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THIS PAGE IS UNCLASSIFIED
DESIGN GUIDE FOR BOLTED JOINTS IN COMPOSITE STRUCTURES

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THIS DOCUMENT IS BEST QUALITY PRACTICABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.
A design guide was developed for bolted composite structural joints. The guide includes general design guidelines for the various joint parameters, an analytical design methodology, a description of the analytical design tools, an illustration of the use of corresponding computer codes (SASCJ and SANCJ), and a listing of the computer codes. The proposed design procedure is purely analytical, and enables the user to rapidly evaluate many different joint concepts for a selected application. When the bolted structure is fabricated using existing (fully characterized) materials, the design requires no complementary test results. Presented analytical design tools are currently restricted to primarily uniaxially loaded joints and fastener arrangements that are currently used in aircraft structures. Also, the bolted joint is assumed to be strength-critical. However, sample fatigue test results are presented to illustrate a durability check on the joint, assuming a simplified fatigue analysis and assuming that fracture failure is induced by excessive hole elongation. Despite its current restrictions, this guide is the first government document that provides guidance and analytical tools for the design of bolted composite structures.
This report was prepared under Contract F33615-82-C-3317, titled "Bolted Joints in Composite Structures: Design, Analysis and Verification," and administered by the Air Force Wright Aeronautical Laboratories. Dr. V. B. Venkayya was the Air Force project engineer, and was assisted by Capt. M. Sobota and Lt. D. L. Graves as program co-monitors. The program manager and principal investigator at Northrop was Dr. R. L. Ramkumar.

This report is a guide for the design of bolted joints in composite structures, and was prepared under Task 4 in the referenced program (Project 2401).

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SECTION 1

INTRODUCTION

Bolted joints are a prime means of load transfer between structural parts in aircraft. Compared to other joining methods (bonding, welding, etc.), mechanical fastening is more reliable, with a potential for improved structural efficiency, maintainability and cost effectiveness. However, bolted joints are a source of stress concentration and could precipitate structural failures if they are designed improperly.

Prior to the initiation of this Northrop/AFWAL program, no analysis was available to be used as an exclusive design tool for bolted parts, especially if they were laminated composites. Consequently, their design has hitherto been based on extensive testing, empirical data and approximate analyses. The analysis developed in this Northrop/AFWAL program eliminates the need for extensive testing and provides a tool for the rapid evaluation of a bolted joint concept. If the structural part is to be fabricated using a characterized material, it eliminates the need for experimental information.

In the following sub-sections, the scope of this design guide is stated, sample bolted concepts are presented, criteria for the design of bolted joints in composite structures are discussed, the proposed design procedure is described, the analytical and experimental requirements for the design procedure are outlined, and its current restrictions are mentioned. In Section 2, general guidelines for the design of a bolted joint in composite structures are presented, along with summary statements on the effects of critical joint parameters. Section 3 presents the computer codes developed in this program for the strength analyses of single and multiple fastener joints in composites (SASCJ and SAMCJ, respectively). Section 4 demonstrates the use of the developed
analysis in predicting the strength of a realistic structural element.

1.1  Scope of the Design Guide

This design guide summarizes the effects of critical parameters on the strength and lifetime of bolted joints in composite structures, and presents general design guidelines. It also describes a test-independent analytical procedure for the strength evaluation of a bolted concept, based on the analyses developed in this program. The reader is familiarized with the computer codes (SASCJ and SAMCJ) that perform these analyses, and an application to a realistic structural bolted joint is demonstrated. This design guide will enable one to perform a rapid analytical evaluation of many joint configurations, and to select an efficient bolting concept. The described computer codes are currently restricted to uniaxial loading, conventionally used fastener spacing and protruding head fasteners.

1.2  Sample Joint Configurations

Figure 1 presents six composite-to-metal bolted joint configurations used in the F/A-18A aircraft wing (Reference 1). Figures 2 and 3 present joint configurations used in a typical fuselage structure (Reference 2). A skin-to-root fitting bolted joint in the F-20 horizontal stabilizer is shown in Figure 4. Many bolted joint concepts have been studied recently as potential alternative joining concepts for the F/A-18A wing root section and the F/A-18A vertical tail root section (Figures 5 and 6, respectively). The sample bolted configurations in Figures 1 to 6 illustrate the possible variety in this joining concept.

1.3  Overview of Design Methodology

There are many variables in the design of a bolted joint in composite structures. These include the geometry and the
Figure 1. Sample Bolted Joints in the F/A-18A Aircraft Wing (Reference 1).
Figure 2. A Bolted Joint Concept for a Fuselage Structure (Reference 2).
Figure 3. Bolted Joint Concepts for Composite Fuselage Structures (Reference 2).
Figure 5. Alternative Bolted Joint Concept Evaluated for the F/A-18A Wing Root Section (Reference 1).
material properties of the bolted parts, the size and arrangement of the fasteners, the fastener material properties and torque, applied loading and the load transfer mechanism (single versus double shear), etc. The design of a bolted joint involves a parametric study of the effects of the above variables on the joint efficiency, for a specified loading condition. A preliminary analysis of a structural component, based on conventional assumptions, yields the general biaxial loading transferred at the joint location (see Figure 7). The design procedure recommended in this guide assumes a predominantly uniaxial loading at the joint location.

The design of a uniaxially loaded joint in composite structures may be performed using the analyses developed in this Northrop/AFWAL program. Section 3 describes the use of the SASCJ and the SAMCJ computer codes for the strength prediction of single and multiple fastener joints in composites, respectively. The SASCJ code predicts the strength of joints when a single fastener transfers the applied load between the bolted plates. This analysis accounts for material nonlinearity in the bolted plates, the non-uniform fastener load distribution in the thickness direction of the bolted plates, and the progression of ply-level failures based on a choice among a few failure criteria. The SAMCJ code predicts the strength of plates bolted together by one or many fasteners. It computes the magnitude and orientation of the load at every fastener location, the applied load level for averaged stress components to reach critical levels at fastener and cut-out locations, the failure value of the applied load, the failure location and the failure mode (net section, shear-out or bearing). Failure predictions are made at the laminate level using average stress failure criteria.

The proposed design procedure involves the use of the developed analyses to evaluate the effect of joint variables on joint efficiency. If the bolted plates are fabricated using characterized materials, the joint design is tested-independent.
Computation of the Magnitude and Orientation of Load at Every Fastener Location

Failure Load and Mode at Every Fastener Location Based on Assumed Failure Criteria

Component Joint Strength

Figure 7. Overview of the Strength Analysis of Bolted Structures.
Candidate bolted joint concepts are selected following the general guidelines outlined in Section 2. The fastener size and arrangement (spacing between fasteners), the geometry of the bolted plates, the load transfer mechanism, etc. are varied without violating the constraints imposed by the structural application. The strength and durability of each bolted joint concept, along with its impact on manufacturing costs and maintenance, are evaluated to establish joint efficiency. An efficient bolted joint concept can thus be designed using a purely analytical tool on a finite number of concepts that are selected in accordance with established guidelines.

1.4 Analytical Requirements

The design of a bolted joint for composite structures requires the analyses developed in this Northrop/AFWAL program (References 6 and 7). The analysis of plates bolted together by a single fastener may be performed using the SASCJ (Strength Analysis of Single Fastener Composite Joint) or the SAMCJ (Strength Analysis of Multiple Fastener Composite Joints) computer code. Plates bolted together by many fasteners are analyzed using SAMCJ computer code. Section 3 presents a brief description of these analyses. The reader is referred to References 6 and 7 for further details.

1.5 Test Requirements

A test-independent, purely analytical design tool has been developed to design a bolted joint for composite structures that are fabricated using characterized materials. The engineering properties (Young's moduli in the fiber and transverse directions, major Poisson's ratio and the shear modulus in the fiber coordinate system), the strengths or failure strains (under tension, compression and shear), and the failure parameters for the assumed failure criteria (characteristic distances for net section, shear-out and bearing failure predictions using the average stress...
failure criteria, for example) are known for a characterized composite material (lamina). Tests required to obtain the above material properties must be performed on a new (uncharacterized) material system, prior to designing bolted joints for structural parts made from this material. When previously characterized materials are used in the bolted plates, the test requirements are nil for the design of an efficient bolted joint concept.

1.6 Current Restrictions

The design of bolted joints in composite structures is influenced by the current restrictions in the developed analytical tools. The primary restrictions are listed below:

(1) The developed strength analyses (SASCJ and SAMCJ computer codes) do not account for countersunk fastener effects.

(2) SASCJ and SAMCJ contain a stress analysis that approximates the fastener/plate contact problem by an assumed radial stress distribution.

(3) SASCJ AND SAMCJ are restricted to a uniaxial applied loading, in tension or in compression.

(4) The prediction of the durability of a joint is restricted to the incorporation of the bearing stress at critical fastener locations into experimentally obtained curves for joint life.

(5) SAMCJ restricts the user to rectangular element geometries and currently used fastener spacing and arrangement.

Despite the above restrictions, the developed analyses and the proposed design procedure mark a significant improvement
over the state-of-the-art with respect to the design and analysis of bolted joints in composite structures.
SECTION 2

GENERAL DESIGN GUIDELINES AND JOINT VARIABLES

The design of bolted joints in composite structures involves the definition of many variables. The major design considerations are listed below:

(a) The loads that must be transferred from one part to another.

(b) The load transfer location in the structure.

(c) Geometric constraints, if any, at the load transfer location.

(d) Fastener type, size and arrangement.

(e) The environmental range the joint will be exposed to.

(f) The effect of the joint concept on structural efficiency and reliability.

The following sub-sections discuss the primary variables that influence the design of bolted joints in composite structures. Design guidelines corresponding to the discussed joint parameters are highlighted within the sub-sections.

2.1 Joint Location in the Structure

The location of the joint in a structure influences the selection of the joint variables significantly. Design guidelines pertaining to selected joint locations are presented below:

(a) When aerodynamic surfaces in an aircraft structure are joined to substructural parts, or segments of a surface are joined together, the requirement of a smooth outer moldline should not be
violated. The use of protruding head fasteners on such surfaces, or
the presence of any other geometric discontinuity (step) at the
joint location, will adversely affect the lift distribution on these
surfaces and their aerodynamic performance.

On aerodynamic surfaces, fasteners must be installed to be flush with the surface, without exposed fastener heads, and joined members must retain a smooth outer moldline.

(b) When structural members are joined together in fuel-containment areas, measures must be taken to preclude leakage of the fuel and service-related hazards. The use of metallic fasteners on the outer surface, for instance, introduce the threat of arcing within the fuel cell in the event of a lightning strike. In designing joints for these locations, special consideration must be given to the mentioned sealing requirements.

In fuel containment areas, joints must be sealed to be leak-proof. Fasteners must also be sealed to prevent arcing within the fuel cell in the event of a lightening strike.

(c) When bolted joints are designed for structural regions with limited or restricted access, special fastener types have to be used.

In areas of restricted accessibility, blind fasteners must be used.

(d) When a laminated part is bolted to a metallic substructure, the threat of joint corrosion must be considered.

In composite-to-metal joint locations, corrosion barriers like fiberglass layers must be used.
2.2 Joint Configurations

Selected joint configurations are significantly influenced by their structural locations. Figures 1 to 6 present typical structural joint configurations in current aircraft. Figure 8 presents the localized structural joint configurations along with their equivalent configurations that are analyzed. The configurations that transfer loads in single shear introduce localized bending effects that could adversely affect the strength and durability of the joint. Stepped lap and scarf configurations involve thickness changes that provide an additional design variable (layup) in bolted laminates.

2.3 Joint Loading

Structural joints are designed to be effective over their design lifetime, when subjected to the anticipated design spectrum fatigue loading. The durability considerations for structural joints are discussed in Section 4. This design guide emphasizes the strength analysis of a bolted joint, and presents computer codes that perform it. The reader must supplement the joint design based on a strength analysis with a durability check, using information similar to that presented in Section 2.9. The effect of joint loading is discussed further below, at three levels -- structural, among fastener rows, and at an isolated fastener location.

2.3.1 Joint Loads at the Structural Level

Joint loads at the structural level fall into two basic categories -- inplane loads and out-of-plane or bending loads. Figure 9 presents some possible inplane load conditions in typical wing skin-to-substructure attachments. The analyses developed in this Northrop/AFWAL program, and described in Section 3, assume that the joint at each location is subjected to a predominant unidirectional load. Figure 9 illustrates that this assumption will
Figure 8. Structural and Analyzed Bolted Joint Configurations.
Figure 9. Inplane Loads in Typical Wing Skin-to-Substructure Attachments.
not be valid at some locations.

