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A COMPARISON OF BUFFER STRIP AND
NON-BUFFER STRIP JOINT DESIGNS

James Michael Gill

NAVAL POSTGRADUATE SCHOOL

Monterey, California



THESIS

A COMPARISON OF BUFFER STRIP AND NON-BUFFER
STRIP JOINT DESIGNS

by

James Michael Gill

June 1976

Thesis Advisor:

M.H. Bank II

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A COMPARISON OF BUFFER STRIP AND NON-BUFFER STRIP
JOINT DESIGNS

by

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from the

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June 1976

ABSTRACT

Buffer strip and non-buffer strip bolted wing skin type joints made from NARMCO 5208/T300 graphite-epoxy material were designed, and the excess bearing capacity and weight of these joints were calculated for a wide range of laminate compositions, bolt hole sizes, and number of bolt holes. Design load conditions representative of an advanced fighter type aircraft were chosen. Joint designs were arbitrarily restrained by assumed manufacturing conditions, assumed interface conditions, and imposed laminate composition restrictions. Charts were prepared from which relative joint efficiencies could be determined but no attempt was made to analyze the effect of the arbitrary design restrictions. The advantages and penalties for buffer strip design were discussed and recommendations for future studies were made.

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LIST OF SYMBOLS

- AD = overall buffer strip joint width (in.)
- A_n = constant of proportionality between the bolt load P and the portion of P reacted each of the primary strips of a buffer strip joint
- B = excess bearing capacity
- D = bolt hole diameter (in.)
- E_x = tensile modulus (lbf./in.²)
- E_{x_1} = tensile modulus of the primary strips in a buffer strip joint (lbf./in.²)
- E_{x_2} = tensile modulus of the buffer strip material in a buffer strip joint (lbf./in.²)
- F_{BP} = bypass force (lbf.)
- F_S = shear load passing P_1 from a buffer strip to a primary strip (lbf.)
- F_r = reaction force (lbf.)
- $f(\frac{a}{r})_Q^i$ = effective isotropic stress concentration factor at location i for load condition Q
- f_s = shear stress between the buffer and primary strips of a buffer strip joint (lbf./in.²)
- i = indicator of exact position on the hole
- L = tensile load (lbf.)
- ℓD = side length (in.)
- M = number of rows of bolts in a buffer strip joint
- m = reaction moment (in.-lbf.)
- N = number of rows of bolts in a non-buffer strip joint
- N_x = tensile load (lbf./in.)

N_{xy} = shear load (lbf./in.)

P = tensile bolt load (lbf.)

P_s = shear bolt load (lbf.)

P_1 = portion of P reacted in each of the primary strips
of a buffer strip joint (lbf.)

P_2 = portion of P reacted in the buffer strip material of
a buffer strip joint (lbf.)

R = resultant bolt load (lbf.)

S_1 = representative applied stress (lbf./in.²)

S_2 = representative failure stress (lbf./in.²)

t = plate thickness (in.)

t^* = effective plate thickness (in.)

$t_{\pm 45}$ = total thickness of $\pm 45^\circ$ laminae (in.)

W_{BD} = width of buffer strip material (in.)

W_{1D} = half-width of primary laminate material in a buffer
strip joint (in.)

Z = percentage of zero degree plies in the primary
strips of a buffer strip joint

α = subscript denoting applied load conditions as
follows:

= bx bearing in x direction

= by bearing in y direction

= tx tension in x direction

= ty tension in y direction

= xy shear

ϵ = strain (in./in.)

λ_{α}^i = finite width correction factor at location i for

applied load condition α

η = indicator of position in a joint

σ_{BR} = resultant bolt bearing stress (lbf./in.²)

σ^i = net tangential stress at location i

σ_{α} = applied stress for load condition α

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I. INTRODUCTION

A. BACKGROUND

Aerospace structural design requirements have often been characterized by a demand for high strength and low weight. In many cases, the design possibilities have been limited by the available manufacturing technology and the acceptable manufacturing costs. The most successful designs were usually those which met all these constraints most efficiently.

The demand for high structural efficiency led to the development of advanced laminated composites which have higher strength-to-weight ratios and better fatigue properties than conventional structural materials (Ref. 1). As discussed in Ref. 2, it has also been possible to build laminated composite materials with higher modulus values than those characteristic of conventional materials. Accurate methods for tailoring the properties of such materials have evolved and such tailoring has become accepted design practice (Refs. 3,4,5). Waddoups, in Ref. 6, explained that significant gains in structural efficiency have been demonstrated by doing no more than substituting such a tailored composite for a conventional material keeping the geometry and mating interfaces the same.

These gains were realized because the composite materials used were less dense than the conventional

structural materials which they replaced. These material substitutions did not exploit the high strength and high modulus values achievable with advanced laminated composites.

B. OBJECTIVES

This study was intended to demonstrate the structural efficiencies which could be achieved by designs which took into account some of the high strength and high modulus properties of advanced composites. It was decided to demonstrate these efficiencies by analyzing the behavior of a plate of laminated material in the region of a bolted joint. This situation corresponded to that of a wing skin attached by a bolted fitting to the fuselage of an aircraft.

It was assumed that the wing skin would be attached to the aircraft fuselage through an aluminum alloy fitting. A maximum interbolt strain level, ϵ , of 3000 micro-inches per inch and an inter-bolt spacing of four hole diameters were taken as representative of such fittings.

Design conditions representative of an advanced fighter type aircraft were chosen. The joint was to carry a tensile load, N_x , of 20,000 lbf. per inch of chord. It was assumed that the joint fittings would be covered by an aerodynamic fairing, and a maximum joint length of ten inches was allowed.

To keep the joint manufacture as simple as possible, it was decided that the skin thickness would vary linearly in the joint and that for any given joint design, all holes

would be of the same diameter. To simplify the analysis it was decided to limit the candidate materials to balanced design laminates composed of zero and ± 45 degree plies of uniform thickness and material composition. No attempt was made to judge the effect of these restrictions on design efficiency.

The interface requirements determined by the aluminum fitting, and the geometric requirements to satisfy manufacturing simplicity, limited the possible joint designs and prevented full utilization of the high strength and high modulus properties available in the selected materials. It was felt, however, that even under these restrictions it would still be possible to demonstrate significant structural efficiencies by properly tailoring the laminates used in the wing skin.

C. RELIABILITY CONSIDERATIONS

Aerospace structural designs have had to meet difficult requirements for reliability. These designs have had to be sufficiently strong to carry the required loads and light enough to work in the aerospace environment. In addition to these requirements, critical components of aerospace structures have been expected to demonstrate that they are "fail-safe" and, in military applications at least, to some degree battle damage tolerant.

Early composite materials were judged inadequate for aerospace applications because they could not meet these reliability conditions. At first, quantity production of

advanced laminates was impossible because the required quality control technology did not exist. Wide batch-to-batch variation of the properties of these early materials justified only low confidence levels in their structural reliability. Although the early advanced composites were considered unreliable, materials research continued, driven by the anticipated structural efficiencies such materials could make possible. In 1973, Kaminski reported that NARMCO 5208/T300 graphite-epoxy laminates could meet the anticipated requirements for high strength, high modulus, and low weight and could be manufactured reliably and delivered with minimal batch-to-batch variation of material properties (Ref. 2). This was chosen as the structural material to be used in this study.

The requirement for battle damage tolerance and fail-safe design is met by a variety of methods in designs with conventional materials. These methods include built in high excess load bearing capacity, alternate load paths, and various crack stoppage stress relief devices. All of these techniques can be applied to design with composite materials. In addition to these techniques there is a "buffer strip" material fabrication technique applicable to laminated composites which provides an integral crack stoppage capability. Kaminski and Eisenmann explained this technique in Ref. 7.

In buffer strip design, integral "buffer strips" of low modulus, high fracture toughness material are included

in the laminate. These strips are spaced so that cracks originating in the high modulus load bearing primary strips are arrested when they run into the buffer strips. Using this technique, structures can be built in which cracks would be arrested before entire structural components failed. It appears that this could be an effective and efficient way to increase battle damage tolerance and the capability of a structural component to function after crack initiation.

D. RANGE OF THE STUDY

NARMCO 5208/T300 $[0/\pm 45]$ buffer strip and non-buffer strip joints were designed for widely varying laminate compositions, numbers and sizes of bolts. To simplify joint fabrication, the joint thickness was varied linearly between the inboard and outboard thicknesses, and all bolt holes for any given joint design were of the same diameter. To interface with the aluminum alloy fittings, the interbolt strain level was held to a maximum of 3000 micro-inches per inch, and the interbolt spacing was set at four hole diameters. The designs were compared to determine the effects of variation of hole size, number of holes, and laminate composition upon joint weight and excess bearing capacity.

Joint weight was considered a measure of the joint structural efficiency. Joint excess bearing capacity was considered a measure of allowable fabrication error. Since drilling holes in fibrous laminated composites has been

found to be both difficult and expensive, it was felt that the number of holes in any joint would be a measure of the relative joint fabrication cost (Ref. 5).

II. ANALYSIS OF THE NON-BUFFER STRIP JOINT

A. SIZING THE NON-BUFFER STRIP JOINT

Figure 1 is a schematic drawing showing the wing skin configuration used in the non-buffer strip joint design. All bolt holes are of the same diameter. For this analysis, wing taper is disregarded and the bolt hole centers are assumed placed in parallel rows and columns four hole diameters apart.

In the following theoretical development, it is assumed that the applied tensile load, N_x , and the applied shear load, N_{xy} , are constant across the outboard edge of the joint. Thus it is possible to size the joint considering only one column of bolts. It is further assumed that fittings were designed so that each bolt transfers the same portion, P , of the applied tensile load and that each bolt in the inboard row transfers, in addition to P , the same portion P_s of the shear load. In actual practice it is doubtful that this idealization could be achieved. However, it is a standard design assumption used in industry today (Ref. 8). This assumption implies a high resultant bolt load, R , in the inboard row of bolts.

From experimental analysis, it was known that layups of all ± 45 degree laminae would have a superior bolt load

bearing capacity (Ref. 9). Since the wing skin would be required to carry no applied load beyond the inboard row of bolts, it was decided to take advantage of this high bearing load capacity for all designs by requiring that, at the inboard row of bolts, the skin be composed of 100 per cent ± 45 degree plies.

Considering a four-hole-diameters-wide column of bolts, the total tensile load L in the skin is given by

$$(1) \quad L = N_x 4D$$

where D is the bolt diameter used in the joint. If there are N bolts in each column,

$$(2) \quad P = \frac{L}{N} = \frac{N_x 4D}{N}$$

As explained in Ref. 10, the bearing stresses in a plate due to bolt loads are a function of the magnitude of the bolt load, the diameter of the bolt hole, and the effective thickness of the plate. For this study t^* , the effective bolt bearing thickness of the plate, is defined as follows:

$$\text{for } t \leq 2D, \quad t^* = t$$

$$\text{for } t > 2D, \quad t^* = 2D$$

where t is the plate thickness. This definition of effective bearing plate thickness is adopted to account for the fact that in thick plates loaded through a bolt hole the bolt loads tend to distribute themselves so that higher portions of the load are carried at the plate edges than at the plate center. The thickness definition was not chosen

through rigorous experimental or analytical processes but rather in light of engineering experience with metal plates. The bolt bearing stress, σ_{BR} , is

$$(3) \quad \sigma_{BR} = \frac{\text{Bolt Load}}{D t^*}$$

On all but the inboard row of bolts,

$$(4) \quad \sigma_{bx} = \frac{4 N_x}{N t^*}$$

Since the inboard bolts in the non-buffer strip joints are assumed to react the shear as well as a share of the tensile load, they carry a bolt load, R, given by:

$$(5) \quad R^2 = \left(\frac{N_x 4D}{N} \right)^2 + (N_{xy} 4D)^2$$

$$(6) \quad R = 4DN_x \left[\left(\frac{1}{N} \right)^2 + \left(\frac{N_{xy}}{N_x} \right)^2 \right]^{\frac{1}{2}}$$

The bearing stress on these inboard bolts is

$$(7) \quad \sigma_{BR} = \frac{4N_x}{t^*} \left[\left(\frac{1}{N} \right)^2 + \left(\frac{N_{xy}}{N_x} \right)^2 \right]^{\frac{1}{2}}$$

Test specimens composed of NARMCO 5208/T300 $[\pm 45]$ layers were found to be able to withstand

$$\sigma_{BR}^{\text{max}} = 78000 \text{ lbf./in.}^2$$

when this load was applied through untorqued bolts (Ref. 9). This value is used in Eq. 7 to determine the minimum allowable joint thickness at the inboard bolt holes. In cases where this is a critical design parameter, the geometry illustrated in Fig. 2(a) is used to size the joint. Otherwise, the geometry illustrated in Fig. 2(b) is used.

The bolt hole center locations are numbered from one to N beginning with location 1 at the first or outboard bolt and ending with location N at the last or inboard bolt. To simplify the analysis, other locations in the joints are specified by a parameter η , defined relative to the bolt hole numbers. $\eta = 1$ means at the position of the first bolt hole center, $\eta = 2$ means at the position of the second bolt hole center, and $\eta = N$ means at the position of the inboard bolt hole center. Intermediate positions are defined as follows:

$\eta = 1.5$ means halfway between $\eta = 1$ and $\eta = 2$

$\eta = 2.5$ means halfway between $\eta = 2$ and $\eta = 3$

$\eta = N-.5$ means halfway between $\eta = N-1$ and $\eta = N$

The bypass force, F_{BP} , in the joint is defined as the tensile load passed from station η to station $\eta+1$, thus,

$$F_{BP} = N_x 4D \left(1 - \frac{\eta}{N}\right) \quad (\eta = \text{integer})$$

The bypass stress, σ_{tx} , is defined as

$$\sigma_{tx} = \frac{F_{BP}}{4Dt}$$

The bypass strain ϵ is defined as

$$\epsilon = \frac{\sigma_{tx}}{E_x}$$

where E_x is the tensile modulus of the material.

The strain level halfway between station η and $\eta+1$ is given by

$$(8) \quad \epsilon_{\eta+0.5} = \frac{N_x (1 - \frac{\eta}{N})}{t E_x \eta+0.5} \quad (\eta = \text{integer})$$

Both thickness and tensile modulus of the material are allowed to change with location within the joint.

The stress-strain behavior of a zero degree NARMCO 5208/T300 lamina is linear to failure. As reported in Ref. 2, the modulus of elasticity of such a lamina in the direction of the graphite fibers was determined by experiment to be 20.5×10^6 lbf./in.². The stress-strain behavior of a NARMCO 5208/T300 45 degree lamina is not linear. Tests performed in 1974, (Ref. 11), for a NARMCO 5208/T300 45 degree lamina under room temperature dry conditions reported the stress-strain behavior in the form of a secant modulus, which varied with strain level from 2.9×10^6 lbf./in.² at zero strain to 1.3×10^6 lbf./in.² at a strain level of 13000 micro-in./in. as shown in Fig. 3. (Secant modulus is the slope of a line through a point on the stress-strain curve and the origin.)

As explained in Ref. 3, the strain state for a balanced laminate composed of n layers is described by

$$(9) \quad \begin{bmatrix} N_x \\ N_y \\ N_{xy} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{14} \\ A_{12} & A_{22} & A_{24} \\ A_{14} & A_{24} & A_{44} \end{bmatrix} \begin{bmatrix} \epsilon_x \\ \epsilon_y \\ \epsilon_{xy} \end{bmatrix}$$

where $[N]$ is a vector of applied tensile and shear loads and $[\epsilon]$ is a vector describing the strain state of the plate. The components of the $[A]$ matrix are defined as

follows:

$$(10) A_{ij} = \sum_{k=1}^n \bar{C}_{ij}^k t_k$$

where \bar{C}_{ij}^k are the elements of the compliance matrix of the k^{th} lamina.

This study is concerned only with balanced design laminates made from laminae of uniform thickness and material composition and oriented at either zero or ± 45 degrees to the spanwise direction. For such laminates, it is seen from Eqs. 9 and 10 that the various moduli vary linearly with the per cent of zero degree plies in the laminate. Because the ± 45 degree data on secant modulus was available, and because the secant modulus is convenient for design use, a laminate value of secant modulus was calculated. Figure 4 shows the variation of secant modulus with laminate composition for NARMCO 5208/T300 $[0/\pm 45]$ material at $\epsilon = 3000$ micro-in./in. It was prepared assuming that this modulus varies linearly between the experimentally determined values for such laminates with zero and 100 per cent zero degree plies. Figure 4 is used to determine the tension modulus of the various NARMCO 5208/T300 $[0/\pm 45]$ laminates used in the study joint designs.

The laminate composition at station $\eta = 1.5$ is assumed to be the same as that of the wing skin outboard of the joint. It determines the tensile modulus at this position. Equation 8 is then used to determine $t_{1.5}$.

The laminate composition at station $\eta = N-.5$ is initially

determined by assuming that the percentage of zero degree plies varies linearly from station $\eta = 1.5$ to station $\eta = N$ where the laminate is to be composed of 100 per cent ± 45 degree plies. An additional constraint, applicable only to the non-buffer strip joint, is that the laminate at station $\eta = N-.5$ can have no fewer than 5 per cent zero degree plies. This is done to ensure that there are sufficient load bearing zero degree plies to carry the bypass load between the second to last and the last, or inboard, row of bolts.

Having fixed the laminate composition, the tensile modulus and, through Eq. 8, the thickness at station $N-.5$ are determined.

The remaining joint thicknesses are determined assuming a linear variation of joint thickness between $\eta = 1.5$ and $\eta = N-.5$. Laminate compositions midway between each pair of adjacent bolts are determined using the thickness distribution and the desired strain level.

$$(11) \quad E_{x\eta+.5} = \frac{N_x (1 - \frac{\eta}{N})}{t_{\eta+.5} \epsilon} \quad (\eta = \text{integer})$$

The tension modulus, E_x , of the material is assumed to vary linearly with distance between the values determined from Eq. 11. Thus,

$$(12) \quad E_{x\eta} = \frac{E_{x\eta-.5} + E_{x\eta+.5}}{2} \quad (\eta = \text{integer})$$

These modulus values determine the laminate composition throughout the joint.

Joints are sized using 0.25, 0.375, 0.4375, and 0.5 inch bolts with laminate compositions at the first bolt varying from 60 to 10 per cent zero degree plies. These laminate compositions cover the range over which the Eisenmann strength model to be described in the next section was considered accurate. In all cases, the same interbolt strain level, 3000 micro-inches per inch, is maintained. The minimum number of bolts used in any joint design is three. This is done to provide a mechanism by which the desired strain level can be maintained. The maximum number of bolts in any joint is determined by the desired interbolt spacing of four bolt hole diameters and the requirement that the joint length not exceed ten inches.

B. DETERMINING THE STRENGTH OF A NON-BUFFER STRIP JOINT

Waddoups, Eisenmann, and Kaminski, in Ref. 12, showed experimentally that graphite-epoxy laminates are statically brittle and exhibit many of the failure characteristics of brittle materials first explained by Griffith in Ref. 13. They formulated a model which assumed that crack growth behavior in graphite-epoxy laminates was a function of stress intensity and critical energy level, and they verified their model by experiment.

In Ref. 14, Eisenmann continued this work and developed a bolted joint strength model for composite materials. This model accounted for the material ultimate strengths, local stress intensity factors, and geometric width correction factors. With the Eisenmann model, it was

possible to calculate the total stress at any point on a loaded circular hole in an orthotropic plate by linearly combining the various stresses acting upon the plate using Eq. 13. Because of the internal curve fitting techniques used in this model, it was considered to give accurate results for laminate compositions varying from 10 to 60 per cent zero degree plies (Ref. 14).

$$\begin{aligned}
 (13) \quad \sigma^i &= \lambda_{tx}^i f\left(\frac{a}{r}\right)^i_{tx} \sigma_{tx} + \lambda_{ty}^i f\left(\frac{a}{r}\right)^i_{ty} \sigma_{ty} \\
 &+ \lambda_{xy}^i f\left(\frac{a}{r}\right)^i_{xy} \sigma_{xy} + \lambda_{bx}^i f\left(\frac{a}{r}\right)^i_{bx} \sigma_{bx} \\
 &+ \lambda_{by}^i f\left(\frac{a}{r}\right)^i_{by} \sigma_{by}
 \end{aligned}$$

where:

i = indicator of the exact position on the hole.

λ_{α}^i = finite width correction factor at location i for applied load condition α

$f\left(\frac{a}{r}\right)^i_{\alpha}$ = effective isotropic stress concentration factor at location i for applied load condition α

σ_{α} = applied stress for load condition α

σ^i = net tangential stress at location i

α = subscript denoting applied load condition as follows:

xy = shear

tx = tension in x - direction

ty = tension in y - direction

bx = bearing in x - direction

by = bearing in y - direction

The stress definitions are sketched in Fig. 5. The λ and f factors are determined by plate geometry and material composition.

The failure modes of NARMCO 5208/T300 $[0/\pm 45]$ plates with loaded holes were determined by test (Ref. 14).

Crack initiation in the test specimens most often occurred on the hole edge at positions $\beta=0, \pm 45, \pm 90, \pm 135$, or 180 degrees measured from the X axis. From symmetry it was determined that all these failure modes could be adequately described by description of the failure modes encountered at $\beta = 0, 45$, and 90 degrees. Laminate strength for each of these positions was determined by experiment (Ref. 14). In these tests the bolts used to load the holes were untorqued.

The Eisenmann static strength model was used to calculate stress intensity and geometric width correction factors based upon an interbolt spacing of four hole diameters. Equation 13 was used to prepare Figs. 6-29 which define the failure modes expected for laminates whose composition varies from 60 to 10 per cent zero degree plies with 0.25, 0.375, 0.4375, and 0.50 inch holes. Only the effects of σ_{xy} , σ_{tx} , and σ_{bx} were considered in the preparation of these curves.

One of the parameters of interest in this study is the excess bearing capacity of each joint design. For purposes of this study the excess bearing capacity of the joint is defined as the smallest excess bearing capacity at any

bolt hole in the joint. At each hole a representative stress load, S_1 , which accounts for the combined bearing and bypass stresses is calculated as follows:

$$(14) \quad S_1 = \left[\sigma_{bx}^2 + \sigma_{tx}^2 \right]^{\frac{1}{2}} \quad \text{as loaded}$$

A representative ultimate strength, S_2 , is calculated from:

$$(15) \quad S_2 = \left[\sigma_{bx}^2 + \sigma_{tx}^2 \right]^{\frac{1}{2}} \quad \text{at failure}$$

where the failure state is the state at which

$$(16) \quad \left[\frac{\sigma_{bx}}{\sigma_{tx}} \right]_{\text{failure}} = \left[\frac{\sigma_{bx}}{\sigma_{tx}} \right]_{\text{loaded}}$$

Then, as shown in Fig. 30, the excess bearing capacity, B is defined as

$$(17) \quad B = \frac{S_2 - S_1}{S_1}$$

$B > 0$ at all holes in a joint implies that there is some margin of safety.

$B = 0$ at any hole in a joint implies that there is no margin of safety.

$B < 0$ at any hole in a joint implies that the joint would fail under the applied load.

The effect of laminate composition and bolt hole size on excess bearing capacity is shown in Figs. 31, 32, and 33.

C. DETERMINING THE WEIGHT OF A NON-BUFFER STRIP JOINT

The weights per inch of chord for the non-buffer strip joints were calculated by multiplying the cross-sectional

areas of each joint by the density of NARMCO 5208/T300 graphite-epoxy laminate material. The effect of laminate composition, hole size, and number of bolt holes upon joint weight is shown in Figs. 34, 35, and 36.

III. ANALYSIS OF THE BUFFER STRIP JOINT

A. SIZING THE BUFFER STRIP JOINT

Figure 37 is a schematic of the buffer strip joint design. All bolt holes are of the same diameter. Except for the inboard row, all bolt holes are placed in the buffer strips. This placement was chosen for two reasons:

1. It took advantage of the high bearing capacity of NARMCO 5208/T300 $[\pm 45]$ laminates.
2. It reduced stress concentrations in the heavily loaded primary strips.

The bolt holes in the buffer strips are spaced so that there is a distance of four hole diameters between adjacent hole centers. Two bolt holes are placed in each primary strip which is located between two buffer strips. These bolt holes are placed in a row with the inboard bolt in the buffer strip. In the joint analysis, wing taper is disregarded and the spanwise edges of the buffer and primary strips are considered parallel. It is assumed that joint thicknesses at any position are the same in the buffer and primary strips.

The buffer strips used in the joints analyzed in this study are four hole diameters wide, and the two primary

strips are each 3.335 hole diameters wide. This gives an overall buffer strip joint width of 10.67 hole diameters. These dimensions were chosen because it was felt that they were representative of a geometry which could be used in an advanced fighter type aircraft wing skin application. No attempt is made to justify these dimensions either analytically or experimentally, and no attempt is made to assess the effect of this choice of dimensions upon joint efficiency.

In the following theoretical development, as in the case of the non-buffer strip joint, a tensile load N_x and a shear load N_{xy} are assumed constant across the outboard edge of the joint. It is also assumed that fittings were designed so that each row of bolts in the joint transfers the same portion P of the applied tensile load and so that the shear load is reacted by the inboard row of bolts, each of the inboard bolts carrying an equal share of the shear load as well as a share of the tensile load. To utilize the high bearing capacity of a NARMCO 5208/T300 [± 45] laminate, it was decided to impose a requirement that at the inboard row of bolts, the primary strips be composed of 100 per cent ± 45 degree plies.

Considering the joint sketched in Fig. 37, the load, L , on a single buffer strip joint, is given by:

$$(18) \quad L = N_x AD$$

where AD is the overall joint width. The bolt load in all bolts except those in the inboard row is given by

$$(19) \quad P = \frac{L}{M} = \frac{N_x AD}{M}$$

where M is the number of rows of bolts in the joint.

Since the shear load N_{xy} and a total tensile bolt load P are reacted equally by each of the three bolts in the inboard row of bolts, the resultant load, R, on each of these bolts is calculated from

$$(20) \quad R^2 = \left[\frac{N_x AD}{3(M)} \right]^2 + \left[\frac{N_{xy} AD}{3} \right]^2$$

$$(21) \quad R = \frac{ADN_x}{3} \left[\left[\frac{1}{M} \right]^2 + \left[\frac{N_{xy}}{N_x} \right]^2 \right]^{\frac{1}{2}}$$

As in the non-buffer strip joint design, the desired interbolt strain level, 3000 micro-inches per inch, is the primary consideration determining the joint geometry for the buffer strip design. Locations in the joint are described by station numbers, just as in the non-buffer strip design. In the case of the buffer strip design, however, the station numbers vary from $\eta=1$, which corresponds to the location of the outboard bolt-hole center, to station $\eta=M$ which corresponds to the location of the row of centers of the inboard bolts.

The thickness at station $\eta=1.5$ is determined by the applied load, the joint geometry, the joint material composition, and the desired interbolt strain level. The average modulus of the joint, $E_{x_{ave}}$, as defined in Ref. 7, is used in calculating this thickness.

$$(22) \quad E_{x_{ave}} = \frac{D(A-W_B) E_{x_1} + W_B D E_{x_2}}{AD}$$

where $W_B D$ = width of the buffer strip

E_{x_1} = tensile modulus of the primary strip

E_{x_2} = tensile modulus of the buffer strip

As shown in Fig. 4, E_{x_1} is determined by the percentage of zero degree plies in the primary laminate. As shown in Fig. 3, E_{x_2} varies with strain level.

The thickness at station $\eta=1.5$ is derived from

$$(23) \quad \epsilon = \frac{ADN_x \left[1 - \frac{1}{M}\right]}{ADt E_{x_{ave}}}$$

where ϵ is the desired interbolt strain level. Thus,

$$(24) \quad t_{1.5} = \frac{AN_x \left[1 - \frac{1}{M}\right]}{\left[(A-W_B)E_{x_1} + W_B E_{x_2}\right] \epsilon}$$

Similarly,

$$(25) \quad t_{M-.5} = \frac{AN_x \left[\frac{1}{M}\right]}{\left[(A-W_B)E_{x_1} + W_B E_{x_2}\right] \epsilon}$$

The bolt bearing stress in the inboard row of bolts is given by

$$(26) \quad \sigma_{BR} = \frac{R}{t^*}$$

where t^* , the effective bearing thickness, is defined as in the non-buffer strip joint.

As stated earlier, the bearing strength of NARMCO 5208/T300 $[\pm 45]$ degree laminates is 73000 lbf./in.². This determines the minimum allowable joint thickness at station

$\eta = M$ for any given load condition.

The laminate composition in the primary strips is initially assumed to vary linearly with distance from the composition at station $\eta = 1.5$, where it is the same as that of the plate outboard of the joint, to 100 per cent ± 45 degree plies at station $\eta = M$ where the applied shear loads are reacted.

The joint thickness at station $\eta = M-.5$ is determined by the desired interbolt strain level.

$$(27) \quad t_{M-.5} = \frac{AN_x}{M[(A-W_B) E_{x_1} + W_B E_{x_2}] \epsilon}$$

The remaining joint thicknesses are then determined geometrically from those at $\eta = 1.5$ and $\eta = M-.5$ using the same techniques as for the non-buffer strip joint. If possible, a cross-section similar to that shown in Fig. 2(b) is used. When this yields a thickness at the last bolt which is too small, using the maximum bearing stress criteria discussed above and Eq. 26, a cross-section similar to that of Fig. 2(a) is used.

Having fixed the joint geometry, the laminate composition is determined by the requirement that the design strain level be maintained between each pair of bolt holes.

At any station $\eta = k+.5$, $k=1, 2, \dots, M-1$,

$$(28) \quad \epsilon = \frac{N_{x_1} A \left[1 - \frac{k}{M}\right]}{[E_{x_1} (A-W_B) + E_{x_2} W_B] t}$$

Since the composition of the buffer strips is fixed and E_{x_2}

is determined by the interbolt strain level, it is necessary to vary E_{x_1} and hence the composition of the primary strips to maintain the desired strain level as the bypass loads in the joint vary from hole to hole.

$$(29) \quad E_{x_1} = \frac{1}{(A-W_B)} \left[\frac{N_x A [1 - \frac{k}{M}]}{t \eta \epsilon} - W_B E_{x_2} \right]$$

It is assumed that E_{x_1} varies linearly with distance between stations $\eta = k-.5$ and $\eta = k+.5$. Thus

$$(30) \quad E_{x_1 k} = \frac{E_{x_1 k+.5} + E_{x_1 k-.5}}{2}$$

Determination of $E_{x_1 k}$ determines the required percentage of zero degree plies in the primary laminate at station k.

Having determined the joint geometry and laminate composition, it is then possible to determine the joint weight and excess bearing capacity.

B. DETERMINING THE STRENGTH OF A BUFFER STRIP JOINT

The bolt load P is not carried entirely in the buffer strip. Part of it is transmitted, in shear, to the primary strips. This load splitting is shown in Fig. 38 in which P_1 is the portion of the bolt load P reacted through each of the primary strips and P_2 is the portion of P reacted through the buffer strip. The relationship between P_1 and P_2 is determined analytically as follows:

Referring to Fig. 38,

$$(31) \quad P = 2P_1 + P_2$$

The bypass strain levels in the buffer and primary strips

are assumed the same. Defining

$$(32) \quad 2W_1 D = AD - W_B D$$

$$(33) \quad 2W_1 = (A - W_B)$$

$$(34) \quad \frac{P_1}{E_{x_1} W_1 t} = \frac{P}{2E_{x_1} W_1 t + E_{x_2} W_B t}$$

Rearranging Eq. 34 gives an expression for P_1 in terms of P , the joint composition, and the joint geometry.

$$(35) \quad \frac{P_1}{P} = \frac{E_{x_1} W_1 t}{2E_{x_1} W_1 t + E_{x_2} W_B t}$$

This equation is rewritten in the form

$$(36) \quad P_1 = A_n P$$

where A_n is determined by knowledge of the joint laminate composition, geometry, and strain level.

$$(37) \quad A_n = \frac{E_{x_1} W_1}{2E_{x_1} W_1 + E_{x_2} W_B}$$

The bolt load splitting discussed above is dependent upon the ability of the ± 45 degree laminae to transfer a shear load, F_S , from the buffer to the primary strips. It was experimentally determined that failure of this load transferring mechanism could be expected when the shear stress in these fibers, f_s , reached a magnitude of 90,000 lbf./in.² (Ref. 9). At any station in the joint

$$(38) \quad F_{S_\eta} = \frac{P_1}{4D t_{\pm 45}} \quad (\eta = \text{integer})$$

where $t_{\pm 45}$ is the total thickness of ± 45 degree laminae through which P_1 is transferred. Defining Z = percentage of zero degree plies in the primary strips,

$$(39) \quad t_{\pm 45} = t \frac{(100-Z)}{100}$$

$$(40) \quad f_{s\eta} = \frac{N_x A A_n}{4M t \eta \frac{(100-Z)}{100}} \quad (\eta = \text{integer})$$

The shear stress f_s varies from bolt to bolt in a given buffer strip joint design. In all designs, however, the highest values for f_s occur at the first bolt hole. Thus f_{s1} determines the upper limit on the percentage of zero degree plies in the primary strip laminate. From Eq. 24,

$$(41) \quad t_1 = \frac{AN_x \left[1 - \frac{1}{M} \right]}{\left[(A-W_B)E_{x1} + W_B E_{x2} \right] \epsilon}$$

Fig. 4 yields the following relationship between laminate composition and modulus,

$$(42) \quad E_{x1} = 10^6 \left[20.7 - (100-Z) \left[\frac{20.7-2.3}{100} \right] \right] (\text{lb./in.}^2)$$

Then,

$$(43) \quad \frac{100-Z}{100} = \left[20.7 - \frac{E_{x1}}{10^6} \right] \frac{1}{17.9}$$

Substituting Eqs. 37, 41, and 43 into Eq. 40,

$$(44) \quad f_{s1} = \frac{W_1 E_{x1}}{(M-1)} \frac{1}{4} \frac{\epsilon_1}{\left[20.7 - \frac{E_{x1}}{10^6} \right]} \frac{1}{17.9}$$

From Eq. 44 it is seen that f_{s1} is determined by the joint

geometry, laminate composition, and design strain level. Fixing the joint geometry and the design strain level determines the maximum allowable modulus for the primary strips and hence provides an upper limit on the per cent zero degree plies which can be used in the primary strips. This limit is determined by setting f_{s_1} equal to its experimentally determined maximum, 90,000 lbf./in.² and using Eq. 45 to determine $E_{x_{1_{\max}}}$.

$$(45) \quad E_{x_{1_{\max}}} = \frac{4(M-1)(20.7)f_{s_1}}{17.9(W_1)(\epsilon_1)10^6 + 4(M-1)f_{s_1}} \quad 10^6(\text{lbf./in.}^2)$$

Under the design conditions applicable to this study, Eq. 45 implies an upper limit of 92 to 98 per cent zero degree plies in the primary strips.

Three other failure modes of a buffer strip joint were found to be most probable under N_x and N_{xy} loading (Ref. 15). Type I and Type II failure occurred in the buffer strip at the loaded bolt holes. Type I failure was characterized by radial cracks at 45 degrees to the X axis. Type II failure was characterized by radial cracks originating at the edge of the hole at 90 degrees to the X axis. Type III failure occurred when the load bearing fibers in the primary strips were broken. These three failure modes are sketched in Fig. 39.

The Type I failure mode characterizes the interaction of bearing and shear stresses in the buffer strip. It was found to be essentially independent of the bypass

stress. The load curves describing this failure mode were derived from experimental results (Ref. 15). Single hole specimens of buffer strip joint material were clamped in test machines along either one or two sides as shown in Fig. 40. With the bolts torqued, the specimens were loaded, and the failure bolt load stresses measured. Tests were run for specimens with 0.25 inch and 0.4375 inch diameter holes. For the doubly clamped test cases Type I failure occurred under the following loads:

$$D = 0.250 \text{ in. } \sigma_{bx_{\max}} = 151,200 \text{ lbf./in.}^2$$

$$D = 0.4375 \text{ in. } \sigma_{bx_{\max}} = 144,100 \text{ lbf./in.}^2$$

For the test specimens clamped at only one edge, Type I failure occurred under the following loads:

$$D = 0.25 \text{ in. } \sigma_{bx} = 111,000 \text{ lbf./in.}^2$$

$$D = 0.4375 \text{ in. } \sigma_{bx} = 107,000 \text{ lbf./in.}^2$$

Satisfactory test results for the pure shear load case could not be obtained.

An attempt was made to approximate the shear effects by superposition of the singly and doubly clamped test results. The finite element computer program ISANIS, listed in Appendix A, was used to analyze the stress concentration field in various orthotropic plates. It was found that for a square plate made from uniform material with a central hole and sides at least four hole diameters in length, the stress field at the hole due to pure applied

shear could be closely approximated by an appropriate superposition of the stress fields resulting from singly and doubly clamped load cases. The superposition used is shown schematically in Fig. 41. The key assumption in this superposition is that the moment reaction which is representative of the single clamped edge load case can be replaced by a couple of equal magnitude resulting from shear loads applied on the upper and lower edges of the specimen. This assumption is really an application of the St. Venant principle that points in a body removed from load application locations react to the load applied rather than its mechanism of application. ISANIS was used to test this assumption and, under the conditions stated above, it was found to be reasonable.

The test specimens were thin and hence $t^*=t$. Therefore,

$$(46) \quad P = \sigma_{bx}Dt$$

For the double clamped specimen, the reaction force, F_{RD} , is given by

$$(47) \quad F_{RD} = \frac{P}{2} = \frac{\sigma_{bx}Dt}{2}$$

Assuming that this force is uniformly distributed across the clamped edges, an edge stress is defined

$$(48) \quad \sigma_{RD} = \frac{F_{RD}}{\ell Dt}$$

where $\ell \times D$ equals the length of the clamped edge.

For the single clamped specimen, the reaction force,

F_{RS} , is equal to the applied bolt load P . The reaction moment, m , is given by

$$(49) \quad m = P \frac{\ell D}{2}$$

This moment is approximated by a couple of the same magnitude formed by forces acting on the edges of the specimen which are normal to the clamped edge. For square specimens of side length ℓD , the magnitude of these forces, F , is given by

$$(50) \quad F \ell D = m$$

$$(51) \quad F \ell D = \frac{P \ell D}{2}$$

$$(52) \quad F = \frac{P}{2}$$

This development is also shown schematically in Fig. 41.

Assuming that each force F is distributed uniformly along the specimen edge upon which it is applied, an edge shear is defined

$$(53) \quad \sigma_{xy} = \frac{F}{\ell D t}$$

$$(54) \quad \sigma_{xy} = \frac{P}{2 \ell D t}$$

For the test specimens each side was four hole diameters in length. From Eqs. 47 and 54, the superposition yields

$$(55) \quad \sigma_{xy} = \frac{\sigma_{bx}}{8}$$

Under these assumptions, the experimental data listed previously yield the following failure states:

$$D = 0.25 \text{ in.}$$

$$\sigma_{xy} = 0$$

$$\sigma_{bx} = 151,200 \text{ lbf./in.}^2$$

$$\sigma_{xy} = 13,875 \text{ lbf./in.}^2$$

$$\sigma_{bx} = 111,000 \text{ lbf./in.}^2$$

$$D = 0.4375 \text{ in.}$$

$$\sigma_{xy} = 0$$

$$\sigma_{bx} = 144,100 \text{ lbf./in.}^2$$

$$\sigma_{xy} = 13,375 \text{ lbf./in.}^2$$

$$\sigma_{bx} = 107,000 \text{ lbf./in.}^2$$

Figure 42 was prepared from these data points assuming that the ultimate bearing stress-shearing stress interaction curve was linear for the graphite-epoxy laminates used in this study.

Buffer strip Type II failure curves were experimentally determined for buffer strip joint specimens with 0.4375 inch bolt holes, a buffer strip width of 1.5 inches, and primary strips each 1.25 inches wide (Ref. 15). The hole centers were spaced four diameters apart. These tests were run with primary strips composed of 30 per cent zero degree plies and 50 per cent zero degree plies with bolt loads applied through torqued bolts. These test specimens were thin enough so that $t^*=t$. Tests were also run on buffer strips alone to determine the ultimate bypass stress of the buffer strip material (Ref. 15). With no applied bearing stress it was found that the ultimate bypass stress in the buffer strip material was 25000 lbf./in.². The results of this series of tests indicated that the Type II failure mode for these test specimens could be closely described by the empirical relationship

$$(56) \quad \sigma_{\text{net buffer}} = \frac{P_2 + .25(2P_1)}{D(W_B - 1) t_2} + \sigma_{\text{tx}_2}_{\text{net area}}$$

$\sigma_{\text{net buffer}}$ is the ultimate bypass stress in the buffer strip normalized to the width of the buffer strip minus the diameter of the bolt hole. $\sigma_{\text{tx}_2}_{\text{net area}}$ is the actual bypass stress in the buffer strip normalized to the width of the buffer strip minus the hole diameter. Thus,

$$(57) \quad \sigma_{\text{net buffer}_{\text{max}}} = 25000 \text{ lbf./in.}^2 \left(\frac{W_B}{W_B - 1} \right)$$

$$(58) \quad \sigma_{\text{tx}_2}_{\text{net area}} = \frac{\sigma_{\text{tx}_2} W_B}{(W_B - 1)}$$

Assuming that the strain levels in the buffer and primary strips are the same at any station η ,

$$(59) \quad \frac{\sigma_{\text{tx}_1}}{E_{x_1}} = \frac{\sigma_{\text{tx}_2}}{E_{x_2}} = \epsilon$$

Thus,

$$(60) \quad \sigma_{\text{tx}_2}_{\text{net area}} = \frac{\sigma_{\text{tx}_1}}{E_{x_1}} E_{x_2} \frac{W_B}{(W_B - 1)}$$

$$(61) \quad \sigma_{\text{bx}} = \frac{P}{Dt}$$

$$(62) \quad 25000 \left(\frac{W_B}{W_B - 1} \right) = \frac{\sigma_{\text{bx}} (1 - 1.5 A_n)}{(W_B - 1)} + \frac{\sigma_{\text{tx}_1} E_{x_2}}{E_{x_1}} \frac{W_B}{(W_B - 1)}$$

For a fixed laminate composition in the primary strips, different values of σ_{tx_1} produce different strain levels. This implies variation in E_2 , the modulus of the buffer

strip material, with bypass stress in the primary strips. This variation in modulus explains why the Type II failure is not linear in σ_{bx} and σ_{tx_1} .

Type III failure is characterized by fracture of the zero degree fibers in the primary strips. As reported in Ref. 2, this failure mode is encountered when the strain level in these strips reaches 10,000 micro-inches per inch. This failure mode is mathematically predicted by considering the presence of both the bypass stress and the stress due to P_1 in the primary strips. Thus,

$$(63) \quad \sigma_{tx_1} + \frac{A_n P}{W_1 D t} = \sigma_1$$

$$(64) \quad \sigma_{1_{ult}} = \epsilon_{ult} E_1$$

$$(65) \quad P = \sigma_{bx} D t^*$$

$$(66) \quad \sigma_{tx_1} + \frac{A_n \sigma_{bx} D t^*}{(A - W_B) D t} = \epsilon_{ult} E_1$$

The results of these tests are summarized in Fig. 43. The Type I failure line is drawn for a zero shear case and is determined from experiment with a double clamped test specimen, the Type II failure lines are drawn from Eq. 62, and the Type III failure lines are drawn from Eq. 66. For the joints used in this study, Eq. 62 becomes

$$(67) \quad \frac{\sigma_{bx} (1 - 1.5 A_n)}{3} + \sigma_{tx_1} \frac{E_{x_2} \frac{4}{3}}{E_{x_1} \frac{4}{3}} = 25 \frac{4}{3}$$

and Eq. 66 becomes

$$(63) \quad \sigma_{tx_1} + \frac{A_n \sigma_{bx}}{6.67} = \epsilon_{ult} E_1$$

Figures 44 and 45 describe the expected failure states for the buffer strips used in the study joints. The Type I failure lines on these figures are taken from the zero shear ultimate bearing stresses indicated on Fig. 42. The Type II and Type III failure lines shown in these figures are drawn from Eqs. 67 and 68.

