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# FLANGE: A Computer Program for the Analysis of Flanged Joints with Ring-Type Gaskets


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# FLANGE: A COMPUTER PROGRAM FOR THE ANALYSIS OF FLANGED JOINTS WITH RING-TYPE GASKETS

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## FOREWORD

The work reported here was performed at Oak Ridge National Laboratory and at Battelle-Columbus Laboratories under Union Carbide Corp., Nuclear Division, Subcontract No. 291৴ as part of the ORNL Design Criteria for Piping and Nozzles Program, S. E. Moore, Manager. This program is funded by the Division of Reactor Safety Research (RSR) of the U.S. Nuclear Regulatory Commission as part of a cooperative effort with industry to develop and verify analytical methods for assessing the safety of pressure-vessel and piping-system design. The cognizant RSR project engineer is E. K. Lynn. The cooperative effort is coordinated through the Pressure Vessel Research Committee of the Welding Research Council under the Subcommittee on Piping, Pumps, and Valves.

The study described in this report was conducted under the general direction of W. L. Greenstreet and S. E. Moore, Solid Mechanics Department, Reactor Division, ORNL, and is a continuation of work supported in prior years by the Division of Reactor Research and Development, U.S. Energy Research and Development Administration (formerly the USAEC).

Prior reports and open-literature publications in this series are:

1. W. L. Greenstreet, S. E. Moore, and E. C. Rodabaugh, "Investigations of Piping Components, Valves, and Pumps to Provide Information for Code Writing Bodies," ASME Paper 68-WA/PTC-6, American Society of Mechanical Engineers, New York, Dec. 2, 1968.

2. W. L. Greenstreet, S. E. Moore, and R. C. Gwaltney, *Progress Report on Studies in Applied Solid Mechanics*, ORNL-TM-4576 (August 1970).

3. E. C. Rodabaugh, *Phase Report No. 115-1 on Stress Indices for Small Branch Connections with External Loadings*, ORNL-TM-3014 (August 1970).

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# 1. INTRODUCTION

## Purpose and Scope

The *ASME Boiler and Pressure Vessel Code*[1] gives rules for designing bolted flange connections with ring-type gaskets based on a stress analysis developed by Waters et al.[2] These rules give formulas and graphs for calculating stresses due to a moment applied to the flange ring. The Code rules, however, do not require that stresses due to internal pressure be taken into account, although Ref. 2 briefly discusses such stresses.

The computer program FLANGE was written to calculate not only the stresses due to moment loads on the flange ring but also stresses due to internal pressure; stresses due to a temperature difference between the hub and ring; and stresses due to the variations in bolt load that result from pressure, hub-ring temperature gradient, and/or bolt-ring temperature difference. The program FLANGE is applicable to tapered-hub, straight, and blind flanges. The analysis method is based on the differential equations for thin plates and shells rather than on the strain-energy method used by Waters et al.[2] The stresses due to moment loading calculated by the two methods are essentially identical for identical boundary conditions. The analysis provided herein also includes a different, and perhaps more realistic, set of boundary conditions than those used in Ref. 2.

The nomenclature used in this report is identified in the remainder of this chapter. In Chapter 2 a description of the general model of flanges used in the theoretical development of the computer code is provided. The actual mathematical expressions for calculating stresses and displacements due to moment and pressure loads are derived in Chapters 3, 4, and 5 for tapered-hub, straight hub, and blind flanges, respectively. In Chapters 6 and 7, these expressions are extended to include the effects of thermal gradients and variations in bolt loads. The computer program FLANGE is described in the last chapter of this report. Example calculations, listings, and flowcharts of the program and its subroutines are included as appendices.

## Nomenclature

$a$ = outside radius of ring

$A = 2a$ = outside diameter of ring

$A_b$ = cross-sectional bolt area

$A_g$ = gasket area

$b$ = inside radius of ring and mean radius of pipe

$B = 2b$ = inside diameter of ring

$b_n$ = Bessel function of n

$c$ = bolt-circle radius

$C = 2c$ = bolt-circle diameter

$C_i$ = constant of integration

$C_i' = C_i/b$

$D = Et^3/12(1 - \nu^2)$

$D_{ij}$ = constants of integration (blind-flange analysis)

$E = E_f$ = modulus of elasticity of flange material

$E_b$ = modulus of elasticity of bolt material

$E_g$ = modulus of elasticity of gasket material

$f$ = ASME Code design parameter

$F$ = ASME Code design parameter

$g_0$ = wall thickness of pipe

$g_1$ = wall thickness of hub at intersection with ring

$g$ = gasket centerline radius

$G = 2g$ = gasket centerline diameter

$h$ = length of tapered-wall hub

$K = a/b = A/B$

$\ell_0$ = bolt length

$M$ = total moment applied to ring, in.-lb

$M_i$ or $M_{ij}$ = moment resultants, in.-lb/in.

$p$ = internal pressure

$P_i$ = shear resultants, lb/in.

$p^* = \dfrac{[1 - (\nu/2)]bp}{g_0 E}$ = nondimensional pressure parameter

$r$ = radial coordinate, ring

$t$ = ring thickness

$t_x$ = hub thickness

$u$ = radial displacement, hub

$u_1$ = radial displacement, pipe

$u_r$ = radial displacement, ring

$V$ = ASME Code design parameter

$v_0$ = undeformed gasket thickness

$w$ = axial displacement, ring

$W_1$ = initial bolt load, lb

$W_2$ = residual bolt load, lb

$x$ = axial coordinate, hub

$x_1$ = axial coordinate, pipe

$\alpha = (g_1 - g_0)/g_0 = \rho - 1$ = nondimensional wall-thickness parameter

$\beta = [3(1 - \nu^2)/b^2 g_0^2]^{1/4}$ = dimensional parameter used in the analysis

$\gamma = [12(1 - \nu^2)/b^2 g_0^2]^{1/4}(h)$ = dimensional parameter used in the analysis

$\Delta$ = temperature difference between hub/pipe and ring

$\delta_i$ = axial displacement of ring

$\epsilon_f$ = coefficient of thermal expansion, flange material

$\epsilon_b$ = coefficient of thermal expansion, bolt material

$\epsilon_g$ = coefficient of thermal expansion, gasket material

$\eta = 2\gamma(\psi/\alpha)^{1/2}$ = nondimensional argument of the modified Bessel functions

$\nu$ = Poisson's ratio (0.3 used herein)

$\xi = x/h$ = nondimensional distance parameter

$\rho = g_1/g_0$ = nondimensional wall-thickness parameter

$\sigma$ = stress, with subscripts:

- $\ell$ = longitudinal (pipe or hub)
- $c$ = circumferential (pipe or hub)
- $t$ = tangential (ring)
- $r$ = radial (ring)
- $b$ = bending
- $m$ = membrane
- $o$ = outside surface of the pipe or hub on the hub side of ring
- $i$ = inside surface of the pipe or hub on the gasket-face side of ring

$\psi = \xi + (1/\alpha)$ = nondimensional parameter

## 2. GENERAL DESCRIPTION OF THE ANALYSIS

The model used for the analysis of tapered-hub flanges is shown in Fig. 1. The three parts involved are the pipe, hub, and ring, respectively. The analysis presented here is based on the theory of thin plates and shells. The pipe is considered to be a uniform-wall-thickness cylindrical shell with midsurface radius b. The hub is considered to be a linearly variable-wall-thickness cylindrical shell with midsurface radius [illegible]. The ring is considered to be a flat annular plate with constant thickness t, inside radius b, and outside radius a. The effects of the bolt holes are neglected.

Three different types of loadings on bolted flanges are considered:

1. Bolt load, represented by W in Fig. 1. In application, the moment M applied to the flange ring is converted into an equivalent bolt load by the relationship $W(a - b) = M$. This is the same approach used in the ASME Code calculation method.[1]

2. Internal pressure, acting radially on the pipe, hub, and ring and axially on an (assumed remote) end closure on the pipe.

3. A temperature difference between the pipe and the ring. The pipe and the hub are assumed to be at the same uniform temperature. The ring is also assumed to be at a uniform temperature, which may be different from that of the pipe or hub.

Upon integration of the shell and plate differential equations, algebraic equations in terms of dimensions, materials properties and loadings, and 12 integration constants are obtained, 4 for each part. These constants are evaluated by the usual discontinuity analysis method of writing continuity equations at the junctures of the parts and at the boundaries. After numerical values are determined for the constants, the algebraic equations provide the means for computing the stresses and deflections. In the development of the equations for stresses, the assumption is made that the bolt load W does not change with pressure or temperature. Later the analysis is modified to include changes in W as a function of these loadings. Because the relations are linear, it is possible to determine the stresses (or stress range) due to combinations

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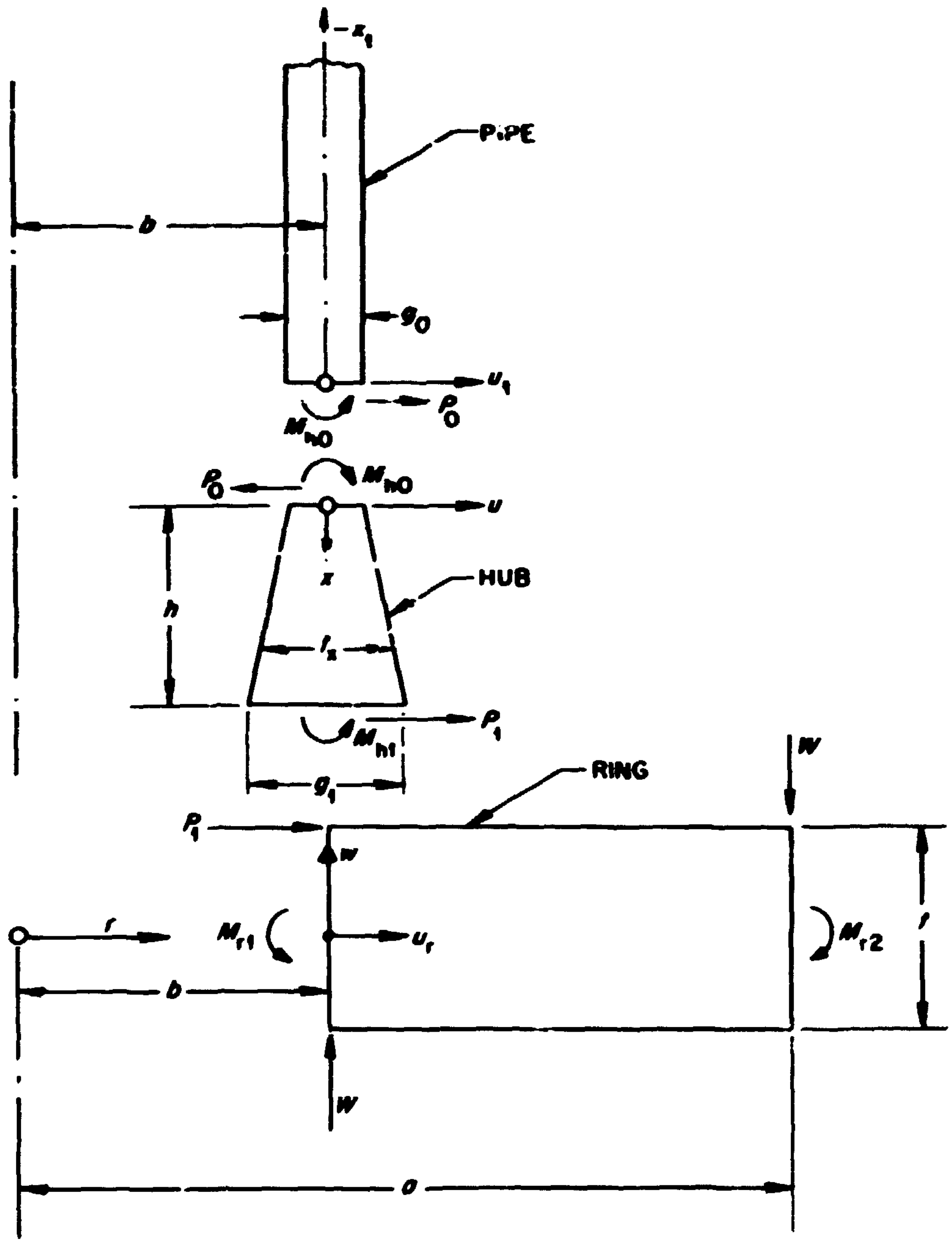


Fig. 1. Analysis model of a tapered-hub flange.

of initial bolt loading, pressure, and temperature change. The model used for straight-hub flanges is a simplification of the tapered-hub case in that only two parts are involved, the pipe and the ring.

In common with all shell-type analyses, the analysis gives anomalous results at points of abrupt thickness change or meridional direction change. In particular, the stresses at the juncture of the hub to the ring represent only the gross loading effect; detailed local stresses are not determined by the theory. Displacements, however, are represented fairly accurately.

## 3. FLANGE WITH A TAPERED-WALL HUB

The first step in deriving the stress equations is to state the basic shell/plate equations for the ring, the hub, and the pipe. We then inspect the boundary conditions, compute the constants, and calculate the stresses and displacements.

### Equations for the Annular Ring

The basic differential equation for the displacement w of a circular plate given by Timoshenko[3] is

$$\frac{1}{r}\frac{d}{dr}\left\{r\frac{d}{dr}\left[\frac{1}{r}\frac{d}{dr}\left(r\frac{dw}{dr}\right)\right]\right\} = \frac{q}{D} , \tag{1}$$

where the coordinate r and displacement w are illustrated in Fig. 1 and q = a uniformly distributed lateral load on the plate, $D = Et^3/12(1 - \nu^2)$ = the flexural rigidity of the plate, E = modulus of elasticity of the flange material, t = plate thickness, and $\nu$ = Poisson's ratio. Equation (1) can be integrated to give a relation for the displacement in terms of arbitrary constants:

$$w = C_7 r^2 \ln r + C_8 r^2 + C_9 \ln r + C_{10} + \frac{r^4 q}{64D} , \tag{2}$$

where numerical values for the constants $C_7$, ..., $C_{10}$ are established from boundary conditions. Derivatives of w, required in the subsequent analysis, are:

$$\frac{dw}{dr} = C_7(2r \ln r + r) + 2C_8 r + \frac{C_9}{r} + \frac{r^3 q}{16D} , \tag{3}$$

$$\frac{d^2w}{dr^2} = C_7(2 \ln r + 3) + 2C_8 - \frac{C_9}{r^2} + \frac{3r^2 q}{16D} , \tag{4}$$

and

$$\frac{d^3w}{dr^3} = C_7\left(\frac{2}{r}\right) + \frac{2C_9}{r^3} + \frac{3rq}{8D} . \qquad (5)$$

In the subsequent analysis the distributed load q is taken as zero.

The radial and tangential moments are given[3] by the equations:

$$M_r = -D\left(\frac{d^2w}{dr^2} + \frac{\nu}{r}\frac{dw}{dr}\right) \qquad (6)$$

and

$$M_t = -D\left(\frac{1}{r}\frac{dw}{dr} + \nu\frac{d^2w}{dr^2}\right) . \qquad (7)$$

Using Eqs. (3) and (4), these moments can be expressed as

$$M_r = -D\left\{C_7[2(1+\nu)\ \ln r + (3+\nu)] + C_8[2(1+\nu)] - C_9\left(\frac{1-\nu}{r^2}\right)\right\} \qquad (8)$$

and

$$M_t = -D\left\{C_7[2(1+\nu)\ \ln r + (1+3\nu)] + C_8[2(1+\nu)] + C_9\left(\frac{1-\nu}{r^2}\right)\right\} . \qquad (9)$$

## Equations for the Tapered Hub

The basic differential equation for the radial displacement u of a cylindrical shell with a linearly variable wall thickness $t_x$ is given by Timoshenko[3] as

$$\frac{d^2}{dx^2}\left(t_x^3 \frac{d^2u}{dx^2}\right) + \frac{12(1 - \nu^2)t_x u}{b^2} - \frac{12(1 - \nu^2)[1 - (\nu/2)]p}{E} = 0 \; . \tag{10}$$

The solution of Eq. (10) can be shown* to be:

$$u = \frac{b}{\psi^{1/2}}(C_1 b_1 + C_2 b_2 + C_3 b_3 + C_4 b_4) + \frac{bP^*}{1 + \alpha\xi} \; , \tag{11}$$

where $P^* = [1 - (\nu/2)]bp/g_0E$. Derivatives of u, required in the subsequent analysis, are

$$u' = \frac{du}{dx} = \frac{b}{2\psi^{3/2}h}(C_1 b_5 + C_2 b_6 + C_3 b_7 + C_4 b_8) - \frac{b\alpha P^*}{h(1 + \alpha\xi)^2} \; , \tag{12}$$

$$u'' = \frac{d^2u}{dx^2} = \frac{b}{4\psi^{5/2}h^2}(C_1 b_9 + C_2 b_{10} + C_3 b_{11} + C_4 b_{12}) + \frac{2b\alpha^2P^*}{h^2(1 + \alpha\xi)^3} \; , \tag{13}$$

and

$$u''' = \frac{d^3u}{dx^3} = \frac{b}{8\psi^{7/2}h^3}(C_1 b_{13} + C_2 b_{14} + C_3 b_{15} + C_4 b_{16}) - \frac{6r\alpha^2P^*}{h^3(1 + \alpha\xi)^4} \; . \tag{14}$$

The $b_n$'s used in Eqs. (11) through (14) are modified Bessel functions of argument $\eta = 2\gamma(\psi/\alpha)^{1/2}$ defined in Table 1, which gives equations for n = 1 through 20; $\psi$, $\alpha$, and $\xi$ are defined in the nomenclature.

---

*A solution to an equation that is essentially the same as Eq. (10) is given by Timoshenko,[3] who credits the original solution to G. Kirchoff in 1879.

Table 1. Modified Bessel functions of argument $\eta$[a]

| |
|---|
| $b_1 = \text{ber}' \eta$ |
| $b_2 = \text{bei}' \eta$ |
| $b_3 = \text{ker}' \eta$ |
| $b_4 = \text{kei}' \eta$ |
| $b_5 = -\eta \text{ bei } \eta - 2 \text{ ber}' \eta$ |
| $b_6 = \eta \text{ ber } \eta - 2 \text{ bei}' \eta$ |
| $b_7 = -\eta \text{ kei } \eta - 2 \text{ ker}' \eta$ |
| $b_8 = \eta \text{ ker } \eta - 2 \text{ kei}' \eta$ |
| $b_9 = 4\eta \text{ bei } \eta + 8 \text{ ber}' \eta - \eta^2 \text{ bei}' \eta$ |
| $b_{10} = -4\eta \text{ ber } \eta + 8 \text{ bei}' \eta + \eta^2 \text{ ber}' \eta$ |
| $b_{11} = 4\eta \text{ kei } \eta + 8 \text{ ker}' \eta - \eta^2 \text{ kei}' \eta$ |
| $b_{12} = -4\eta \text{ ker } \eta + 8 \text{ kei}' \eta + \eta^2 \text{ ker}' \eta$ |
| $b_{13} = -\eta^3 \text{ ber } \eta - 24\eta \text{ bei } \eta - 48 \text{ ber}' \eta + 8\eta^2 \text{ bei}' \eta$ |
| $b_{14} = -\eta^3 \text{ bei } \eta + 24\eta \text{ ber } \eta - 48 \text{ bei}' \eta - 8\eta^2 \text{ ber}' \eta$ |
| $b_{15} = -\eta^3 \text{ ker } \eta - 24\eta \text{ kei } \eta - 48 \text{ ker}' \eta + 8\eta^2 \text{ kei}' \eta$ |
| $b_{16} = -\eta^3 \text{ kei } \eta + 24\eta \text{ ker } \eta - 48 \text{ kei}' \eta - 8\eta^2 \text{ ker}' \eta$ |
| $b_{17} = -\eta \text{ ber } \eta + 2 \text{ bei}' \eta$ |
| $b_{18} = -\eta \text{ bei } \eta - 2 \text{ ber}' \eta$ |
| $b_{19} = -\eta \text{ ker } \eta + 2 \text{ kei}' \eta$ |
| $b_{20} = -\eta \text{ kei } \eta - 2 \text{ ker}' \eta$ |

[a]The argument $\eta = 2\gamma(\psi/\alpha)^{1/2}$, where $\gamma = [12(1 - \nu^2)/b^2 g_0{}^2]^{1/4}(h)$, $\psi = \xi + (1/\alpha)$, $\xi = x/h$, and $\alpha = (g_1 - g_0)/g_0$.

## Equations for the Pipe

The basic differential equation for the radial displacement $u_1$ of a cylindrical shell with uniform wall thickness is:

$$g_0^3 \frac{d^4 u_1}{dx_1^4} + \frac{12(1 - \nu^2) g_0}{b^2} u_1 - \frac{12(1 - \nu^2)[1 - (\nu/2)]p}{E} = 0 . \qquad (15)$$

The solution of Eq. (15) is:

$$u_1 = e^{-\beta x_1} (C_{11} \sin \beta x_1 + C_{12} \cos \beta x_1)$$

$$+ e^{\beta x_1} (C_5 \sin \beta x_1 + C_6 \cos \beta x_1) + bP^* . \qquad (16)$$

For large negative values of $x_1$, $u_1 = bP^*$. Hence, $C_{11} = C_{12} = 0$. Derivatives of $u_1$ needed in the subsequent analysis are

$$u_1' = \frac{du_1}{dx_1} = \beta e^{\beta x_1} [C_5 (\sin \beta x_1 + \cos \beta x_1)$$

$$+ C_6 (\cos \beta x_1 - \sin \beta x_1)] , \qquad (17)$$

$$u_1'' = \frac{d^2 u_1}{dx_1^2} = 2\beta^2 e^{\beta x_1} [C_5 \cos \beta x_1 - C_6 \sin \beta x_1] , \qquad (18)$$

and

$$u_1''' = \frac{d^3 u_1}{dx_1^3} = -2\beta^3 e^{\beta x_1} [C_5 (\sin \beta x_1 - \cos \beta x_1)$$

$$+ C_6 (\sin \beta x_1 + \cos \beta x_1)] . \qquad (19)$$

## Boundary Conditions

The equations listed above involve ten unknown constants: $C_1$, $C_2$, ..., $C_{10}$. These can be determined from the ten boundary-condition equations shown in Table 2 [Eq. (20)]. The ASME Code stress-calculation method[1] is based on the assumption that the radial displacement at the hub-to-ring juncture is zero. A more realistic assumption (particularly for internal pressure loading) is that the displacement of the hub equals the displacement of the surface of the ring where it joins the hub. Boundary-condition equations for both of these alternatives are provided in Table 2. [See Eqs. (20-5).] In Eq. (20-5b) a positive dw/dr gives a negative radial displacement at the surface of the ring adjacent to the hub. Also in Eq. (20-5b), $u_r$ is the radial expansion of the ring due to internal pressure as given by Lame's equation:

$$u_r = \frac{b}{E}\left[\frac{(1 + \nu)k^2 + (1 - \nu)}{k^2 - 1}\right]\left(p - \frac{P_1}{t}\right) , \quad (21)$$

where $k = a/b$. In this expression, it is assumed that in addition to internal pressure p, the shear resultant $P_1$ is uniformly distributed around the inner edge of the ring.

## Boundary Equations

When the equations in Table 2 are satisfied simultaneously, they establish the values of the ten constants ($C_1$, $C_2$, ..., $C_{10}$) in terms of the dimensions, Poisson's ratio, and the loads (total bolt load W and internal pressure p). After algebraic manipulation, the equations are reduced to the forms shown in Table 3. This table provides the elements for the matrix equation $[A]|C| + |B| = 0$, where the terms in the coefficient matrix [A] are given under the headings of the corresponding constants in the column matrix |C|. The loading parameters constitute the column matrix |B|.

To derive numerical values for the constants, three items should be noted.

1. It is convenient to define two new constants, $C_5' = C_5/b$ and $C_6' = C_6/b$.
2. The radial expansion of the ring $u_r$ is defined in Eq. (21).

Table 2. Equations for the boundary conditions for a tapered-hub flange

| | Hub-to-pipe juncture | | Hub-to-ring juncture | | Ring | |
|---|---|---|---|---|---|---|
| | Equation | Eq. No. | Equation | Eq. No. | Equation | Eq. No. |
| Displacements[a] | $(u)_{x=0} = (u_1)_{x_1=0}$ | (20-1) | $(u)_{x=h} = 0$ | (20-5a) | $(w)_{r=b} = 0$ (Footnote b) | (20-8) |
| | | | $(u)_{x=h} = \left(u_r - \frac{t}{2}\frac{dw}{dr}\right)_{r=b}$ | (20-5b) | | |
| Rotations | $(u')_{x=0} = (u_1')_{x_1=0}$ | (20-2) | $(u')_{x=h} = \left(\frac{dw}{dr}\right)_{r=b}$ | (20-6) | | |
| Moments[c] | $(u'')_{x=0} = (u_1'')_{x_1=0}$ | (20-3) | $M_{h1} = -M_{r1} + \frac{1}{2} P_1 t$ (Footnote d) | (20-7) | $M_{r2} = 0$ | (20-9) |
| Shears | $\left(\frac{3\alpha}{h} u'' + u'''\right)_{x=0} = (u_1''')_{x_1=0}$ | (20-4) | | | $Q = -\frac{dM_r}{dr} + \frac{M_t - M_r}{r} + \frac{W}{2\pi r}$ | (20-10) |

[a]Radial for hub-to-pipe and hub-to-ring junctures and axial for the ring.

[b]Setting $(w)_{r=b}$ equal to zero provides a reference point for all other axial displacements.

[c]Radial for ring.

[d]The assumption is that the shear $P_1$ of the hub on the ring produces an additional moment on the ring.

Table 3. Matrix coefficients of the discontinuity equations[a] for a flange with a tapered wall hub

| Eq. No. | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5'$ | $C_6'$ | $C_7$ | $C_8$ | $C_9$ | $C_{10}$ | Loading parameters |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| (20-1)[b] | $b_1^0$ | $b_2^0$ | $b_3^0$ | $b_4^0$ | 0 | [illegible] | 0 | 0 | 0 | 0 | 0 |
| (20-2) | $b_5^0$ | $b_6^0$ | $b_7^0$ | $b_8^0$ | [illegible] / $\sqrt{2}$ | [illegible] / $\sqrt{2}$ | 0 | 0 | 0 | 0 | [illegible] |
| (20-3) | $b_9^0$ | $b_{10}^0$ | $b_{11}^0$ | $b_{12}^0$ | [illegible] | 0 | 0 | 0 | 0 | 0 | [illegible] |
| (20-4) | $b_{13}^0$ | $b_{14}^0$ | $b_{15}^0$ | $b_{16}^0$ | [illegible] / $\sqrt{2}$ | [illegible] / $\sqrt{2}$ | 0 | 0 | 0 | 0 | 0 |
| (20-5a)[c] | $b_1'$ | $b_2'$ | $b_3'$ | $b_4'$ | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] |
| (20-5b)[d] | $b_1' + U_1b_5' - U_2U_3b_{17}'$ | $b_2' + U_1b_6' - U_2U_3b_{18}'$ | $b_3' + U_1b_7' - U_2U_3b_{19}'$ | $b_4' + U_1b_8' - U_2U_3b_{20}'$ | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] |
| (20-6) | $b_5'$ | $b_6'$ | $b_7'$ | $b_8'$ | 0 | 0 | [illegible] | [illegible] | [illegible] | 0 | [illegible] |
| (20-7)[d] | $b_9' + U_5b_{17}'$ | $b_{10}' + U_5b_{18}'$ | $b_{11}' + U_5b_{19}'$ | $b_{12}' + U_5b_{20}'$ | 0 | 0 | [illegible] | [illegible] | [illegible] | 0 | [illegible] |
| (20-8) | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] | [illegible] | [illegible] | [illegible] | 0 |
| (20-9) | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] | [illegible] | [illegible] | 0 | 0 |
| (20-10) | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] | 0 | 0 | 0 | [illegible] |

[a] These equations are in the form [A]{C} = {B} = 0, where [A] is the coefficient matrix, {C} is the column matrix of unknown constants, and {B} is the column matrix of loading parameters.

[b] A superscript "0" on the b's indicates that the Bessel function is to be evaluated at [illegible].

[c] A prime (') on the b's indicates that the Bessel function is to be evaluated at [illegible].

[d] $U_1$ = [illegible]; $U_2$ = [illegible] $(1 - \nu^2)$; $U_3$ = (h/k) [illegible], where k = a/h; $U_4$ = [illegible]; $U_5$ = [illegible];
$U_6$ = [illegible].

3. The ASME Code stress-calculation method uses a moment M, applied to the flange ring, rather than a bolt load W, where the correlation between M and W is $M = W(a - b)$. In the present analysis, however, Eq. (20-10) from Table 2 is used with the loading parameter M, rather than W.

## Stresses

After having solved the set of equations in Table 3 for the constants $C_1, \ldots, C_{10}$, the stresses can be obtained anywhere in the structure. The equations for these stresses, used in other reports[4,5] in this series, are given in Table 4 [Eqs. (22)–(45)] for the same locations as those given by the ASME Code stress-calculation method; these are (1) at the hub-to-pipe juncture, (2) in the hub at the hub-to-ring juncture, and (3) at the inside edge of the ring ($r = b$).

## Displacements

In Chapter 7 the displacements w of the flange ring are used. The equations for these displacements (with w arbitrarily set to zero at $r = b$) are:

$$w_g = C_7 g^2 \ln g + C_8 g^2 + C_9 \ln g + C_{10} \qquad (46)$$

at the gasket centerline radius, $g = G/2$; and

$$w_c = C_7 c^2 \ln c + C_8 c^2 + C_9 \ln c + C_{10} \qquad (47)$$

at the bolt-circle radius, $c = C/2$.

Table 4. Equations for the stresses in a tapered-hub flange

| Type | Hub-to-pipe juncture, longitudinal and circumferential: Equation | Eq. No. | Hub-to-ring juncture, longitudinal and circumferential: Equation | Eq. No. | Inside edges of ring, tangential and radial: Equation | Eq. No. |
|---|---|---|---|---|---|---|
| Longitudinal or tangential | | | | | | |
| Bending | $(\sigma_\ell)_b = \pm \frac{Eg_0}{2(1-\nu^2)} (2\beta^2)C_? b$ | (22) | $(\sigma_\ell)_b = \pm \frac{Eg_1}{2(1-\nu^2)} \left[ \frac{b}{4\rho_1^{3/2}h^2} (C_1 b_1' + C_2 b_{12}') + C_3 b_{11}' + C_4 [illegible]) + \frac{2h\nu P^*}{h^2(1+\alpha)} \right]$ | (30) | $(\sigma_t)_b = \pm(6/t^2)(M_t)_{rab} \pm [Et/2(1-\nu^2)] \times [C_?(2.6 \ln h + 1.9) + 2.6C_? + 0.7C_?/h^2]$ | (38) |
| Membrane | $(\sigma_\ell)_m = pb/2g_0$ | (23) | $(\sigma_\ell)_m = pb/2g_1$ | (31) | $(\sigma_t)_m = \frac{K^2+1}{K^2-1}\left(p - \frac{P_1}{t}\right)$ | (39)[a] |
| Outside | $(\sigma_\ell)_o = pb/2g_0 - 1.818C_?$ | (24) | $(\sigma_\ell)_o = pb/2g_1 - (\sigma_\ell)_b$ | (32) | $(\sigma_t)_o = (\sigma_t)_m + (\sigma_t)_b$ | (40)[b] |
| Inside | $(\sigma_\ell)_i = pb/2g_0 + 1.818C_?$ | (25) | $(\sigma_\ell)_i = pb/2g_1 + (\sigma_\ell)_b$ | (33) | $(\sigma_t)_i = (\sigma_t)_m - (\sigma_t)_b$ | (41)[c] |
| Circumferential or radial | | | | | | |
| Bending | $(\sigma_c)_b = \nu(\sigma_\ell)_b$ | (26) | $(\sigma_c)_b = \nu(\sigma_\ell)_b$ | (34) | $(\sigma_r)_b = \pm \frac{6M_{r?}}{t^2} \pm \frac{Et}{2(1-\nu^2)} \times [C_?(2.6 \ln h + 3.3) + 2.6C_? - 0.7C_?/h^2]$ | (42) |
| Membrane | $(\sigma_c)_m = (Eu_0/b) + \nu(pb/2g_0)$ | (27)[d] | $(\sigma_c)_m = (Eu_h/b) + \nu(pb/2g_1)$ | (35)[e] | $(\sigma_r)_m = -p + P_1/t$ | (43) |
| Outside | $(\sigma_c)_o = (Eu_0/b) + \nu(\sigma_\ell)_o$ | (28) | $(\sigma_c)_o = (Eu_h/b) + \nu(\sigma_\ell)_o$ | (36) | $(\sigma_r)_o = (\sigma_r)_m + (\sigma_r)_b$ | (44)[b] |
| Inside | $(\sigma_c)_i = (Eu_0/b) + \nu(\sigma_\ell)_i$ | (29) | $(\sigma_c)_i = (Eu_h/b) + \nu(\sigma_\ell)_i$ | (37) | $(\sigma_r)_i = (\sigma_r)_m - (\sigma_r)_b$ | (45)[c] |

[a] Here, $K = a/b$, and $\frac{P_1}{t} = -\frac{Eg_1^2}{(1-\nu^2)} \frac{bn_1^2}{8h^3\rho_1^{7/2}} (C_1 b_{17}' + C_2 b_{18}' + C_3 b_{19}' + C_4 b_{20}')$.

[b] Hub-side surface of ring.

[c] Gasket-side surface of ring.

[d] $u_o = b(C_6' + P^*)$.

[e] $u_h = \frac{b}{\rho_1^{1/2}} (C_1 b_1' + C_2 b_2' + C_3 b_3' + C_4 b_4') + bP^*/(1+\alpha)$.

## 4. FLANGE WITH A STRAIGHT HUB

Although the mathematical expressions for the straight hub can be obtained by letting $g_0 = g_1$, this would result in indeterminate quantities in the computer program. Therefore, the direct solution to the ring with a straight hub was obtained by using the previously given basic equations for only the pipe and the ring. There are six constants of integration to be established; the boundary-condition equations are displayed in Table 5 [Eq. (48)].

After algebraic manipulation, the equations displayed in Table 5 are reduced to the matrix-equation form $[A]|C| + |B| = 0$, where the terms in the coefficient matrix $[A]$ are given in Table 6 under the headings of the corresponding constants in the column matrix $|C|$. Solving this set of equations for the six constants ($C_5'$, $C_6'$, $C_7$, $C_8$, $C_9$, and $C_{10}$) allows calculation of the stresses in the structure. The equations for the stresses in the pipe at the pipe-to-ring juncture and in the ring at the inner edge ($r = b$) are analogous to those previously derived for the flange with a tapered hub (see Table 4).

One can calculate the displacements $w_g$ and $w_c$ for a straight-hub flange from Eqs. (46) and (47), respectively, using the constants $C_7, \ldots, C_{10}$, identified in Table 6.

Table 5. Equations for the boundary conditions for a straight-hub flange

| | Hub-to-ring juncture | | Ring | |
|---|---|---|---|---|
| | Equation | Eq. No. | Equation | Eq. No. |
| Displacements | $(u_1)_{x_1=0} = 0$ | (48-1a)[a,b] | $(w)_{r=b} = 0$ | (48-4)[c] |
| | $(u_1)_{x_1=0} = \left(u_r - \frac{t}{2}\frac{dw}{dr}\right)_{r=b}$ | (48-1b)[a,b] | | |
| Rotations | $(u_1')_{x_1=0} = \left(\frac{dw}{dr}\right)_{r=b}$ | (48-2) | | |
| Moments | $M_{r1} = -M_{ho} + \frac{1}{2} P_0 t$ | (48-3) | $M_{r2} = 0$ | (48-5)[d] |
| Shear along radius r | | | $Q = -\frac{dM_r}{dr} + \frac{M_t - M_r}{r} = \frac{W}{2\pi r}$ | (48-6) |

[a]Radial displacements.

[b]For an ASME-type calculation, Eq. (48-1a) is used.

[c]Axial displacements; $(w)_{r=b} = 0$ is the reference point for all other axial displacements.

[d]Radial moment at outside edge of ring $(r = a)$.

Table 6. Matrix coefficients of the discontinuity equations[a] for a flange with a straight hub

| Eq. No. | Coefficients of $C_n$ | | | | | | Loading parameters |
|---|---|---|---|---|---|---|---|
| | $C_5'$ | $C_6'$ | $C_7$ | $C_8$ | $C_9$ | $C_{10}$ | |
| (48-1a) | 0 | 1.0 | 0 | 0 | 0 | 0 | $bP^* + bc_g$[illegible]$ - U_3P$ |
| (48-1b)[b] | $U_{34} - U_{33}$ | $1 + U_{34} + U_{33}$ | 0 | 0 | 0 | 0 | 0 |
| (48-2) | $\beta$ | $\beta$ | $-(2b \ln b + b)$ | $-2b$ | | 0 | 0 |
| (48-3) | $2\beta^2 + 2\beta^3 t/2$ | $-2\beta_1^3 t/2$ | $-(2.6 \ln b + 3.3) \times (t/g_0)^3$ | $-2.6(t/g_0)^3$ | $(0.7/b^2)(t/g_0)^3$ | 0 | 0 |
| (48-4) | 0 | 0 | $b^2 \ln b$ | $b^2$ | $\ln b$ | 1.0 | 0 |
| (48-5) | 0 | 0 | $2.6 \ln a + 3.3$ | 2.6 | $-0.7/a^2$ | 0 | 0 |
| (48-6) | 0 | 0 | 1.0 | 0 | 0 | 0 | $\frac{-3(1 - \nu^2)M}{2\pi Et^3(a - b)}$ |

[a]These equations are in the form $[a]|C| + |B| = 0$, where $[A]$ is the coefficient matrix, $|C|$ is the column matrix of unknown constants, $|B|$ is the column matrix of loading parameters.