Figure 10 presents sample situations where considerable out-of-plane (bending) loads are introduced at the joint location. This is inherent in single shear load transfer configurations (see Figure 8), and adversely affects joint strength and durability. If one of the bolted plates is very stiff compared to the other, the deleterious effects of load eccentricity in a single shear configuration are minimized. In double-shear load transfer configurations (see Figure 8), the out-of-plane loads are reduced to a negligible level.

| Single-shear load transfer joint configurations introduce out-of-plane (bending) loads that could significantly reduce the strength of the joint. When one of the bolted members is very stiff, the effect of the out-of-plane loads is minimized. | (5) |
| Double-shear load transfer joint configurations essentially introduce inplane loads in the bolted plates. | (6) |

2.1.2 Load Distribution Among Rows of Fasteners

Assuming a unidirectional applied load, the fasteners in a row are arranged perpendicular to the load direction. Joint configurations affect the distribution of the applied load among the various rows of fasteners in a joint, and the distribution of the row-wise load fraction among the fasteners in any row. Hitherto, the fasteners in a row have been assumed to carry equal loads, and only the row-wise load distribution has been analytically predicted. The SAMCJ code developed in this Northrop/AFWAL program overcomes this limitation, and predicts the two-dimensional load distribution (magnitude and orientation of fastener loads at all locations) for a selected fastener pattern.
A. OUT-OF-PLANE JOINT LOADING DUE TO INTERNAL PRESSURE (e.g., FUEL PRESSURE, FUSELAGE CABIN PRESSURE, ETC.)

B. OUT-OF-PLANE JOINT LOAD DUE TO LOAD PATH ECCENTRICITY

Figure 10. Sample Joint Configurations that Introduce Significant Out-of-Plane Loads at the Joint Location.
Figure 11 presents the load distributions for two and five fastener, doubleshear joint configurations tested in this program (References 7 and 8). The bolted plates in Figure 11 were uniform in thickness. Figure 12 illustrates how the load distribution among four rows of fasteners can be varied by changing the joint configuration. In the strongest configuration (4), a combination of tapering and reinforcing of the splice plates minimizes the bearing load where the by-pass load is the largest (station 1), and maximizes the bearing load where there is no by-pass load (station 4). The plate width-to-bolt diameter ratio (W/D) is 5 at station 1, and 4 at stations 2 and 3. A larger bolt is used at station 4 (W/D=3). This results in a reduction of the bearing stresses at stations 2 to 4, and the strongest configuration (see References 9 and 10).

In bolted metallic plates, the fastener load distribution is similar to those shown in Figure 11 for low values of the applied load. But, as the applied joint load increases toward the failure value, yielding will occur at peak fastener load locations. This causes the incremental applied load to be carried by the remaining fasteners, generally resulting in a uniform fastener load distribution near failure. For the five fastener configuration in Figure 11, for example, every fastener will carry one-fifth of the applied load at failure. However, laminated plates generally exhibit a linear elastic and brittle behavior, with negligible ductility or yielding. The non-uniform load distribution among rows of fasteners in composite laminates, therefore, remains non-uniform at failure. This reduces the failure load level if the peaks in the load distribution are not accompanied by appropriate thickness tapering and other changes in the joint configuration. Joint efficiency is determined by the overall load-carrying capability of the joint.

The load distribution among rows of fasteners in a bolted laminate generally remains non-uniform at the failure load level, in contrast to what is
Note: Double-shear load transfer between 50/40/10, AS1/3301-6 graphite/epoxy laminate and aluminum using 3/16-inch diameter, protruding head steel fasteners torqued to 100 in-lb; static tension; RTD.

Figure 11. Fastener Load Distribution in the Laminated Plate for Two Double-Shear Configurations (References 7, 8).
Figure 12. Effect of Joint Configuration on Fastener Load Distribution (Reference 9).
assumed in bolted ductile metals. This adversely influences the failure load for bolted laminates, unless thickness tapering or other configuration changes are introduced.

(7)

2.3.3 Bearing and By-Pass Loads at an Isolated Fastener Location

Figure 13 illustrates the bearing and by-pass loads, and the interaction between them, at an isolated fastener location in a bolted laminate. The failure of the bolted plate is generally assumed to coincide with the failure at the most critical fastener location. The identification of the most critical fastener location requires knowledge of the load distribution among the fasteners, and an understanding of the interaction between the bearing and by-pass loads at a fastener location (Figure 13).

In ductile metals, minimal interaction is assumed between the bearing load and the by-pass load. However, in composites, a significant interaction has been demonstrated between the two loads under tensile loading (see Figure 13). Only a minimal interaction is observed under compression (see Figure 13). The open hole and bearing strengths of laminates (under tension and compression) are dependent on the laminate layup. The bearing stress at failure is also dependent on the edge distance (geometry) of the bolted laminate when its layup contains more than 40% of 0-degree plies.

Under tensile loading, an increase in the bearing stress reduces the by-pass stress value at failure in bolted laminates.

(8)

Under compressive loading, a minimal or negligible interaction between the bearing and by-pass loads is observed in bolted laminates.

(9)
Figure 13. Interaction Between Bearing and By-Pass Loads at a Fastener Location.
2.4 Failure Modes in Bolted Laminates

Bolted laminates exhibit one or more among a variety of failure modes, depending on their layup and geometry, the fastener type and the loading configuration. Figure 14 presents the basic failure modes observed in bolted laminates and possible fastener or fastener-induced failures. In the design of bolted laminates using the SAMCJ computer code, only the net section, shear-out and bearing modes of failures in the laminate are considered, and fastener-related failures are assumed to be precluded a priori. Net section and shear-out failures lead to catastrophic joint failures, while bearing failure is generally non-catastrophic. Critical, highly-loaded structural joints should, therefore, be designed to fail in a bearing mode.

Ensuring that fastener-related failures are predicted, highly-loaded structural joints must be designed to fail in a bearing mode to avoid the catastrophic failures induced by net section and shear-out modes of failure.

2.5 Fastener Type, Material and Installation Variables

In selecting fasteners for bolted composite structures, many variables have to be considered. These are briefly discussed below.

2.5.1 Fastener Type

Fasteners are available in different forms for different applications, and are broadly classified as protruding head fasteners or countersunk (flush head) fasteners. Countersunk fasteners generally have a 100 degree head angle, and are referred to as tension head or shear head fasteners based on the countersunk depth. Special fastener types include hi-lok, big foot, Jo-bolt, Eddie-bolt, k-Lobe, composite fasteners, etc. (Reference 11).
Figure 14. Basic Failure Modes in Bolted Laminates and Fastener-Related Failures.
The joint location influences the selected fastener type and introduces sealing requirements (see Section 2.1). The three guidelines corresponding to this are repeated below:

Flush head (countersunk) fasteners should be used on aerodynamic surfaces to maintain contour smoothness.

In fuel containment areas, the fastener locations must be sealed to be leak-proof and to prevent arcing in the fuel cell in the event of a lightning strike.

In areas of restricted accessibility, blind fasteners must be used.

Tension head countersunk fasteners have a larger countersunk depth than shear head countersunk fasteners. Tension head fasteners, therefore, rest over a larger area of the bolted plate, and carry the load primarily in tension along the fastener axis. Shear head fasteners have a smaller countersunk depth, and carry the load primarily in shear over the fastener cross-section. Consequently, tension head fasteners are capable of carrying larger loads than shear head fasteners. But, when the countersunk depth exceeds approximately 70% of the bolted plate thickness, the fastener effectiveness is reduced due to the local "knife edge" effect, influencing the selection of the fastener type.

Tension head fasteners are preferred over shear head fasteners when the countersunk depth is below approximately 70% of the bolted plate thickness.

2.5.2 Fastener Material
The main considerations in the selection of the fastener material are its compatibility with the bolted plate material and its mechanical properties. Galvanic corrosion is a problem when steel or aluminum is used adjacent to graphite/epoxy composites, especially in a salt spray atmosphere (see Table 1, Figure 15 and Reference 12). Titanium does not corrode when it is in contact with graphite/epoxy composites. The compatibility of other materials with graphite/epoxy composites is rated in Table 1. Consequently, titanium fasteners are preferred for use in bolted composite structures. Also, a corrosion barrier is generally introduced between bolted composite and metallic parts, if the metal is steel or aluminum (see Figure 15).

Titanium fasteners are preferred for use with graphite-reinforced composites. Steel and aluminum fasteners are not recommended for use with these composites due to their corrosion susceptibility. (12)

2.5.3 Fastener Size

The fastener size is generally selected to preclude excessive fastener bending effects that could reduce its load transfer capability and induce premature fastener failure. As a general rule, the ratio of the fastener diameter (D) to the bolted plate thickness (t) should be greater than 1 (see Figure 16).

The fastener diameter must be larger than the thickness of either bolted plate. (13)

2.5.4 Fastener Fit and Hole Quality

Structural parts that are mechanically fastened together are drilled in accordance with established process specifications. Nevertheless, the presence of flaws at fastener locations is commonplace. These flaws include improper fastener seating,
### Table 1. Galvanic Compatibility of Fastener Materials with Composites (Reference 12)

<table>
<thead>
<tr>
<th>Fastener Material</th>
<th>Compatibility with Graphite/epoxy Composites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titanium and its alloys</td>
<td>Very Good</td>
</tr>
<tr>
<td>MP-35N, INCO 600 (Nickel, Cobalt alloys)</td>
<td>Good</td>
</tr>
<tr>
<td>A286, PH13-8MO (Molybdenum alloys)</td>
<td>Acceptable</td>
</tr>
<tr>
<td>Monel</td>
<td>Marginal</td>
</tr>
<tr>
<td>Low Alloy Steel</td>
<td>Not Compatible</td>
</tr>
<tr>
<td>Silver Plate, Chrom. Plate</td>
<td>Adequate with/A286, PH13 13-8MO</td>
</tr>
<tr>
<td>Cadmium or Zinc Plate</td>
<td>Not Compatible</td>
</tr>
<tr>
<td>Aluminum of Magnesium Alloys</td>
<td>Not Compatible</td>
</tr>
</tbody>
</table>

**Figure 15.** Galvanic Compatibility and Corrosion Prevention.
Figure 16. Effect of Fastener Size on the Load Distribution (Reference 6).
cratering of the hole boundary, broken and separated fibers at the drill exit side, delaminations near the exit surface, and a slight tilt (<10 degrees) in the hole axis away from the normal to the bolted plate (Reference 13). Interference fit of fasteners will also affect hole quality and influence the efficiency of the joint. The effects of interference fits and fastener hole flaws were studied in Reference 13 (see Table 2). A summary of the results is presented below:

| Interference fastener fits (up to 0.008 inch of interference) induce negligible tensile strength losses. Nevertheless, they are generally not recommended due to installation problems and their effect on hole quality. | (14) |
| If the countersunk fastener seating (assuming 50% of the bolted plate thickness to be the nominal countersunk depth) is increased beyond 80% of the bolted plate thickness, the joint strength is decreased considerably (20 to 50%). | (15) |
| If the countersunk hole axis is at least 10 degrees away from the normal to the bolted plate, significant joint strength losses result (over 20% for a 10 degree tilt). | (16) |
| Other flaws (exit side broken fibers and delaminations, less than a moderate level of porosity in bolted laminates, holes offset by less than 0.005 inch, etc.) at fastener locations introduce negligible joint strength losses (<10%). | (17) |

2.5.5 **Fastener Torque-Up**

Static and fatigue tests on composite-to-metal joints
### Table 2. Effects of Flaws at Fastener Hole Locations (Reference 13).

<table>
<thead>
<tr>
<th></th>
<th>Percent Change in Strength*</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>COMPRESSION</td>
<td>TENSION</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RTW</td>
<td>250W</td>
<td>RTD</td>
</tr>
<tr>
<td><strong>Out-of-round Holes</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• 50/40/10 Laminate</td>
<td></td>
<td></td>
<td>&lt;2.0</td>
</tr>
<tr>
<td>• 30/60/10 Laminate</td>
<td></td>
<td></td>
<td>&lt;4.8</td>
</tr>
<tr>
<td><strong>Broken Fibers Exit Side of Hole</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Severe</td>
<td>-12.2</td>
<td>12.2</td>
<td>-9.5</td>
</tr>
<tr>
<td>• Moderate</td>
<td>&lt;2.0</td>
<td></td>
<td>-4.9</td>
</tr>
<tr>
<td><strong>Porosity Around Hole</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Severe</td>
<td>-12.1</td>
<td>32.8</td>
<td>&lt;2.0</td>
</tr>
<tr>
<td>• Severe with Freeze-Thaw</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Moderate</td>
<td>-13.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Moderate with Freeze Thaw</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Porosity Around Hole</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Improper Fastener Seating Depth (50% of Normal)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• 80% Thickness</td>
<td></td>
<td></td>
<td>-23.2</td>
</tr>
<tr>
<td>• 100% Thickness</td>
<td></td>
<td></td>
<td>-56.9</td>
</tr>
<tr>
<td><strong>Tilted Countersinks</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Away from Bearing Surface</td>
<td></td>
<td></td>
<td>&lt;2.0</td>
</tr>
<tr>
<td>• Toward Bearing Surface</td>
<td></td>
<td></td>
<td>&lt;2.0</td>
</tr>
<tr>
<td><strong>Interference Fit Tolerances (Inch)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• 50/40/10 @ 0.000</td>
<td></td>
<td></td>
<td>&lt;2.0</td>
</tr>
<tr>
<td>• 0.000</td>
<td></td>
<td></td>
<td>&lt;2.0</td>
</tr>
<tr>
<td>• 30/60/10 @ 0.000</td>
<td></td>
<td></td>
<td>&lt;2.0</td>
</tr>
<tr>
<td>• 0.000</td>
<td></td>
<td></td>
<td>&lt;2.0</td>
</tr>
<tr>
<td><strong>Fastener Removal and Reinstallation</strong></td>
<td></td>
<td>2.4</td>
<td>#2.0</td>
</tr>
<tr>
<td>• 100 Cycles</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* RTD - Room Temperature, Dry; RTW - Room Temperature, Wet; 250W - 250°F, Wet; Wet - 0.86% Moisture by Weight.
were conducted in Reference 13, varying the fastener torque-up value from 0 in-lb to 150 in-lbs. Fastener torque-up significantly improved the static strength of the joint (15 to 30%), and its fatigue life at a selected stress level. Similar results were observed in Reference 14. Under fatigue loading, the torque-up inhibits the initial growth of local failures in the joint, and the results in a more abrupt fatigue failure due to excessive hole elongation than a joint with no applied torque.