Excess bearing capacity calculations were made for buffer strip joints just as had been done for non-buffer strip joints. In the case of the buffer strip joints, however, only 0.25 and 0.4375 inch holes were considered since Type I failure test data was available only for these hole sizes. The results of these calculations are presented in Figs. 46 and 47.

C. DETERMINING THE WEIGHT OF A BUFFER STRIP JOINT

The weight per inch of chord of each buffer strip design was calculated just as had been done for the non-buffer strip joints by multiplying the cross-sectional area of each joint by the density of the NARMCO 5208/T300 graphite-epoxy material used in the study. The variation of joint weight with primary strip laminate composition, bolt hole size, and number of bolts is shown in Figs. 48 and 49.

IV. DISCUSSION OF RESULTS

A. NON-BUFFER STRIP JOINTS

The following generalizations about non-buffer strip joints were found to be valid:

1. For a given hole size, the joint weight decreased as the percentage of zero-degree plies in the joint increased.
2. For a given hole size, the fewer the number of bolt holes per unit chord, the lighter the joint.
3. The smaller the bolt holes, the lighter the joint could be made.
4. The smaller the bolt holes, the greater the range in number of allowable bolt holes per unit chord.
5. For a given laminate composition, the smaller the bolt holes the larger the minimum number of bolt holes per unit chord required.
6. The smaller the bolt holes, the larger the allowable range of laminate composition.
7. For a given laminate composition, the smaller the bolt holes, the larger the excess bearing capacity.

B. BUFFER STRIP JOINTS

Observations 1-6, above, are also true for buffer strip joints. The excess bearing capacity of the buffer

strip joint, as seen in Figs. 48 and 49, is, in a gross sense, independent of hole size and more heavily influenced by laminate composition, the number of holes, and the load condition.

C. COMPARISON OF NON-BUFFER STRIP AND BUFFER STRIP JOINTS

In Ref. 16 it is explained that the bearing strength of bolted plates is higher when the bearing loads are applied through torqued bolts than when they are applied through untorqued bolts. Since the failure modes of the buffer strip joints were derived from experiments in which the bolt loads were applied through torqued bolts, and since the failure modes of the non-buffer strip joints were derived from experiments in which the bearing loads were applied through untorqued bolts, this may explain at least part of the apparently higher excess bearing capacities available with buffer strip joints. Buffer strip joints generally weigh more than non-buffer strip joints. The fact that buffer strip joints require fewer bolts per inch of chord than non-buffer strip joints can be used to offset some of this weight difference if bolt weights are included in the net joint weight. The reduced number of bolts per inch of chord possible with buffer strip joints should also reduce joint fabrication costs by reducing the number of drilling operations required. Buffer strip joints can be constructed for a larger range of laminate composition than non-buffer strip joints.

V. CONCLUSIONS AND RECOMMENDATIONS

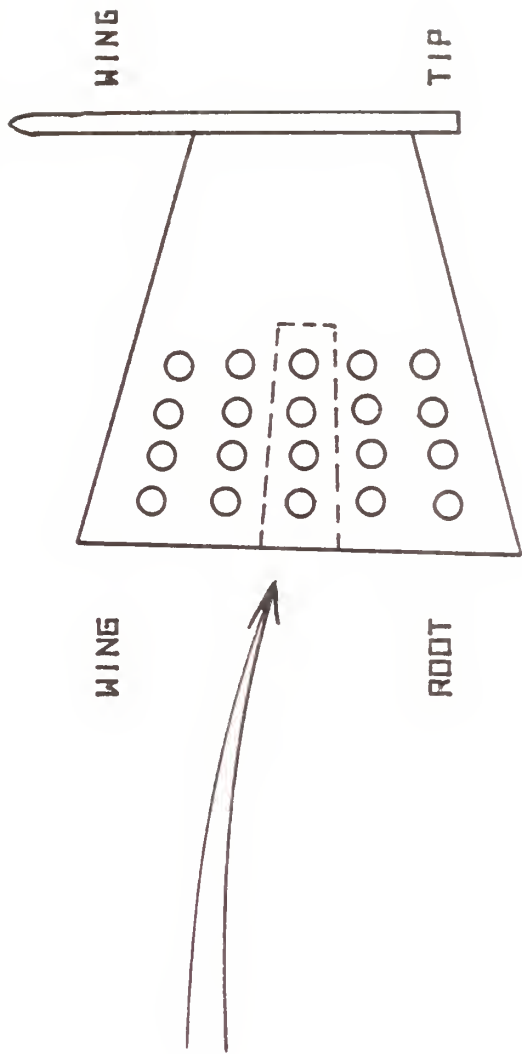
The design methodology used in this study is shown to be capable of producing workable joint designs. The wide range of weights and excess bearing capacities exhibited by the different joint designs indicates that the joint efficiencies achieved by geometric substitution of advanced composites for conventional structural materials were probably minimal when compared with those which would be achieved by designs which took advantage of the special high strength and high modulus properties of advanced composites.

Under the design conditions adopted in this study, buffer strip joints were found to be stronger and more cheaply manufactured than non-buffer strip joints. These advantages are offset by the increased joint weights characteristic of buffer strip joints. In spite of this weight penalty, it is felt that the high excess bearing capacity and integral crack stoppage capability of buffer strip joints makes them promising candidates for aerospace applications.

It is felt that Figs. 31-36 and 46-49 can be used to compare various design proposals and to estimate the costs of variation in laminate composition, hole size, or number of holes. No attempt was made to determine the effect of the design limitations summarized in TABLE I which were placed upon allowable joint geometry and

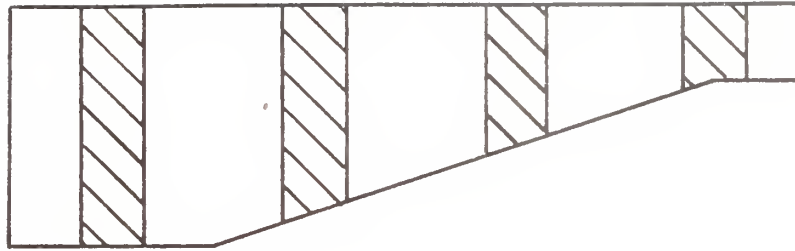
composition by such factors as manufacturing considerations and fitting interface requirements. It is recommended that the effect of these restrictions be determined by an analysis similar to this one with the restrictions removed.

It is recommended that application of the buffer strip technique to critical components be preceded by further experimentation to more accurately determine the behavior of buffer strip joints under shear loads.



PER CENT ZERO DEG. PLYS IN JOINT
 DECREASES FROM VALUE AT OUTBOARD
 BOLT TO ZERO AT INBOARD BOLT

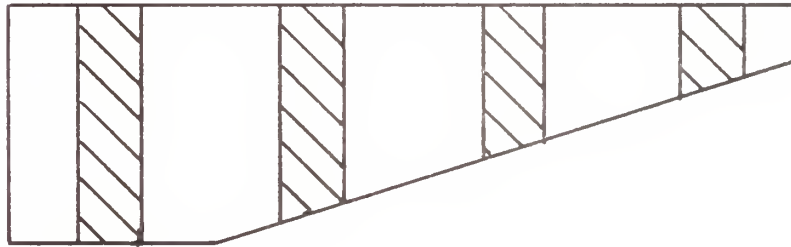
FIGURE 1. SCHEMATIC OF A WING WITH A NON-BUFFER STRIP JOINT



OUTBOARD END

A

INBOARD END



OUTBOARD END

B

INBOARD END

FIGURE 2. PERMISSIBLE JOINT CROSS SECTIONS

VARIATION OF SECANT MODULUS WITH STRAIN
OF NARMCO 5208/T300 (± 45 DEG.)
LAMINATED MATERIAL AT ROOM
TEMPERATURE

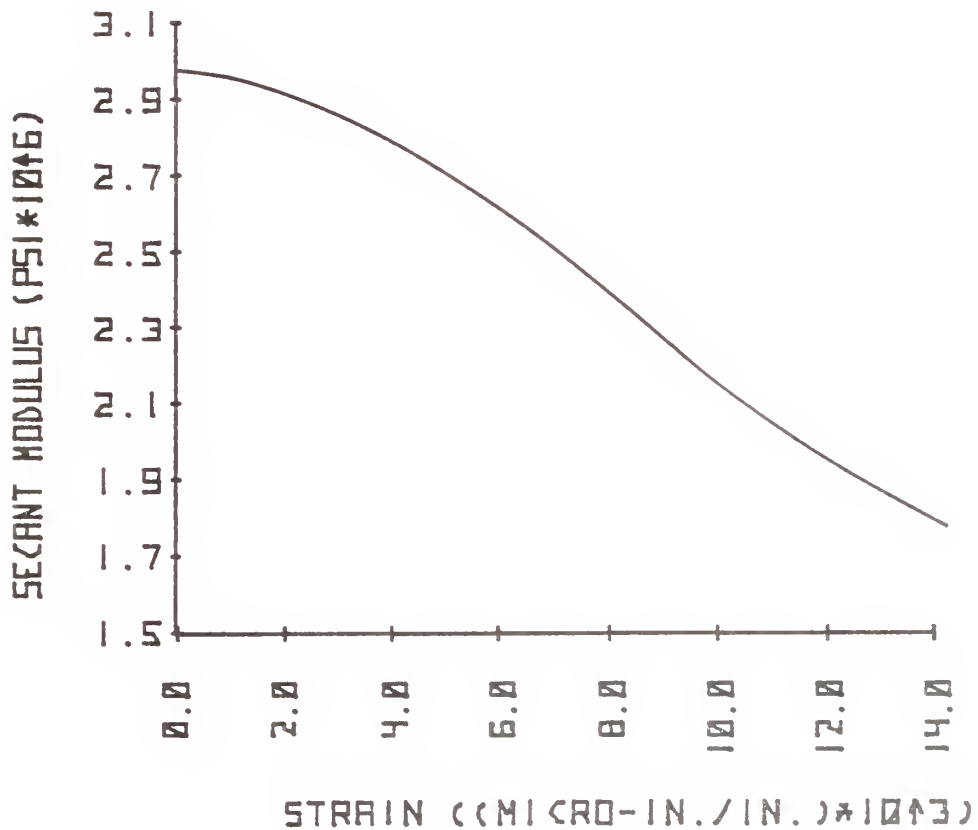


FIGURE 3. VARIATION OF SECANT MODULUS WITH STRAIN OF NARMCO
5208/T300 (± 45 DEG.) LAMINATED MATERIAL AT ROOM TEMPERATURE

NARMCO 5208/T300 (0/±45) LAMINATES

E (SECANT MODULUS) VS. PERCENT
ZERO DEGREE PLIES

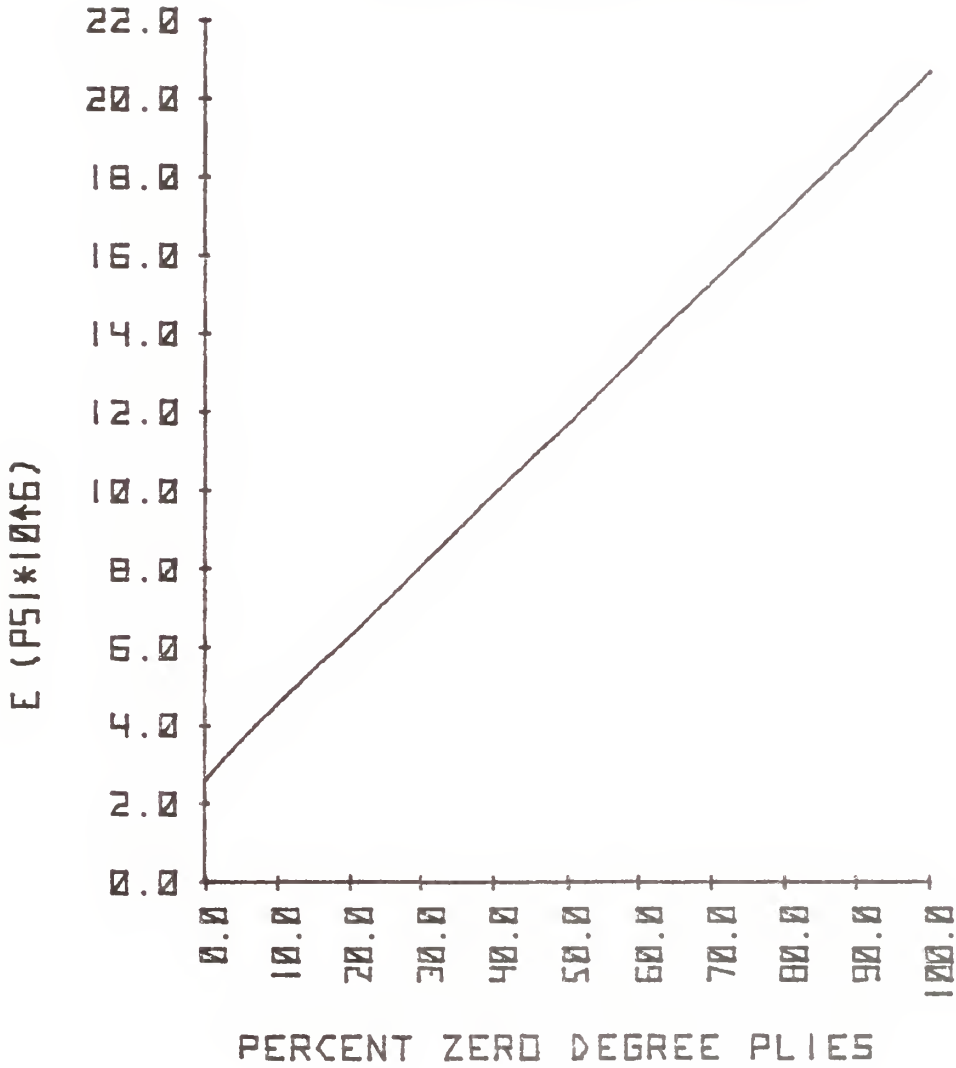


FIGURE 4. SECANT MODULUS OF NARMCO 5208/T300 [0/±45]
LAMINATES VS. PER CENT ZERO DEGREE PLIES

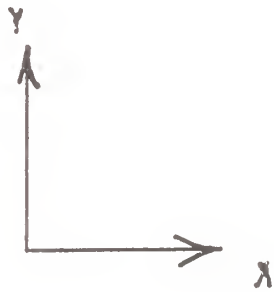
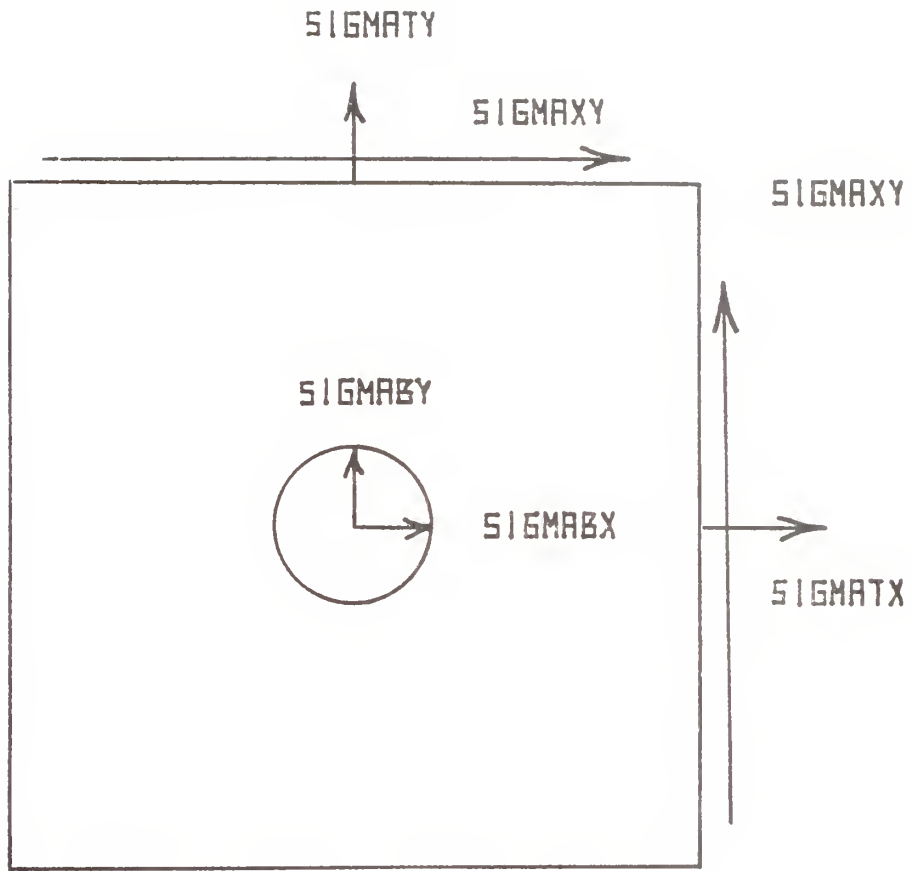


FIGURE 5. BOLTED JOINT APPLIED STRESS DEFINITIONS

0.25 IN. DIAM. HOLE
10% ZERO DEG. PLYS

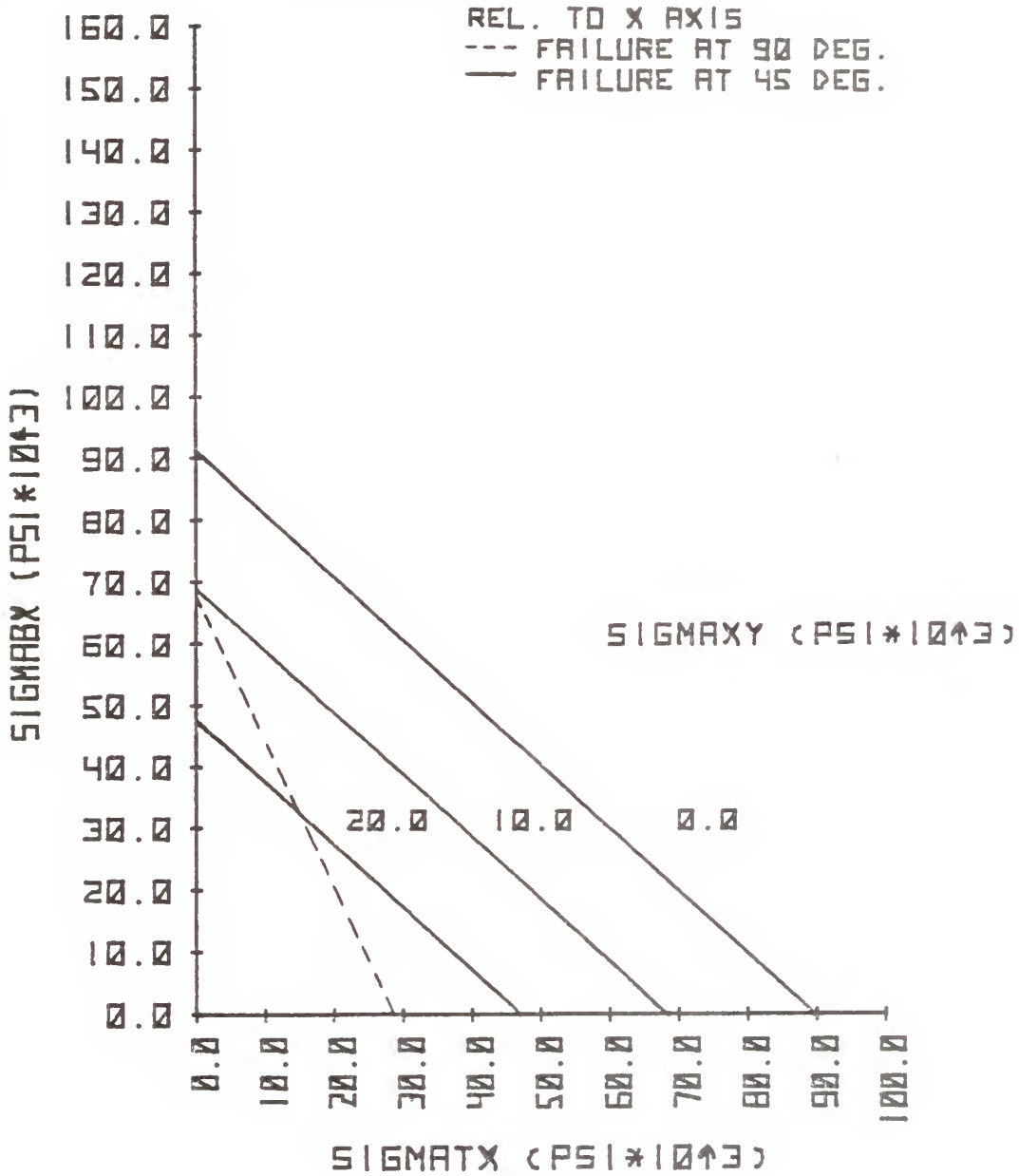


FIGURE 6. ULTIMATE STRESS INTERACTION CURVE FOR A ONE IN. SQUARE PLATE OF NARMCO 5209/T300 [0/±45] MATERIAL WITH A 0.25 IN. DIAMETER CENTRAL HOLE AND 10 PER CENT ZERO DEGREE PLYS

0.25 IN. DIAM. HOLE
20% ZERO DEG. PLYS

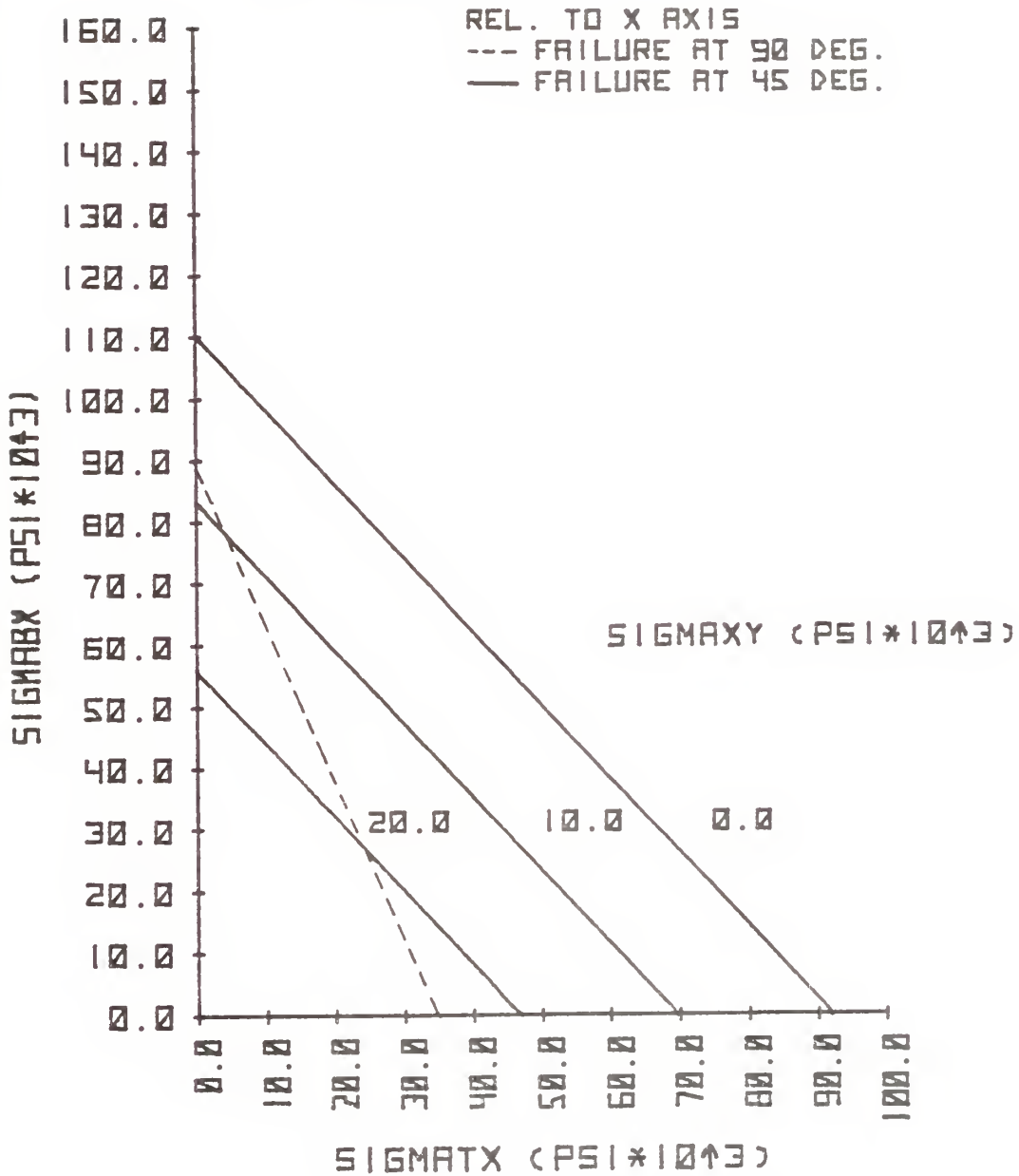


FIGURE 7. ULTIMATE STRESS INTERACTION CURVE FOR A ONE IN. SQUARE PLATE OF NARMCO 5203/T300 [0/+45] MATERIAL WITH A 0.25 IN. DIAMETER CENTRAL HOLE AND 20 PER CENT ZERO DEGREE PLYS

0.25 IN. DIAM. HOLE
30% ZERO DEG. PLYS

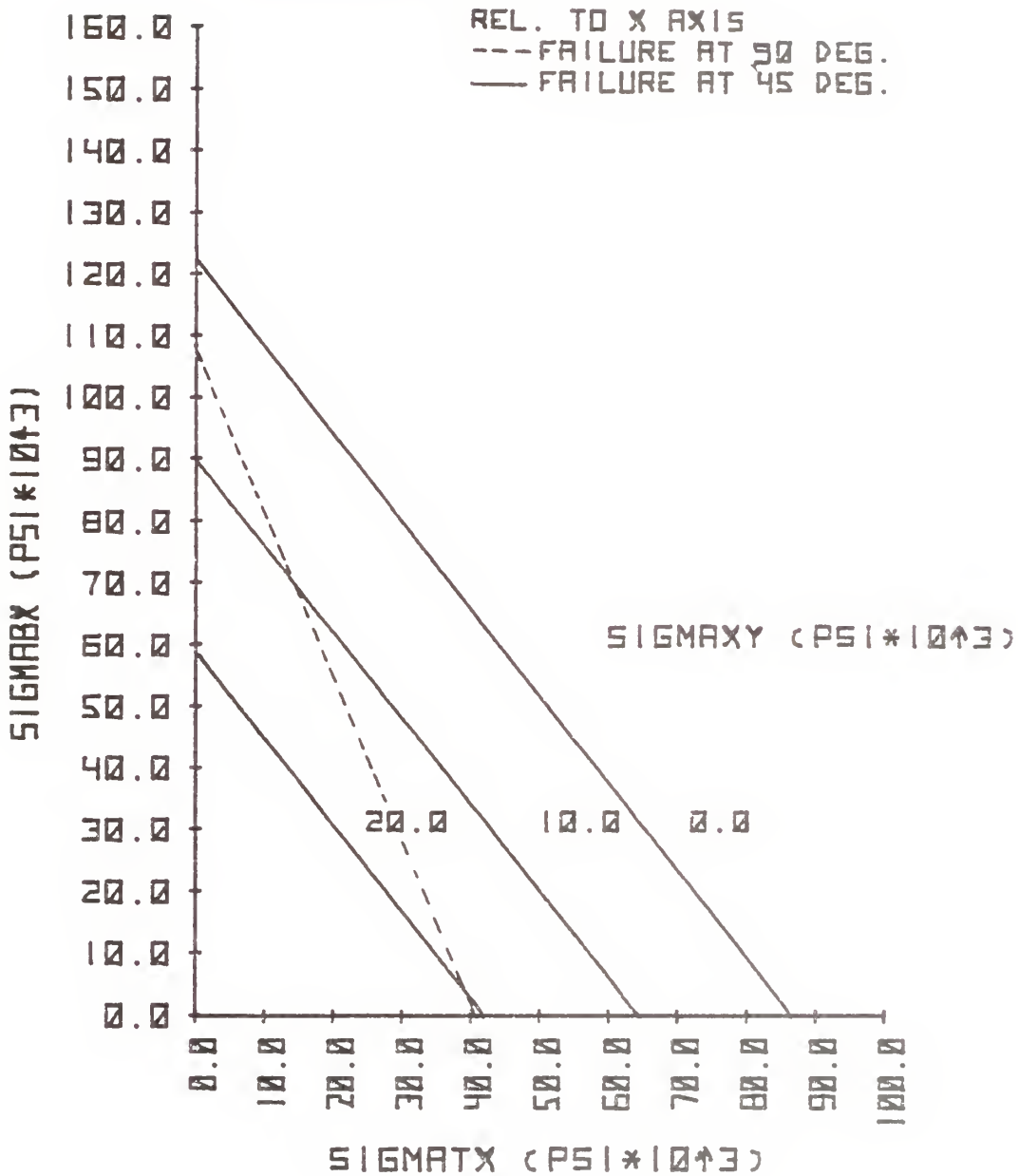


FIGURE 3. ULTIMATE STRESS INTERACTION CURVE FOR A ONE IN. SQUARE PLATE OF NARMCO 5203/T300 [0/±45] MATERIAL WITH A 0.25 IN. DIAMETER CENTRAL HOLE AND 30 PER CENT ZERO DEGREE PLYS

0.25 IN. DIAM. HOLE
40% ZERO DEG. PLYS

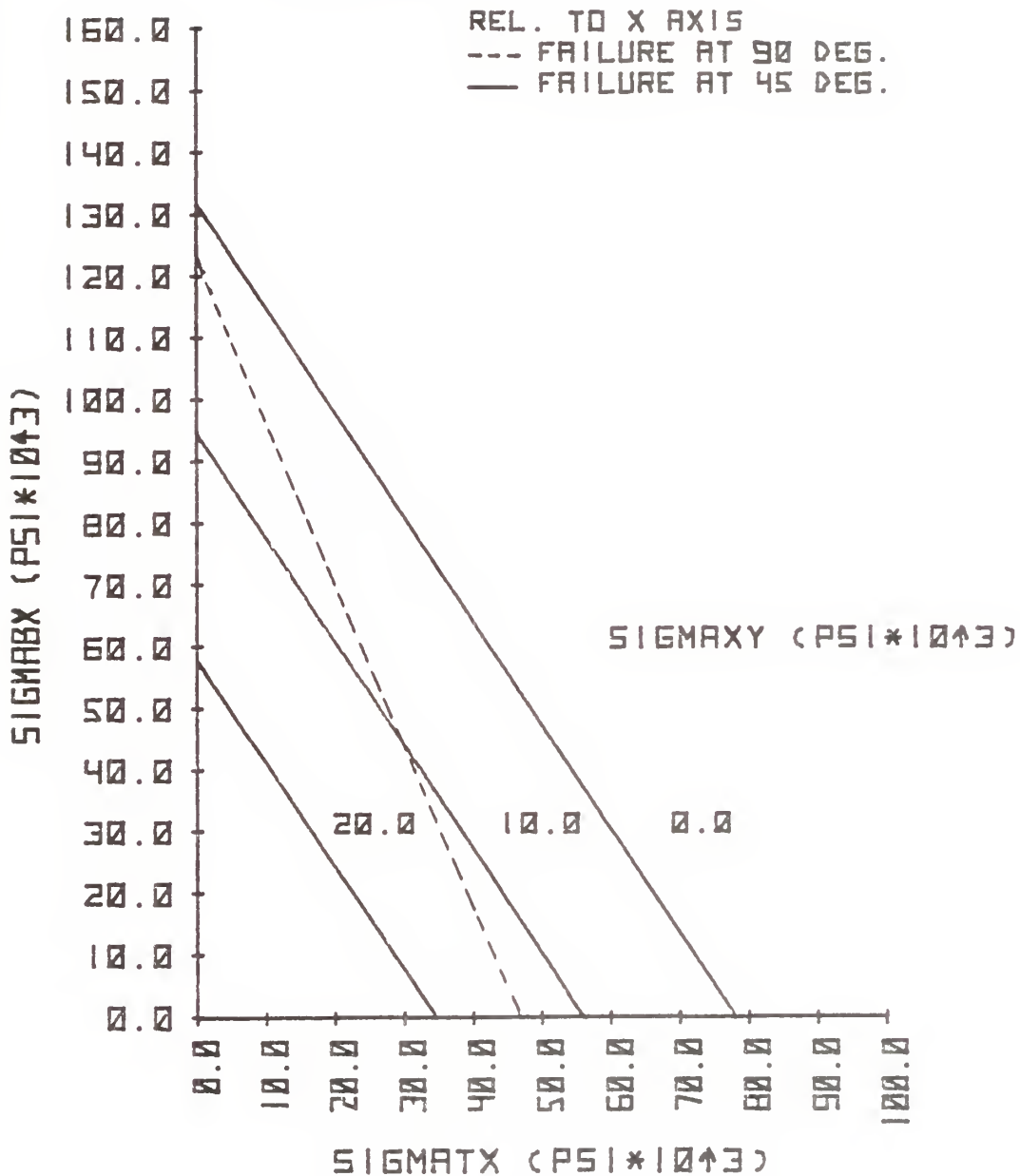


FIGURE 9. ULTIMATE STRESS INTERACTION CURVE FOR A ONE IN. SQUARE PLATE OF NARMCO 5208/T300 [0/±45] MATERIAL WITH A 0.25 IN. DIAMETER CENTRAL HOLE AND 40 PER CENT ZERO DEGREE PLYS

0.25 IN. DIAM. HOLE
 50% ZERO DEG. PLYS

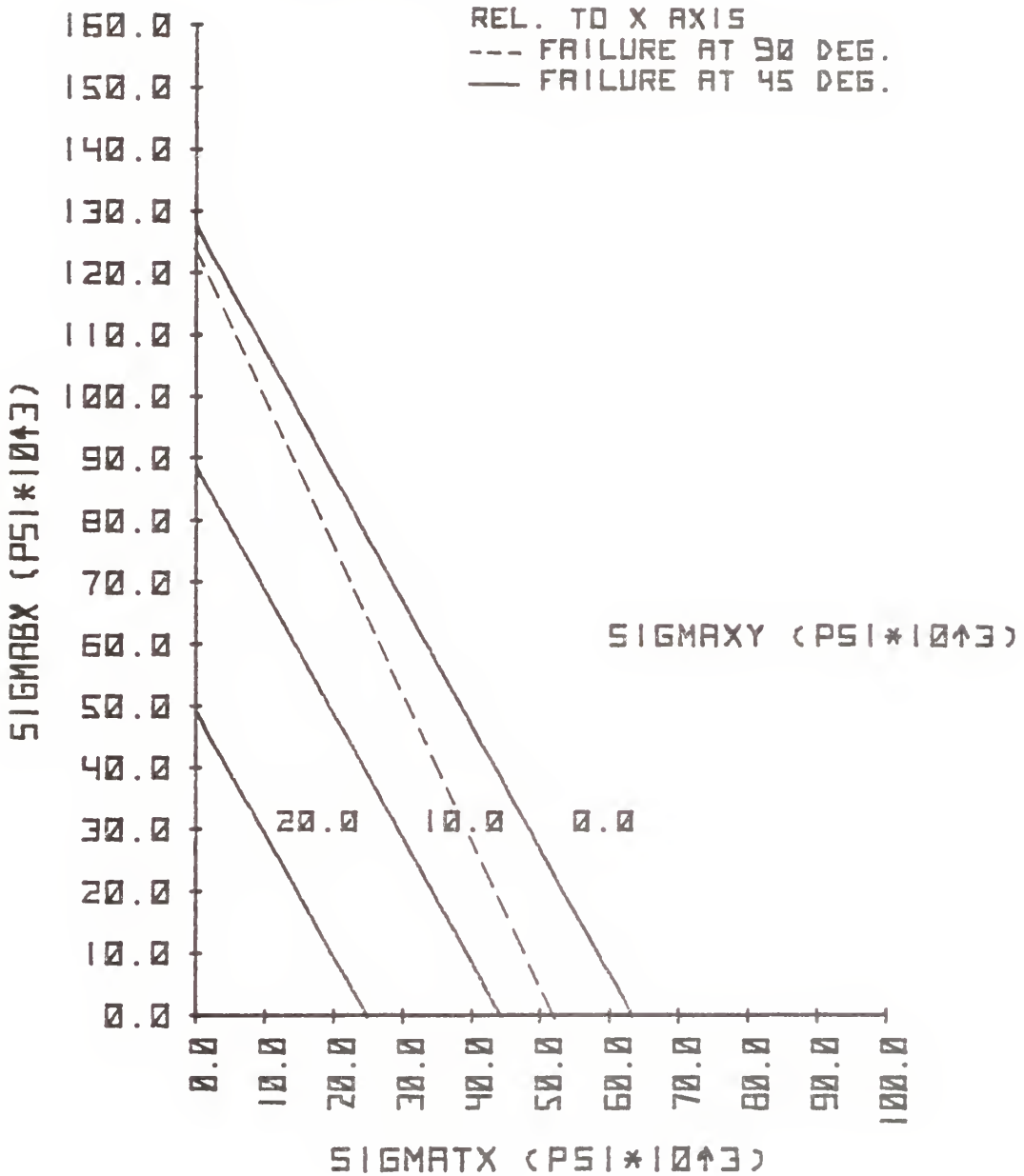


FIGURE 10. ULTIMATE STRESS INTERACTION CURVE FOR A ONE IN. SQUARE PLATE OF NARMCO 5203/T300 [0/±45] MATERIAL WITH A 0.25 IN. DIAMETER CENTRAL HOLE AND 50 PER CENT ZERO DEGREE PLYS

0.25 IN. DIAM. HOLE
60% ZERO DEG. PLIES

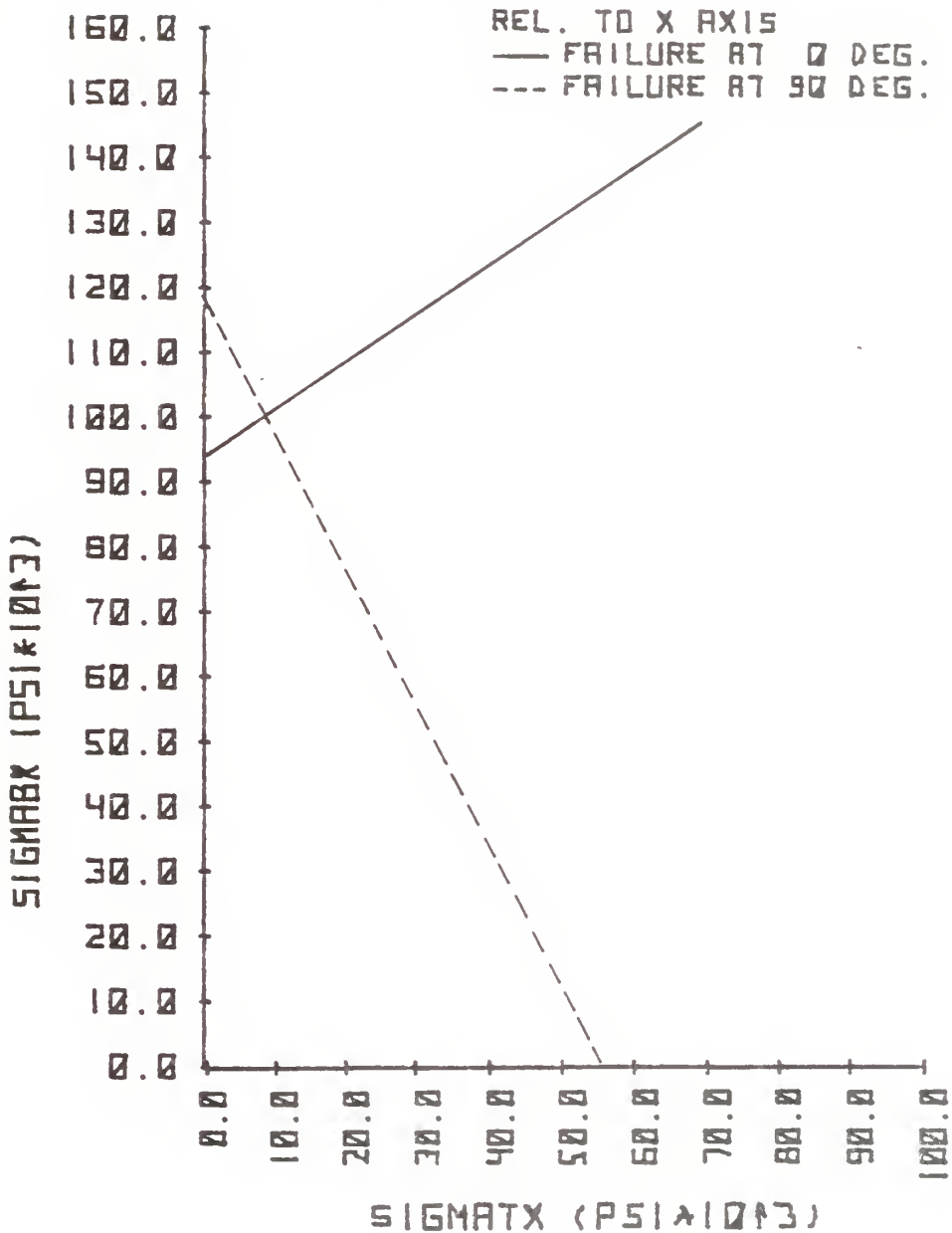


FIGURE 11. ULTIMATE STRESS INTERACTION CURVE FOR A ONE IN. SQUARE PLATE OF NARMCO 5208/T300 [0/+45] MATERIAL WITH A 0.25 IN. DIAMETER CENTRAL HOLE AND 60 PER CENT ZERO DEGREE PLIES