[b]$U_3 = (b/E)\left[\frac{(1 + \nu)K^2 + (1 - \nu)}{K^2 - 1}\right]$, where $K = a/b$; $U_{33} = \frac{2U_3 E g_0^3 \beta^3}{12(1 - \nu^2)t}$; $U_{34} = t\theta/2$.

# 5. BLIND FLANGES

## Analysis Method

Blind flanges (or flat heads) are modeled as shown in Fig. 2. The general equations for a circular flat plate are:[3]

$$w = D_1 r^2 \ln r + D_2 r^2 + D_3 \ln r + D_4 + r^4 p/64D \ , \tag{49}$$

$$\frac{dw}{dr} = D_1(2r \ln r + r) + D_2(2r) + D_3/r + r^3 p/16D \ , \tag{50}$$

$$\frac{d^2w}{dr^2} = D_1(2 \ln r + 3) + D_2(2) - D_3/r^2 + 3r^2 p/16D \ , \tag{51}$$

and

$$\frac{d^3w}{dr^3} = D_1(2/r) + D_3(2/r^3) + 3rp/8D \ . \tag{52}$$

The radial and tangential moments $M_r$ and $M_t$ (see Fig. 2) are given by

$$M_r = -D\left(\frac{d^2w}{dr^2} + \frac{\nu}{r}\frac{dw}{dr}\right) \tag{53}$$

and

$$M_t = -D\left(\frac{1}{r}\frac{dw}{dr} + \nu\frac{d^2w}{dr^2}\right) \ ; \tag{54}$$

and the shear is given by

$$Q = -\frac{dM_r}{dr} + \frac{M_t - M_r}{r} \ . \tag{55}$$

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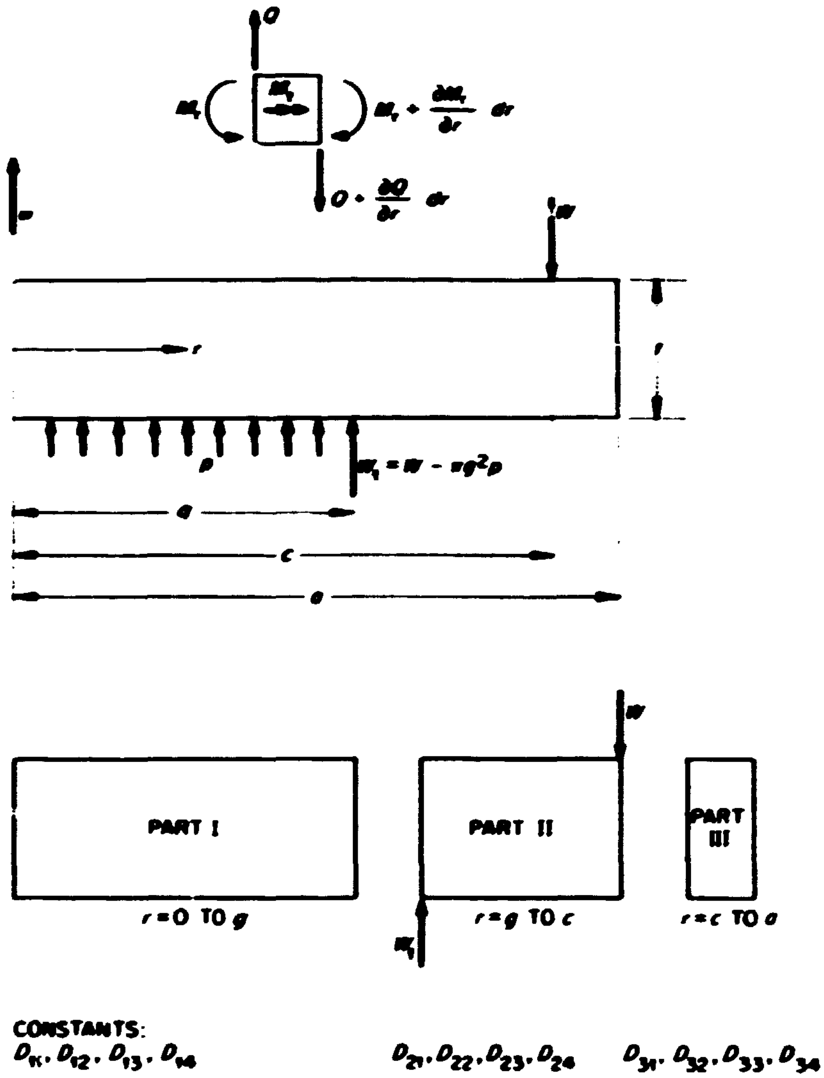


Fig. 2. Flat-plate analysis model of a blind flange or cover plate.

The moments and shears, in terms of the integration constants $D_1$ through $D_4$, are:

$$M_r = -D\{D_1[2(1 + \nu)\ \ln r + (3 + \nu)] + D_2[2(1 + \nu)] - D_3[(1 - \nu)/r^2]\}$$

$$- r^2 p/16(3 + \nu)\ , \qquad (56)$$

$$M_t = -D\{D_1[2(1 + \nu)\ \ln r + (1 + 3\nu)] + D_2[2(1 + \nu)] + D_3[(1 - \nu)/r^2]\} - r^2p/16(1 + 3\nu) , \qquad (57)$$

and

$$Q = D\left(\frac{4D_1}{r}\right) + \frac{rp}{2} . \qquad (58)$$

For analysis, the plate is divided into three parts as shown in Fig. 2. There are four integration constants for each segment. The boundary-condition equations used to evaluate these constants are shown in Table 7. These boundary conditions show that 3 of the 12 constants are zero. The set of simultaneous equations to be solved to establish the remaining 9 constants is shown in Table 8. Again, this table presents the elements of the matrix equation $[A]|C| + |B| = 0$.

Table 7. Boundary condition equations used for blind-flange analysis

| Equation No. | Boundary condition |
|---|---|
| 1 | $2\pi rQ = \pi r^2 p$ for all of Part I. This gives $D_{11} = 0$. |
| 2 | $(dw/dr)_I = 0$ at $r = 0$. This gives $D_{13} = 0$. |
| 3 | $(w)_I = 0$ at $r = g$ |
| 4 | $(dw/dr)_I = (dw/dr)_{II}$ at $r = g$ |
| 5 | $(Q)_{II} = (W/2\pi r) - (\pi g^2 p/2\pi g)$ at $r = g$. This gives $D_{21} = W/8\pi D - g^2p/8D$. |
| | (For pressure loading, $W = \pi g^2 p$; hence $D_{21} = 0$.) |
| 6 | $(w)_{II} = 0$ at $r = g$ |
| 7 | $(M_r)_I = (M_r)_{II}$ at $r = g$ |
| 8 | $(dw/dr)_I = (dw/dr)_{II}$ at $r = g$ |
| 9 | $(Q)_{III} = 0$. This gives $D_{31} = 0$. |
| 10 | $(M_r)_{II} = (M_r)_{III}$ at $r = c$ |
| 11 | $(M_r)_{III} = 0$ at $r = a$ |
| 12 | $(w)_{II} = (w)_{III}$ at $r = c$ |

Table 8. Boundary equations[a] for a blind flange

| No.[b] | Coefficients of $D_{ij}$ | | | | | | | | | Loading parameter |
|---|---|---|---|---|---|---|---|---|---|---|
| | $D_{12}$ | $D_{14}$ | $D_{21}$ | $D_{22}$ | $D_{23}$ | $D_{24}$ | $D_{32}$ | $D_{33}$ | $D_{34}$ | |
| 3 | $g^2$ | 1.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $g^4p/64D$ |
| 4 | $-2g$ | 0 | $2g \ln g + g$ | $2g$ | $1/g$ | 0 | 0 | 0 | 0 | $-g^3p/16D$ |
| 5 | 0 | 0 | 1.0 | 0 | 0 | 0 | 0 | 0 | 0 | $-W/8\pi D$ |
| 6 | 0 | 0 | $g^2 \ln g$ | $g^2$ | $\ln g$ | 1.0 | 0 | 0 | 0 | 0 |
| 7 | -2.6 | 0 | $2.6 \ln g + 3.3$ | 2.6 | $-0.7/g^2$ | 0 | 0 | 0 | 0 | $-3.3g^2p/16D$ |
| 8 | 0 | 0 | $2c \ln c + c$ | $2c$ | $1/c$ | 0 | $-2c$ | $-1/c$ | 0 | 0 |
| 10 | 0 | 0 | $2.6 \ln c + 3.3$ | 2.6 | $-0.7/c^2$ | 0 | -2.6 | $0.7/c^2$ | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 2.6 | $-0.7/a^2$ | 0 | 0 |
| 12 | 0 | 0 | $c^2 \ln c$ | $c^2$ | $\ln c$ | 1.0 | $-c^2$ | $-\ln c$ | -1.0 | 0 |

[a]These equations are in the form $|A||C| + |B| = 0$, where $|A|$ is the coefficient matrix, $|C|$ is the column matrix of unknown constants, and $|B|$ is the column matrix of loading parameters.

[b]Boundary condition number from Table 4.

## Stresses

After having established values for the integration constants, the stresses at any point in the blind flange can be readily obtained. Equations for stresses at the center of the flange and at r = g and r = c are given by

$$\sigma_t = \pm 6M_t/t^2 = \pm EtM_t/[2(1 - \nu^2)]D \qquad (59a)$$

and

$$\sigma_r = \pm 6M_r/t^2 = \pm EtM_r/[2(1 - \nu^2)]D \; . \qquad (59b)$$

At the center of the flange (r = 0),

$$M_t = M_r = -D\{D_{12}[2(1 + \nu)]\} \; . \qquad (60)$$

At the gasket (r = g),

$$M_r = -D\{D_{12}[2(1 + \nu)] + g^2p(3 + \nu)/16D\} \; , \qquad (61)$$

and

$$M_t = -D\{D_{12}[2(1 + \nu)] + g^2p(1 + 3\nu)/16D\} \; . \qquad (62)$$

At the bolt circle (r = c),

$$M_r = -D\{D_{32}[2(1 + \nu)] - D_{33}(1 - \nu)/c^2\} \; , \qquad (63)$$

and

$$M_t = -D\{D_{32}[2(1 + \nu)] + D_{33}(1 - \nu)/c^2\} \; . \qquad (64)$$

In all of the above, a positive moment produces a tensile stress on the back of the flange (positive w side of Fig. 2).

## Displacements

In the third and sixth boundary conditions listed in Table 7, the axial displacement at the gasket has been arbitrarily set equal to zero. The relative displacement of the bolt circle to the gasket is therefore

$$w_c = D_{32}c^2 + D_{33} \ln c + D_{34} \; . \tag{65}$$

## 6. THERMAL GRADIENTS

Two kinds of thermal gradients are included in the analysis: (1) a constant temperature in the pipe and hub that may be different from the assumed constant temperature in the ring and (2) a constant temperature in the bolts that may be different from the assumed constant temperature in the ring.

The significance of the bolt-to-ring thermal gradients is dependent upon the dimensional and material characteristics of the flanged joint and is covered later in Chapter 7.

The pipe/hub-to-ring temperature gradient is included in the analysis by an appropriate change in the "loading parameters" shown in Table 3. We define $\Delta$ as the difference in temperature between the pipe/hub and the ring; $\Delta$ is positive if the pipe/hub is hotter than the ring. The radial expansion of the tapered hub at its juncture with the ring is then:

$$u = \frac{b}{\sqrt{\psi_1}} (C_1 b_1' + C_2 b_2' + C_3 b_3' + C_4 b_4') + b\epsilon_f \Delta \ , \qquad (66)$$

where b is the pipe radius; $b_i'$ terms are the Bessel functions defined in Table 1 evaluated at $x = h$, $\eta = 2\gamma\rho^{1/2}/\alpha$, as indicated in footnote *c* of Table 3; and $\epsilon_f$ is the coefficient of thermal expansion of the flange material.

The effects of such a thermal gradient are taken into account by adding $(\sqrt{\psi_1}/b)(b\epsilon_f\Delta)$ to the existing terms in the loading-parameter column in Table 3 [Eqs. (20-5a) and (20-5b)]. The analogous term is already included in Table 6.

## 7. CHANGE IN BOLT LOAD WITH PRESSURE, TEMPERATURE, AND EXTERNAL MOMENTS

A flanged joint is a statically indeterminate structure. Thus, in order to determine the residual bolt load in the joint, it is necessary to calculate the relative displacements of the parts when the joint is subjected to (1) initial bolt loading, (2) moment loading, (3) internal pressure, and (4) thermal gradients.

The object of the analysis is to determine the residual bolt load $W_2$ in terms of (1) the loadings $W_1$, p, $\Delta$, and $\Delta'$; (2) the component temperatures $T_b$, $T_g$, $T_f$, and $T_f'$; (3) the flanged-joint dimensions; and (4) the material properties.

The basic analysis is given by Wesstrom and Bergh,[6] and we follow their nomenclature, with additions as necessary. Reference 6 covers only the effect of initial bolt loading and part of the influence of internal pressure; the remaining influence from the internal pressure is discussed by Rodabaugh.[7] The extension of the analysis to cover thermal gradients is relatively simple and is covered below.

The nomenclature used in this development is:

A = cross-sectional area of bolts or gasket
B = inside diameter of ring
C = bolt-circle diameter
E = modulus of elasticity
$g_0$ = wall thickness of pipe
G = gasket centerline diameter
$\ell$ = bolt length
p = internal pressure
$p^*$ = equivalent pressure for external moment loading
q = elastic deformation coefficients
t = ring thickness
T = final-state temperature (initial-state temperature is defined as zero)
v = gasket thickness
W = bolt load

$\delta$ = relative axial displacement between the gasket centerline and the bolt circle

$\varepsilon$ = coefficient of thermal expansion

$\Delta$ = temperature between hub/pipe and ring

The subscripts 0, 1, and 2 refer to the undeformed, initial deformed, and final deformed states, respectively; subscripts b, g, and f refer to the bolts, gasket, and flange, respectively. Quantities with a prime (') are for one of the flanges in a pair (e.g., $T_f'$ refers to the temperature of the right-hand flange in Fig. 3); quantities without a prime are for the other flange.

## Analysis

Figure 3 shows a schematic illustration of the general case of two dissimilar flanges and their mode of deformation. When the bolts are initially tightened to make up the joint, the resulting initial deformed bolt length is

$$\ell_1 = v_1 + t_1 + t_1' - \delta_1 - \delta_1' \; . \qquad (67)$$

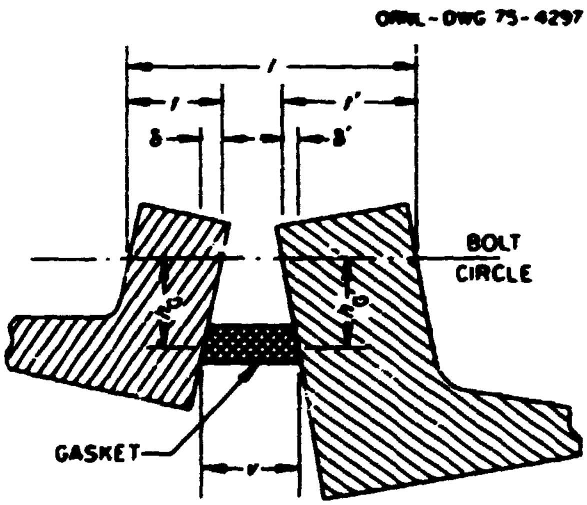


Fig. 3. General case of two dissimilar flanges and their mode of deformation.

After application of loadings, the bolt length becomes

$$\ell_2 = v_2 + t_2 + t_2' - \delta_2 - \delta_2' \ . \tag{68}$$

The basic displacement relationship is thus

$$\ell_2 - \ell_1 = (v_2 - v_1) + (t_2 - t_1) + (t_2' - t_1') - (\delta_2 - \delta_1) - (\delta_2' - \delta_1') \ . \tag{69}$$

We also use the following relationships:

$$
\begin{aligned}
&\ell_2 = \ell_0 + T_b \epsilon_b \ell_0 + q_{b2} W_2 \ , && \text{(a)} \\
&v_2 = v_0 + T_g \epsilon_g v_0 - q_{g2} (W_2 - H_{D2} - H_{T2}) \ , && \text{(b)} \\
&t_2 = t_0 + T_f \epsilon_f t_0 \ , && \text{(c)} \\
&t_2' = t_0' + T_f' \epsilon_f' t_0' \ , && \text{(d)} \\
&\delta_2 = q_{f2} M_2 h_G + q_p p h_G + q_t \Delta h_g \ , && \text{(e)} \\
&\delta_2' = q_{f2}' M_2' h_G + q_p' p h_G + q_t' \Delta' h_G \ , && \text{(f)} \\
&\ell_1 = \ell_0 + q_{b1} W_1 \ , && \text{(g)} \\
&v_1 = v_0 - q_{g1} W_1 \ , && \text{(h)} \\
&t_1 = t_0 \ , && \text{(i)} \\
&t_1' = t_0' \ , && \text{(j)} \\
&\delta_1 = q_{f1} M_1 h_G \ , && \text{(k)} \\
&\delta_1' = q_{f1}' M_1 h_G \ . && \text{(l)}
\end{aligned}
\tag{70}
$$

The elastic deformation coefficients $q_{b1}$, $q_{g1}$, $q_{b2}$, and $q_{g2}$ in Eqs. (70a–ℓ) are further defined as

$$q_{b1} = \frac{\ell_0}{A_b E_{b1}} , \tag{71a}$$

$$q_{g1} = \frac{v_0}{A_g E_{g1}} , \tag{71b}$$

$$q_{b2} = \frac{\ell_0}{A_b E_{b2}} , \tag{71c}$$

$$q_{g2} = \frac{v_0}{A_g E_{g2}} . \tag{71d}$$

In Eqs. (70a–ℓ), the term $q_{f_1}$ is a rotation of the flange due to a unit moment load, $q_p$ is a rotation of the flange due to a unit internal pressure, and $q_t$ is a rotation of the flange due to a unit temperature gradient between the hub and the ring. The quantities $q_{f1}$, $q_p$, and $q_t$ are obtained from the functional expression

$$q(L) = \frac{-w_c(L) + w_g(L)}{h_G} , \tag{72}$$

where $h_G = (C - G)/2$, C is the bolt-circle diameter, and G is the gasket-centerline diameter. Values for the displacements $w_c(L)$ and $w_g(L)$ are obtained from Eqs. (46) and (47) with the appropriate unit values for the loads Δ, P, and M.

For $q_{f1}$ the modulus of elasticity used is that for the initial condition. For $q_p$ and $q_t$, the moduli used are those for the final condition. The term $q_{f2}$ is obtained from $q_{f1}$ and the ratio of the initial and final elastic moduli; thus:

$$q_{f2} = q_{f1} \frac{E_1}{E_2} .$$

The moments and loads are defined by Eqs. (73a–n). The nomenclature used in these equations is analogous to that used in the ASME Code.[1] The symbol H represents a load, h represents a lever arm, and M represents a moment. The term $H_D$ is the hydrostatic end force (in pounds) on the area inside the flange, $H_G$ is the gasket load in pounds, $H_T$ is the difference between the total hydrostatic end force and the hydrostatic end force on the area inside the flange, $h_D$ is the radial distance in inches from the bolt circle to the circle on which $H_D$ acts (as prescribed in Table UA-50 of the Code), $h_G$ is the radial distance in inches from the gasket-load reaction to the bolt circle, and $h_T$ is the radial distance in inches from the bolt circle to the circle on which $H_T$ acts (as prescribed in Table UA-50). Symbols, C, B, G, $g_0$, and p are defined earlier in this chapter. Again, a subscript 1 refers to the initial deformed state, a subscript 2 refers to the final deformed state, and primed quantities refer to the mating flange.

$$h_D = (C - B - g_0)/2 \,, \qquad \text{(a)}$$

$$h_D' = (C - B' - g_0')/2 \,, \qquad \text{(b)}$$

$$h_T = [C - (G + B)/2]/2 \,, \qquad \text{(c)}$$

$$h_T' = [C - (G + B')/2]/2 \,, \qquad \text{(d)}$$

$$h_G = (C - G)/2 \,, \qquad \text{(e)}$$

$$H_{D2} = \frac{\pi}{4} B^2 p \,, \qquad \text{(f)}$$

$$H_{D2}' = \frac{\pi}{4} (B')^2 p \,, \qquad \text{(g)} \qquad (73)$$

$$H_{T2} = \frac{\pi}{4} (G^2 - B^2) p \,, \qquad \text{(h)}$$

$$H_{T2}' = \frac{\pi}{4} [G^2 - (B')^2] p \,, \qquad \text{(i)}$$

$$H_{G2} = W_2 - H_{D2} - H_{T2} \,, \qquad \text{(j)}$$

$$H_{G2}' = W_2 - H_{D2}' - H_{T2}' \,, \qquad \text{(k)}$$

$$M_1 = W_1 h_G = H_{G1} h_G \, , \qquad (\ell)$$

$$M_2 = H_{D2} h_D + H_{T2} h_T + H_{G2} h_G \, , \qquad (m)$$

and

$$M_2' = H_{D2}' h_D' + H_{T2}' h_T' + H_{G2} h_G \, . \qquad (n)$$

Substituting Eqs. (70a–ℓ) into Eq. (69) gives

$$T_b \varepsilon_b \ell_0 + q_{b2} W_2 - q_{b1} W_1 = T_g \varepsilon_g v_0 - q_{g2}(W_2 - H_{D2} - H_{T2})$$
$$+ q_{g1} W_1 + T_f \varepsilon_f t_0 + T_f' \varepsilon_f' t_0' - h_G(q_{f2} M_2 + q_p p + q_t \Delta - q_{f1} M_1)$$
$$- h_G(q_{f2}' M_2' + q_p' p + q_t' \Delta' - q_{f1}' M_1) \, . \qquad (74)$$

In order to eliminate $M_1$ and $M_2$ from Eq. (74), Eqs. (73ℓ and m) are used; the sixth term on the right-hand side of Eq. (74) then becomes

$$-h_G\{q_{f2}[H_{D2} h_D + H_{T2} h_T + (W_2 - H_{D2} - H_{T2}) h_G] + q_p p + q_t \Delta - q_{f1} W_1 h_G\} \, .$$

The last term in Eq. (74) is treated similarly. Collecting terms containing $W_2$ on the left gives:

$$(q_{b2} + q_{g2} + h_G^2 q_{f2} + h_G^2 q_{f2}') W_2 = (q_{b1} + q_{g1} + h_G^2 q_{f1} + h_G^2 q_{f1}') W_1$$
$$+ T_g \varepsilon_g v_0 + T_f \varepsilon_f t_0 + T_f' \varepsilon_f' t_0' - T_b \varepsilon_b \ell_0 + q_{g2}(H_{D2} + H_{T2})$$
$$- h_G q_{f2}[H_{D2}(h_D - h_G) + H_{T2}(h_T - h_G)]$$
$$- h_G q_{f2}'[H_{D2}'(h_D' - h_G) + H_{T2}'(h_T' - h_G)]$$
$$- h_G(q_p + q_p')p - h_G(q_t \Delta + q_T' \Delta') \, . \qquad (75)$$

Defining

$$Q_1 = q_{b1} + q_{g1} + h_G^2 q_{f1} + h_G^2 q'_{f1}$$

and

$$Q_2 = q_{b2} + q_{g2} + h_G^2 q_{f2} + h_G^2 q'_{f2}$$

and using the given definitions of $H_D$, $H'_D$, $H_T$, and $H'_T$, Eq. (75) becomes

$$W_2 = \frac{Q_1}{Q_2} W_1 + \frac{1}{Q_2} \left(T_g \epsilon_g v_0 + T_f \epsilon_f t_0 + T'_f \epsilon'_f t'_0 - T_b \epsilon_b \ell_0\right)$$

$$+ \frac{\pi h_G}{4Q_2} \left\{ \left[ \frac{q_{g2}}{h_G} - q_{f2}(h_T - h_G) - q'_{f2}(h_T - h_G) - q'_{f2}(h'_T - h_G) \right] G^2 \right.$$

$$\left. - \left[q_{f2} B^2 (h_D - h_T) + q'_{f2}(B')^2 (h'_D - h'_T)\right] \right\} p$$

$$- \frac{h_G}{Q_2} (q_p + q'_p) p - \frac{h_G}{Q_2} (q_t \Delta + q'_t \Delta') \quad . \qquad (76)$$

In order to compute the flange stresses under the various loading conditions, it is necessary to compute the flange moment $M_2$ or $M'_2$. From Eq. (73m) and the definitions in Eqs. (73a-k),

$$M_2 = \frac{\pi}{4} p [B^2 h_D + (G^2 - B^2) h_T - G^2 h_G] + W_2 h_G \quad . \qquad (77a)$$

And similarly for the mating flange,

$$M'_2 = \frac{\pi}{4} p \left\{ (B')^2 h'_D + [G^2 - (B')^2] h'_T - G^2 h_G \right\} + W_2 h_G \quad . \qquad (77b)$$

The computer program was written to separately evaluate the various effects involved in bolt-load changes. The residual bolt load due to temperature differences that produce differential axial strain is

$$W_{2a} = W_1 + \frac{1}{Q_1} (T_g \epsilon_g v_0 + T_f \epsilon_f t_0 + T_f' \epsilon_f' t_0' - T_b \epsilon_b \ell_0) . \qquad (78)$$

The residual bolt load, after internal pressure (acting in an axial direction) has transferred the bolt load on the gasket to a tensile load on the attached pipes due to a shift in lever arms, is given by:

$$W_{2b} = W_1 + \frac{\pi}{4} \frac{h_G}{Q_1} \left\{ \left[ \frac{q_{g1}}{h_G} - q_{f1}(h_T - h_G) - q_{f1}'(h_T' - h_G) \right] G^2 - [q_{f1} B^2 (h_D - h_T) + q_{f1}'(B')^2 (h_D' - h_T')] \right\} p . \qquad (79)$$

The total effect of internal pressure due to both the shift in the lever arms and the radial effect of pressure acting on the integral flange(s) and/or on the inside surface of a blind flange is given by:

$$W_{2c} = W_{2b} - \frac{h_G}{Q_1} (q_p + q_p')p . \qquad (80)$$

The residual bolt load due to a temperature difference between the hub and the ring is given by:

$$W_{2d} = W_1 - \frac{h_G}{Q_1} (q_t \Delta + q_t' \Delta') . \qquad (81)$$

A slight modification of the above is required for the case of a blind flange. If we designate the blind flange as that with the "primed" nomenclature, then all* of Eqs. (70a–ℓ) are valid except Eqs. (70f and ℓ) for $\delta_1'$ and $\delta_2'$.

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*For $v_2$ it should be noted that $H_{D2} - H_{T2} = \pi G^2 p/4$; hence, this equation is valid for blind flanges.

For blind flanges, $W$ is used rather than $M$ as the loading parameter because the relationship $M = W(a - b)$ is not valid for the blind-flange analysis. For blind-flange analysis, Eq. (65) gives a value of $w_c$; here $-w_c$ is the equivalent of $-w_c + w_g$ in Eq. (72) because $w_g \equiv 0$ in the blind-flange analysis. For blind flanges we define

$$q_f' = \frac{(-w_c)_W}{h_G^2} , \tag{82}$$

where $(-w_c)_W$ is the axial displacement per unit total bolt load $W$. The equation for $W_2$ for a blind flanged joint is then:

$$W_2 = \frac{Q_1}{Q_2} W_1 + \frac{1}{Q_2} (T_g \varepsilon_g v_0 + T_f \varepsilon_f t_0 + T_f' \varepsilon_f' t_0' - T_b \varepsilon_b \ell_0)$$

$$+ \frac{\pi}{4} \frac{h_G}{Q_2} \left\{ \left[ \frac{q_{g2}}{h_G} - q_{f2}(h_T - h_G) \right] G^2 - q_{f2} B^2 (h_D - h_T) \right\} p$$

$$- \frac{h_G}{Q_2} (q_p + q_p') p - \frac{h_G}{Q_2} q_t \Delta . \tag{83}$$

In Eq. (83) the primed values refer to properties of the blind flange.

After the internal pressure has transferred the bolt load on the gasket to a tensile load on the attached pipe due to a shift in the lever arms, the residual bolt load for the case where a blind flange is used is

$$W_{2b} = W_1 + \frac{\pi}{4} \frac{h_G}{Q_1} \left\{ \left[ \frac{q_{g1}}{h_G} - q_{f1}(h_T - h_G) \right] G^2 - q_{f1} B^2 (h_D - h_T) \right\} p . \tag{84}$$

It should be noted that $q_t' \Delta'$ does not exist for an integral flange mated to a blind flange.

The combined effect of all of the above is also obtained from the computer program by calculating $W_2$ from Eqs. (76) and (83).

## External Moment Loading

Up to this point, all loads considered have been axisymmetric. For flanged joints in pipe lines, there is one other significant loading; that is, the bending moment imposed on the flanged joint by the attached pipe. To distinguish this from the local moments applied to the flange ring, the bending moment will be designated as an "external" moment. The external moment can be represented by a distributed axial edge force acting on the attached pipe:

$$F_M(\theta) = F_m \cos\theta , \tag{85}$$

where $\theta$ = angle around the circumference ($\theta = 0$ at the point of maximum tensile stress in the pipe due to the external moment). Since this report deals only with cases in which all contact occurs within the bolt-hole circle, a reasonably good first approximation for the effects of the external moment loading can be obtained by replacing the distributed axial force $F_M(\theta)$ with the axisymmetric tensile force $F_m = F_M(\max)$. Then, since $F_m$ is axisymmetric, there is some pressure $p^*$ that will produce the same axial force in the pipe; or alternately, there is an equivalent pressure $p^*$ that will produce an axial stress in the pipe which is equal to the maximum tensile stress $S_b$ produced by an external moment. The relation between $p^*$ and $S_b$ is given by

$$p^* = 4S_b g_0/D_o , \tag{86}$$

where $S_b$ is the bending stress in the attached pipe due to the external moment. The change in bolt load $W_{2b}$ is then obtained by replacing $p$ with $p + p^*$ in Eqs. (79) and (84). It should be noted that this equivalent pressure is included only in Eqs. (79) and (84) and not in Eq. (80).

# 8. COMPUTER PROGRAM

A Fortran computer program named FLANGE has been written to carry out the calculations according to the analyses described in this report. The program calculates appropriate loads, stresses, and displacements for the flanges, bolts, and gaskets when the flanged joint is subjected to internal pressure, moment, and/or thermal gradient loadings; thus, the program is much more general than that needed only to determine compliance with the ASME Boiler and Pressure Vessel Code. The program also has the advantage of internally computing the values of the Code variables F, V, and f that must otherwise be extracted manually from the curves given in Code Figs. UA-51.2, UA-51.3, and UA-51.6. Loose hubbed flanges, which are covered by the Code, however, are not covered by the computer program.

The main function of this chapter is to describe the input and output for the various computational options available to the user. For more detailed information, the reader is urged to carefully study the examples given in Appendix A where a flanged joint, selected from API Standard 605 (Ref. 8), is analyzed. Several sample problems are worked, and the data input and program output are given for the various program options along with a discussion of the results. Flowcharts and listings of the program and its subroutines are given in Appendix B. In the following sections, the input data for option control and the input data and program output for Code compliance calculations and for more general calculations are discussed.

## Option Control Data Card

The first card of each data set, herein called the option control card, contains control information for execution of the various program options. It contains information specifying the type of flange being analyzed, the boundary condition placed on the displacement $(u_r)_{x=h}$, the stresses and other variables to be calculated, and the joint configuration and which flange (of the pair) is to be analyzed. These specifications are under control of the four variables ITYPE, IBØND, ICØDE, and MATE. The admissible values and their significance are as follows.

ITYPE (indicates the type of flange being analyzed)

1 for a tapered-hub flange

2 for a straight-hub flange

3 for a blind hub

IBØND (specifies the displacement $u_r$ at $x = h$)

0 for $(u_r)_{x=h} = 0$ to conform with the ASME Code basis

1 (see footnote)*

2 for $(u_r)_{x=h} \neq 0$ [see Eq. (20-6) of this report]

ICØDE (controls the amount of output data)

0 for a wide variety of stresses, moments, and loads for specified moment, pressure, and $\Delta T$

1 (see footnote)*

2 for a select list for checking Code compliance in accordance with Section VIII, Div. 1 of the ASME Code

MATE (specifies the joint configuration and the flange to be analyzed)

1 for only one flange to be analyzed (This is the situation for ASME-Code related calculations.)

2 for two identical flanges mated together

3 for the first of two flanges that are not identical, neither of which is a blind flange

4 for the second of two flanges that are not identical, neither of which is a blind flange

5 for a blind flange

6 for a flange that is mated with a blind flange.

The data card with the above information is followed by other data cards containing physical-property data, etc., for the particular flange being analyzed. Since the program can be used to analyze any number of flanges

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*In the original conception of the program, IBØND and ICØDE were envisioned as controlling additional calculations that were not implemented in the present version. As it is now written, the program does not distinghish between values of 0 or 1 nor between 2 and numbers greater than 2 for either IBØND or ICØDE.

or flanged joints sequentially (as done in the examples of Appendix A), the data card set for each flange must start with an option-control data card.

Different types of flanges and different types of calculations have different input data requirements. These data and their formats are discussed in the following sections.

## Input for Code-Compliance Calculations

Since the ASME Code calculation procedures consider only one flange at a time, the input data requirements for the computer program are quite simple and straightforward. Input data are completely prescribed by the three data cards illustrated in Table 9. The nomenclature is the same as that used in the Code.

The first card is the option control card discussed in the previous sections. The first variable ITYPE may be equal to 1, 2, or 3, depending on the type of flange being analyzed. The next variable IBØND will always be 0, in which case the displacement $u_r$ will be equal to zero at $x = h$, as specified by the Code. The third variable ICØDE will always be 2 and will therefore cause the program to compute the stresses in accordance with Code paragraph UA-50 for straight or tapered-hub flanges or paragraph UG-34(c)(2) for blind flanges. The last variable MATE will always be 1 for Code-compliance calculations. This variable essentially controls the bolt-load-change calculations made by the program. Since the ASME Code does not consider bolt-load changes in determining compliance, when MATE = 1 these calculations are not performed.

The second card in the data set enters the physical dimensions of the flange being analyzed, as shown in Table 9. These dimensions are the outside and inside diameters of the flange ring A and B, the ring thickness t, the pipe-wall thickness $g_0$, the hub thickness at the hub-to-ring juncture $g_1$, the hub length h, the bolt-circle diameter C, and the internal pressure. All dimensions are expressed in inches; the pressure is in pounds per square inch.

Table 9. Input data for ASME bolt and flange stress calculation, using symbols defined in ASME Code, Section VIII, Division 1, Appendix II

Option-Control Card (Read-in in FLANGE)

| Column number | 5 | 10 | 15 | 20 |
|---|---|---|---|---|
| Variable | ITYPE[a] | IBOND | ICODE | MATE |
| Value | 1, 2, or 3 | 0 | 2 | 1 |

Second Card (Read-in in TAPHUB, STHUB, or BLIND)[b,c]

| Column number | 0-10 | 11-20 | 21-30 | 31-40 | 41-50 | 51-60 | 61-70 | 71-80 |
|---|---|---|---|---|---|---|---|---|
| Quantity | Flange outer diameter $A$ | Flange inner diameter $B$ | Ring thickness $t$ | Pipe-wall thickness $g_0$ | Hub thickness $g_1$ | Hub length $h$ | Bolt-circle diameter $C$ | Pressure $p$ |
| Variable | XA | XB | TH | G0 | G1 | HL | C | PRESS |

Third Card (Read-in in ASMEIN)[d]

| Column number | 0-10 | 11-20 | 21-30 | 31-40[d] | 41-50 | 51-60 | 61-70[e] | 72[d] | 73-80[d] |
|---|---|---|---|---|---|---|---|---|---|
| Quantity | Gasket factor $m$ | Minimum design seating stress $y$ | Gasket outer diameter $G_o$ | Gasket inner diameter $G_i$ | Allowable bolt stress at design temperature $S_b$ | Allowable bolt stress at atmospheric temperature $S_a$ | Bolt cross-sectional area $A_b$ | Option $I$ | Basic gasket seat width $b_o$ |
| Variable | XM | Y | GOUT | GIN | SB | SA | AB | INBO | BO |

[a]When ITYPE = 2 for a ring flange, $g_0$, on the second card, should be a suitably small value, but not zero (e.g., 0.01).

[b]Subroutines TAPHUB and STHUB call both ASMEIN and FLGDW; BLIND calls ASMEIN.

[c]For ITYPE = 2, $g_0$ must be entered; $g_1$ and $h$ are not used. For ITYPE = 3, $B$, $g_0$, $g_1$, and $h$ are not used.

[d]If I (Column 72) is 0, the program computes $b$, $b_0$, and $G$ for the particular case of $b_0 = N/2 = 1/2(G_0 - G_i)/2$ as defined in Table UA-49.2 sketches (1a) and (1b) of the Code. Columns 73-80 may then be left blank. For other values of $b_0$, enter I = 2. In this case, the value of $G_i$ is not used and thus columns 31-40 may be left blank.

[e]Column 71 is blank.

The third card inputs other physical data, including the gasket factor m, the minimum-design seating stress y, the outside diameter of the gasket $G_o$, the inside diameter of the gasket $G_i$, the allowable bolt stress at design temperature $S_b$, the allowable bolt stress at ambient temperature $S_a$, the total cross-sectional area of the bolts $A_b$, an option-selecting variable I, and the basic gasket-seating width $b_o$. The option variable I controls the calculation of b and G.

## Output for Code-Compliance Calculations

For Code-compliance calculations, all of the output for each flange being analyzed is printed on a single page (e.g., see examples 1 and 2 of Appendix A). The program prints the input data followed by the effective gasket seating width $b_o$ and the loads, bolt stresses, and moments identified under the headings shown in Table 10. For compliance with Code criteria, the value of SB1 must not exceed the allowable bolt stress at design temperature, and the value of SB2 must not exceed the allowable bolt stress at atmospheric* temperature.