Fastener torque-up increases the static strength of a joint and its fatigue life at a selected stress level. (18)

2.6 Bolted Laminates Properties

The basic material and its layup (stacking sequence) in bolted laminates influence the joint performance considerably. When graphite/epoxy laminates are bolted to metallic substructures, galvanic corrosion must be addressed (see Figure 15 and Table 1). For example, a corrosion barrier like a glass/epoxy layer must be used between graphite-reinforced composites and aluminum substructures.

When graphite-reinforced composites are bolted to metallic substructures, corrosion barriers must be introduced if the metal is not compatible with the composite material (see Table 1). (19)

The bolted laminate layup is generally denoted by the percentages of plies with fiber orientations of 0, + or -45 and 90 degrees, with respect to the primary loading direction, for most structural laminates. The envelope within which a bearing failure mode and the maximum bearing strength are realized is shown in Figure 17. Within this envelope, the strength is independent of the actual stacking sequence. This assumes a laminate width-to-fastener diameter ratio (W/D) of at least 4, and an edge distance (E) of at
Figure 17. The Envelop of Bolted Laminate Layups for Realizing a Bearing Mode of Failure and the Maximum Bearing Strength (Reference 10).
least 3D. When the percentage of 0 degree plies exceeds 40, a shear-out mode of failure is introduced, reducing the bearing stress value at failure. Section 2.7 presents the effects of fastener spacing and the geometry of a bolted plate on its strength.

The bearing strength of a laminate is maximum when it contains less than 10% each of 0, + or -45 and 90 degree plies. The corresponding failure occurs in a bearing mode. (20)

In addition, the individual plies must be arranged such that adjacent plies have different fiber orientations. If the stacking sequence contains groups of plies with identical fiber orientations, delamination-related failures will occur and reduce the joint strength.

Plies with different fiber orientations should be interspersed within the laminate, to the maximum possible extent, to minimize delamination-induced strength losses. Group of identical plies should not exceed 0.02 inch in thickness. (21)

2.7 Fastener Spacing and Arrangement

The geometrical parameters that define the fastener spacing and the fastener arrangement in a bolted plate are illustrated in Figure 18. E is the edge distance, $S_L$ and $S_T$ are the fastener spacings in the loading and transverse directions, and $W = S_T$ for a single fastener joint. The effects of these geometrical parameters were studied in References 8, 13 and 14. The results are summarized below:

The bearing and net section strengths decrease when the fastener size increases (see Figure 19). (22)
PREDOMINANT LOAD DIRECTION

Figure 18. Geometrical Parameters for a Bolted Plate.
NOTE: 20-Ply, 50/40/10, AS1/3501-6 Layup; 0.31 in. Aluminum Plate; Torque = 100 in-lbs, E/D = 3, W/D = 6, Protruding Head Steel Fasteners; RTD; Net Section Strength = 1.2 x Gross Strength

Figure 19. Effect of Fastener Size on the Tensile Response of Composite-to-Metal Joints in Single Shear.
significantly when E/D is reduced below 3 (see Figure 20). A bearing mode of failure is observed only when E/D>4, and the percentage of 0 degree plies is less than 40. A shear-out mode of failure results when E/D<3, or when the percentage of 0 degree plies is >40.

The bearing stress at failure decreases significantly when S /D (W/D for a single-fastener joint) is reduced below 4 (see Figure 21). When E/D>3, W/D>4, and the percentage of 0 degree plies is below 40, a bearing mode of failure occurs. When W/D<4, a net section failure occurs in the same laminate.

When the fastener spacing in the loading direction (S_L/D) is decreased below 4, the joint strength decreases due to stress concentration interaction (see Figure 22). The same effect is observed with S_T/D (see Figure 21).

In summary, ensure that D/t>1, E/D>3, W/D (S_T/D)>4, S_L/D>4, and the percentage of plies in any orientation is <40, to achieve a bearing failure mode and to realize the maximum joint strength.

2.8 Joint Tailoring for Maximum Efficiency

The design of a joint should achieve the following objectives to be considered efficient: (1) It should be capable of transferring the design ultimate loads without failing any member; (2) It should possess the design life when subjected to the design spectrum fatigue loading; (3) It should be the least weight design that meets (1) and (2); and (4) The complexity of the design concept
NOTE: Composite-to-metal joints in single shear; 20-ply AS1/3501-6 layups; 0.31 in. aluminum plate; W/D = 6, Torque = 100 in-lbs; Protruding Head, steel fastener; D = 6/16 in.

Figure 20. Effect of E/D on the Bearing Strength of Bolted Laminates.
NOTE: Composite-to-metal joints in single shear; 20-ply, AS1/3501-6 layup; 0.31 in. aluminum plate; E/D = 3; Protruding head steel fastener; D = 5/16 in.; Torque = 100 in-lbs

Figure 21. Effect of W/D on the Bearing Strength of Bolted Laminates.
Figure 22. Effect of $S_L/D$ on the Strength of Bolted Laminates.

Note: Composite-to-metal, two fasteners-in-a-row joint; 20-ply, 50/40/10 layup; AS1/3501-6 graphite/epoxy; 0.31 in. aluminum plate, single shear; RTD; static tension; $S_{\text{u}}/D=6$; protruding head steel fastener; $D=5/16$ in.; $T=100$ in-lbs.
should be controlled to aid producibility and maintainability of the structural joint.

A joint can be tailored to improve its efficiency. For example, when the number of fastener rows (a row being perpendicular to the primary loading direction) is increased, the peak load fraction is generally carried by the innermost or outermost fastener row (see Figures 11 and 12). If the failure mode at the critical fastener location is bearing or net section, the thickness and width of the bolted plate at that location will influence the joint failure load. In an efficient design, the width and the thickness of the bolted plates will be tailored such that every fastener location is equally critical (see Figure 5). The peak bearing stress at the design ultimate load level will be lowered to a level that ensures a minimal bearing/by-pass interaction, if possible (see Figure 13).

Some experimental concepts have also been demonstrated to be efficient joint tailoring concepts, despite the difficulty they introduce in applying the concept at the production level. An example is shown in Figure 23, where the 0 degree plies in the bolted skin are replaced by + and -45 degree plies in the joint region (Reference 15). This causes a smaller fraction of the running load to be transferred at the joint location, and also increases the local bearing strength. An alternative, equivalent concept would be to replace the stiffer material by a tougher material at the joint location. For example, graphite/epoxy plies can be replaced by aramid fiber/epoxy plies at the joint location. It is reiterated, though, that these validated tailoring concepts are difficult to implement in a production environment.

The geometry of bolted laminates must be tailored, in the width and thickness directions, to render every fastener location equally critical. (27)
Figure 23. A Sample Tailored Joint.
2.9 **Durability Considerations**

The design of a bolted joint is currently based on an assumed design ultimate load level and a static strength analysis (see Section 3). The assumed design ultimate load level should account for durability considerations also. Generally, irrespective of the static failure mode, a bolted joint suffers fatigue failure via excessive hole elongation (bearing). This possible change in the failure mode from the static loading case to the fatigue loading case has been observed by many in the literature (see References 13 and 14).

If the joint statically fails in a bearing mode, it could suffer premature excessive hole elongation (fatigue failure) when subjected to the spectrum fatigue loading. Figures 24 and 25 present sample constant amplitude fatigue test results from Reference 14 for a fully reversed loading case (R=-1). Similar results should be used to approximately and conservatively estimate the fatigue life of a joint using a fatigue analysis (Miner's rule, for example). Based on the fatigue analysis, the bearing stress at the critical fastener location should be designed to be sufficiently lower than the static bearing strength, to ensure the design life of the joint. The final joint design, therefore, will be capable of statically transferring the design ultimate load, with the peak bearing stress value ensuring the design fatigue life.
Figure 24. Effect of Maximum Cyclic Bearing Stress on the Number of R=1 Fatigue Cycles to Cause Specified Hole Elongations in a Bolted Laminate.
Figure 25. Effect of Maximum Cyclic Bearing Stress on the Hole Elongation Rate for a Bolted Laminate under R=1 Loading.
SECTION 3

STRENGTH ANALYSIS OF BOLTED COMPOSITE STRUCTURES

As mentioned in Section 1.4, two computer codes were developed in this Northrop/AFWAL program to predict the strength of bolted joints containing a single fastener (SASCJ and SAMCJ) or multiple fasteners (SAMCJ). Most of the structural joints contain multiple fasteners, and SAMCJ is adequate for the design of these joints. SAMCJ is also capable of predicting the strength of single fastener joints, without accounting for the nonlinear joint load versus deflection behavior introduced by ply level failures. However, if the user wishes to interrogate an isolated fastener location, accounting for the nonlinear joint behavior due to progressive (two-stage) ply failures, the SASCJ code is useful. The reader is referred to References 6 and 7 for detailed descriptions of the SASCJ and SAMCJ analyses, respectively.

In the following sub-sections, brief descriptions of the analyses in the SASCJ and SAMCJ computer codes are presented, along with detailed instructions for the use of these analytical design tools.

3.1 Description of SASCJ Analysis

A two-dimensional anisotropic plate analysis that accounts for finite plate dimensions (FIGEOM), and a finite difference fastener analysis (FDFA), are incorporated into a progressive failure procedure to develop a strength analysis for single fastener joints in composite structures (SASCJ). An isolated fastener location in a bolted structures (see Figure 7) is primarily subjected to the loading shown in Figure 26. The general bolt bearing/by-pass situation can be analyzed as a superposition of an unloaded hole situation and a fully loaded hole situation (see Figure 26). The unloaded hole case is analyzed using the two-dimensional plate analysis (FIGEOM), and does not involve the
Figure 26. Schematic Representation of a General Single-Fastener Situation as a Superposition of Unloaded and Fully Loaded Hole Situations.

\[ P_{\text{bolt}} = \alpha P_{\text{total}} \]

\[ P_{\text{by-pass}} = (1 - \alpha) P_{\text{total}} \]
3.1.1 Strength Analysis Procedure for Fully-Loaded Holes

The strength of laminates with fully loaded holes is predicted using the procedure outlined in Figure 27. A two-dimensional stress analysis (FIGEOM), accounting for finite dimensions of the bolted plates, is initially performed on each bolted plate. Computed plate stresses are used to calculate the effective moduli of the various ply types in each bolted plate (see Reference 6). The inplane strains computed by the FIGEOM code are used to obtain the stress state in each ply. The ply stresses around the hole boundary are integrated to yield the bearing load in each ply (see Reference 6). The inplane stresses in each ply, per unit bearing load, are incorporated into selected failure criteria to compute the ply (bearing) loads corresponding to the various inplane failure modes.

The effective moduli and the ply bearing loads corresponding to the various failure modes, for all the plies in each bolted plate, are incorporated into the fastener analysis. The initial fastener analysis on the undamaged plates computes the distribution of the applied bearing load among the various plies. Comparing these ply loads with the stored failure values for inplane ply failures, the joint load corresponding to the earliest ply failure is obtained. The fastener analysis also computes approximate shear strain values at the interfacial locations between adjacent plies. Incorporating these into an interlaminar failure criterion, the joint load corresponding to the earliest interlaminar failure (delamination) is obtained. The smaller of the two joint loads, corresponding to the earliest inplane and interlaminar
Figure 27. Flowchart for the Strength Analysis of Laminates with Fully Loaded Holes.
failures, determines the first failure in a bolted plate and the corresponding joint load value.