0.375 IN. DIAM. HOLE
 10% ZERO DEG. PLYS

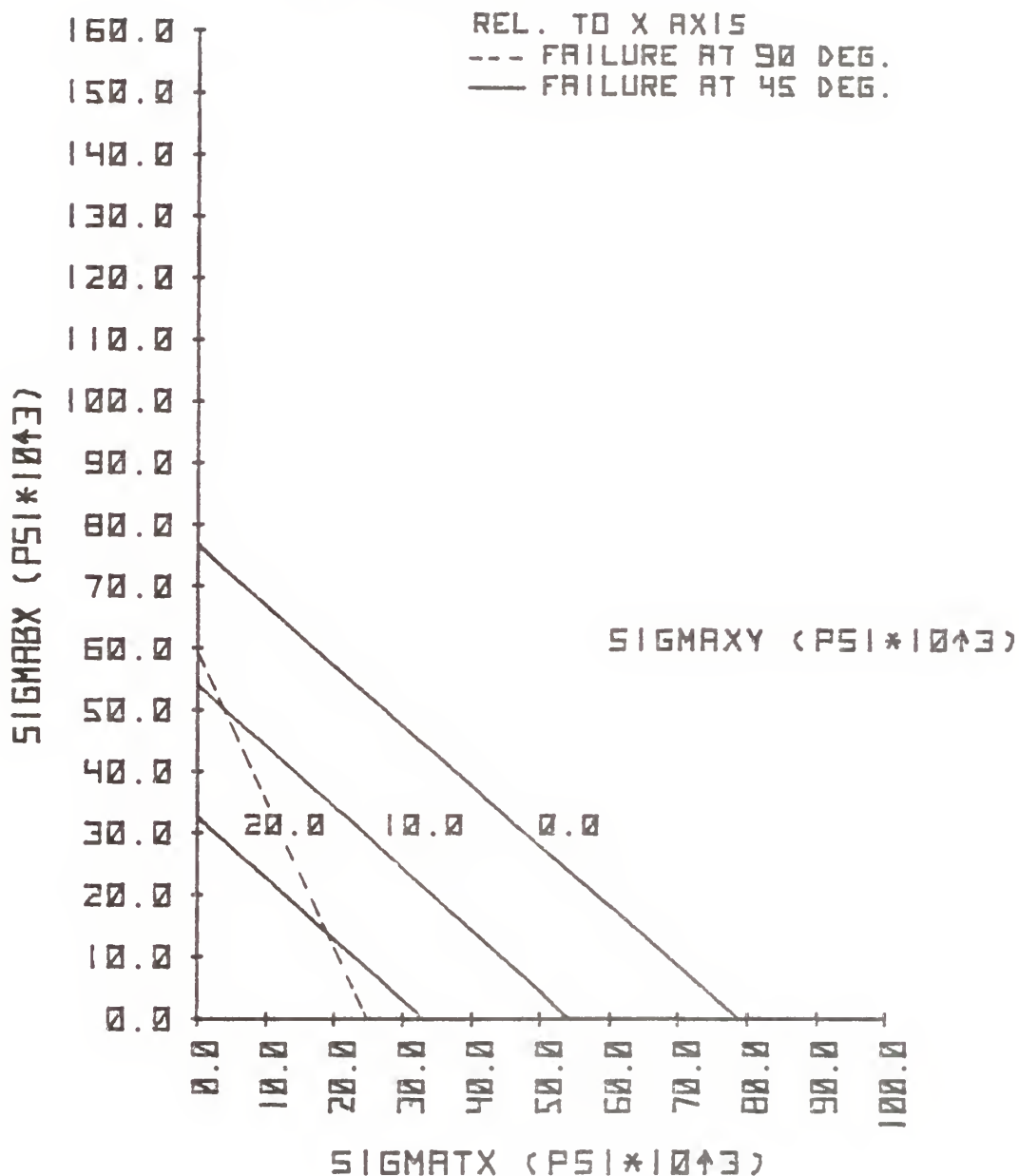


FIGURE 12. ULTIMATE STRESS INTERACTION CURVE FOR A
 1.5 IN. SQUARE PLATE OF NARMCO 5208/T300 [0/±45]
 MATERIAL WITH A 0.375 IN. DIAMETER CENTRAL HOLE AND
 10 PER CENT ZERO DEGREE PLYS

0.375 IN. DIAM. HOLE
20% ZERO DEG. PLYS

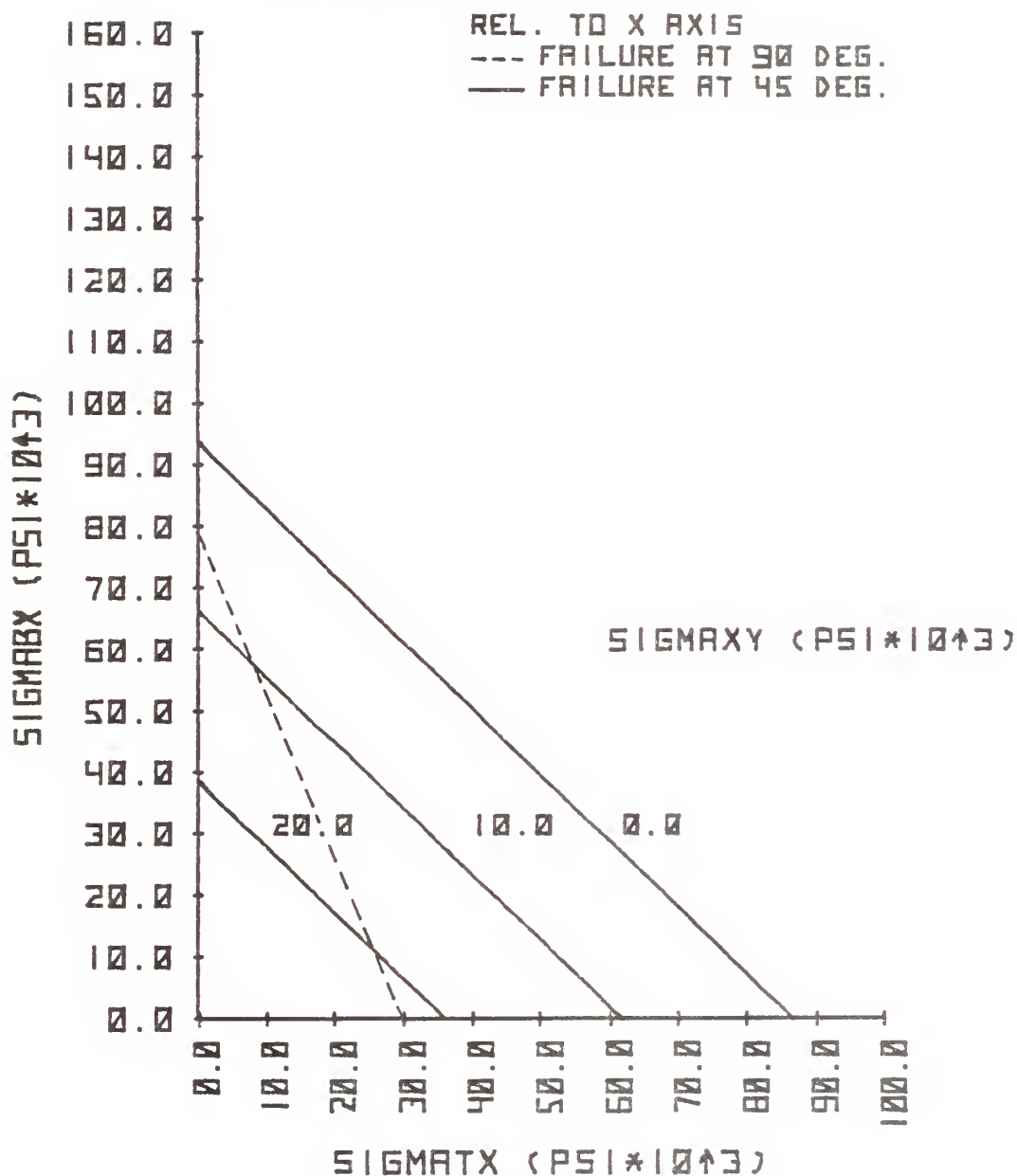


FIGURE 13. ULTIMATE STRESS INTERACTION CURVE FOR A 1.5 IN. SQUARE PLATE OF NARMCO 5208/T300 [0/±45] MATERIAL WITH A 0.375 IN. DIAMETER CENTRAL HOLE AND 20 PER CENT ZERO DEGREE PLYS

0.375 IN. DIAM. HOLE
 30% ZERO DEG. PLYS

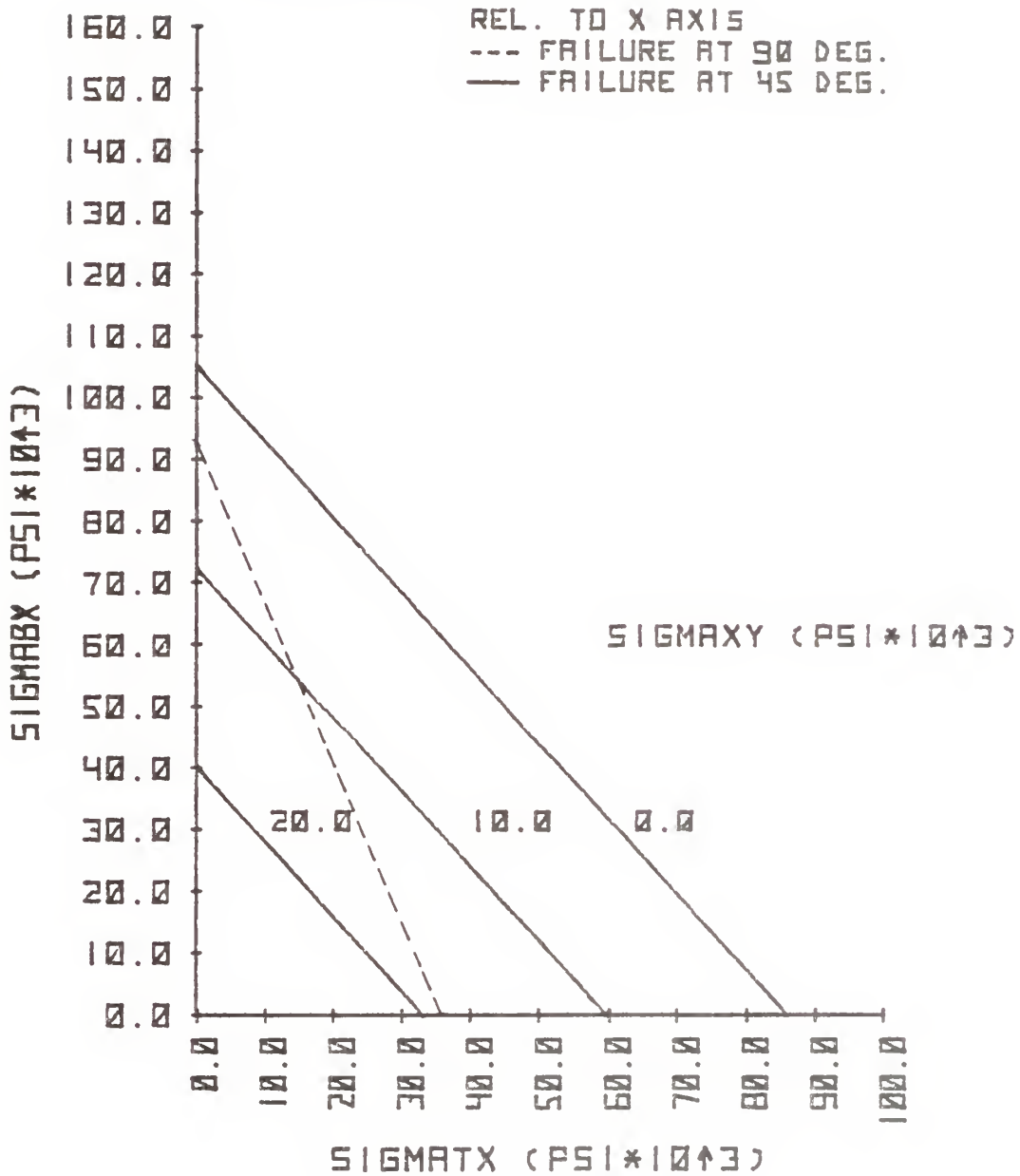


FIGURE 14. ULTIMATE STRESS INTERACTION CURVE FOR A
 1.5 IN. SQUARE PLATE OF NARMCO 5208/T300 [0/±45]
 MATERIAL WITH A 0.375 IN. DIAMETER CENTRAL HOLE AND
 30 PER CENT ZERO DEGREE PLYS

0.375 IN. DIAM. HOLE
 40% ZERO DEG. PLYS

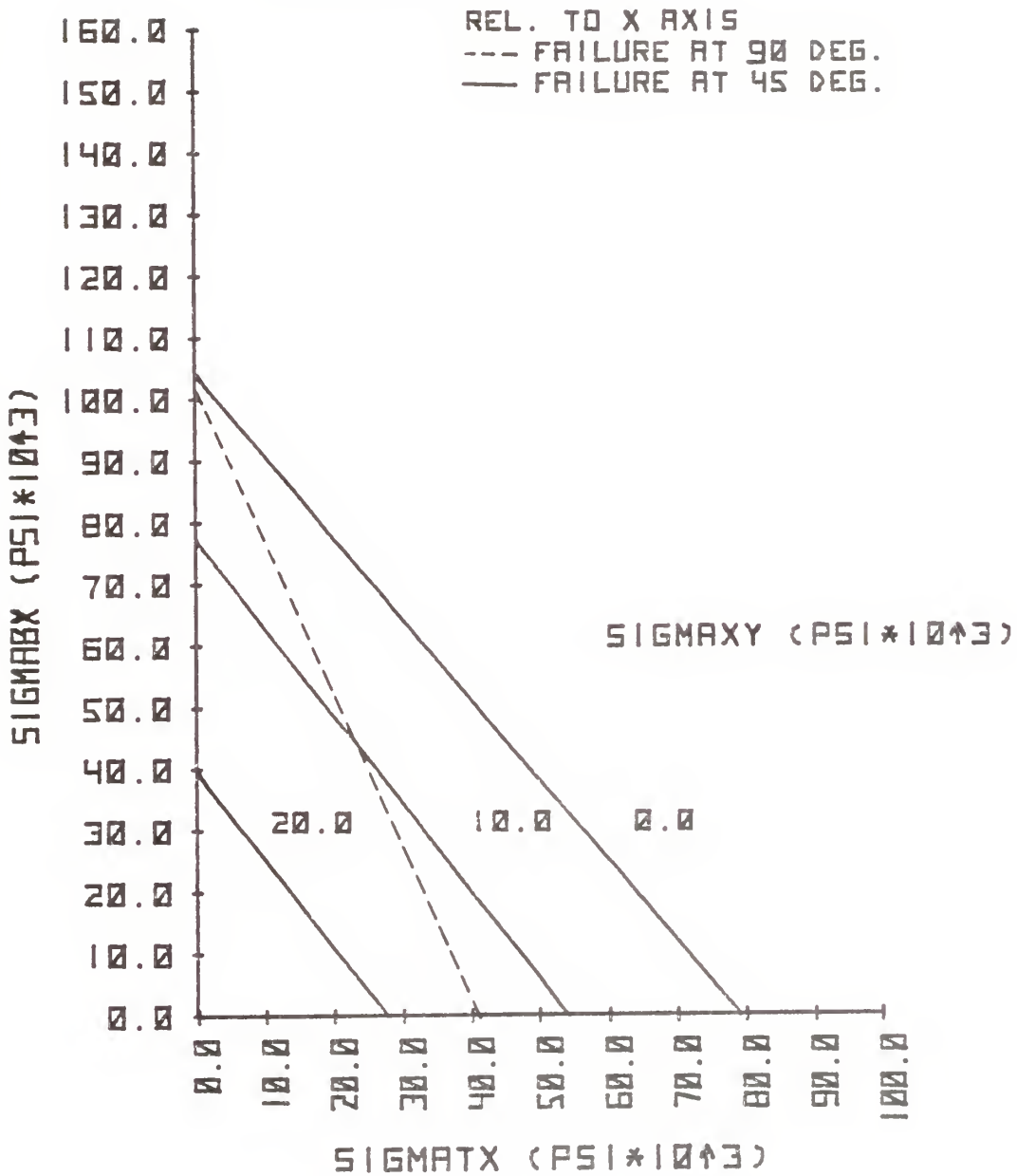


FIGURE 15. ULTIMATE STRESS INTERACTION CURVE FOR A
 1.5 IN. SQUARE PLATE OF NARMCO 5208/T300 [0/±45]
 MATERIAL WITH A 0.375 IN. DIAMETER CENTRAL HOLE AND
 40 PER CENT ZERO DEGREE PLYS

0.375 IN. DIAM. HOLE
50% ZERO DEG. PLYS

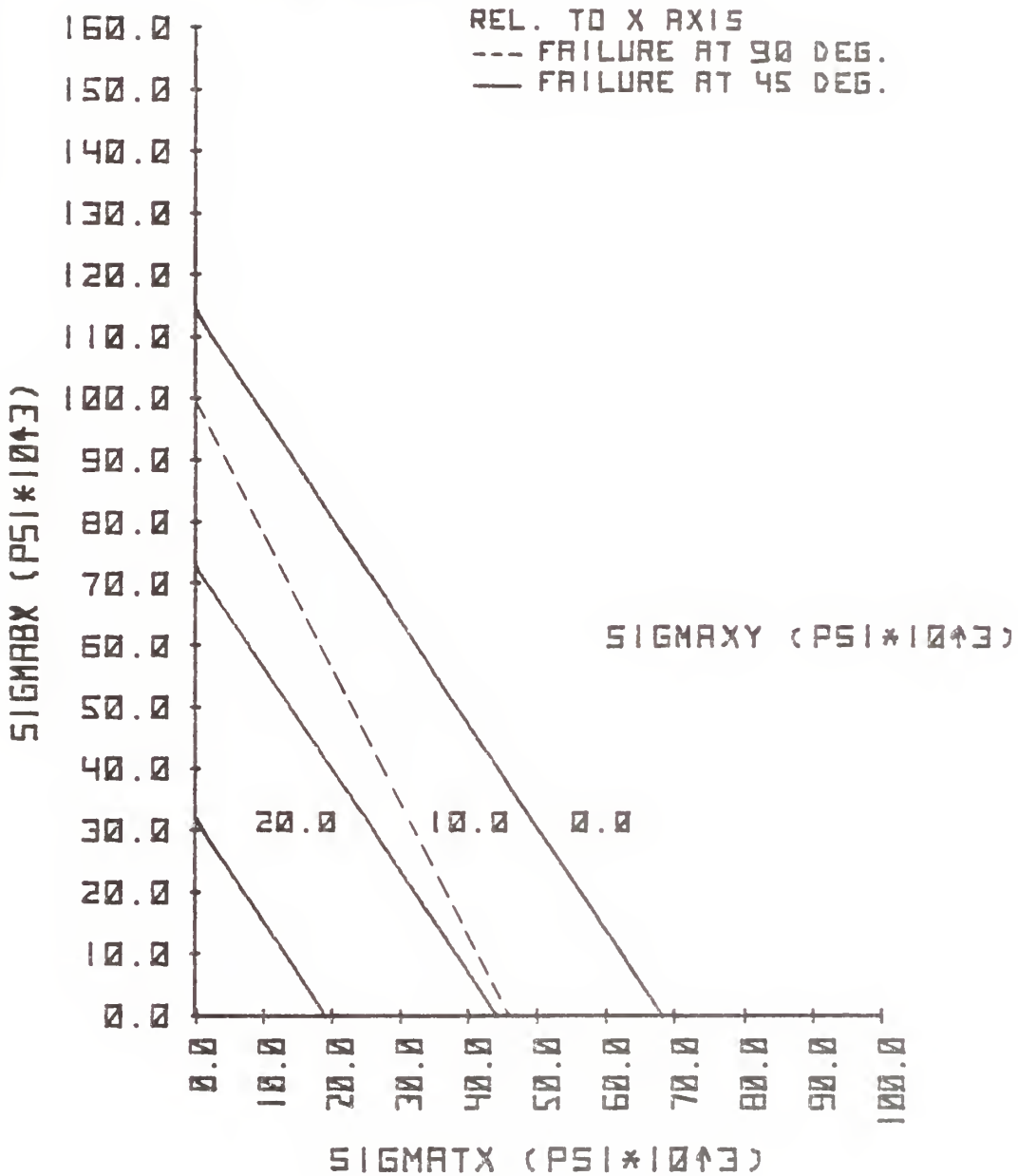


FIGURE 16. ULTIMATE STRESS INTERACTION CURVE FOR A
1.5 IN. SQUARE PLATE OF NARMCO 5203/T300 [0/±45]
MATERIAL WITH A 0.375 IN. DIAMETER CENTRAL HOLE AND
50 PER CENT ZERO DEGREE PLYS

0.375 IN. DIAM. HOLE
60% ZERO DEG. PLYS

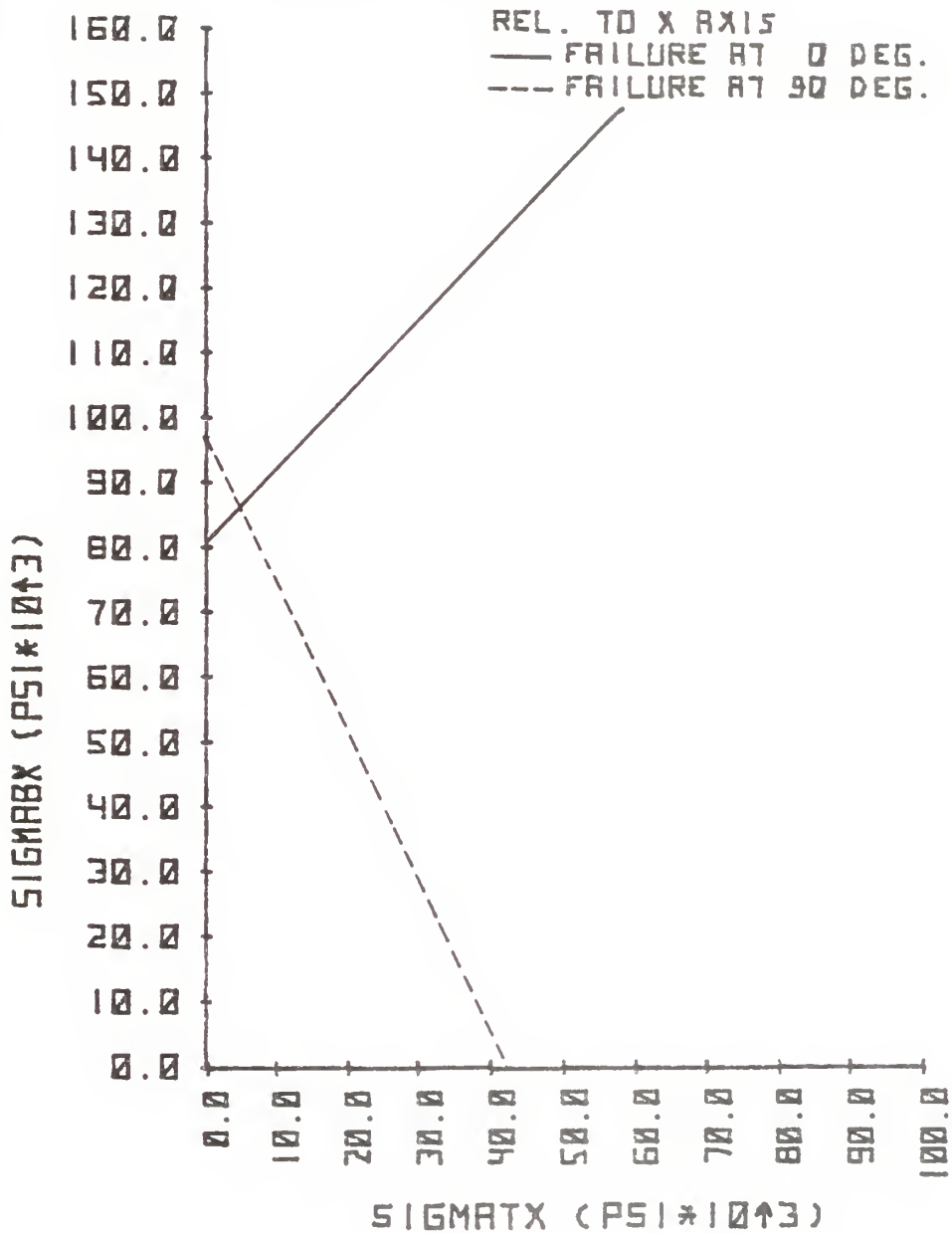


FIGURE 17. ULTIMATE STRESS INTERACTION CURVE FOR A
1.5 IN. SQUARE PLATE OF NARMCO 5208/T300 [0/±45]
MATERIAL WITH A 0.375 IN. DIAMETER CENTRAL HOLE AND
60 PER CENT ZERO DEGREE PLYS

0.4375 IN. DIAM. HOLE
 10% ZERO DEG. PLIES

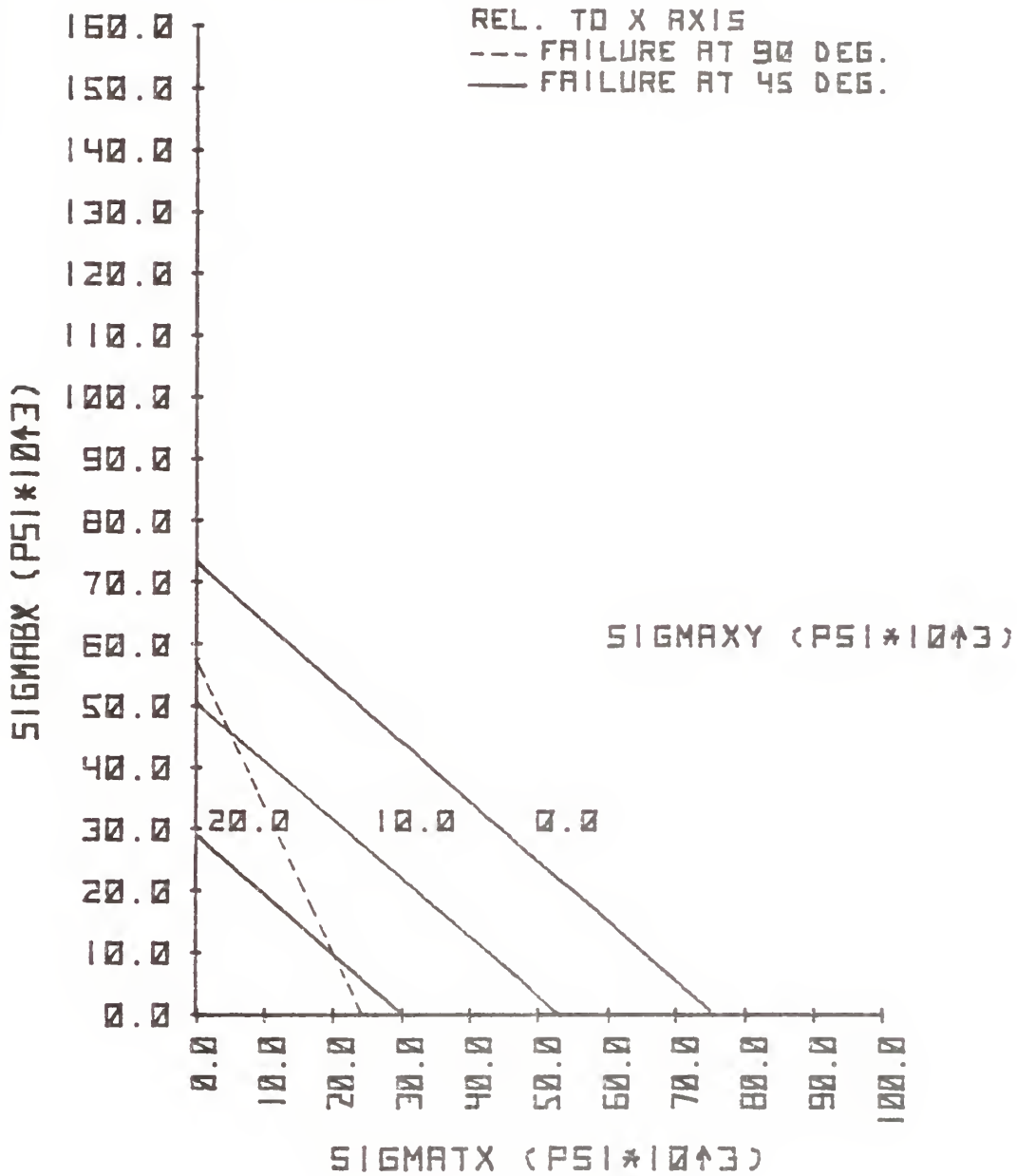


FIGURE 18. ULTIMATE STRESS INTERACTION CURVE FOR A
 1.75 IN. SQUARE PLATE OF NARMCO 5208/T300 [0/±45]
 MATERIAL WITH A 0.4375 IN. DIAMETER CENTRAL HOLE AND
 10 PER CENT ZERO DEGREE PLIES

0.4375 IN. DIAM. HOLE
 20% ZERO DEG. PLYS

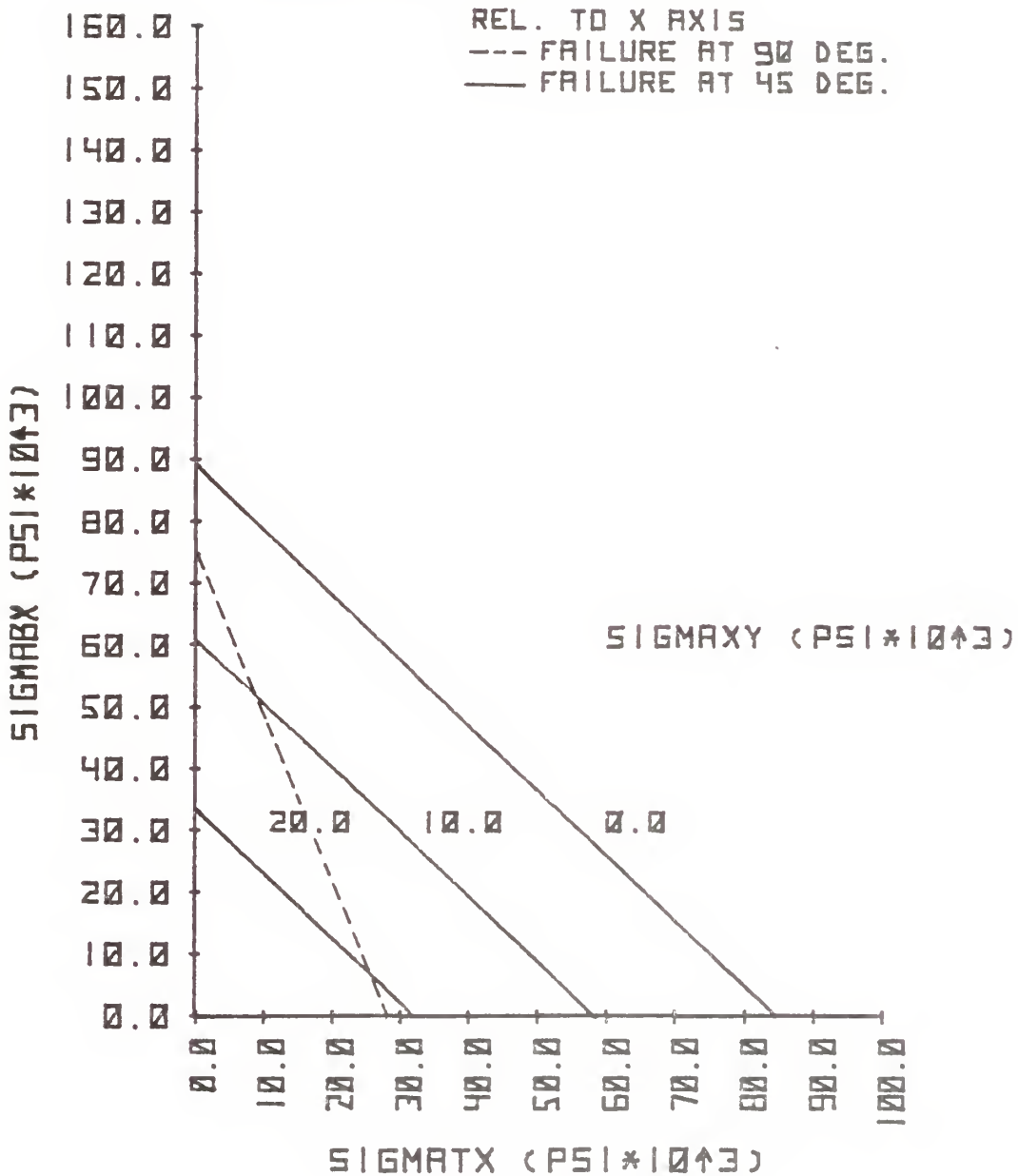


FIGURE 19. ULTIMATE STRESS INTERACTION CURVE FOR A
 1.75 IN. SQUARE PLATE OF NARMCO 5208/T300 [0/±45]
 MATERIAL WITH A 0.4375 IN. DIAMETER CENTRAL HOLE AND
 20 PER CENT ZERO DEGREE PLYS

0.4375 IN. DIAM. HOLE
30% ZERO DEG. PLYS

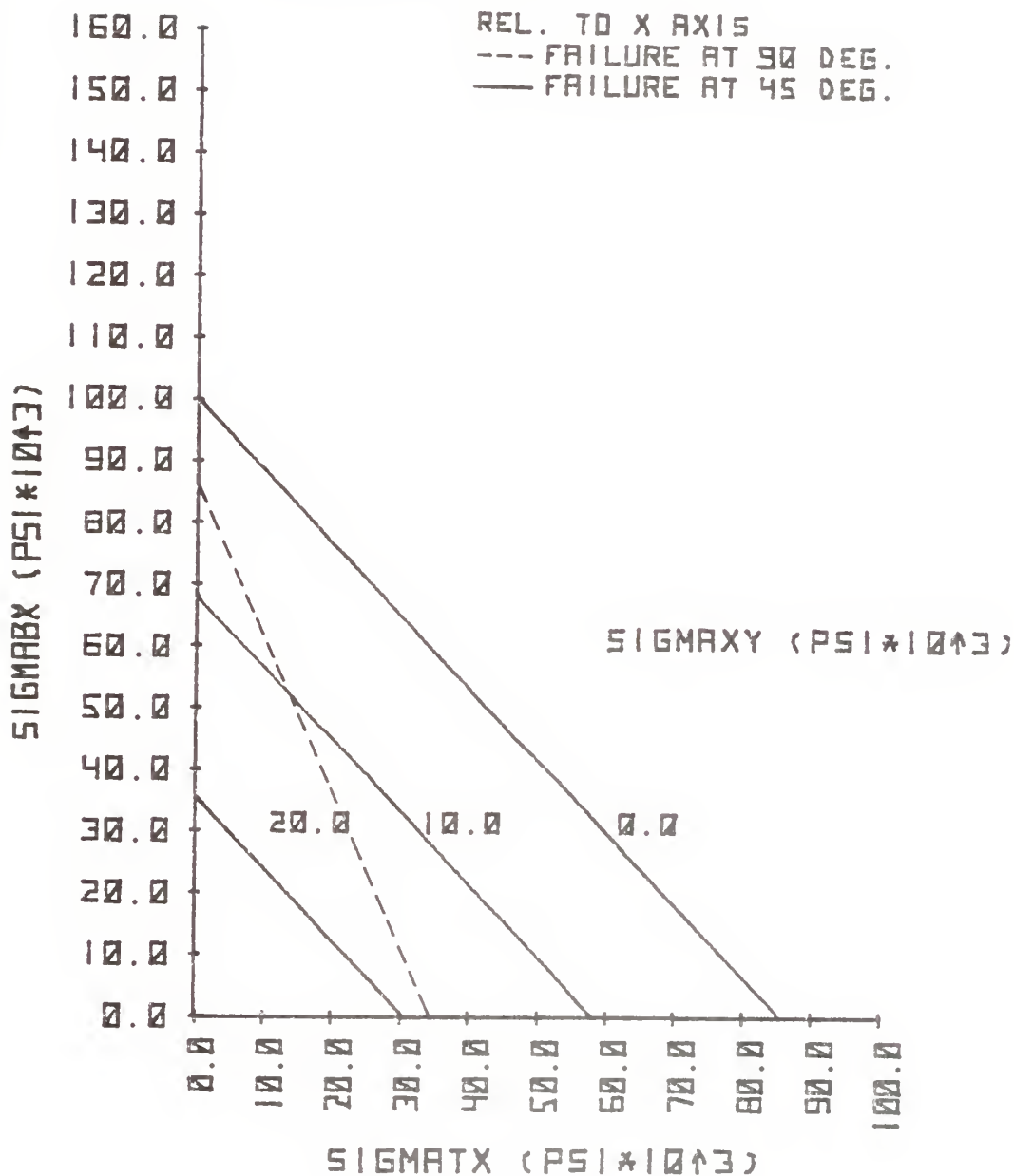


FIGURE 20. ULTIMATE STRESS INTERACTION CURVE FOR A
1.75 IN. SQUARE PLATE OF NARMCO 5209/T300 [0/±45]
MATERIAL WITH A 0.4375 IN. DIAMETER CENTRAL HOLE AND
30 PER CENT ZERO DEGREE PLYS

0.4375 IN. DIAM. HOLE
 40% ZERO DEG. PLYS

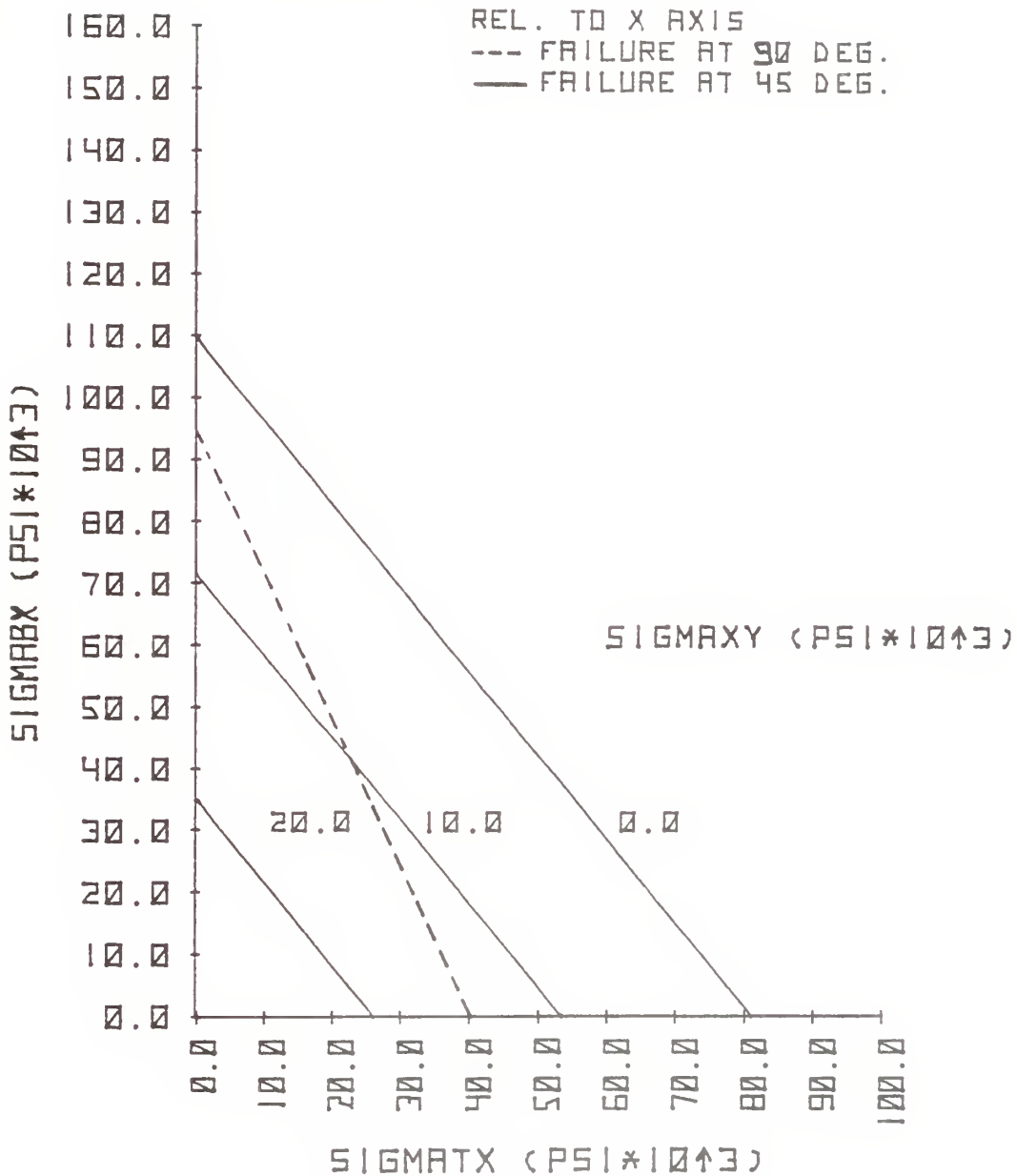


FIGURE 21. ULTIMATE STRESS INTERACTION CURVE FOR A
 1.75 IN. SQUARE PLATE OF NARMCO 5208/T300 [0/±45]
 MATERIAL WITH A 0.4375 IN. DIAMETER CENTRAL HOLE AND
 40 PER CENT ZERO DEGREE PLYS

0.4375 IN. DIAM. HOLE
 50% ZERO DEG. PLYS

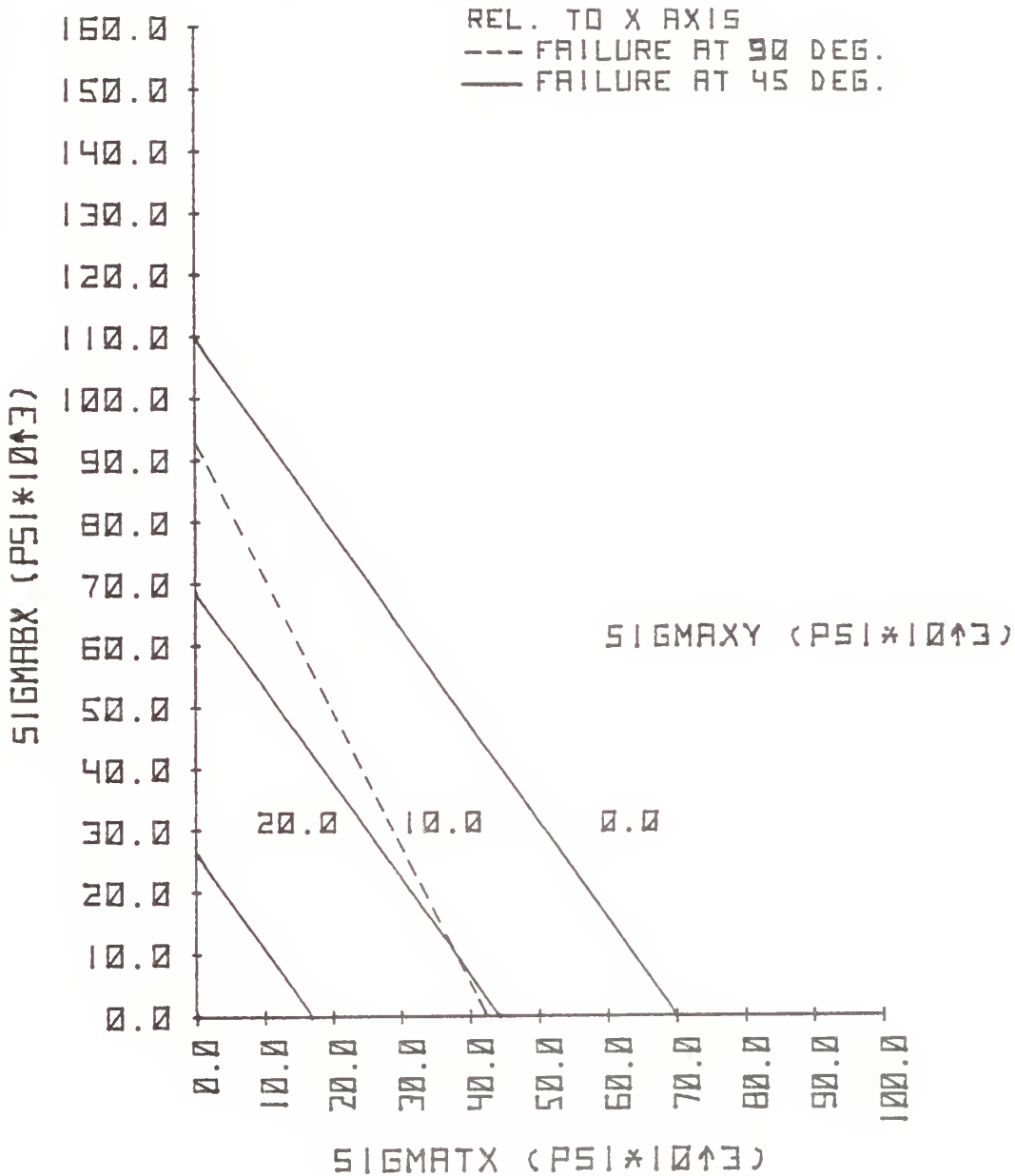


FIGURE 22. ULTIMATE STRESS INTERACTION CURVE FOR A
 1.75 IN. SQUARE PLATE OF NARMCO 5208/T300 [0/+45]
 MATERIAL WITH A 0.4375 IN. DIAMETER CENTRAL HOLE AND
 50 PER CENT ZERO DEGREE PLYS