Immediately below, the program prints the flange stresses needed for comparison with the ASME Code criteria. For tapered-hub and straight-hub flanges (ITYPE = 1 or 2), the program prints five stresses under the two headings "ASME FLANGE STRESSES AT OPERATING MOMENT, MOP" and "ASME FLANGE STRESSES AT GASKET SEATING MOMENT." The stresses are identified as follows:

2/3(SH) = two-thirds of the longitudinal stress on the outside surface at the small end of the hub,

ST = the tangential stress on the hub side of the ring,

SR = the radial stress on the hub side of the ring,

(SH + ST)/2 = the average of SH and ST, and

(SR + ST)/2 = the average of SR and ST.

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*Although "ambient" would probably be a better term here, the word "atmospheric" is used as it is used in the Code.

Table 10. Output data identification, ICODE = 2, (ASME Code stresses)

| ASME Code symbol[a] | Program symbol | Description[a] | |
|---|---|---|---|
| $b_o$ | BO | See ASME Code, Table UA-49.2. (This will be input data for I = 2.)[b] | |
| H | HM11 | $\pi G^2 p/4$ | |
| | HM12 | $2\pi bGmp$ | |
| $W_{m1}$ | WM1 | $\pi G^2 p/4 + 2\pi bGmp$ | |
| | SB1 | Bolt stress, $W_{m1}/A_b$ | |
| $W_{m2}$ | WM2 | $\pi bGy$ | |
| | SB2 | Bolt stress, $W_{m2}/A_b$ | |
| (c) | MOP | $H_G h_G + H_T h_T + H_D h_D$ | |
| (d) | MGS | $[(A_m + A_b)S_a/2] \times [(C - G)/2]$ | Except for ITYPE = 3 (Blind flanges) |
| | MGS1 | $W_{m2} \times [(C - G)/2]$ | |

[a]All symbols are defined in the ASME Boiler Code, Section VIII, Div. 1 (1971), Appendix II.

[b]See Footnote d of Table 9.

[c]MOP is the operating moment as defined by the ASME Code.

[d]MGS is the gasket seating moment as defined by the ASME Code.

For compliance with the Code Criteria, each of the above values printed under the first heading must not exceed the allowable stress for the flange material at the design temperature. The values printed under the second heading must not exceed the allowable stress for the flange material at atmospheric temperature.

For blind flanges (ITYPE = 3), the program prints the following five quantities under the heading "ASME CODE STRESSES FOR BLIND FLANGE":

SP = the stress due to pressure loading only,

SW1 = the stress due to the bolt load $W_{m1}$ only, where $W_{m1}$ = $\pi G^2 p/4 + 2\pi bGmp$,

SOP = the stress at operating conditions,

SW2 = the stress due to the bolt load $W_{m2}$, where $W_{m2} = \pi bGy$, and

SGS = the stress at gasket-seating conditions.

For Code compliance, SOP must not exceed the allowable stress for the flange material at design temperature, and SGS must not exceed the allowable stress at atmospheric temperature.

## Input for General Purpose Calculations

When the computer program is used for general purpose calculations, (i.e., when it is used for calculating displacements and stresses other than those needed specifically for checking Code compliance), the user may select almost any combination of admissible values for the four variables ITYPE, IBØND, ICØDE, and MATE coded in the option control data card. The only specific requirement is that the variable ICØDE must be less than two for other than Code-compliance calculations. In this case the input data are structured somewhat differently than those described in the previous section.

When ICØDE = 0 and MATE = 1, (i.e., only one flange is to be analyzed and the user does not wish to obtain bolt load changes), three data cards are needed as shown in Table 11. These are the option-control card (for which ITYPE may be 1, 2, or 3 and IBØND may be 0 or 2) and two physical-property data cards.

When ICØDE = 0 and MATE = 2, 3, ... 6, the program will analyze a pair of flanges mated together and give bolt load changes. If MATE = 2, the program performs the calculations for a pair of identical flanges mated together. The input data requirements include the data cards shown in Table 11 plus the three cards shown in Table 12. These last three cards contain data on the physical properties of the bolts and gasket, supplemental data on the initial and final state of the flange, and other conditions. For this case, the six cards listed below complete the input data set when MATE = 2.

Table 11. Input data for the general purpose analysis of a single flange and partial data for paired flanges

Option-Control Card: [FØRMAT (4I5) read-in in FLANGE]

| Column number | 5 | 10 | 15 | 20 |
|---|---|---|---|---|
| Variable | ITYPE[a,b] | IBØND | ICØDE | MATE[c] |
| Value | 1, 2, or 3 | 0 to 2 | 0 | 1 or (2) |

Second Card: [FØRMAT (8E10.5); read-in in TAPHUB, STHUB, or BLIND]

| Column number | 0-10 | 11-20 | 21-30 | 31-40 | 41-50 | 51-60 | 61-70 | 71-80 |
|---|---|---|---|---|---|---|---|---|
| Quantity | Flange outer diameter A | Flange inner diameter B | Ring thickness t | Pipe-wall thickness $g_0$ | Hub thickness $g_1$ | Hub length h | Bolt-circle diameter C | Pressure p |
| Variable | XA | XB[b] | TH | G0[a,b] | G1[a,b] | HL[a,b] | C | PRESS |

Third Card: [FØRMAT (5E10.5); read-in in TAPHUB, STHUB, or BLIND]

| Column number | 0-10 | 11-20 | 21-30 | 31-40 | 41-50 |
|---|---|---|---|---|---|
| Quantity | Moment applied to flange ring M | Coefficient of thermal expansion $\epsilon_f$ | Thermal gradient pipe or hub to ring $\Delta$ | Modulus of elasticity flange E | Gasket centerline diameter 2g |
| Variable | XMOA[b] | EF[b] | DELTA[b] | YM | G |

[a]When ITYPE = 2, G0 must be entered; G1 and HL are not used.

[b]When ITYPE = 3, XB, G0, G1, HL, EF, and DELTA are not used; the value for XMOA is the total bolt load W.

[c]When MATE = 2, additional data as described in Table 12 are also required.

Table 12. Last three input data cards for the general purpose analysis of paired flanges

Card No. 4 or 7:[a] [FØRMAT (7E10.5); read-in in FLGDW]

| Column number | 0-10 | 11-20 | 21-30 | 31-40 | 41-50 | 51-60 | 61-70 |
|---|---|---|---|---|---|---|---|
| Quantity | Nominal bolt diameter | Initial state; bolt modulus of elasticity $E_b$ | Bolt coefficient of thermal expansion $\epsilon_b$ | Final state; bolt temperature $T_b$ | Outside diameter of gasket | Inside diameter of gasket | Cross-sectional root area of all bolts |
| Variable | BSIZE[b] | YB | EB | TB | XGO[c] | XGI[c] | AB |

Card No. 5 or 8:[a] [FØRMAT (6E10.5); read-in in FLGDW]

| Column number | 0-10 | 11-20 | 21-30 | 31-40 | 41-50 | 51-60 |
|---|---|---|---|---|---|---|
| Quantity | Gasket thickness $v_o$ | Initial state; gasket modulus of elasticity $E_g$ | Gasket coefficient of thermal expansion $\epsilon_g$ | Final state; gasket temperature $T_g$ | A free bolt length variable | Equivalent pressure see Eq. (86) of text $p^*$ |
| Variable | VO | YG | EG | TG[d] | FACE[b] | PBE |

Card No. 6 or 9:[a] [FØRMAT (7E10.5); read-in in FLGDW]

| Column number | 0-10 | 11-20 | 21-30 | 31-40 | 41-50 | 51-60 | 61-70 |
|---|---|---|---|---|---|---|---|
| Quantity | Initial bolt load $W_1$ | Final state temperature of flange, side one $T_{f2}$ | Final state temperature of flange, side two $T'_{f2}$ | Final state flange modulus of elasticity, side one $E_{f2}$ | Final state flange modulus of elasticity, side two $E'_{f2}$ | Final state bolt modulus of elasticity $E_{b2}$ | Final state gasket modulus of elasticity $E_{g2}$ |
| Variable | W1 | TF[d] | TFP[d] | YF2 | YFP2 | YB2 | YG2 |

[a]First card number applies when MATE = 2; second number applies when MATE = 3 and 4 or 5 and 6.

[b]The effective bolt load is calculated as $t_0$ = XLB = TH + THP + VO + BSIZE + FACE.

[c]Values for $G_1$ and $A_g$ are calculated using input variables XGO and XGI.

[d]Initial-state temperatures are defined as zero.

| Card No. | Identification |
| --- | --- |
| 1 | Option control card with MATE = 2 |
| 2, 3 | Data cards per Table 11 |
| 4, 5, 6 | Data cards per Table 12 |

When ICØDE = 0 and MATE = 3, the program performs the calculations for a pair of nonidentical flanges, neither of which, however, is blind (i.e., ITYPE = 1 or 2 ≠ 3 on the option-control card). Data for the first flange of the pair follows the option-control card. Data for the second flange in the pair will follow an option-control card with MATE = 4. The three cards described in Table 12 will then complete the data requirements. The complete input data set for analyzing a pair of nonidentical flanges (neither of which is blind) consists of the following nine cards.

| Card No. | Identification |
| --- | --- |
| 1 | Option-control card, ITYPE ≠ 3, ICØDE = 0, MATE = 3 |
| 2, 3 | Data cards per Table 11 for first flange of pair |
| 4 | Option-control card, ITYPE ≠ 3, ICØDE = 0, MATE = 4 |
| 5, 6 | Data cards per Table 11 for second flange of pair |
| 7, 8, 9 | Data cards per Table 12 |

When ICØDE = 0 and MATE = 5, the program performs the calculations for a flanged joint that is closed with a blind flange. For this option, the blind flange is designated as the first flange and the mating flange is designated as the second with MATE = 6. As before, the input data set is completed by using the data cards described in Table 12. The complete input data set for this case consists of the following nine cards.

| Card No. | Identification |
|---|---|
| 1 | Option-control card, ITYPE = 3, ICØDE = 0, MATE = 5 |
| 2, 3 | Data cards per Table 11 for blind flange |
| 4 | Option-control card, ITYPE = 1 or 2, ICØDE = 0, MATE = 6 |
| 5, 6 | Data cards per Table 11 for second flange |
| 7, 8, 9 | Data cards per Table 12 |

## Output from General Purpose Calculations

The amount and format of the data printed out are determined predominantly by the number and types of flanges being analyzed, which in turn are determined by the value of the option-control variable MATE. When MATE = 1, the output consists of one page of printout, which gives (1) the input data; (2) the three sets of stresses for moment loading only (the bolt load for blind flanges), pressure loading only, and temperature-gradient (hub to ring) loading only (except for blind flanges); and (3) the displacements produced by the calculated stresses. The symbols used on the printout are explained in Tables 13 and 14.

When MATE = 2, the output consists of three pages of printout. The first page gives (1) the input data and (2) the parameters involved in the bolt-load-change calculations. The second page gives (1) the loadings, (2) the residual bolt loads, and (3) the initial and residual moments. The symbols used in the first and second page of printout are explained in Tables 15 and 16. The third page gives the stresses and

Table 13. Output data identification, stresses, displacements, and rotation

| Theory Symbol | Program symbol | Description |
|---|---|---|
| $(\sigma_\ell)_o$ | SLSO[a] | Stress, longitudinal, small end of hub, outside surface |
| $(\sigma_\ell)_i$ | SLSI[a] | Stress longitudinal, small end of hub, inside surface |
| $(\sigma_c)_o$ | SCSO[a] | Stress, circumferential, small end of hub, outside surface |
| $(\sigma_c)_i$ | SCSI[a] | Stress, circumferential, small end of hub, inside surface |
| $(\sigma_\ell)_o$ | SLLO | Stress, longitudinal, large end of hub, outside surface |
| $(\sigma_\ell)_i$ | SLLI | Stress, longitudinal, large end of hub, inside surface |
| $(\sigma_c)_o$ | SCLO | Stress, circumferential, large end of hub, outside surface |
| $(\sigma_c)_i$ | SCLI | Stress, circumferential, large end of hub, inside surface |
| $(\sigma_t)_o$ | STH | Stress, tangential, hub side of ring, at $r = b$ |
| $(\sigma_t)_i$ | STF | Stress, tangential, face side of ring, at $r = b$ |
| $(\sigma_r)_o$ | SRH | Stress, radial, hub side of ring, at $r = b$ |
| $(\sigma_r)_i$ | SRF | Stress, radial, face side of ring, at $r = b$ |
| $\delta_g$ | ZG | Axial displacement at $r = g$ } ($\delta \equiv 0$ at $r = b$) |
| $\delta_c$ | ZC | Axial displacement at $r = c$ } ($\delta \equiv 0$ at $r = b$) |
| $q_f h_G$ | QFHG | $-\delta_c + \delta_g$ |
| $y_0$ | YO | Radial displacement, small end of hub |
| $y_1$ | Y1 | Radial displacement, large end of hub |
| | THETA | Rotation of ring at $r = b$ |
| | | For blind flanges[b] |
| $\sigma_r, \sigma_t, r = o$ | SORT | Stress, $r = o$, radial and tangential |
| $\sigma_r, r = g$ | SGR | Stress, $r = g$ radial |
| $\sigma_t, r = g$ | SGT | Stress, $r = g$, tangential |
| $\sigma_r, r = c$ | SCR | Stress, $r = c$, radial |
| $\sigma_t, r = c$ | SCT | Stress, $r = c$, tangential |
| $\sigma_t, r = a$ | SAT | Stress, $r = a$, tangential |
| $\delta_c$ | ZC | Axial displacement at $r = c$ ($\delta \equiv 0$ at $r = g$) |

[a]For "Straight Hub Flange," these are at juncture of hub with ring.

[b]All stresses are for the side of the flange opposite the pressure-bearing side. Stresses on the pressurized side of the flange have reversed signs.

Table 14. Output data identification when MATE = 2, 3 and 4, or 5 and 6

| Theory symbol | Program symbol | Description |
|---|---|---|
| $q_{f1}h_G$ | QFHG | Axial displacement from C to G, unit moment load |
| $q_{p1}h_G$ | QPHG | Axial displacement from C to G, unit pressure load |
| $q_{t1}h_G$ | QTHG[a] | Axial displacement from C to G, unit DELTA |
| 2b | XB[a,b] | Inside diameter |
| $g_0$ | GO[a,b] | Pipe wall thickness |
| t | TH | Ring thickness |
| $E_{f1}$ | YM[b] | Modulus of elasticity of flange material, initial state |
| $E_{f2}$ | YF2[c] | Modulus of elasticity of flange material, final state |
| $\epsilon_f$ | EF[b] | Coefficient of thermal expansion of flange material |
| ( )' | ( )P | The above nine symbols with a prime mark (') on the theory symbols are for the mating flange. The program symbol has the added final letter "P." |

[a]For blind flanges, these values are not significant; an artificial value of -1.0000 is printed out.

[b]These values are input data for flange side one, input cards 2 and 3 (see Table 11). For MATE = 2, these values, along with calculated values of QFHG, QPHG, and QTHG, are used for side one and side two (i.e., an identical pair). If MATE = 3 or 5, the primed values are stored; the unprimed values are read in by input cards 5 and 6, and values of QFHGP, QPHGP, and QTHGP are calculated.

[c]Input from card 6 for MATE = 2, card 9 for MATE = 3 and 4 or 5 and 6 (see Table 11).

Table 15. Output data identification, MATE = 2, 3 and 4, or 5 and 6, bolts, gasket, and loadings data

| Theory symbol | Program symbol | Description[a] |
|---|---|---|
| $\ell$ | XLB | Effective bolt length |
| $A_b$ | AB | Cross-sectional root area of all bolts |
| C | C | Bolt-circle diameter |
| $E_{b1}$ | YB | Modulus of elasticity, bolts, initial state |
| $E_{b2}$ | YB2 | Modulus of elasticity, bolts, final state |
| $\epsilon_b$ | EB | Coefficient of thermal expansion, bolts |
| $v_0$ | VO | Gasket thickness |
| | XGO | Outside diameter of gasket |
| | XGI | Inside diameter of gasket |
| $E_{g1}$ | YG | Modulus of elasticity of gasket, initial state |
| $E_{g2}$ | YG2 | Modulus of elasticity of gasket, final state |
| $\epsilon_g$ | EG | Coefficient of thermal expansion, gaskets |
| $W_1$ | W1 | Initial total bolt load |
| $T_b$ | TB | Temperature of bolts, final state |
| $T_{f2}$ | TF | Temperature of flange ring, side one, final state |
| $T'_{f2}$ | TFP | Temperature of flange ring, side two, final state |
| $T_g$ | TG | Temperature of gasket, final state |
| $\Delta$ | DELTA | Thermal gradient, pipe/hub to ring, side one |
| $\Delta'$ | DELTAP | Thermal gradient, pipe/hub to ring, side two |
| P | PRESS | Internal pressure |

[a]All values are input data, except XLB which is calculated by the equation: XLB = TH + THP + VO + BSIZE + FACE.

Table 16. Output data identification, MATE 2, 3 and 4, or 5 and 6, residual bolt loads and moments

| Theory symbol | Program[a] symbol | Effect included |
|---|---|---|
| $W_{2a}$ | W2A | Relative change in temperature of bolts, gasket, flange (AXIAL THERMAL) |
| $W_{2b}$ | W2B | Change in moment arms (MOMENT SHIFT) |
| $W_{2c}$ | W2C | Total pressure |
| $W_{2d}$ | W2D | Thermal gradient, pipe/hub to ring (DELTA THERMAL) |
| $W_2$ | W2 | All of the above, plus change in modulus of elasticity (COMBINED) |

[a]The change in bolt load (e.g., W1 - W2A) and ratio of residual to initial bolt load (e.g., W2A/W1) are also printed out, along with the corresponding values of the initial moment (M1) and residual moments, M2A, ..., M2P. The residual moment identifiers with final letter P (for prime) are for the first entered of a pair of nonidentical flanges. If the pair of flanges are identical, then M2B = M2BP, etc. The residual moment values are not significant for blind flanges, ITYPE = 3; therefore, residual bolt loads are used for blind flanges.

displacements as for the case when MATE = 1 plus the stresses and displacements for combined loading. The heading includes the value of the residual moments M2 = M2P used for the combined-loading calculations.

When MATE = 3 and 4 or 5 and 6, the output consists of four pages of printout. The first two pages have the same format as for the case when MATE = 2, except input data for both of the (nonidentical) flanges are printed. The residual moments on the last line of page 2 apply to flange one; those on the preceding line apply to flange two. The last two pages of printout are for flange one and flange two, respectively, and are identical in format to the third page of the printout for the case when MATE = 2.

## Acknowledgment

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## References

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# APPENDIX A

## EXAMPLES OF APPLICATION OF COMPUTER PROGRAM FLANGE

# APPENDIX A

## CONTENTS

## INTRODUCTION

Several examples have been selected to illustrate the input/output data of the computer program FLANGE and the significance of the results. The flange selected for analysis is one included in API Standard 605.* The particular size and rating selected was the 60-in., 300-lb tapered-hub flange. This particular flange represents a design in which the bolt stresses and flange stresses are close to the upper limits set in API-605.

Six examples are included:

1. A Code stress calculation is performed for a tapered-hub flange at its rated pressure of 720 psi at 100°F. The results show that this particular flange does indeed meet the criteria given in API-605 at 720 psi and 100°F.
2. A Code stress calculation is performed for a blind flange to match the 60-in., 300-lb API-605 tapered-hub flange. The thickness of the blind flange was selected so that its maximum stress was the allowable flange stress of 17,500 psi used in API-605.
3. A blind flange bolted to a tapered-hub flange under pressure loading only is analyzed.
   (a) For an initial bolt stress equal to the API-605 allowable stress for the bolting material of 20,000 psi, the results indicate that the flanged joint will probably leak at its rated pressure of 720 psi at 100°F.
   (b) For an initial bolt stress of 44,300 psi, the results indicate that the flanged joint will pass a hydrostatic test of 1.5 × 720 psi at ambient temperature.
4. A tapered-hub flange bolted to an identical tapered-hub flange with an initial bolt stress of 46,100 psi is analyzed.

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*_Large-Diameter Carbon Steel Flanges (Size: 26 Inches to 30 Inches, Inclusive, Nominal Pressure Rating: 75, 150, and 300 lb)_, API Standard 605, 1st Ed., American Petroleum Inst., New York, 1967.

(a) For pressure loading only, the results indicate that the flanged joint will hold a hydrostatic test pressure of 1.5 × 720 psi.

(b) For pressure loading of 300 psi (API-605 rated pressure at 850°F) plus an external bending moment that produces an axial stress in the attached pipe of 7500 psi, the results indicate that the flanged joint is adequate to carry these loads.

## DETAILS OF THE FLANGE USED IN THE EXAMPLES

A sketch of the tapered-hub flange is shown in Fig. A.1. The dimensions are as specified in API-605. The inside diameter and dimensions B (and therefore $g_0$ and $g_1$) are not specified in API-605. For the purpose of checking ratings, the following equation given in API-605 was used to establish B:

$$B = D_o - 2t_p \, , \tag{A.1}$$

where

$D_o$ = nominal outside diameter of pipe, in.;

$t_p$ = $p_1 D_o / 2(0.875)S$ (but not less than 0.25), in.;

$p_1$ = rated pressure at 100°F, psi;

0.875 = assumed pipe-wall tolerance; and

S = 20,000 psi, the allowable stress at 100°F.

The definition of $t_p$, with $D_o$ = 60 in. and $p_1$ = 720 psi, leads to $t_p$ = $g_0$ = 1.2343 in. Equation (A.1) gives B = 57.5314 in. and $g_1$ = (X-B)/2 = 2.7030 in.

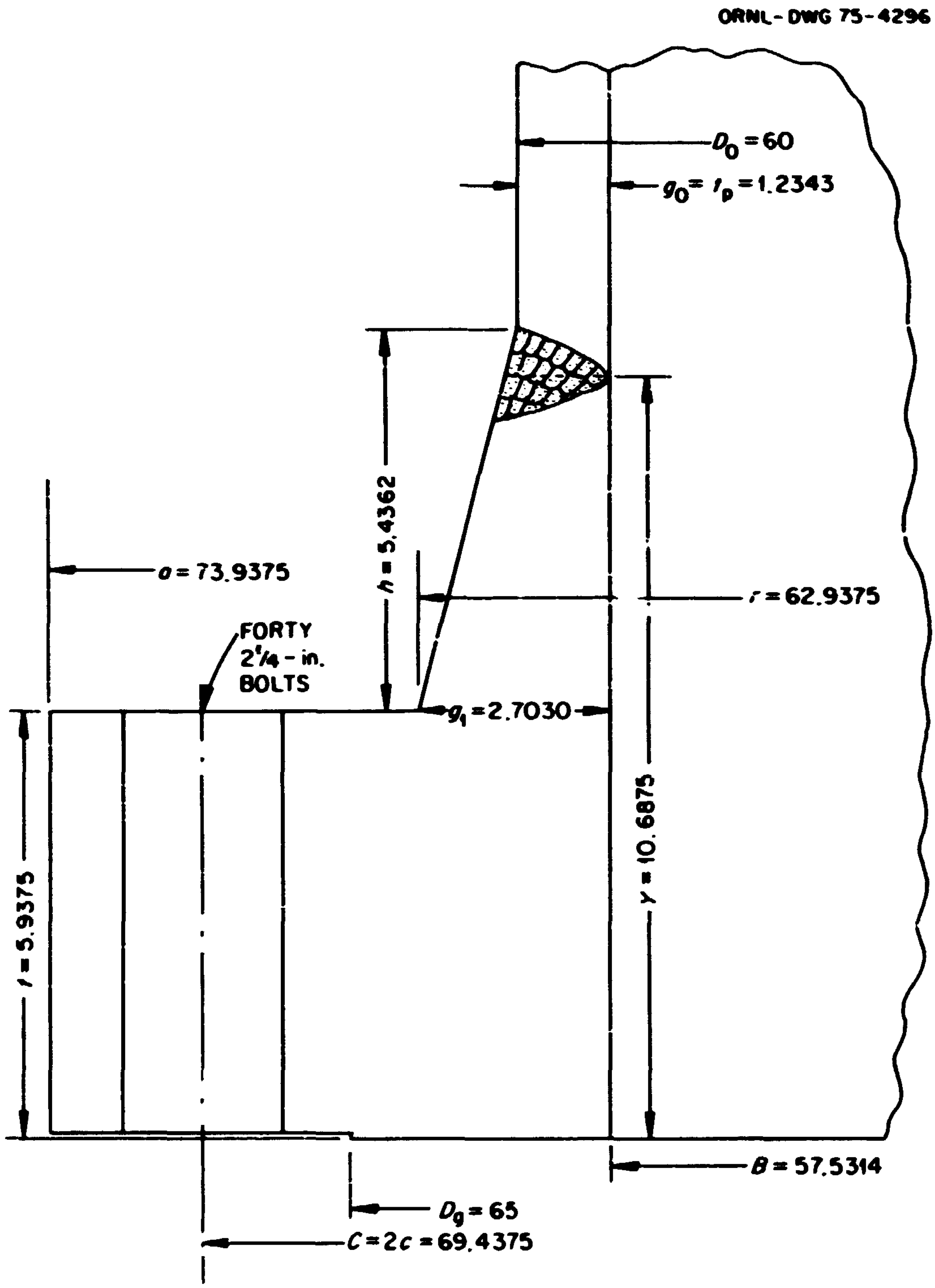
For the purpose of checking ratings, the hub length h was calculated by the equation given in API-605:

$$h = Y - t + 0.176g_0 + 0.469 \, .$$

Dimensions Y and t are shown in Fig. A.1. For this flange:

$$h = 10.6875 - 5.9375 + 0.176(1.2343) + 0.469 = 5.4362 \text{ in.}$$

The API-605 standard states that flange ratings were based on use of a 1/16-in.-thick, compressed-asbestos, flat ring-shaped gasket, with an inside diameter 1/4 in. larger than the outside diameter of the pipe and with an outside diameter equal to the raised-face diameter. For the 60-in., 300-lb flange, the gasket inside diameter is 60.25 in.; its




DIMENSIONS IN INCHES

Fig. A.1. Dimensions (in inches) of 60-in., 300-lb API-605 tapered-hub flange. The terms B, R, C, $D_o$, X, and A are diameters expressed in inches.

outside diameter is 65 in. According to the ASME Code, for a 1/16-in.-thick asbestos gasket, m = 2.75, and y = 3700 psi.

The 60-in., 300-lb flange has forty 2-1/4-in.-diam. bolts. For an 8-pitch thread, the root area per bolt is 3.423 in.$^2$, giving a total bolt root area of 136.92 in.$^2$.

## ASME CODE CALCULATIONS, EXAMPLES 1 AND 2

The input data for examples 1 and 2 are shown in Table A.1. The source of all input for Cards 2 and 3 are contained in the previous section on flange details, except that the thickness of the blind flange was selected* so that the controlling flange stress is 17,500 psi. Note that Card 2 is identical for examples 1 and 2 except for the value of t; however, B, $g_0$, $g_1$, and h are not used for example 2 (blind flange), and any number (including zero) can be entered for these dimensions.

Example 1 is a Code stress calculation for the 60-in., 300-lb API-605 tapered-hub flange at its rated pressure of 720 psi at 100°F. The output data are shown in Table A.2. The value of SB1 = 20,033 psi is the controlling bolt stress, which essentially meets the API criterion value of a bolt stress not greater than 20,000 psi. The value of (SH + ST)/2 = 17,293 psi under the heading "ASME FLANGE STRESSES AT OPERATING MOMENT, MOP" is the controlling flange stress and meets the API-605 criterion of a controlling flange stress not greater than 17,500 psi. The results, therefore, confirm that the 60-in., 300-lb API-605 tapered-hub flange meets the stated criteria.

The reader who is accustomed to using hand calculations for checking flange designs according to Code rules will note that the program input does not require either the factors T, U, Y, Z from Code Fig. UA-51.1, or F, V, and f from Code Figs. UA-51.2, UA-51.3, and UA-51.6, respectively. These factors are calculated by the computer program. In addition to simplifying the input, the program accurately calculates F, V, and f values for any values of $h/h_0$ and $g_1/g_0$, including those beyond the range of the Code figures.

Example 2 is a Code stress calculation for a blind flange to match the 60-in., 300-lb API-605 tapered-hub flange. The calculation method is that given in UG-34 [Eq. (2)], with C = 0.3. The output data are shown in Table A.3. The controlling flange stress is SOP = 17,500 psi;

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*API-605 does not give blind-flange thicknesses.

Table A.1. Input data for ASME Code stress calculations, examples 1 and 2

First card

| Column number | 5 | 10 | 15 | 20 |
|---|---|---|---|---|
| Variable | ITYPE | IBØND | ICØDE | MATE |
| Example 1 | 1 | 0 | 2 | 1 |
| Example 2 | 3 | 0 | 2 | 1 |

Second card

| Column number | 0-10 | 11-20 | 21-30 | 31-40 | 41-50 | 51-60 | 61-70 | 71-80 |
|---|---|---|---|---|---|---|---|---|
| Variable | A | B | t | $g_0$ | $g_1$ | h | C | P |
| Example 1 | 73.9375 | 57.5314 | 5.9375 | 1.2343 | 2.7030 | 5.4362 | 69.4375 | 720. |
| Example 2 | 73.9375 | 57.5314[a] | 7.9044 | 1.2343[a] | 2.7030[a] | 5.4362[a] | 69.4375 | 720. |

Third card

| Column number | 0-10 | 11-20 | 21-30 | 31-40 | 41-50 | 51-60 | 61-70[b] | 72 | 73-80 |
|---|---|---|---|---|---|---|---|---|---|
| Variable | m | y | $G_o$ | $G_i$ | $S_b$ | $S_a$ | $A_b$ | I | $b_o$ |
| Example 1 | 2.75 | 3700. | 65. | 60.25 | 20000. | 20000. | 136.92 | 0 | 0 |
| Example 2 | 2.75 | 3700. | 65. | 60.25 | 20000. | 20000. | 136.92 | 0 | 0 |

[a] Not used in calculations for a blind flange.

[b] Column 71 is blank.

Table A.2. Output data for example 1, ASME Code analysis of a tapered-hub flange

| FLANGE O.D.,A | FLANGE I.D.,B | FLANGE THICK.,T | PIPE WALL,G0 | HUB AT BASE,G1 | HUB LENGTH,H | BOLT CIRCLE,C | PRESSURE, P |
|---|---|---|---|---|---|---|---|
| 73.93750 | 57.53140 | 5.93750 | 1.23430 | 2.70300 | 5.43620 | 69.43750 | 720.000 |

| M | Y | GOUT | GIN | SB | SA | AB |
|---|---|---|---|---|---|---|
| 2.75000 | 3700.00000 | 65.00000 | 60.25000 | 20000.00000 | 20000.00000 | 136.92060 |

| BO | WM11 | WM12 | WM1 | SB1 | WM2 | SB2 |
|---|---|---|---|---|---|---|
| 1.1875D 00 | 2.3097D 06 | 4.3322D 05 | 2.7430D 06 | 2.0033D 04 | 4.0477D 05 | 2.9563D 03 |

| MOP | MGS | MGS1 |
|---|---|---|
| 1.1719D 07 | 7.5742D 06 | 1.1186D 06 |

ASME FLANGE STRESSES AT OPERATING MOMENT, MOP

(2/3)*SH= 1.5608D 04  ST = 1.1174D 04  SR = 8.4442D 03  (SH+ST )/2= 1.7293D 04  (SH+SR )/2= 1.5928D 04

ASME FLANGE STRESSES AT GASKET SEATING MOMENT, MGS

(2/3)*SH= 1.0087D 04  ST = 7.2216D 03  SR = 5.4576D 03  (SH+ST )/2= 1.1176D 04  (SH+SR )/2= 1.0294D 04

Table A.3. Output data for example 2, ASME Code analysis of a blind flange

| FLANGE O.D.,A | FLANGE I.D.,B | FLANGE THICK.,T | PIPE WALL,G0 | HUB AT BASE,G1 | HUB LENGTH,H | BOLT CIRCLE,C | PRESSURE, P |
|---|---|---|---|---|---|---|---|
| 73.93750 | 0.0 | 7.90440 | 0.0 | 0.0 | 0.0 | 69.43750 | 720.000 |

| M | Y | GOUT | GIN | SB | SA | AB |
|---|---|---|---|---|---|---|
| 2.75000 | 3700.00000 | 65.00000 | 60.25000 | 20000.00000 | 20000.00000 | 136.92000 |

| BO | WM11 | WM12 | WM1 | SB1 | WM2 | SB2 |
|---|---|---|---|---|---|---|
| 1.1875D 00 | 2.3097D 06 | 4.3322D 05 | 2.7430D 06 | 2.0033D 04 | 4.0477D 05 | 2.9563D 03 |

ASME CODE STRESSES FOR BLIND FLANGE

| SP | SH1 | SOP | SH2 | SGS |
|---|---|---|---|---|
| 1.4121D 04 | 3.3792D 03 | 1.7500D 04 | 4.9865D 02 | 3.3763D 03 |

the flange thickness of 7.9044 in. was selected to obtain this result. This example was included to illustrate that a blind flange may have to be considerably thicker than a mating flange in order for both to meet the Code stress limitations.

# BLIND-TO-TAPERED-HUB FLANGED JOINT, EXAMPLES 3(a) AND 3(b)

## Input Data

The input data for examples 3(a) and 3(b) are shown in Table A.4. In addition to the basic purpose of illustrating input/output data for the program FLANGE, this pair of examples was selected to show how the program can be used to estimate required initial bolt stresses. In addition, example 3(a) shows how the general purpose option (ICODE ≠ 2) gives stresses as obtained from Code calculations plus deformation data and additonal stresses.

Examples 3(a) and (b) do not involve temperature gradients or temperatures other than ambient; hence, the modulus of elasticity is the same for the initial and final states. Values of temperatures for the flanges, bolts, and gaskets in the final state have been entered as zero. The initial-state reference temperature is zero; hence, a zero in the final state denotes a zero thermal gradient. However, the value of DELTA (the hub-to-ring thermal gradient) cannot be entered as zero without causing a divide-check error, so a value of 0.01 was used. A smaller value could be used (e.g., 0.001 or 0.0001), but the output data shows that DELTA = 0.01 is sufficiently small so that its influence is negligible. A coefficient of thermal expansion of $6 \times 10^{-6}$ has been entered but is not significant in these examples.

The value of FACE, which is intended to permit use of a bolt length other than $\ell_0$ = TH + THP + VO + BSIZE, was entered as zero. The modulus of elasticity for both the flanges and the bolts was assumed to be $3 \times 10^7$ psi. The modulus of elasticity for the 1/16-in.-thick asbestos gasket was assumed to be $3 \times 10^6$ psi.

Some comments on the use of a modulus of elasticity of $3 \times 10^6$ for a 1/16-in. asbestos gasket may be appropriate. The stress-strain relationship for such a gasket, which is confined between the two rigid flange faces, is highly nonlinear and both time and history dependent. Starting out with a new gasket, the first increment of bolt stress to produce a gasket stress of 1000 psi might decrease the gasket thickness

Table A.4. Input data for blind-to-tapered-hub flanged joint, examples[a] 3a and 3b

| Card No. | Variables and numerical values | | | | | | | | Read format |
|---|---|---|---|---|---|---|---|---|---|
| 1 | ITYPE | IBOND | ICODE | MATE | | | | | |
| | 3 | 0 | 0 | 5 | | | | | 4I5 |
| 2 | A | B | t | $g_0$ | $g_1$ | h | C | P | |
| | 73.9375 | 57.5314 | 7.9044 | 1.2343 | 2.7030 | 5.4362 | 69.4375 | 720. (1080.) | 8E10.5 |
| 3 | XMGA[b] | EF | DELTA[c] | YM | G | | | | |
| | 2.7430D+6 (6.0656D+6) | 6. D-6 | .01 | 3. D+7 | 62.625 | | | | 5E10.5 |
| 4 | ITYPE | IBOND | ICODE | MATE | | | | | |
| | 1 | 0 | 0 | 6 | | | | | 4I5 |
| 5 | A | B | t | $g_0$ | $g_1$ | h | C | P | |
| | 73.9375 | 57.5314 | 5.9375 | 1.2343 | 2.7030 | 5.4362 | 69.4375 | 720. (1080.) | 8E10.5 |
| 6 | XMGA | EF | DELTA[c] | YM | G | | | | |
| | 1.1719D+7 (2.0661D+7) | 6. D-6 | .01 | 3. D+7 | 62.625 | | | | 5E10.5 |
| 7 | BSIZE | YB | EB | TB | XG0 | XG1 | AB | | |
| | 2.25 | 3. D+7 | 6. D-6 | 0 | 65. | 60.25 | 136.92 | | 7E10.5 |
| 8 | VO | YG | EG | TG | FACE | PBE | | | |
| | .0625 | 3. D+6 | 6. D-6 | 0 | 0 | 0 | | | 6E10.5 |
| 9 | W1 | TF | TFB | YF2 | YFP2 | YB2 | YG2 | | |
| | 2.7430D+6 (6.0656D+6) | 0 | 0 | 3. D+7 | 3. D+7 | 3. D+7 | 3. D+6 | | 7E10.5 |

[a] Values in parentheses are for example 3b.

[b] Initial bolt load is used here since ITYPE = 3; see footnote *b* to Table 11 in the text.