The effective moduli of the damaged plies are reset to appropriately represent the predicted failure modes. The revised moduli are incorporated into the fastener analysis, and the procedure is repeated to predict the next failure mode and the corresponding joint load. When any ply is predicted to fail totally, the analysis computes the redistribution of the corresponding joint load among the remaining effective plies, and determines if any other concomitant ply failure is precipitated. This process is repeated until one of the bolted plates becomes ineffective in transferring the applied load (joint failure).

The SASCJ computer code is restricted to protruding head fasteners, and assumes that fastener failure is precluded. However, when a countersink fastener is specified, SASCJ assumes an appropriate boundary condition at the head location, and expects the user to input an equivalent (larger) uniform fastener diameter. It can analyze any combination of laminated and metallic plates, bolted together in a single-lap or double-lap configuration.

3.1.2 Strength Analysis Procedure for Partially-Loaded Holes

A general fastener location in a bolted plate transfers a fraction \( a \) of the total applied load via the fastener, the remainder \( (1-a) \) being by-passed to the next fastener location (see Figures 7 and 26). In this case, the stress state at the fastener location is computed as a superposition of the stress states corresponding to the unloaded and fully-loaded hole situations. Figure 28, for example, presents a schematic representation of how the averaged stresses are obtained to predict net section, shear-out and bearing failures in the plies using average stress failure criteria. For a unit applied load, the averaged stresses in the laminate with an unloaded hole, when subjected to a load of \( (1-a) \), and the averaged stresses in the laminate with a fully loaded hole,
Figure 28. Strength Analysis of Laminates with Partially-Loaded Holes using Average Stress Failure Criteria.
when subjected to a load of $\alpha$, are computed separately and added. Incorporating the combined averaged stresses into the appropriate failure criteria, the applied load corresponding to a ply failure is computed.

In the case of fully loaded holes, progressive failure prediction involves the repetition of the fastener analysis with revised ply properties after every ply failure. The two-dimensional analysis (FIGEM) is only carried out once. But, in the case of partially loaded holes, a ply failure will affect the unloaded and the fully loaded hole contributions to the local stresses. Hence, progressive failure prediction in the partially loaded case involves repeating FIGEM and FDFA analyses after total ply failures.

3.1.3 In-plane Failure Criteria

The SASCJ code permits the user to select any of the following five failure criteria for the prediction of ply failures based on inplane stresses and strains: (1) point stress failure criterion, (2) average stress failure criterion, (3) maximum (fiber directional) strain criterion, (4) Hoffman criterion, and (5) Tsai-Hill criterion. The first two criteria predict three modes of failure in each ply—net section, shear-out and bearing. The maximum strain criterion predicts ply failure based on fiber failure. The Hoffman and Tsai-Hill criteria predict ply failure accounting for biaxial stress interaction that is ignored by the first three criteria.

The point stress failure criterion predicts net section, shear-out and bearing failures when the appropriate stress components at selected locations attain unnotched specimen failure values (see Figure 29). $a_{ons}$, $a_{oso}$ and $a_{obrg}$ are called characteristic distances. When $\sigma_x (0, D + a_{ons})$ exceeds the unnotched tensile or compressive strength of the ply, as appropriate, a net section ply failure is predicted. When $\tau_x (D + a_{obrg} - 0)$ exceeds the unnotched compressive strength of the ply, a bearing mode of ply failure is
The $\sigma_x$ value at this location determines net section failure.

The $\tau_{xy}$ value at this location determines shear-out failure.

The $\sigma_x$ value at this location determines bearing failure.

Figure 29. The Characteristic Distances used in the Point Stress Failure Criteria.

\[ D/2 + d_{ons} \]
\[ \int \sigma_x(o,y) dy \] determines net section failure.

\[ D/2 \]
\[ \int \tau_{xy}(x,D/2) dx \] determines shear-out failure.

\[ d_{os} \]
\[ \int \sigma_x(x,0) dx \]

\[ D/2 + d_{obrg} \]
\[ D/2 \]
determines bearing failure.

Figure 30. The Characteristic Distances Used in the Average Stress Failure Criteria.
predicted. When \( \tau_{xy} (a_{osu}, D/2) \) exceeds the unnotched ply shear strength, a shear-out mode of ply failure is predicted. The average stress failure criterion predicts these failures based on averaged values of the mentioned stress components over selected characteristic distances \( (d_{ono}, d_{oso}, \text{ and } d_{obos}) \) that are larger in magnitude compared to those used in conjunction with the point stress criterion (see Figure 30).

Of the three ply failure modes, only the net section mode causes the ply to become almost ineffective (total failure). The bearing node of failure causes the ply to suffer a reduction in its effective modulus without losing its load-carrying capacity. The shear-out mode of failure causes a ply to become ineffective only when it is delaminated from the adjacent plies. When a ply suffers any of the above failures, its load versus deflection response is at the knee of the bilinear representation in Figure 31. The damaged ply can carry additional load until total ply failure precipitated. The SASCJ computer code automatically stores the damage state in every ply in the bolted plates, and reassigns values for ply moduli to appropriately represent predicted ply failures. When a ply suffers total failure, its modulus is set equal to zero, and the redistribution of the joint load among the remaining plies is computed. A typical overall load versus deflection behavior of the joint is shown in Figure 32, indicating the effects of local or total ply failures.

The maximum strain (fiber directional), Hoffman and Tsai-Hill criteria are applied along a path that is concentric to the fastener hole, at a characteristic distance \( (a_e) \) from the hole boundary (see Figure 33). The location along this path where the selected criterion is satisfied determines the failure location. The maximum strain criterion predicts fiber failure in a ply (total ply failure) when its fiber directional strain exceeds the failure values \( (\epsilon_{tu}^{u} \text{ or } \epsilon_{cu}^{u}) \).

The Hoffman failure criterion, based on inplane ply
\[ K_2 = aK_1 \]

\[ p_{\text{ULTIMATE}} = \beta p_{\text{INITIAL}} \]

\[ q_i = \frac{p_i}{h_i} \]

**Figure 31. Bilinear Elastic Behavior of a Ply.**
Figure 32. A Schematic Representation of the Overall Load Versus Deflection Response of the Joint.

Figure 33. The Characteristic Distance ($a_0$) Defining the Region Where the Maximum Strain, Hoffman or Hill Criterion is Applied.
stresses, states that total ply failure will occur when the failure index \( H \) in the following equation reaches a value of unity:

\[
\begin{align*}
\sigma_1^2 - \sigma_2^2 & = \frac{\sigma_1 (X_c - X_t)}{X_c} X_t + \frac{\sigma_2 (Y_c - Y_t)}{Y_c} Y_t + \frac{\sigma_0^2}{S^2} - H
\end{align*}
\]

In the above equation, \( \sigma_1, \sigma_2 \) and \( \sigma_0 \) are the ply stresses in the fiber coordinate system, \( X_t \) and \( X_c \) are the uniaxial tensile and compressive material strengths along the fiber direction (1), \( Y_t \) and \( Y_c \) are the uniaxial tensile and compressive material strengths perpendicular to the fiber direction (2), and \( S \) is the material shear strength in the 1-2 plane.

In the SASCJ code, the Hoffman criterion is applied along a path that is concentric to the fastener hole, defined by the characteristic distance \( a_0 \) (see Figure 33). At selected points along this path, the following expressions for the failure values of the ply load \( P_f \) are computed:

\[
P_f = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}
\]

where

\[
\begin{align*}
a & = \left[ \frac{(\sigma_1^2 - \sigma_2^2) X_c X_t + \sigma_2^2 Y_c Y_t + \sigma_0^2 S^2}{S^2} \right] / P_1^2 \\
b & = \left[ \frac{(X_c - X_t) \sigma_1 X_c X_t + (Y_c - Y_t) \sigma_2 Y_c Y_t}{S^2} \right] / P_1 \\
c & = -1, \text{ and}
\end{align*}
\]

\( P_1 \) = ply load at which \( \sigma_1, \sigma_2 \) and \( \sigma_0 \) are computed.
The location where the smallest non-negative value for $P_f$ is computed identifies the failure initiation point.

The Hoffman criterion predicts total ply failure and the failure location, but does not identify the mode of failure. The failure location, though, generally indicates the possible failure mode. Referring to Figure 33, if failure is predicted near $\theta = 0^\circ$, a bearing mode of failure is suspected. If the failure location is near $\theta = 90^\circ$, a net section mode of failure is suspected. And, intermediate values of $\theta$ indicate a shear-out mode of failure. The Tsai-Hill criterion can be obtained from the Hoffman criterion by setting $X_t = X_c$ and $Y_t = Y_c$. This criterion, therefore, does not account for different strengths under tension and compression. The ply failure load ($P_f$) in this case is computed to be $1/\sqrt{a}$.

3.1.4 Interlaminar Failure Criterion

Delamination between plies is predicted by incorporating computed shear strains at the interfacial locations into a maximum shear strain criterion. At the interface between plies $i$ and $j$, for example, the shear strain is computed to be:

$$\gamma_{xz}^{i-j} = (u_i^j - u_j^i) / h_0$$

where $h_0$ is the ply thickness in the plate containing plies $i$ and $j$. This expression for the shear strain is approximate. Plies $i$ and $j$ are assumed to delaminate when $\gamma_{xz}^{i-j}$ exceeds a failure value. The failure value for $\gamma_{xz}^{i-j}$ is determined by correlating predictions with observations for a sample test case.

3.2 SASCJ Input Description

SASCJ assumes a uniaxial tensile or compressive load to
be applied to a single fastener bolted joint, in a single or a double shear configuration (see Figures 34 and 35). The code requests information for a general bearing/by-pass situation. If the joint is a symmetric double shear configuration, only half the joint is analyzed (see Figure 35). For example, if plate 2 in Figure 35 is metallic, the input thickness should be half the actual value, and if plate 2 is a laminate, only the layup from the surface to its midplane should be input. The analysis accounts for the joint symmetry through appropriate symmetry conditions at the midplane location (see Figure 35).

A sample SASCJ problem is now presented to describe the input requirements for the code. It addresses a steel-to-composite joint in a single shear configuration (see Figure 34). The input is requested by SASCJ in an interactive mode. Figure 36 presents the code requests and the user replies for the sample joint. Though the information in Figure 36 is self-explanatory, a description of the input quantities is presented below.

The first input quantity specifies that the problem addresses a bearing/by-pass situation with a by-pass ratio of 0.99 -- nearly an open hole situation. The second and third input quantities specify that a static tensile load is applied in a single shear configuration. Subsequently, the two bolted plates are specified to be either a composite laminate or a metal. If the bolted plate is a laminate, SASCJ requests the user to specify the number of plies in that plate (20). Note again that, for a double shear configuration, only half the thickness of the second plate should be defined (see Figure 35). SASCJ then requests the user to specify the thickness of the metallic plate (0.25). For the laminated plate, SASCJ requests, in sequence, the average cured ply thickness (0.006), the number of distinct ply orientations (4), definition of the four orientations (0.0, +45.0, -45.0 and 90.0), and the laminate stacking sequence -- ([45/0/-45/0]_2/0/90). SASCJ automatically assumes a metallic plate to be divided into thirty identical layers. The number of layers in a laminate is controlled.
Figure 34. SASCJ Analysis of a Joint in Single Shear.
Figure 35. SASCJ Analysis of a Joint in Double Shear.
Figure 36. Sample SASCJ input.
Figure 36. Sample SASCJ Input (Continued).
TO AVOID LENGTHY RUN TIMES DUE TO
STRESS FIELD RECOMPUTATION SPECIFY THE
NUMBER OF ULTIMATE PLY FAILURES AFTER
W/ J-OINT FAILURE WILL BE PREDICTED.
ENTER: NO. OF ULTIMATE FAILURES

20
ENTER NO VALUES CORRESPONDING TO THE THREE
PLY FAILURE MODES IN PLATE NO.

DNY = NET SECTION
DNYR = BEARING
DNYO = SHEAR OUT
INPUT DNY, DNYR, DNYO

0.1 0.025 0.00 F

FOR PLATE NUMBER 1 ENTER THE THREE STRENGTHS
REQUIRED TO PREDICT THE THREE FAILURE MODES
FSC = UNNOTCHED STRENGTH IN TENSION
FUSC = NOTCHED STRENGTH IN COMPRESSION
FSO = UNNOTCHED STRENGTH IN SHEAR-OUT

INPUT FSC,FSC,FSC

250.043 300.042 200.043

FOR PLATE NO. 2 ENTER FIBER ULTIMATE
STRAIN VALUES

EPSILON ULT IN COMPRESSION
EPSILON ULT IN TENSION
EPSILON ULT IN SHEAR

(UNITS: KN/IN)

0.01 0.011 0.012

SASCJ ASSUMES A BILINEAR PLY BEHAVIOR, THE
INITIAL MODULUS, K1, IS COMPUTED BY THE CODE.
The REduced modulus, K2, FOR INITIAL FAILURE IN NET SECTION, SHEAROUT OR BEARING IS COMPUTED
BY THE FORMULA K2=ALPHAKE.