0.4375 IN. DIAM. HOLE
60% ZERO DEG. PLYS

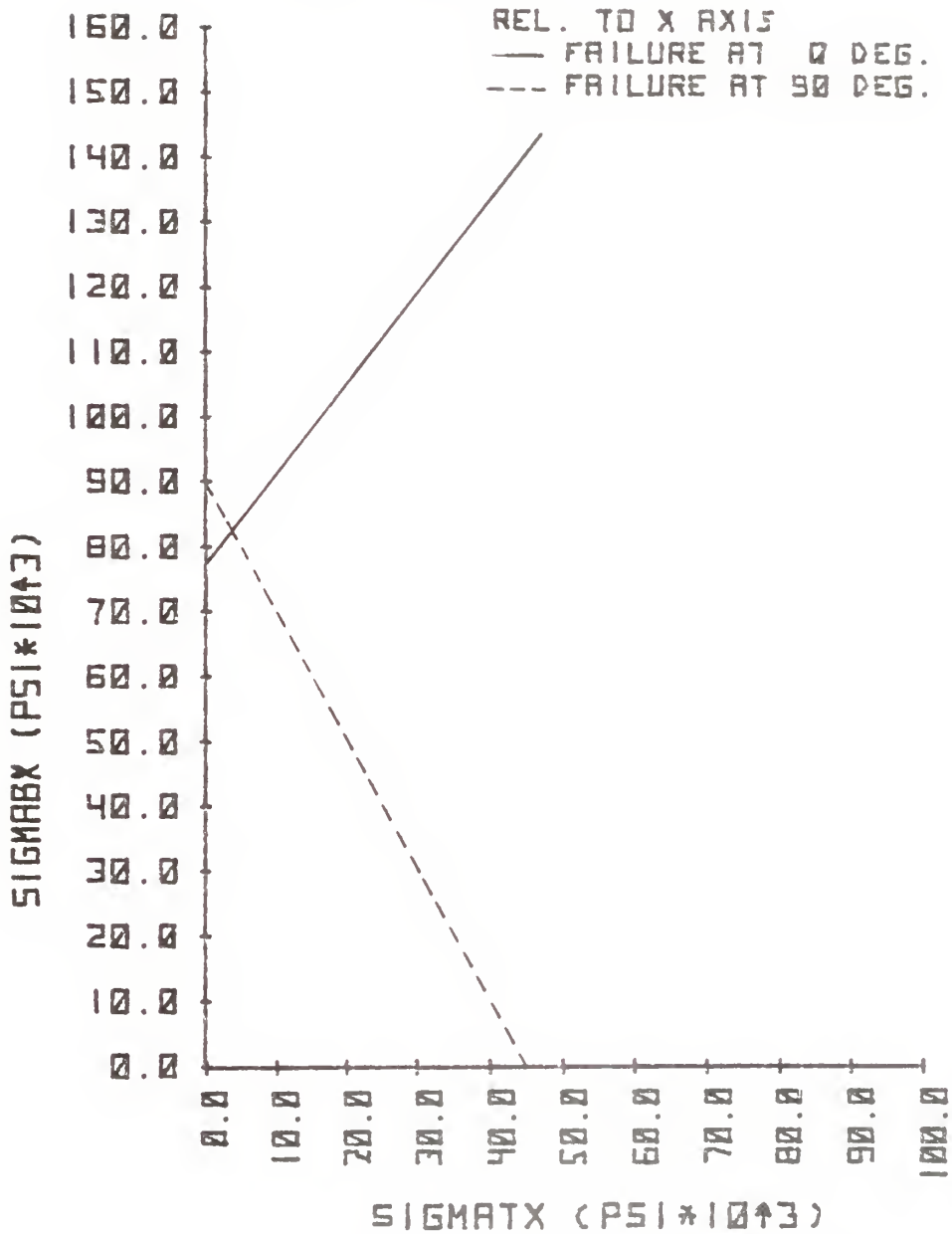


FIGURE 23. ULTIMATE STRESS INTERACTION CURVE FOR A
1.75 IN. SQUARE PLATE OF NARMCO 5203/T300 [0/±45]
MATERIAL WITH A 0.4375 IN. DIAMETER CENTRAL HOLE AND
60 PER CENT ZERO DEGREE PLYS

0.5 IN. DIAM. HOLE
 10% ZERO DEG. PLIES

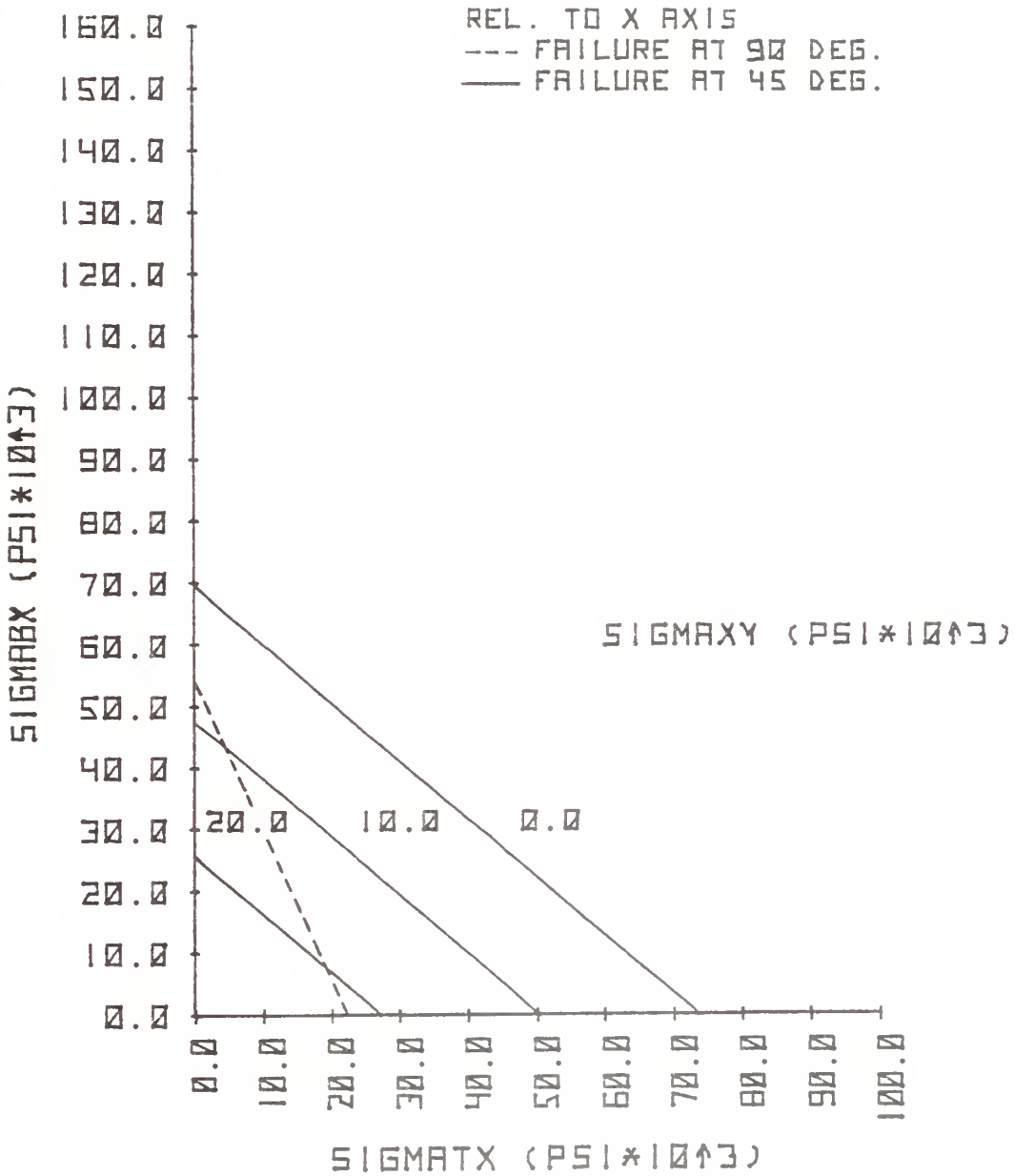


FIGURE 24. ULTIMATE STRESS INTERACTION CURVE FOR A
 2.0 IN. SQUARE PLATE OF NARMCO 5208/T300 [0/±45]
 MATERIAL WITH A 0.5 IN. DIAMETER CENTRAL HOLE AND 10
 PER CENT ZERO DEGREE PLYS

0.5 IN. DIAM. HOLE
 20% ZERO DEG. PLYS

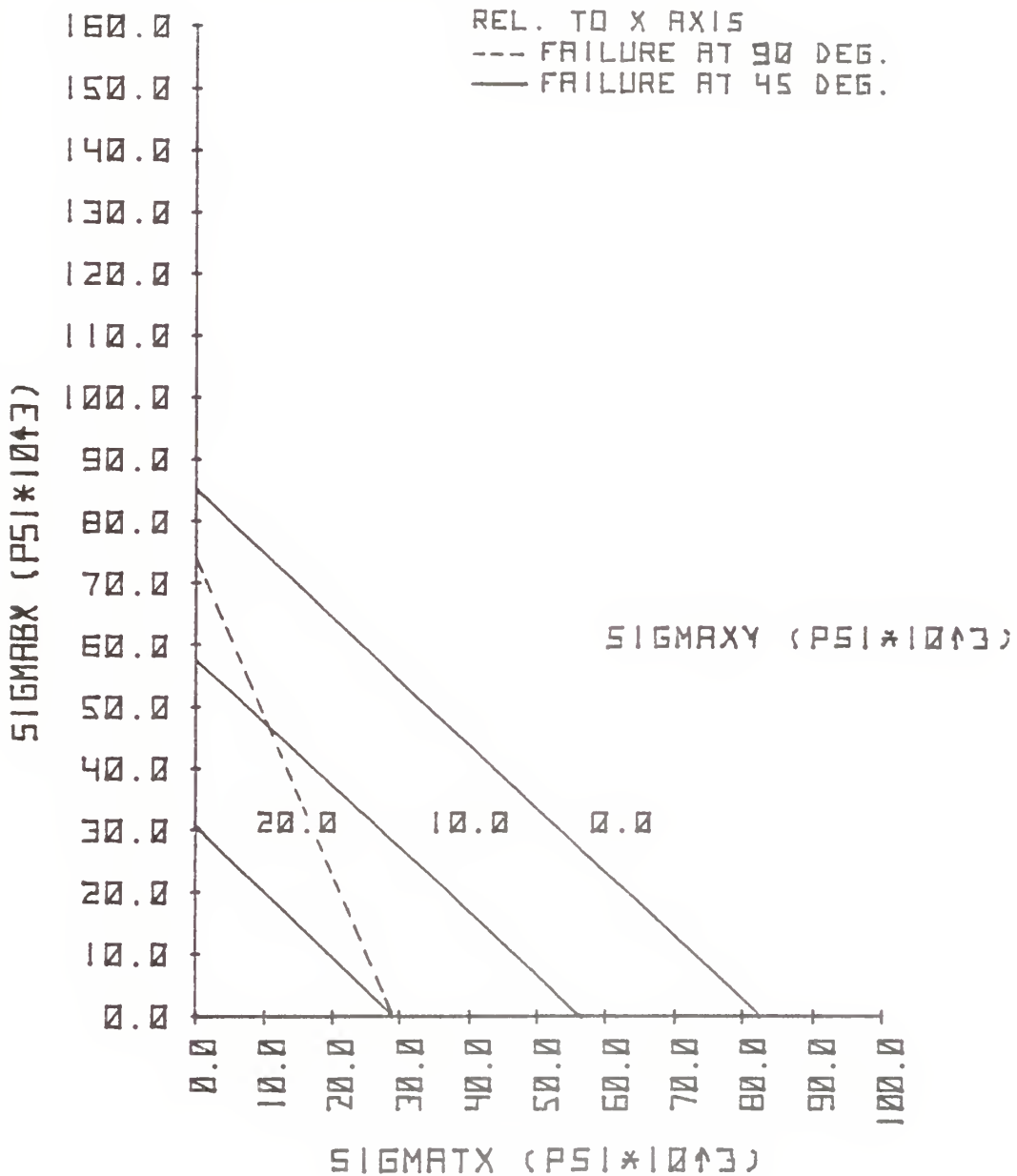


FIGURE 25. ULTIMATE STRESS INTERACTION CURVE FOR A
 2.0 IN. SQUARE PLATE OF NARMCO 5208/T300 [0/±45]
 MATERIAL WITH A 0.5 IN. DIAMETER CENTRAL HOLE AND 20
 PER CENT ZERO DEGREE PLYS

0.5 IN. DIAM. HOLE
30% ZERO DEG. PLYS

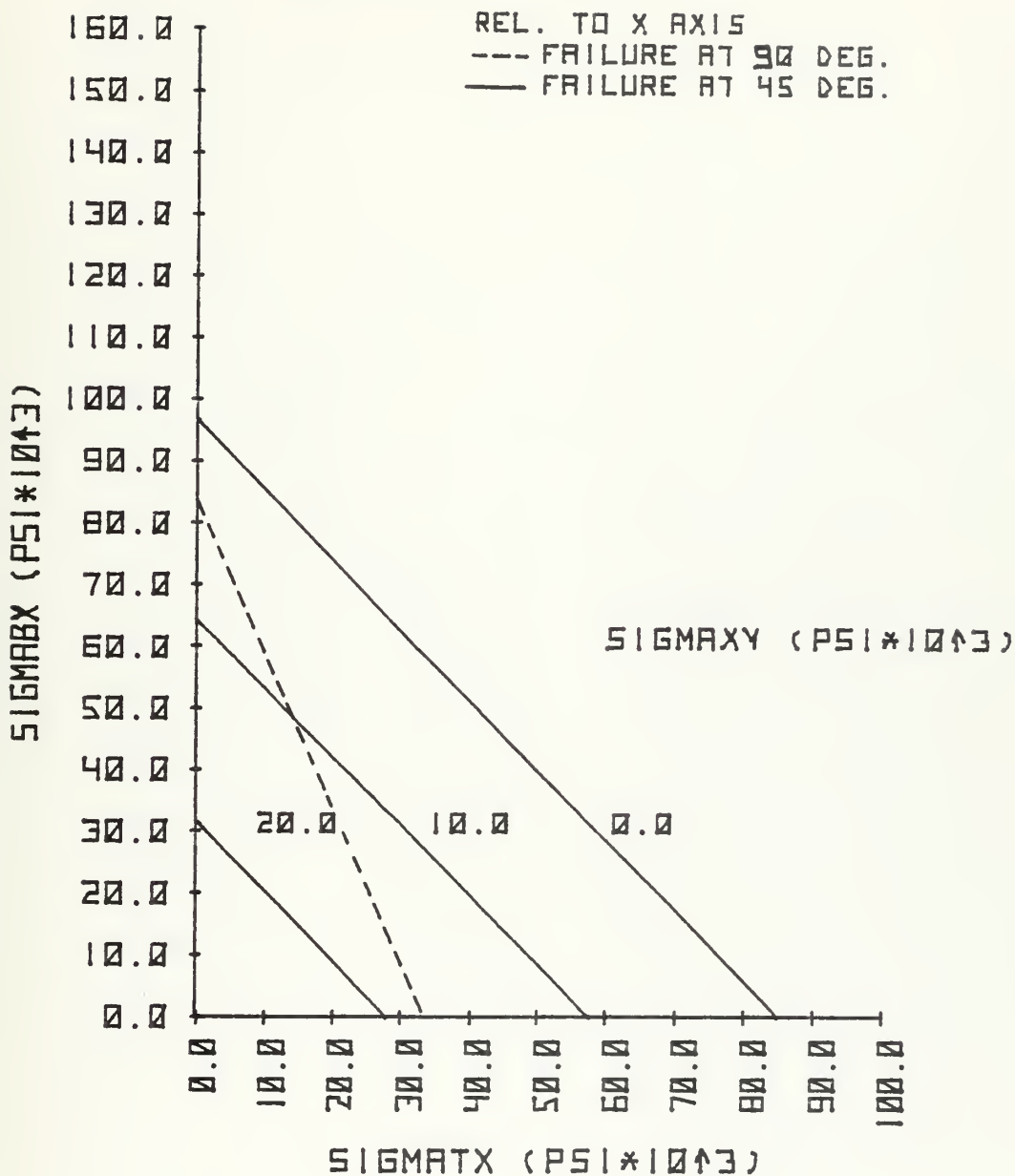


FIGURE 26. ULTIMATE STRESS INTERACTION CURVE FOR A
2.0 IN. SQUARE PLATE OF NARMCO 5208/T300 [0/±45]
MATERIAL WITH A 0.5 IN. DIAMETER CENTRAL HOLE AND 30
PER CENT ZERO DEGREE PLYS

0.5 IN. DIAM. HOLE
40% ZERO DEG. PLYS

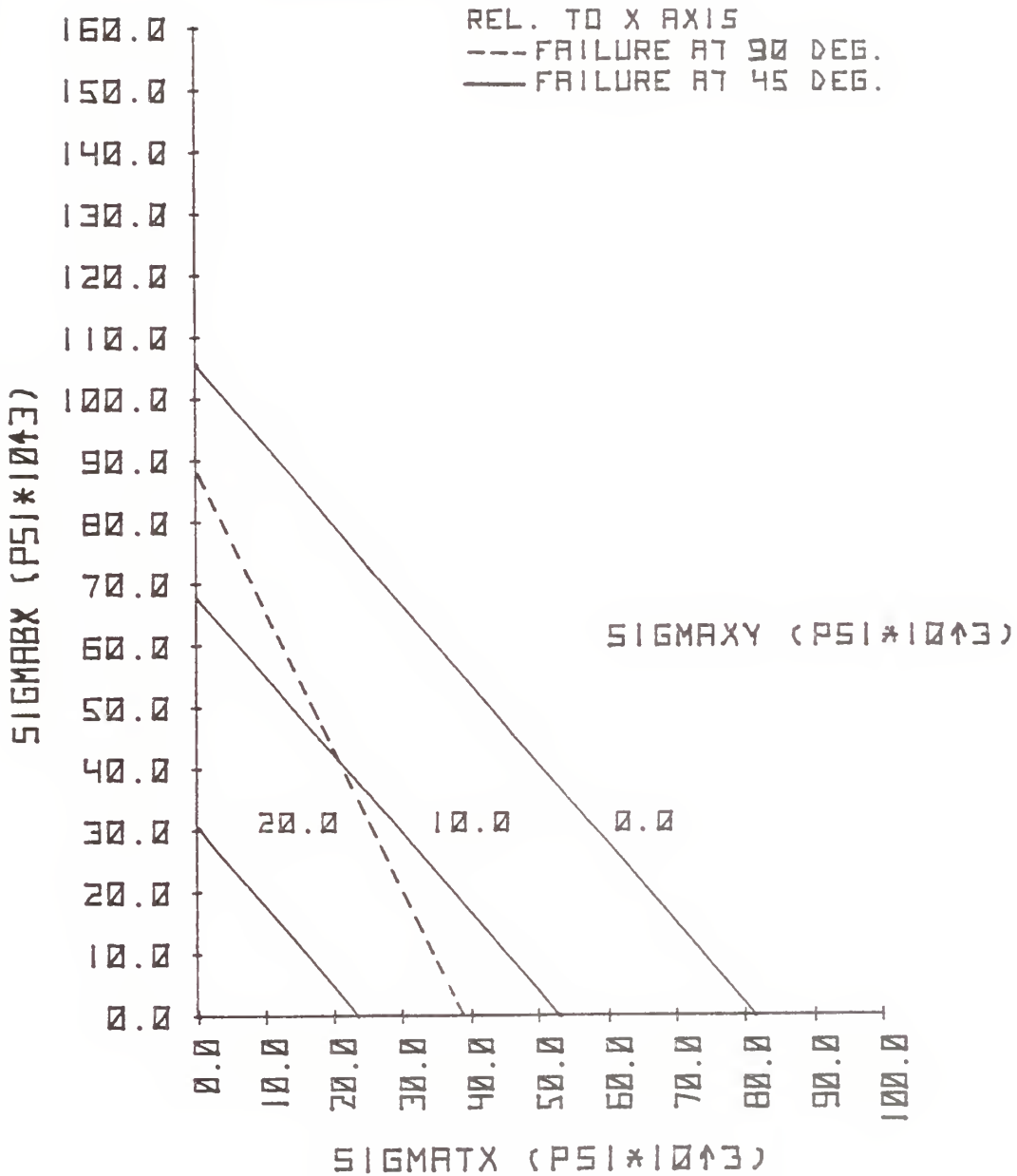


FIGURE 27. ULTIMATE STRESS INTERACTION CURVE FOR A
2.0 IN. SQUARE PLATE OF NARMCO 5203/T300 [0/±45]
MATERIAL WITH A 0.5 IN. DIAMETER CENTRAL HOLE AND 40
PER CENT ZERO DEGREE PLYS

0.5 IN. DIAM. HOLE
50% ZERO DEG. PLYS

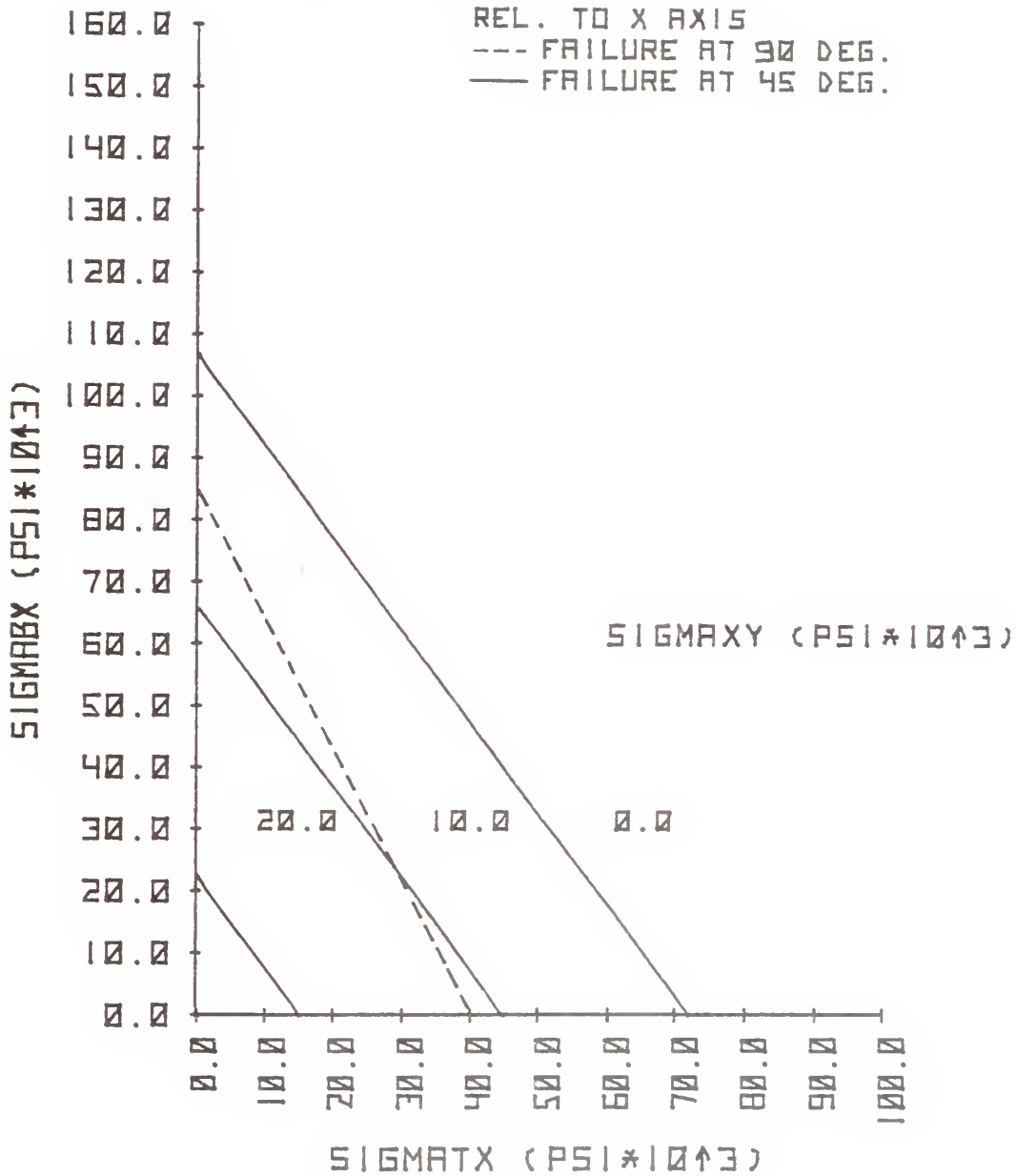


FIGURE 28. ULTIMATE STRESS INTERACTION CURVE FOR A
2.0 IN. SQUARE PLATE OF NARMCO 5208/T300 [0/+45]
MATERIAL WITH A 0.5 IN. DIAMETER CENTRAL HOLE AND 50
PER CENT ZERO DEGREE PLYS

Ø.500 IN. DIAM. HOLE
60% ZERO DEG. PLYS

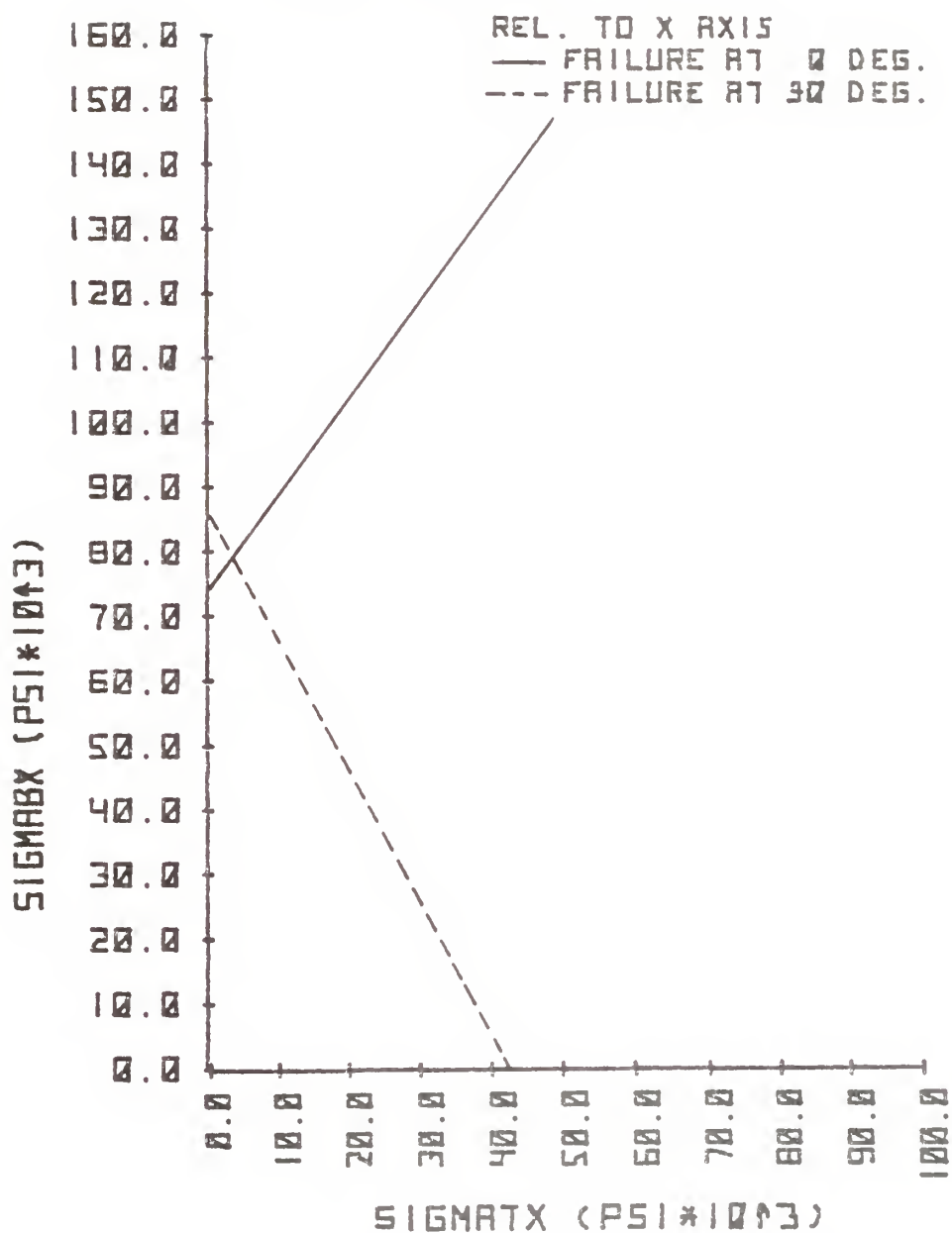


FIGURE 29. ULTIMATE STRESS INTERACTION CURVE FOR A
2.0 IN. SQUARE PLATE OF NARMCO 5208/T300 [0/+45]
MATERIAL WITH A 0.5 IN. DIAMETER CENTRAL HOLE AND 60
PER CENT ZERO DEGREE PLYS

EXCESS BEARING CAPACITY CALCULATIONS

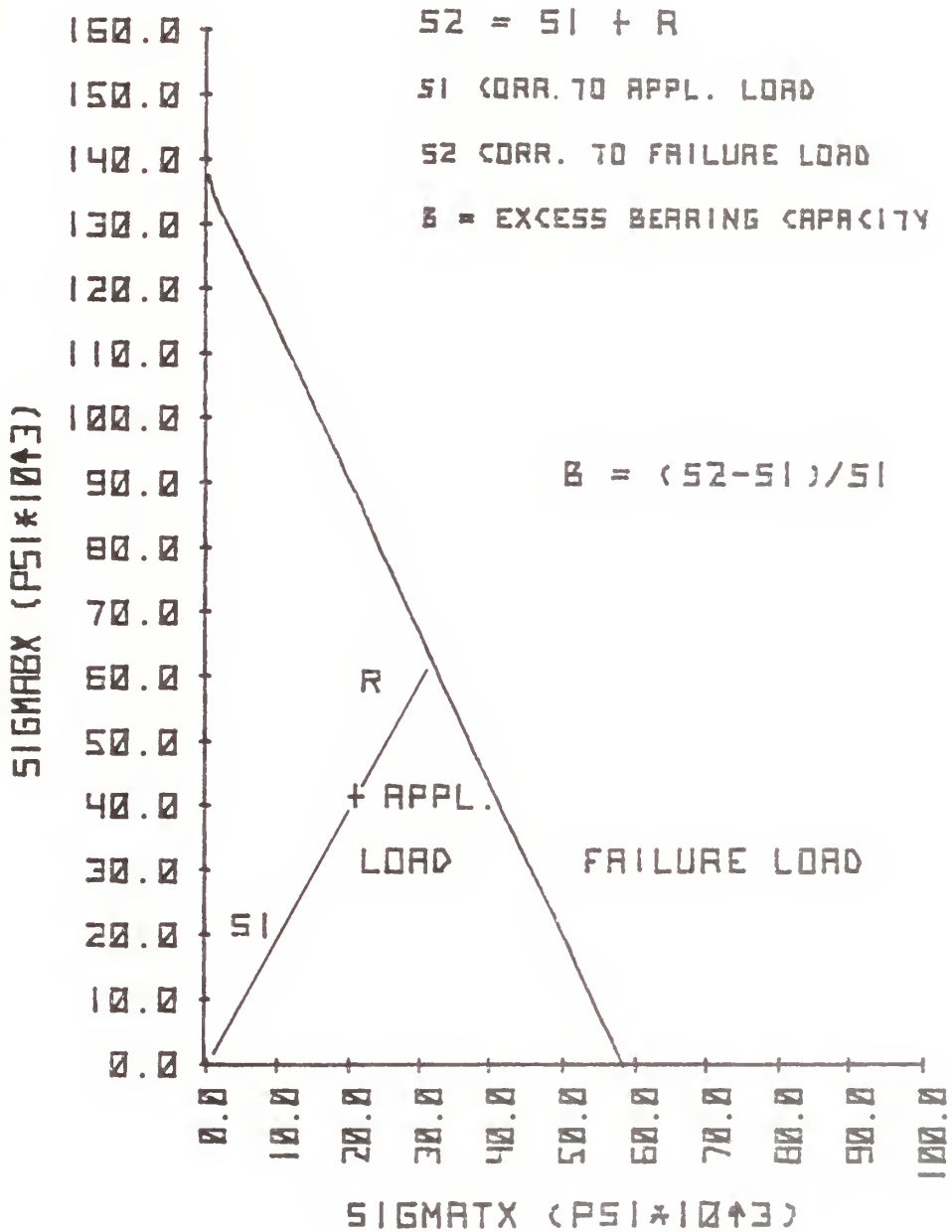
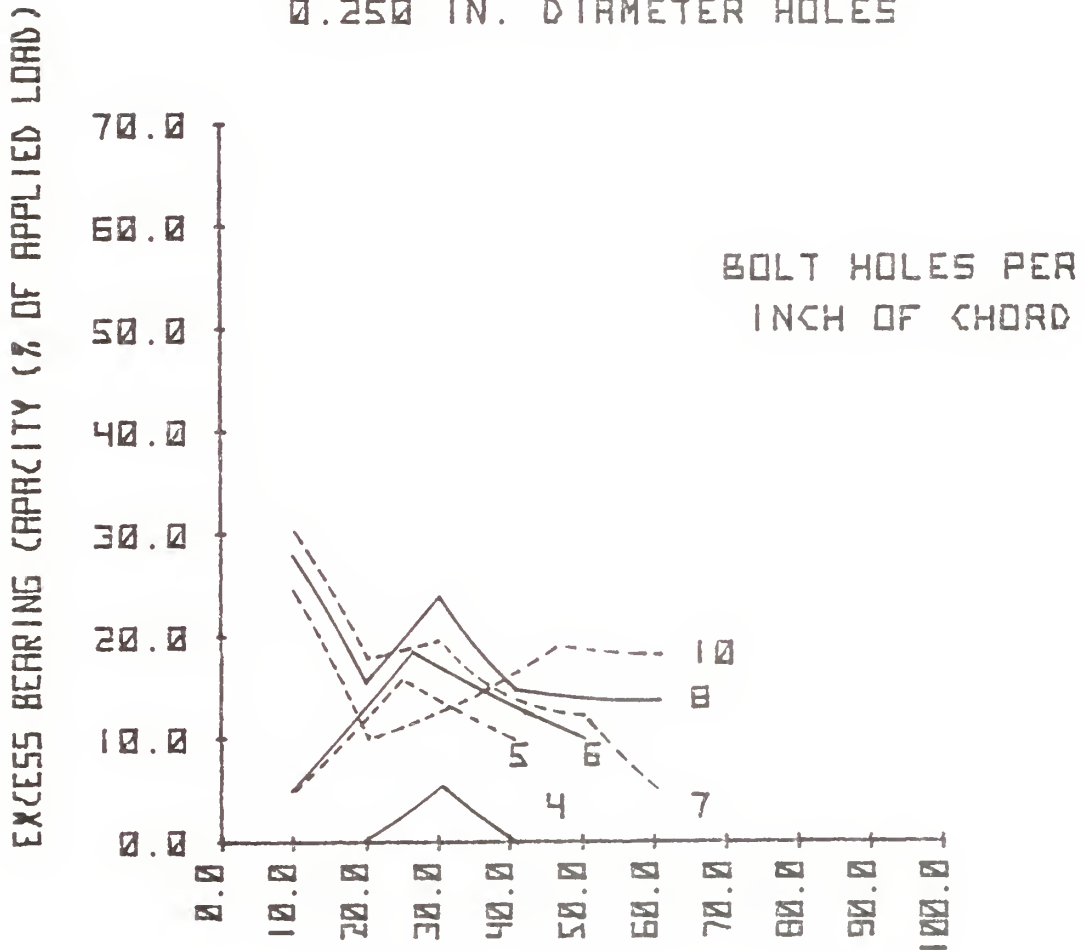


FIGURE 30. EXCESS BEARING CAPACITY CALCULATIONS

VARIATION OF EXCESS BEARING CAPACITY
 WITH LAMINATE COMPOSITION
 NON-BUFFER STRIP JOINT
 0.250 IN. DIAMETER HOLES



PER CENT ZERO DEG. PLIES AT OUTBOARD HOLE

FIGURE 31. VARIATION OF EXCESS BEARING CAPACITY
 WITH LAMINATE COMPOSITION FOR NON-BUFFER STRIP
 JOINTS WITH 0.25 IN. DIAMETER BOLT HOLES

VARIATION OF EXCESS BEARING CAPACITY
 WITH LAMINATE COMPOSITION
 NON-BUFFER STRIP JOINT
 0.375 IN. DIAMETER HOLES

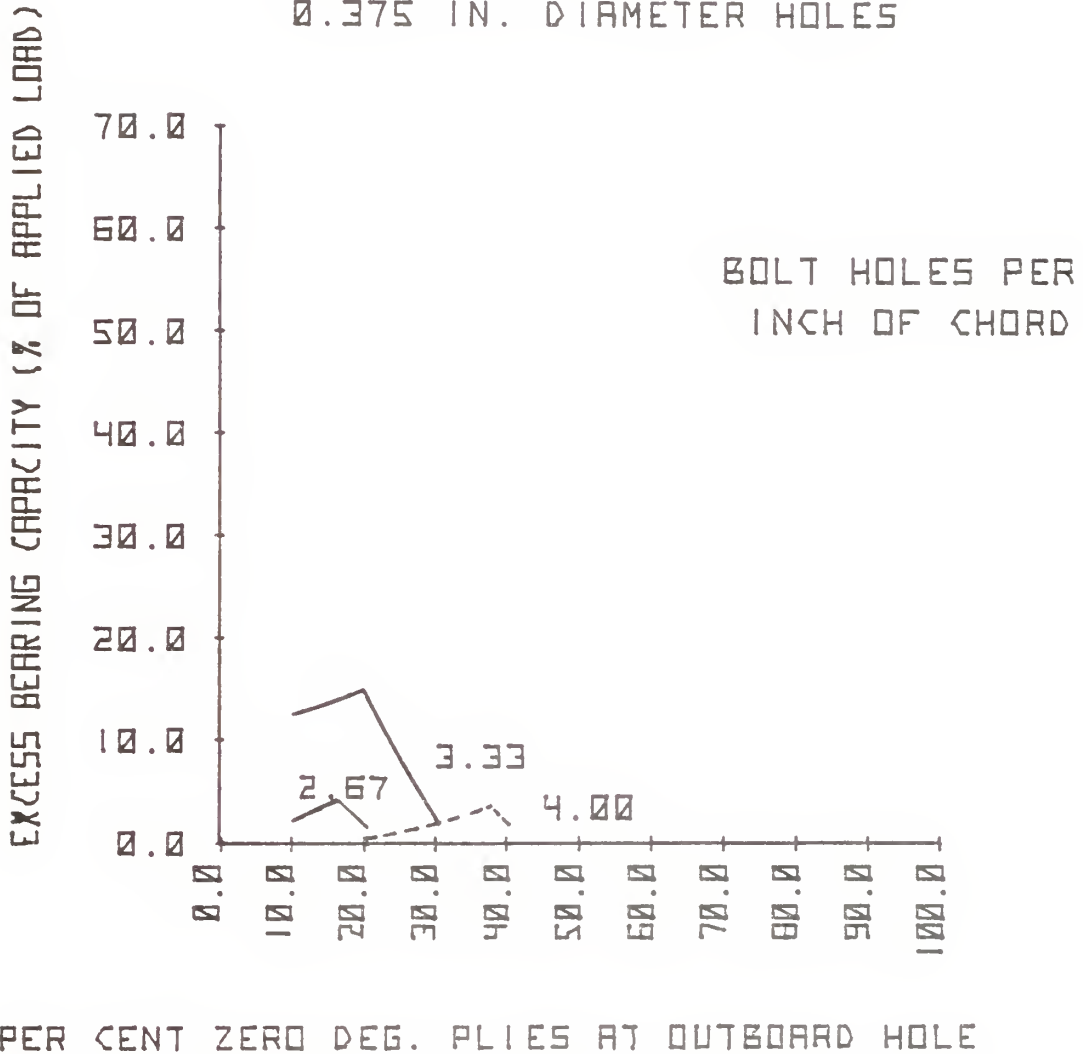
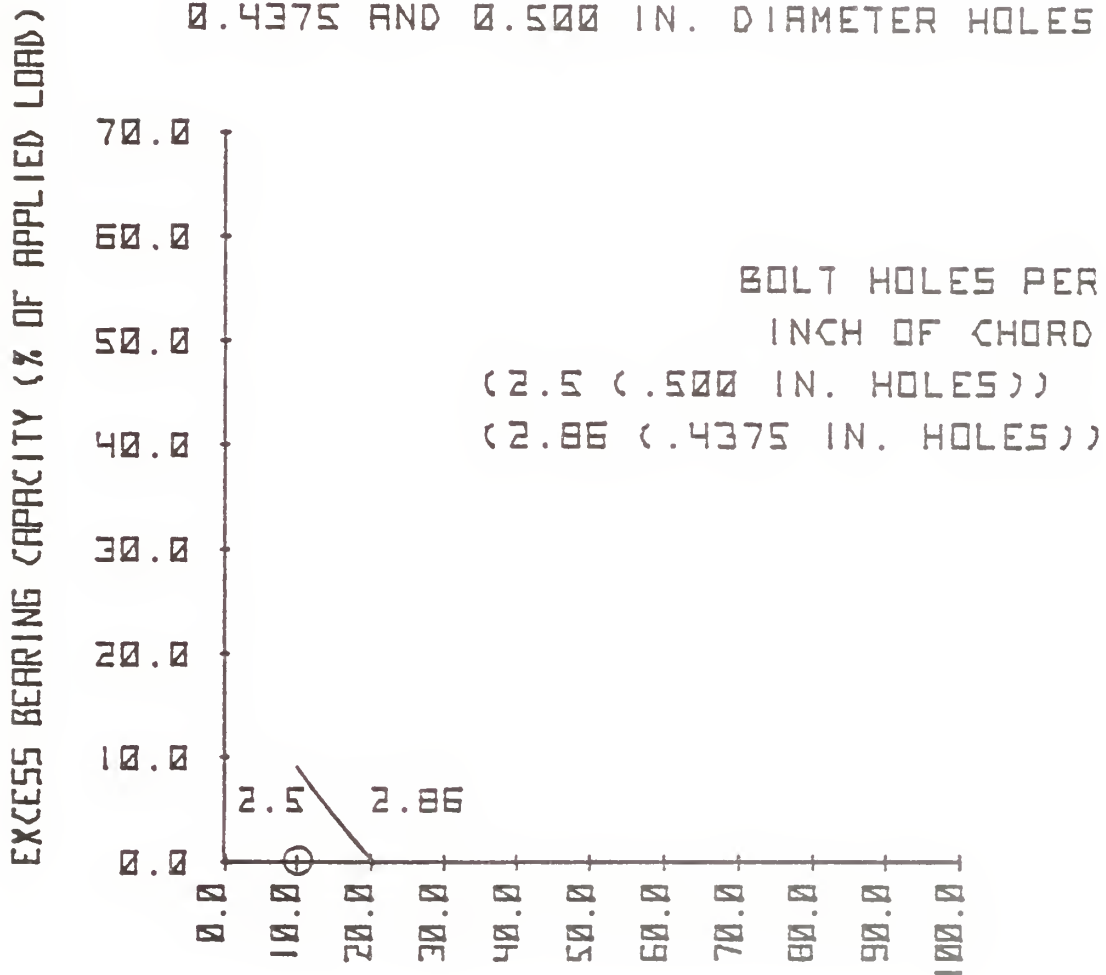