[c] Since DELTA cannot be entered as zero, 0.01 was used as a satisfactorily small value.

by 20%, so that the modulus would be 1000/(0.2 × 0.0625) = $8 \times 10^4$ psi. Crude observations indicate that, at a bolt stress that produces a gasket stress of 40,000 psi, the gasket thickness is about one-half of its original thickness, so that the average modulus up to this stress is 40,000/0.03125 = $1.28 \times 10^6$ psi. These numbers are dependent upon the ratio of width to thickness of the gasket and the time under stress, particularly for low gasket stress. However, for the flanged-joint analysis, we are not interested in the gasket stress-strain characteristics when the bolt load is applied but rather in the gasket stress-strain characteristics when the gasket stress is decreased after the gasket has been under bolt load for several days or many months. No data on the "spring-back" of asbestos gaskets are available, but in most flanged joints using 1/16-in.-thick asbestos gaskets, the assumed modulus of elasticity of the gasket is not very significant provided it is not unrealistically low. This can be shown for example 3 by noting that the change in the bolt load depends upon the sum of the load-displacement characteristics of the bolts, the flanges, and the gasket. The displacements for a unit bolt load are —

$$\text{for bolts:} \quad \frac{\ell_0}{A_b E_b} = \frac{16.15}{136.92 \times 3 \times 10^7} = 3.93 \times 10^{-9} ,$$

$$\text{for flanges:} \quad 2 \times QFHG = 2(1.197 \times 10^{-9}) = 2.40 \times 10^{-9} ,$$

and

$$\text{for gasket:} \quad \frac{V_0}{A_G E_G} = \frac{0.0625}{467.26 \times E_G} = \frac{1.34 \times 10^{-4}}{E_G} .$$

As $E_G$ varies from $10^5$ to $10^7$, the sum of these three displacements varies as follows:

| $E_G$ | $10^5$ | $3 \times 10^5$ | $10^6$ | $3 \times 10^6$ | $10^7$ |
|---|---|---|---|---|---|
| Sum of displacements ($\times 10^9$ in.) | 7.67 | 6.78 | 6.46 | 6.37 | 6.34 |

From the above, it can be seen that changing the gasket modulus by two orders of magnitude changes the sum of the displacement by only 17%.

The initial bolt stress used in example 3(a) is 20,033 psi, giving an initial bolt load of W1 = $S_b A_b$ = 20,033 × 136.92 = 2.743 × $10^6$ lb; W1 is entered in place of XMOA on card 6 (see footnote *b* to Table 11 of text). The initial moment, XMOA, used in example 3(a) is 1.1719 × $10^7$ in.-lb. The initial bolt stress used in example 3(b) is 44,300 psi, giving an initial bolt load of W1 = 6.0656 × $10^6$ lb. The initial moment, XMOA, used in example 3(b) is 2.0661 × $10^7$ in.-lb. The reasons for using these particular values of W1 and XMOA are discussed in connection with the output data for these examples.

## Output Data

### Residual Bolt Loads

The output data for example 3(a) are shown in Table A.5. The output starts with a printout of all input data on the first page (Table A.5a).* The parameters involved in the bolt-load-change calculations are then printed, followed by residual bolt loads and moments, all on the second page (Table A.5b). The initial bolt load under "LOADINGS" is 2.743 × $10^6$ lb; the residual bolt load after application of the pressure of 720 psi is given following "COMBINED" as W2 = 1.0948 × $10^6$ lb. The loss in bolt load is given by W1 - W2 = 1.6482 × $10^6$ lb, and the ratio of residual to initial bolt load is given by W2/W1 = 0.39911. Calculated stresses for the blind flange and for the tapered-hub flange are printed on the third and fourth pages (Tables A.5c and A.5d, respectively). These are discussed later.

---

*For convenience in referring to specific pages of multipage tables, we have used alphabetic suffixes on table numbers. For example, the first page of Table A.5 is designated Table A.5a; the second page is Table A.5b, the third is Table A.5c, etc.

Table A.5a. Output data for example 3(a), blind flange bolted to a tapered-hub flange, with initial bolt stress = 20,033 psi*

```
 FLANGE    FLANGE     FLANGE      PIPE       HUB AT      HUB        BOLT     PRESSURE,
 O.D.,A    I.D.,B    THICK.,T   WALL,GO    BASE,G1    LENGTH,H   CIRCLE,C     P
73.93750  57.53140    7.90440    1.23430    2.70300    5.43620   69.43750   720.000

  BOLT    COEFF. OF    DELTA      MOD. OF MEAN GASKET  ITYPE       IBCND      ICODE      MATE
 LOAD     THERMAL EXP.            ELASTICITY DIAMETER
2.743D 06 6.000D-06 1.000D-02 3.000D 07 6.263D 01      3           0          0           5


 FLANGE    FLANGE     FLANGE      PIPE       HUB AT      HUB        BOLT     PRESSURE,
 O.D.,A    I.D.,B    THICK.,T   WALL,GO    BASE,G1    LENGTH,H   CIRCLE,C     P
73.93750  57.53140    5.93750    1.23430    2.70300    5.43620   69.43750   720.000

 MOMENT   COEFF. OF    DELTA      MOD. OF MEAN GASKET  ITYPE       IBCND      ICODE      MATE
          THERMAL EXP.            ELASTICITY DIAMETER
1.172D 07 6.000D-06 1.000D-02 3.000D 07 6.263D 01      1           0          0           6


     BSIZE            YB             EB             TB              XGO           XGI           AB
   2.2500D 00     3.0000D 07     6.0000D-06     0.0            6.5000D 01    6.0250D 01    1.3692D 02
     VO               YG             EG             TG              FACE          PBE
   6.2500D-02     3.0000D 06     6.0000D-06     0.0            0.0           0.0
     W1               TF             TFF            YF2             YFF2          YB2           YG2
   2.7430D 06     0.0            0.0            3.0000D 07     3.0000D 07    3.0000D 07    3.0000D 06

    FLANGE JOINT BOLT LOAD CHANGE DUE TO APPLIED LOADS, BLIND TO INTEGRAL PAIR

      FLANGE JOINT SIDE ONE (PRIMED QUANTITIES)

QPNG=  9.4994D-10  QPMG=  6.5359D-06  QTNG= -1.0000D 00   XB = -1.0000D 00      GO= -1.0000D 00       TN  =  7.9044D 00
      YN =  3.0000D 07          YF2 =  3.0000D 07    EF =  6.0000D-06

      FLANGE JOINT SIDE TWO (UNPRIMED QUANTITIES)

QPNG=  1.1946D-09  QPMG=  8.0422D-06  QTNG=  9.5590D-05   XB =  5.7531D 01      GO=  1.2343D 00       TN  =  5.9375D 00
      YN =  3.0000D 07          YF2 =  3.0000D 07    EF =  6.0000D-06

       BOLTING

BOLT LENGTH=  1.6154D 01  BOLT AREA=  1.3692D 02  BOLT CIRCLE=  6.9438D 01
      YB =  3.0000D 07          YB2 =  3.0000D 07    EB =  6.0000D-06

       GASKET

  VO   =  6.2500D-02  XGO =  6.5000D 01  XGI =  6.0250D 01
     YG  =  3.0000D 06          YG2 =  3.0000D 06    EG =  6.0000D-06
```

*For the convenience of the user, the first page of Table A.5 is designated Table A.5a, the second page is Table A.5b, the third is Table A.5c, etc. This convention is also used in the following tables.

Table A.5b (continued)

```
       LOADINGS

INITIAL BOLT LOAD=  2.7430D 06  BOLT TEMP.=  0.0          FLANGE ONE TEMP.=  0.0          FLANGE TWO TEMP.=  0.0
GASKET TEMP.=  0.0           DELTA=  1.0000D-02   DELTAF=  1.0000D-02  PRESSURE=  7.2000D 02

   RESIDUAL BOLT LOADS AFTER THERMAL-PRESSURE LOADS

AXIAL THERMAL,W2A=  2.7430D 06  MOMENT SHIFT,W2B=  2.2294D 06

TOTAL PRESSURE,W2C=  1.0949E 06   DELTA THERMAL,W2D=  2.7429D 06

COMBINED,W2=  1.0948D 06

W1-W2A=  0.0          W1-W2B=  5.1359D 05  W1-W2C=  1.6481D 06  W1-W2D=  1.0333D 02  W1-W2=   1.6482D 06

W2A/W1=  1.0000D 00  W2B/W1=  8.1276D-01  W2C/W1=  3.9915D-01  W2D/W1=  9.9996D-01  W2/W1=  3.9911D-01

    INITIAL AND RESIDUAL MOMENTS AFTER THERMAL PRESSURE LOADS.

M1=  9.3433D 06  M2A=  9.3433D 06  M2B=  1.1646D 07  M2C=  7.7818D 06  M2D=  9.3430D 06  M2=  7.7814D 06

M2BP=  4.2880D 07  M2CP=  3.9015D 07  M2P=  3.9C15D 07
```

Table A.5c (continued)

```
        BLIND FLANGE
    CALCULATIONS FOR BOLT LOADING

SORT=  4.0213D 03   SGR=  4.0213D 03   SGT=  4.0213D 03   SCR= -1.6157D 02   SCT=  2.5764D 03   SAT=  2.4148D 03
    ZC= -2.6097D-03

    CALCULATIONS FOR PRESSURE LOADING

SORT=  1.3144D 04   SGR= -8.3815D 02   SGT=  5.0937D 03   SCR= -2.8472D 02   SCT=  4.5403D 03   SAT=  4.2555D 03
    ZC= -4.7052D-03

   CALCULATIONS FOR COMBINED LOADING,W2 OR W2P FOR ITYPE=1 OR 2,  W2 FOR ITYPE=3,  =   1.0948D 06

SORT=  1.4749D 04   SGR=  7.6681D 02   SGT=  6.6987D 03   SCR= -3.4921D 02   SCT=  5.5685D 03   SAT=  5.2193D 03
    ZC= -5.7452D-03
```

Table A.5d (continued)

```
        TAPERED HUB FLANGE
   CALCULATIONS FOR MOMENT LOADING

SLSO=  2.3042D 04  SLSI= -2.3042D 04  SCSO=  1.9763D 04  SCSI=  5.9379D 03
SLLO=  2.3411D 04  SLLI= -2.3411D 04  SCLO=  7.0234D 03  SCLI= -7.0234D 03
 STH=  1.1173D 04   STF= -1.8482D 04   SRH=  8.4441D 03   SRF= -6.6480D 03
ZG= -1.0421D-02  ZC= -2.4446D-02  QPHG=  1.4026D-02  YO=  1.2322D-02  Y1=  1.0058D-18  THETA= -4.0579D-03
   CALCULATIONS FOR PRESSURE LOADING

SLSO=  1.4194D 04  SLSI=  2.5863D 03  SCSO=  1.4398D 04  SCSI=  1.0915D 04
SLLO=  1.8645D 03  SLLI=  5.7979D 03  SCLO=  5.5935D 02  SCLI=  1.7394D 03
 STH=  9.3311D 03   STF= -1.1062D 03   SRH= -2.2932D 03   SRF=  2.7038D 02
ZG= -4.5114D-03  ZC= -1.0302D-02  QPHG=  5.7904D-03  YO=  9.7224D-03  Y1=  6.0715D-18  THETA= -1.8088D-03
   CALCULATIONS FOR TEMPERATURE LOADING

SLSO=  1.2228D 00  SLSI= -1.2228D 00  SCSO=  1.0649D-01  SCSI= -6.2722D-01
SLLO= -1.3977D-01  SLLI=  1.3977D-01  SCLO= -1.8419D 00  SCLI= -1.7581D 00
 STH=  1.1087D 00   STF= -6.1330D-01   SRH= -2.7247D-01   SRF=  1.5072D-01
ZG= -7.4476D-07  ZC= -1.7007D-06  QPHG=  9.5590D-07  YO= -2.4965D-07  Y1= -1.7259D-06  THETA= -2.9860D-07
  CALCULATIONS FOR COMBINED LOADING,M2 OR M2P FOR ITYPE=1 OR 2, W2 FOR ITYPE=3,  =   7.7814D 06

SLSO=  3.3385D 04  SLSI= -1.6605D 04  SCSO=  3.0857D 04  SCSI=  1.5860D 04
SLLO=  2.1362D 04  SLLI= - .3700D 04  SCLO=  6.4068D 03  SCLI= -4.1117D 03
 STH=  1.0638D 04   STF= -1.6493D 04   SRH=  4.7191D 03   SRF= -5.2661D 03
ZG= -1.3191D-02  ZC= -3.0663D-02  QPHG=  1.7472D-02  YO=  1.9984D-02  Y1= -1.7259D-06  THETA= -5.1086D-03
```

To avoid leakage,* the residual bolt load must not be less than the critical value $W_c$, which may be obtained from simple equilibrium considerations; thus,

$$W_c = \frac{\pi}{4} G_0^2 p , \qquad (A.2)$$

where

$W_c$ = "critical" bolt load,
$G_0$ = outside diameter of gasket (65 in. in this example), and
$p$ = pressure (720 psi in this example).

In this example, the value of $W_c$ is

$$W_c = \frac{\pi}{4} \times 65^2 \times 720 = 2.389 \times 10^6 \text{ lb} .$$

Because $W_c$ is significantly greater than $W2 = 1.0948 \times 10^6$ lb, the results for example 3(a) indicate that the joint will leak at the rated pressure with the initial bolt stress of 20,033 psi. The results illustrate an aspect of ASME-designed flanges that is well known to many users; that is, the joints often cannot be made leaktight (especially in order to pass the hydrostatic test) by applying an initial bolt stress equal to the Code-allowable bolt stress.

The output data for example 3(b) are shown in Table A.6. Example 3(b) is the same as 3(a), except that the initial bolt stress has been increased from 20,033 psi to 44,300 psi (W1 input under XMOA increased to $2.0661 \times 10^7$); the initial moment has been correspondingly increased; and the pressure has been increased from 720 psi to 1080 psi, the latter being the hydrostatic-test pressure of 1.5 times the cold rating pressure. It can be seen in Table A.6 (on the second page, Table A.6b) that the

---

*Leakage is defined as the gross type of leakage that occurs when the load on the gasket is reduced to zero. Slow, diffusion-type leakage may occur at lower pressures.

Table A.6a. Output data for example 3(b), blind flange bolted to a tapered-hub flange, with initial bolt stress = 44,300 psi

```
FLANGE     FLANGE     FLANGE     PIPE       HUB AT     HUB        BOLT       PRESSURE,
O.D.,A     I.D.,B     THICK.,T   WALL,GO    BASE,G1    LENGTH,H   CIRCLE,C   P
73.93750   57.53140   7.90440    1.23430    2.70300    5.43620    69.43750   1080.000

 BOLT     COEFF. OF   DELTA      MOD. OF  MEAN GASKET  ITYPE      IBOND      ICODE      MATE
 LOAD     THERMAL EXP.          ELASTICITY DIAMETER
6.066D 06 6.000D-06 1.000D-02 3.000D 07 6.263D 01       3          0          0          5


FLANGE     FLANGE     FLANGE     PIPE       HUB AT     HUB        BOLT       PRESSURE,
O.D.,A     I.D.,B     THICK.,T   WALL,GO    BASE,G1    LENGTH,H   CIRCLE,C   P
73.93750   57.53140   5.93750    1.23430    2.70300    5.43620    69.43750   1080.000

MOMENT    COEFF. OF   DELTA      MOD. OF  MEAN GASKET  ITYPE      IBOND      ICODE      MATE
          THERMAL EXP.          ELASTICITY DIAMETER
2.046D 07 6.000D-06 1.000D-02 3.000D 07 6.263D 01       1          0          0          6


      BSIZE            YB              EB            TB              XGO             XGI             AB
    2.2500D 00     3.0000D 07     6.0000D-06     0.0            6.5000D 01     6.0250D 01     1.3692D 02
      WO               YG              EG            TG              FACE            PBE
    6.2500D-02     3.0000D 06     6.0000D-06     0.0            0.0            0.0
      W1               TP              TPP           YP2             YPP2            YB2             YG2
    6.0656D 06     0.0            0.0            3.0000D 07     3.0000D 07     3.0000D 07     3.0000D 06

    FLANGE JOINT BOLT LOAD CHANGE DUE TO APPLIED LOADS, BLIND TO INTEGER PAIR

      FLANGE JOINT SIDE ONE (PRIMED QUANTITIES)

QFHG=  9.4994D-10  QPHG=  6.5350D-06  QTHG= -1.0000D 00  XB = -1.0000D 00      GO= -1.0000D 00      TH  =  7.9044D 00
      YH =  3.0000D 07         YP2 =  3.0000D 07     EP =  6.0000D-06

      FLANGE JOINT SIDE TWO (UNPRIMED QUANTITIES)

QFHG=  1.1968D-09  QPHG=  8.0422D-06  QTHG=  9.5590D-05  XB =  5.7531D 01      GO=  1.2343D 00      TH  =  5.9375D 00
      YH =  3.0000D 07         YP2 =  3.0000D 07     EP =  6.0000D-06

        BOLTING

BOLT LENGTH=  1.6154D 01  BOLT AREA=  1.3692D 02  BOLT CIRCLE=  6.9438D 01
      YB =  3.0000D 07        YB2 =  3.0000D 07    EB =  6.0000D-06

        GASKET

  WO  =  6.2500D-02  XGO =  6.5000D 01  XGI =  6.0250D 01
     YG  =  3.0000D 06        YG2 =  3.0000D 06    EG =  6.0000D-06
```

Table A.6b (continued)

```
        LOADINGS

INITIAL BOLT LOAD=  6.0656D 06  BOLT TEMP.=  0.0          FLANGE ONE TEMP.=  0.0          FLANGE TWO TEMP.=  0.0
GASKET TEMP.=  0.0          DELTA=  1.0000D-02   DELTAP=  1.0000D-02  PRESSURE=  1.0000D 03

   RESIDUAL BOLT LOADS AFTER THERMAL-PRESSURE LOADS

AXIAL THERMAL,W2A=  6.0656D 06  MOMENT SHIFT,W2B=  5.2952D 06

TOTAL PRESSURE,W2C=  3.5934D 06   DELTA THERMAL,W2D=  6.0655D 06

COMBINED,W2=  3.5933D 06


W1-W2A=  0.0          W1-W2B=  7.7038D 05  W1-W2C=  2.4722D 06  W1-W2D=  1.0333D 02  W1-W2=   2.4723D 06

W2A/W1=  1.0000D 00  W2B/W1=  8.7299D-01  W2C/W1=  5.9242D-01  W2D/W1=  9.9998D-01  W2/W1=  5.9240D-01

    INITIAL AND RESIDUAL MOMENTS AFTER THERMAL PRESSURE LOADS.

M1=  2.0661D 07  M2A=  2.0661D 07  M2B=  2.4115D 07  M2C=  1.8319D 07  M2D=  2.0661D 07  M2=  1.8318D 07

M2BP=  7.0966D 07  M2CP=  6.5169D 07  M2P=  6.5168D 07
```

Table A.6c (continued)

```
        BLIND FLANGE
   CALCULATIONS FOR BOLT LOADING

SORT=  8.8924D 03   SGR=  8.8924D 03   SGT=  8.8924D 03   SCR= -3.5727D 02   SCT=  5.6971D 03   SAT=  5.3399D 03
    ZC= -5.7620D-03

   CALCULATIONS FOR PRESSURE LOADING

SORT=  1.9716D 04   SGR= -1.2572D 03   SGT=  7.6405D 03   SCR= -4.2709D 02   SCT=  6.8104D 03   SAT=  6.3833D 03
    ZC= -7.0578D-03

  CALCULATIONS FOR COMBINED LOADING,W2 OR W2P FOR ITYPE=1 OR 2, W2 FOR ITYPE=3, =  3.5933D 06

SORT=  2.4984D 04   SGR=  4.0107D 03   SGT=  1.2908D 04   SCR= -6.3873D 02   SCT=  1.0185D 04   SAT=  9.5467D 03
    ZC= -1.0871D-02
```

Table A.6d (continued)

```
        TAPERED HUB FLANGE
   CALCULATIONS FOR MOMENT LOADING

SLSO=  4.0624D 04  SLSI= -4.0624D 04  SCSO=  3.4843D 04  SCSI=  1.0469D 04
SLLO=  4.1275D 04  SLLI= -4.1275D 04  SCLO=  1.2382D 04  SCLI= -1.2382D 04
 STN=  1.9699D 04   STP= -3.2584D 04   SRN=  1.4887D 04   SRP= -1.1721D 04
SG= -1.8372D-02  SC= -4.3100D-02  QPNG=  2.4728D-02  Y0=  2.1724D-02  Y1=  2.1553D-19  THETA= -7.1542D-03
   CALCULATIONS FOR PRESSURE LOADING

SLSO=  2.1290D 04  SLSI=  3.8794D 03  SCSO=  2.1596D 04  SCSI=  1.6373D 04
SLLO=  2.7967D 03  SLLI=  8.69[illegible]8D 03  SCLO=  8.3902D 02  SCLI=  2.6090D 03
 STN=  1.3997D 04   STP= -1.6503D 03   SRN= -3.4397D 03   SRP=  4.0556D 02
SG= -6.7671D-03  SC= -1.5[illegible]53D-02  QPNG=  8.6856D-03  Y0=  1.4584D-02  Y1=  6.0715D-18  THETA= -2.7132D-03
   CALCULATIONS FOR TEMPERATURE LOADING

SLSO=  1.2228D 00  SLSI= -1.2228D 00  SCSO=  1.0649D-01  SCSI= -6.2722D-01
SLLO= -1.3977D-01  SLLI=  1.3977D-01  SCLO= -1.8419D 00  SCLI= -1.7581D 00
 STN=  1.1087D 00   STP= -6.1330D-01   SRN= -2.7247D-01   SRP=  1.5072D-01
SG= -7.4476D-07  SC= -1.7007D-06  QPNG=  9.5590D-07  Y0= -2.4965D-07  Y1= -1.7259D-06  THETA= -2.9860D-07
  CALCULATIONS FOR COMBINED LOADING,M2 OR M2P FOR ITYPE=1 OR 2,  M2 FOR ITYPE=3,  =   1.8318D 07

SLSO=  5.7309D 04  SLSI= -3.2139D 04  SCSO=  5.2489D 04  SCSI=  2.5654D 04
SLLO=  3.9392D 04  SLLI= -2.7898D 04  SCLO=  1.1814D 04  SCLI= -8.3712D 03
 STN=  3.1463D 04   STP= -3.0541D 04   SRN=  9.7592D 03   SRP= -9.9860D 03
SG= -2.3057D-02  SC= -5.3667D-02  QPNG=  3.0610D-02  Y0=  3.3844D-02  Y1= -1.7259D-06  THETA= -9.0565D-03
```

residual bolt load after application of a pressure of 1080 psi is $W2 = 3.5933 \times 10^6$ lb. The value of the critical bolt load to prevent gross leakage is

$$W_c = \frac{\pi}{4} \times 65^2 \times 1080 = 3.584 \times 10^6 \text{ lb} .$$

With an initial bolt stress of 44,300 psi, the residual bolt load is now greater than $W_c$. Accordingly, the results of example 3(b) indicate that an initial bolt stress of 44,300 psi is sufficient for the joint to pass a hydrostatic test to 1080 psi, albeit with no margin of safety. As the reader may have surmised, the initial bolt stress of 44,300 psi was preselected for example 3(b) to achieve this final result. It is pertinent to note that, because of the linear nature of the calculations, it is not necessary to iterate in order to find a value for the initial bolt stress that would make $W2 = W_c$. Note that $(W1 - W2) = 1.648 \times 10^6$ in example 3(a) and that (W1 - W2) varies linearly with pressure. To find the required value of W1 to make $W2 = W_c$ at an arbitrary pressure p, we need only solve the equation:

$$W1 = \frac{\pi}{4} G_0^2 p + \frac{p}{720} (1.648 \times 10^6) . \qquad (A.3)$$

For p = 1080, Eq. (A.3) gives $W1 = 6.056 \times 10^6$, and the corresponding initial bolt stress is $W1/A_b = 6.056 \times 10^6/136.92 = 44,228$ psi, which was rounded off to 44,300 psi for Example 3(b).

<u>Blind Flange Stresses, Example 3(a)</u>

Example 3(a) was run with an initial bolt stress of 20,033 psi to permit direct comparison of the blind-flange stresses with the stresses calculated in example 2, where the controlling bolt stress was SB1 = 20,033 psi.

Stresses for the blind flange are shown in Table A.5c. The maximum stress due to initial bolt loading only is SORT = 4021.3 psi. A comparable stress from the Code calculation (Table A.3), is SGS = 3376.3 psi.

This also represents a stress at the center of the blind flange due to bolt loading only. The maximum stress due to pressure loading only of the blind flange (Table A.5c) is SORT = 13,144 psi. A Comparable stress from the Code calculation (Table A.3) is SP = 14,121 psi.

The maximum stress due to combined bolt loading and pressure loading (Table A.5c) is SORT = 14,749 psi. Note that this combined stress is not the sum of the stress due to the initial bolt load and the stress due to pressure. Rather, the program recognizes that the pressure changes the bolt load — in this example, from $2.743 \times 10^6$ lb down to $1.0948 \times 10^6$ (Table A.5b). Stresses for combined loadings are related to stresses for initial bolt loading only and pressure only by the equation

$$\sigma_c = \sigma_b \cdot \frac{W2}{W1} + \sigma_p \; , \qquad \text{(A.4)}$$

where $\sigma_c$ = combined stress, $\sigma_b$ = stress due to initial bolt load only, W2 = bolt load at pressure, W1 = initial bolt load, and $\sigma_p$ = stress due to pressure only.

The Code equation for combined stresses [i.e., $S = (d/t)^2(0.3p + 1.78Wh_G)$ from paragraph UG-34 and Figs. UG-34 (j) and (k)] can be derived by assuming that the blind flange is a flat circular plate of outside diameter equal to the effective gasket diameter d. The metal outside the diameter d is ignored. The plate is simply supported along d and loaded by edge moment $Wh_G$ and pressure p. $Wh_G$ is either the operating moment or the gasket-seating moment, as obtained in Appendix II of the Code. The method used in this report is theoretically more accurate than that used in the Code, and the relatively good agreement between stresses in Table A.5c and those in Table A.3 is, in part, coincidental. Large differences can exist, particularly when there is a significant amount of flange material outside the gasket diameter d.

## Tapered-Hub Flange Stresses, Example 3(a)

Example 3(a) was run with an initial moment of $1.1719 \times 10^7$ in.-lb to permit direct comparison with the stresses given for example 1 in

Table A.2 under the heading "ASME FLANGE STRESSES AT OPERATING MOMENT, MOP." In example 1, the value for MOP was determined to be $1.1719 \times 10^7$ in.-lb. To be consistent with the Code calculation in this example [3(a)], we chose IBØND = 0.

Calculated stresses for the tapered-hub flange are shown in Table A.5d. The Code method covers only moment loading. The stresses in Table A.5d for initial moment loading only are the same as those in Table A.2 for operating moment, MOP:

| Stress values from Table A.5d | Stress values from Table A.2 |
|---|---|
| SLLO = 23,411 psi | SH = 23,412 psi |
| STH = 11,173 psi | ST = 11,174 psi |
| SRH = 8,444 psi | SR = 8,444 psi |

The Code method gives stresses at the small end of the hub if the Code factor f is greater than 1.0; otherwise, it gives stresses for the large end of the hub. The Code method calculates radial and tangential stresses on the hub side of the flange only. Usually these are higher than the corresponding stresses on the face side of the flange, but in this example, STH = 11,173 psi is less than STF = -18,482 psi in absolute magnitude. The Code method does not give circumferential stresses in the hub.

Stresses for pressure loading only, temperature loading only, and combined loadings are shown as the 2nd, 3rd, and 4th groups of stresses in Table A.5d. The small values under the heading "CALCULATIONS FOR TEMPERATURE LOADINGS" come from using DELTA = 0.01, since DELTA = 0 is not a permissible input value.

Combined stresses are not the sum of the stresses due to the three individual loads. Rather, the program recognizes that pressure and temperature change the moment from M1 = $9.3433 \times 10^6$ in.-lb to M2 = $7.7814 \times 10^6$ in.-lb in this example* (Table A.5b). The maximum stress

---

*It should be noted that M1 is not the same as the input moment XMOA. The program will accept any value for calculating stresses but, for calculating bolt load changes, it assumes that the moment is equal to W(C-G)/2.

under combined loads (in this example, residual moment and pressure) is SLSO = 33,385 psi. Under initial moment only, the maximum stress is SLLO = 23,411 psi.

Blind and Tapered-Hub Flange Stresses, Example 3(b)

Stresses are shown in Table A.6c and A.6d for blind and tapered-hub flanges, respectively. It can be seen that maximum stresses are quite high for the realistic initial bolt stress of 44,300 psi needed to pass the hydrostatic test pressure of 1080 psi [i.e., SORT = 24,984 psi for the blind flange (Table A.6c) and SLSO = 57,309 psi for the tapered-hub flange (Table A.6d]. Comments on the significance of these high calculated stresses are included later in the discussion of examples 4a and 4b.

Displacements

Tables A.5 and A.6 include, along with stresses, the displacements ZC for the blind flange or ZG, ZC, QFHG, Y0, Y1, and THETA for the tapered-hub flange. One potential application for these displacements is discussed later in connection with examples 4(a) and 4(b).

# IDENTICAL PAIR OF TAPERED-HUB FLANGES, EXAMPLES 4(a) AND 4(b)

## Input Data

The input data for Examples 4(a) and 4(b) are shown in Table A.7. The initial bolt stress of 46,100 psi and corresponding W1 = 6.312 × $10^6$ lb were selected by a preliminary calculation so that W2 would equal $W_c$ at the hydrostatic-test pressure of 1080 psi. The value of W1 = 6.312 × $10^6$ lb leads to initial moment XMOA = W1(C-G)/2 = 2.1500 × $10^7$ in.-lb. Example 4(a) is for hydrostatic test conditions at atmospheric temperature. Example 4(b) is for steady-state operating conditions at the rated pressure of 300 psi and corresponding API-605 temperature of 850°F.

The modulus of elasticity of the flange, bolt, and gasket materials was assumed to be 2.25 × $10^7$ psi at 800°F, as compared with 3.0 × $10^7$ at atmospheric temperature. It is assumed that at steady-state operating conditions there is an external bending moment such that the axial stress in the attached pipe is 7500 psi. This axial stress gives 617 psi as the input value for PBE for example 4(b), as shown below:

$$PBE = 4\ S_b g_0/D_o = 4 \times 7500 \times 1.2343/60 = 617\ \text{psi}\ .$$

## Output Data

### Residual Bolt Loads

The output data for example 4(a) are shown in Table A.8. The output data starts with a printout of all input data. The parameters involved in the bolt-load-change calculations are then printed, followed by residual bolt loads and moments (Table A.8b).

The residual bolt load is given by W2 = 3.585 × $10^6$ lb. The critical bolt load, derived from Eq. (A.2), is $W_c = \pi G_0^2\ p/4 = 3.584 \times 10^6$ lb. Accordingly, the results of example 4(a) indicate that an initial bolt stress of 46,100 psi is sufficient for the joint to pass a hydrostatic test to 1080 psi, albeit with no margin of safety.

Table A.7. Input data for tapered-hub-to-tapered-hub flanged joint, examples[a] 4a and 4b

| Card No. | Variables and numerical values | | | | | | | | Read format |
|---|---|---|---|---|---|---|---|---|---|
| 1 | ITYPE | IBOND | ICODE | MATE | | | | | |
| | 1 | 0 | 0 | 2 | | | | | 4I5 |
| 2 | A | B | t | $g_0$ | $g_1$ | h | C | p | |
| | 73.9375 | 57.5314 | 5.9375 | 1.2343 | 2.7030 | 5.4362 | 69.4375 | 1080. | 8E10.5 |
| | | | | | | | | (300.) | |
| 3 | XMOA | EF | DELTA[b] | YM | G | | | | |
| | 2.1500D+7 | 6. D-6 | .01 | 3. D+7 | 62.625 | | | | 5E10.5 |
| 4 | BSIZE | YB | EB | TB | XGO | XGI | AB | | |
| | 2.25 | 3. D+7 | 6. D-6 | 0 | 65. | 60.25 | 136.92 | | 7E10.5 |
| 5 | VO | YG | EG | TG | FACE | PBE | | | |
| | .0625 | 3. D+6 | 6. D-6 | 0 | 0 | 0 | | | 6E10.5 |
| | | | | | | (617.) | | | |
| 6 | W1 | TF | TFP | YF2 | YFP2 | YB2 | YG2 | | |
| | 6.3120D+6 | 0 | 0 | 3. D+7 | 3. D+7 | 3. D+7 | 3. D+6 | | 7E10.5 |
| | | | | (2.25D+7) | (2.25D+7) | (2.25D+7) | (2.25D+6) | | |

[a]Values in parentheses are for example 4b.

[b]Since DELTA cannot be entered as zero, 0.01 was used as a satisfactorily small value.

Table A.8a. Output data for example 4(a), identical pair of tapered-hub flanges, with initial bolt stress of 46,100 psi

```
FLANGE    FLANGE    FLANGE    PIPE     HUB AT    HUB       BOLT      PRESSURE,
O.D.,A    I.D.,B    THICK.,T  WALL,GO  BASE,G1   LENGTH,H  CIRCLE,C   P
73.93750  57.53140  5.93750   1.23430  2.70300   5.43620   69.43750  1080.000

MOMENT  COEFF. OF   DELTA     MOD. OF  MEAN GASKET ITYPE     IBOND     ICODE     MATE
        THERMAL EXP.          ELASTICITY DIAMETER
2.150D 07 6.000D-06 1.050D-02 3.000D 07 6.263D 01    1         0         0         2


   BSIZE          YB            EB            TB            XGO           XGI           AB
 2.2500D 00    3.0000D 07    6.0000D-06    0.0           6.5000D 01    6.0250D 01    1.3692D 02
   VO             YG            EG            TG            FACE          PBE
 6.2500D-02    3.0000D 06    6.0000D-06    0.0           0.0           0.0
   W1             TP            TPP           YP2           YPP2          YR2           YG2
 6.3120D 06    0.0           0.0           3.0000D 07    3.0000D 07    3.0000D 07    3.0000D 06

 FLANGE JOINT BOLT LOAD CHANGE DUE TO APPLIED LOADS, IDENTICAL PAIR

   FLANGE JOINT SIDE ONE (PRIMED QUANTITIES)

QPHG=  1.1968D-09  QPRG=  8.0422D-06  QTHG=  9.5590D-05   XB =  5.7531D 01     GO=  1.2343D 00      TH  =  5.9375D 00
   YH =  3.0000D 07         YP2 =  3.0000D 07    EP =  6.0000D-06

   FLANGE JOINT SIDE TWO (UNPRIMED QUANTITIES)

QPHG=  1.1968D-09  QPRG=  8.0422D-06  QTHG=  9.5590D-05   XB =  5.7531D 01     GO=  1.2343D 00      TH  =  5.9375D 00
   YH =  3.0000D 07         YP2 =  3.0000D 07    EP =  6.0000D-06

     BOLTING

BOLT LENGTH=  1.4188D 01  BOLT AREA=  1.3692D 02  BOLT CIRCLE=  6.9438D 01
   YB =  3.0000D 07        YB2 =  3.0000D 07    EB =  6.0000D-06

     GASKET

  VO  =  6.2500D-02  XGO =  6.5000D 01  XGI =  6.0250D 01
   YG  =  3.0000D 06        YG2 =  3.0000D 06    EG =  6.0000E-06
```

Table A.8b (continued)

```
        LOADINGS

INITIAL BOLT LOAD=  6.3120D 06  BOLT TEMP.=  0.0           FLANGE ONE TEMP.=  0.0           FLANGE TWO TEMP.=  0.0
GASKET TEMP.=  0.0           DELTA=  1.0000D-02   DELTAP=  1.0000D-02  PRESSURE=  1.0000D 03

   RESIDUAL BOLT LOADS AFTER THERMAL-PRESSURE LOADS

AXIAL THERMAL,W2A=  6.3120D 06  MOMENT SHIFT,W2B=  5.0760D 06

TOTAL PRESSURE,W2C=  3.5852D 06   DELTA THERMAL,W2D=  6.3118D 06

COMBINED,W2=  3.5850D 06

W1-W2A=  0.0          W1-W2B=  1.2360D 06  W1-W2C=  2.7268D 06  W1-W2D=  1.6400D 02  W1-W2=   2.7270D 06

W2A/W1=  1.0000D 00  W2B/W1=  8.0418D-01  W2C/W1=  5.6799D-01  W2D/W1=  9.9997D-01  W2/W1=  5.6796D-01

    INITIAL AND RESIDUAL MOMENTS AFTER THERMAL PRESSURE LOADS.

M1=  2.1500D 07  M2A=  2.1500D 07  M2B=  2.3369D 07  M2C=  1.8291D 07  M2D=  2.1500D 07  M2=  1.8290D 07

M2BP=  2.3369D 07  M2CP=  1.8291D 07  M2P=  1.8290D 07
```

Table A.8c (continued)

```
        TAPERED HUB FLANGE
   CALCULATIONS FOR MOMENT LOADING

SLSO=  4.2273D 04  SLSI= -4.2273D 04  SCSO=  3.6258D 04  SCSI=  1.0094D 04
SLLO=  4.2951D 04  SLLI= -4.2951D 04  SCLO=  1.2005D 04  SCLI= -1.2005D 04
 STH=  2.0499D 04   STP= -3.3907D 04   SBH=  1.5492D 04   SBP= -1.2197D 04
ZG= -1.9110D-02  ZC= -4.4050D-02  QPHG=  2.5732D-02  YO=  2.2606D-02  Y1=  1.6524D-10  THETA= -7.4440D-03
   CALCULATIONS FOR PRESSURE LOADING

SLSO=  2.1290D 04  SLSI=  3.0794D 03  SCSO=  2.1596D 04  SCSI=  1.6373D 04
SLLO=  2.7967D 03  SLLI=  8.6968D 03  SCLO=  0.3002D 02  SCLI=  2.6090D 03
 STH=  1.3997D 04   STP= -1.6503D 03   SBH= -3.4397D 03   SBP=  4.0556D 02
ZG= -6.7671D-03  ZC= -1.5453D-02  QPHG=  0.6056D-03  YO=  1.6504D-02  Y1=  6.0715D-10  THETA= -2.7132D-03
   CALCULATIONS FOR TEMPERATURE LOADING

SLSO=  1.2220D 00  SLSI= -1.2220D 00  SCSO=  1.0649D-01  SCSI= -6.2722D-01
SLLO= -1.3977D-01  SLLI=  1.3977D-01  SCLO= -1.0419D 00  SCLI= -1.7501D 00
 STH=  1.1007D 00   STP= -6.1330D-01   SBH= -2.7247D-61   SBP=  1.5072D-01
ZG= -7.4476D-07  ZC= -1.7007D-06  QPHG=  9.5590D-07  YO= -2.4965D-07  Y1= -1.7259D-06  THETA= -2.9060D-07
  CALCULATIONS FOR COMBINED LOADING,M2 OR M2P FOR ITYPE=1 OR 2, M2 FOR ITYPE=3,  =   1.0290D 07

SLSO=  5.7253D 04  SLSI= -3.2003D 04  SCSO=  5.2441D 04  SCSI=  2.5640D 04
SLLO=  3.9335D 04  SLLI= -2.7041D 04  SCLO=  1.1759D 04  SCLI= -0.3541D 03
 STH=  3.1436D 04   STP= -3.0496D 04   SBH=  9.7306D 03   SBP= -9.9690D 03
ZG= -2.3032D-02  ZC= -5.3600D-02  QPHG=  3.0576D-02  YO=  3.3014D-02  Y1= -1.7259D-06  THETA= -9.0466D-03
```

The output data for example 4(b) are shown in Table A.9, which is identical in format to Table A.8 for example 4(a). The residual bolt load for example 4(b) is given by W2 = $3.2718 \times 10^6$ lb. The pressure is lower in example 4(b) than in 4(a), but there is a modulus-of-elasticity decrease which, by itself, makes W2 = W1 $\times\ 2.25 \times 10^7/(3 \times 10^7)$ and makes the effect of the equivalent pressure correspond to the external moment PBE. We can check to see if the residual bolt load is sufficient to prevent leakage by an extension of the concept of the initial bolt load $W_c$, which was discussed in the previous section. We made the conservative assumption that the maximum tensile stress due to the external bending moment (which exists only at one point on the pipe circumference) acts around the complete circumference of the pipe. The value of $W_c$, the critical bolt load to prevent gross leakage, is then the sum of Eq. (A.2) and the axial load due to the bending moment; thus

$$W_c = \frac{\pi}{4} G_0^2\, p + A_p S_b \ , \qquad \text{(A.5)}$$

where

$A_p = \pi(B + g_0)\, g_0$ = cross-sectional area of attached pipe, and

$S_b$ = axial stress in attached pipe due to an external moment.

