077	3.108
1.224	1.702	1.942
1.416	1.031	1.367
1.607	0.784	0.877
1.832	1.027	1.044
2.120	0.740	0.942
2.409	0.712	0.945

FORCE AND PAD



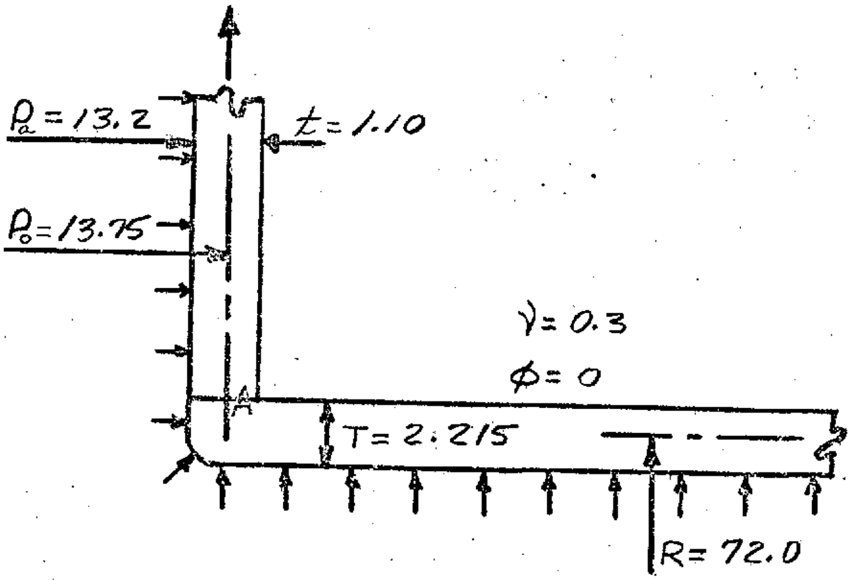
P/P_a	I/S SCF	O/S SCF
1.832 @ B	1.316	0.941
INNER PAD @ $\phi = 0$		
1.000	3.364	2.704
1.033	2.899	2.544
1.224	1.816	1.660
1.416	1.300	1.228
1.607	1.071	0.846
1.832	0.945	0.410
2.120	0.853	0.571
—	—	—

FORCE AND PADS



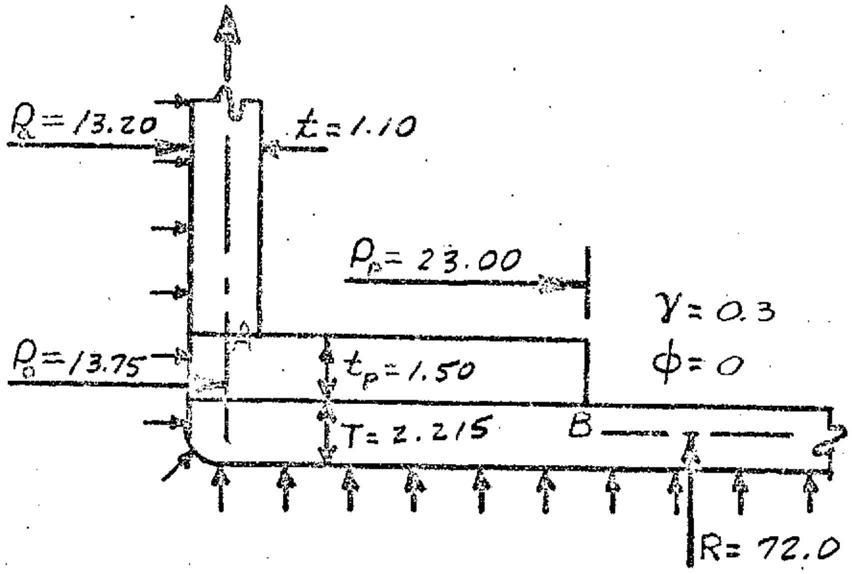
P/P_a	I/s SCF	O/s SCF
1.000	5.233	3.592
1.042	4.699	3.268
1.125	4.083	2.550
1.288	3.134	1.717
1.553	2.244	1.006
1.742	1.857	0.770
1.894	1.622	0.675
2.045	1.440	0.634

FORCE



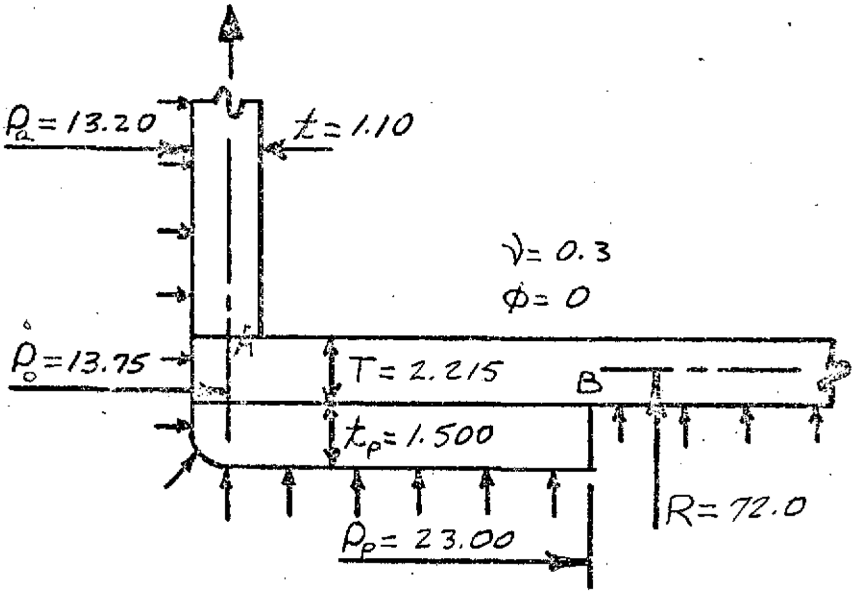
ρ/ρ_o	I/S SCF	O/S SCF
1.000 @ A	2.149	2.257
SHELL @ $\phi = 0$		
0.960	2.809	.2.407
1.000	2.652	2.141
1.080	2.478	1.755
1.236	2.227	1.279
1.491	2.021	0.797
1.673	1.922	0.596
1.818	1.851	0.488
1.964	1.785	0.419