FIGURE 32. VARIATION OF EXCESS BEARING CAPACITY
 WITH LAMINATE COMPOSITION FOR NON-BUFFER STRIP
 JOINTS WITH 0.375 IN. DIAMETER BOLT HOLES

VARIATION OF EXCESS BEARING CAPACITY
 WITH LAMINATE COMPOSITION
 NON-BUFFER STRIP JOINT
 0.4375 AND 0.500 IN. DIAMETER HOLES



PER CENT ZERO DEG. PLYS AT OUTBOARD HOLE

FIGURE 33. VARIATION OF EXCESS BEARING CAPACITY
 WITH LAMINATE COMPOSITION FOR NON-BUFFER STRIP
 JOINTS WITH 0.4375 AND 0.5 IN. DIAMETER BOLT HOLES

VARIATION OF JOINT WEIGHT WITH
 LAMINATE COMPOSITION
 0.25 IN. DIAMETER HOLES
 NON-BUFFER STRIP JOINT

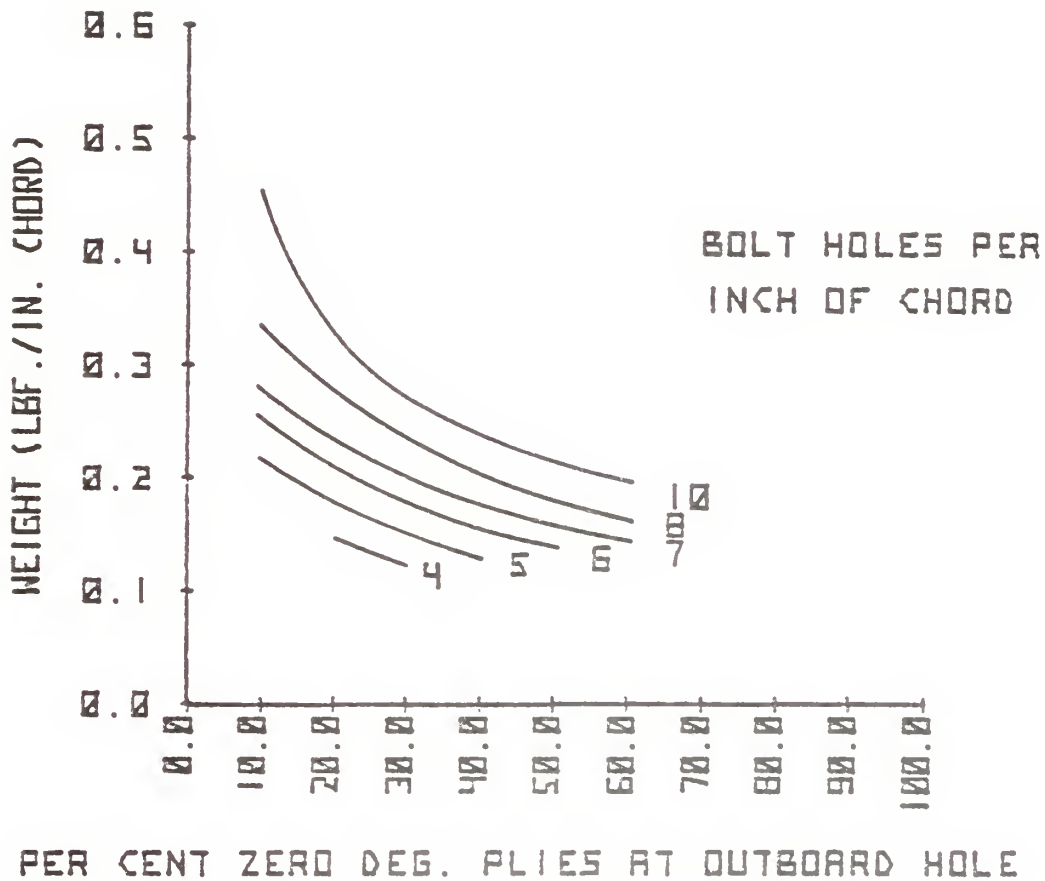


FIGURE 34. VARIATION OF JOINT WEIGHT WITH LAMINATE
 COMPOSITION FOR NON-BUFFER STRIP JOINTS WITH 0.25
 IN. DIAMETER BOLT HOLES

VARIATION OF JOINT WEIGHT WITH
 LAMINATE COMPOSITION
 0.375 IN. DIAMETER HOLES
 NON-BUFFER STRIP JOINT

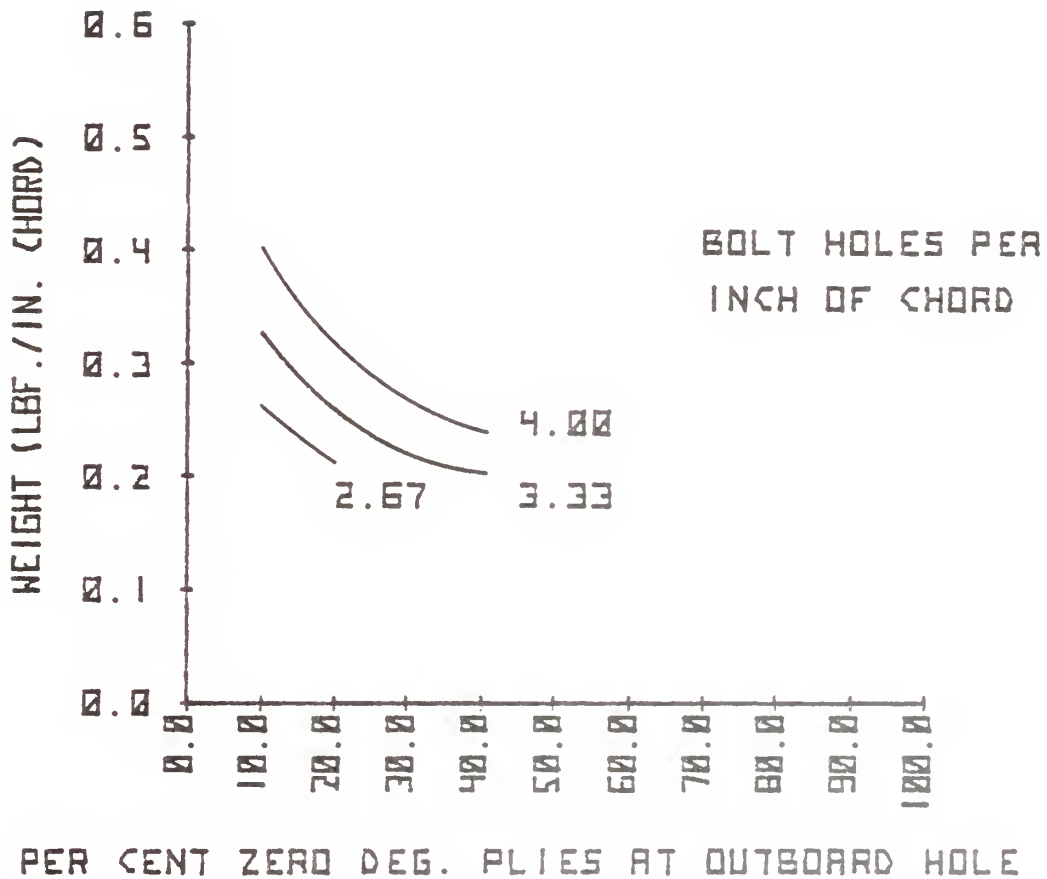


FIGURE 35. VARIATION OF JOINT WEIGHT WITH LAMINATE COMPOSITION FOR NON-BUFFER STRIP JOINTS WITH 0.375 IN. DIAMETER BOLT HOLES

VARIATION OF JOINT WEIGHT WITH
 LAMINATE COMPOSITION
 0.4375 AND 0.500 IN. DIAMETER HOLES
 NON-BUFFER STRIP JOINT

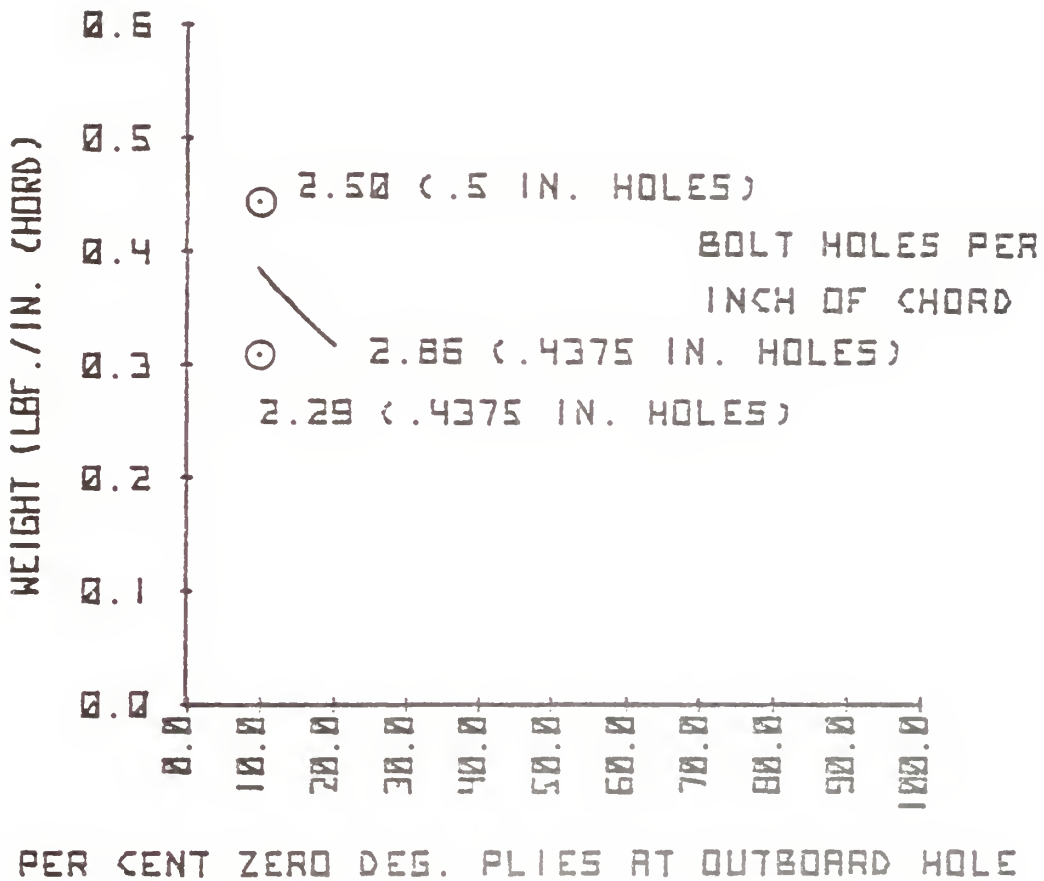
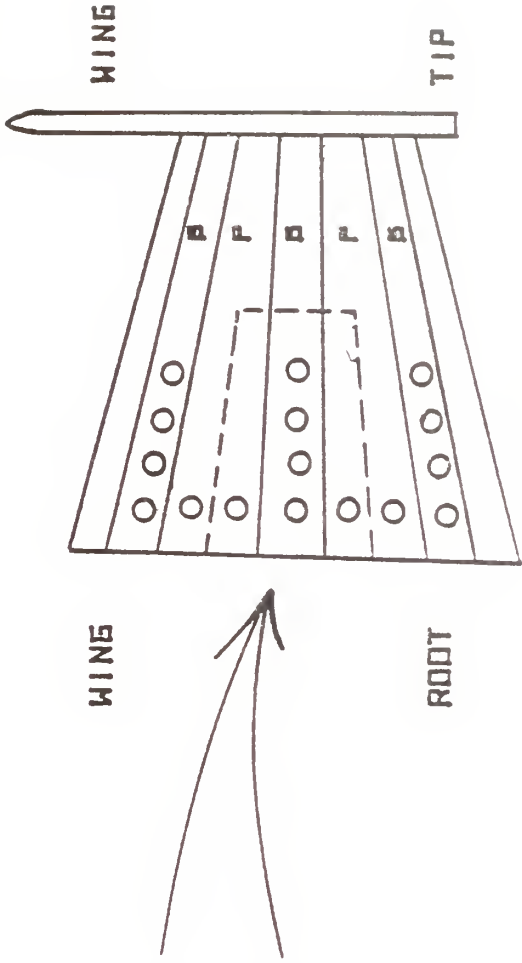
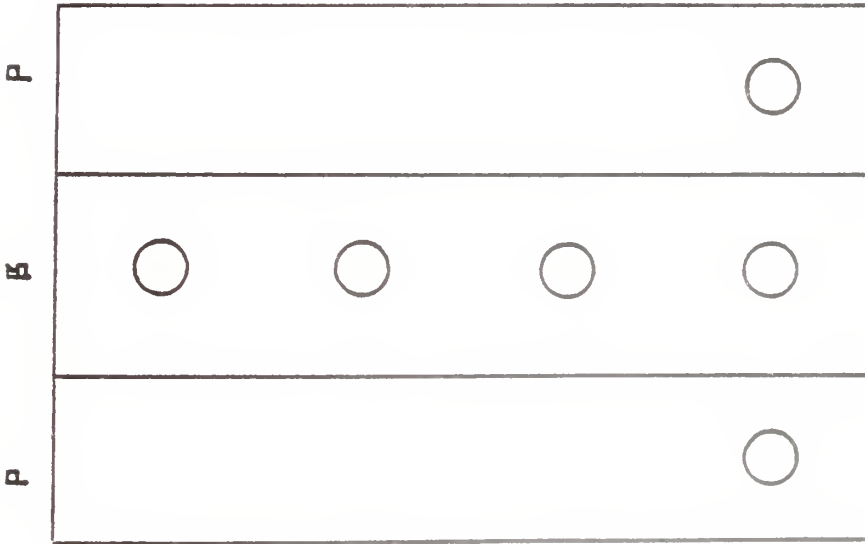


FIGURE 36. VARIATION OF JOINT WEIGHT WITH LAMINATE COMPOSITION FOR NON-BUFFER STRIP JOINTS WITH 0.4375 AND 0.5 IN. DIAMETER BOLT HOLES

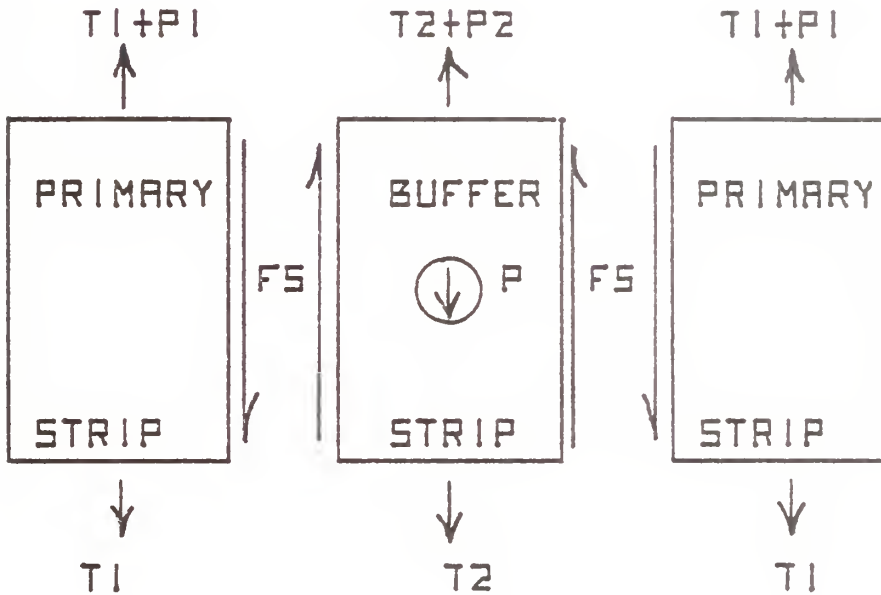


P = PRIMARY STRIP
 B = BUFFER STRIP

PER CENT ZERO DEG. PLYS IN PRIMARY STRIPS
 DECREASES FROM VALUE AT OUTBOARD BOLT TO
 ZERO AT INBOARD ROW OF BOLTS

FIGURE 37. SCHEMATIC OF A WING WITH A BUFFER STRIP JOINT

MECHANISM BY WHICH BOLT LOADS ARE
 REACTED IN A BUFFER STRIP JOINT



T_1 = TENSILE LOAD IN PRIMARY STRIP

T_2 = TENSILE LOAD IN BUFFER STRIP

P = BOLT LOAD APPLIED AT HOLE

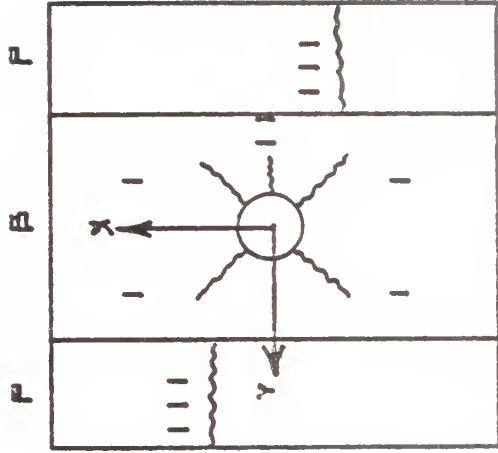
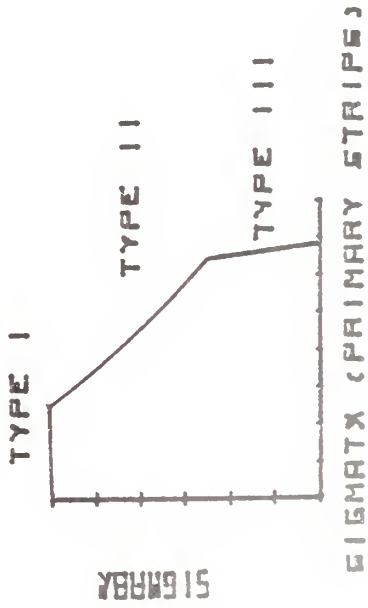
P_1 = BOLT LOAD REACTED IN PRIMARY STRIP

P_2 = BOLT LOAD REACTED IN BUFFER STRIP

FS = SHEAR PASSING P_1 TO PRIMARY STRIP

FIGURE 38. MECHANISM BY WHICH BOLT LOADS ARE
 REACTED IN A BUFFER STRIP JOINT

BUFFER STRIP FAILURE MODES



TYPE I AT 45 DEG. TO X AXIS

B = BUFFER STRIP

EFFECT OF STRESS ON FAILURE TYPE P = PRIMARY STRIP

FAILURE TYPE DEFINITIONS

FIGURE 39. DESCRIPTION OF THE EXPECTED BUFFER STRIP FAILURE MODES

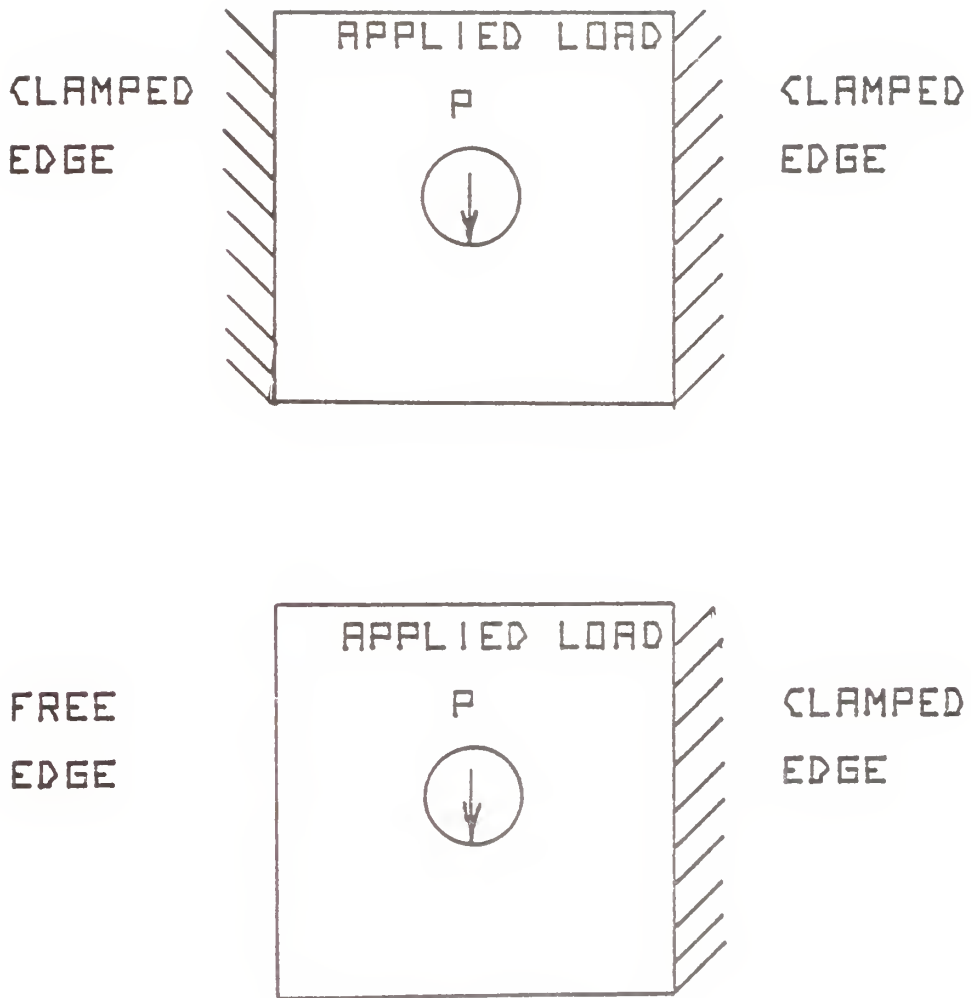


FIGURE 40. SCHEMATIC OF SHEAR LOADING TEST SPECIMENS

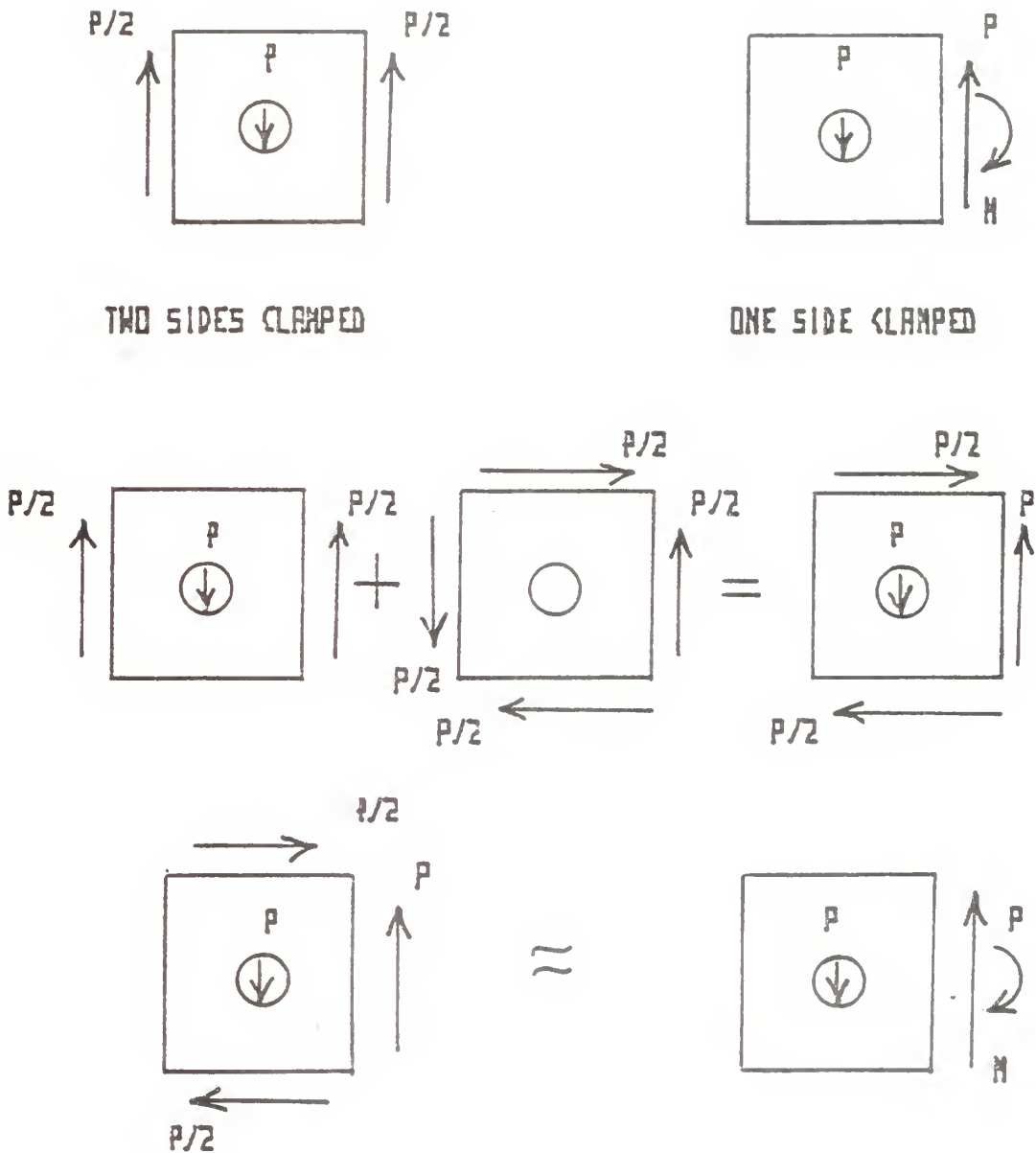


FIGURE 41. SCHEMATIC OF THE SUPERPOSITION USED TO DETERMINE SHEAR EFFECTS ON A BUFFER STRIP WITH A CENTRAL HOLE

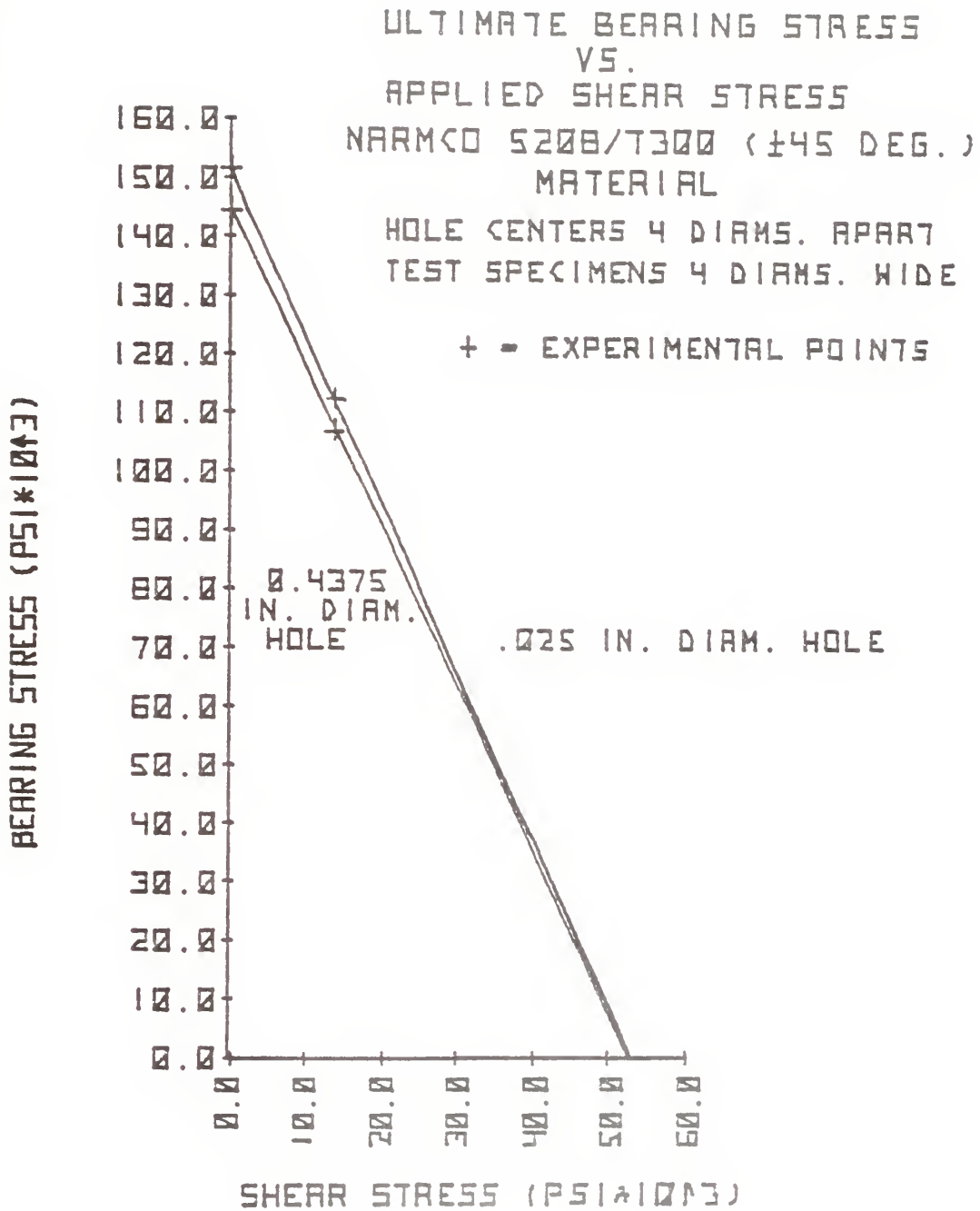


FIGURE 42. ULTIMATE BEARING STRESS-SHEAR STRESS
 INTERACTION CURVE FOR A FOUR HOLE DIAMETER
 SQUARE PLATE OF NARMCO 5203/T300 [± 45]
 MATERIAL WITH A CENTRAL HOLE

VARIATION OF ULTIMATE BEARING STRESS
WITH BYPASS STRESS IN THE PRIMARY
STRIPS - BUFFER STRIP JOINT

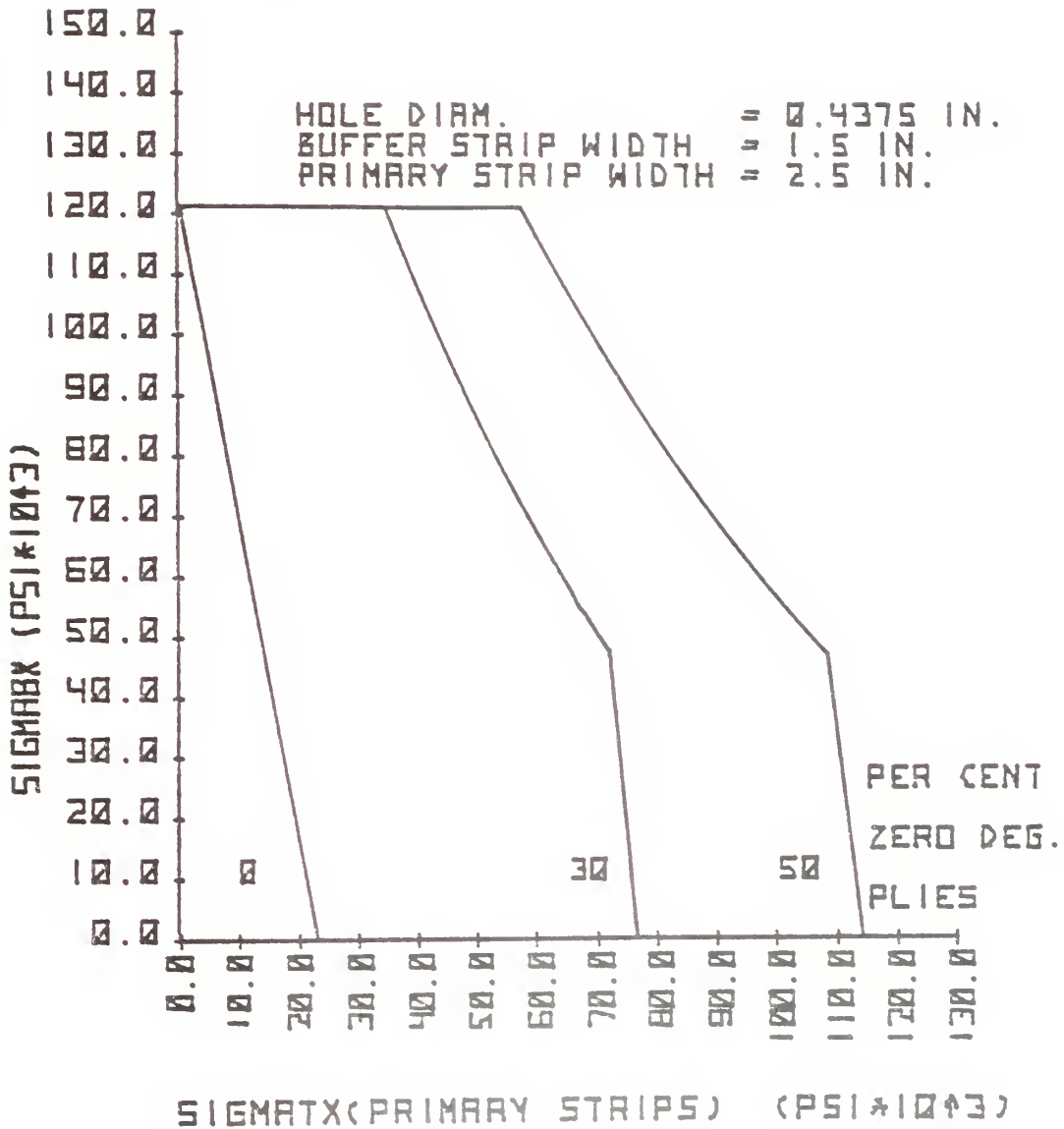


FIGURE 43. ULTIMATE STRESS INTERACTION CURVE FOR A BUFFER STRIP JOINT MADE FROM NARMCO 5208/T300 [0/±45] MATERIAL WITH 2.5 IN. WIDE PRIMARY STRIPS, A 1.5 IN. WIDE BUFFER STRIP, AND A 0.4375 IN. DIAMETER CENTRAL HOLE

VARIATION OF ULTIMATE BEARING STRESS
WITH BYPASS STRESS IN THE PRIMARY
STRIPS - BUFFER STRIP JOINT

HOLE DIAM. = 0.250 IN.
BUFFER STRIP WIDTH = 4.00 DIAM.
PRIMARY STRIP WIDTH = 3.33 DIAM.

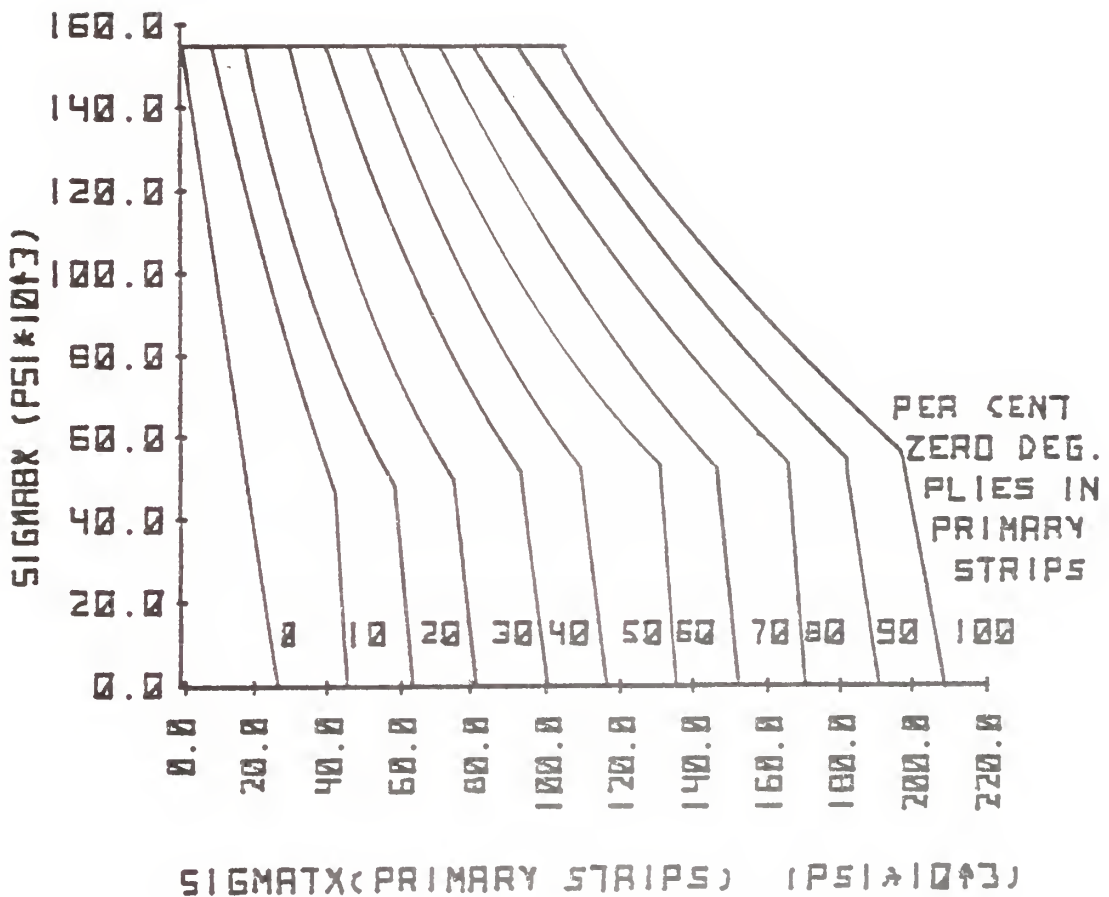


FIGURE 44. ULTIMATE STRESS INTERACTION CURVE FOR A 1.0 IN. LONG BUFFER STRIP PLATE MADE FROM NARMCO 5208/T300 [0/+45] MATERIAL WITH 0.833 IN. WIDE PRIMARY STRIPS, A 1.0 IN. WIDE BUFFER STRIP, AND A 0.25 IN. DIAMETER CENTRAL HOLE

VARIATION OF ULTIMATE BEARING STRESS
WITH BYPASS STRESS IN THE PRIMARY
STRIPS - BUFFER STRIP JOINT

HOLE DIAM. = 0.4375 IN.
BUFFER STRIP WIDTH = 4.00 DIAM.
PRIMARY STRIP WIDTH = 3.33 DIAM.