For example 4(b), Eq. (A.5) gives:

$$W_c = \left(\frac{\pi}{4} \times 65^2 \times 300\right) + (\pi \times 58.7657 \times 1.2343 \times 7500)$$

$$= 2.7045 \times 10^6 \text{ lb} \ .$$

Because W2 = $3.2718 \times 10^6$ lb is greater than $W_c = 2.7045 \times 10^6$ lb, the results indicate that the flanged joint with an initial bolt stress of 46,100 psi can carry, at least for a short time at 850°F, an external moment giving both an axial bending stress of 7500 psi in the attached pipe of 1.2343-in. wall thickness and an internal pressure of 300 psi.

At 850°F, the carbon-steel flanges and bolts would be expected to undergo significant relaxation due to creep in the flanges and bolts,

Table A.9a. Output data for example 4(b), identical pair of tapered-hub flanges, steady-state operation at 300 psi and 850°F

```
FLANGE    FLANGE    FLANGE    PIPE      HUB AT    HUB       BOLT      PRESSURE,
O.D.,A    I.D.,B    THICK.,T  WALL,G0   BASE,G1   LENGTH,H  CIRCLE,C   P
73.93750  57.53140  5.93750   1.23430   2.70300   5.43620   69.43750  300.000

MOMENT  COEFF. OF  DELTA     MOD. OF    HEAD GASKET  ITYPE   IBOND   ICODE   MATE
        THERMAL EXP.         ELASTICITY DIAMETER
2.150D 07 6.000D-06 1.000D-02 3.000D 07 6.263D 01    1       0       0       2

    BSIZE        YB           EB           TB           EGO          EGI          AB
  2.2500D 00   3.0000D 07   6.0000D-06   0.0          6.5000D 01   6.0250D 01   1.3692D 02
    VO           YG           EG           TG           FACE         PBE
  6.2500D-02   3.0000D 06   6.0000D-06   0.0          0.0          6.1700D 02
    W1           TP           TPP          YP2          YPP2         YB2          YG2
  6.3120D 06   0.0          0.0          2.2500D 07   2.2500D 07   2.2500D 07   2.2500D 07
```

FLANGE JOINT BOLT LOAD CHANGE DUE TO APPLIED LOADS, IDENTICAL PAIR

FLANGE JOINT SIDE ONE (PRIMED QUANTITIES)

```
QPMC=  1.1960D-09  QPMG=  8.0422D-06  QTMG=  9.5590D-05  HD =  5.7531D 01   GO=  1.2343D 00   TH  =  5.9375D 00
    YH =  3.0000D 07        YP2 =  2.2500D 07   EP =  6.0000D-06
```

FLANGE JOINT SIDE TWO (UNPRIMED QUANTITIES)

```
QPMG=  1.1960D-09  QPMG=  8.0422D-06  QTMG=  9.5590D-05  HD =  5.7531D 01   GO=  1.2343D 00   TH  =  5.9375D 00
    YH =  3.0000D 07        YP2 =  2.2500D 07   EP =  6.0000D-06
```

BOLTING

```
BOLT LENGTH=  1.4180D 01  BOLT AREA=  1.3692D 02  BOLT CIRCLE=  6.9430D 01
    YB =  3.0000D 07        YB2 =  2.2500D 07   EB =  6.0000D-06
```

GASKET

```
 VO  =  6.2500D-02  EGO =  6.5000D 01  EGI =  6.0250D 01
   YG  =  3.0000D 06        YG2 =  2.2500D 07   EG =  6.0000D-06
```

Table A.9b (continued)

```
        LOADINGS

INITIAL BOLT LOAD=  6.3120D 06  BOLT TEMP.=  0.0          FLANGE ONE TEMP.=  0.0          FLANGE TWO TEMP.=  0.0
GASKET TEMP.=  0.0           DELTA=  1.0000D-02   DELTAF=  1.0000D-02  PRESSURE=  1.0000D 02

   RESIDUAL BOLT LOADS AFTER THERMAL-PRESSURE LOADS

AXIAL THERMAL,W2A=  6.3120D 06  MOMENT SHIFT,W2B=  5.2625D 06

TOTAL PRESSURE,W2C=  4.8484D 06   DELTA THERMAL,W2D=  6.3118D 06

COMBINED,W2=  3.2718D 06

W1-W2A=  0.0          W1-W2B=  1.0495D 06  W1-W2C=  1.4636D 06  W1-W2D=  1.6408D 02  W1-W2=   3.0402D 06

W2A/W1=  1.0000D 00  W2B/W1=  8.3374D-01  W2C/W1=  7.6813D-01  W2D/W1=  9.9997D-01  W2/W1=  5.1835D-01

    INITIAL AND RESIDUAL MOMENTS AFTER THERMAL PRESSURE LOADS.

M1=  2.1500D 07  M2A=  2.1500D 07  M2B=  1.9614D 07  M2C=  1.8203D 07  M2D=  2.1500D 07  M2=  1.2833D 07

M2BP=  1.9614D 07  M2CP=  1.8203D 07  M2P=  1.2833D 07
```

Table A.9c (continued)

```
        TAPERED HUB FLANGE
   CALCULATIONS FOR MOMENT LOADING

SLSO=  4.2273D 04  SLSI= -4.2273D 04  SCSO=  3.6258D 04  SCSI=  1.0894D 04
SLLO=  4.2951D 04  SLLI= -4.2951D 04  SCLO=  1.2885D 04  SCLI= -1.2885D 04
 STN=  2.0499D 04   STP= -3.3907D 04   SRN=  1.5492D 04   SRP= -1.2197D 04
ZG= -1.9118D-02  ZC= -4.4850D-02  QPMG=  2.5732D-02  YO=  2.2606D-02  Y1=  1.6524D-18  THETA= -7.4448D-01
   CALCULATIONS FOR PRESSURE LOADING

SLSO=  5.9140D 03  SLSI=  1.0776D 03  SCSO=  5.9990D 03  SCSI=  4.5481D 03
SLLO=  7.7687D 02  SLLI=  2.4158D 03  SCLO=  2.3336D 02  SCLI=  7.2471D 02
 STN=  3.8880D 03   STP= -4.5841D 02   SRN= -9.5549D 02   SRP=  1.1266D 02
ZG= -1.8798D-03  ZC= -4.2924D-03  QPMG=  2.4127D-03  YO=  4.0510D-03  Y1=  8.6736D-19  THETA= -7.5365D-04
   CALCULATIONS FOR TEMPERATURE LOADING

SLSO=  1.2228D 00  SLSI= -1.2228D 00  SCSO=  1.0649D-01  SCSI= -6.2722D-01
SLLO= -1.3977D-01  SLLI=  1.3977D-01  SCLO= -1.8419D 00  SCLI= -1.7581D 00
 STN=  1.1087D 00   STP= -6.1330D-01   SRN= -2.7247D-01   SRP=  1.5072D-01
ZG= -7.4476D-07  ZC= -1.7007D-06  QPMG=  9.5590D-07  YO= -2.4965D-07  Y1= -1.7259D-06  THETA= -2.9860D-07
  CALCULATIONS FOR COMBINED LOADING,M2 OR M2P FOR ITYPE=1 OR 2, M2 FOR ITYPE=3,  =   1.2813D 07

SLSO=  3.1147D 04  SLSI= -2.4156D 04  SCSO=  2.7641D 04  SCSI=  1.1050D 04
SLLO=  2.6411D 04  SLLI= -2.3221D 04  SCLO=  7.9222D 03  SCLI= -6.9680D 03
 STN=  1.6125D 04   STP= -2.0698D 04   SRN=  8.2910D 03   SRP= -7.1471D 03
ZG= -1.3292D-02  ZC= -3.1064D-02  QPMG=  1.7772D-02  YO=  1.7544D-02  Y1= -1.7255D-06  THETA= -5.1976D-03
```

particularly with the high bolt stresses and flange stresses involved in example 4(b). For long-term service (many years) at 850°F, one might expect the flanges and/or bolts to creep so that a residual bolt stress of around 20,000 psi would exist, at which time $W2 = 2000 \times 136.92 = 2.7384 \times 10^6$ lb. Because this is larger than $W_c = 2.7045 \times 10^6$ lb obtained from Eq. (A.5), indications are that the flanged joint could still carry the external moment and pressure, albeit with almost no margin of safety.

It should be noted that, if bolts relax in high-temperature service, then the bolt load does not return to its initial value upon returning to initial conditions. The permanent loss in bolt load would be $W2 - S_{br}A_b$, where $S_{br}$ = relaxed bolt stress, assumed here to be 20,000 psi. The permanent loss in bolt load, in this example, is $3.2718 \times 10^6 - 20,000 \times 136.92 = 533,400$ lb. The load is theoretically not sufficient to pass a hydrotest of 1080 psi, but it is extremely unlikely such a hydrotest would be required for a system operating at 500 psi and 850°F.

## Flange Stresses

Tables A.8c and A.9c show the flange stresses for examples 4(a) and 4(b), respectively. The maximum calculated stress occurs in example 4(a) where SLSO = 57,253 psi for combined loadings. Note that this is not the sum of the stresses due to initial moment loading only plus pressure loading only (first two groups of stresses), but rather it is the stress due to the moment as changed by pressure, $M2 = M2P = 1.829 \times 10^7$ in.-lb, plus the stress due to pressure only.

The question arises as to whether the flanges in the flanged joint are strong enough to pass the hydrostatic test. To pursue this question, it is appropriate to tabulate the tangential and radial stresses at initial and pressurized conditions:

| Condition | STH | STF | SRH | SRF |
|---|---|---|---|---|
| Initial | 20,499 | -33,907 | 15,492 | -12,197 |
| Pressurized | 31,436 | -30,496 | 9,739 | -9,970 |

It should be noted that the stresses are, in large part, bending stresses. Before large plastic deformations occur, these stresses must reach about $1.5S_y$, where $S_y$ is the yield strength of the flange material. Further, high stresses in the hub will not lead to large plastic deformations if there is reserve strength in the flange ring as indicated by relatively low tangential and radial stresses. If the capability for calculating these stresses has been attained, the next logical step is to conduct an extensive study to develop suitable design criteria for stress limits in flanged joints. Until such a study is conducted, however, the following limits are suggested as appropriate for stresses under hydrostatic test conditions:

| Stress | Limit |
|---|---|
| Longitudinal hub stresses | $\leq 1.5S_y$ |
| Radial stress or tangential stress | $\leq S_y$ |
| Averages of radial or tangential stress and longitudinal hub stress | $\leq S_y$ |

The above criterion makes the average of SLSO and STH under pressurized conditions [i.e., $1/2(5.7253 \times 10^4 + 3.1436 \times 10^4) = 44{,}344$ psi] the controlling stress and infers that the flanged joint is acceptable, provided the flange-material yield strength is not less than 44,344 psi.

## Displacements

In tightening the bolts to 46,100 psi, the question arises as to whether the flanges will rotate so that contact occurs on the outer edge. Table A.8c shows values of THETA, the rotation of the ring at the mean radius of the pipe wall. An estimate* of the displacement of the ring edge with respect to the gasket centerline can be obtained by

---

*The deformation of the ring is not exactly linear across the ring, but in this example it is sufficiently close to linear.

multiplying THETA by (A-G)/2, the radial distance between the ring edge and gasket centerline. In example 4(a), A = 75.9375, G = 62.625, and THETA = $-9.0466 \times 10^{-3}$ under combined loading; the minus sign means that the rotation is such that clearance is reduced at the outer edge. The displacement of A with respect to G is $9.0466 \times 10^{-3} \times (75.9375 - 62.625)/2 = 0.0512$ in. Because API-605 flanges have 1/16-in. raised faces, the outer edges of the flanges will not contact each other. The clearance will then be $(0.0625 - 0.0512) \div 2 = 0.0056$ in. plus the thickness of the gasket.

## COMPUTER TIME

The six examples discussed in this appendix were run on Battelle's CDC 6400 computer and also on ORNL's IBM 360/91. The IBM FORTRAN source deck (converted to double precision for use on the IBM machine) has 1583 cards. The total length of the program is 80K bytes (10,240 actual words), and it needs no auxiliary storage devices except standard read and write units. The program requires 270K bytes for compilation and has a compilation time of 19.4 sec. The total execution time for the six examples was 1.15 sec.

# APPENDIX B

## FLOWCHARTS AND LISTING OF COMPUTER PROGRAM FLANGE AND ATTENDANT SUBROUTINES

# APPENDIX B

CONTENTS

ORNL-DWG 75-4300

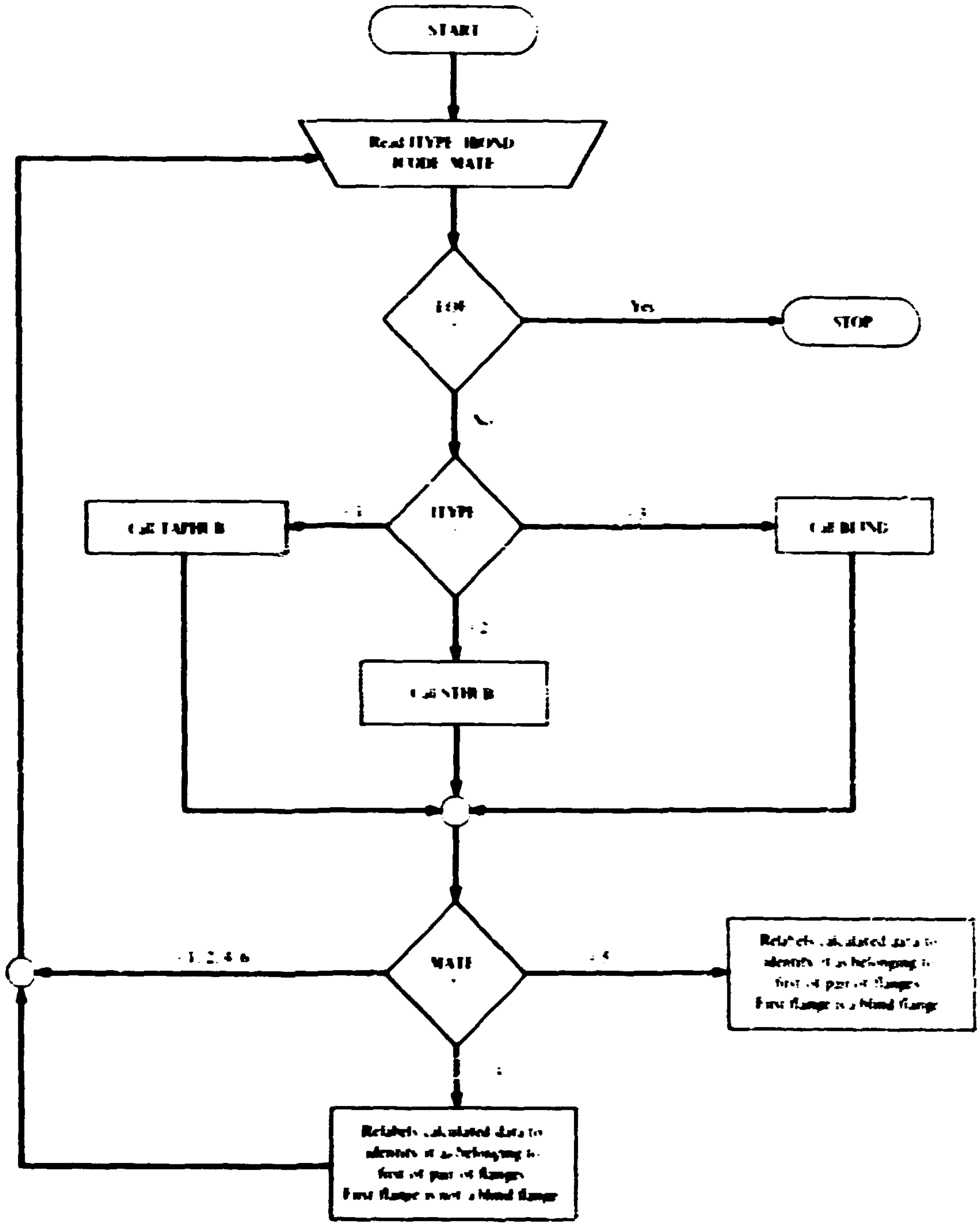


Fig. B.1. Program FLANGE.

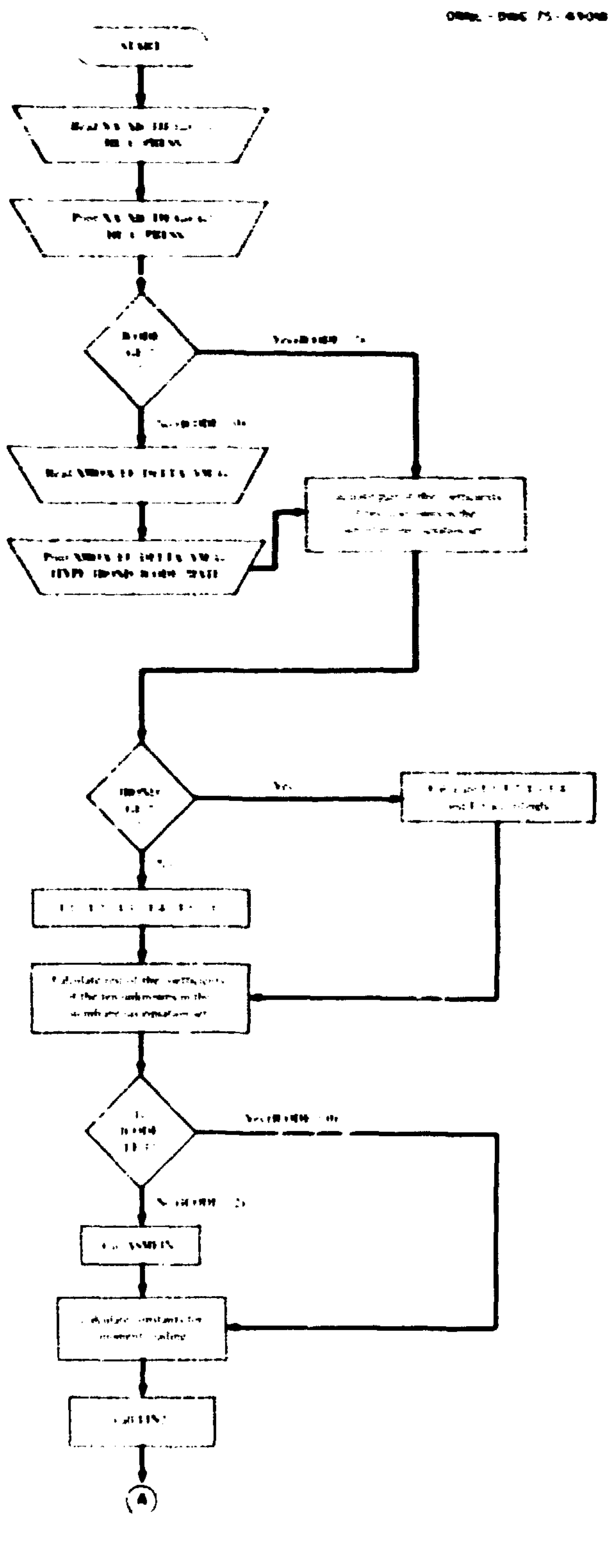

Fig. B.2. Subroutine TAPHUB (Part 1).

ORNL-DWG 75-43020

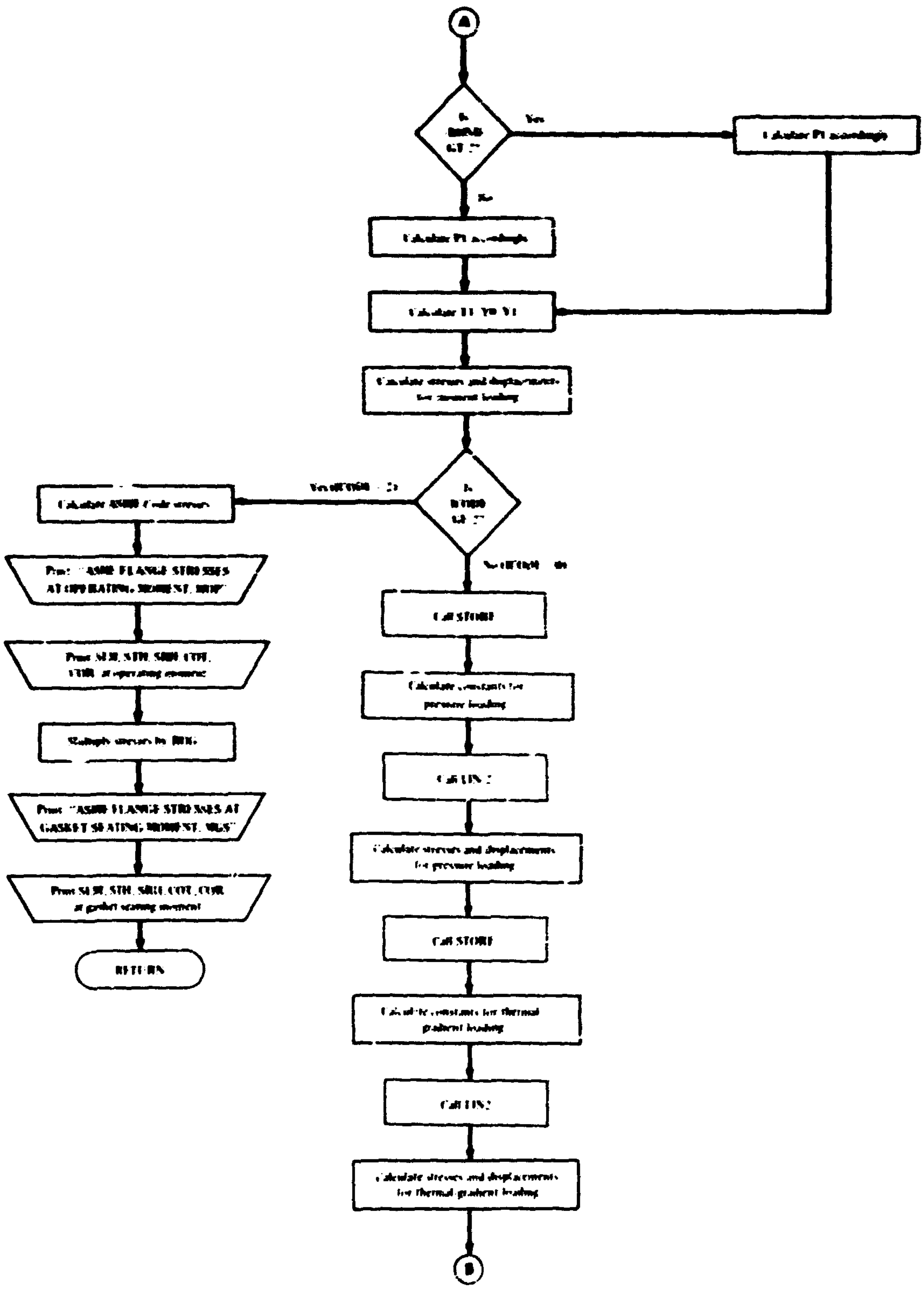


Fig. B.2. Subroutine TAPHUB (Part 2).

ORNL-DWG 75-4303R

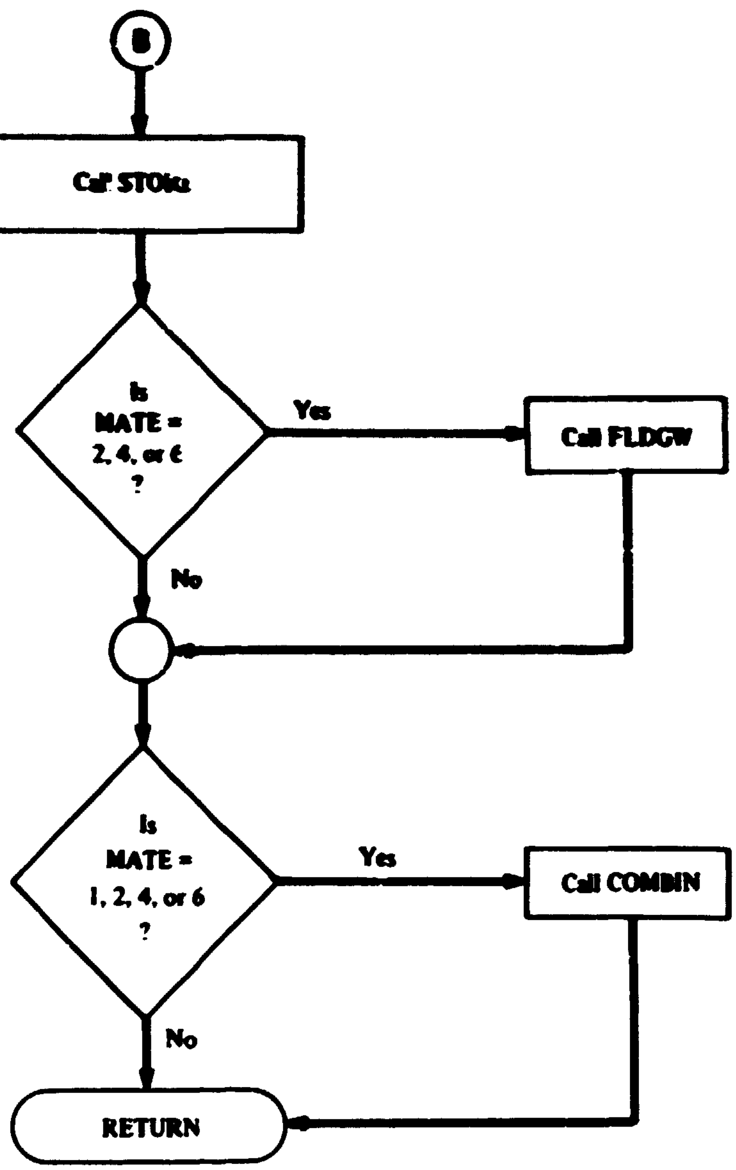


Fig. B.2. Subroutine TAPHUB (Part 3).

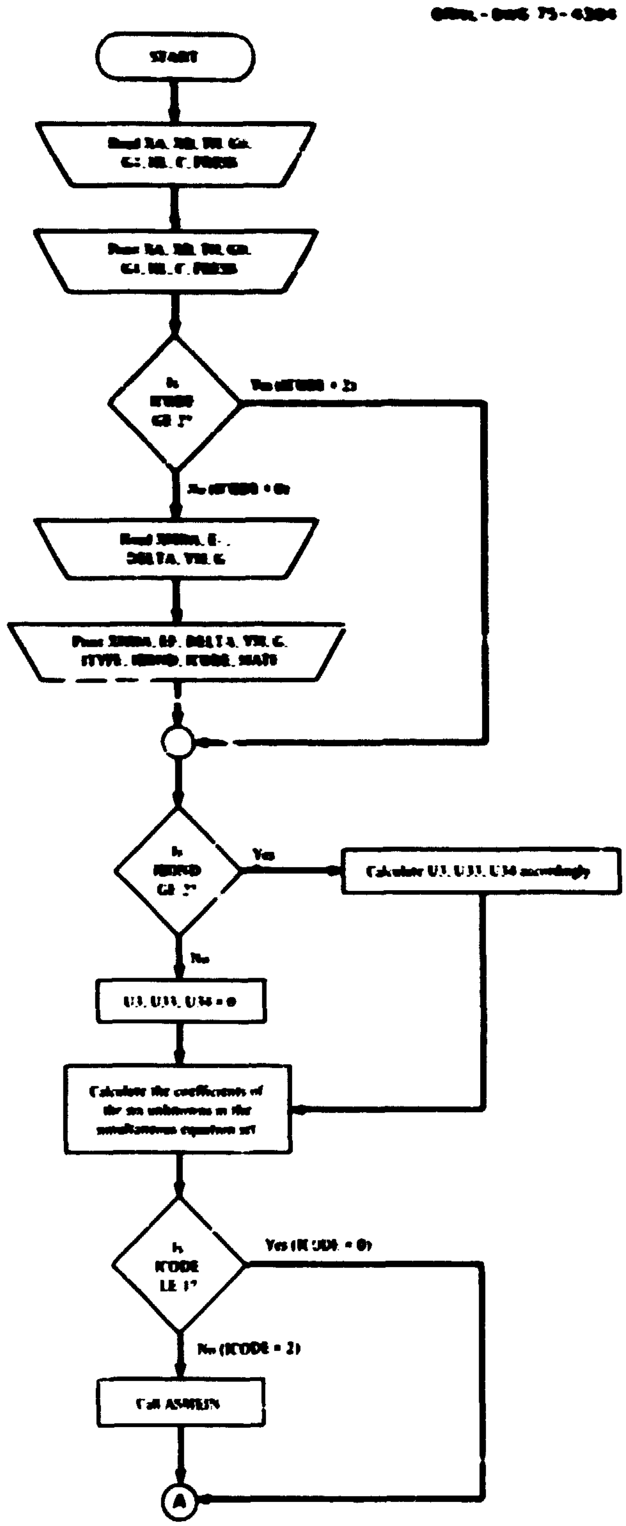


Fig. B.3. Subroutine S"HUB (Part 1).

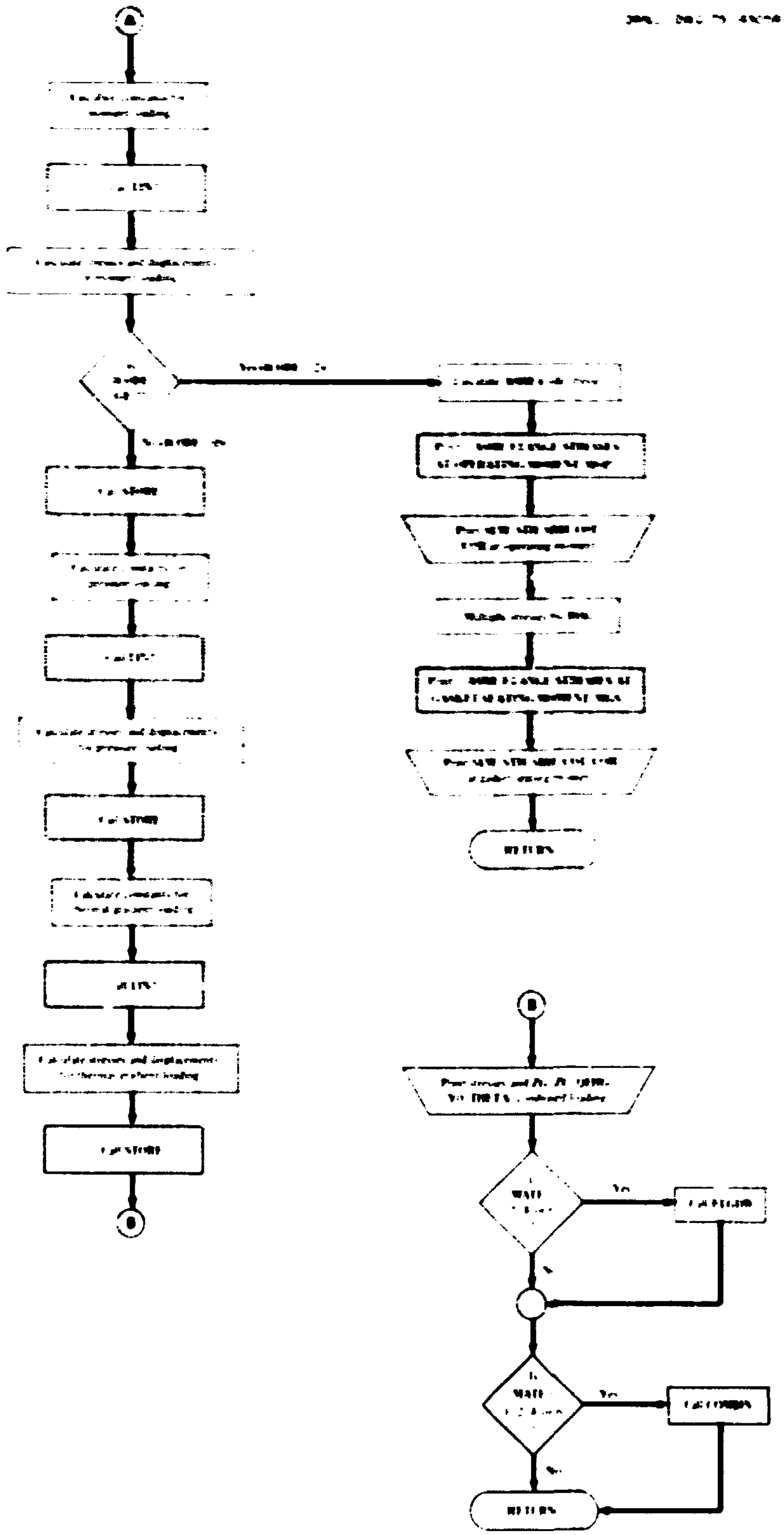


Fig. B.3. Subroutine STHUB (Part 2).

ORNL-DWG 75-4306R

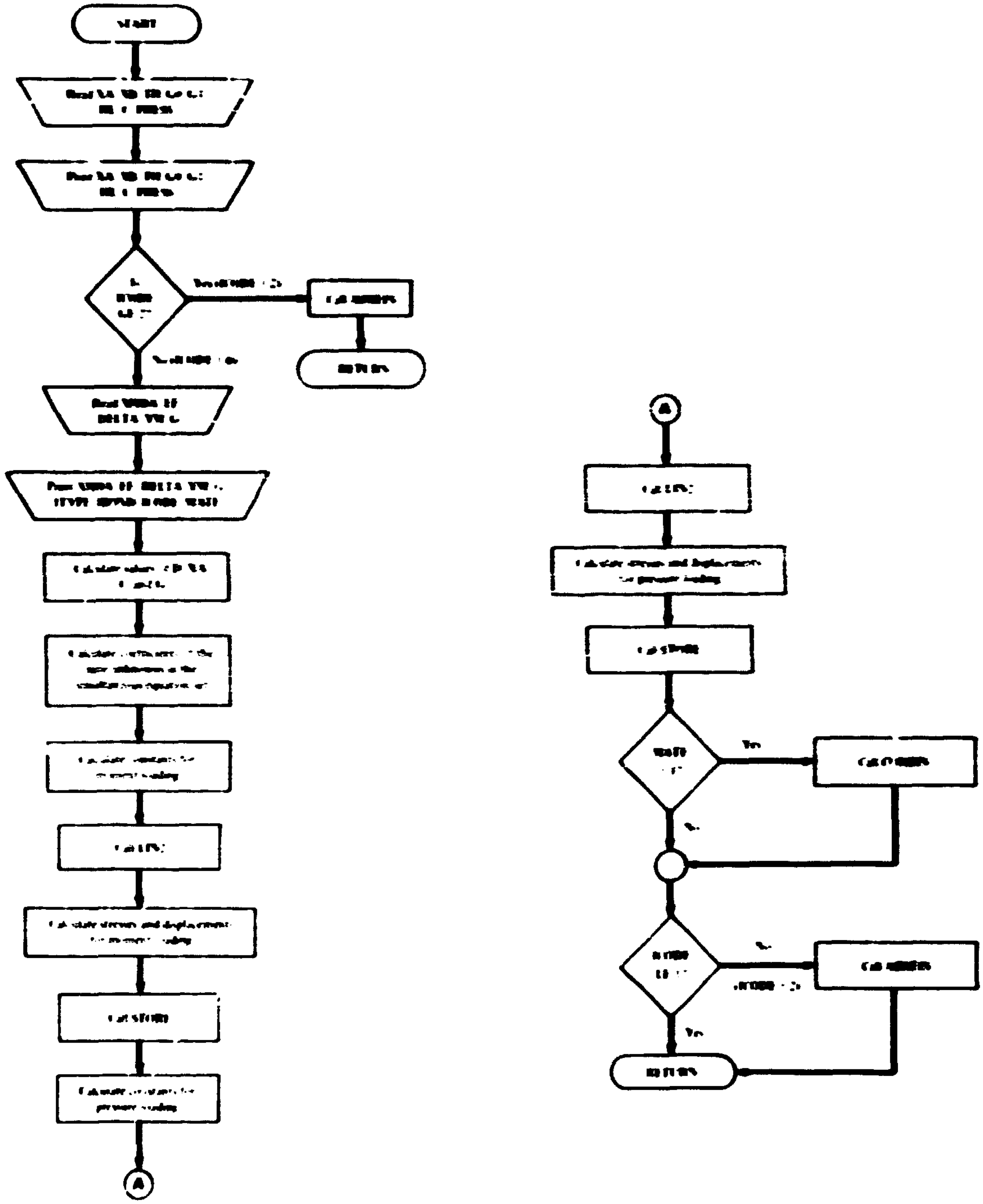

Fig. B.4. Subroutine BLIND.