PIPE



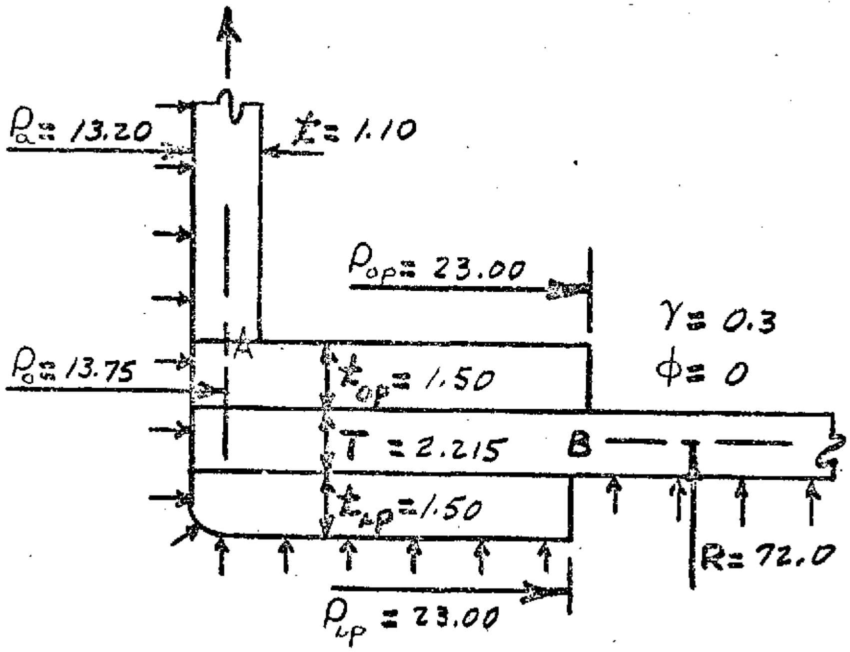
P/P_o	I/S SCF	O/S SCF
1.000 @ A	1.842	2.168
1.673 @ B	0.059	2.662
SHELL @ $\phi = 0$		
0.960	2.783	2.394
1.000	2.163	2.487
1.080	1.901	2.089
1.236	1.564	1.553
1.491	1.300	1.017
1.673	1.015	1.113
1.818	0.942	1.164
1.964	0.891	1.180

PIPE AND PAD



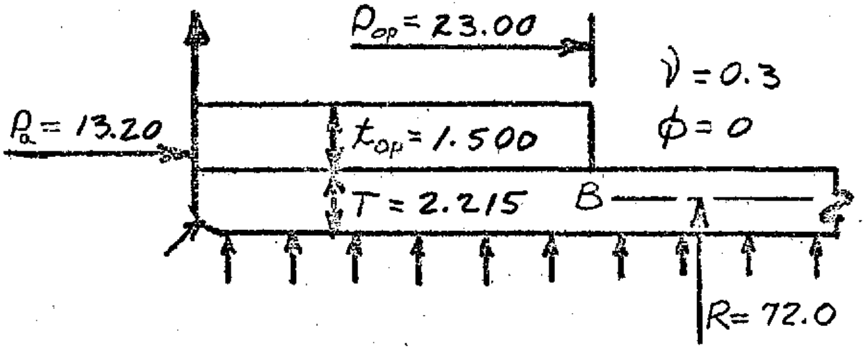
ρ/ρ_o	I/S SCF	O/S SCF
1.000 @ A	0.552	3.019
1.673 @ B	1.483	1.010
SHELL @ $\phi = 0$		
0.960	2.303	2.193
1.000	1.900	2.244
1.164	1.518	1.757
1.336	1.200	1.467
1.509	0.906	1.344
1.673	1.146	1.052
1.836	0.986	0.964
2.000	0.903	0.933

PIPE AND PAD



ρ/ρ_o	I/S SCF	O/S SCF
1.000 @ A	1.317	1.493
1.673 @ B	1.204	1.015
INNER PAD@ $\phi = 0$		
0.960	1.957	1.819
1.000	1.790	1.654
1.080	1.520	1.443
1.236	1.210	1.131
1.491	0.964	0.786
1.673	1.020	0.625
1.818	0.947	0.690
1.964	0.931	0.744

PIPE AND PADS



ρ/ρ_a	I/S SCF	O/S SCF
1.742 @ B	0.319	1.499
SHELL @ $\phi = 0$		
1.000	3.649	2.933
1.042	3.912	1.931
1.125	3.476	1.422
1.288	2.846	0.857
1.553	2.259	0.442
1.742	2.034	0.299
1.894	1.881	0.278
2.045	1.757	0.295

FORCE AND PAD