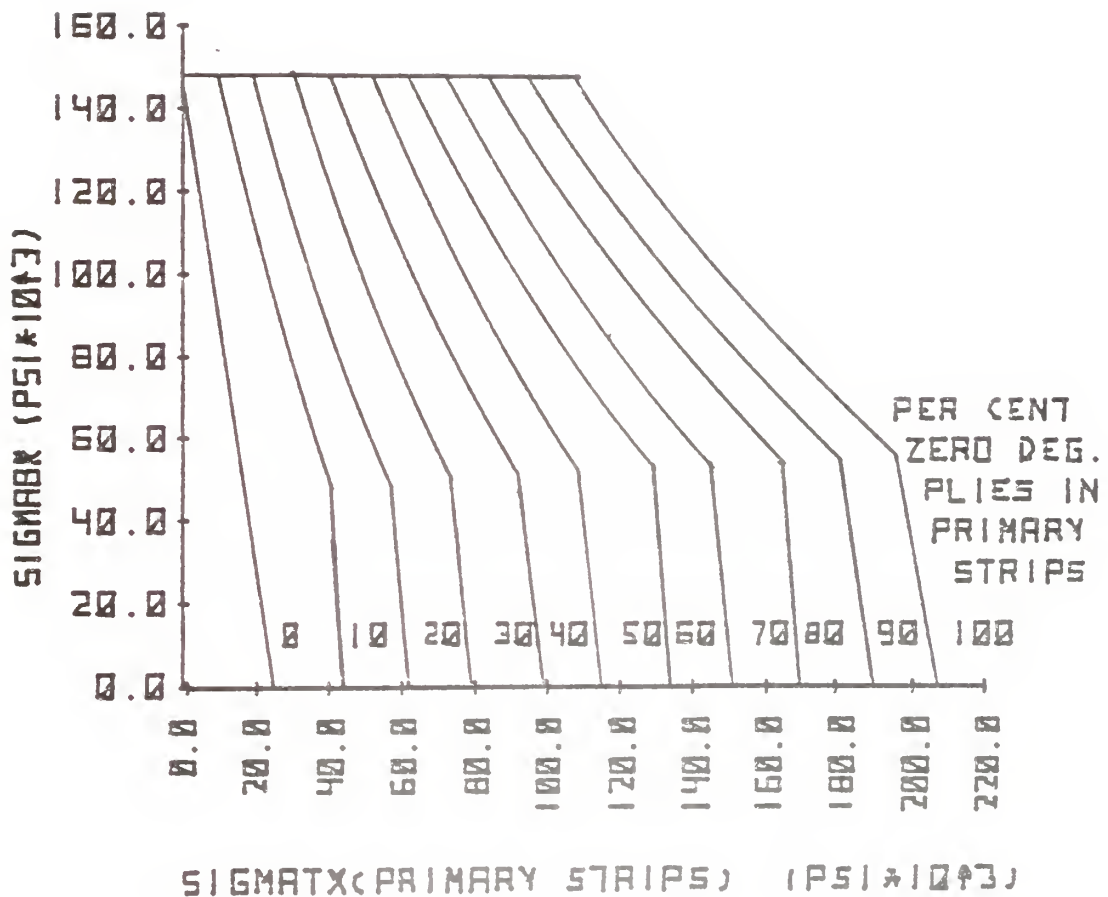
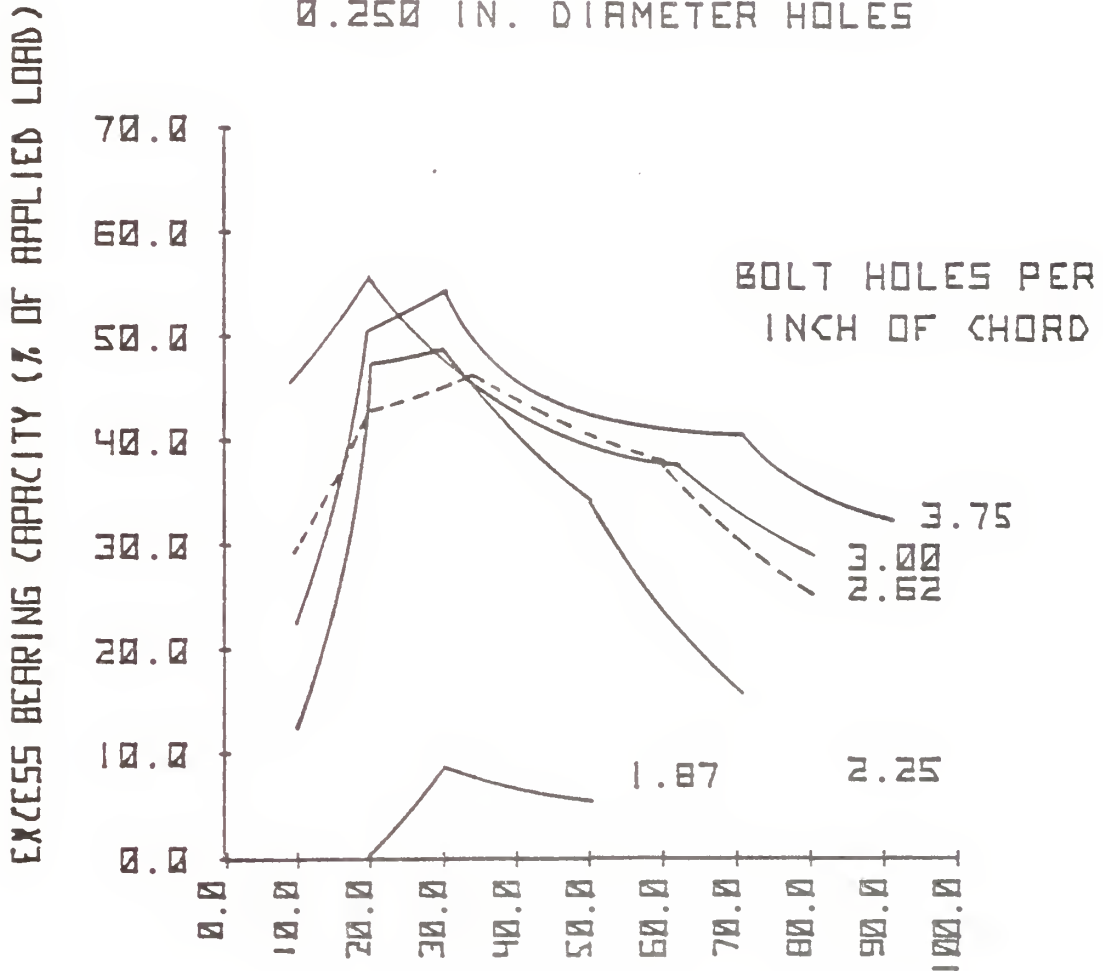


FIGURE 45. ULTIMATE STRESS INTERACTION CURVE FOR A 1.75 IN. LONG BUFFER STRIP PLATE MADE FROM NARMCO 5208/T300 [0/±45] MATERIAL WITH 1.46 IN. WIDE PRIMARY STRIPS, A 1.75 IN. WIDE BUFFER STRIP, AND A 0.4375 IN. DIAMETER CENTRAL HOLE

VARIATION OF EXCESS BEARING CAPACITY
 WITH LAMINATE COMPOSITION
 BUFFER STRIP JOINT
 0.250 IN. DIAMETER HOLES



PER CENT ZERO DEG. PLYS AT OUTBOARD HOLE

FIGURE 46. VARIATION OF EXCESS BEARING CAPACITY WITH LAMINATE COMPOSITION FOR BUFFER STRIP JOINTS WITH 0.25 IN. DIAMETER HOLES

VARIATION OF EXCESS BEARING CAPACITY
 WITH LAMINATE COMPOSITION
 BUFFER STRIP JOINT
 0.4375 IN. DIAMETER HOLES

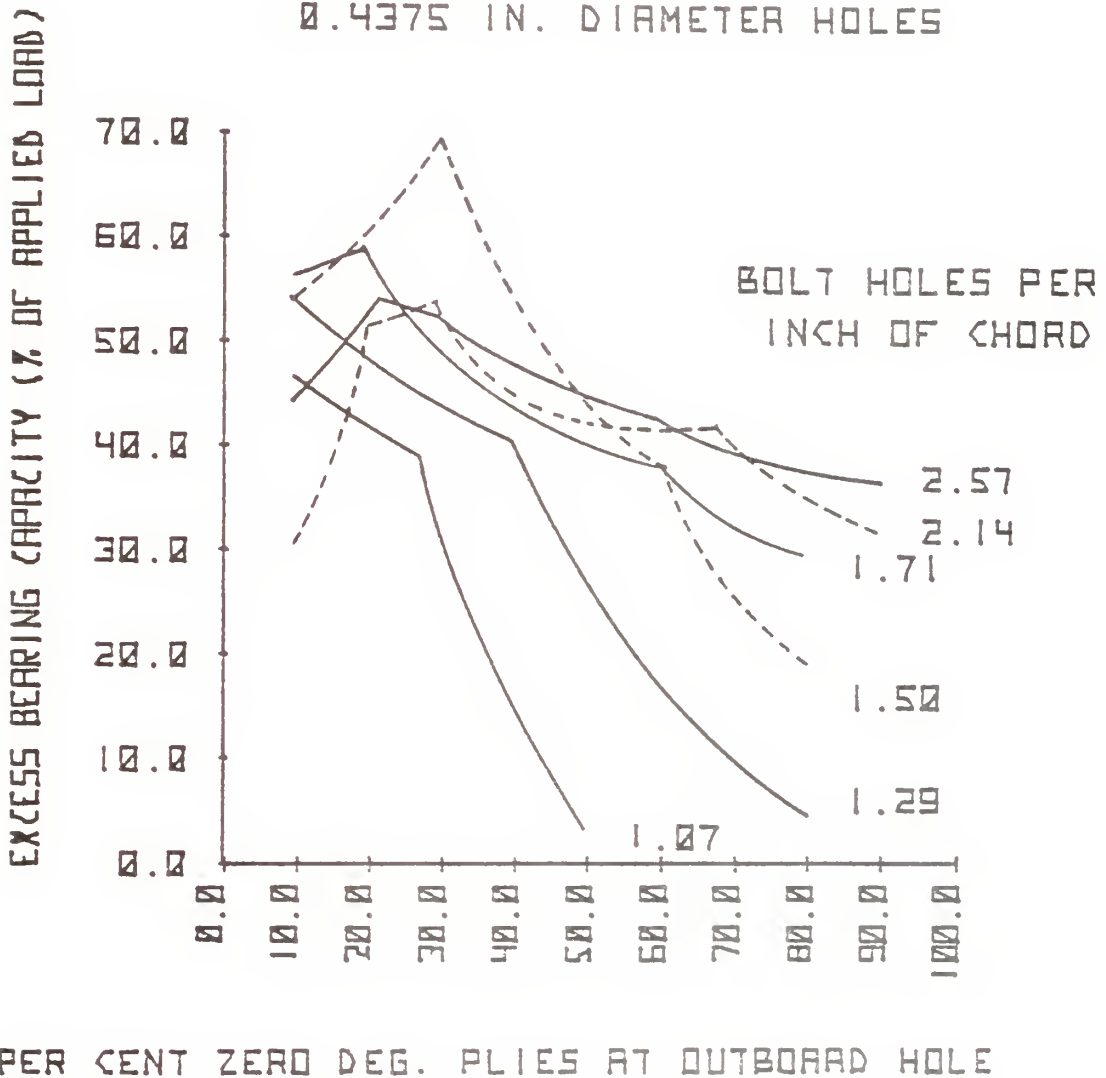


FIGURE 47. VARIATION OF EXCESS BEARING CAPACITY WITH LAMINATE COMPOSITION FOR BUFFER STRIP JOINTS WITH 0.4375 IN. DIAMETER HOLES

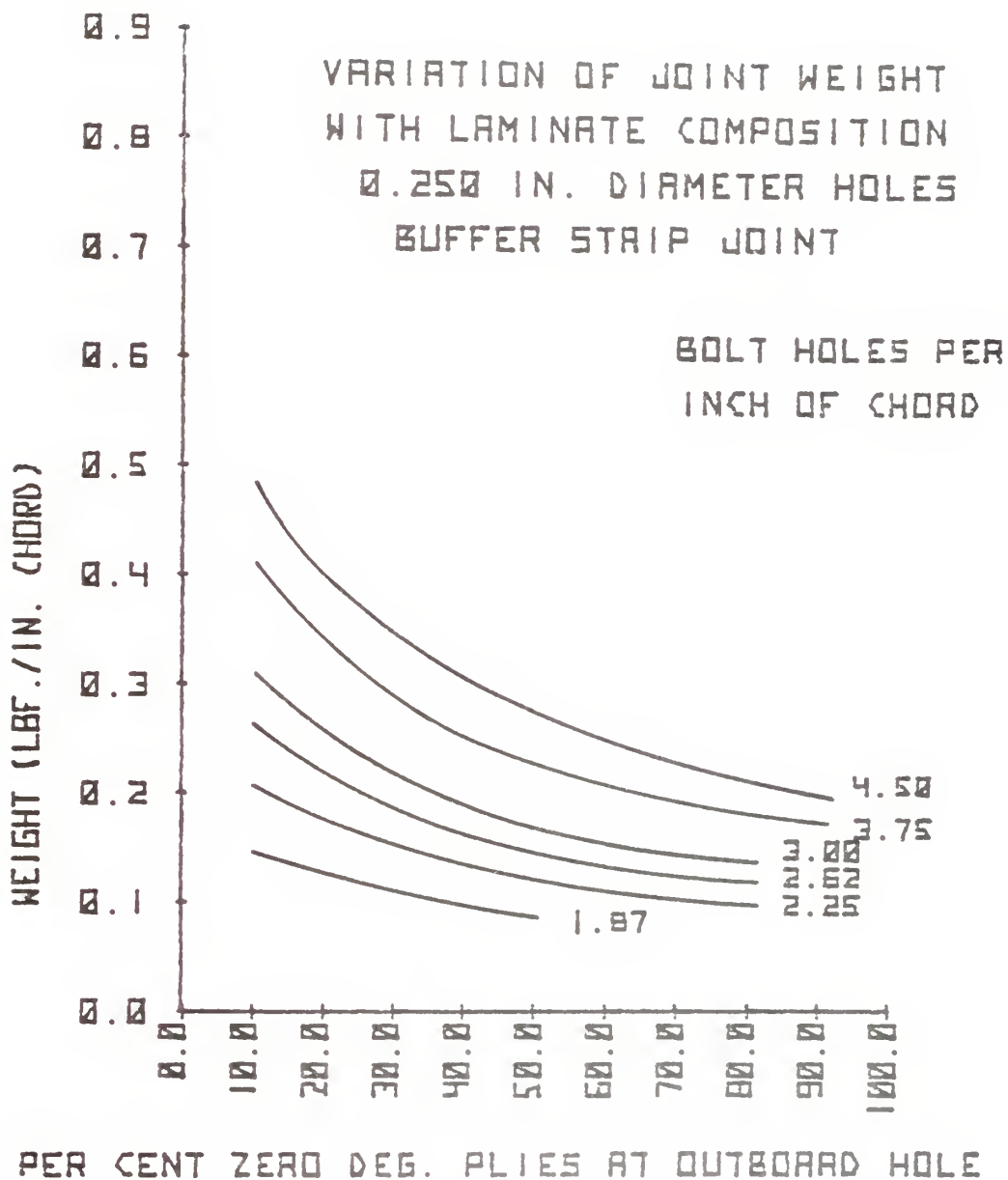


FIGURE 48. VARIATION OF JOINT WEIGHT WITH LAMINATE COMPOSITION FOR BUFFER STRIP JOINTS WITH 0.25 IN. DIAMETER HOLES

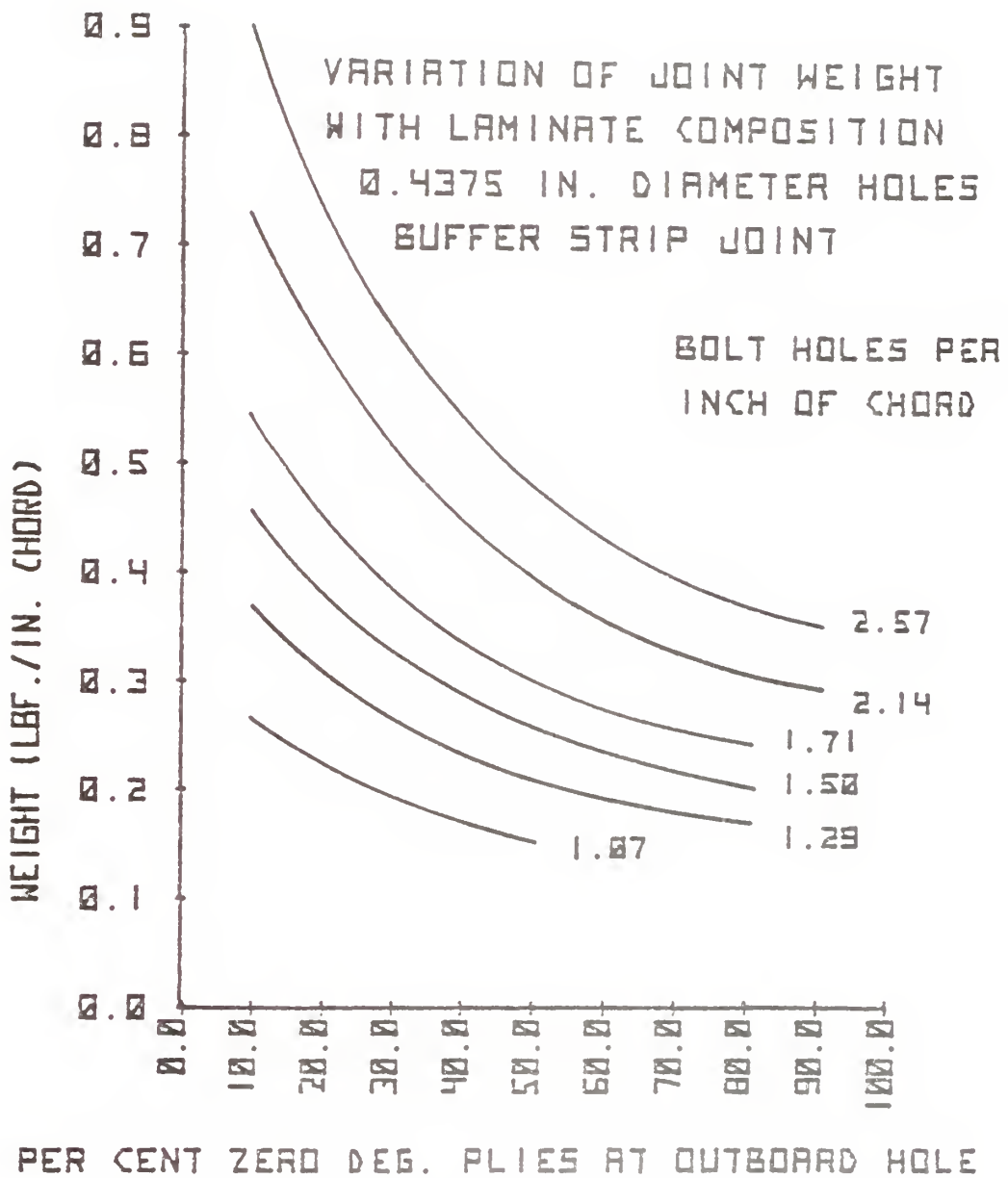


FIGURE 49. VARIATION OF JOINT WEIGHT WITH LAMINATE
 COMPOSITION FOR BUFFER STRIP JOINTS WITH 0.4375 IN.
 DIAMETER HOLES

TABLE I

SUMMARY OF DESIGN CONDITIONS AND ASSUMPTIONS

1. The joints are made from NARMCO 5208/T300 $[0/\pm 45]$ graphite-epoxy laminated material.
2. Skin thickness varies linearly within a joint.
3. All bolt holes in a joint are of the same diameter.
4. The interbolt strain level is 3000 micro-in./in.
5. In the theoretical developments for both buffer strip and non-buffer strip joints it was assumed that only tensile and shear loads were to be carried.
6. Each row of bolts reacts an equal portion of the applied tensile load.
7. The applied shear load is reacted by the inboard row of bolts.
8. The minimum number of rows of bolts in any joint is three.
9. Wing taper is disregarded.
10. The inboard row of bolts is in all ± 45 degree laminate.
11. The maximum joint length is ten inches.
12. In the non-buffer strip joints, there is a four-hole-diameter spacing between adjacent rows of bolt hole centers.
13. In the non-buffer strip joint, the laminate between the inboard and next to inboard bolt holes must contain at least five per cent zero degree plies.
14. In the buffer strip joints, the buffer strip width is

four hole diameters. The primary strips are each 3.335 hole diameters wide.

15. Weight and excess bearing capacity calculations were made for assumed load conditions $N_x = 20,000$ lbf./in. and $N_{xy} = 0$.

56-60 NLEL NUMBER OF LAMINATE TYPES WHOSE MATERIAL PROPERTIES ARE TO BE CALCULATED FROM INPUT LAMINA PROPERTIES. (MAX. 50)

JOINT CARDS (15,5X,4G15.8,I5) NJT CARDS PER PROBLEM
 COLUMN VARIABLE
 1-5 JOINT NUMBER OF THE JOINT (CARTESIAN COORD)
 11-25 X COORDINATE OF THE JOINT (POLAR COORD.)
 26-40 RADIUS VECTOR OF THE JOINT (CARTESIAN COORD)
 41-55 Y-COORDINATE OF THE JOINT (POLAR COORD.)
 56-70 POLAR ANGLE IN DEGREES (CART)
 70-75 X-COMPONENT OF THE LOAD AT THE JOINT (CART)
 Y-COMPONENT OF THE LOAD AT THE JOINT (CART)
 COORDINATE SYSTEM IND. = ZERO IF
 THE COORDINATE SYSTEM IS CARTESIAN, IF
 IS NOT ZERO, THE COORDINATE SYSTEM IS POLAR

MATERIAL PROPERTIES CARDS(2I5,7F10.2) NMAT CARDS PER PROBLEM
 C COLUMN VARIABLE NUMBER
 1-05 MATERIAL NUMBER
 6-10 INDK EQ.0 (ISOTROPIC), EQ.1 (ORTHOTROPIC)
 11-20 YOUNG'S MODULUS (ISOTROPIC MATERIAL)
 E(L) (ORTHOTROPIC MATERIAL)
 21-30 POISSON'S RATIO (ISOTROPIC MATERIAL)
 E(T) (ORTHOTROPIC MATERIAL)
 31-40 NOT USED (ISOTROPIC MATERIAL)
 NU(LT) (ORTHOTROPIC MATERIAL)
 41-50 NOT USED (ISOTROPIC MATERIAL)
 NU(TL) (ORTHOTROPIC MATERIAL)
 FOR ORTHOTROPIC MATERIALS, ONLY 3 OF THE ABOVE 4 ENGIN.
 CONSTANTS (E(L),E(T),NU(LT),NU(TL)) NEED BE KNOWN. FOR AN
 UNKNOWN CONSTANT ENTER -1.0 IN THE APPROPRIATE COLUMN.
 NOT USED (ISOTROPIC MATERIALS)
 G(LT) (ORTHOTROPIC MATERIALS)
 ALPHA COEFF. OF ISOTROPIC MATERIALS
 61-70 NOT USED FOR THERMALLY ANISOTROPIC MATERIALS
 71-80 MATERIAL THICKNESS (USED FOR ELEMENTS
 WHOSE MATERIAL PROPERTIES ARE NOT TO BE
 CALCULATED FROM INPUT LAMINA PROPERTIES.)

ELEMENT CARDS (15I4,F10.5,I5) NEL CARDS PER PROBLEM
 1-4 ELEMENT IDENTIFICATION NUMBER
 5-52 ELEMENT CONNECTIVITY (COUNTER-CLOCKWISE)
 53-56 ELEMENT KIND - USE
 1 FOR A FOUR NODAL POINT ELEMENT
 2 FOR AN EIGHT NODAL POINT ELEMENT
 3 FOR A TWELVE NODAL POINT ELEMENT

CC

57-60
61-70

71-75

MATERIAL / LAMINATE IDENTIFICATION NUMBER
 THETA (DEGREES) USED FOR ORTHOTROPIC MATERIALS
 TO THE ANGLE FROM THE PROBLEM BASED X AXIS
 TO THE MATERIAL BASED L AXIS
 ENTER 1 FOR A LAMINATED ELEMENT WHOSE PROPERTIES
 ARE TO BE CALCULATED FROM INPUT LAMINA
 PROPERTIES.

MAIN 930
 MAIN 940
 MAIN 950
 MAIN 960
 MAIN 970
 MAIN 980
 MAIN 990
 MAIN1000
 MAIN1010
 MAIN1020
 MAIN1030
 MAIN1040
 MAIN1050
 MAIN1060
 MAIN1070
 MAIN1080
 MAIN1090
 MAIN1100
 MAIN1110
 MAIN1120
 MAIN1130
 MAIN1140
 MAIN1150
 MAIN1160
 MAIN1170
 MAIN1180
 MAIN1190
 MAIN1200
 MAIN1210
 MAIN1220
 MAIN1230
 MAIN1240
 MAIN1250
 MAIN1260
 MAIN1270
 MAIN1280
 MAIN1290
 MAIN1300
 MAIN1310
 MAIN1320
 MAIN1330
 MAIN1340
 MAIN1350
 MAIN1360
 MAIN1370
 MAIN1380
 MAIN1390
 MAIN1400

BOUNDARY CONDITION CARDS (2I5) NPBC CARDS PER PROBLEM

COL. VARIABLE
 1-5 JOINT NUMBER
 6-10 CODE

1 FOR A ROLLER ON AN X AXIS, DISP. IN Y DIRECT. IS ZERO
 2 FOR A ROLLER ON AN Y AXIS, DISP. IN X DIRECT. IS ZERO
 3 FOR A FIXED JOINT, BOTH DISP. COMPONENTS ARE ZERO
 4 FOR A ROLLER ON AN X AXIS, THE DISP. IN THE Y DIRECT.
 IS SPECIFIED ON THE JOINT CARD IN COL. 41-50
 5 FOR A ROLLER ON A Y AXIS, THE DISP. IN THE X DIRECT.
 IS SPECIFIED ON THE JOINT CARD IN COL. 31-40
 6 FIXED JOINT WITH DISP. SPECIFIED IN BOTH X AND Y
 DIRECT. ON THE JOINT CARD IN COL. 31-40 AND COL. 41-50
 7 FOR A ROLLER ON AN AXIS INCLINED ALPHA DEGREES
 WITH RESPECT TO THE X AXIS. THE JOINT CARD MAY
 CONTAIN A TANGENTIAL LOAD IN COL. 31-40 AND THE
 ANGLE ALPHA DEGREES IN COL. 41-50

LAMINATE CARD DECK 2(I5) AT LEAST TWO CARDS PER LAMINATE TYPE

CARD ONE VARIABLE
 COLUMN LAMTNP LAMINATE TYPE NUMBER(MAX.50)
 1-5
 6-10 LYRNO NO. LAMINAE IN THIS LAMTP (MAX.100)
 COLUMN 4(I3,F8.3,F9.4)
 1-3 VARIABLE
 4-11 MATERIAL THICKNESS
 12-20 LAMINA THICKNESS
 21-23 LAMINA ORIENTATION (DEG) REL TO L AXIS OF ELEMENT
 24-31 MATERIAL THICKNESS
 32-40 LAMINA THICKNESS
 41-43 LAMINA ORIENTATION (DEG) REL TO L AXIS OF ELEMENT
 44-51 MATERIAL THICKNESS
 52-60 LAMINA THICKNESS
 61-63 LAMINA ORIENTATION (DEG) REL TO L AXIS OF ELEMENT
 64-71 MATERIAL THICKNESS
 72-80 LAMINA ORIENTATION (DEG) REL TO L AXIS OF ELEMENT

AS MANY OF THESE SECOND TYPE CARDS AS NEEDED TO SPECIFY LYRNO LAYER
 MAY BE USED
 REPEAT THE SEQUENCE WITH NEW CARD TYPE 1 AND 2 AS NEEDED TO
 SPECIFY ALL NLEL LAMINATE TYPES


```

C      NPELM = NPEL-1
C
C      DC 4 K=1,NPELM
      LMK = LM(K)
      JK = K+1
C
C      DC 4 L=JK,NPEL
      LML = LM(L)
      4 NBAND2 = MAXO(NBAND2, IABS(LMK-LML))
C      5 CONTINUE
C
C      NEAND = NBAND2
      NBAND = (NBAND+1)*2
      IF (NBAND.GT.MBD) GO TO 16
      WRITE (6,17) NBAND
C
C      DO 6 I=1,NEQ
      ALOAD(I) = ZRO
C
C      DO 6 J=1,NBAND
      BGK(I,J) = ZRO
C
C      CALL MEFGE (NPEL,NEQ)
      CALL BCOND (NBAND)
      CALL LDLT (NEG,NBAND)
C
C      DO 7 I=1,NPBC
      IJT = NBC(I,1)
      7 NCODE(IJT) = NBC(I,2)
C
C
C      DO 10 I=1,NJT
      II = I*2-I
      KODE = NCODE(I)
      IF (KODE.EQ.7) GO TO 9
      IF ((KODE.EQ.5).OR.(KODE.EQ.6)) GO TO 8
      ALOAD(II) = CLOAD(I,1)+ALOAD(II)
      8 II = II+1
      IF ((KODE.EQ.4).OR.(KODE.EQ.6)) GO TO 10
      ALOAD(II) = CLOAD(I,2)+ALOAD(II)
      GO TO 10
      9 ALF = CLOAD(I,2)*PI/180.000
      CCSA = DCOS(ALF)
      SINA = DSIN(ALF)
      IIP = II+1
      AI = ALOAD(II)*COSA+ALOAD(IIP)*SINA+CLOAD(I,1)

```

```

MA IN1890
MA IN1900
MA IN1910
MA IN1920
MA IN1930
MA IN1940
MA IN1950
MA IN1960
MA IN1970
MA IN1980
MA IN1990
MA IN2000
MA IN2010
MA IN2020
MA IN2030
MA IN2040
MA IN2050
MA IN2060
MA IN2070
MA IN2080
MA IN2090
MA IN2100
MA IN2110
MA IN2120
MA IN2130
MA IN2140
MA IN2150
MA IN2160
MA IN2170
MA IN2180
MA IN2190
MA IN2200
MA IN2210
MA IN2220
MA IN2230
MA IN2240
MA IN2250
MA IN2260
MA IN2270
MA IN2280
MA IN2290
MA IN2300
MA IN2310
MA IN2320
MA IN2330
MA IN2340
MA IN2350
MA IN2360

```

```

A2 = ALOAD(IIP)*COSA-ALOAD(II)*SINA
ALOAD(II) = A1
ALOAD(IIP) = A2
CONTINUE
10 C
SXL = ZRO
SYL = ZRO
C
DO 12 I=1,NJT
IX = 2*I-1
IY = IX+1
IF (NCODE(I).EQ.7) GO TO 11
SXL = SXL+ALOAD(IX)
SYL = SYL+ALOAD(IY)
GO TO 12
11 ALF = CLOAD(I,2)*PI/180.000
COSA = DCOS(ALF)
SINA = DSIN(ALF)
SXL = SXL+ALOAD(IX)*COSA-ALOAD(IY)*SINA
SYL = SYL+ALOAD(IX)*SINA+ALOAD(IY)*COSA
12 CCNTINUE
C
WRITE (6,24)
WRITE (6,22) SXL,SYL
CALL SOLV (NEQ,NBAND)
C
DO 13 I=1,NPBC
DC 13 J=1,2
13 REACT(I,J) = ZRO
C
CALL DISPL
WRITE (6,19)
C
DC 14 I=1,NJT
II = I*2-1
III = II+1
14 WRITE (6,18) I,ALOAD(II),ALOAD(III)
C
WRITE (6,20)
C
DC 15 I=1,NPBC
15 WRITE (6,18) NBC(I,1),REACT(I,1),REACT(I,2)
C
WRITE (6,21)
MJP = MJT+1
WRITE (6,22) REACT(MJP,1),REACT(MJP,2)
CALL STRESS (NPBL)

```

```

MA IN2370
MA IN2380
MA IN2390
MA IN2400
MA IN2410
MA IN2420
MA IN2430
MA IN2440
MA IN2450
MA IN2460
MA IN2470
MA IN2480
MA IN2490
MA IN2500
MA IN2510
MA IN2520
MA IN2530
MA IN2540
MA IN2550
MA IN2560
MA IN2570
MA IN2580
MA IN2590
MA IN2600
MA IN2610
MA IN2620
MA IN2630
MA IN2640
MA IN2650
MA IN2660
MA IN2670
MA IN2680
MA IN2690
MA IN2700
MA IN2710
MA IN2720
MA IN2730
MA IN2740
MA IN2750
MA IN2760
MA IN2770
MA IN2780
MA IN2790
MA IN2800
MA IN2810
MA IN2820
MA IN2830
MA IN2840

```

```

C
16 GO TO 1
   WRITE (6,25) MBD,NBAND
   STOP
17 FORMAT (1X,'PROBLEM BANDWIDTH EQUALS ',I5)
18 FORMAT (2X,I3,2G15.4)
19 FORMAT (///,'DISPLACEMENTS',//,3X,' JOINT',1X,' U',12X,' V',//)
20 FORMAT (///,' REACTIONS',//,3X,' JOINT',1X,' RX',12X,' RY',//)
21 FCRRMAT (//,' SUM OF THE REACTIONS AT THE SUPPORTS',//)
22 FORMAT (5X,2G15.4)
23 FORMAT (5X,' MAX. BAND (' ,I13,' ) EXCEEDED; NBAND = ',I14)
24 FCRRMAT (//,' SUM OF THE EXTERNAL LOADS',//)
   END
C
   SUBROUTINE INPUT
   THIS SUBROUTINE READS INPUT DATA FOR THE PROBLEM
   IMPLICIT REAL*8(A-H,O-Z)
   INTEGER*2(I-N)
   COMMON /INT/ NEL,NJT,NMAT,NCLOAD,NPBC,NCON(182,15),NBC(217,2),NSTR
1   IES,NGP,LM(12),LJT(12),NTLD,NTBY,NTIN,NLEL
   COMMON /MDIM/ MEL,MMT,MBD,MDEL,MLYR
   COMMON /FLPL/ COARD(217,2),CLGAD(217,2),ELCON(10,7),TITLE(10),ANGL
1(182),THNP(217)
   COMMON /FLLAM/ TKLAM(50,100),ORLAM(50,100)
   COMMON /INLAM/ LAMAT(50,100),LYRNO(50),INDK(10)
   DATA CHK/,STOP
   ZRC = 0.000
   PI = 3.1415926535900
   READ (5,30) TITLE
   WRITE (6,31) TITLE
   IF (TITLE(1).EQ.CHK) STOP
C
   DO 1 I=1,MMT
     THNP(I) = ZRO
C
   DO 1 J=1,2
     NBC(I,J) = 0
     COARD(I,J) = ZRO
     CLCAD(I,J) = ZRO
C
   DC 2 I=1,MMT
     INDK(I) = 0
C
   DC 2 J=1,7
     ELCON(I,J) = ZRO
C
   DO 3 I=1,MEL

```

```

MAIN2850
MAIN2860
MAIN2870
MAIN2880
MAIN2890
MAIN2900
MAIN2910
MAIN2920
MAIN2930
MAIN2940
MAIN2950
MAIN2960
MAIN2970
INPT 10
INPT 20
INPT 30
INPT 40
INPT 50
INPT 60
INPT 70
INPT 80
INPT 90
INPT 100
INPT 110
INPT 120
INPT 130
INPT 140
INPT 150
INPT 160
INPT 170
INPT 180
INPT 190
INPT 200
INPT 210
INPT 220
INPT 230
INPT 240
INPT 250
INPT 260
INPT 270
INPT 280
INPT 290
INPT 300
INPT 310
INPT 320
INPT 330
INPT 340
INPT 350

```

```

C      ANGL(I) = ZRO
C      DO 3 J=1,15
C      3 NCON(I,J) = 0
C
C      DC 4 I=1,MLEL
C      LYRNO(I) = 0
C
C      DC 4 J=1,MLYR
C      LAMAT(I,J) = 0
C      ORLAM(I,J) = ZRO
C      4 TKLAM(I,J) = ZRO
C
C      READ PRCBLE PARAMETERS
C
C      READ (5,32) NEL,NJT,NMAT,NCLOAD,NPBC,NSTRES,NGP,NTLD,NTBY,NTIN,NLE
11     IF (NEL.GT.MEL) GO TO 23
C      IF (NJT.GT.MJT) GO TO 24
C      IF (NMAT.GT.MMT) GO TO 25
C      IF (NCLOAD.GT.MJT) GO TO 26
C      IF (NPBC.GT.MJT) GO TO 27
C      IF (NLEL.GT.MLEL) GO TO 28
C      WRITE (6,33) NEL,NJT,NMAT,NCLOAD,NPBC,NSTRES,NGP,NLEL
C
C      READ COORDINATES OF JOINTS AND CONCENTRATED LOADS
C
C      WRITE (6,34)
C
C      DC 5 I=1,NJT
C      READ (5,35) IJT,COORD(IJT,1),COORD(IJT,2),CLOAD(IJT,1),CLOAD(IJT,2
1) ,IND
C      IF (IND.EQ.0) GO TO 5
C      ALF = COORD(IJT,2)*PI/180.0D0
C      CGSA = DCOS(ALF)
C      SINA = DSIN(ALF)
C      XC = COORD(IJT,1)*CGSA
C      YC = COORD(IJT,1)*SINA
C      CCARD(IJT,1) = XC
C      CCARD(IJT,2) = YC
C      5 CCONTINUE
C
C      DO 6 I=1,NJT
C      6 WRITE (6,36) I,COORD(I,1),COORD(I,2),CLOAD(I,1),CLOAD(I,2)
C

```

```

INPT 360
INPT 370
INPT 380
INPT 390
INPT 400
INPT 410
INPT 420
INPT 430
INPT 440
INPT 450
INPT 460
INPT 470
INPT 480
INPT 490
INPT 500
INPT 510
INPT 520
INPT 530
INPT 540
INPT 550
INPT 560
INPT 570
INPT 580
INPT 590
INPT 600
INPT 610
INPT 620
INPT 630
INPT 640
INPT 650
INPT 660
INPT 670
INPT 680
INPT 690
INPT 700
INPT 710
INPT 720
INPT 730
INPT 740
INPT 750
INPT 760
INPT 770
INPT 780
INPT 790
INPT 800
INPT 810
INPT 820
INPT 830

```



```

C      NSV = 0
C      DO 13 I=1,NPBC
C      IF (NBC(I,2).NE.7) GO TO 13
C      NSV = NSV+1
C      13 CCNTINUE
C      NPBCM = NPBC-1
C      IF (NSV.EQ.0) GO TO 18
C      DO 16 I=1,NSV
C      DC 15 J=1,NPBCM
C      IF (NBC(J,2).NE.7) GO TO 15
C      NT1 = NBC(J,1)
C      DO 14 K=J,NPBCM
C      KP = K+1
C      NBC(K,1) = NBC(KP,1)
C      14 NBC(K,2) = NBC(KP,2)
C      NBC(NPBC,1) = NT1
C      NBC(NPBC,2) = 7
C      GO TO 16
C      15 CCNTINUE
C      16 CONTINUE
C      WRITE (6,44)
C      DC 17 I=1,NPBC
C      17 WRITE (6,46) (NBC(I,J),J=1,2)
C      18 CCNTINUE
C      IF (NLEL.EQ.0) GO TO 21
C      READ LAMINATE CARD DECK
C      DO 19 I=1,NLEL
C      READ (5,47) LAMTP,LYRNO(LAMTP)
C      L = LYRNO(LAMTP)
C      IF (L.GT.MLYR) GO TO 29
C      READ (5,48) ((LAMAT(LAMTP,J),TKLAM(LAMTP,J),ORLAM(LAMTP,J)),J=1,L)
C      19 CONTINUE
C      WRITE (6,49)
C

```

```

INPT1320
INPT1330
INPT1340
INPT1350
INPT1360
INPT1370
INPT1380
INPT1390
INPT1400
INPT1410
INPT1420
INPT1430
INPT1440
INPT1450
INPT1460
INPT1470
INPT1480
INPT1490
INPT1500
INPT1510
INPT1520
INPT1530
INPT1540
INPT1550
INPT1560
INPT1570
INPT1580
INPT1590
INPT1600
INPT1610
INPT1620
INPT1630
INPT1640
INPT1650
INPT1660
INPT1670
INPT1680
INPT1690
INPT1700
INPT1710
INPT1720
INPT1730
INPT1740
INPT1750
INPT1760
INPT1770
INPT1780
INPT1790

```



```

C      DC 1 J=1,24
      SS(I,J) = ZRO
      1 SA(I,J) = ZRO
C
C      DC 6 IK=1,NEL
C
C      DC 2 NN=1,NPEL
      LJT(NN) = NCON(IK,NN)
      2 LM(NN) = (NCON(IK,NN)-1)*2
C
C      NS = 3*NPEL
C
C      DC 3 I1=1,NPEL
      I2 = LJT(I1)
C
C      DO 3 J1=1,2
      3 CCOORD(I1,J1) = COARD(I2,J1)
C
      INCIC = NCON(IK,15)
      IF (INDIC.NE.1) GO TO 4
      CALL LAMC (IK)
      GO TO 5
      4 THETA = ANGL(IK)
      MATN = NCON(IK,14)
      INDIC = INDK(MATN)
      CALL STFMAT (ELAST,MATN,THETA,INDIC,NSTRES)
      TK = ELCON(MATN,7)
      5 N = NCON(IK,13)*8
      SET THICKNESS=1. FOR PLANE STRAIN
      IF (NSTRES.EQ.1) TK=1.0D0
      CALL QUAD5 (STK,AK,B,NS,N,NGP)
      WRITE (10) SS,SN
      IF (TK.EQ.0.0D0) TK=1.0D0
C
C      DO 6 I=1,NPEL
C
C      DC 6 J=1,NPEL
C
C      DO 6 K=1,2
      IY = LM(I)+K
      KK = 2*(I-1)+K
C
C      DC 6 L=1,2
      JJ = LM(J)+L-II+1
      IF (J.LE.0) GO TO 6
      LL = 2*(J-1)+L

```



```

C          DC 2 K=1,3
C          2 C(J,K) = C(J,K)+ELAST(J,K)*TKLAM(LAMTP,I)
C          3 CCNTINUE
C          DO 4 J=1,3
C          DO 4 K=1,3
C          4 ELAST(J,K) = C(J,K)/TK
C          RETURN
C          END
C          SUBROUTINE STFMAT (C, MATN, THETA, INDIC, NSTRESS)
C          THIS SUBROUTINE ASSEMBLES THE ELASTIC STIFFNESS MATRIX FOR A HOOKEAN
C          ELEMENT. THE SUBROUTINE CALCULATES AND STORES IN C(3X3) THE VALUES
C          OF THE ELEMENTS OF THIS MATRIX FOR ISOTROPIC MATERIALS UNDER
C          EITHER PLANE STRAIN OR PLANE STRESS OR FOR ANISOTROPIC MATERIALS,
C          EXHIBITING TWO DIMENSIONAL ORTHOTROPY. FOR ANISOTROPIC MATERIALS,
C          THE ELEMENTS OF THIS MATRIX ARE FIRST COMPUTED IN THE MATERIAL
C          BASED L-T COORDINATE SYSTEM AND THEN TRANSFORMED TO THE PROBLEM
C          BASED X-Y COORDINATE SYSTEM.
C          IMPLICIT REAL*8(A-H,O-Z)
C          IMPLICIT INTEGER*2(I-N)
C          COMMON /FLPLY/ CUARD(217,2), CLOAD(217,2), ELCON(10,7), TITLE(10), ANGL
C          1 (182), THNP(217)
C          DIMENSION A(3,3), C(3,3)
C          DC 1 I=1,3
C          DO 1 J=1,3
C          A(I,J) = 0.000
C          C(I,J) = 0.000
C          1 CCNTINUE
C          IF (INCIC.EQ.1) GO TO 3
C          IF (NSTRESS.EQ.1) GO TO 2
C          FORM THE ELASTIC STIFFNESS MATRIX FOR ISOTROPIC PLANE STRESS
C          E = ELCCN(MATN,1)
C          XNU = ELCON(MATN,2)
C          E0 = E/(1.000-XNU*XNU)
C          C(1,1) = E0
C          C(1,2) = E0*XNU
C          C(2,1) = C(1,2)
C          C(2,2) = C(1,1)
C          C(3,3) = E0*(1.000-XNU)/2.000

```

```

LAMC 370
LAMC 380
LAMC 390
LAMC 400
LAMC 410
LAMC 420
LAMC 430
LAMC 440
LAMC 450
LAMC 460
LAMC 470
LAMC 480
LAMC 490
LAMC 500
LSTFM 10
STFM 20
STFM 30
STFM 40
STFM 50
STFM 60
STFM 70
STFM 80
STFM 90
STFM 100
STFM 110
STFM 120
STFM 130
STFM 140
STFM 150
STFM 160
STFM 170
STFM 180
STFM 190
STFM 200
STFM 210
STFM 220
STFM 230
STFM 240
STFM 250
STFM 260
STFM 270
STFM 280
STFM 290
STFM 300
STFM 310
STFM 320
STFM 330
STFM 340

```

```

350 RETURN
360 2 CONTINUE
370
380 FORM THE ELASTIC STIFFNESS MATRIX FOR ISOTROPIC PLANE STRAIN
390
400 E = ELCCN(MATN,1)
410 XNU = ELCON(MATN,2)
420 EI = E/((1.000+XNU)*(1.000-2.000*XNU))
430 C(1,1) = EI*(1.000-XNU)
440 C(1,2) = EI*XNU
450 C(2,1) = C(1,2)
460 C(2,2) = C(1,1)
470 C(3,3) = EI*(0.500-XNU)
480 RETURN
490 3 CONTINUE
500
510 FGRM THE ANISOTROPIC ORTHOTROPIC ELASTIC MATRIX IN THE MATERIAL BASED
520 L-T COORDINATE SYSTEM
530
540 EL = ELCON(MATN,1)
550 ET = ELCON(MATN,2)
560 XNUTL = ELCON(MATN,3)
570 XNUTL = ELCON(MATN,4)
580 GLT = ELCON(MATN,5)
590 IF (EL.LT.-0.000) EL=XNUTL*ET/XNUTL
600 IF (ET.LT.-0.000) ET=EL*XNUTL/XNUTL
610 IF (XNUTL.LT.-0.000) XNUTL=EL*XNUTL/ET
620 IF (XNUTL.LT.-0.000) XNUTL=XNUTL*ET/EL
630 Z = 1.000-XNUTL*XNUTL
640 A(1,1) = EL/Z
650 A(1,2) = ET*XNUTL/Z
660 A(2,1) = A(1,2)
670 A(2,2) = ET/Z
680 A(3,3) = GLT
690
700 THIS ARRAY IS NOW TRANSFORMED FROM THE MATERIAL L-T COORDINATE
710 SYSTEM TO THE PROBLEM X-Y COORDINATE SYSTEM. THE TRANSFORMATION IS
720 ACCOMPLISHED BY ROTATION ABOUT THE Z AXIS THROUGH THETA DEGREES.
730
740 PI = 3.1415926535900
750 THRAD = THETA*PI/180.000
760 CCS1 = DCOS(THRAD)**2
770 CCS2 = DCOS(THRAD)**2
780 CCS3 = DCOS(THRAD)**4
790 CCS4 = DCOS(THRAD)**4
800 SIN1 = DSIN(THRAD)**2
810 SIN2 = DSIN(THRAD)**2
820 SIN3 = DSIN(THRAD)**3

```

```

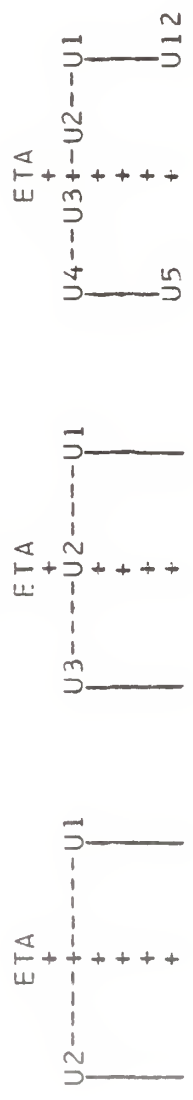
SIN4 = DSIN(THRAD)**4
TWO = 2.0D0
FOUR = 4.0D0
C(1,1) = A(1,1)*COS4+TWO*(A(1,2)+TWO*A(3,3))*SIN2*COS2+A(2,2)*SIN4
C(1,2) = (A(1,1)+A(2,2))-FOUR*A(3,3))*SIN2*CCS2+A(1,2)*(SIN4+COS4)
C(1,3) = (A(1,1)-A(1,2))-TWO*A(3,3))*SINI*CCS3+(A(1,2)-A(2,2)+TWO*(
1A(3,3)))*SIN3*COS1
C(2,2) = A(1,1)*SIN4+TWO*(A(1,2)+TWO*A(3,3))*SIN2*COS2+A(2,2)*COS4
C(2,3) = (A(1,1)-A(1,2))-TWO*A(3,3))*SIN3*COS1+(A(1,2)-A(2,2)+TWO*A
1C(3,3))*SINI*CCS3
1C(3,3) = (A(1,1)+A(2,2)-TWO*(A(1,2)+A(3,3)))*SIN2*COS2+A(3,3)*(SIN
14+COS4)
C(2,1) = C(1,2)
C(3,1) = C(1,3)
C(3,2) = C(2,3)
RETURN
END
SUBROUTINE QUAD5 (STK,AK,B,NS,N,NGP)

```

QUAD5 IS A NUMERICAL INTEGRATION SUBROUTINE THAT FORMS THE STIFFNESS MATRIX FOR ANY OF THE THREE QUADRILATERAL ISOPARAMETRIC ELEMENTS USED IN THIS PROGRAM.
 GAUSSIAN QUADRATURE WITH A MAXIMUM OF FIVE ORDINATES IS USED.