ORNL-DWG 75-4307

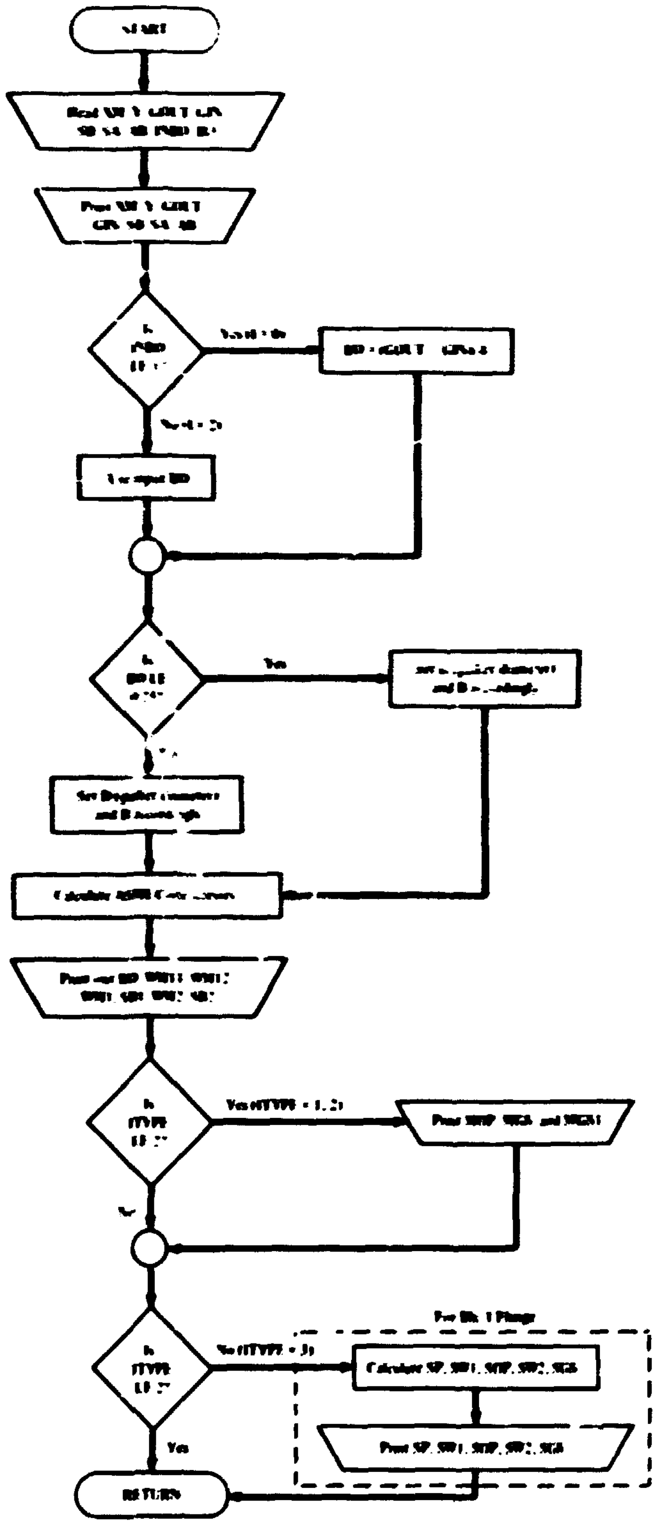


Fig. B.5. Subroutine ASMEIN.

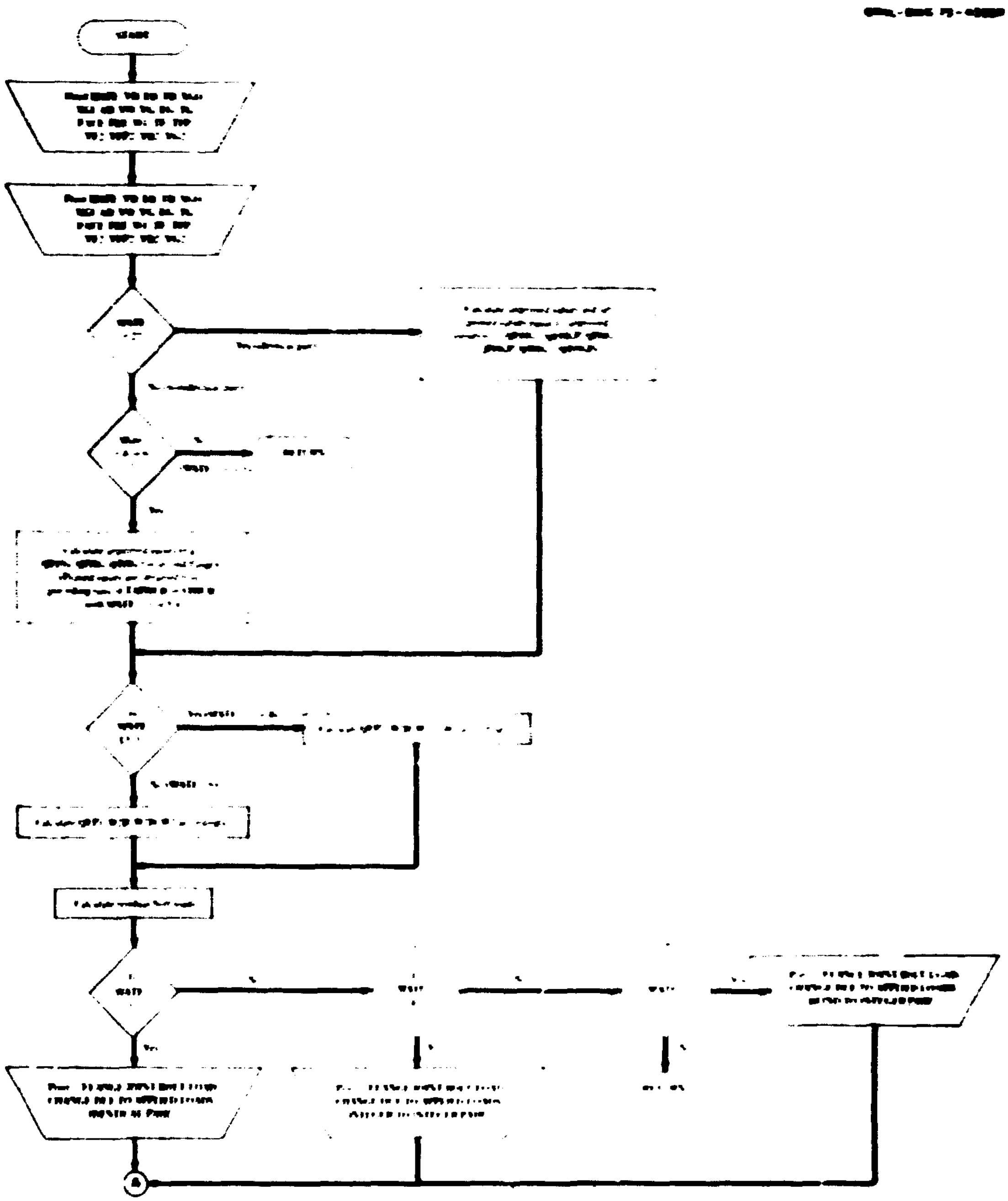

Fig. B.6. Subroutine FLGDW (Part 1).

ORNL-DWG 75-4309R

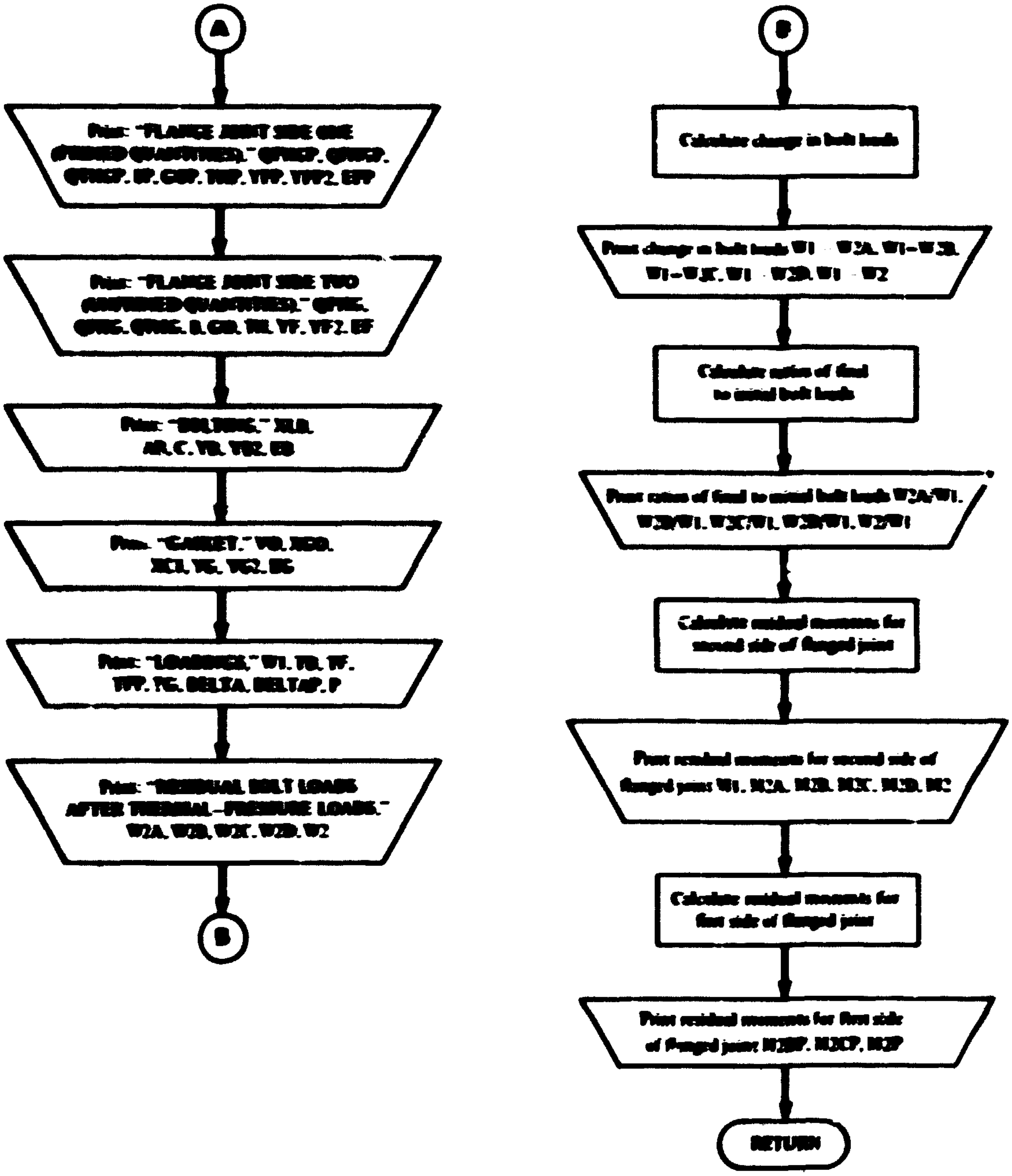


Fig. B.6. Subroutine FLGDW (Part 2).

ORNL-DWG 75-14004

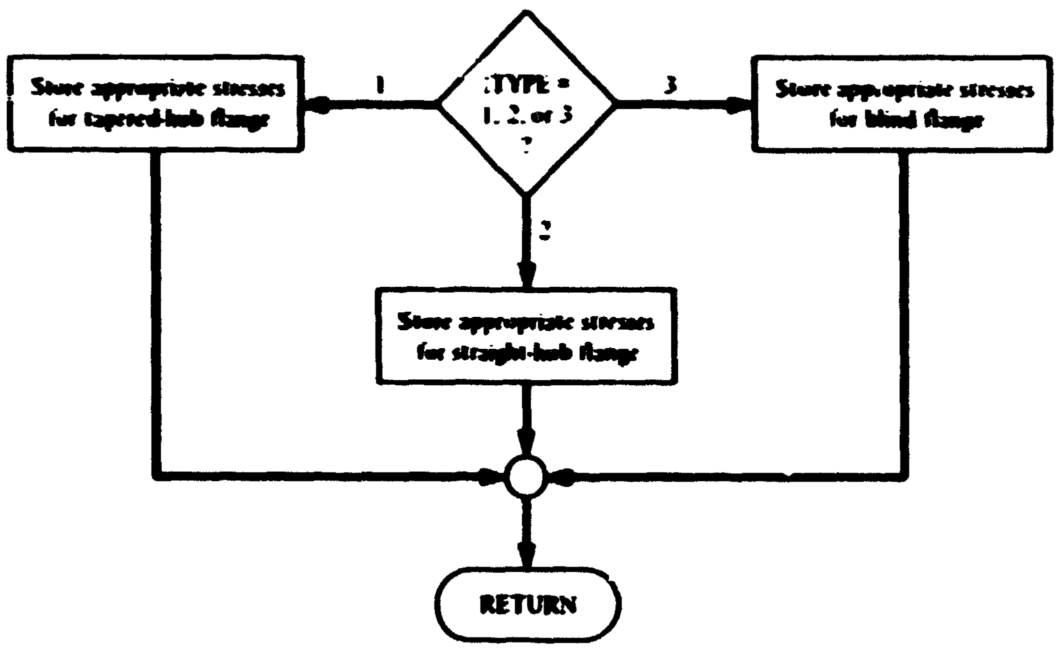


Fig. B.7. Subroutine STORE.

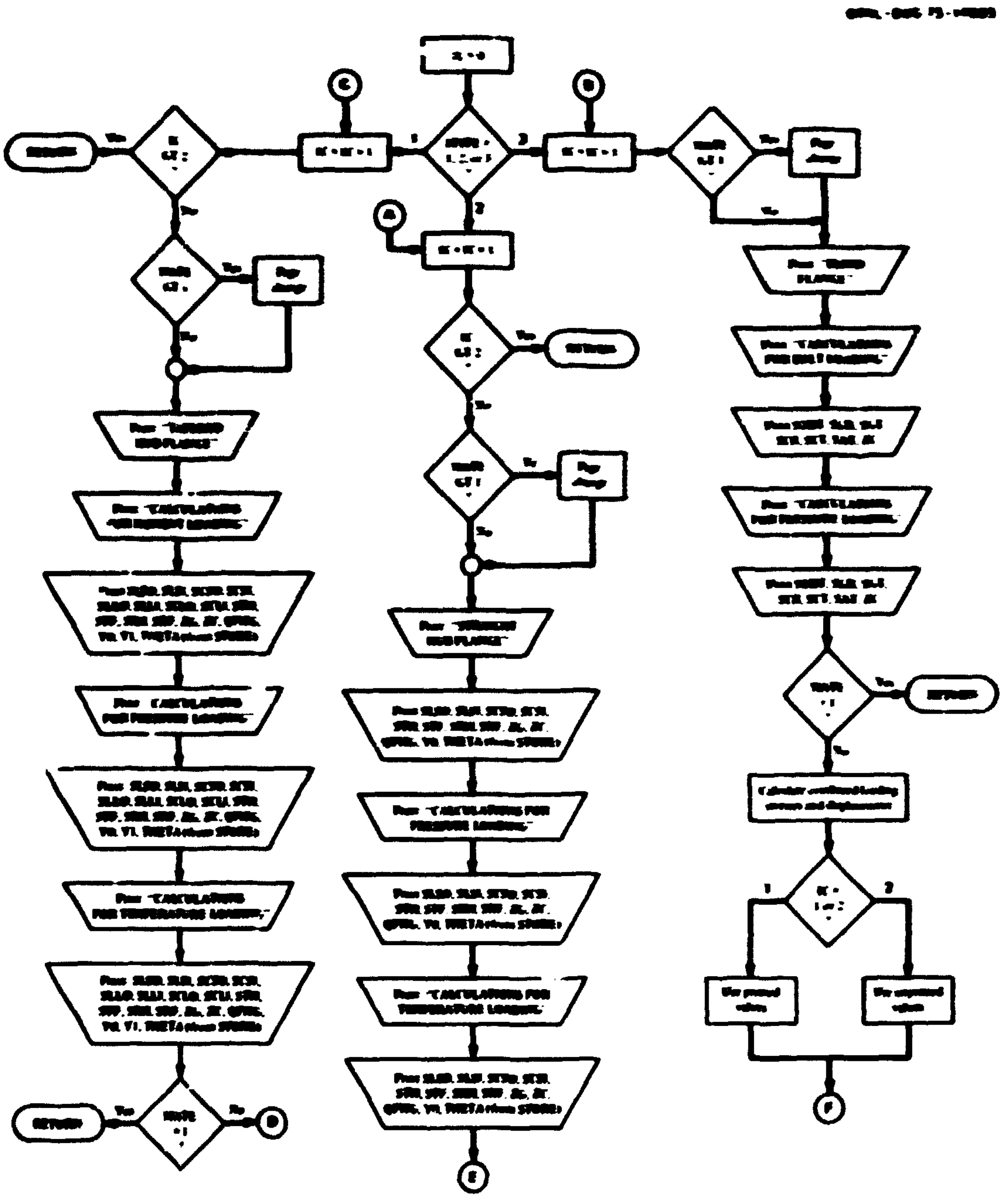

Fig. B.8. Subroutine COMBIN (Part 1).

ORNL DWG 75 14001

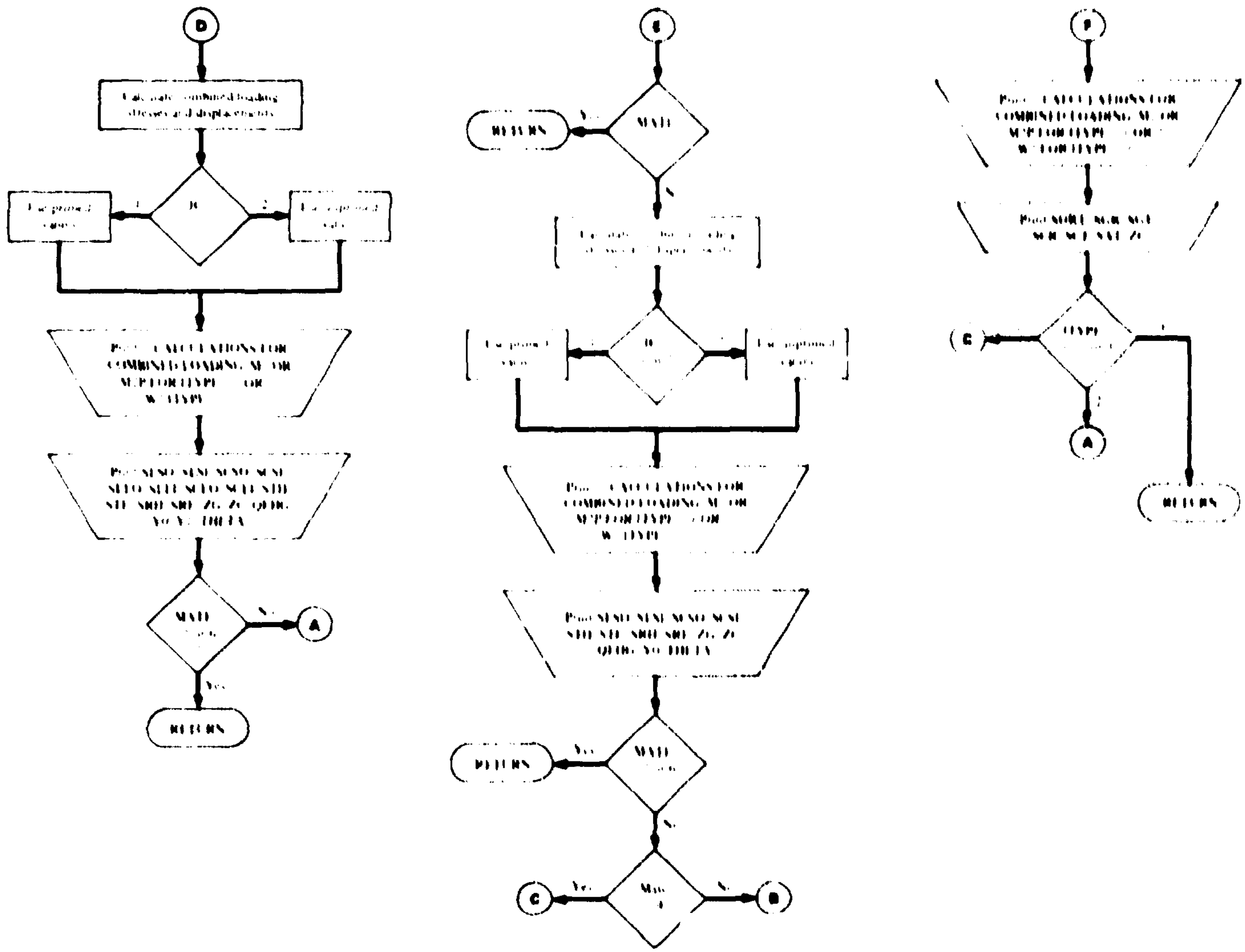


Fig. B.8. Subroutine COMBIN (Part 2).