FOR PLATE NUMBER 1 INPUT ALPHA VALUES FOR
NET SECTION, SHEAROUT AND BEARING FAILURE

0.1 0.1 0.1

INPUT SCALE FACTORS FOR P ULTIMATE
CALCULATION SUCH THAT PULT=BETAMULT(INITIAL)
INPUT BETAI FOR NET SECTION ULTIMATE
BETAI FOR BEARING ULTIMATE
BETAI FOR SHEAROUT ULTIMATE

1.62 1.5 1.12

SASCJ ASSUMES A BILINEAR PLY BEHAVIOR, THE
INITIAL MODULUS, K1, IS COMPUTED BY THE CODE.
The REduced modulus, K2, FOR INITIAL FAILURE
IN NET SECTION, SHEAROUT OR BEARING IS COMPUTED
BY THE FORMULA K2=ALPHAKE.

FOR PLATE NUMBER 2 INPUT ALPHA VALUES FOR
NET SECTION, SHEAROUT AND BEARING FAILURE

0.1 0.1 0.1

INPUT SCALE FACTORS FOR P ULTIMATE
CALCULATION SUCH THAT PULT=BETAMULT(INITIAL)

Figure 36. Sample SASCJ Input
(Concluded)
by the user. In Figure 36, each physical ply is modeled as one layer. For this sample problem, for example, the user could also specify each physical ply to be divided into two identical plies, by setting the number of plies in the laminate to be 40, the cured ply thickness to be 0.003 inch, and repeating each ply orientation in the stacking sequence twice.

Subsequent to the above information, SASCJ requests the material properties for plates 1 and 2 (Young's modulus and Poisson's ratio for a metal, and Young's modulus, shear modulus and the major Poisson's ratio for each lamina, in the fiber coordinate system). The fastener modulus, Poisson's ratio, diameter and head type (protruding head or countersunk) are requested next. Following that, the geometry of the bolted plates is defined by specifying the coordinates for the plate corners, assuming that the origin is located at the center of the fastener hole.

The last block of data addresses the selected failure criterion and the corresponding failure parameters. In the sample problem in Figure 36, the average stress failure criteria are selected for failure prediction (4). The characteristic distances for net section, bearing and shear-out modes of failure are then specified for the two plates. This is followed by the unnotched strengths for the two plates under tension, compression and inplane shear. Next, SASCJ requests the parameters that define the bilinear material behavior. These are the factors that define the modulus change after initial failure, and the ratio of the ultimate ply failure load to the initial ply failure load. Different factors may be specified for the three failure modes. Finally, the approximate ultimate shear strain value is requested for delamination prediction. A large value is generally specified for a metallic plate, to preclude the prediction of delaminations that are not applicable to these materials.
For the sample problem defined in Figure 36, SASCJ provides the output shown in Figure 37. The input data for the bolted plates is initially reproduced for user verification. Subsequently, the sequence of failures in the bolted laminate and the corresponding joint load levels are printed. Note that the ultimate failure of a ply (shear-out of the 45 degree plies) does not necessarily imply joint failure. In the considered sample problem, shear-out of the 0 degree plies limits the load-carrying capacity of the joint. Every ply suffers a two-stage failure as described before (Figure 31).

When executed in some systems, SASCJ could yield underflow messages after many plies have suffered total failure. This may occur when the double precision format is not followed in entering input data. Nevertheless, the user is advised to ignore these messages.

3.4 Description of SAMCJ Analysis

This section presents an overview of the strength analysis in the SAMCJ computer code, a description of the developed special finite elements, and the analytical procedure used in SAMCJ to predict fastener loads, the critical fastener or cut-out location, the corresponding joint strength and the failure mode.

A flow chart of SAMCJ operations is presented in Figure 38. As input, SAMCJ requires the user to specify how the bolted plates are divided into plain elements and elements with loaded or unloaded holes. The bolted plates are currently assumed by SAMCJ to be subjected to uniaxial tensile or compressive loading, in a single or double shear configuration. Additional input requirements for the SAMCJ code include the material properties of the bolted plates and fasteners, and the fastener size, location and torque. The material properties of the bolted laminates include the tensile and compressive failure strains in the fiber direction of the lamina, and the characteristic distances over which stresses are averaged to
PROGRAM SASCI

A SINGLE LAM SHEAR JOINT WILL BE ANALYZED
WITH A PARTIALLY LOADED HOLE
PLATE NO 1
STEEL
T = 0.2500 + 0.00 INCHES
MATERIAL PROPERTIES
E1 = 30.000 + 0.00 PSI
E2 = 30.000 + 0.00 PSI
G12 = 115.000 + 0.00 PSI
NU12 = 300.000 + 0.00
N21 = 300.000 + 0.00
PLATE NO 2
A51/3501-6 ((45/0/-45/0)12/0/0/0)
T = 0.1200 + 0.00 INCHES
MATERIAL PROPERTIES
E1 = 1050 + 0.00 PSI
E2 = 1050 + 0.00 PSI
G12 = 250 + 0.00 PSI
NU12 = 300 + 0.00
N21 = 300 + 0.00
STEEL
FASTENER DIAMETER = 0.3130 + 0.00 INCHES
MATERIAL PROPERTIES
E = 29.000 + 0.00 PSI
NU = 29.000 + 0.00

FAILURE ANALYSIS
AN AVERAGE STRESSES CRITERION WILL BE USED
PLATE NUMBER 1
LAMINATE STRENGTH

NET SECTION ULTIMATE (TEN) = 0.2500 + 0.00 PSI
NET SECTION ULTIMATE (COMP) = 0.3000 + 0.00 PSI
PLATE ULTIMATE = 0.3000 + 0.00 PSI
SHEAROUT ULTIMATE = 0.3000 + 0.00 PSI

CHARACTERISTIC DISTANCES
AOMT = 0.2000 + 0.00 INCHES
AOMB = 0.4000 + 0.00 INCHES
AOS = 0.5000 + 0.00 INCHES

PLATE NUMBER 2
LAMINATE STRENGTH
NET SECTION ULTIMATE (TEN) = 0.1200 + 0.00 PSI
NET SECTION ULTIMATE (COMP) = 0.1500 + 0.00 PSI
BEARING ULTIMATE = 0.1500 + 0.00 PSI
SHEAROUT ULTIMATE = 0.5000 + 0.00 PSI
CHARACTERISTIC DISTANCES
AOMT = 0.1000 + 0.00 INCHES
AOMB = 0.2500 + 0.00 INCHES
AOS = 0.3500 + 0.00 INCHES

GEOMETRY OF PLATE NO 1
COORDINATES OF CORNER VERTEXES
(-3.000, 0.000, 3.000, 0.000)
(-3.000, -0.000, 3.000, -0.000)
FASTENER HOLE DIAMETER = 0.3130 + 0.00 INCHES
E/D RATIO = 0.9000 + 0.01
W/D RATIO = 0.6000 + 0.01

GEOMETRY OF PLATE NO 2
COORDINATES OF CORNER VERTEXES

Figure 37. SASCI Output for the Problem Defined in Figure 36.
<table>
<thead>
<tr>
<th>LOAD</th>
<th>JOINT LOAD</th>
<th>NODE</th>
<th>PLY TYPE</th>
<th>LOAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
<td>0.672094</td>
<td>30</td>
<td>.0 DEGREE</td>
<td>NSU</td>
</tr>
<tr>
<td>27</td>
<td>0.672094</td>
<td>39</td>
<td>.0 DEGREE</td>
<td>NSU</td>
</tr>
<tr>
<td>28</td>
<td>0.672094</td>
<td>38</td>
<td>.0 DEGREE</td>
<td>NSU</td>
</tr>
<tr>
<td>29</td>
<td>0.672094</td>
<td>37</td>
<td>.0 DEGREE</td>
<td>NSU</td>
</tr>
<tr>
<td>30</td>
<td>0.672094</td>
<td>36</td>
<td>.0 DEGREE</td>
<td>NSU</td>
</tr>
<tr>
<td>31</td>
<td>0.672094</td>
<td>35</td>
<td>.0 DEGREE</td>
<td>NSU</td>
</tr>
<tr>
<td>32</td>
<td>0.672094</td>
<td>34</td>
<td>.0 DEGREE</td>
<td>NSU</td>
</tr>
<tr>
<td>33</td>
<td>0.672094</td>
<td>33</td>
<td>.0 DEGREE</td>
<td>NSU</td>
</tr>
<tr>
<td>34</td>
<td>0.672094</td>
<td>32</td>
<td>.0 DEGREE</td>
<td>NSU</td>
</tr>
<tr>
<td>35</td>
<td>0.672094</td>
<td>31</td>
<td>.0 DEGREE</td>
<td>NSU</td>
</tr>
<tr>
<td>36</td>
<td>0.672094</td>
<td>30</td>
<td>.0 DEGREE</td>
<td>NSU</td>
</tr>
</tbody>
</table>

Table: Projected Joint Failure

The Projected Joint Failure Load is 0.886278E+04 N

Legend:
- NS: No Additional Damage at Current Joint Load
- DL: Delamination
- SW: Sweaty-Out
- BR: Bearing
- MS: Metal Section
- SU: Ultimate Failure After 50 and DL
- SU: Ultimate Failure in SO
- NSU: Ultimate Failure in NS
- ULS: Ultimate Failure

Figure 37. SASCI Output for the Problem Defined in Figure 36 (Concluded).
Geometry and type of individual elements (plain element, element with loaded or unloaded hole) in the bolted plates

Material properties of bolted plates and fasteners (including failure parameters)

Load configuration (single or double shear, tension or compression)

Fastener size, location and torque

Stiffness matrices for plain elements, elements with loaded or unloaded holes, and fasteners

Assembled global stiffness matrix for the multiaxial bolted joint

Fastener load distribution for a 1 kip joint load

Average stresses corresponding to net section, shear-out and bearing failures at each fastener and cut-out location, for a 1 kip joint load

Joint failure load, critical fastener or cut-out location, failure mode

Figure 38. Flow chart of SAMCJ operations.
product not section, shear-out and bearing failures at the fastener or cut-out location.

With the above input, SAMCJ performs the following computations. It initially generates stiffness matrices for all the special finite elements, namely, plain elements, elements with loaded or unloaded holes, and effective fastener elements (see Reference 7). The individual stiffness matrices are subsequently assembled to obtain the global stiffness matrix for the bolted joint. A 1 kip uniaxial tensile or compressive joint load is imposed on the left end of the top plate, in accordance with the input instructions (see Figure 3). The nodes at the right end of the bottom plate are constrained from translating in the load direction, and one of these nodes is also constrained in the transverse direction, to preclude all rigid body translations. The solution to this finite element formulation of the bolted joint provides the axial and transverse components of the load at every fastener location, corresponding to the 1 kip joint load. Also computed are the average net section, shear-out and bearing stresses at every fastener and cut-out location, corresponding to a 1 kip joint load.

SAMCJ provides, as output, the failure value of the uniaxial joint load, the critical fastener or cut-out location, and the joint failure mode. These are obtained as follows. The tensile, compressive and shear strengths of the plain laminates are computed based on the input tensile and compressive failure strains in the fiber direction of the lamina. The ratios of the averaged stresses to the corresponding unnotched laminate strengths, at selected locations around each fastener and cut-out boundary, are compared to predict the failure mode, the critical fastener or cut-out location and the joint failure load. SAMCJ predicts net section, shear-out and bearing modes of failure at the laminate level. In the SASC-7 code, similar failure predictions for single fastener joints in composites are made at the lamina level. Consequently, the failure parameters characteristic distances for
Figure 39. Application of Load and Displacement Boundary Conditions in the SANCJ Code.
the three failure modes) used with SAMCJ are different from those used with SASCJ.

The incorporation of the transverse effective fastener stiffness values provides SAMCJ the capability to account for fastener flexibility, torque, and load eccentricity (single versus double shear load transfer). The FDFA code, developed in Reference 6, is used to compute the effective fastener transverse stiffnesses, along and perpendicular to the load direction (see Reference 7). The effect of the laminate stacking sequence is also accounted for in this analysis. SAMCJ executes FDFA twice to account for the layup variation (by 90 degrees) from the loading direction to the perpendicular direction.

SAMCJ accounts for stress concentration interaction effects introduced by neighboring cut-outs, free edges and proximate fastener locations. This is made possible by the use of the FIGEOM stress analysis, developed in Reference 6, to generate element stiffness matrices (see Reference 7). FIGEOM accounts for finite planform plate dimensions through a boundary collocation solution procedure (see Reference 6).

SAMCJ computes the magnitude and the orientation of the load at each fastener location. It is a two-dimensional load distribution analysis that does not rely on an experimental measurement of "joint stiffness." In a design situation, many fastener arrangements can be analytically and economically evaluated by SAMCJ to arrive at the best fastener pattern for the assumed loading conditions.