STK IS AN ARRAY DIMENSIONED NXN THAT WILL CONTAIN THE STIFFNESS MATRIX UPON RETURN TO THE CALLING PROGRAM
 SS AND SN ARE THE STRESS AND STRAIN VERSUS NODAL POINT DISPLACEMENT TRANSFORMATION MATRICES, BOTH ARE DIMENSIONED NSXN WHERE NS= 3*NPT AND N= 2*NPT
 AK IS AN ARRAY DIMENSIONED NXN REQUIRED IN FORMK
 B IS AN ARRAY DIMENSIONED 2XN REQUIRED IN FORMK

NGP IS THE NUMBER OF GAUSS POINTS USED IN THE INTEGRATION
 COORD(12,2) IS AN ARRAY CONTAINING THE COORDINATES OF ALL THE NODAL POINTS OF THE ELEMENT TO BE CONSTRUCTED
 ELAST(3,3) IS AN ARRAY CONTAINING ALL THE ELASTIC CONSTANTS OF THE ELEMENT, THE ORDER OF THE STRESS COMPONENTS IS: SIGMAX,SIGMAY,TAUXY



STFM 830
 STFM 840
 STFM 850
 STFM 860
 STFM 870
 STFM 880
 STFM 890
 STFM 900
 STFM 910
 STFM 920
 STFM 930
 STFM 940
 STFM 950
 STFM 960
 STFM 970
 STFM 980
 STFM 990
 QUAD 10
 QUAD 20
 QUAD 30
 QUAD 40
 QUAD 50
 QUAD 60
 QUAD 70
 QUAD 80
 QUAD 90
 QUAD 100
 QUAD 110
 QUAD 120
 QUAD 130
 QUAD 140
 QUAD 150
 QUAD 160
 QUAD 170
 QUAD 180
 QUAD 190
 QUAD 200
 QUAD 210
 QUAD 220
 QUAD 230
 QUAD 240
 QUAD 250
 QUAD 260
 QUAD 270
 QUAD 280
 QUAD 290
 QUAD 300
 QUAD 310

CC


```

11 X = XYQ(I,1)
12 Y = XYQ(I,2)
GC TO I3
12 X = XYC(I,1)
13 Y = XYC(I,2)
13 CALL FORMK (AK,X,Y,B,N)
C
C CC 14 L=1,3
C DO 14 M=1,N
AK(L,M) = 0.000
C
C DO 14 NN=1,3
14 AK(L,M) = AK(L,M)+ELAST(L,NN)*B(NN,M)
C
C II = 3*(I-1)
C DO 15 J=1,3
IJ = II+J
C
C DO 15 K=1,N
SS(IJ,K) = AK(J,K)
15 SN(IJ,K) = B(J,K)
C
C 16 CCNTINUE
C
C RETURN
END
SUBROUTINE FORMK (AK,X,Y,B,N)
FCRMK FORMS THE STIFFNESS MATRIX AND THE B MATRIX AS FUNCTIONS
C OF XI AND ETA FOR THE ISOPARAMETRIC ELEMENTS USED IN THIS PROGRAM
C
C IMPLICIT REAL*8(A-H,O-Z)
C IMPLICIT INTEGER*2(I-N)
C DIMENSION AJ(2,2), AJIN(2,2), DNX(2,2), W1(2,12), B(3,24), BI(24,
13), AK(24,24)
C CMMCN COORD(12,2),ELAST(3,3),SS(36,24),SN(36,24),TK
C ZERO = 0.000
C DO 1 I=1,3
C DO 1 J=1,N
1 B(I,J) = ZERO
C
C CNE = 1.000
C TWO = 2.000
C FOUR = 4.000
C NPT = N/2

```

```

QUAD1280
QUAD1290
QUAD1300
QUAD1310
QUAD1320
QUAD1330
QUAD1340
QUAD1350
QUAD1360
QUAD1370
QUAD1380
QUAD1390
QUAD1400
QUAD1410
QUAD1420
QUAD1430
QUAD1440
QUAD1450
QUAD1460
QUAD1470
QUAD1480
QUAD1490
QUAD1500
QUAD1510
QUAD1520
QUAD1530
QUAD1540
QUAD1550
FRMK 10
FRMK 20
FRMK 30
FRMK 40
FRMK 50
FRMK 60
FRMK 70
FRMK 80
FRMK 90
FRMK 100
FRMK 110
FRMK 120
FRMK 130
FRMK 140
FRMK 150
FRMK 160
FRMK 170
FRMK 180
FRMK 190
FRMK 200

```

```

C FORM (2XNPT) MATRIX OF DERIV. OF THE INTERP. FUNCT. WRT XI AND ETA
C
C   IGC = N/8
C   GO TO (2,3,4), IGC
C
C   LINEAR FUNCTIONS
C
2  W1(1,3) = -(ONE-Y)/FOUR
   W1(1,4) = -W1(1,3)
   W1(1,1) = (ONE+Y)/FOUR
   W1(1,2) = -W1(1,1)
   W1(2,3) = -(ONE-X)/FOUR
   W1(2,4) = -(ONE+X)/FOUR
   W1(2,1) = -W1(2,4)
   W1(2,2) = -W1(2,3)
   GO TO 5
3  CONTINUE
C
C   QUADRATIC FUNCTIONS
C
C   TXPY = TWO*X+Y
C   TXMY = TWO*X-Y
C   TYPX = TWO*Y+X
C   TYMX = TWO*Y-X
C   CMY = ONE-Y
C   CPMY = ONE+Y
C   OPX = ONE+X
C   OPMX = ONE-X
C   W1(1,5) = OMY*TXPY/FOUR
C   W1(1,6) = -OMY*X
C   W1(1,7) = OMY*TXMY/FOUR
C   W1(1,8) = OPY*OMY/TWO
C   W1(1,1) = OPY*TXPY/FOUR
C   W1(1,2) = -OPY*X
C   W1(1,3) = OPY*TXMY/FOUR
C   W1(1,4) = -OPY*OMY/TWO
C   W1(2,5) = OMX*TYPX/FOUR
C   W1(2,6) = -OPX*OMX/TWO
C   W1(2,7) = OPX*TYMX/FOUR
C   W1(2,8) = -Y*OPX
C   W1(2,1) = OPMX*TYPX/FOUR
C   W1(2,2) = OPMX*OMX/TWO
C   W1(2,3) = OMX*TYMX/FOUR
C   W1(2,4) = -Y*OMX
C   GO TO 5
4  CONTINUE
C

```

```

FRMK 210
FRMK 220
FRMK 230
FRMK 240
FRMK 250
FRMK 260
FRMK 270
FRMK 280
FRMK 290
FRMK 300
FRMK 310
FRMK 320
FRMK 330
FRMK 340
FRMK 350
FRMK 360
FRMK 370
FRMK 380
FRMK 390
FRMK 400
FRMK 410
FRMK 420
FRMK 430
FRMK 440
FRMK 450
FRMK 460
FRMK 470
FRMK 480
FRMK 490
FRMK 500
FRMK 510
FRMK 520
FRMK 530
FRMK 540
FRMK 550
FRMK 560
FRMK 570
FRMK 580
FRMK 590
FRMK 600
FRMK 610
FRMK 620
FRMK 630
FRMK 640
FRMK 650
FRMK 660
FRMK 670
FRMK 680

```



```

C      DC 6 I=1,2
C      DO 6 J=1,2
C      AJ(I,J) = ZERO
C      DO 6 K=1,NPT
C      6 AJ(I,J) = AJ(I,J)+WL(I,K)*COORD(K,J)
C      CALCULATE DETERMINANT OF THE JACOBIAN
C      DTJ = AJ(1,1)*AJ(2,2)-AJ(1,2)*AJ(2,1)
C      INVERT JACOBIAN IN AJIN
C      AJIN(1,1) = AJ(2,2)/DTJ
C      AJIN(1,2) = -AJ(1,2)/DTJ
C      AJIN(2,1) = -AJ(2,1)/DTJ
C      AJIN(2,2) = AJ(1,1)/DTJ
C      FORM (2XNPT) MATRIX OF DERIVATIVES OF INTERP. FUNCT WRT X AND Y
C      DC 7 I=1,2
C      DO 7 J=1,NPT
C      DNX(I,J) = ZERO
C      DC 7 K=1,2
C      7 DNX(I,J) = DNX(I,J)+AJIN(I,K)*WL(K,J)
C      FORM E(I,J) MATRIX
C      DC 8 I=1,NPT
C      IOO = 2*I-1
C      IEV = 2*I
C      B(1,IOO) = DNX(1,I)
C      B(2,IEV) = DNX(2,I)
C      B(3,IEV) = DNX(1,I)
C      8 B(3,IOO) = DNX(2,I)
C      FORM STIFFNESS BY THE CONGRUENT TRANSFORMATION BT*D*B
C
FRMK1170
FRMK1180
FRMK1190
FRMK1200
FRMK1210
FRMK1220
FRMK1230
FRMK1240
FRMK1250
FRMK1260
FRMK1270
FRMK1280
FRMK1290
FRMK1300
FRMK1310
FRMK1320
FRMK1330
FRMK1340
FRMK1350
FRMK1360
FRMK1370
FRMK1380
FRMK1390
FRMK1400
FRMK1410
FRMK1420
FRMK1430
FRMK1440
FRMK1450
FRMK1460
FRMK1470
FRMK1480
FRMK1490
FRMK1500
FRMK1510
FRMK1520
FRMK1530
FRMK1540
FRMK1550
FRMK1560
FRMK1570
FRMK1580
FRMK1590
FRMK1600
FRMK1610
FRMK1620
FRMK1630
FRMK1640

```

```

C      DC 9  I=1,N
C      DO 9  J=1,3
C      BI(I,J) = ZERO
C      DO 9  K=1,3
C      BI(I,J) = BI(I,J)+B(K,I)*ELAST(K,J)
C      DC 10 I=1,N
C      DO 10 J=1,N
C      AK(I,J) = ZERO
C      DC 10 K=1,3
C      AK(I,J) = AK(I,J)+BI(I,K)*B(K,J)
C      DC 11 I=1,N
C      DC 11 J=I,N
C      AK(I,J) = ((AK(I,J)+AK(J,I))/2.0D0)*DTJ
C      AK(J,I) = AK(I,J)
C      RETURN
C      END
C      SUBROUTINE LDLT (N,M)
C      THIS SUBROUTINE DECOMPOSES THE COEFFICIENT MATRIX A* OF THE LINEAR
C      BANDED SYMMETRICAL SYSTEM (A*)(X) = (B), INTO THE PRODUCT (L)(D)(LT)
C      THE UPPER BAND ONLY IS USED, AND IT MUST BE STORED IN A RECTANGULAR
C      ARRAY (A) WITH ALL ITS DIAGONAL ELEMENTS IN THE FIRST COLUMN
C      MATRIX (A) IS DESTROYED IN THE PROCESS AND THE RESULTS RETURNED IN
C      THE SAME ARRAY. MATRIX (D) IS PUT IN THE FIRST COLUMN AND THE REST
C      OF THE MATRIX CONTAINS THE ELEMENTS OF THE UNIT TRIANGULAR MATRIX
C      IN BANDED FORM WITHOUT ITS IMPLIED UNIT DIAGONAL ELEMENTS.
C      A IS THE NAME OF THE COEFFICIENT MATRIX
C      N IS THE NUMBER OF EQUATIONS IN THE SYSTEM
C      M IS THE HALF BAND WIDTH OF THE SYSTEM
C      CODED BY GILLES CANTIN, NAVAL POSTGRADUATE SCHOOL, MAY 1972
C      IMPLICIT REAL*8(A-H,O-Z)
C      IMPLICIT INTEGER*2(I-N)
C      COMMON /SOL/ A(434,86),B(434),ABGN
C      AN = N
C      APZRO = ABGN*1.0D-30/AN

```

```

FRMK1650
FRMK1660
FRMK1670
FRMK1680
FRMK1690
FRMK1700
FRMK1710
FRMK1720
FRMK1730
FRMK1740
FRMK1750
FRMK1760
FRMK1770
FRMK1780
FRMK1790
FRMK1800
FRMK1810
FRMK1820
FRMK1830
FRMK1840
FRMK1850
FRMK1860
FRMK1870
FRMK1880
FRMK1890
FRMK1900
LDLT 10
LDLT 20
LDLT 30
LDLT 40
LDLT 50
LDLT 60
LDLT 70
LDLT 80
LDLT 90
LDLT 100
LDLT 110
LDLT 120
LDLT 130
LDLT 140
LDLT 150
LDLT 160
LDLT 170
LDLT 180
LDLT 190
LDLT 200
LDLT 210
LDLT 220

```



```

C ** CODED BY GILLES CANTIN, NAVAL POSTGRADUATE SCHOOL, MAY 1972
C ** *****
C ** IMPLICIT REAL*8(A-H,O-Z)
C ** IMPLICIT INTEGER*2(I-N)
C ** COMMON /SOL/ A(434,86),B(434),ABGN
C ** NM = N-1
C
C   DC 1 I=1,NM
C   BI = B(I)
C
C   DC 1 J=2,M
C   L = I+J-1
C   IF (L.GT.N) GO TO 1
C   B(L) = B(L)-A(I,J)*BI
C   1 CCNTINUE
C
C   DC 2 I=1,N
C   2 B(I) = B(I)/A(I,1)
C
C   DC 3 L=2,N
C   IR = N-L+1
C   BIRP = B(IR+1)
C
C   DC 3 J=2,M
C   IRO = IR-J+2
C   IF (IRO.LE.0) GO TO 3
C   B(IRO) = B(IRO)-A(IRO,J)*BIRP
C   3 CCNTINUE
C
C   RETURN
C   END
C   SUBROUTINE STRESS (NPEL)
C   IMPLICIT REAL*8(A-H,O-Z)
C   IMPLICIT INTEGER*2(I-N)
C   COMMON /SOL/ BGK(434,86),DISP(434),ABGN
C   COMMON /INT/ NCL,NTIN,NMAT,NLOAD,NPBC,NCON(182,15),NBC(217,2),NSTRS
C   1ES,NGP,LM(12),LJT(12),NTLD,NTBY,NTIN,NLEL
C   COMMON /FLPL/ COORD(217,2),CLOAD(217,2),ELCCN(10,7),TITLE(10),ANGL
C   1(182),THNP(217)
C   COMMON COORD(12,2),ELAST(3,3),SS(36,24),SN(36,24),TK
C   DIMENSION SSJNT(217,7),SNJNT(217,7),SSEL(36),DSPEL(36)
C   1)
C   DIMENSION TEEL(12)
C   EQUIVALENCE (BGK(1,1),SSJNT(1,1),SNJNT(1,1)),(BGK(1,5),SNJNT(1,1)),
C   1),SSEL(1)),(BGK(1,10),SNEL(1)),(BGK(1,11),DSPEL(1))
C   PI = 3.14159265359D0

```

STRS 160
 STRS 170
 STRS 180
 STRS 190
 STRS 200
 STRS 210
 STRS 220
 STRS 230
 STRS 240
 STRS 250
 STRS 260
 STRS 270
 STRS 280
 STRS 290
 STRS 300
 STRS 310
 STRS 320
 STRS 330
 STRS 340
 STRS 350
 STRS 360
 STRS 370
 STRS 380
 STRS 390
 STRS 400
 STRS 410
 STRS 420
 STRS 430
 STRS 440
 STRS 450
 STRS 460
 STRS 470
 STRS 480
 STRS 490
 STRS 500
 STRS 510
 STRS 520
 STRS 530
 STRS 540
 STRS 550
 STRS 560
 STRS 570
 STRS 580
 STRS 590
 STRS 600
 STRS 610
 STRS 620
 STRS 630

```

ZRC = 0.000
REWIND IO
DC 1 I=1,NJT
DO 1 J=1,7
  SSJNT(I,J) = ZRO
  SSJNT(I,J) = ZRO
1
CC
DC 1 I=1,NEL
  READ (IO) SS,SN
  IF (NTLD.EQ.0) GO TO 3
  MATN = NCON(I,14)
  YMOD = ELCON(MATN,1)
  PRAT = ELCON(MATN,2)
  ALPH = ELCON(MATN,3)
  IF (NSTRES.EQ.0) GO TO 2
  CCNST = ALPH*YMOD/(1.000-2.000*PRAT)
  GO TO 3
2
3
CCONST = ALPH*YMOD/(1.000-PRAT)
3
CONTINUE
C
DC 4 J=1,NPEL
  NCIJ = NCON(I,J)
  JA = NCIJ*2-1
  JJ = J*2-1
  IF (NTLD.NE.0) TEEL(J) = THNP(NCIJ)
  DSPEL(JJ) = DISP(JA)
  JJ = JJ+1
  JA = JA+1
4
  DSPEL(JJ) = DISP(JA)
C
  NJLM = NPEL*2
  NPELT = NPEL*3
C
DC 5 I1=1,NPELT
  SSEL(I1) = ZRO
  SSEL(I1) = ZRO
C
DO 5 J1=1,NJLM
  SSEL(I1) = SSEL(I1)+SS(I1,J1)*DSPEL(J1)
  SSEL(I1) = SSEL(I1)+SN(I1,J1)*DSPEL(J1)
5
  IF (NTLD.EQ.0) GO TO 7
C
DC 6 J=1,NPEL
  JJ0 = J*3-2
C

```

```

640 STRS
650 STRS
660 STRS
670 STRS
680 STRS
690 STRS
700 STRS
710 STRS
720 STRS
730 STRS
740 STRS
750 STRS
760 STRS
770 STRS
780 STRS
790 STRS
800 STRS
810 STRS
820 STRS
830 STRS
840 STRS
850 STRS
860 STRS
870 STRS
880 STRS
890 STRS
900 STRS
910 STRS
920 STRS
930 STRS
940 STRS
950 STRS
960 STRS
970 STRS
980 STRS
990 STRS
1000 STRS
1010 STRS
1020 STRS
1030 STRS
1040 STRS
1050 STRS
1060 STRS
1070 STRS
1080 STRS
1090 STRS
1100 STRS
1110 STRS

JJD = JJO+1
CCRT = CONST*TEEL(J)
SSEL(JJO) = SSEL(JJG)-CORT
SSEL(JJD) = SSEL(JJD)-CORT
6 CCNTINUE
C

7 CONTINUE
IF (NMAT.EQ.1) GO TO 9
WRITE (6,19) I
ILO = 0
IUP = 0
C

DC 8 J=1,NPEL
IJT = NCON(I,J)
ILC = IUP+1
IUP = ILO+2
8 WRITE (6,18) IJT, (SSEL(K),K=ILO,IUP), (SNEL(L),L=ILO,IUP)
C

9 CCNTINUE
ICT = 0
C

DG 11 I2=1,NPEL
I2A = NCON(I,I2)
C

DO 10 J2=1,3
ICT = ICT+1
SSJNT(I2A,J2) = SSEL(ICT)+SSJNT(I2A,J2)
10 SAJNT(I2A,J2) = SNEL(ICT)+SNJNT(I2A,J2)
C

11 SAJNT(I2A,7) = SNJNT(I2A,7)+1.
C
C
DC 15 I3=1,NJT
SCNT = SNJNT(I3,7)
C

DC 12 J3=1,3
SSJNT(I3,J3) = SSJNT(I3,J3)/SCNT
12 SAJNT(I3,J3) = SNJNT(I3,J3)/SCNT
C

GAU = SSJNT(I3,3)
SXPSY = (SSJNT(I3,1)+SSJNT(I3,2))/2.0D0
SXMSY = (SSJNT(I3,1))-SSJNT(I3,2))/2.0D0
AINT = DSQRT(SXMSY*SXMSY+GAU*GAU)
SSJNT(I3,4) = SXPSY+AINT
SSJNT(I3,5) = SXPSY-AINT
SSJNT(I3,6) = (SSJNT(I3,4)-SSJNT(I3,5))/2.0D0
IF (DABS(SXMSY).LE.1.D-10) GO TO 13
RAN = DATAN2(GAU,SXMSY)

```


BCND 130
 BCND 140
 BCND 150
 BCND 160
 BCND 170
 BCND 180
 BCND 190
 BCND 200
 BCND 210
 BCND 220
 BCND 230
 BCND 240
 BCND 250
 BCND 260
 BCND 270
 BCND 280
 BCND 290
 BCND 300
 BCND 310
 BCND 320
 BCND 330
 BCND 340
 BCND 350
 BCND 360
 BCND 370
 BCND 380
 BCND 390
 BCND 400
 BCND 410
 BCND 420
 BCND 430
 BCND 440
 BCND 450
 BCND 460
 BCND 470
 BCND 480
 BCND 490
 BCND 500
 BCND 510
 BCND 520
 BCND 530
 BCND 540
 BCND 550
 BCND 560
 BCND 570
 BCND 580
 BCND 590
 BCND 600

```

IJJT = NBC(I,1)
IEQ = IJJT*2-1
KCDE = NBC(I,2)
ICIA = 0
GC TO (1,3,4,6,10,11,13), KODE
1 IEQ = IEQ+1
2 BGK(IEQ,1) = ABGN
  IF (IDIA.EQ.1) GO TO 5
  GC TO 16
  GG TO 2
3 IDIA = 1
4 GC TO 2
5 IDIA = 0
  GO TO 1 CLOAD(IJT,2)
6 CXY = CLOAD(IJT,2)
  IEQ = IEQ+1
7 ALOAD(IEQ) = ALOAD(IEQ)-BGK(IEQ,1)*DXY
  BGK(IEQ,1) = ABGN
C
DC 9 J=2,NBAND
  IROW = IEQ-J+1
  ICOL = IEQ-1+J
  IF (IROW.LT.1) GO TO 8
  ALOAD(IROW) = ALOAD(IROW)-BGK(IROW,J)*DXY
  IF (ICOL.GT.NEQ) GO TO 9
  ALOAD(ICOL) = ALOAD(ICOL)-BGK(IEQ,J)*DXY
  CCNTINUE
C
  IF (IDIA.EQ.1) GO TO 12
  GC TO 16
10 DXY = CLOAD(IJT,1)
  GO TO 7
11 IDIA = 1
  DXY = CLOAD(IJT,1)
  GG TO 7
12 IDIA = 0
  GC TO 6
13 ALPHA = CLOAD(IJT,2)*PI/180.0D0
  CAL = DCOS(ALPHA)
  SAL = CSIN(ALPHA)
  IECP = IEQ+1
C
DC 15 J=3,NBAND
  IROW = IEQ-J+2
  JM = J-1
  IF (IROW.LT.1) GO TO 14
  A1 = BGK(IROW,JM)*CAL+BGK(IROW,J)*SAL
  A2 = BGK(IROW,J)*CAL-BGK(IROW,JM)*SAL

```

```

14  BGK(IROW,JM) = A1
    BGK(IROW,J) = A2
    IF ((IEQ+J-1).GT.NEQ) GO TO 15
    A3 = BGK(IEQ,J)*CAL+BGK(IEQ,JM)*SAL
    A4 = BGK(IEQ,JM)*CAL-BGK(IEQ,J)*SAL
    BGK(IEQ,J) = A3
    BGK(IEQ,JM) = A4
15  CCNTINUE
C
    A1 = BGK(IEQ,1)*CAL*CAL+BGK(IEQ,2)*CAL*SAL*2.0+BGK(IEQ,1)*SAL*SAL
    A2 = BGK(IEQ,2)*((CAL*CAL-SAL*SAL)+(BGK(IEQ,1)-BGK(IEQ,1))*SAL*CAL
    BGK(IEQ,1) = A1
    BGK(IEQ,2) = A2
    BGK(IEQ,1) = ABGN
16  CCNTINUE
C
    RETURN
    END
    SUBROUTINE DISPL(A-H,O-Z)
    IMPLICIT REAL*8(A-H,O-Z)
    IMPLICIT INTEGER*2(I-N)
    COMMON /SOL/ BGK(434,86), DISP(434),ABGN
    IES,NGP,LM(12),LJF(12),NTLO,NTBY,NTIN,NLEL
    COMMON /FLPL/ COORD(217,2),CLOAD(217,2),ELCON(10,7),TITLE(10),ANGL
    I(162),THNP(217)
    COMMON /MDIM/ MEL,MJT,MMT,MBD,MLEL,MLYR
    DIMENSION REACT(218,2)
    EQUIVALENCE (BGK(1,1),REACT(1,1))
    PI = 3.1415926535900
C
    DO 11 I=1,NPBC
    IJT = NBC(I,1)
    IEQ = IJT*2-1
    KODE = NBC(I,2)
    ICIA = 0
    DPBC = 0.000
    GO TO (1,3,4,6,7,8,10), KODE
    1 IEQ = IEQ+1
    JR = 2
    2 REACT(I,JR) = -DISP(IEQ)*ABGN
    REACT(IEQ) = DPBC
    IF (IDIA.EQ.1) GO TO 5
    IF (IDIA.EQ.2) GO TO 9
    GO TO 11
    3 JR = 1
    GO TO 2
    4 IDIA = 1

```

```

610 BCND
620 BCND
630 BCND
640 BCND
650 BCND
660 BCND
670 BCND
680 BCND
690 BCND
700 BCND
710 BCND
720 BCND
730 BCND
740 BCND
750 BCND
760 BCND
770 BCND
780 BCND
790 DISP
800 DISP
810 DISP
820 DISP
830 DISP
840 DISP
850 DISP
860 DISP
870 DISP
880 DISP
890 DISP
900 DISP
910 DISP
920 DISP
930 DISP
940 DISP
950 DISP
960 DISP
970 DISP
980 DISP
990 DISP
1000 DISP
1010 DISP
1020 DISP
1030 DISP
1040 DISP
1050 DISP
1060 DISP
1070 DISP
1080 DISP
1090 DISP
1100 DISP
1110 DISP
1120 DISP
1130 DISP
1140 DISP
1150 DISP
1160 DISP
1170 DISP
1180 DISP
1190 DISP
1200 DISP
1210 DISP
1220 DISP
1230 DISP
1240 DISP
1250 DISP
1260 DISP
1270 DISP
1280 DISP
1290 DISP
1300 DISP

```

```

310 DISP
320 DISP
330 DISP
340 DISP
350 DISP
360 DISP
370 DISP
380 DISP
390 DISP
400 DISP
410 DISP
420 DISP
430 DISP
440 DISP
450 DISP
460 DISP
470 DISP
480 DISP
490 DISP
500 DISP
510 DISP
520 DISP
530 DISP
540 DISP
550 DISP
560 DISP
570 DISP
580 DISP
590 DISP
600 DISP
610 DISP
620 DISP
630 DISP
640 DISP
650 DISP
660 DISP
670 DISP
680 DISP
690 DISP
700 DISP

JR = 1
GO TO 2
ICIA = 0
GC TO 1 CLOAD(IJT,2)
6 DPBC = CLOAD(IJT,2)
GO TO 1
7 JR = 1 CLOAD(IJT,1)
DPBC = CLOAD(IJT,1)
GC TO 2
8 ICIA = 2
JR = 1 CLOAD(IJT,1)
DPBC = CLOAD(IJT,1)
GC TO 2
9 ICIA = 0
DPBC = CLOAD(IJT,2)
GO TO 1
10 ALPHA = CLOAD(IJT,2)*PI/180.000
CAL = DCOS(ALPHA)
SAL = DSIN(ALPHA)
A1 = DISP(IEQ)*CAL
A2 = DISP(IEQ)*SAL
IEQP = IEQ+1
A3 = -DISP(IEQP)*SAL*ABGN
A4 = DISP(IEQP)*CAL*ABGN
DISP(IEQ) = A1
DISP(IEQP) = A2
REACT(I,1) = -A3
REACT(I,2) = -A4
11 CGCONTINUE

C
MJP = MJT+1
REACT(MJP,1) = 0.000
REACT(MJP,2) = 0.000

C
DC 12 I=1,NPBC
REACT(MJP,1) = REACT(MJP,1)+REACT(I,1)
12 REACT(MJP,2) = REACT(MJP,2)+REACT(I,2)

C
RETURN
END

```


C	C	VARIABLE	450	MAIN
C	C	JOINT NUMBER	460	MAIN
C	C	X COORDINATE OF THE JOINT (CARTESIAN COORD)	470	MAIN
C	C	RADIUS VECTOR LENGTH (POLAR COORD.)	480	MAIN
C	C	Y-COORDINATE IN DEGREES (POLAR COORD.)	490	MAIN
C	C	POLAR ANGLE IN DEGREES AT THE JOINT (CART)	500	MAIN
C	C	X-COMPONENT OF THE LOAD AT THE JOINT (CART)	520	MAIN
C	C	Y-COMPONENT OF THE LOAD AT THE JOINT (CART)	530	MAIN
C	C	COORDINATE SYSTEM INDICATOR. IND. = ZERO IF	540	MAIN
C	C	THE COORDINATE SYSTEM IS CARTESIAN, IF	550	MAIN
C	C	IS NOT ZERO, THE COORDINATE SYSTEM IS POLAR	560	MAIN
C	C	MATERIAL PROPERTIES CARDS(215,7F10.2)	570	MAIN
C	C	VARIABLE	580	MAIN
C	C	MATERIAL NUMBER	590	MAIN
C	C	INDK=0 FOR ISOTROPIC, INDK=1 FOR ORTHOTROPIC	600	MAIN
C	C	YOUNG'S MODULUS (ISOTROPIC MATERIAL)	610	MAIN
C	C	E(L) (ORTHOTROPIC MATERIAL)	620	MAIN
C	C	POISSON'S RATIO (ISOTROPIC MATERIAL)	630	MAIN
C	C	E(T) (ORTHOTROPIC MATERIAL)	640	MAIN
C	C	NOT USED (ISOTROPIC MATERIAL)	650	MAIN
C	C	NU(LT) (ORTHOTROPIC MATERIAL)	660	MAIN
C	C	NOT USED (ISOTROPIC MATERIAL)	670	MAIN
C	C	NU(TL) (ORTHOTROPIC MATERIAL)	680	MAIN
C	C	FOR ORTHOTROPIC MATERIALS, ONLY 3 OF THE ABOVE 4 ENGIN.	690	MAIN
C	C	CONSTANTS (E(L), E(T), NU(LT), NU(TL)) NEED BE KNOWN. FOR AN	700	MAIN
C	C	UNKNOWN CONSTANT ENTER -1.0 IN THE APPROPRIATE COLUMN.	710	MAIN
C	C	NOT USED (ISOTROPIC MATERIALS)	720	MAIN
C	C	G(LT) (ORTHOTROPIC MATERIALS)	730	MAIN
C	C	ALPHA COEFF. OF ISOTROPIC THERMAL EXPANSION	740	MAIN
C	C	NOT USED FOR THERMALLY ANISOTROPIC MATERIALS	750	MAIN
C	C	MATERIAL THICKNESS. THIS IS USED FOR ELEMENTS	760	MAIN
C	C	WHOSE PROPERTIES ARE NOT TO BE CALCULATED FROM	770	MAIN
C	C	INPUT LAMINA PROPERTIES.	780	MAIN
C	C	(15I4,F10.5,I5)	790	MAIN
C	C	ELEMENT IDENTIFICATION NUMBER	800	MAIN
C	C	ELEMENT CONNECTIVITY (COUNTER-CLOCKWISE)	810	MAIN
C	C	ELEMENT KIND - USE	820	MAIN
C	C	1 FOR A FOUR NODAL POINT ELEMENT	830	MAIN
C	C	2 FOR AN EIGHT NODAL POINT ELEMENT	840	MAIN
C	C	3 FOR A TWELVE NODAL POINT ELEMENT	850	MAIN
C	C	MATERIAL/LAMINATE IDENTIFICATION NUMBER	860	MAIN
C	C	THETA (DEGREES) USED FOR ORTHOTROPIC MATERIALS	870	MAIN
C	C	THETA IS THE ANGLE FROM THE PROBLEM BASED X AXIS	880	MAIN
C	C	TO THE MATERIAL BASED L AXIS	890	MAIN
C	C	ENTER 1 FOR A LAMINATED ELEMENT WHOSE	900	MAIN
C	C	PROPERTIES ARE TO BE CALCULATED FROM	910	MAIN
C	C	ELEMENT CARDS	920	MAIN
C	C	1-4		
C	C	5-52		
C	C	53-56		
C	C	57-60		
C	C	61-70		
C	C	71-75		

CCCCCCCCCCCCCCCCCCCC

INPUT LAMINA PROPERTIES.

BOUNDARY CONDITION CARDS (215) NPBC CARDS PER PROBLEM

COL. VARIABLE

1-5 JOINT NUMBER

6-10 CODE

- 1 FOR A ROLLER ON AN X AXIS, DISP. IN Y DIRECT. IS ZERO
 - 2 FOR A ROLLER ON AN Y AXIS, DISP. IN X DIRECT. IS ZERO
 - 3 FOR A FIXED JOINT, BOTH DISP. COMPONENTS ARE ZERO
 - 4 FOR A ROLLER ON AN X AXIS, THE DISP. IN THE Y DIRECT. IS SPECIFIED ON THE JOINT, CARD IN COL. 41-50
 - 5 FOR A ROLLER ON THE Y AXIS, THE DISP. IN THE X DIRECT. IS SPECIFIED ON THE JOINT, CARD IN COL. 31-40
 - 6 FIXED JOINT WITH DISP. SPECIFIED IN BOTH X AND Y
 - 7 DIRECT. ON THE JOINT CARD IN COL. 31-40 AND COL. 41-50
- FOR A ROLLER ON AN X AXIS INCLINED ALPHA DEGREES WITH RESPECT TO THE X AXIS. THE JOINT CARD MAY CONTAIN A TANGENTIAL LOAD IN COL. 31-40 AND THE ANGLE ALPHA DEGREES IN COL. 41-50

LAMINATE CARD DECK

USED AT LEAST TWO CARDS PER LAMINATE TYPE TO CALCULATE THE PROPERTIES OF A LAMINATE FROM THE PROPERTIES OF THE INDIVIDUAL LAMINAE.

CARD ONE 2 (15)

COLUMN VARIABLE

1-5 LAMTP

6-10 LYRNO

CARD TWO 4 (13, F8.3, F9.4)

COLUMN VARIABLE

1-3 MATERIAL NUMBER

4-11 LAMINA THICKNESS

12-20 LAMINA ORIENTATION (DEG) REL TO L AXIS OF ELEMENT

21-23 MATERIAL NUMBER

24-31 LAMINA THICKNESS

32-40 LAMINA ORIENTATION (DEG) REL TO L AXIS OF ELEMENT

41-43 MATERIAL NUMBER

44-51 LAMINA THICKNESS

52-60 LAMINA ORIENTATION (DEG) REL TO L AXIS OF ELEMENT

61-63 MATERIAL NUMBER

64-71 LAMINA THICKNESS

72-80 LAMINA ORIENTATION (DEG) REL TO L AXIS OF ELEMENT

AS MANY OF THESE SECOND TYPE CARDS AS NEEDED TO SPECIFY LYRNO LAYERS

MAY BE USED

REPEAT THE SEQUENCE WITH NEW CARD TYPE 1 AND 2 AS NEEDED TO

SPECIFY ALL LAMINATE TYPES

CONSISTENT LOAD VECTOR INFORMATION (15, 5F15.0) NJT CARDS

COL. VARIABLE

1-5 JOINT NUMBER

MAIN 930
MAIN 940
MAIN 950
MAIN 960
MAIN 970
MAIN 980
MAIN 990
MAIN 1000
MAIN 1010
MAIN 1020
MAIN 1030
MAIN 1040
MAIN 1050
MAIN 1060
MAIN 1070
MAIN 1080
MAIN 1090
MAIN 1100
MAIN 1110
MAIN 1120
MAIN 1130
MAIN 1140
MAIN 1150
MAIN 1160
MAIN 1170
MAIN 1180
MAIN 1190
MAIN 1200
MAIN 1210
MAIN 1220
MAIN 1230
MAIN 1240
MAIN 1250
MAIN 1260
MAIN 1270
MAIN 1280
MAIN 1290
MAIN 1300
MAIN 1310
MAIN 1320
MAIN 1330
MAIN 1340
MAIN 1350
MAIN 1360
MAIN 1370
MAIN 1380
MAIN 1390
MAIN 1400

```

C      6-20      TEMPERATURE AT THE NODE
C      21-35      X COMP. OF BODY FORCE INTENSITY AT THE NODE
C      36-50      Y COMP. OF BODY FORCE INTENSITY AT THE NODE
C      51-65      X COMP. OF INITIAL DISP. AT THE NODE
C      66-80      Y COMP. OF INITIAL DISP. AT THE NODE
C
C      AS MANY PRBLEMS AS ONE DESIRES MAY BE STACKED, BUT THE LAST CARD OF
C      A RUN MUST CONTAIN THE WORD STOP IN THE FIRST FOUR COLUMNS
C
C      IMPLICIT REAL*8(A-H,O-Z)
C      INTEGER*2(I-N)
C      COMMON /INT/ NEL,NJT,NMAT,NCLOAD,NPBC,NCON(182,15),NBC(217,2),NSTR
1     IES,NGP,LM(12),LJT(12),NLEL
C      COMMON /MDIM/ MEL,MJT,MMT,MBD,MLEL,MLYR
C      COMMON /FLPL/ COARD(217,2),TLOAD(217,2),ELCON(10,7),TITLE(10),THNP
1     I(217),BYNP(217,2),DPIN(217,2),ANGL(182)
C      COMMON /LOAD/ TEMP(12),BDFY(12,2),DSPN(12,2),TK,ALPHA,NN,NTLD,NTBY
1     NTIN,NCARD
C      COMMON /CC/ COORD(12,2),ELAST(3,3)
C      COMMON /INLAM/ LAMAT(50,100),LYRND(50),INDK(10)
C      COMMON /FLLAM/ TKLAM(50,100),ORLAM(50,100)
C      DIMENSION FVEC(24), CLOAD(217,2)
C      PI = 3.14159265359D0
C      MEL = 182
C      MJT = 217
C      MMT = 10
C      MBD = 86
C      MLEL = 50
C      MLYR = 100
C      NZRO = 0
C      ZRC = 0.0D0
C      CALL INPUT
C
C      DO 2 I=1,MJT
C
C      DC 2 J=1,2
C      CLCAD(I,J) = ZRO
C
C      NA = NSTRES
C      NEG = 2*NJT
C
C      DO 15 I=1,NEL
C      NPCL = NCON(I,15)*4
C      NJPE = NPCL*2
C      INDIC = NCON(I,15)
C      IF (INDIC.NE.1) GO TO 3
C      CALL LAMC (I)
C      GO TO 5

```

```

MAINI410
MAINI420
MAINI430
MAINI440
MAINI450
MAINI460
MAINI470
MAINI480
MAINI490
MAINI500
MAINI510
MAINI520
MAINI530
MAINI540
MAINI550
MAINI560
MAINI570
MAINI580
MAINI590
MAINI600
MAINI610
MAINI620
MAINI630
MAINI640
MAINI650
MAINI660
MAINI670
MAINI680
MAINI690
MAINI700
MAINI710
MAINI720
MAINI730
MAINI740
MAINI750
MAINI760
MAINI770
MAINI780
MAINI790
MAINI800
MAINI810
MAINI820
MAINI830
MAINI840
MAINI850
MAINI860
MAINI870
MAINI880

```

```

3  IMAT = NCON(I,14)
   THETA = ANGL(I)
   CALL STFMAT (IMAT, THETA, INDIC, NSTRES)
   IF (INDIC.NE.0) GO TO 4
   ALPHA = ELCON(IMAT,6)
   IF (NN.NE.0) ALPHA = ALPHA*(1.000+ELCON(IMAT,2))
4  CCNTINUE
   TK = ELCON(IMAT,7)
   IF (NSTRES.EQ.1) TK=1.000
5  CCNTINUE
   DO 6 J=1,NPEL
   IJ = NCCN(I,J)
   LM(J) = IJ
   TEMP(J) = THNP(IJ)
   C
6  DO 6 JJ=1,2
   BCFY(J,JJ) = BYNP(IJ,JJ)
   DSPN(J,JJ) = DPIN(IJ,JJ)
   COORD(J,JJ) = COARD(IJ,JJ)
   C
   IF (NTLD.EQ.0) GO TO 9
   LCODE = I
   CALL FLOAD (FVEC,NJPE,LCODE,NGP)
   WRITE (6,23) I,NILD,NZRO,NZRO
   C
7  DO 7 L=1,NPEL
   IO = 2*L-1
   IE = IO+1
   J = NCCN(I,L)
   WRITE (6,24) J,FVEC(IO),FVEC(IE)
   C
8  DO 8 J=1,NPEL
   IJ = LM(J)
   IO = 2*J-1
   IE = IO+1
   CLOAD(IJ,1) = FVEC(IO)+CLOAD(IJ,1)
   CLOAD(IJ,2) = FVEC(IE)+CLOAD(IJ,2)
   C
9  IF (NTBY.EQ.0) GO TO 12
   LCODE = 2
   CALL FLOAD (FVEC,NJPE,LCODE,NGP)
   WRITE (6,23) I,NZRO,NTBY,NZRO
   C
10 DO 10 L=1,NPEL
   IO = 2*L-1