## LISTING OF PROGRAM FLANGE AND ATTENDANT SUBROUTINES

```
COMMON/ [illegible]                                               
        [illegible]
C      PROGRAM FLANGE [illegible]                                FLA     1
C      [illegible]                                               FLA     2
C      [illegible]                                               [illegible]
C      [illegible]                                               FLANGE
C ** [illegible]
       [illegible]                                               [illegible]
       [illegible]                                               FLA     3
       [illegible]                                               FLA    [illegible]
       [illegible]                                               FLA     [illegible]
       [illegible]                                               FLA     [illegible]
       [illegible]                                               FLA     6
       [illegible]                                               FLA    [illegible]
       [illegible]                                               FLA    [illegible]
       [illegible]                                               FLA    [illegible]
C
C      ITYPE = 1   INTEGRAL HUB                                  FLA     7
C      ITYPE = 2   STRAIGHT HUB                                  FLA     8
C      ITYPE = 3   BLIND                                         FLA     9
C      [illegible]                                               FLA    10
C      [illegible]                                               FLA    11
C      [illegible]                                               FLA    12
C      [illegible]                                               FLA    13
C      [illegible]                                               FLA    14
C      [illegible]                                               FLA    15
C      [illegible] CALCULATES LOAD CHANGE [illegible]            FLA    16
C      [illegible] CALCULATES LOAD CHANGE [illegible]            FLA    17
C      [illegible] CALCULATES LOAD CHANGE [illegible]            FLA    18
C      [illegible] CALCULATES LOAD CHANGE [illegible]            FLA    19
C      [illegible] CALCULATES LOAD CHANGE [illegible]            FLA    20

C      [illegible]                                               FLA   [illegible]
C    1 [illegible]                                               FLA    22
C      IF [illegible]                                            FLA    23
     2 IT2=ITYPE
     1 [illegible]                                               [illegible]
       IF (ITYPE-2) 3,4,5                                        FLA    24
     3 CALL [illegible]                                          FLA    25
       GO TO 6                                                   FLA    26
     4 CALL [illegible]                                          FLA    27
       GO TO 6                                                   FLA    28
     5 CALL [illegible]                                          FLA    29
       GO TO 6                                                   FLA    30
     6 GO TO [illegible]                                         FLA    31
     7 GO TO 1                                                   FLA    32
     8 [illegible]                                               FLA    33
       [illegible]                                               FLA    34
       [illegible]                                               FLA    35
       [illegible]                                               FLA    36
       [illegible]                                               FLA    37
       [illegible]                                               FLA    38
       [illegible]                                               FLA    39
       [illegible]                                               FLA    40
       [illegible]                                               FLA    41
       [illegible]                                               FLA   [illegible]
       GO TO 1                                                   FLA    42
     9 [illegible]                                               FLA    43
       [illegible]                                               FLA    44
       [illegible]                                               FLA    45
       [illegible]                                               FLA    46
       [illegible]                                               FLA    47
       [illegible]                                               FLA    48
       [illegible]                                               FLA    49
       [illegible]                                               FLA    50
```

```
      [illegible]                                                  [illegible]
      [illegible]                                                  [illegible]
      [illegible]                                                  [illegible]
   1. [illegible]                                                  [illegible]
C                                                                  [illegible]
   11 FORMAT ([illegible])                                         [illegible]
   1. FORMAT ([illegible])                                         [illegible]
      END                                                          [illegible]
```

```
      SUBROUTINE TAP[illegible]                                    TAP   2
C     THIS CALCULATION IS FOR [illegible]                          TAP   4
      IMPLICIT REAL*8 (A-H,O-Z)                                    [illegible]
      DIMENSION A(1[illegible]), [illegible]                       TAP   6
      DIMENSION [illegible]                                        TAP  7A
      COMMON [illegible]                                           TAP   [illegible]
     1[illegible]                                                  TAP  1[illegible]
     2[illegible]                                                  TAP  1[illegible]
     3[illegible]                                                  TAP  1[illegible]
     4[illegible]                                                  TAP  1[illegible]
     5[illegible]                                                  TAP  1[illegible]
      DATA [illegible]
    1 READ 4[illegible], XA,XB,[illegible]                         TAP  14
      PRINT 47                                                     TAP  16
      PRINT 5[illegible], XA,XB,[illegible]                        TAP  18
      [illegible]1.                                                TAP  20
      YY=1.                                                        TAP  22
      IF ([illegible]) GO TO 2                                     TAP  24
      READ 51, [illegible]                                         TAP  26
      PRINT 5[illegible]                                           TAP  28
      AL=[illegible]                                               TAP  30
      PRINT [illegible]                                            TAP  32
    2 [illegible] = [illegible]/[illegible](X[illegible]*G0)       TAP 34A
      XA=XA/2.                                                     TAP  36
      XB=XB/2.                                                     TAP  38
      [illegible]/2.                                               TAP  40
      [illegible]/2.                                               TAP  42
      [illegible]                                                  TAP  44
      ALPHA=[illegible]-1                                          TAP  46
      GAMMA = (1[illegible]**0.25)*[illegible]                     TAP 48A
      PHIO=1./ALPHA                                                TAP  50
      PHI1=PHO/ALPHA                                               TAP  52
      [illegible]TAO=2.*GAMMA/ALPHA                                TAP  54
      [illegible]TA1=(PHI**.5)*[illegible]TAO                      TAP  56
      YK=XA/X[illegible]                                           TAP  58
      J=1                                                          TAP  60
      X=[illegible]                                                TAP  62
      [illegible]=([illegible]*X[illegible]/(YY*G0))*[illegible]   TAP  64
    3 CONTINUE                                                     TAP  66
      IF (X-10.0) 4,4,5                                            TAP  68
    4 T=X/10.0                                                     TAP  70
      [illegible] = [illegible](X/2.0)                             TAP 72A
      T2=T*T                                                       TAP  74
      T3=T2*T                                                      TAP  76
      T4=T3*T                                                      TAP  78
      T8=T4*T4                                                     TAP  80
      T12=T8*T4                                                    TAP  82
      T1[illegible]=T1[illegible]*T4                               TAP  84
      T20=T16*T4                                                   TAP  86
```

```
      T24=T20*T4                                                        TAP   88
      T28=T24*T4                                                        TAP   90
      T32=T28*T4                                                        TAP   92
C ** CORR. TO CARDS TAP96-105 OF SUBR. TAPER, 02-27-75.
      BERX=.99999999999997... -T4*.2499999999997010D0*T8+67... T12+AP   96A
     1D-T4*70.550279588996... T12+93.85... T16-7.2622567473... TAP   98A
     2*T20+.2597773C0078EG*T24-.CC0698712372... T28+.00... T32 TAP   99A
      BEIX=T2*(-24.99999999999999... -T4*...277777777... -T8*...    TAP  100A
     1907D0*T8+260.3067... T12-29.969... T16+1.49... TAP  102A
     2697829D0*T20-.03... T24+.00... T28-.00... -5*T32 TAP  104A
     42)                                                                TAP  105A
      DBERX=T*(-62.4999... -T4*...2222222... *T8-... T12+...   TAP  106A
     1949900D0*T8+150.17547... T12-1... T16+.62... TAP  108A
     2692030D0*T20-.01... T24+.17... T28-.14... -5*T32 TAP  110A
     32)                                                                TAP  111A
      DBEIX=-T*(-4.99999999999990D0+206.01... T4-676.1... TAP  112A
     1539D0*T8+336.3... T12-52.1... T16+3.... TAP  114A
     2085790D0*T20-.09... T24+.00... T28-.00... TAP  116A
     38*D0*T32)                                                         TAP  117A
      B1X=T2*(24.999999999999D0-795.7175925... T4+1300.4... TAP  118A
     1920D0*T8-623.61... T12+81.95... T16-4.51... TAP  120A
     239D0*T20+.1222... T24-.00... T28+.15... -0* TAP  122A
     3T32)                                                              TAP  123A
      B2X=T4*(230.375-1012.65... T4+... T8-25 TAP  124A
     15.047... T12+21.2123... T16-.00... T20+ TAP  126A
     2.01593... T24-.C00179762799... T28+.000001216... T32)       TAP  128A
      D21X=T*(4.99999999999975D0-677.43055555...D0*T4+1500.4... TAP  130A
     1500*T8-872.2191... T12+147.51... T16-9.9... TAP  132A
     2972500*T20+.3177... T24-.005... T28+.000... TAP  134A
     3490*T32)                                                          TAP  135A
      D22X=T3*(93.7499999999... -1130.2... T4+1354.5... TAP  136A
     1245200*T8-408.155... T12+2.62... T16-1.93... TAP  138A
     2229237D0*T20+.000... T24-.00C575... T28+.00... TAP  140A
     3053D0*T32)                                                        TAP  141A
      BERX= -.7853981633974D0* BEIX+ B1X- (.5772156649D0+C3) *BERX      TAP  142A
      BEIX= +.7853981633974D0* BERX- B2X- (.5772156649D0+C3) *BEIX      TAP  144A
      DKERX=+.7853981633974D0*DBEIX-D22X-(BERX/X)-(.5772156649D0+C3)*DB TAP 146A
     1ERX                                                               TAP  147A
      DKEIX=-.7853981633974D0*DBERX+D21X-(BEIX/X)-(.5772156649D0+C3)*DB TAP 148A
     1EIX                                                               TAP  149A
      GO TO 6                                                           TAP  150
    5 T=10.0/X                                                          TAP  152
      C1 = (DEXP(+X/1.41421356237100) /DSQRT(6.2831853071800*X))        TAP  154B
      C2 = (DEXP(-X/1.4142135623710D) *DSQRT(1.5707963267900/X))        TAP  156B
      SIN1 = DSIN((X/1.4142135623710D)+(.3926990816990D))               TAP  158B
      SIN2 = DSIN((X/1.4142135623710D)-(.3926990816990D))               TAP  160B
      COS1 = DCOS((X/1.4142135623710D)+(.3926990816990D))               TAP  162B
      COS2 = DCOS((X/1.4142135623710D)-(.3926990816990D))               TAP  164B
      T2=T*T                                                            TAP  166
      T3=T2*T                                                           TAP  168
      T4=T3*T                                                           TAP  170
      T5=T4*T                                                           TAP  172
      T6=T5*T                                                           TAP  17[illegible]
      T7=T6*T                                                           TAP  1[illegible]
      T8=T7*T                                                           TAP  178
      S=1.+.0088388346D0*T+.7D-9*T2-.0000517869D0*T3-.0000114207D0*T4-.0TAP 180A
     1000016192D0*T5+.135D-8*T6+.1052D-6*T7+.492D-7*T8                  TAP  182A
      TT=-.0088388340D0*T-.00C70312D0*T2-.00005180D0*T3-.72D-8*T4+.1TAP 184A
     1603100-5*T5+.3929E-6*T6+.7500-7*T7-.2635-7*T8                     TAP  186A
      U=1.-.02551650D0*T-.8D-9*T2+.725024D-4*T3+.1842530-4*T4+.197800-TAP 188A
     15*T5-.147D-7*T6-.1671E-6*T7-.3630-7*T8                            TAP  190A
      V=+.0265165D3D0*T+.0011718750D0*T2+.725179D-4*T3+.79D-8*T4-.20002TAP 192A
     1D-5*T5-.6992D-6*T6-.8830-6*T7+.2690-6*T8                          TAP  194A
      BERX=C1*((S*COS2)-(TT*SIN2))                                      TAP  196
      BEIX=C1*((TT*COS2)+(S*SIN2))                                      TAP  198
      DBERX=C1*((U*COS1)-(V*SIN1))                                      TAP  200
      DBEIX=C1*((V*COS1)+(U*SIN1))                                      TAP  202
      T=-T                                                              TAP  204
      T2=T*T                                                            TAP  206
      T3=T2*T                                                           TAP  208
```

```
      T4=T3*T                                                          TAP  210
      T5=T4*T                                                          TAP  212
      T6=T5*T                                                          TAP  214
      T7=T6*T                                                          TAP  216
      T8=T7*T                                                          TAP  218
      S=1.+.9C[illegible]*T+.7D-9*T2-.5178[illegible]D-6*T3-.114407D-4*T4-.161920-[illegible]TAP 222A
     1*T5+.1353-9*T6+.1652E-9*T7+.6920-7*T8                            TAP  222A
      C1=-.[illegible]D-2*T-.7531[illegible]D-3*T2-.5180[illegible]E-4*T3-.72[illegible]D-4*T4+.164310-5*TAP 224A
     1*T5+.59[illegible]D-6*T6+.35C0-7*T7-.[illegible]D-7*T8                TAP  226A
      U=1.+.0[illegible]5163[illegible]*T-.[illegible]D-9*T2+.725020E-4*T3+.1042[illegible]D-4*T4+.19763-5*TAP 228A
     1*T5-.1675-7*T6-.16710-6*T7-.56[illegible]D-7*T8                      TAP  230A
      V=+.3[illegible]516[illegible]D0*T+.117[illegible]D-2*T2+.7251[illegible]E-4*T3+.7[illegible]D-4*T4-.[illegible]20-[illegible]TAP 232A
     1*T5-.[illegible]920-6*T6-.[illegible]E-6*T7+.269D-6*T8                  TAP  234A
      CBSX=C2*((S*COS1)+(T*SIN1))                                      TAP  236
      CBSX=C2*((T*COS1)-(S*SIN1))                                      TAP  238
      DBEX=-C2*((U*COS2)+(V*SIN2))                                     TAP  240
      DBEX=-C2*((V*COS2)-(U*SIN2))                                     TAP  242
    6 COSX=SCC                                                         TAP  244
      IF (J-1) 7,7,8                                                   TAP  246
    7 PO=(1./(RHO-1.))**.5                                             TAP  248
      J=J+1                                                            TAP  250
      A(1,1)=BBEX                                                      TAP  252
      A(1,2)=BBEX                                                      TAP  254
      A(1,3)=BKEX                                                      TAP  256
      A(1,4)=BKEX                                                      TAP  258
      A(1,5)=0.                                                        TAP  260
      A(1,6)=-PO                                                       TAP  262
      A(1,7)=0.                                                        TAP  264
      A(1,8)=0.                                                        TAP  266
      A(1,9)=0.                                                        TAP  268
      A(1,10)=0.                                                       TAP  270
      A(2,1)=-X*BEX-2.*BBEX                                            TAP  272
      A(2,2)=X*BEX-2.*BBEX                                             TAP  274
      A(2,3)=-X*CEX-2.*BKEX                                            TAP  276
      A(2,4)=X*CEX-2.*BKEX                                             TAP  278
      A(2,5)=-(X*PO/(2.**.5))                                          TAP  280
      A(2,6)=A(2,5)                                                    TAP  282
      A(2,7)=0.                                                        TAP  284
      A(2,8)=0.                                                        TAP  286
      A(2,9)=0.                                                        TAP  288
      A(2,10)=0.                                                       TAP  290
      A(3,1)=4.*X*BEX+X*X*BBEX-X*X*CBSX                                TAP  292
      A(3,2)=-4.*X*BEX+4.*BE-X*X*X*DBEX                                TAP  294
      A(3,3)=4.*X*CEX+4.*BKEX-X*X*DKEX                                 TAP  296
      A(3,4)=-4.*X*CEX+4.*CKEX+X*X*CKEX                                TAP  298
      A(3,5)=-X*X*PO                                                   TAP  300
      A(3,6)=C.                                                        TAP  302
      A(3,7)=0.                                                        TAP  304
      A(3,8)=C.                                                        TAP  306
      A(3,9)=C.                                                        TAP  308
      A(3,10)=0.                                                       TAP  310
      A(4,1)=(-X*BEX+2.*BBEX)                                          TAP  312
      A(4,2)=(-X*BEX-2.*BBEX)                                          TAP  314
      A(4,3)=(-X*CEX+2.*BKEX)                                          TAP  316
      A(4,4)=(-X*CEX-2.*BKEX)                                          TAP  318
      A(4,5)=A(2,5)                                                    TAP  320
      A(4,6)=-A(2,5)                                                   TAP  322
      A(4,7)=0.                                                        TAP  324
      A(4,8)=C.                                                        TAP  326
      A(4,9)=C.                                                        TAP  328
      A(4,10)=0.                                                       TAP  330
      X=X*RHO**.5                                                      TAP  332
      GO TO 3                                                          TAP  334
    4 PO=(RHO/(RHO-1.))**.5                                            TAP  336
      IF (IBOXD-1) 9,10,10                                             TAP  338
    9 U1=0.                                                            TAP  340
      U2=0.                                                            TAP  342
      U3=0.                                                            TAP  344
      U4=0.                                                            TAP  346
      U5=0.                                                            TAP  348
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      GO TO 11                                                          TAP  350
   10 PHI1=PO*PO                                                        TAP  352
      P=PRESS                                                           TAP  354
      XK2=XK*XK                                                         TAP  356
      U1=TH/(4.*PHI1*HL)                                                TAP  358
      U2=X*X*TH*G1**3/(87.36*TH*(PHI1*HL)**3)                           TAP  360
      U3=(XB/TH)*((1.3*XK2+.7)/(XK2-1.))                                TAP  362
      U4=-TH*XB*ALPHA*FS/(2.*HL*(1.+ALPHA)**2)                          TAP  364
      U5=ALPHA*G0*XB*P/(4.*HL*TH)                                       TAP  366
   11 AA11=DBEIX                                                        TAP  368
      AA12=DBERX                                                        TAP  370
      AA13=DKEIX                                                        TAP  372
      AA14=DKERX                                                        TAP  374
      AA21=-X*BEIX-2.*DBERX                                             TAP  376
      AA22=X*BERX-2.*DBEIX                                              TAP  378
      AA23=-X*CKEIX-2.*DKERX                                            TAP  380
      AA24=X*CKERX-2.*DKEIX                                             TAP  382
      AA31=(-X*BERX+2.*DBEIX)                                           TAP  384
      AA32=(-X*BEIX-2.*DBERX)                                           TAP  386
      AA33=(-X*CKERX+2.*DKEIX)                                          TAP  388
      AA34=(-X*CKEIX-2.*DKERX)                                          TAP  390
      A(5,1)=AA11+U1*AA21-U2*U3*AA31                                    TAP  392
      A(5,2)=AA12+U1*AA22-U2*U3*AA32                                    TAP  394
      A(5,3)=AA13+U1*AA23-U2*U3*AA33                                    TAP  396
      A(5,4)=AA14+U1*AA24-U2*U3*AA34                                    TAP  398
      A(5,5)=0.                                                         TAP  400
      A(5,6)=0.                                                         TAP  402
      A(5,7)=0.                                                         TAP  404
      A(5,8)=0.                                                         TAP  406
      A(5,9)=0.                                                         TAP  408
      A(5,10)=0.                                                        TAP  410
      A(6,1)=-X*BEIX-2.*DBERX                                           TAP  412
      A(6,2)=X*BERX-2.*DBEIX                                            TAP  414
      A(6,3)=-X*CKEIX-2.*DKERX                                          TAP  416
      A(6,4)=X*CKERX-2.*DKEIX                                           TAP  418
      A(6,5)=0.                                                         TAP  420
      A(6,6)=0.                                                         TAP  422
      A(6,7) = -2.0*PHI1**1.5*HL*(2.0*DLOG(XB)+1.0)                     TAP 424A
      A(6,8)=-4.*PHI1**1.5*HL                                           TAP  426
      A(6,9)=-2.*PHI1**1.5*HL/(XB*XB)                                   TAP  428
      A(6,10)=0.                                                        TAP  430
      A(7,1)=4.*X*DBEIX+8.*DBERX-X*X*BBEIX+((GAMMA**2.*TH)/(HL*ALPHA))*(-TAP  432
     1X*BERX+2.*DBEIX)                                                  TAP  434
      A(7,2)=-4.*X*DBERX+8.*DBEIX+X*X*BBERX+((GAMMA**2.*TH)/(HL*ALPHA))*(TAP  436
     1-X*BEIX-2.*DBERX)                                                 TAP  438
      A(7,3)=4.*X*DKEIX+8.*DKERX-X*X*DKEIX+((GAMMA**2.*TH)/(HL*ALPHA))*(-TAP  440
     1X*CKERX+2.*DKEIX)                                                 TAP  442
      A(7,4)=-4.*X*CKEIX+8.*DKEIX+X*X*DKERX+((GAMMA**2.*TH)/(HL*ALPHA))*(TAP  444
     1-X*CKEIX-2.*DKERX)                                                TAP  446
      A(7,5)=0.                                                         TAP  448
      A(7,6)=0.                                                         TAP  450
      TEMP=-4.*PHI1**2.5*HL*HL*TH**3./((G1**3.)*XB)                     TAP  452
      A(7,7) = TEMP*(2.0*DLOG(XB)+3.3)                                  TAP 454A
      A(7,8)=TEMP*2.6                                                   TAP  456
      A(7,9)=-TEMP*0.7/(XB*XB)                                          TAP  458
      A(7,10)=0.                                                        TAP  460
      A(8,1)=0.                                                         TAP  462
      A(8,2)=0.                                                         TAP  464
      A(8,3)=0.                                                         TAP  466
      A(8,4)=0.                                                         TAP  468
      A(8,5)=0.                                                         TAP  470
      A(8,6)=0.                                                         TAP  472
      A(8,7) = XB*XB*DLOG(XB)                                           TAP 474A
      A(8,8)=XB*XB                                                      TAP  476
      A(8,9) = DLOG(XB)                                                 TAP 478A
      A(8,10)=1.0                                                       TAP  480
      A(9,1)=0.                                                         TAP  482
      A(9,2)=0                                                          TAP  484
      A(9,3)=0                                                          TAP  486
      A(9,4)=0                                                          TAP  488
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      A(9,5)=0                                                          TAP  490
      A(9,6)=0                                                          TAP  492
      A(9,7) = 2.6*ALOG(XA)+3.3                                         TAP 494A
      A(9,8)=2.6                                                        TAP  496
      A(9,9)=-0.7/(XA*XA)                                               TAP  498
      A(9,10)=0.                                                        TAP  500
      A(10,1)=0.                                                        TAP  502
      A(10,2)=0.                                                        TAP  504
      A(10,3)=0.                                                        TAP  506
      A(10,4)=0.                                                        TAP  508
      A(10,5)=0.                                                        TAP  510
      A(10,6)=0.                                                        TAP  512
      A(10,7)=1.0                                                       TAP  514
      A(10,8)=0.                                                        TAP  516
      A(10,9)=0.                                                        TAP  518
      A(10,10)=0.                                                       TAP  520
C     PRINT 3,A(1), A(2), A(3), A(4), A(5), A(6),A(7),A(8),A(9),A(10)   TAP  522
      DO 13 I=1,10                                                      TAP  524
      DO 12 J=1,10                                                      TAP  526
      AM(I,J)=A(I,J)                                                    TAP  528
   12 CONTINUE                                                          TAP  530
   13 CONTINUE                                                          TAP  532
C     CALCULATIONS FOR MOMENT LOADING, TAPERED HUB                      TAP  534
      P=0.                                                              TAP  536
      PS=0.                                                             TAP  538
      DELT=0.                                                           TAP  540
      IF (ICODE-1) 14,14,15                                             TAP  542
   14 XNO=XNOA                                                          TAP  544
      GO TO 16                                                          TAP  546
   15 CALL ASHEIB                                                       TAP  548
      XNO=XOP                                                           TAP  550
      G=(GOBI+GIB)/2.                                                   TAP  552
C  16 PRINT 50                                                          TAP 554A
   16 CONTINUE                                                          TAP 554B
      DO 17 I=1,10                                                      TAP  556
      B(I)=0.                                                           TAP  558
   17 CONTINUE                                                          TAP  560
      B(10)=-(2.73/(6.2832*YM*TH**3.*(XA-XB)))*XNO                      TAP  562
      CALL LIN2 (A,10,10,B,1,10,LTEMP,IERR,DET,BEST,A,V,LPA,LPC)        TAP  564
      B17=(-X*BERX+2.*DBEIX)                                            TAP  566
      B18=(-X*BEIX-2.*DBERX)                                            TAP  568
      B19=(-X*KERX+2.*DKEIX)                                            TAP  570
      B20=(-X*KEIX-2.*DKERX)                                            TAP  572
      P1=(-YM*G**3.*XB*ETA**2./(87.36*PHI**3.5*HL**3.))*(B17*B(1)+B18*TAP  574
     *B(2)+B19*B(3)+B20*B(4))                                           TAP  576
      B9=4.*X*BEIX+8.*DBERX-X*X*DBEIX                                   TAP  578
      B10=-4.*X*BERX+8.*DBEIX+X*X*DDBERX                                TAP  580
      B11=4.*X*KEIX+8.*DKERX-X*X*DKEIX                                  TAP  582
      B12=-4.*X*KERX+8.*DKEIX+X*X*DDKERX                                TAP  584
      A1=(1./(4.*PHI**2.5))*(B9*B(1)+B10*B(2)+B11*B(3)+B12*B(4))+2.*ALPTAP  586
     *HA**2*PS/((1.+ALPHA)**3)                                          TAP  588
      T1 = B(7)*(2.6*XB*ALOG(XB)+XB)+2.6*B(8)*XB+B(9)/XB                TAP 590A
      P1A1=P1/A1                                                        TAP  592
      COF=-(YM*GO*HI*HC**3.)/(XB*2.73**.25*GAMMA**3.)                   TAP  594
      F=P1A1/COF                                                        TAP  596
      T1A1=T1/A1                                                        TAP  598
      COV=(XB*2.73**.25*HO**3.)/(HL*GAMMA)                              TAP  600
      V=T1A1/COV                                                        TAP  602
C-----------------------------------------------------------------------01-17-75
C     IF (IBOND-1) 18,18,19                                             TAP  604
C  18 CONTINUE                                                          TAP  606
C-----------------------------------------------------------------------01-17-75
   19 IB=0                                                              TAP  608
      NA=1                                                              TAP  610
   20 SLBS=1.816*TS*B(5)                                                TAP  612
      IF (IBOND-2) 21,21,22                                             TAP  614
   21 P1=(-YM*G**3*XB*ETA**2/(87.36*PHI**3.5*HL**3))*(B17*B(1)+B18*B(TAP  616
     12)+B19*B(3)+B20*B(4))                                             TAP  618
      GO TO 23                                                          TAP  620
   22 P1=(-YM*G**3*XB*ETA**2/(87.36*PHI**3.5*HL**3))*(B17*B(1)+B18*B(TAP  622
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     1Z)*E1**5(3)*...(4))...*ZZ/(6.*ZI)                                TAP  620
  23 T1 = S(7)*(2.0*XB*ALOG(XA)*XA)+2.0*S(8)*X+S(9)/XE                   TAP  626A
     T3*XE*(S(8)*FS)                                                     TAP  628
     T1*(XB/TO)*(DEE3L*S(1)*DB...(2)*DR...(3)*DEL...(4))*...             TAP  630
     SLSO=-SLSO*P*XE/(2.*CO)                                             TAP  632
     SLS=SLS*P*XE/(2.*CO)                                                TAP  634
     SCSO=.5*SLSO*XE*T/XB                                                TAP  636
     SCSI=.5*SLSI*XE*TO/XB                                               TAP  638
     SLBL=(TX*C1/1.82)*((XE/(6.*PHI1**2.5*...))*(...S(1)*...(4)*2...     TAP  640
    1*S(3)*S(2)*S(4))*2.*XB*ALFA**2*FS/(XL*...(1.*A...)**3))             TAP  642
     SLLO=-SLBL*P*XE/(2.*C1)                                             TAP  644
     SLLI=SLBL*P*XE/(2.*C1)                                              TAP  646
     SCLO=.5*SLLO*XE*T/XB                                                TAP  648
     SCLI=.5*SLLI*XE*T/XB                                                TAP  650
     STB = -(TX*TX/1.82)*((2.0*ALOG(XB)+1.5)*S(7)+2.0*S(8)*(-.7/(XA*XB)  TAP  652A
    1)*S(9))                                                             TAP  654A
     ST7=((XA*XA*1.)/(XB*XB-1.))*(P-P1/TR)                               TAP  656
     STM=STB*ST7                                                         TAP  658
     STP=-STB*ST7                                                        TAP  660
     SBS = -(TX*TR/1.82)*((2.0*ALOG(XB)+3.3)*S(7)+2.0*S(8)-6.7*S(9)/(XB  TAP  662A
    1*XB))                                                               TAP  664A
     SBM=SBS-P*T1/TR                                                     TAP  666
     SBP=-SBS-P*T1/TR                                                    TAP  668
     FB=SLSO/SLLO                                                        TAP  670
     ZG = S(7)*G*G*ALOG(G)+S(8)*G*G+S(9)*ALOG(G)+S(10)                   TAP  672A
     ZC = S(7)*C*C*ALOG(C)+S(8)*C*C+S(9)*ALOG(C)+S(10)                   TAP  674A
     DPNG=-ZC+ZG                                                         TAP  676
     GTMP(NA)=DPNG                                                       TAP  678
     IF (ICODE-4) 20,25,25                                               TAP  680
  20 CALL STORE                                                          TAP  681A
C 26 PRINT 55, ...                                                       TAP  682A
C   1,...                                                                TAP  684A
     GO TO 26                                                            TAP  686
  25 SIMAX = AMAX1( ABS(SLSO),ABS(SLLO) )                                TAP  688A
     SLT=.0006*S.MAX                                                     TAP  690
     COT=(SIMAX+SIM)/2.                                                  TAP  692
     COB=(SIMAX+SIM)/2.                                                  TAP  694
     PRINT 56                                                            TAP  696
     PRINT 57, SLS,STM,SBM,COT,COB                                       TAP  698
     PRINT 58                                                            TAP  700
     SLS=SLS*SOG                                                         TAP  702
     STM=STM*SOG                                                         TAP  704
     SBM=SBM*SOG                                                         TAP  706
     COT=COT*SOG                                                         TAP  708
     COB=COB*SOG                                                         TAP  710
     PRINT 57, SLS,STM,SBM,COT,COB                                       TAP  712
     PRINT 62                                                            TAP  714
     GO TO 47                                                            TAP  716
  26 IP=IP+1                                                             TAP  718
C    GO TO( 47,36,40,46 ),IP                                             TAP  720A
     GO TO( 47,36,40      ),IP                                           TAP  721A
C    CALCULATION FOR PRESSURE LOADING, TAPER IS 402                      TAP  722
  27 XNO=0.                                                              TAP  724
     P=PRESS                                                             TAP  726
     DELT=0.                                                             TAP  728
     PS=(.05*XB/(XE*GC))*0.                                              TAP  730
C    PRINT 57                                                            TAP  732A
     DO 28 I=1,10                                                        TAP  734
     S(I)=0.                                                             TAP  736
  28 CONTINUE                                                            TAP  738
     F0=(1./(XB)-1.))**.5                                                TAP  740
     S(4)=-2.*F0*F                                                       TAP  742
     S(3)=6.*F0*F2                                                       TAP  744
C---------------------------------------------------------------------01-17-75
C ** ... THE ... AC ... 09-17-75.
     IF( ...-2 ) ...,36,47                                               TAP  746A
  47 S(4) = -1.*...                                                      TAP  746B
C---------------------------------------------------------------------01-17-75
  ..  ...(...-1.))**.5                                                   TAP  750
     IF (...) 31,31,32                                                   TAP  752
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31 B(5)=(PC/ED)*((ALP*S/(1.+ALPHA)),-B3*P*B*ES*ELP*DELS)          TMP  750
   B(7)=8.*PO*S/(EMC)                                              TMP  756
   GO TO 33                                                        TMP  758
32 B(5)=(PC/ED)*((ALP*S/(1.+ALPHA))-B3*P*B*E3*B5*B*ALP*DELS)       TMP  760
   B(7)=8.*PO*ES/(EMC)-5.*P*TMP*EP*B/(G*EB*EF)**.5*ALEM**1.5*PB)   TMP  762
33 B(6)=-2.*PO*S/(1.+ALPHA)                                        TMP  764
   DO 35 I=1,10                                                    TMP  766
   DO 34 J=1,10                                                    TMP  768
   A(I,J)=AT(I,J)                                                  TMP  770
34 CONTINUE                                                        TMP  772
35 CONTINUE                                                        TMP  774
   CALL LIN2 (A,B,10,[illegible],1,10,ITEMP,IERR,DET,BEIV,EIV,LRA,LRC)  TMP  776
   NE=2                                                            TMP  778
   GO TO 40                                                        TMP  780
C     CALCULATIONS FOR DELTA TEMPERATURE, CASE [illegible] ONE       TMP  782
36 P=0.                                                            TMP  784
   PS=0.                                                           TMP  786
   DELT=DELTB                                                      TMP  788
C     PRINT 60                                                     TMP 788A
   DO 37 I=1,10                                                    TMP  792
   B(I)=0.                                                         TMP  794
37 CONTINUE                                                        TMP  796
   B(5)=(PC/ED)*(AS*AL*DELTA)                                      TMP  798
   DO 39 I=1,10                                                    TMP  800
   DO 38 J=1,10                                                    TMP  802
   A(I,J)=AT(I,J)                                                  TMP  804
38 CONTINUE                                                        TMP  806
39 CONTINUE                                                        TMP  808
   CALL LIN2 (A,B,10,[illegible],1,10,ITEMP,IERR,DET,BEIV,EIV,LRA,LRC)  TMP  810
   NE=3                                                            TMP  812
   GO TO 40                                                        TMP  814
C ** CARDS TMP810-866 DELETED 09-19-75.                             TMP 866A
C  40 PRINT 6.                                                      TMP 866B
40 CONTINUE                                                        TMP 866C
   GO TO (44,45,46,45,46,45), NE                                   TMP  868
45 CALL FLGDN                                                      TMP  870
46 CONTINUE                                                        TMP  872
   GO TO( 70,76,71,70,71,70 ),NE                                   TMP 873A
70 CALL COMBIN                                                     TMP 873B
71 CONTINUE                                                        TMP 873C
47 RETURN                                                          TMP  874
C                                                                  TMP  876
48 FORMAT (9E16.5)                                                 TMP  878
49 FORMAT (90H  FLANGE    FLANGE     FLANGE     PIPE      [illegible]    [illegible] TMP  880
  1B        BOLT     PRESSURE,   /90H G.L.A    I.D.,   THICK.,I  [illegible]TMP  882
  2LL,GW     RASE,GI    LENGTH,E  CIRCLE,C     F             )        TMP  884
50 FORMAT (7F13.5,1F16.3/)                                         TMP  886
51 FORMAT (5E13.5)                                                 TMP  888
52 FORMAT (94H  MOMENT  COEFF. OF   DELTA      NO. OF [illegible] [illegible] [illegible]TMP  890
  1TYPE      LOOSE    MCBE      RATE          /51H         [illegible] [illegible]TMP  892
  2I.       ELASTICITY DIAMETER   )                                TMP  894
53 FORMAT (1P5E16.5,5E,3E16//)                                     TMP  896
54 FORMAT (54H CALCULATIONS FOR MOMENT LOADING, TAPERED HUB FLANGE//)TMP  898
55 FORMAT (7F  SLSO=1PE11.4,7H  SLS1=E12.4,7P  SCSO=E1[illegible],7H  [illegible]=E1[illegible]TMP  900
  12.4//7H  SLLO=E12.4,7H  SLL1=E12.4,7H  SCLO=E12.4,7H  SC[illegible]=E12.4//[illegible]TMP  902
  27H  STM=E12.4,7H  STP=E12.4,7H  S[illegible]=E12.4,7H  [illegible]=E12.4//5H  [illegible]TMP  904
  3B=E12.4,5H  LC=E12.4,7H  [illegible]=E12.4,5H  YC=E12.4,5H  Y[illegible]=E12.4,6H  TMP  906
  4THETA=E12.4/)                                                   TMP  908
56 FORMAT (69H    [illegible] FLANGE STRESSES AT [illegible] [illegible], [illegible] //)   TMP  910
57 FORMAT (11H   (2/3)*SA=,1PE12.4,6H  SC =,E12.4,6H  [illegible] =,E12.4,13H  TMP  912
  1(SB*ST )/2=,E12.4,13H   (SB*SR )/2=,E12.4///)                   TMP  914
58 FORMAT (55H    [illegible] FLANGE STRESSES AT GASKET SEATING [illegible], [illegible]   TMP  916
  1//)                                                             TMP  918
59 FORMAT (30H CALCULATIONS FOR PRESSURE LOADING//)                TMP  920
60 FORMAT (37H CALCULATIONS FOR TEMPERATURE LOADING//)             TMP  922
61 FORMAT (30H CALCULATIONS FOR COMBINED LOADING//)                TMP  924
62 FORMAT (1H1)                                                    TMP  926
   END                                                             TMP  928
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      SUBROUTINE STNO9                                                  STN    2
C     THIS CALCULATION IS FOR ITYPE = 2, STRAIGHT FIN FLANGES           STN    4
      IMPLICIT REAL*8 (A-H,O-Z)                                         01-20-75
      DIMENSION A(10,10), B(10), LPEMP(10), LPF(10), LPC(10), AN(10,10) STN    6
      DIMENSION S2(6,10),SC(10)                                         STN   6A
      COMMON ITYPE,IDCAL,ICODE,RATE,XA,XB,G,C,PRESS,HGS,ADP,G1,G0,TH,TR,STN    8
     1ZB,TEMP(8),AL,DELTA,AXL,XNOR,QFASF,DPHGP,CTHGP,BI,GUE,TBP,TPP,EPP,STN   10
     2DELTAE,DOUT,GIS,GCG                                               STN   12
     3,SISC,SISI,SCSC,SCSI,SIAC,SIAI,SCLA,SCLI,STB                      STN   8A
     4,STF,STP,SEF,ZA,ZC,JFNG,YC,Y1,Z1,THETA,SOFT,SGL,SG2,SC2,SC1,SAP   STN   8B
     5,U2,U1,S3,WA,ZT,AP1,AP2,XP2E                                      STN   8C
      DATA A/100*0./,B/10*0./,LTEMP/10*0/,LPF/10*0/,LPC/10*0/,AN/100*0./
C
    1 READ 32, XA,XB,TH,G0,G1,HL,C,PRESS                                STN   14
      PRINT 33                                                          STN   16
      PRINT 34, XA,XB,TH,G0,G1,HL,C,PRESS                               STN   18
      Z=1.                                                              STN   20
      YY=1.                                                             STN   22
      IF (ICODE.GE.3) GO TO 2                                           STN   24
      READ 35, XNOR,EF,DELTA,TH,G                                       STN   26
      PRINT 36                                                          STN   28
      AL=EF                                                             STN   30
      PRINT 37, XNOR,EF,DELTA,TH,G,ITYPE,IDOSE,ICODE,RATE               STN   32
    2 XA=XA/2.                                                          STN   34
      XB=XB/2.                                                          STN   36
      XK=XA/XB                                                          STN   38
      XK2=XK*XK                                                         STN   40
      G=G/2.                                                            STN   42
      C=C/2.                                                            STN   44
      BETA = 1.73**(.25/DSQRT(XB*G0))                                   STN  46A
      IF (IBOKE-1) 3,4,4                                                STN   48
    3 T3=0.                                                             STN   50
      T33=0.                                                            STN   52
      U34=0.                                                            STN   54
      GO TO 5                                                           STN   56
    4 U3=(XB/Y3)*((1.+Z*)K2+.7)/(XK2-1.,)                               STN   58
      T33=2.*U3*Y**(G0*BETA)**3/(TH*10.92)                              STN   60
      U34=TH*BETA/2.                                                    STN   62
    5 XT1=U34-U33                                                       STN   64
      XT2=1.+U34+T33                                                    STN   66
      P5=(.05*XB/(Y**G0))*PRESS                                         STN   68
      A(1,1)=XT1                                                        STN   70
      A(1,2)=XT2                                                        STN   72
      A(1,3)=0.                                                         STN   74
      A(1,4)=0.                                                         STN   76
      A(1,5)=0.                                                         STN   78
      A(1,6)=0.                                                         STN   80