When the bolted plates are tapered, the SAMCJ user can input equivalent uniform thickness elements to approximate the tapering effect (see Figure 40). Adjacent elements in the tapered plate will have different thickness values. This feature is essential in the analysis of practical structural joints.
Figure 40. Finite Element Model of a Sample Tapered Bolted Joint.
SAMCJ has been developed for the strength prediction of bolted laminated structural parts. It currently assumes that the selected fasteners preclude fastener failure. Also, it applies the same failure procedure to both the bolted plates, accounting for net section, shear-out and bearing failures via the averaged stress failure criteria applied at the laminate level. Joint failure is assumed to be a one-step (catastrophic) process. The strength of a bolted plate corresponds to the initial failure at a fastener or a cut-out location, in the bearing, shear-out or net section failure.

The unnotched laminate strengths, under tension, compression and in-plane shear, are computed by SAMCJ based on input fiber-directional failure strain values (tensile and compressive). Laminate strengths under $N_x$ and $N_{xy}$ loadings (in-plane normal and shear stress resultants, respectively) are assumed to correspond to first fiber failure in a ply. This simplistic strength prediction procedure introduces inaccuracies that have been acknowledged and discussed in the literature. Nevertheless, SAMCJ adopts this procedure for lack of a validated alternative.

Despite its versatility, SAMCJ has limitations that the user should be aware of. Reference 7 discusses the limitations of the five-noded (10 degrees of freedom) loaded hole element and the four-noded (8 degrees of freedom) unloaded hole element. In addition, when dividing a bolted plate into many elements (loaded or unloaded hole elements, as well as plain elements), it is advisable to maintain element geometries that do not render the generated stiffness matrices inaccurate. Figure 41 presents results from a study conducted on a singly-fastened metallic plate. $P_r$ is the recovered load that is obtained by integrating the stresses along a line transverse to the load direction as shown in Figure 41. $P$ is the applied load or the sum of the nodal loads (especially in the interior elements in a general multifastened plate). The recovered load ($P_r$) approaches the applied load value ($P$) when the plate aspect ratio ($a/b$) increases beyond unity, and when $a/D$ and $b/D$ have a minimum value of approximately three. In predicting failure in
Figure 41. Element Load Recovery for Various a/D and b/D Ratios.
the net section, bearing and shear-out modes, the computed average stress values are multiplied by \( P/P_r \), to remove geometry (modeling) effects from the computed stresses.

3.5 SAMCJ Input Description

To familiarize the user with SAMCJ input requirements, a sample problem is presented here (see Figure 42). The sample problem considers a six fastener composite-to-metal joint, with a one inch diameter circular cut-out adjacent to the first row of fasteners. Figure 42 presents the assumed nine element model of each of the two bolted plates, analyzed by SAMCJ. Figure 43 presents SAMCJ requests and user input in response to these requests, for the sample problem in Figure 42.

Though self-explanatory, the interactively entered SAMCJ input in Figure 43, for the sample problem in Figure 42, is described here for completeness. The first entry (1) identifies the loading configuration to be a single shear configuration. The second entry (1) identifies the load to be in static tension. The next two entries say that the top plate is a metal (M), identified as "Aluminum." The two entries following these say that the bottom plate is a composite laminate (C), identified as follows: "(45/0/-45/0)2/0/90)2s." Subsequently, the Young's modulus (10.0D6) and Poisson's ratio (0.3) for aluminum, and the fiber-directional, transverse and shear moduli and Poisson's ratio (18.5D6, 0.85D6 and 0.3, respectively) for the composite lamina are input. The next five entries specify that four (4) different fiber orientations are present in the laminate (0, 45, -45 and 90 degrees with respect to the loading direction). The following three entries say that the elements in the bottom plate contain one (1) layup of forty (40) plies, of 0.006175 inch thickness each. The stacking sequence for this layup is input next, where 1, 2, 3 and 4 refer to 0, 45, -45 and 90 degree fiber orientations, respectively. Subsequently, the fastener is identified as "Steel," and its Young's modulus, Poisson's ratio, and head type (30.0D6, 0.3, 0.3125 and
Figure 42. Nine Element Model of Each of the Two Bolted Plates in the Sample Joint.
Figure 43. SAMCI Input for the Sample Problem in Figure 42.
Figure 43. SANCJ Input for the Sample Problem in Figure 42 (Continued).
Figure 43. SANCJ Input for the Sample Problem in Figure 42 (Continued).
FOR ELEMENT NO 7 ENTER: ELEMENT ID, M1, M2, M3, M4, M5, ELEMENT TYPE
107 115 116 120 119 1 1
ENTER ELEMENT THICKNESS
8
FOR ELEMENT NO 8 ENTER: ELEMENT ID, M1, M2, M3, M4, M5, ELEMENT TYPE
108 117 118 120 119 1 3
ENTER ELEMENT THICKNESS, X AND Y COORDINATES OF OPEN HOLE AND HOLE RADIUS
0.5 2.5 0.5 0.5
FOR ELEMENT NO 9 ENTER: ELEMENT ID, M1, M2, M3, M4, M5, ELEMENT TYPE
109 117 118 121 120 1 1
ENTER ELEMENT THICKNESS
0.5
FOR ELEMENT NO 10 ENTER: ELEMENT ID, M1, M2, M3, M4, M5, ELEMENT TYPE
129 129 130 131 132 133 3
ENTER ELEMENT LAYUP NO
1
FASTENERS ARE MODELED BY EFFECTIVE FASTENER ELEMENTS WHICH PROVIDE THE ELASTIC LINK BETWEEN THE TOP AND BOTTOM PLATES
ENTER NUMBER OF FASTENERS IN JOINT
6

EFFECTIVE FASTENER ELEMENTS ARE NUMBERED AS SHOWN
M1 (TOP PLATE)
M2 (BOTTOM PLATE)
WHERE M1 AND M2 CORRESPOND TO THE CENTRAL NODES IN LOADED HOLE ELEMENTS

FOR ELEMENT NO 16 ENTER: ELEMENT ID, M1, M2, M3, M4, M5, ELEMENT TYPE
207 215 216 220 219 1 1
ENTER ELEMENT LAYUP NO
1
FOR ELEMENT NO 17 ENTER: ELEMENT ID, M1, M2, M3, M4, M5, ELEMENT TYPE
208 216 217 221 220 1 3
ENTER ELEMENT LAYUP NUMBER, X AND Y COORDINATES OF THE OPEN HOLE AND THE HOLE RADIUS
1 2.5 0.5 0.5
FOR ELEMENT NO 18 ENTER: ELEMENT ID, M1, M2, M3, M4, M5, ELEMENT TYPE
209 217 218 222 221 1 1
ENTER ELEMENT LAYUP NO
1
WHERE M1 AND M2 CORRESPOND TO THE CENTRAL NODES IN LOADED HOLE ELEMENTS

FOR ELEMENT NO 1 ENTER: ELEMENT ID, M1, M2, M3, M4, M5, ELEMENT TYPE
101 105 206
ENTER ELEMENT NO 1
1
FOR ELEMENT NO 2 ENTER: ELEMENT ID, M1, M2, M3, M4, M5, ELEMENT TYPE
102 106 206
ENTER ELEMENT NO 2
1
FOR ELEMENT NO 3 ENTER: ELEMENT ID, M1, M2, M3, M4, M5, ELEMENT TYPE
103 107 207
ENTER ELEMENT NO 3
1
FOR ELEMENT NO 4 ENTER: ELEMENT ID, M1, M2, M3, M4, M5, ELEMENT TYPE
104 110 210
ENTER ELEMENT NO 4
1
FOR ELEMENT NO 5 ENTER: ELEMENT ID, M1, M2, M3, M4, M5, ELEMENT TYPE
105 113 213
ENTER ELEMENT NO 5
1
FOR ELEMENT NO 6 ENTER: ELEMENT ID, M1, M2, M3, M4, M5, ELEMENT TYPE
106 114 214

Figure 43. SAMCI Input for the Sample Problem in Figure 42 (Continued).
TO REDUCE RUN TIMES, ELEMENTS MAY BE
GROUPED INTO SETS WHICH WILL BE ASSIGNED
IDENTICAL STIFFNESS MATRICES
ENTER 1 TO USE THIS OPTION
2 OTHERWISE

FOR THE TOP PLATE INPUT NUMBER OF GROUPS
FOR THE EFFECTIVE FASTENER, LOADED HOLE; UNLOADED
HOLE AND PLAIN ELEMENT
(INPUT 0 IF ELEMENT TYPE IS NOT USED)

1 6 1 1
GROUPING OF EFFECTIVE FASTENER ELEMENTS;
ENTER NUMBER OF ELEMENTS IN GROUP NUMBER

6
ENTER 6 ELEMENT IDS
101 102 103 104 105 106

GROUPING OF LOADED HOLE ELEMENTS;
ENTER NUMBER OF ELEMENTS IN GROUP NUMBER

1
INPUT 1 ELEMENT IDS
101
ENTER NUMBER OF ELEMENTS IN GROUP NUMBER

1
INPUT 1 ELEMENT IDS
102
ENTER NUMBER OF ELEMENTS IN GROUP NUMBER

1
INPUT 1 ELEMENT IDS
103
ENTER NUMBER OF ELEMENTS IN GROUP NUMBER

1
INPUT 1 ELEMENT IDS
104
ENTER NUMBER OF ELEMENTS IN GROUP NUMBER

1
INPUT 1 ELEMENT IDS
105
ENTER NUMBER OF ELEMENTS IN GROUP NUMBER

1
INPUT 1 ELEMENT IDS
106
ENTER NUMBER OF ELEMENTS IN GROUP NUMBER

1
INPUT 1 ELEMENT IDS
107

GROUPING OF UNLOADED HOLE ELEMENTS
ENTER NUMBER OF ELEMENTS IN GROUP NUMBER

1
INPUT 1 ELEMENT IDS
108

GROUPING OF PLAIN ELEMENTS
ENTER NUMBER OF ELEMENTS IN GROUP NUMBER

1
ENTER 8 ELEMENT IDS
109 110 111 112 113 114 115 116

FOR THE BOTTOM PLATE INPUT NUMBER OF GROUPS
FOR THE LOADED HOLE, UNLOADED HOLE, AND PLAIN
ELEMENTS
(INPUT 0 IF AN ELEMENT TYPE IS NOT USED)

1 6 1 1
GROUPING OF LOADED HOLE ELEMENTS
ENTER NUMBER OF ELEMENTS IN GROUP NUMBER

1
INPUT 1 ELEMENT IDS
201
ENTER NUMBER OF ELEMENTS IN GROUP NUMBER

2
INPUT 1 ELEMENT IDS
202
ENTER NUMBER OF ELEMENTS IN GROUP NUMBER

3
INPUT 1 ELEMENT IDS
203
ENTER NUMBER OF ELEMENTS IN GROUP NUMBER

4
INPUT 1 ELEMENT IDS
204
ENTER NUMBER OF ELEMENTS IN GROUP NUMBER

5
INPUT 1 ELEMENT IDS
205
ENTER NUMBER OF ELEMENTS IN GROUP NUMBER

6
INPUT 1 ELEMENT IDS
206

Figure 43. SANCJ Input for the Sample Problem in Figure 42 (Continued).
GROUPING OF UNLOADED NO. ELEMENTS
ENTER NUMBER OF ELEMENTS IN GROUP NUMBER 1
? 1
ENTER 1 ELEMENT IDS
208
GROUPING OF PLAIN ELEMENTS
ENTER NUMBER OF ELEMENTS IN GROUP NUMBER 2
? 2
ENTER 2 ELEMENT IDS
207 288

INPUT DATA FOR FAILURE ANALYSIS:
ENTER METALLIC STRENGTHS:
TENSILE STRENGTH
COMPRESSIVE STRENGTH
SHEAR STRENGTH
?
250.003 250.003 250.003

AN AVERAGE STRESS CRITERIA IS USED TO
PREDICT FAILURE. NO VALUES ARE REQUIRED AS
CHARACTERISTIC DISTANCES OVER WHICH STRESSES
ARE TO BE AVERAGED AND COMPARED TO UNNOTCHED
LAMINATE STRENGTHS TO PREDICT FAILURE.

ENTER NO VALUES FOR STRESSES AVERAGING
FOR EACH FAILURE MODE IN PLATE NO.
1

A05 = NET SECTION
A05 = BEARING
A05 = SHEAROUT
?
0.5 0.5 0.5

ENTER FIBER ULTIMATE STRAIN VALUES
IN PLATE NO.
2

EPSILON ULT IN COMPRESSION
EPSILON ULT IN TENSION
EPSILON ULT IN SHEAR
?
0.015 0.012 0.012

AN AVERAGE STRESS CRITERIA IS USED TO
PREDICT FAILURE. NO VALUES ARE REQUIRED AS
CHARACTERISTIC DISTANCES OVER WHICH STRESSES
ARE TO BE AVERAGED AND COMPARED TO UNNOTCHED
LAMINATE STRENGTHS TO PREDICT FAILURE.