```

```

MAIN1890
MAIN1900
MAIN1910
MAIN1920
MAIN1930
MAIN1940
MAIN1950
MAIN1960
MAIN1970
MAIN1980
MAIN1990
MAIN2000
MAIN2010
MAIN2020
MAIN2030
MAIN2040
MAIN2050
MAIN2060
MAIN2070
MAIN2080
MAIN2090
MAIN2100
MAIN2110
MAIN2120
MAIN2130
MAIN2140
MAIN2150
MAIN2160
MAIN2170
MAIN2180
MAIN2190
MAIN2200
MAIN2210
MAIN2220
MAIN2230
MAIN2240
MAIN2250
MAIN2260
MAIN2270
MAIN2280
MAIN2290
MAIN2300
MAIN2310
MAIN2320
MAIN2330
MAIN2340
MAIN2350
MAIN2360

```



```

SINA = DSIN(ALF)
CLCAD(NJT,1) = CLOAD(NJT,1)*COSA+CLOAD(NJT,2)*SINA
CLCAD(NJT,2) = ZRO
15 CCNTINUE
C
NJT = KJT
WRITE (6,22)
C
DC 20 I=1,NJT
IF (NCARD.NE.0) WRITE (7,21) I,CLOAD(I,1),CLOAD(I,2),THNP(I)
WRITE (6,21) I,CLOAD(I,1),CLOAD(I,2),THNP(I)
20 CCNTINUE
C
GC TO 1
C
21 FORMAT (5X,115,2G25.16,1G15.8)
22 FORMAT (//,10X,' RESULTANT LOAD VECTOR (NTLD+NTBY+NTIN)',/,
1 4X,' JOINT X COMPONENT',12X,' Y COMPONENT',10X,'NODAL TEM
2P,'//)
23 FORMAT (//,5X,'ELEMENT',113,' LOAD VECTOR',313,/,5X,' JOINT',7X,
1FX,13X,'FY',//)
24 FORMAT (5X,115,2G15.6)
END
SUBROUTINE INPUT
IMPLICIT REAL*8(A-H,O-Z)
IMPLICIT INTEGER*2(I-N)
COMMON /INT/ NEL,NJT,NMAT,NCLOAD,NPBC,NCON(182,15),NBC(217,2),NSTR
1ES,NGP,LM(12),LJT(12),NLEL
COMMON /MDIM/ MEL,MJT,MMT,MBD,MLEL,MLYR
COMMON /FLPL/ COORD(217,2),CLOAD(217,2),ELCON(10,7),TITLE(10),THNP
1(217),BYNP(217,2),DPIN(217,2),ANGL(182)
COMMON /LOAD/ TEMP(12),BDFY(12,2),DSPN(12,2),TK,ALPHA,NN,NTLD,NTBY
1,NTIN,NCARD
COMMON /INLAM/ LAMAT(50,100),LYRNO(50),INDK(10)
COMMON /FLLAM/ TKLAM(50,100),ORLAM(50,100)
DATA CHK/,STOP
PI = 3.14159265359D0
ZRC = 0.0D0
READ (5,25) TITLE
WRITE (6,26) TITLE
IF (TITLE(1).EQ.CHK) STOP
C
DC 1 I=1,MJT
THNP(I) = ZRO
C
DC 1 J=1,2
COORD(I,J) = ZRO
CLCAD(I,J) = ZRO

```



```

5 CONTINUE
C
DO 6 I=1,NJT
6 WRITE (6,31) I,COORD(I,1),COORD(I,2),CLOAD(I,1),CLOAD(I,2)
C
READ MATERIAL PROPERTIES CARDS
C
DC 7 I=1,NMAT
7 READ (5,32) IMAT,INDK(IMAT),(ELCON(IMAT,J),J=1,7)
C
WRITE (6,33)
C
DC 8 I=1,NMAT
8 WRITE (6,34) I,(ELCON(I,J),J=1,7),INDK(I)
C
READ THE ELEMENT CARDS
C
WRITE (6,35)
WRITE (6,36)
C
DO 9 I=1,NEL
9 READ (5,37) IJT,(NCON(IJT,J),J=1,14),ANGL(IJT),NCON(IJT,15)
C
DC 10 I=1,NEL
10 WRITE (6,38) I,(NCON(I,J),J=1,14),ANGL(I),NCON(I,15)
C
READ BOUNDARY CONDITION CARDS
C
WRITE (6,39)
C
DC 11 I=1,NPBC
11 READ (5,40) (NBC(I,J),J=1,2)
WRITE (6,41) (NBC(I,J),J=1,2)
C
DO 12 I=1,NPBC
12 J=I,NPBC
IF (NBC(I,1).LE.NBC(J,1)) GO TO 12
NT1 = NBC(I,1)
NT2 = NBC(I,2)

```

```

INPT 740
INPT 750
INPT 760
INPT 770
INPT 780
INPT 790
INPT 800
INPT 810
INPT 820
INPT 830
INPT 840
INPT 850
INPT 860
INPT 870
INPT 880
INPT 890
INPT 900
INPT 910
INPT 920
INPT 930
INPT 940
INPT 950
INPT 960
INPT 970
INPT 980
INPT 990
INPT 1000
INPT 1010
INPT 1020
INPT 1030
INPT 1040
INPT 1050
INPT 1060
INPT 1070
INPT 1080
INPT 1090
INPT 1100
INPT 1110
INPT 1120
INPT 1130
INPT 1140
INPT 1150
INPT 1160
INPT 1170
INPT 1180
INPT 1190
INPT 1200
INPT 1210

```

```

NBC(I,1) = NBC(J,1)
NBC(I,2) = NBC(J,2)
NBC(J,1) = NT1
NBC(J,2) = NT2
12 CCNTINUE
C
NSV = 0
C
DO 13 I=1,NPBC
IF (NBC(I,2).NE.7) GO TO 13
NSV = NSV+1
13 CCNTINUE
C
NPBCM = NPBC-1
IF (NSV.EQ.0) GO TO 18
DC 16 I=1,NSV
C
DO 15 J=1,NPBCM
IF (NBC(J,2).NE.7) GO TO 15
NT1 = NBC(J,1)
C
DO 14 K=J,NPBCM
KP = K+1
NBC(K,1) = NBC(KP,1)
NBC(K,2) = NBC(KP,2)
14
C
NBC(NPBC,1) = NT1
NBC(NPBC,2) = 7
GO TO 16
15 CONTINUE
C
16 CONTINUE
WRITE (6,39)
C
DC 17 I=1,NPBC
17 WRITE (6,41) (NBC(I,J),J=1,2)
C
18 CCNTINUE
IF (NLEL.EQ.0) GO TO 21
READ LAMINATE CARD DECK
C
C
DO 19 I=1,NLEL
READ (5,42) LAMTP,LYRNO(LAMTP)
L = LYRNO(LAMTP)
19
C

```

```

INPT1 220
INPT1 230
INPT1 240
INPT1 250
INPT1 260
INPT1 270
INPT1 280
INPT1 290
INPT1 300
INPT1 310
INPT1 320
INPT1 330
INPT1 340
INPT1 350
INPT1 360
INPT1 370
INPT1 380
INPT1 390
INPT1 400
INPT1 410
INPT1 420
INPT1 430
INPT1 440
INPT1 450
INPT1 460
INPT1 470
INPT1 480
INPT1 490
INPT1 500
INPT1 510
INPT1 520
INPT1 530
INPT1 540
INPT1 550
INPT1 560
INPT1 570
INPT1 580
INPT1 590
INPT1 600
INPT1 610
INPT1 620
INPT1 630
INPT1 640
INPT1 650
INPT1 660
INPT1 670
INPT1 680
INPT1 690

```

```

19 READ (5,43) ((LAMAT(LAMTP,J),TKLAM(LAMTP,J),ORLAM(LAMTP,J)),J=1,L) INPT1700
   CONTINUE INPT1710
C          INPT1720
C          WRITE (6,44) INPT1730
C          DO 20 I=1,NLEL INPT1740
   WRITE (6,45) I,LYRNO(I) INPT1750
   LL = LYRNO(I) INPT1760
C          INPT1770
C          DO 20 J=1,LL INPT1780
   WRITE (6,46) J,LAMAT(I,J),TKLAM(I,J),ORLAM(I,J) INPT1790
C          INPT1800
C          21 NLDC = NTLD+NTBY+NTIN INPT1810
   IF (NLDC.EQ.0) GO TO 24 INPT1820
C          READ CONSISTENT LOAD VECTOR INFORMATION INPT1830
C          WRITE (6,47) INPT1840
C          DO 22 I=1,NJT INPT1850
   22 READ (5,48) II,THNP(II),BYNP(II,1),BYNP(II,2),DPIN(II,1),DPIN(II,2) INPT1860
C          INPT1870
C          INPT1880
C          INPT1890
C          DO 23 I=1,NJT INPT1900
   23 WRITE (6,49) I,THNP(I),BYNP(I,1),BYNP(I,2),DPIN(I,1),DPIN(I,2) INPT1910
C          INPT1920
C          INPT1930
C          INPT1940
C          INPT1950
C          INPT1960
C          INPT1970
C          INPT1980
C          INPT1990
C          INPT2000
C          INPT2010
C          INPT2020
C          INPT2030
C          25 FORMAT (10A8) INPT2040
   26 FORMAT (1X,10A8) INPT2050
   27 FCRMAT (12F5) INPT2060
   28 1,15,/,/, NUMBER OF ELEMENTS=,15,/,/, TCTAL NUMBER OF JOINTS=, INPT2070
   2S=,15,/,/, NUMBER OF MATERIALS=,15,/,/, NUMBER OF CONCENTRATED LOAD INPT2080
   3E VALUE OF NSTRES=,15,/,/, NUMBER OF JOINTS WITH BOUNDARY CONDITIONS=,15,/,/, THINPT2090
   4/,/, THERMAL LOAD INPT2100
   5, INITIAL STRESS LOAD INPT2110
   6E TYPES USED,15) INPT2120
   29 FCRMAT (/,/,/, JOINT NUMBER,5X, X COORDINATE,5X, Y COORDINATE,7X INPT2130
   1, X LOAD,9X, Y LOAD,/,/ INPT2140
   30 FORMAT (15,5X,4G15.8,15) INPT2150
   31 FORMAT (5X,13,10X,G14.5,3X,G14.5,5X,G14.5,3X,G14.5) INPT2160
   32 FCRMAT (2I5,7F10.2) INPT2170
   33 1,7X, NU,E(LT),5X, NU(LT),8X, NU(TL),10X, G(LT),12X, ALPHA,9X INPT2180

```

```

2  THICKNESS, 2X, 'INDK')
34 FORMAT (//, 1X, I3, 5X, 7(2X, G13.6), 2X, I5)
35 FORMAT (//, 1X, I3, 5X, 7(2X, G13.6), 2X, I5)
36 FORMAT (//, 1X, I3, 5X, 7(2X, G13.6), 2X, I5)
37 FCORMAT (15I4, F10.5, I5)
38 FCORMAT (6X, I3, 6X, I2I5, 1X, I5, 5X, I5, 1X, F10.5, 5X, I5)
39 FCORMAT (//, 1X, I3, 5X, 7(2X, G13.6), 2X, I5)
40 FCORMAT (2I5)
41 FCORMAT (5X, I5, I10)
42 FCORMAT (2I5)
43 FCORMAT (4I3, F8.3, F9.4)
44 FCORMAT (//, 1X, I3, 5X, 7(2X, G13.6), 2X, I5)
1 LAYERS, 1X, LAYER NUMBER, 5X, MATERIAL NO., 5X, THICKNESS, 5X,
2 ORIENTATION, //)
45 FCORMAT (4X, I5, 11X, I5)
46 FCORMAT (30X, I5, 8X, I7, 10X, F9.3, 5X, F9.3)
47 FCORMAT (//, 1X, I3, 5X, 7(2X, G13.6), 2X, I5)
1  JOINT, 24X, BODY FORCE, INITIAL DISP., /, 2X, Y COMP., //)
2  JOINT, 24X, TEMP., X COMP., Y COMP., //)
48 FCORMAT (115, 5F15.0)
49 FCORMAT (4X, I3, 3X, 5G10.3)
50 FCORMAT (//, 1X, I3, 5X, 7(2X, G13.6), 2X, I5)
END
SUBROUTINE LAMC (IK)
THIS SUBROUTINE CALCULATES THE STIFFNESS MATRIX FOR LAMINATED
COMPOSITE MATERIALS. THIS SUBROUTINE ASSUMES THAT THE LAMINATED
COMPOSITE IS OF BALANCED DESIGN SO THAT THE STIFFNESS AND BENDING
PROPERTIES ARE UNCOUPLED. IT CALCULATES AN AVERAGE STIFFNESS MATRIX
FROM THE STIFFNESS PROPERTIES OF EACH LAMINA.
IK IS THE ELEMENT NUMBER
IMPLICIT REAL*8(A-H,O-Z)
INTEGER*2(I-N)
COMMON /FLPL/ COARD(217,2), TLOAD(217,2), ELCON(10,7), TITLE(10), THNP
1(217), BYNP(217,2), DPIN(217,2), ANGL(182)
COMMON /INT/ NEL, NJT, NMAT, NLOAD, NPBC, NCON(182,15), NBC(217,2), NSTR
1ES, NGP, LM(12), LJT(12), NLEL
COMMON /LOAD/ TEMP(12), BDFY(12,2), DSPN(12,2), TK, ALPHA, NN, NTLD, NTBY
1, NNTIN, NCARD
COMMON /INLAM/ LAMAT(50,100), LYRNO(50), INDK(10)
COMMON /FLLAM/ TKLAM(50,100), ORLAM(50,100)
COMMON /CC/ COORD(12,2), ELAST(3,3)
DIMENSION C(3,3)
LAMTP = NCON(IK, 14)
THETA = ANGL(IK)
TK = 0.00
DC 1 I=1,3

```

```

C          DC 1 J=1,3
C          1 C(I,J) = 0.D0
C          LYRS = LYRNO(LAMTP)
C          DO 3 I=1,LYRS
C            MATN = LAMAT(LAMTP,I)
C            PHI = THETA+ORLAM(LAMTP,I)
C            INDIC = INDK(MATN)
C            NSTRES = NN
C            CALL STFMAT (MATN,PHI,INDIC,NSTRES)
C            TK = TK+TKLAM(LAMTP,I)
C          DC 2 J=1,3
C          DC 2 K=1,3
C          2 C(J,K) = C(J,K)+ELAST(J,K)*TKLAM(LAMTP,I)
C          3 CCNTINUE
C          DO 4 J=1,3
C            DC 4 K=1,3
C            4 ELAST(J,K) = C(J,K)/TK
C          RETURN
C          END
C          SUBROUTINE STFMAT (MATN,THETA,INDIC,STIFFNES
C            THIS SUBROUTINE ASSEMBLES THE ELASTIC STIFFNES S MATRIX FOR A HOOKEAN
C            ELEMENT. THE SUBROUTINE CALCULATES AND STORES IN C(3X3) THE VALUES
C            OF THE ELEMENTS OF THIS MATRIX FOR ISOTROPIC MATERIALS UNDER
C            EITHER PLANE STRAIN OR PLANE STRESS OR FOR ANISOTROPIC MATERIALS
C            EXHIBITING TWO DIMENSIONAL ORTHOTROPY. FOR ANISOTROPIC MATERIALS,
C            THE ELEMENTS OF THIS MATRIX ARE FIRST COMPUTED IN THE MATERIAL
C            BASED L-T COORDINATE SYSTEM AND THEN TRANSFORMED TO THE PROBLEM
C            BASED X-Y COORDINATE SYSTEM.
C            IMPLICIT REAL*8(A-H,O-Z)
C            ICMPLICIT INTEGER*2(I-N)
C            COMMON /FLPL/ COORD(217,2),TLOAD(217,2),ELCON(10,7),TITLE(10),THNPS
C            1(217),BYNPP(217,2),DPIN(217,2),ANGL(182)
C            CCMCN /CC/ COORD(12,2),C(3,3)
C            DIMENSION A(3,3)
C          DC 1 I=1,3
C          DC 1 J=1,3

```

```

LAMC 250
LAMC 260
LAMC 270
LAMC 280
LAMC 290
LAMC 300
LAMC 310
LAMC 320
LAMC 330
LAMC 340
LAMC 350
LAMC 360
LAMC 370
LAMC 380
LAMC 390
LAMC 400
LAMC 410
LAMC 420
LAMC 430
LAMC 440
LAMC 450
LAMC 460
LAMC 470
LAMC 480
LAMC 490
LAMC 500
LAMC 510
LAMC 520
LAMC 530
STFM 10
STFM 20
STFM 30
STFM 40
STFM 50
STFM 60
STFM 70
STFM 80
STFM 90
STFM 100
STFM 110
STFM 120
STFM 130
STFM 140
STFM 150
STFM 160
STFM 170
STFM 180
STFM 190

```



```

A(2,2) = ET/Z
A(3,3) = GLT
C
C THIS ARRAY IS NOW TRANSFORMED FROM THE MATERIAL L-T COORDINATE
C SYSTEM TO THE PROBLEM X-Y COORDINATE SYSTEM. THE TRANSFORMATION IS
C ACCOMPLISHED BY ROTATION ABOUT THE Z AXIS THROUGH THETA DEGREES.
C
PI = 3.1415926535900
THRAD = THETA*PI/180.000
CCS1 = DCOS(THRAD)
CCS2 = DCOS(THRAD)**2
CCS3 = DCOS(THRAD)**3
CCS4 = DCOS(THRAD)**4
SIN1 = DSIN(THRAD)
SIN2 = DSIN(THRAD)**2
SIN3 = DSIN(THRAD)**3
SIN4 = DSIN(THRAD)**4
TWO = 2.000
FOUR = 4.000
C(1,1) = A(1,1)*COS4+TWO*(A(1,2)+TWO*A(3,3))*SIN2*COS2+A(2,2)*SIN4
C(1,2) = (A(1,1)+A(2,2))-FOUR*A(3,3))*SIN2*COS2+A(1,2)*(SIN4+COS4)
C(1,3) = (A(1,1)-TWO*A(3,3))*SINI*COS3+(A(1,2)-A(2,2))+TWO*(
1A(3,3))*SIN3*COS1
C(2,2) = A(1,1)*SIN4+TWO*(A(1,2)+TWO*A(3,3))*SIN2*COS2+A(2,2)*COS4
C(2,3) = (A(1,1)-A(1,2)-TWO*A(3,3))*SIN3*COS1+(A(1,2)-A(2,2))+TWO*A
1C(3,3))*SINI*COS3
1C(3,3) = (A(1,1)+A(2,2)-TWO*(A(1,2)+A(3,3)))*SIN2*COS2+A(3,3)*(SIN
14+COS4)
C(2,1) = C(1,2)
C(3,1) = C(1,3)
C(3,2) = C(2,3)
RETURN
ENC
SUBROUTINE FORMB (B,X,Y,N,DTJ,IND)
C
C THIS SUBROUTINE FORMS THE B MATRIX AS A FUNCTION OF
C XI AND ETA FOR THE THREE DIFFERENT QUADRILATERAL ELEM. IN THIS FAMILY
C
IMPLICIT REAL*8(A-H,O-Z)
INTEGER*2(I-N)
DIMENSION AJ(2,2), AJIN(2,2), DNX(2,12), W1(2,12), B(3,24)
COMMON /CC/ COORD(12,2),ELAST(3,3)
ZERO = 0.000
DO 1 I=1,3
C
DO 1 J=1,N
1 B(I,J) = ZERO

```

```

STFM 680
STFM 690
STFM 700
STFM 710
STFM 720
STFM 730
STFM 740
STFM 750
STFM 760
STFM 770
STFM 780
STFM 790
STFM 800
STFM 810
STFM 820
STFM 830
STFM 840
STFM 850
STFM 860
STFM 870
STFM 880
STFM 890
STFM 900
STFM 910
STFM 920
STFM 930
STFM 940
STFM 950
STFM 960
STFM 970
STFM 980
STFM 990
STFM1000
FRMB 10
FRMB 20
FRMB 30
FRMB 40
FRMB 50
FRMB 60
FRMB 70
FRMB 80
FRMB 90
FRMB 100
FRMB 110
FRMB 120
FRMB 130
FRMB 140
FRMB 150

```

```

C
ONE = 1.0D0
TWO = 2.0D0
FCUR = 4.0D0
NPT = N/2
FORM (2XNPT) MATRIX OF DERIV. OF THE INTERP. FUNCT. WRT XI AND ETA
C
IGC = N/8
GO TO (2,3,4), IGC
C
C
LINEAR FUNCTIONS
2  W1(1,3) = -(ONE-Y)/FOUR
   W1(1,4) = -W1(1,3)
   W1(1,1) = (ONE+Y)/FOUR
   W1(1,2) = -W1(1,1)
   W1(2,3) = -(ONE-X)/FOUR
   W1(2,4) = -W1(2,3)
   W1(2,1) = -W1(2,4)
   W1(2,2) = -W1(2,3)
GO TO 5
3  CCNTINUE
C
QUAERATIC FUNCTIONS
TXPY = TWO*X+Y
TXMY = TWO*X-Y
TYPX = TWO*Y+X
TYMX = TWO*Y-X
OMY = ONE-Y
OPX = ONE+X
OMX = ONE-X
W1(1,5) = OMY*TXPY/FOUR
W1(1,6) = -OMY*X
W1(1,7) = OMY*TXMY/FOUR
W1(1,8) = OPY*OMY/TWO
W1(1,1) = OPY*TXPY/FOUR
W1(1,2) = -OPY*X
W1(1,3) = OPY*TXMY/FOUR
W1(1,4) = -OPY*OMY/TWO
W1(2,5) = OMX*TYPX/FOUR
W1(2,6) = -OPX*OMX/TWO
W1(2,7) = OPX*TYMX/FOUR
W1(2,8) = -Y*OPX
W1(2,1) = OPX*TYPX/FOUR
W1(2,2) = OPX*OMX/TWO

```

```

FRMB 160
FRMB 170
FRMB 180
FRMB 190
FRMB 200
FRMB 210
FRMB 220
FRMB 230
FRMB 240
FRMB 250
FRMB 260
FRMB 270
FRMB 280
FRMB 290
FRMB 300
FRMB 310
FRMB 320
FRMB 330
FRMB 340
FRMB 350
FRMB 360
FRMB 370
FRMB 380
FRMB 390
FRMB 400
FRMB 410
FRMB 420
FRMB 430
FRMB 440
FRMB 450
FRMB 460
FRMB 470
FRMB 480
FRMB 490
FRMB 500
FRMB 510
FRMB 520
FRMB 530
FRMB 540
FRMB 550
FRMB 560
FRMB 570
FRMB 580
FRMB 590
FRMB 600
FRMB 610
FRMB 620
FRMB 630

```

FRMB 640
FRMB 650
FRMB 660
FRMB 670
FRMB 680
FRMB 690
FRMB 700
FRMB 710
FRMB 720
FRMB 730
FRMB 740
FRMB 750
FRMB 760
FRMB 770
FRMB 780
FRMB 790
FRMB 800
FRMB 810
FRMB 820
FRMB 830
FRMB 840
FRMB 850
FRMB 860
FRMB 870
FRMB 880
FRMB 890
FRMB 900
FRMB 910
FRMB 920
FRMB 930
FRMB 940
FRMB 950
FRMB 960
FRMB 970
FRMB 980
FRMB 990
FRMB1000
FRMB1010
FRMB1020
FRMB1030
FRMB1040
FRMB1050
FRMB1060
FRMB1070
FRMB1080
FRMB1090
FRMB1100
FRMB1110

W1(2,3) = OMX*TYMX/FOUR
W1(2,4) = -Y*OMX
GO TO 5
4 CCNTINUE

CUBIC FUNCTIONS

CFX = ONE+X
OPY = ONE+Y
CMX = ONE-X
GMY = ONE-Y
TPTMNX = 3.000+2.000*X-9.000*X*X
TPTMNX = 3.000-2.000*X-9.000*X*X
TPTMNY = 3.000+2.000*Y-9.000*Y*Y
TPTMNY = 3.000-2.000*Y-9.000*Y*Y
TYFO = 3.000*Y+ONE
TYPO = 3.000*X+ONE
TXMO = 3.000*X-ONE
TMTPEX = 10.000-27.000*X*X+18.000*X-9.000*X*Y
TMTPEY = 10.000-27.000*X*X+18.000*X-9.000*X*Y
TMNPEY = 10.000-9.000*X*X-18.000*Y-27.000*X*Y
TTT = 32.000
TTN = 32.000/9.000
W1(1,7) = OMY*TMTPEX/TTT
W1(1,8) = -TPTMNX*OMY/TTN
W1(1,9) = TMTMNX*OMY/TTN
W1(1,10) = -OMY*TMTMEX/TTT
W1(1,11) = -OPY*OMY*TYMO/TTN
W1(1,12) = OMY*OMY*TYPO/TTN
W1(1,1) = -OPY*TMTMEX/TTT
W1(1,2) = TMTMNX*OPY/TTN
W1(1,3) = -TPTMNX*OPY/TTN
W1(1,4) = OMY*TMTPEX/TTT
W1(1,5) = -OPY*OMY*TYPO/TTN
W1(1,6) = OMY*OMY*TYMO/TTN
W1(2,7) = OMX*TMNPEY/TTT
W1(2,8) = OMY*OMX*TXMO/TTN
W1(2,9) = -OPX*OMX*TXPO/TTN
W1(2,10) = OMY*TMNPEY/TTT
W1(2,11) = -TPTMNY*OPX/TTN
W1(2,12) = TMTMNY*OPX/TTN
W1(2,1) = -OPX*TMNMEY/TTT
W1(2,2) = OMY*OMX*TXPO/TTN
W1(2,3) = -OPX*OMX*TXMO/TTN
W1(2,4) = -OMX*TMNMEY/TTT
W1(2,5) = OMY*TMTMNY/TTN

C
C
C

```

C      W1(2,6) = -OMX*TPTMNY/TTN
5      CCNTINUE
C      FORM JACOBIAN OF THE TRANSFORMATION IN AJ(I,J)
C
C      DO 6 I=1,2
C      DO 6 J=1,2
C      AJ(I,J) = ZERO
C
C      DC 6 K=1,NPT
6      AJ(I,J) = AJ(I,J)+W1(I,K)*COORD(K,J)
C
C      CALCULATE DETERMINANT OF THE JACOBIAN
C
C      DTJ = AJ(1,1)*AJ(2,2)-AJ(1,2)*AJ(2,1)
C      IF (IND.NE.0) RETURN
C
C      INVERT JACOBIAN IN AJIN
C
C      AJIN(1,1) = AJ(2,2)/DTJ
C      AJIN(1,2) = -AJ(1,2)/DTJ
C      AJIN(2,1) = -AJ(2,1)/DTJ
C      AJIN(2,2) = AJ(1,1)/DTJ
C
C      FORM (2XNPT) MATRIX OF DERIVATIVES OF INTERP. FUNCT WRT X AND Y
C
C      DC 7 I=1,2
C      DO 7 J=1,NPT
C      DNX(I,J) = ZERO
C
C      DO 7 K=1,2
7      DNX(I,J) = DNX(I,J)+AJIN(I,K)*W1(K,J)
C
C      FORM B(I,J) MATRIX
C
C      DC 8 I=1,NPT
C      ICD = 2*I-1
C      IEV = 2*I
C      B(1,ICD) = DNX(1,I)
C      B(2,IEV) = DNX(2,I)
C      B(3,IEV) = DNX(1,I)
FRMB1120
FRMB1130
FRMB1140
FRMB1150
FRMB1160
FRMB1170
FRMB1180
FRMB1190
FRMB1200
FRMB1210
FRMB1220
FRMB1230
FRMB1240
FRMB1250
FRMB1260
FRMB1270
FRMB1280
FRMB1290
FRMB1300
FRMB1310
FRMB1320
FRMB1330
FRMB1340
FRMB1350
FRMB1360
FRMB1370
FRMB1380
FRMB1390
FRMB1400
FRMB1410
FRMB1420
FRMB1430
FRMB1440
FRMB1450
FRMB1460
FRMB1470
FRMB1480
FRMB1490
FRMB1500
FRMB1510
FRMB1520
FRMB1530
FRMB1540
FRMB1550
FRMB1560
FRMB1570
FRMB1580
FRMB1590

```

```

C      8 B(3,IOD) = DNX(2,I)
C      RETURN
C      END
C      SUBROUTINE FLOAD (FVEC,N,LCCDE,NGP)
C      FLOAD IS A NUMERICAL INTEGRATION SUBROUTINE THAT FORMS THE
C      CONSISTENT LOAD VECTORS FOR ANY OF THE THREE ELEMENTS OF THIS
C      FAMILY OF ISOPARAMETRIC ELEMENTS
C      GAUSSIAN QUADRATURE WITH A MAXIMUM OF FIVE ORDINATES IS USED.
C      FVEC(24) IS THE OUTPUT ARRAY CONTAINING THE LOAD VECTOR UPON EXIT
C      N IS EQUAL TO TWICE THE NUMBER OF NODAL POINTS IN THE ELEMENT
C      LCCDE MUST BE EQUAL TO
C      1 FOR A TEMPERATURE LOAD, VECTOR,
C      2 FOR A BODY FORCE LOAD, VECTOR,
C      3 FOR AN INITIAL DEFORMATION LOAD VECTOR.
C      NGP IS THE NUMBER OF GAUSS POINTS USED FOR INTEGRATION
C      COORD(12,2) IS AN ARRAY CONTAINING THE COORDINATES OF ALL
C      ELAST(3,3) IS AN ARRAY CONTAINING THE ELEMENT TO BE CONSTRUCTED
C      OF THE ELEMENT, THE ORDER OF THE ELASTIC CONSTANTS
C      IS: SIGMAX,SIGMAY,TAUXY
C      TEMP(12) IS A VECTOR OF NODAL TEMPERATURES
C      BDFY(12,2) IS A VECTOR OF NODAL VALUES OF THE BODY FORCE
C      DSPN(12,2) IS A VECTOR OF INITIAL VALUES OF DISPLACEMENTS
C      TK IS THE THICKNESS OF THE ELEMENT (UNITY FOR PLANE STRAIN)
C      ALPHA IS THE COEFFICIENT OF EXPANSION OF THE MATERIAL
C      NN IS EQUAL TO 1 FOR PLANE STRAIN, 0 FOR PLANE STRESS
C      NTLC IS EQUAL TO 1 FOR A THERMAL LOAD, 0 OTHERWISE
C      NTBY IS EQUAL TO 1 FOR A BODY FORCE LOAD, 0 OTHERWISE
C      NTIN IS EQUAL TO 1 FOR AN IN-STR. LOAD, 0 OTHERWISE
C      NCARD IS THE PUNCH CONTROL CARD
C      CODEC BY PROFESSOR GILLES CANTIN AT THE NAVAL POSTGRADUATE SCHOOL
C      IMPLICIT REAL*8(A-H,O-Z)
C      IMPLICIT INTEGER*2(I-N)
C      COMMON /LOAD/ TEMP(12),BDFY(12,2),DSPN(12,2),TK,ALPHA,NN,NTLD,NTBY
C      1,NTIN,NCARD
C      DIMENSION FVEC(24), VAL(12),BTD(24,3), WVEC(24), SK(24,24), B(3,2
C      14)
C      DIMENSION DSPO(24)
C      DIMENSION XI(5), AI(5), AIA(5,5)
C      DIMENSION X2(2), X3(3), X4(4), X5(5), A2(2), A3(3), A4(4), A5(5)
C      DATA X2/.577350269189626D0,-.577350269189626D0/
C      DATA A2/1.0D0,1.0D0/
C      DATA X3/.774596669241483D0,0.0D0,-.774596669241483D0/
C      DATA A3/.555555555555556D0,.8888888888889D0,.555555555555556D0/
C      DATA X4/.8611363115940D0,.3399810435848D0,-.3399810435848D0,-.8611
C      1363115940D0/
C      DATA A4/.3478548451574D0,.6521451548625D0,.6521451548625D0,.347854

```

```

FRMB1600
FRMB1610
FRMB1620
FRMB1630
FLOOD 10
FLOOD 20
FLOOD 30
FLOOD 40
FLOOD 50
FLOOD 60
FLOOD 70
FLOOD 80
FLOOD 90
FLOOD 100
FLOOD 110
FLOOD 120
FLOOD 130
FLOOD 140
FLOOD 150
FLOOD 160
FLOOD 170
FLOOD 180
FLOOD 190
FLOOD 200
FLOOD 210
FLOOD 220
FLOOD 230
FLOOD 240
FLOOD 250
FLOOD 260
FLOOD 270
FLOOD 280
FLOOD 290
FLOOD 300
FLOOD 310
FLOOD 320
FLOOD 330
FLOOD 340
FLOOD 350
FLOOD 360
FLOOD 370
FLOOD 380
FLOOD 390
FLOOD 400
FLOOD 410
FLOOD 420
FLOOD 430
FLOOD 440

```

```

18451374D0/
DATA X5/.9061798459386D0,.5384693101056D0,0.0D0,-.5384693101056D0,
1-.9061798459386D0/
LATA A5/.2369268850561D0,.4786286704993D0,.5688888888888D0,.478628
16704993D0,.2369268850561D0/
IF (NGP.EQ.0) NGP = 5
IF (TK.EQ.0.0D0) TK=1.0D0
C
DC 1 I=1,24
FVEC(I) = 0.0D0
1 WVEC(I) = 0.0D0
C
JUMP = NGP-1
C
DC 6 I=1,NGP
GO TO (2,3,4,5), JUMP
2 XI(I) = X2(I)
AI(I) = A2(I)
GO TO 6
3 XI(I) = X3(I)
AI(I) = A3(I)
GO TO 6
4 XI(I) = X4(I)
AI(I) = A4(I)
GO TO 6
5 XI(I) = X5(I)
AI(I) = A5(I)
6 CCNTINUE
C
DC 7 I=1,NGP
DO 7 J=1,NGP
7 AIA(I,J) = AI(I)*AI(J)
C
NPEL = N/2
C
DC 24 I=1,NGP
X = XI(I)
C
DO 24 J=1,NGP
Y = XI(J)
GC TO (8,13,17), LCODE
8 ILT = 0
CALL FORMB (B,X,Y,N,DIJ,ILT)
C
DO 9 II=1,N
C

```

```

FLOD 450
FLOD 460
FLOD 470
FLOD 480
FLOD 490
FLOD 500
FLOD 510
FLOD 520
FLOD 530
FLOD 540
FLOD 550
FLOD 560
FLOD 570
FLOD 580
FLOD 590
FLOD 600
FLOD 610
FLOD 620
FLOD 630
FLOD 640
FLOD 650
FLOD 660
FLOD 670
FLOD 680
FLOD 690
FLOD 700
FLOD 710
FLOD 720
FLOD 730
FLOD 740
FLOD 750
FLOD 760
FLOD 770
FLOD 780
FLOD 790
FLOD 800
FLOD 810
FLOD 820
FLOD 830
FLOD 840
FLOD 850
FLOD 860
FLOD 870
FLOD 880
FLOD 890
FLOD 900
FLOD 910
FLOD 920

```

```

C      DO 9 JJ=1,3
      BTD(II, JJ) = 0.000
C
C      DO 9 KK=1,3
      9 BTD(II, JJ) = BTD(II, JJ)+B(KK, II)*ELAST(KK, JJ)
C      CALL SHAPE (VAL, X, Y, NPEL)
      CFT = 0.000
C
C      DC 10 II=1, NPEL
      10 CFT = CFT+VAL(II)*TEMP(II)
C      CFT = CFT*ALPHA*TK*DTJ
C
C      DO 11 II=1, N
      11 WVEC(II) = (BTD(II, 1)+BTD(II, 2))*CFT
C
C      DC 12 II=1, N
      12 FVEC(II) = FVEC(II)+WVEC(II)*AIA(I, J)
C
C      GC TO 24
      13 CALL SHAPE (VAL, X, Y, NPEL)
      ILT = I
      CALL FORMB (B, X, Y, N, DTJ, ILT)
      CFTX = 0.000
      CFTY = 0.000
C
C      DC 14 II=1, NPEL
      CFTX = CFTX+VAL(II)*BDFY(II, 1)
      14 CFTY = CFTY+VAL(II)*BDFY(II, 2)
C
C      DC 15 II=1, NPEL
      IC = 2*II-1
      IE = IO+1
      WVEC(IE) = VAL(II)*CFTX*DTJ*TK
      15 WVEC(IE) = VAL(II)*CFTY*DTJ*TK
C
C      DC 16 II=1, N
      16 FVEC(II) = FVEC(II)+WVEC(II)*AIA(I, J)
C
C      GC TO 24
      17 ILT = 0
      CALL FORMB (B, X, Y, N, DTJ, ILT)
C      DO 18 II=1, N

```

```

FLOD 930
FLOD 940
FLOD 950
FLOD 960
FLOD 970
FLOD 980
FLOD 990
FLOD 1000
FLOD 1010
FLOD 1020
FLOD 1030
FLOD 1040
FLOD 1050
FLOD 1060
FLOD 1070
FLOD 1080
FLOD 1090
FLOD 1100
FLOD 1110
FLOD 1120
FLOD 1130
FLOD 1140
FLOD 1150
FLOD 1160
FLOD 1170
FLOD 1180
FLOD 1190
FLOD 1200
FLOD 1210
FLOD 1220
FLOD 1230
FLOD 1240
FLOD 1250
FLOD 1260
FLOD 1270
FLOD 1280
FLOD 1290
FLOD 1300
FLOD 1310
FLOD 1320
FLOD 1330
FLOD 1340
FLOD 1350
FLOD 1360
FLOD 1370
FLOD 1380
FLOD 1390
FLOD 1400

```

```

C      DO 18 JJ=1,3
C      BTD(II, JJ) = 0.000
C
C      DO 18 KK=1,3
C      BTD(II, JJ) = BTD(II, JJ)+B(KK, II)*ELAST(KK, JJ)
C
C      DO 19 II=1, N
C      DO 19 JJ=1, N
C      SK(II, JJ) = 0.000
C
C      DO 19 KK=1, 3
C      SK(II, JJ) = SK(II, JJ)+BTD(II, KK)*B(KK, JJ)
C
C      DC 20 II=1, NPEL
C      IC = 2*II-1
C      IE = IO+1
C      DSFO(IO) = DSPN(II, 1)
C      DSPO(IE) = DSPN(II, 2)
C
C      DO 21 II=1, N
C      WVEC(II) = 0.000
C
C      DC 21 JJ=1, N
C      WVEC(II) = WVEC(II)+SK(II, JJ)*DSPC(JJ)
C
C      DC 22 II=1, N
C      WVEC(II) = -WVEC(II)*TK*DTJ
C
C      DC 23 II=1, N
C      FVEC(II) = FVEC(II)+WVEC(II)*AIA(I, J)
C      CCNTINUE
C      RETURN
C      END
C      SCBRoutine SHAPE (VAL, X, Y, NPEL)
C      IMPLICIT REAL*8(A-H, O-Z)
C      IMPLICIT INTEGER*2(I-N)
C      DIMENSION VAL(12), XYL(4, 2), XYQ(8, 2), XYC(12, 2), IPERM(4)
C      DATA XYL/1.000, -1.000, -1.000, -1.000, -1.000, 1.000, 1.000, 1.000, -1.000, -1.000, -1.000, -1.000/
C      DATA XYQ/1.000, 0.000, -1.000, -1.000, -1.000, -1.000, 0.000, 1.000, 1.000, 1.000, 1.000, 1.000,
FL0D1410
FL0D1420
FL0D1430
FL0D1440
FL0D1450
FL0D1460
FL0D1470
FL0D1480
FL0D1490
FL0D1500
FL0D1510
FL0D1520
FL0D1530
FL0D1540
FL0D1550
FL0D1560
FL0D1570
FL0D1580
FL0D1590
FL0D1600
FL0D1610
FL0D1620
FL0D1630
FL0D1640
FL0D1650
FL0D1660
FL0D1670
FL0D1680
FL0D1690
FL0D1700
FL0D1710
FL0D1720
FL0D1730
FL0D1740
FL0D1750
FL0D1760
FL0D1770
FL0D1780
FL0D1790
FL0D1800
FL0D1810
FL0D1820
SHPE 10
SHPE 20
SHPE 30
SHPE 40
SHPE 50
SHPE 60

```

```

1 1.000,1.000,0.000,-1.000,-1.000,-1.000,0.000/
DATA X,Y,C/1.000,33333333333300,-.33333333333300,-1.000,-1.000,-1.000,-1.000,-1.000,70
1.000,-1.000,-.33333333333300,.33333333333300,1.000,1.000,1.000,1.000,1.000,80
2.000,1.000,1.000,1.000,33333333333300,-.33333333333300,-1.000,1.000,1.000,90
3 1.000,-1.000,-1.000,-.33333333333300,.33333333333300,1.000,1.000,1.000,1.000,100
FL(X,Y,X1,Y1) = (ONE+X*X1)*(ONE+Y*Y1)/FOUR
FQC(X,Y,X1,Y1) = (ONE+X*X1)*(ONE+Y*Y1)*(X*X1+Y*Y1-ONE)/FOUR
FQM(X,Y,X1,Y1) = (ONE-X*X1)*(ONE+Y*Y1)/TWO
FCC(X,Y,X1,Y1) = (ONE-X*X1)*(ONE+Y*Y1)*(.9D1*(X*X+Y*Y)-.1D2)/3.2D1
FCM(X,Y,X1,Y1) = (ONE-X*X1)*(ONE+Y*Y1)*(ONE+Y*Y1)*(.9D1*X*X1)*(.9D1/5.2D1)
CNE = 1.000
TWO = 2.000
FOUR = 4.000
IGO = NPEL/4
GO TO (1,3,7), IGO
1 CCNTINUE
  LINEAR FUNCTIONS
DO 2 I=1,4
X1 = XYL(I,1)
Y1 = XYL(I,2)
2 VAL(I) = FL(X,Y,X1,Y1)
C
3 RETURN
  QUADRATIC FUNCTIONS
DO 4 I=1,7,2
X1 = XQC(I,1)
Y1 = XYQ(I,2)
4 VAL(I) = FQC(X,Y,X1,Y1)
C
5 I=2,6,4
Y1 = XYQ(I,2)
5 VAL(I) = FQM(X,Y,Y1)
C
6 I=4,8,4
X1 = XYQ(I,1)
Y1 = XYQ(I,2)
6 VAL(I) = FQM(Y,X,X1)
C
7 CCNTINUE
  CUBIC FUNCTIONS
DO 8 I=1,10,3
X1 = XYC(I,1)

```

```

      C      Y1 = XYC(I,2)
      8 VAL(I) = FCC(X,Y,X1,Y1)
      C
      C      IPERM(1) = 2
      IPERM(2) = 3
      IPEKM(3) = 8
      IPERM(4) = 9
      C
      DO 9 I=1,4
      IJ = IPERM(I)
      X1 = XYC(IJ,1)
      Y1 = XYC(IJ,2)
      9 VAL(IJ) = FCM(X,Y,X1,Y1)
      C
      C      IPERM(1) = 5
      IPERM(2) = 6
      IPERM(3) = 11
      IPERM(4) = 12
      C
      DO 10 I=1,4
      IJ = IPERM(I)
      X1 = XYC(IJ,1)
      Y1 = XYC(IJ,2)
      10 VAL(IJ) = FCM(Y,X,Y1,X1)
      C      RETURN
      END

```

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