      A(2,1)=BETA                                                       STN   82
      A(2,2)=BETA                                                       STN   84
      A(2,3) = -(2.0*XB*DLOG(XB)+XB)                                    STN  86A
      A(2,4)=-2.*XB                                                     STN   88
      A(2,5)=-1./XB                                                     STN   90
      A(2,6)=0.                                                         STN   92
      A(3,1)=2.*BETA**2*(1.+BETA*TH/2.)                                 STN   94
      A(3,2)=-2.*BETA**3*TH/2.                                          STN   96
      A(3,3) = -(2.6*DLOG(XB)+3.3)*(TH/G0)**3                           STN  98A
      A(3,4)=-2.6*(TH/G0)**3                                            STN  100
      A(3,5)=(.7/(XB*XB))*(TH/G0)**3                                    STN  102
      A(3,6)=0.                                                         STN  104
      A(4,1)=0.                                                         STN  106
      A(4,2)=0                                                          STN  108
      A(4,3) = XB*XB*DLOG(XB)                                           STN 110A
      A(4,4)=XB*XB                                                      STN  112
      A(4,5) = DLOG(XB)                                                 STN 114A
      A(4,6)=1.                                                         STN  116
      A(5,1)=0.                                                         STN  118
      A(5,2)=0.                                                         STN  120
      A(5,3) = 2.6*DLOG(XA)+3.3                                         STN 122A
      A(5,4)=2.6                                                        STN  124
```

```
      A(5,5)=-.7/(AA*EA)
      A(5,6)=0.
      A(6,1)=0.
      A(6,2)=0.
      A(6,3)=1.
      A(6,4)=0.
      A(6,5)=0.
      A(6,6)=0.
      DO 7 I=1,6
      DO 6 J=1,6
      AH(I,J)=A(I,J)
    6 CONTINUE
    7 CONTINUE
C     CALCULATIONS FOR PLANAR LOADING, STRAIGHT [illegible]
      P=0.
      PS=0.
      DELI=0.
      IF (ICOPT-1) 8,8,9
    8 [illegible]
      GO TO 10
    9 CALL [illegible]
      [illegible]
C  10 PRINT 30
   10 CONTINUE
      DO 11 I=1,6
      B(I)=0.
   11 CONTINUE
      B(6)=-2.7*[illegible]
      CALL LIS2 (A,6,10,[illegible])
      IP=0
      NA=1
   12 C5=B(1)
      C6=B(2)
      D1=B(3)
      D2=B(4)
      D3=B(5)
      D4=B(6)
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      IF ([illegible]) 13,14,14
C  13 PRINT [illegible]
   13 CALL [illegible]
      GO TO 15
   14 [illegible]
      [illegible]
      [illegible]
      PRINT [illegible]
      PRINT [illegible]
      PRINT [illegible]
      [illegible]
      [illegible]
```

```
      [illegible]                                                       STR  262
      COT=COT*DOS                                                       STR  264
      [illegible]                                                       STR. 266
      PRINT 41, SLB,STB,SBB,COT,CHB                                     STR  268
      PRINT 46                                                          STR  270
      GO TO 31                                                          STR  272
   15 IP=IP+1                                                           STR  274
C     GO TO( 16,20,25,20 ),IP                                           STR 276A
      GO TO( 16,20,20     ),IP                                          STR 276B
C     CALCULATIONS FOR PRESSURE LOADING, STRAIGHT HUB                   STR  278
   16 [illegible]                                                       STR  280
      DELT=0.                                                           STR  282
      P=PRESS                                                           STR  284
      [illegible]                                                       STR  286
C     PRINT 43                                                          STR 288A
      DO 17 I=1,6                                                       STR  290
      B(I)=0.                                                           STR  292
   17 CONTINUE                                                          STR  294
      [illegible]                                                       STR  296
      DO 19 I=1,6                                                       STR  298
      DO 18 J=1,6                                                       STR  300
      A(I,J)=AA(I,J)                                                    STR  302
   18 CONTINUE                                                          STR  304
   19 CONTINUE                                                          STR  306
      CALL LINE2 (A,6,10,0.,B,1,1C,LTEMP,IERR,DET,NPIV,PIV,LPR,LPC)      STR  308
      NA=2                                                              STR  310
      GO TO 12                                                          STR  312
C     CALCULATIONS FOR DELTA TEMPERATURE LOADING, STRAIGHT HUB          STR  314
   20 P=0.                                                              STR  316
      PS=0.                                                             STR  318
      DELT=DELTA                                                        STR  320
C     PRINT 44                                                          STR 322A
      DO 21 I=1,6                                                       STR  324
      B(I)=0.                                                           STR  326
   21 CONTINUE                                                          STR  328
      B(1)=ED*ALPHA*BEIT                                                STR  330
      DO 23 I=1,6                                                       STR  332
      DO 22 J=1,6                                                       STR  334
      A(I,J)=AA(I,J)                                                    STR  336
   22 CONTINUE                                                          STR  338
   23 CONTINUE                                                          STR  340
      CALL LINE2 (A,6,10,0.,B,1,1C,LTEMP,IERR,DET,NPIV,PIV,LPR,LPC)      STR  342
      NA=3                                                              STR  344
      GO TO 12                                                          STR  346
C ** DELETED CARDS STR346-384 OF SUBR. STONE 09-19-75.
C  25 PRINT 46                                                          STR 386A
   26 CONTINUE                                                          STR 386B
      GO TO (30,29,30,29,30,29), MATE                                   STR  388
   29 CALL TLOAD                                                        STR  390
   30 CONTINUE                                                          STR  392
      GO TO( 70,70,71,70,71,70 ),MATE                                   STR 392A
   70 CALL CONSIS                                                       STR 392B
   71 CONTINUE                                                          STR 392C
   31 RETURN                                                            STR  394
C                                                                       STR  396
   32 FORMAT (8E10.5)                                                   STR  398
   33 FORMAT (80H   FLANGE    FLANGE    FLANGE     PIPE      HUB AT    HUBSTR  400
     1B        BOLT     PRESSURE,    /80H  O.D.,A    I.D.,B  THICK.,T   HASTR  402
     2LL,G0    BASE,G1    LENGTH,H  CIRCLE,C    P           )           STR  404
   34 FORMAT (7F10.4, 1F10.3/)                                          STR  406
   35 FORMAT (5E10.5)                                                   STR  408
   36 FORMAT (90H   INSERT  COEFF. OF    DELTA     MOD. OF MEAN GASKET  ITSTR  410
     1YPE     BOUND    SCODE     RATE             /51H          THERMAL ESTR  412
     2XP.          ELASTICITY DIAMETER  )                               STR  414
   37 FORMAT (1P5E10.3, I6, 3I10//)                                     STR  416
   38 FORMAT (53H CALCULATIONS FOR MOMENT LOADING, STRAIGHT HUB FLANGE//STR  418
     1)                                                                 STR  420
   39 FORMAT (7H  SLSO= 1PE12.4,7H  SLSI=E12.4,7H  SCSO=E12.4,7H  SCSI=ESTR  422
     112.4//7H   STH=E12.4,7H   STP=E12.4,7H   SBH=E12.4,7H   SRP=E12.4//STR  424
     25H  SG=E12.4,5H  SC=E12.4,7H  QPHG=E12.4,5H  TQ=E12.4,8H  THETA=ESTR  426
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   32.0/)                                                              STR   020
40 FORMAT (49H   ASME FLANGE STRESSES AT OPERATING TORQUE, 13x //)     STR   030
41 FORMAT (11H   (2/3)*SH=, E12.4,6H   ST =,E12.4,6H   SR =,E12.4,13H  STR   032
  1(SH+ST )/2=,E12.4,13H   (SH+SR )/2=,E12.4///)                       STR   034
42 FORMAT (55H   ASME FLANGE STRESSES AT GASKET SEATING TORQUE, 8GS    STR   036
  1//)                                                                 STR   038
43 FORMAT (30H CALCULATIONS FOR PRESSURE LOADING//)                    STR   040
44 FORMAT (33H CALCULATIONS FOR TEMPERATURE LOADING//)                 STR   042
45 FORMAT (30H CALCULATIONS FOR COMBINED LOADING//)                    STR   044
46 FORMAT (1H1)                                                        STR   046
   END                                                                 STR   048
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      SUBROUTINE BLIND                                                 BLI     2
C     THIS CALCULATION IS FOR ITYPE = 3, BLIND FLANGES                 BLI     4
      IMPLICIT REAL*8 (A-H,O-Z)                                        01-20-75
      DIMENSION A(10,10), B(10), ITEMP(10), LPR(10), LPC(10), AA(10,10) BLI    6
      DIMENSION SB(6,18),SC(18)                                        BLI    6A
      COMMON ITYPE,IBOLT,ICODE,MATL,RA,RB,C,PRESS,BGS,EOP,B1,G0,ZN,TR, BLI    8
     1RB,TP(4),AL,DELTA,RHO,APCA,CPAGE,CPRGP,CTRGE,ST...,AP,TPF,EPF,   BLI   10
     2DELTAP,SOUT,GIN,SIG                                              BLI   12
     3,SLSO,SLSI,SCSO,SCSI,SLLO,SLLI,SCLO,SCLI,STA                     BLI   12A
     4,STP,SAP,SPF,ZB,ZC,GFAC,TO,T1,Z1,THETA,STRT,SG,SG..,SCS,...      BLI   12B
     5,W2,W1,SW,TA,IT,XP1,XP2,XP2E                                     BLI   12C
      DATA A/100*0./,B/10*0./,ITEMP/10*0/,LPR/10*0/,LPC/10*0/,AA/100*0./
C
    1 READ 17, RA,RB,TR,G0,G1,HL,C,PRESS                               BLI    14
      PRINT 18                                                         BLI    16
      PRINT 19, RA,RB,T1,G0,G1,HL,C,PRESS                              BLI    18
      G=1.                                                             BLI    20
      TP=1.                                                            BLI    22
      IF (ICODE.EQ.2) GO TO 15                                         BLI    24
      READ 20, RHOA,EF,DELTA,TR,G                                      BLI    26
      PRINT 21                                                         BLI    28
      AL=EF                                                            BLI    30
      PRINT 22, RHOA,EF,DELTA,TR,G,ITYPE,IBOLT,ICODE,MATL              BLI    32
      D=E*T**3/10.92                                                   BLI    34
      XA=RA/2.                                                         BLI    36
      C=C/2.                                                           BLI    38
      G=G/2.                                                           BLI    40
      A(1,1)=G*G                                                       BLI    42
      A(1,2)=1.                                                        BLI    44
      A(1,3)=0.                                                        BLI    46
      A(1,4)=0.                                                        BLI    48
      A(1,5)=0.                                                        BLI    50
      A(1,6)=0.                                                        BLI    52
      A(1,7)=0.                                                        BLI    54
      A(1,8)=0.                                                        BLI    56
      A(1,9)=0.                                                        BLI    58
      A(2,1)=-2.*G                                                     BLI    60
      A(2,2)=0.                                                        BLI    62
      A(2,3) = 2.0*G*DLOG(G)*G                                         BLI    64
      A(2,4)=2.*G                                                      BLI    66
      A(2,5)=1./G                                                      BLI    68
      A(2,6)=0.                                                        BLI    70
      A(2,7)=0.                                                        BLI    72
      A(2,8)=0.                                                        BLI    74
      A(2,9)=0.                                                        BLI    76
      A(3,1)=0.                                                        BLI    78
      A(3,2)=0.                                                        BLI    80
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      A(3,3)=1.                                              BLI  82
      A(3,4)=0.                                              BLI  84
      A(3,5)=0.                                              BLI  86
      A(3,6)=0.                                              BLI  88
      A(3,7)=0.                                              BLI  90
      A(3,8)=0.                                              BLI  92
      A(3,9)=0.                                              BLI  94
      A(4,1)=0.                                              BLI  96
      A(4,2)=0.                                              BLI  98
      A(4,3) = G*G*DLOG(G)                                   BLI 100A
      A(4,4)=G*G                                             BLI 102
      A(4,5) = DLOG(G)                                       BLI 104A
      A(4,6)=1.                                              BLI 106
      A(4,7)=0.                                              BLI 108
      A(4,8)=0.                                              BLI 110
      A(4,9)=0.                                              BLI 112
      A(5,1)=-2.0                                            BLI 114
      A(5,2)=0.                                              BLI 116
      A(5,3) = 2.6*DLOG(G)+3.3                               BLI 118A
      A(5,4)=2.6                                             BLI 120
      A(5,5)=-.7/(G*G)                                       BLI 122
      A(5,6)=0.                                              BLI 124
      A(5,7)=0.                                              BLI 126
      A(5,8)=0.                                              BLI 128
      A(5,9)=0.                                              BLI 130
      A(6,1)=0.                                              BLI 132
      A(6,2)=0.                                              BLI 134
      A(6,3) = 2.0*C*DLOG(C)+C                               BLI 136A
      A(6,4)=2.*C                                            BLI 138
      A(6,5)=1./C                                            BLI 140
      A(6,6)=0.                                              BLI 142
      A(6,7)=-2.*C                                           BLI 144
      A(6,8)=-1./C                                           BLI 146
      A(7,4)=2.6                                             BLI 156
      A(7,8)=.7/(C*C)                                        BLI 144
      A(6,9)=0.                                              BLI 148
      A(7,1)=0.                                              BLI 150
      A(7,2)=0.                                              BLI 152
      A(7,3) = 2.6*DLOG(C)+3.3                               BLI 154A
      A(7,5)=-.7/(C*C)                                       BLI 158
      A(7,6)=0.                                              BLI 160
      A(7,7)=-2.6                                            BLI 162
      A(7,9)=0.                                              BLI 166
      A(8,1)=0.                                              BLI 168
      A(8,2)=0.                                              BLI 170
      A(8,3)=0.                                              BLI 172
      A(8,4)=0.                                              BLI 174
      A(8,5)=0.                                              BLI 176
      A(8,6)=0.                                              BLI 178
      A(8,7)=2.6                                             BLI 180
      A(8,8)=-.7/(XA*XA)                                     BLI 182
      A(8,9)=0.                                              BLI 184
      A(9,1)=0.                                              BLI 186
      A(9,2)=0.                                              BLI 188
      A(9,3) = C*C*DLOG(C)                                   BLI 190A
      A(9,4)=C*C                                             BLI 192
      A(9,5) = DLOG(C)                                       BLI 194A
      A(9,6)=1.                                              BLI 196
      A(9,7)=-C*C                                            BLI 198
      A(9,8) = -DLOG(C)                                      BLI 200A
      A(9,9)=-1.                                             BLI 202
      DO 3 I=1,9                                             BLI 204
      DO 2 J=1,9                                             BLI 206
      AM(I,J)=A(I,J)                                         BLI 208
    2 CONTINUE                                               BLI 210
    3 CONTINUE                                               BLI 212
C     CALCULATION FOR THRUST LOADING, PLANE FLANGES          BLI 214
      XA = 1                                                 BLI 215A
      T=0.                                                   BLI 216
      W=X*XA                                                 BLI 218
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C      PRINT 23                                                          BLT 220A
       DO 4 I=1,9                                                        BLT  222
       B(I)=0.                                                           BLT  224
     4 CONTINUE                                                          BLT  226
       B(3)=-W/(25.132*T)                                                BLT  228
       CALL LIS2 (A,9,10,C,..,B,1,IC,LIERP,IERR,DLT,NPIV,PIV,LRO,LRC)    BLT  230
       IP=0                                                              BLT  232
     5 2C = C*COS(T) ...                                                 BLT 234A
       UF35(IP+1)=2C                                                     BLT  236
       SQR=-(NU*TH/1.82)*2.6*B(1)                                        BLT  238
       SGR=-(NU*TH/1.82)*(2.6*B(7)+3*G*2*1.3/(10.*D))                    BLT  240
       SGT=-(NU*TH/1.82)*(2.6*B(1)+3*G*1.3*E/(10.*L))                    BLT  242
       SCR=-(NU*TH/1.82)*(2.6*B(7)-.7*3(8)/(C*C))                        BLT  244
       SCT=-(NU*TH/1.82)*(2.6*B(7)+.7*B(8)/(C*C))                        BLT  246
       SAT=-(NU*TH/1.82)*(2.6*B(7)+.7*B(8)/(R1*R1))                      BLT  248
C      PRINT 24, ETC, ETC.                                               BLT 250A
       IP=IP+1                                                           BLT  252
       CALL STOPS                                                        BLT 250B
C      GO TO( 6, 16, 14 ), IP                                            BLT 250D
       GO TO( 6,10       ),IF                                            BLT 250C
C      CALCULATION FOR PRESSURE LOADING, BLIND FLANGES                   BLT  256
     6 P=PRESS                                                           BLT  258
       NA = 2                                                            BLT 258A
       W=0.                                                              BLT  260
C      PRINT 25                                                          BLT 262A
       DO 7 I=1,9                                                        BLT  264
       B(I)=0.                                                           BLT  266
     7 CONTINUE                                                          BLT  268
       B(1)=5*R*R*P/(64.*D)                                              BLT  270
       B(2)=-C*P*P/(16.*D)                                               BLT  272
       B(5)=-5*C*P*3.3/(16.*E)                                           BLT  274
       DO 9 I=1,9                                                        BLT  276
       DO 8 J=1,9                                                        BLT  278
       A(I,J)=AS(I,J)                                                    BLT  280
     8 CONTINUE                                                          BLT  282
     9 CONTINUE                                                          BLT  284
       CALL LIS2 (A,9,10,0.,B,1,IC,LIERP,IERR,DLT,NPIV,PIV,LRO,LRC)      BLT  286
       GO TO 5                                                           BLT  288
C ** DELETED CARDS BLT290-322 OF SUBR. BLT, 09-19-75.
C   14 CONTINUE                                                          BLT 320A
    10 CONTINUE                                                          BLT 320B
       IF( NATE.EQ.1 ) CALL COMBIN                                       BLT 320C
       IF( ICODE-1 )  16,16,15                                           BLT 320A
    15 C=C/2.                                                            BLT  328
       CALL ASFEIN                                                       BLT  330
C      FLSOD IS CALLED THRU TASHUE OF SINE3, ASE TIME THRU               BLT  332
       PRINT 27                                                          BLT 334A
    16 CONTINUE                                                          BLT 334B
       RETURN                                                            BLT  336
C                                                                        BLT  338
    17 FORMAT (6E10.5)                                                   BLT  340
    18 FORMAT (90H   FLANGE    FLANGE     FLANGE      PIPE      NUMBER OF   BUBLT  342
     1B        BOLT      PRESSURE,   /90H  O.D.,A    I.D.,B   INSIDE,I  BLT  344
     2LL,G6    BASE,G1    LENGTH,H  CIRCLE,C      F            )        BLT  346
    19 FORMAT (7F16.5,1F16.3/)                                           BLT  348
    20 FORMAT (5E19.5)                                                   BLT  350
    21 FORMAT (90H   BOLT   COEFF. OF   DELTA      MOD. OF BEAM GASKET   TYBLT  352
     1YPE       ICOND     ICODE       RATE              /              BLT  354
     2              STP  LOAD    THERMAL EXP.        ELASTICITY DIAMETER )BLT  356
    22 FORMAT (1F5.1C.3,16,3E1C//)                                       BLT  358
    23 FORMAT (40H CALCULATIONS FOR BOLT LOADING, BLIND FLANGES//)       BLT  360
    24 FORMAT (7H  SQRT= 1E12.4,7H    SGR=E12.4,7H    SGT=E12.4,7H   SCR=E1BLT  362
     12.4,7H    SCT=E12.4,7H   SAT=E12.4//7H       ZC=E12.4//)           BLT  364
    25 FORMAT (40H CALCULATIONS FOR PRESSURE LOADING//)                  BLT  366
    26 FORMAT (30H CALCULATIONS FOR COMBINED LOADINGS//)                 BLT  368
    27 FORMAT (1H1)                                                      BLT  370
       END                                                               BLT  372
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```
      SUBROUTINE ASPEID
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION SS(6,10),SI(10)
      COMMON ITYPE,INCSE,ICODE,RATE,XX,Xa,S,C,PFAST,[illegible]
     1AB,OFF=(4),[illegible],DELTA,END,[illegible]
     2DELTAP,GOUT,GIN,ECG
     3,SLSO,SLS1,SCSO,SCS1,[illegible]
     4,SIP,SIN,SEP,[illegible]
     5,Z2,B1,SS,[illegible],IE,ER1,ER2,ER2P
C
      READ 10, XR,T,GOUT,GIN,Sa,SA,[illegible],IKSO,[illegible]
      PRINT 11
      PRINT 12
      PRINT 13, XR,T,GOUT,GIN,SB,SA,[illegible]
      XA=XA*2.
      XB=XB*2.
      C=C*2.
      IF (IKRO-1) 1,1,2
    1 DO=(GOUT-GIN)/4.
    2 IF (DO-.25) 3,3,4
C     D = GASKET DIAMETER IN THIS SUBROUTINE
    3 D=(GOUT+GIN)/2.
      B=D0
      GO TO 5
    4 B = DSQRT(DO)/2.0
      D=GOUT-2.*B
    5 P=PRESS
      WR11=.785*D*D*P
      WR12=6.28*B*D*M*P
      W31=.785*D*D*P+6.28*B*D*M*P
      SB1=WR1/AB
      WR2=3.14*B*D*Y
      SB2=WR2/AB
      AB1=WR1/SB
      AB2=WR2/SA
      AR = DMAX1(AB1,AB2)
      WGS=(AR+AB)*SA/2.
      MGS=WGS*(C-D)/2.
      MGS1=WR2*(C-D)/2.
      B=(C-XB)/2.-G1
      H=WR11
      HD=.785*HD*XB*B
      HT=H-HD
      HG=WR1-H
      XD=(D+.5*G1)*HC
      XT=((B+G1+(C-D)/2.)/2.)*HT
      XG=((C-D)/2.)*HG
      XOP=XD+XT+XG
      MOS=MGS1/XOP
      PRINT 15
      PRINT 15, DO,WR11,WR12,AB1,SB1,AB2,AB2
      IF (ITYPE-2) 6,6,7
    6 PRINT 16
      PRINT 17, XOP,XGS,XGS1
C     [illegible] WOT, [illegible], [illegible]
    7 IF (ITYPE-2) 9,9,8
    8 SP=((B/XB)**2)*(1.7*B)
      SO1=(((E/TB)**2)*(1.78*W1*(C-B)/2./(B**3)))
      SOP=SP+SO1
      SO2=(((E/TB)**2)*(1.78*WG*(C-B)/2./(B**3)))
      SS3=(((B/TB)**2)*(1.78*WGS*(C-D)/2./(B**3)))
      PRINT 18
      PRINT 19
      PRINT 20, SP,SO1,SO2,SO3,SOS
    9 XA=XA/2.
      XB=XB/2.
      C=C/2.
      RETURN
C
   16 FORMAT (7E16.5,1X4,1E4.5)
```

```
11 FORMAT (1H1)                                                  [illegible] 130
12 FORMAT (1G[illegible]   [illegible]   T   [illegible]         [illegible] 132
 1 [illegible]   [illegible]   [illegible]   [illegible]   )     [illegible] 134
13 FORMAT (7F1[illegible]/)                                      [illegible] 136
14 FORMAT (1[illegible]   [illegible]   [illegible]   [illegible]  [illegible] 138
 [illegible]   [illegible]   [illegible]   [illegible]   )       [illegible] 140
15 FORMAT (1P7E1[illegible]/)                                    [illegible] 142
16 FORMAT ([illegible]   [illegible]   [illegible]   [illegible] ) [illegible] 144
17 FORMAT (1P[illegible]/)                                       [illegible] 146
18 FORMAT ([illegible]   [illegible]   //)                       [illegible] 148
19 FORMAT ([illegible]   [illegible]   [illegible]   [illegible]  [illegible] 150
 [illegible]   [illegible]   )                                   [illegible] 152
20 FORMAT (1[illegible])                                         [illegible] 154
   END                                                           [illegible] 156
```

```
      SUBROUTINE [illegible]                                     FL5    4
C     THIS SUBROUTINE IS CALLED ONLY IF [illegible] = [illegible] FL6   6
      [illegible]                                                [illegible]-20-75
      DIMENSION [illegible]                                      FL5   [illegible]
      COMMON [illegible]                                         FL6    8
     [illegible]                                                 FL5    8
     [illegible]                                                 FL6   [illegible]
     [illegible]                                                 FL5   [illegible]
     [illegible]                                                 FL5   [illegible]
     [illegible]                                                 FL6   [illegible]
C
      [illegible]                                                FL6   12
     [illegible]                                                 FL5   14
      PRINT 22                                                   FL5   16
      PRINT [illegible]                                          FL6   18
      PRINT 2[illegible]                                         FL5   20
      PRINT [illegible]                                          FL6   22
      PRINT [illegible]                                          FL6   24
      PRINT [illegible]                                          FL5   26
      [illegible]                                                FL6   28
      DO 10 [illegible]                                          FL5   30
    1 [illegible]                                                FL5   32
      [illegible]                                                FL6   34
      [illegible]                                                FL5   36
      [illegible]                                                FL5   38
      [illegible]                                                FL6   40
      [illegible]                                                FL5   42
      [illegible]                                                FL6   44
      [illegible]                                                FL6   46
      [illegible]                                                FL5   48
      [illegible]                                                FL6   50
      [illegible]                                                FL5   52
      [illegible]                                                FL6   54
      [illegible]                                                FL6   56
      [illegible]                                                FL5   58
      [illegible]                                                FL6   60
      [illegible]                                                FL5   62
      [illegible]                                                FL6   64
      [illegible]                                                FL6   66
      [illegible]                                                FL5   68
      [illegible]                                                FL6   70
      [illegible]                                                FL5   72
      [illegible]                                                FL6   74
    4 [illegible]                                                FL6   76
```

```
      QTHG=QFHG(2)/THESS
      QTHG=QFHG(3)/DELTA
      G=XM*2.
      YF=YT
      ZF=Z.
      VA=THI+TA+VC+FACT+BSIZE
    3 P=PRESS
      QG1=XL9/(AG*YF)
      QF2=XLI/(AP*YF2)
      G=(XGO+XGI)/2.
      AG=(HGO-HGI)*1.570796
      QG1=VO/(AG*YG)
      QG2=VO/(AG*YG2)
      HG=(C-G)/2.
      QF1=QFHG/HG
      QF2=QF1*(YF/YF2)
      IF (MATE-5) 5,5,4
    4 QFP1=QFHG/(HG*HG)
      GO TO 6
    5 QFP1=QFHGP/HG
    6 QFP2=QFP1*(YFP/YFP2)
      Q1=Q01+QG1+HG*HG*(QF1+QFP1)
      Q2=Q02+QG2+HG*HG*(QF2+QFP2)
      HT=(C-(G+E)/2.)/2.
      HTP=(C-(G+EF)/2.)/2.
      HD=(C-P-GO)/2.
      HDP=(C-EP-GOP)/2.
      COPAL=.7854*HG/Q1
      W2A=W1+(1./Q1)*(-TB*ZB*XLB+TG*ZG*VC+TF*ZF*TH*TFP*ZFP*TAP)
      IF (MATE-5) 8,8,7
    7 W2B=W1+COPAL*(((QG1/HG-QF1*(HT-HG))*G*G-QF1*E*E*(HI-HT))*P
      GO TO 9
    8 W2B=W1+COPAL*(((QG1/HG-QP1*(HT-HG)-QFP1*(HTP-HG))*G*G-(QF1*E*E*(HD-
     1HT)+QFP1*EP*EP*(HDP-HTP)))*(P+PBB)
    9 W2C=W2B-(QFHG/HG+QFHGP/HG)*P*HG/Q1
      IF (MATE-5) 11,11,10
   10 W2D=W1-(QTHG/HG)*DELTA*HG/Q1
      GO TO 12
   11 W2D=W1-(QTHG*DELTA+QTHGP*DELTAP)/Q1
   12 IF (MATE-5) 14,14,13
   13 W2=(Q1/Q2)*W1+(1./Q2)*(-TB*ZB*XLB+TG*ZG*VC+TF*ZF*TH*TFP*ZFP*THP)+(FLG
     1Q1/Q2)*COPAL*(((QG2/HG-QF2*(HT-HG))*G*G-QF2*E*E*(HI-HT))*P-((QFHG/HFLG
     2G)*(YF/YF2)+(QFHGP/HG)*(YFP/YFP2))*P*HG/Q2-(QTHG/HG)*(YF/YF2)*DELTFLG
     3A*HG/Q2
      GO TO 15
   14 W2=(Q1/Q2)*W1+(1./Q2)*(-TB*ZB*XLB+TG*ZG*VC+TF*ZF*TH*TFP*ZFP*THP)+(FLG
     1Q1/Q2)*COPAL*(((QG2/HG-QF2*(HT-HG)-QFP2*(HTP-HG))*G*G-(QF2*E*E*(HD-FLG
     2HT)+QFP2*EP*EP*(HDP-HTP)))*(P+PBB)-((QFHG/HG)*(YF/YF2)+(QFHGP/HG)*(FLG
     3(YFP/YFP2))*P*HG/Q2-(QTHG*DELTA*(YF/YF2)+QTHGP*DELTAP*(YFP/YFP2))/FLG
     4Q2
   15 GO TO (20,16,20,17,20,18), MATE
   16 PRINT 28
      GO TO 19
   17 PRINT 29
      GO TO 19
   18 PRINT 30
   19 PRINT 31
      PRINT 32, QFHGF,QFHGF,QTHGF,3P,GOF,THF,YFF,YFF2,EF
      PRINT 33
      PRINT 32, QFHG,QFHG,QTHG,E,GO,TH,YF,YF2,ZF
      PRINT 34
      PRINT 35, XLB,AP,C,YB,YB2,ZB
      PRINT 36
      PRINT 37, VO,XGO,XGI,YG,YG2,ZG
      PRINT
      PRINT 38
      PRINT 39, W1,TD,TF,TFP,TG,DELTA,DELTAP,P
      PRINT 40
      PRINT 41, W2A,W2B,W2C,W2D,W2
      DWA=W1-W2A
```

```
      DBD=B1-B2F
      BAC=B1-B2C
      DBD=B1-B2D
      BAC=B1-B2
      PRINT 42, DAA,DBB,DBC,DBD,DBCD
      AA=BAA/B1
      BB=BBE/B1
      FC=BAC/B1
      DB=B2B/B1
      ACC=B2/B1
      PRINT 43, AA,FF,AC,FD,ACC
      PRINT 47
   47 FORMAT(//6X,*INITIAL AND RESIDUAL MOMENTS AFTER THERMAL PASSAGE*,
     F,* LOADS.* / )
      XR1=B1*HG
      XR2A=B2A*HG
      XR2B=B2B*HG*.785*P*(DP+BD*(GPG-B*A))*ALT-G*G*HG)
      XR2C=B2C*HG*.785*P*(DP+BD*(GPG-B*B))*ALT-G*G*HG)
      XR2D=B2D*HG
      XR2=B2*HG*.785*P*(DP+BD*(GPG-B*B))*ALT-G*G*HG)
      PRINT 44, XR1,XR2A,XR2B,XR2C,XR2D,XR2
      XR2BP=B2B*HG*.785*P*(DP+BP*BIP*(GPG-BI*BB)*BTP-G*G*HG)
      XR2CP=B2C*HG*.785*P*(DP+BP*BIP*(GPG-BI*BB)*BTP-G*G*HG)
      XR2P=B2*HG*.785*P*(BI*BI*BIP*(GPG-BI*BB)*BTP-G*G*HG)
      PRINT 45, XR2BP,XR2CP,XR2P
C     PRINT 46,WT1,WT2,S,AG,CG1,CG2,AG,WF1,WF2,WFF1,WFF2,W1,W2,
C    1  WT, WTP, WC, WCC, CCFAL
C  30 FORMAT (//3E12.4// 8E12.4)
C  20 PRINT 40
   20 CONTINUE
      RETURN
C
   21 FORMAT (7E16.5/6E16.5/7E16.5)
   22 FORMAT (10H          ESIZE              TD                   L
     1H             HGC              HGI              AG              )
   23 FORMAT (10H          TO               TG                   L
     1S             FACE             FAL                               )
   24 FORMAT (10H          B1               CF                 TFP
     1Z             TFP2             TB2              TG2              )
   25 FORMAT (1P7E15.4)
   26 FORMAT (1P6E15.4)
   27 FORMAT (1P7E15.4//)
   28 FORMAT (86H          FLANGE JOINT BOLT LOAD CHANGE DUE TO APPLIED LOAD
     1S, IDENTICAL PAIR          //)
   29 FORMAT (92H          FLANGE JOINT BOLT LOAD CHANGE DUE TO APPLIED LOAD
     1S, INTEGER TO INTEGER PAIR //)
   30 FORMAT (90H          FLANGE JOINT BOLT LOAD CHANGE DUE TO APPLIED LOAD
     1S, BLIND TO INTEGER PAIR //)
   31 FORMAT (50H          FLANGE JOINT SIDE ONE  (PRIMED QUANTITIES)     /
     1)
   32 FORMAT (7H   WFAC=1PE12.4,7H   GRAG=E12.4,7H   GTRG=E12.4,7H   AB =E
     112.4,9H        GO=E12.4,12H        IB  =E12.4/16H         TS =E12.4,10H
     2             TF2 =E12.4,4H       EF =E12.4/)
   33 FORMAT (50H          FLANGE JOINT SIDE TWO  (UNPRIMED QUANTITIES)   /
     1)
   34 FORMAT (17H             ECITING/)
   35 FORMAT (16H   BOLT LENGTH=1PE12.4,14H   BOLT LEN=E12.4,16H   BOLT CI
     1RCL=E12.4/14H            TB =E12.4,11H          TB2 =E12.4,5H      AB =E1
     22.4/)
   36 FORMAT (16H             GASKET/)
   37 FORMAT (9H     TC  =1PE12.4,7H   AGC =E12.4,7H   XGI =E12.4/14H
     1 TG  =E12.4,13H       TGA =E12.4,6H     EG =E12.4/)
   38 FORMAT (18H             LOADINGS/)
   39 FORMAT (23H   INITIAL BOLT LOAD=1PE12.4,13H   BOLT TEMP.=E12.4,20H
     1 FLANGE ONE TEMP.=E12.4,20H   FLANGE TWO TEMP.=E12.4/15H   GASKET TE
     2MP.=E12.4,9H   DELTA=E12.4,10H   DELTTT=E12.4,11H   PRESSURE=E12.4/
     3/)
   40 FORMAT (53H          RESIDUAL BOLT LOADS AFTER THERMAL-PRESSURE LOADS/)
   41 FORMAT (26H   AXIAL THERMAL,W2A=1PE12.4,19H   POINT SHIFT,W2B=E12.4/
     1//21H   TOTAL PRESSURE,W2C=E12.4,21H   TOTAL THERMAL,W2D=E12.4//10H
```

```
  2 COMBINED,W2=E12.4)
42 FORMAT (//9H  W1-W2A=1PE12.4,9H  W1-W2B=E12.4,9H  W1-W2C=E12.4,9H
  1 W1-W2E=E12.4,9H  W1-W2= E12.4)
43 FORMAT (/9H  W2A/W1=1PE12.4,9H  W2B/W1=E12.4,9H  W2C/W1=E12.4,9H
  1 W2D/W1=E12.4,8H  W2/W1=E12.4)
44 FORMAT (/5H  P1=1PE12.4,6H  P2A=E12.4,6H  P2B=E12.4,6H  P2C=E12.4,
  1 6H  P2D=E12.4,5H  P2=E12.4)
45 FORMAT (/7H  W2P=1PE12.4,7H  W2TP=E12.4,6H  W2P=E12.4)
46 FORMAT (1H1)
   END
```

```
      SUBROUTINE LINS(A,N,ND,EPS,B,M,MD,LTEMP,IERR,DET,MAXV,KIV,LPR,
     1                 LRC)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION A(ND,N),B(MD,M)
      DIMENSION LTEMP(1),LRR(1),LRC(1)
C
C SUBROUTINE LINS
C DECK B006A
C
C SUBROUTINES CALLED - NONE
C
C THIS ROUTINE SOLVES THE MATRIX EQUATION AX=B=C OVERWRITING B WITH THE
C SOLUTION MATRIX X. A MUST BE SQUARE AND NON-SINGULAR. B MUST
C HAVE THE SAME NUMBER OF ROWS AS A. THE DETERMINANT OF A IS
C COMPUTED. BOTH A AND B ARE DESTROYED.
C
C THIS ROUTINE IS RECOMMENDED FOR THE SOLUTION OF SIMULTANEOUS LINEAR
C EQUATIONS.
C
C THE METHOD CONSISTS OF GAUSSIAN ELIMINATION FOLLOWED BY BACK
C SUBSTITUTIONS. THIS IS MORE EFFICIENT THAN SOLUTION BY MATRIX
C INVERSION REGARDLESS OF THE NUMBER OF COLUMNS IN B. BOTH ROWS AND
C COLUMNS ARE SEARCHED FOR MAXIMAL PIVOTS. INTERCHANGING OF ROWS OR
C COLUMNS OF A IS AVOIDED. CHAPTER 1 OF E.L. STIEFEL,INTRODUCTION TO
C NUMERICAL MATHEMATICS,ACADEMIC PRESS,N.Y.,1963,SHOULD BE HELPFUL IN
C FOLLOWING THE CODE.
C
C THE CALLING PROGRAM MUST SET A,B,ND,EPS,N,M,MD,LTEMP TO-
C
C      A-THE COEFFICIENT MATRIX
C
C      N-THE ORDER OF A
C
C      ND-THE NUMBER OF WORDS OF STORAGE PROVIDED FOR EACH COLUMN OF
C         A IN THE CALLING PROGRAM
C
C      EPS-A NON-NEGATIVE NUMBER WHICH EACH PIVOT IN THE ELIMINATION
C          PROCESS IS REQUIRED TO EXCEED IN ABSOLUTE VALUE (CUSTOMARILY
C          ZERO)
C
C      B-THE CONSTANT TERM MATRIX
C
C      M-THE NUMBER OF COLUMNS OF B
C
C
C         B IN THE CALLING PROGRAM
C      MD-THE NUMBER OF WORDS OF STORAGE PROVIDED FOR EACH COLUMN OF
C
C      LTEMP-A BLOCK OF AT LEAST N WORDS OF TEMPORARY INTEGER STORAGE
```

```
C
C IN ADDITION TO OVERWRITING B WITH THE SOLUTION MATRIX X,THE ROUTINE
C SETS IERR,DET,NPIV,PIV,LPR,AND LPC TO
C
C     IERR- 1 IF NO COLUMNS OF X ARE FOUND, THE ELIMINATION PROCESS
C              BEING HALTED BECAUSE THE CURRENT PIVOT FAILS TO EXCEED
C              EPS IN MAGNITUDE
C
C            0 IF ALL COLUMNS OF X ARE FOUND, NO TROUBLE BEING DETECTED
C
C     DET-PLUS OR MINUS THE PRODUCT OF THE CURRENT AND ALL PRECEDING
C         PIVOTS
C
C     NPIV-THE NUMBER OF THE CURRENT PIVOT (FIRST,SECOND,ETC.)
C
C     PIV-THE CURRENT PIVOT
C
C     LPR-THE FIRST NPIV POSITIONS LIST THE PIVOT ROW INDICES IN ORDER
C         OF USE,A VECTOR OF LENGTH N
C
C     LPC-THE FIRST NPIV POSITIONS LIST THE PIVOT COLUMN INDICES IN
C         ORDER OF USE,A VECTOR OF LENGTH N
C
C IF THE ELIMINATION PROCESS IS HALTED PREMATURELY (IERR POSITIVE),THEN
C THE DATA NPIV,PIV,LPR,LPC,MAY BE HELPFUL IN DIAGNOSING THE UNDERLYING
C CAUSE OF THE TROUBLE. IF THE PROCESS GOES TO COMPLETION THEN NPIV=N,
C DET SHOULD BE THE DETERMINANT OF A,PIV WILL BE THE NTH PIVOT,AND LPR
C AND LPC LIST ALL PIVOT POSITIONS.
C
C DO INITIALIZATIONS
C
    1 IERR=0
      DET=1.
      DO 2 I=1,N
      LPR(I)=I
    2 LPC(I)=I
C
C BEGIN ELIMINATION PROCESS
C
      DO 10 NP=1,N
      NPIV=NP
C
C SELECT PIVOT
C
      PIV=0.
      DO 4 K=NP,N
      I=LPR(K)
      DO 4 L=NP,N
      J=LPC(L)
      IF( DABS(A(I,J))-DABS(PIV) ) 4,3,3
    3 KPIV=K
      LPIV=L
      IPIV=I
      JPIV=J
      PIV=A(I,J)
    4 CONTINUE
C
C UPDATE DETERMINANT AND PIVOT ROW AND COLUMN LISTS
C
      DET=DET*PIV
      ITEMP=LPR(NP)
      LPR(NP)=LPR(KPIV)
      LPR(KPIV)=ITEMP
      ITEMP=LPC(NP)
      LPC(NP)=LPC(LPIV)
      LPC(LPIV)=ITEMP
C
C EXIT IF PIVOT TOO SMALL
C
      IF( EPS-DABS(PIV) ) 6,7,7
```

```
    7 IERR= 2
      RETURN
C
C MODIFY PIVOT ROW OF A AND B (ELEMENTS IN PRESENT OR PREVIOUS PIVOT
C    COLUMNS OF A ARE SKIPPED)
C
    8 IF(NP-N)9,11,9
    9 NP1=NP+1
      DO 10 L=NP1,N
      J=LPC(L)
   10 A(IPIV,J)=-A(IPIV,J)/PIV
   11 DO 12 J=1,M
   12 B(IPIV,J)=-B(IPIV,J)/PIV
C
C SUBJECT NON-PIVOT ROWS OF A AND B (ELEMENTS IN PRESENT OR PREVIOUS
C    PIVOT ROWS OR COLUMNS ARE SKIPPED)
C
      IF(NP-N)13,18,13
   13 DO 17 K=NP1,N
      I=LPR(K)
      TEMP=A(I,JPIV)
      IF(TEMP)14,17,14
   14 DO 15 L=NP1,N
      J=LPC(L)
   15 A(I,J)=A(I,J)+A(IPIV,J)*TEMP
      DO 16 J=1,M
   16 B(I,J)=B(I,J)+B(IPIV,J)*TEMP
   17 CONTINUE
   18 CONTINUE
C
C END  ELIMINATION PROCESS
C
C DO BACK SUBSTITUTIONS
C
      DO 23 J=1,M
      DO 21 K=2,N
      KK=N-K+1
      I=LPR(KK)
      DO 21 L=2,K
      LL=N-L+2
      II=LPR(LL)
      JJ=LPC(LL)
   21 B(I,J)=B(I,J)+B(II,J)*A(I,JJ)
   23 CONTINUE
C
C UNSCRAMBLE ROWS OF SOLUTION MATRIX AND ADJUST SIGN OF DETERMINANT
C
      DO 24 I=1,N
      L=LPR(I)
   24 LTEMP(L)=LPC(I)
      DO 28 I=1,N
   25 K=LTEMP(I)
      IF(I-K)26,28,26
   26 DET=-DET
      DO 27 J=1,M
      TEMP=B(I,J)
      B(I,J)=B(K,J)
   27 B(K,J)=TEMP
      LTEMP(I)=LTEMP(K)
      LTEMP(K)=K
      GO TO 25
   28 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE COMBIN
      IMPLICIT REAL*8 (A-H,O-Z)                                          COMBIN
      DIMENSION S(6,10) , SC(10)
      DATA SC/10*0.0/                                                    COMBIN
      COMMON ITYPE,IMODL,ICODE,MATE,A1,B1,[illegible],PRESS,MCS,[illegible],G1,[illegible],IA,TR,FIA    4
     1AE,[illegible],A1,DELTA,IPO,IPCA,CPRGE,CPEGT,CPGP,[illegible],IMP,ITP,[illegible],FIA       5
     2DELTAP,[illegible],CIB,DOG,SLSA,SLSI,SCSA,SCSI,SILO,SLII,[illegible],SI4,
     3 STP,S[illegible],S[illegible],ZG,ZC,[illegible],TC,TL,T1,[illegible],SC[illegible],[illegible]
     4 W2, W1, S, SA, I1, IP1, IP2, [illegible]
C
      IC = 0
      IF(MATE.LE.2) IT=ITYPE
      GO TO( 1,4,3 ),IT                                                  COMBIN
    1 IC = IC + 1
      IF(IC.GT.2) GO TO 99
      IF(MATE.GT.1) PRINT 49
      PRINT 50
      NN = 10
      DO 8 NA = 1,3
      GO TO( 5,6,7 ),NA                                                  COMBIN
    5 PRINT 53
      GO TO 8
    6 PRINT 54
      GO TO 8
    7 PRINT 55
    8 GO TO( 12,13 ),IC                                                  COMBIN
   12 PRINT 60, (S (NA, I), I=1,NN)
      GO TO 8
   13 PRINT 60, (S (NA+3,I), I=1,NN)
    8 CONTINUE
      IF(MATE.EQ.1) GO TO 99
      DO 9 I=1,NN
      GO TO( 10,11 ),IC                                                  COMBIN
   10 SC(I) = S(1,I)*RR2B/RR1*S(2,I) + S(3,I)
      GO TO 9
   11 SC(I) = S(4,I)*RR2/RR1* S(5,I) + S(6,I)
    9 CONTINUE
      GO TO( 40,41 ),IC                                                  COMBIN
   40 PRINT 56, RR2B
      GO TO 42
   41 PRINT 56, RR2
   42 PRINT 60, (SC(I),     I=1,NN)
      IF(MATE.EQ.2) GO TO 99
      IF(IT.EQ.IT2) GO TO 1
      IF(MATE.EQ.4) GO TO 2
      IF(MATE.EQ.4) GO TO 99
    2 IC = IC + 1
      IF(IC.GT.2) GO TO 99
      IF(MATE.GT.1) PRINT 49
      PRINT 51
      NN = 13
      DO18 NA = 1,3
      GO TO( 15,16, 17 ),NA                                              COMBIN
   15 PRINT 53
      GO TO 18
   16 PRINT 54
      GO TO 18
   17 PRINT 55
   18 GO TO( 22,23 ),IC                                                  COMBIN
   22 PRINT 61, (S (NA, I), I=1,NN)
      GO TO18
   23 PRINT 61, (S (NA+3,I), I=1,NN)
   18 CONTINUE
      IF(MATE.EQ.1) GO TO 99
      DO19 I=1,NN
      GO TO( 20,21 ),IC                                                  COMBIN
   20 SC(I) = S(1,I)*RR2B/RR1*S(2,I) + S(3,I)
      GO TO19
   21 SC(I) = S(4,I)*RR2/RR1* S(5,I) + S(6,I)
   19 CONTINUE
      GO TO( 43,44 ),IC                                                  COMBIN
```

```
63 PRINT 56, XM2F
   GO TO 65
64 PRINT 56, XM2
65 PRINT 61, (SC(I),    I=1,NN)
   IF(MATE.EQ.2) GO TO 99
   IF(IT.EQ.IT2) GO TO 2
   IF(MATL.EQ.0) GO TO 1
   IF(MATE.EQ.0) GO TO 99
 1 IC = IC + 1
   IF(MATE.GT.1) PRINT 65
   PRINT 52
   NS = 7
   DO 28 NA=1,2
   GO TO( 25,26 ),NA                                                   COMBIN
25 PRINT 53
   GO TO 28
26 PRINT 54
28 PRINT 62, (S (NA,I), I=1,NN)
28 CONTINUE
   IF(MATE.EQ.1) GO TO 99
   DO 29 I=1,NN
   SC(I) = S(1,I)*W2/W1 + S(2,I)
29 CONTINUE
   PRINT 56 , W2
   PRINT 62, (SC(I), I=1,NN)
   GO TO( 1,2 ), ITYPE                                                 COMBIN
99 PRINT 69
   RETURN
69 FORMAT (1H1)
50 FORMAT (//50H             TAPERED HUB FLANGE                     /)
51 FORMAT (//50H             STRAIGHT HUB FLANGE                    /)
52 FORMAT (//50H             BLIND FLANGE                           /)
53 FORMAT(50H       CALCULATIONS FOR MOMENT LOADING                //)
54 FORMAT(50H       CALCULATIONS FOR PRESSURE LOADING              //)
55 FORMAT(50H       CALCULATIONS FOR TEMPERATURE LOADING           //)
56 FORMAT( 50H      CALCULATIONS FOR COMBINED LOADING, W2 IS NOT FOR ITY
  1PE=1 OR 2, W2 FOR ITYPE=3,  =     1PE12.4 //)
57 FORMAT(50H       CALCULATIONS FOR BOLT LOADING                  //)
60 FORMAT (7H  SLSO= 1PE12.4,7H  SLSI=E12.4,7H  SCSO=E12.4,7H  SCSI=E TAP   900
  12.4//7H  SLLO=E12.4,7H  SLLI=E12.4,7H  SCLO=E12.4,7H  SCLI=E12.4//7 TAP  902
  27H   STH=E12.4,7H   STF=E12.4,7H   SRH=E12.4,7H   SRF=E12.4//5H  TAP    904
  3G=E12.4,5H  ZC=E12.4,7H  QPHG=E12.4,5H  YC=E12.4,5H  Y1=E12.4,8H  TAP    906
  4THETA=E12.4/)                                                    TAP    908
61 FORMAT (7H  SLSO= 1PE12.4,7H  SLSI=E12.4,7H  SCSO=E12.4,7H  SCSI=E STR  922
  12.4//7H    STH=E12.4,7H    STF=E12.4,7H    SRH=E12.4,7H   SRF=E12.4//5 STR 924
  25H  ZG=E12.4,5H  ZC=E12.4,7H  QPHG=E12.4,5H  Y0=E12.4,8H  THETA=E STR  926
  312.4/)                                                           STR    928
62 FORMAT (7H  SORT= 1PE12.4,7H   SOR=E12.4,7H   SOT=E12.4,7H   SCR=E BLI  362
  12.4,7H   SCT=E12.4,7H   SAT=E12.4//9H      ZC=E12.4//)           BLI    364
   END
```

```
      SUBROUTINE STORE
      IMPLICIT REAL*8 (A-H,O-Z)                                        STORE
      DIMENSION S(6,18), SC(18)
      COMMON ITYPE,IBOLT,ICODE,MATE,XA,XB,[illegible],PRESS,RGS,AOP,G1,G0,AH,TR,FLA     4
     1HB,QPHA(4),AL,DELTA,XMO,XFCA,CPHGF,QFFCL,CTHGF,BF,[illegible],ANP,TFF,ATF,FLA     5
     2DELTAP,[illegible],ACG,SLSO,SLSI,SCSO,SCSI,SLLO,SLLI,SCLO,SCLI,STH,
     3  STF,SRH,SRF,ZG,ZC,QPHG,Y0,Y1,T1,THETA,SCAT,SOR,SOT,SCR,SCT,SAT,
     4 W2, W1, S, NA, IT, XM1, XM2, XM2F
C
```

```
      GO TO( 4,4,4,4,4,5 ),NSK                                    [illegible]
5     NA = NA +1
4     GO TO( 1,2,3 ),ICWE                                         [illegible]
1     S(NA,1 ) = SLSC
      S(NA,2 ) = SLSS
      S(NA,3 ) = SCSD
      S(NA,4 ) = SCSS
      S(NA,5 ) = SLLS
      S(NA,6 ) = SLSI
      S(NA,7 ) = SCLD
      S(NA,8 ) = SCSI
      S(NA,9 ) = STF
      S(NA,10) = SLF
      S(NA,11) = SFE
      S(NA,12) = SBF
      S(NA,13) = TC
      S(NA,14) = SC
      S(NA,15) = JFWS
      S(NA,16) = Y0
      S(NA,17) = Y1
      S(NA,18) = ZT
      GO TO 50
2     S(NA,1 ) = SLSC
      S(NA,2 ) = SLSI
      S(NA,3 ) = SCSC
      S(NA,4 ) = SCSI
      S(NA,5 ) = STE
      S(NA,6 ) = STF
      S(NA,7 ) = SEB
      S(NA,8 ) = SFF
      S(NA,9 ) = SS
      S(NA,10) = SC
      S(NA,11) = JFWS
      S(NA,12) = Y0
      S(NA,13) = [illegible]
      GO TO 50
3     S(NA,1 ) = SCFC
      S(NA,2 ) = SGB
      S(NA,3 ) = SGT
      S(NA,4 ) = SCS
      S(NA,5 ) = SCT
      S(NA,6 ) = SAT
      S(NA,7 ) = SC
50    RETURN
      END
```