ENTER NO VALUES FOR STRESSES AVERAGING
FOR EACH FAILURE MODE IN PLATE NO.
8

A05 = NET SECTION
A05 = BEARING
A05 = SHEAROUT
?
0.1 0.05 0.25

Figure 43. SAMCJ Input for the Sample Problem in Figure 42 (Concluded).
protruding head) are input.

Twenty-two (22) grid points each are specified in the top and bottom plates (101 to 122 and 201 to 222, respectively), along with their x and y coordinates (see Figure 42). Following this, nine (9) elements are specified in each plate, along with their nodal connectivity and element type information. Nodal connectivity is specified starting from the bottom left node, going clockwise around the element boundary, and ending at the fastener (internal) node. Element 101 in the top plate, for example, has 101, 102, 109 and 108 as its corner nodes, and 105 as its fastener node. The fifth node will be entered as 0 for plain and unloaded hole elements. The element type information follows the fifth node identification. It is 1, 2 and 3 for plain, loaded hole and unloaded hole elements, respectively. The element definitions are succeeded by the definition of six (6) effective fasteners (101 to 106). Fastener 101, for example, is identified as a fastener that connects node 105 in the top plate to node 205 in the bottom plate.

Following the above input, additional element data are specified for the two plates. These include the element thicknesses (for metallic plates) or layup identification number (for laminated plates), for plain and loaded hole elements, with additional information (x and y coordinates of the hole center and the hole radius) for unloaded hole elements. For the sample problem in Figure 42, all the elements in the top plate (metal) are specified to be 0.50 inch thick, and all the elements in the bottom plate (composite) are specified to contain the stacking sequence identified as one (1). Elements 108 and 208 specify the cut-out size and location. The one (1) following this states that groups of identical elements will be specified in the two plates. If two (2) is entered here, all elements will be assumed to be different from one another, resulting in larger computational costs. The entry "1 6 1 1" refers to the number of groups of effective fasteners, loaded hole, unloaded hole and plain elements, respectively, in the top plate. A zero (0) specifies the absence of an element type.
The number of elements in each group, and the corresponding element numbers, are input subsequently. Following this, the number of groups of loaded hole, unloaded hole and plain elements in the bottom plate (6, 1 and 1, respectively) is entered.

The last four lines of input introduce the failure parameters for the materials in the two plates. For metallic plates, the tensile, compressive and shear strengths (250.000 each), and the averaging distances for the net section, bearing and shear-out modes of failure (0.5 each) are input. Since the joints were designed to fail the laminated plates, and SAMCJ was developed primarily for the prediction of the strength of bolted laminates, the failure parameters for the metallic plates were input to be arbitrarily high. This information is followed by the failure parameters for the bottom (composite) plate. The first line specifies the fiber directional failure strains for the material under tension (0.012) and compression (0.0175). These values are used by SAMCJ to compute the unnotched laminate tensile, compressive and shear strengths, based on laminated plate theory and the assumption of laminate failure corresponding to the first fiber failure in any of its plies. The last line in Figure 43 specifies the distance over which the longitudinal (0.10 and 0.25) and shear (0.25) stress components are averaged, to predict net section, bearing and shear-out modes of failure, respectively.

3.6 SAMCJ Output Description

For the sample problem introduced in Section 3.5, the SAMCJ code yields the output presented in Figure 44. The initial part of the output reprints critical user-supplied information for verification purposes. Subsequently, SAMCJ prints the x and y components of the element nodal forces for all the elements in the bolted plates. This is followed by a list of the computed joint load levels that correspond to the three failure modes (net section, shear-out and bearing) at every loaded and unloaded hole element location. The smallest among these loads yields the joint failure.
PROGRAM SANCJ

A SINGLE LAP SHEAR PANEL WILL BE ANALYZED
LOADED IN STATIC TENSION

ALUMINUM

MATERIAL PROPERTIES

E1 = 0.1200E+00 PSI
E2 = 0.1200E+00 PSI
G12 = 0.1200E+00 PSI
G12 = 0.2600E+00
K21 = 0.3000E+00

PLATE NO. 1

AGI 3541-6

MATERIAL PROPERTIES

E1 = 0.1453E+00 PSI
E2 = 0.1453E+00 PSI
G12 = 0.2513E+00 PSI
G12 = 0.3900E+00
K21 = 0.3900E+00

FASTERER DESCRIPTION

STEEL

DIAMETER = 0.3125E+00 INCHES

MATERIAL PROPERTIES

E = 0.3000E+00 PSI
K = 0.3000E+00

FAILURE ANALYSIS

AN AVERAGE STRESSES CRITERION WILL BE USED

PLATE NUMBER 1

METALLIC STRENGTHS

TENSILE STRENGTH = 0.2500E+00
COMPRRESSIVE STRENGTH = 0.2500E+00
SHEAR STRENGTH = 0.2500E+00

CHARACTERISTIC DISTANCES

AXI = 0.5000E+00 INCHES
AY = 0.5000E+00 INCHES
AZ = 0.5000E+00 INCHES

PLATE NUMBER 2

FIBER STRAIN ULTIMATES

EPSILON ULT COMP = 0.1500E+01
EPSILON ULT TEN = 0.1500E+01
GAMMA ULT SHEAR = 0.1250E+01

CHARACTERISTIC DISTANCES

AXI = 0.1000E+00 INCHES
AY = 0.2500E+00 INCHES
AZ = 0.2500E+00 INCHES

PAUSE FOR STIFFNESS MATRIX CALCULATIONS

ELEMENT FORCES

(P APPLIED = 10.000 LBS)

ELEMENT ID 101
GRID FX FY

ELEMENT ID 102
GRID FX FY

ELEMENT ID 103
GRID FX FY

Figure 44. SANCJ Output for the Problem Defined in Figure 43.
<table>
<thead>
<tr>
<th>ELEMENT ID</th>
<th>104</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRID</td>
<td>Fx</td>
</tr>
<tr>
<td>108</td>
<td>-0.757+00</td>
</tr>
<tr>
<td>109</td>
<td>-0.160+02</td>
</tr>
<tr>
<td>110</td>
<td>-0.240+01</td>
</tr>
<tr>
<td>111</td>
<td>0.710+01</td>
</tr>
<tr>
<td>112</td>
<td>0.150+03</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ELEMENT ID</th>
<th>105</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRID</td>
<td>Fx</td>
</tr>
<tr>
<td>113</td>
<td>-0.770+02</td>
</tr>
<tr>
<td>114</td>
<td>-0.760+02</td>
</tr>
<tr>
<td>115</td>
<td>-0.180+02</td>
</tr>
<tr>
<td>116</td>
<td>-0.960+01</td>
</tr>
<tr>
<td>117</td>
<td>0.170+03</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ELEMENT ID</th>
<th>106</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRID</td>
<td>Fx</td>
</tr>
<tr>
<td>118</td>
<td>-0.970+02</td>
</tr>
<tr>
<td>119</td>
<td>-0.750+02</td>
</tr>
<tr>
<td>120</td>
<td>0.700+01</td>
</tr>
<tr>
<td>121</td>
<td>0.260+01</td>
</tr>
<tr>
<td>122</td>
<td>0.700+03</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ELEMENT ID</th>
<th>107</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRID</td>
<td>Fx</td>
</tr>
<tr>
<td>123</td>
<td>-0.710+01</td>
</tr>
<tr>
<td>124</td>
<td>0.340+01</td>
</tr>
<tr>
<td>125</td>
<td>0.370+01</td>
</tr>
<tr>
<td>126</td>
<td>0.720+02</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ELEMENT ID</th>
<th>108</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRID</td>
<td>Fx</td>
</tr>
<tr>
<td>127</td>
<td>0.370+01</td>
</tr>
<tr>
<td>128</td>
<td>0.360+01</td>
</tr>
<tr>
<td>129</td>
<td>-0.370+01</td>
</tr>
<tr>
<td>130</td>
<td>-0.370+01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ELEMENT ID</th>
<th>109</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRID</td>
<td>Fx</td>
</tr>
<tr>
<td>131</td>
<td>0.370+01</td>
</tr>
<tr>
<td>132</td>
<td>-0.750+01</td>
</tr>
<tr>
<td>133</td>
<td>-0.150+11</td>
</tr>
<tr>
<td>134</td>
<td>0.370+01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ELEMENT ID</th>
<th>201</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRID</td>
<td>Fx</td>
</tr>
<tr>
<td>135</td>
<td>-0.850+01</td>
</tr>
<tr>
<td>136</td>
<td>0.650+02</td>
</tr>
<tr>
<td>137</td>
<td>0.160+01</td>
</tr>
<tr>
<td>138</td>
<td>-0.170+01</td>
</tr>
</tbody>
</table>

Figure 44. SAMCJ Output for the Problem Defined in Figure 43 (Continued).
<table>
<thead>
<tr>
<th>ELEMENT ID</th>
<th>287</th>
</tr>
</thead>
<tbody>
<tr>
<td>GIRD</td>
<td>FX</td>
</tr>
<tr>
<td>215</td>
<td>-1.20E+03</td>
</tr>
<tr>
<td>216</td>
<td>-1.62E+03</td>
</tr>
<tr>
<td>217</td>
<td>0.176E+01</td>
</tr>
<tr>
<td>218</td>
<td>0.163E+01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ELEMENT ID</th>
<th>288</th>
</tr>
</thead>
<tbody>
<tr>
<td>GIRD</td>
<td>FX</td>
</tr>
<tr>
<td>216</td>
<td>-2.12E+03</td>
</tr>
<tr>
<td>217</td>
<td>-3.11E+03</td>
</tr>
<tr>
<td>218</td>
<td>0.212E+01</td>
</tr>
<tr>
<td>219</td>
<td>0.211E+01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ELEMENT ID</th>
<th>289</th>
</tr>
</thead>
<tbody>
<tr>
<td>GIRD</td>
<td>FX</td>
</tr>
<tr>
<td>217</td>
<td>-1.15E+03</td>
</tr>
<tr>
<td>218</td>
<td>-1.29E+03</td>
</tr>
<tr>
<td>222</td>
<td>0.162E+01</td>
</tr>
<tr>
<td>221</td>
<td>0.126E+03</td>
</tr>
</tbody>
</table>

Joint load levels corresponding to net section (NS), shear-out (SO) and bearing (BR) failures at every loaded and unloaded hole element are predicted as follows:

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>NS</th>
<th>SO</th>
<th>BR</th>
</tr>
</thead>
<tbody>
<tr>
<td>101</td>
<td>0.532E+06</td>
<td>0.993E+06</td>
<td>0.460E+06</td>
</tr>
<tr>
<td>102</td>
<td>0.546E+06</td>
<td>0.978E+06</td>
<td>0.501E+06</td>
</tr>
<tr>
<td>103</td>
<td>0.417E+06</td>
<td>0.635E+06</td>
<td>0.192E+06</td>
</tr>
<tr>
<td>104</td>
<td>0.292E+07</td>
<td>0.151E+07</td>
<td>0.738E+06</td>
</tr>
<tr>
<td>105</td>
<td>0.211E+07</td>
<td>0.142E+07</td>
<td>0.877E+06</td>
</tr>
<tr>
<td>106</td>
<td>0.283E+07</td>
<td>0.171E+07</td>
<td>0.727E+06</td>
</tr>
<tr>
<td>107</td>
<td>0.146E+06</td>
<td>0.893E+06</td>
<td>0.527E+06</td>
</tr>
<tr>
<td>201</td>
<td>0.344E+06</td>
<td>0.123E+06</td>
<td>0.129E+06</td>
</tr>
<tr>
<td>202</td>
<td>0.259E+06</td>
<td>0.973E+05</td>
<td>0.105E+06</td>
</tr>
<tr>
<td>203</td>
<td>0.513E+06</td>
<td>0.123E+06</td>
<td>0.130E+06</td>
</tr>
<tr>
<td>204</td>
<td>0.764E+06</td>
<td>0.644E+05</td>
<td>0.777E+05</td>
</tr>
<tr>
<td>205</td>
<td>0.552E+05</td>
<td>0.411E+05</td>
<td>0.677E+05</td>
</tr>
<tr>
<td>206</td>
<td>0.808E+05</td>
<td>0.555E+05</td>
<td>0.812E+05</td>
</tr>
<tr>
<td>207</td>
<td>0.373E+05</td>
<td>0.174E+06</td>
<td>0.392E+07</td>
</tr>
</tbody>
</table>

Failure is predicted to occur in element number 208 at an applied joint load value of 0.372E+06 lbs.

The predicted failure mode is net section.

Figure 44. SAMCJ output for the problem defined in Figure 43 (Concluded).
load, the failure location and the failure mode. For the considered sample problem, a net section failure is predicted across the one inch diameter cut-out (element 208) in the graphite/epoxy plate, at a joint load level of 37.3 kips. Figure 45 compares SAMCJ predictions with test results from Reference 8.
**Test Case 243, Static Tension, Single Lap**

40-Ply, 50/40/10 Laminate, \( t = 0.247 \) in., \( t_{AL} = 0.50 \) in.,
\( D = 5/16 \) in., \( d = 1 \) in., \( S_L / S_T / D = 4 \), \( W / D = 14.4 \), \( E / D = 3.2 \)

---

### SAMCJ Prediction vs. Test Results (Ref. 2)

<table>
<thead>
<tr>
<th></th>
<th>SAMCJ Prediction</th>
<th>Test Results (Ref. 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P_1 / P )</td>
<td>0.165</td>
<td>0.162</td>
</tr>
<tr>
<td>( P_2 / P )</td>
<td>0.191</td>
<td>0.150</td>
</tr>
<tr>
<td>( P_3 / P )</td>
<td>0.165</td>
<td>0.168</td>
</tr>
<tr>
<td>( P_4 / P )</td>
<td>0.167</td>
<td>0.177</td>
</tr>
<tr>
<td>( P_5 / P )</td>
<td>0.175</td>
<td>0.161</td>
</tr>
<tr>
<td>( P_6 / P )</td>
<td>0.168</td>
<td>0.166</td>
</tr>
<tr>
<td>( P_{\text{failure}} ) (kips)</td>
<td>37.3 (52.7)*</td>
<td>42.0</td>
</tr>
<tr>
<td>Failure Location</td>
<td>7 (5)</td>
<td>7 and 4, 5, 6</td>
</tr>
<tr>
<td>Failure Mode(s)</td>
<td>Net Section (Net Section)</td>
<td></td>
</tr>
</tbody>
</table>

* Next possible failure mode and location at a higher load level

Figure 45. Comparison of SAMCJ Predictions for the Sample Problem with Test Results from Reference 8.

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SECTION 4

DESIGN VERIFICATION OF A BOLTED STRUCTURAL ELEMENT

The design of a highly-loaded structural bolted joint is verified in this section using the analytical tool (SAMCJ computer code) proposed for the recommended design methodology (Section 1.3).

4.1 Description of the Bolted Structural Element

In Reference 5, a bolted joint concept was studied as an alternative to a highly loaded composite-to-titanium, step lap bonded joint. The vertical tail structure of the F/A-18A was used as the baseline for this study. A preliminary design of the bolted structural element, representative of the critical F/A-18A vertical tail root section, was performed based on approximate analyses and available test results. The test element was designed to transfer a design ultimate load of 70.2 kips (obtained from the F/A-18A empennage stress analysis report), and to survive two lifetimes of a representative design spectrum fatigue loading.

The design of the bolted structural element studied in Reference 5 differs from the existing F/A-18A vertical tail root joint significantly. It eliminates the graphite/epoxy skin-to-titanium bonded joint, and directly attaches the skins to the fuselage frame. In doing so, it also uses a light root rib, in contrast to the highly-loaded attachment root rib used in Reference 4. The AS4/3501-6 graphite/epoxy skins of the element have a 41-ply layup away from the attachment location. The skins increase in thickness to a 60-ply layup near the tab region that bolts the vertical tail skin to the fuselage frame. The graphite/epoxy tabs are machined, prior to assembly, to introduce a taper at the joint location. In Reference 5, the fuselage attachment fitting was made out of steel, and the skins were bolted to it using 3/8 inch diameter, countersunk high strength steel bolts. Figure 46 shows a
Figure 46. Photograph of an Assembled Test Element.
photograph of an assembled test element. The element spar and the root rib were fabricated using an aluminum alloy.

4.2 Test Results

Elements fabricated based on this preliminary design were subjected to static and fatigue loads in Reference 5. They survived two lifetimes of a spectrum fatigue load that was significantly more severe than the actual F/A-18A vertical tail design spectrum load, and their static strengths were approximately 30% larger than the design ultimate load. During the static test, failure occurred in the graphite/epoxy skin tab in a combined mode (see Figure 17). The observed failure modes were significantly influenced by the tilting or "digging in" of the countersunk fasteners - a phenomenon that cannot be accounted for by the fastener analysis in the SAMCJ computer code.

4.3 Design Verification of the Element Using SAMCJ

The critical vertical tail skin-to-fuselage joint region is analyzed below using the SAMCJ code that is recommended as an analytical design tool. Though the analysis was performed retrospectively, the assumed material and failure parameters are identical to those used in Reference 7.

Figure 48 presents the dimensions of the analyzed graphite/epoxy skin tabs and the fuselage attachment frame. The tapered skin has a $[0_{28}^{28}/+45_{12}/90_7]_C$ layup at the top of the tab region. Across the top row of fasteners, it has an average of 58 plies, and across the bottom row of fasteners, it has an average of 52 plies. For analytical purposes, the tapered tab region is modeled as two uniform regions of different thicknesses. The top region is modeled to contain a $[0_{28}^{28}/+45_{12}/90_5]_C$ layup, and the bottom region is assumed to be a $[0_{26}^{26}/+45_{10}/90_6]_C$ laminate. The average thickness of a ply in the skin was measured to be 0.0049 inch. The fuselage attachment frame is, likewise, divided into a
Figure 47. Photograph of the Tab Region of the Failed Element.
Figure 48. Dimensions of the Critical Skin Tab and the Fuselage Attachment Frame.
0.41 inch thick region and a 0.46 inch thick region (see Figure 48).

The modeled joint segment is half of the symmetric skin tab-to-fuselage attachment. The total joint failure load is, therefore, twice the predicted load. A single shear load transfer between the AS4/3501-6 graphite/epoxy skin tab and the steel attachment frame is analyzed. The graphite/epoxy tab and the steel plate are divided into four elements each. The average width of the slightly tapered tab is used in the analytical model (3.57 in.). The fiber-directional tensile and compressive failure strains for AS4/3501-6 graphite/epoxy are assumed to be 0.012 and 0.0175, respectively (References 7, 13). The characteristic distances for net section, bearing and shear-out failure modes are assumed to be 0.10, 0.25 and 0.25 inch, respectively (Reference 7). The basic AS4/3501-6 lamina properties are assumed to be 18.5 Msi, 1.9 Msi and 0.85 Msi for \( E_{11} \), \( E_{22} \) and \( G_{12} \), respectively, and 0.3 for the major Poisson's ratio.

The skins are attached to the fuselage frame by 3/8 inch diameter, countersunk fasteners (100 degree tension head). The fastener analysis in SAMCJ cannot accurately account for the effects of the countersunk head geometry. However, it approximates the actual effects by assuming free rotation at the fastener head location, and requires the user to input an equivalent protruding head fastener diameter. In the discussed element analysis, the average fastener diameter is assumed to be 0.458 inch, to account for the 100 degree tension head geometry.

Analytically predicted load distribution among the fasteners in each tab is presented in Figure 49. The symmetry in the fastener arrangement results in low values for the transverse components of fastener loads (perpendicular to the load direction). Also, the loads in the top row of fasteners are approximately 14\% larger than those in the bottom row of fasteners. This leads to a prediction of failure initiation from the top row of fasteners (see Figure 49). The predicted failure site (critical location) is in
Figure 49. Load Distribution Among Fasteners, Failure Location and Failure Mode in the Graphite/Epoxy Tabs.
agreement with experimental observation.

Figure 50 presents the analytically predicted element load levels to precipitate net section, bearing and shear-out modes of failure at the various fastener locations. The lowest among these provides the element failure load, the failure location and the failure mode. SAMCJ predicts element failure to be caused by a shear-out mode of failure at the top left fastener location in Figure 50. The failure mode observed in Reference 5, however, was severe damage around the fastener hole, introduced by the tilting of the countersunk fasteners (see Figure 47). This included some amount of shear-out and local bearing, and severe delaminations around the fastener hole boundaries. Since SAMCJ cannot account for the severe local three-dimensional stress state introduced by the countersunk fasteners, the predicted failure mode (shear-out) does not correlate well with the observed combined failure mode (partial shear-out, local bearing, and severe delaminations).

Despite the approximate failure mode prediction, however, SAMCJ correctly predicts the failure location, and the failure load predicted by SAMCJ (96.0 kips) is only 7% larger than the measured value (91.8 kips). The approximation of the countersunk fasteners by equivalent protruding head fasteners (larger diameter, unconstrained at the head location), therefore, predicts the element failure load with adequate accuracy. The SAMCJ analysis and the test results in Reference 5 independently verify the 30% margin of safety in the static strength of the test element, due to the approximate analyses used in its preliminary design.
Tab Load = F; Element Load = 2F

The numbers below are the values of the applied element load (2P), in kips to precipitate the three failure modes at each fastener location.

Figure 50. Analytically Predicted Element Load Levels to Precipitate Net Section, Bearing and Shear-Out Modes of Tab Failure at Each Fastener Location.
SECTION 5

CONCLUSIONS

A design guide was developed to enable the user in designing efficient bolted joints in composite structures. The guide highlights general design guidelines for the various parameters that are to be considered in selecting a bolted joint concept. A purely analytical design methodology is presented. It is devoid of complementary test requirements when a previously characterized material is used to fabricate the bolted structure. The design guide also illustrates the use of two computer codes (SASCJ and SAMCJ) that were developed in this Northrop/AFWAL program and are required for design purposes. A listing of these computer codes is appended to this report.
REFERENCES


REFERENCES (Concluded)


APPENDIX A

SASCJ Program Listing
PROGRAM SASCJ

STRENGTH ANALYSIS OF SINGLE-FASTENER COMPOSITE JOINTS

SASCJ PREDICTS LOAD-DEFORMATION CURVES AND FAILURE LOADS OF MECHANICALLY FASTENED, COMPOSITE LAMINATE, SINGLE LAP OR
SYMMETRICAL DOUBLE LAP SHEAR JOINTS. THE BASIS OF THE FSMC:
ANALYSIS IS A NONLINEAR FINITE DIFFERENCE SOLUTION OF A BEAM
(FASTENER) ON AN ELASTIC FOUNDATION (COMPOSITE LAMINATE). SELECTED FAILURE CRITERIA ARE USED TO PREDICT INDIVIDUAL PLY
FAILURES AND/AND CILES (INCLUDING INTERLAMINAR SHEAR). THE LOAD IS AUTOMATICALLY INCREMENTED TO FINAL FAILURE TO ACCOUNT FOR
THE NONLINEAR JOINT BEHAVIOR.

IMPLICIT REALS(A-H,O-Z)

READ IN REQUIRED INPUT DATA
PROGRAM SASCJ PREDICTS FAILURE LOADS OF MECHANICALLY FASTENED, COMPOSITE LAMINATE, SINGLE OR DOUBLE LAP SHEAR JOINTS. PROGRAM ASSUMES THAT INPUT PARAMETERS ARE N IN ENGLISH UNITS - LENGTHS ARE INPUT IN INCHES AND MODULI AND STRENGTHS ARE EXPRESSED IN PSI.

WRITE(6,401)
401 FORMAT(' ENTER BYPASS RATIO ALPHA:', ...

WRITE(6,911)
911 FORMAT(' ENTER:', ...

READ(5,106) CM(K)
106 FORMAT(A1)
106 CONTINUE

READ(5,204) MTL(K,I)
204 FORMAT(A4)
204 CONTINUE

DO 300 K=NPLY,1,-1
300 ...

IF(CM(K).EQ.CMC) GO TO 15
15 ...

WRITE(6,721) 721 FORMAT(' NOTE: NUMERICAL DESIGNATIONS FOR THE PLATES ARE: ...

WRITE(6,949)
949 FORMAT(' ENTER A SINGLE PLATE WITH AN OPEN HOLE DESIGNATED AS PLATE NUMBER 1:', ...

DO 301 K=1,NLIM
301 ...

IF(CM(K).EQ.CMC) GO TO 15
15 ...

WRITE(6,494)
494 FORMAT(' ...)
GO TO 301
15 CONTINUE
   IF(NSDLS.EQ.2.AND.K.EQ.1) WRITE(6,932)
932 FORMAT(/,' NOTE: FOR THE DOUBLE LAP SHEAR CASE HAVING ',/)
   * A COMPOSITE PLATE NUMBER 2, ENTER ONLY HALF',/)
   * OF THE LAYUP - IE HALF THE NUMBER OF ACTUAL',/)
   * PLIES ')
   WRITE(6,205) K
205 FORMAT(/,' INPUT NUMBER OF PLIES IN PLATE NO',I5,/)
   * NF (N > OR = 2) ')
   READ(5,*) NPLY(K)
   NLIM2=2*NPLY(K)+1
301 CONTINUE
   DO 302 K=1,NLIM
      IF(CM(K).EQ.CMC) GO TO 25
   302 CONTINUE
   IF(NSDLS.EQ.2.AND.K.EQ.2) WRITE(6,933)
933 FORMAT(/,' FOR THE DOUBLE LAP SHEAR CASE HAVING ',/)
   * A METALLIC PLATE NUMBER TWO, ENTER HALF THE ',/)
   * ACTUAL PLATE THICKNESS ')
   WRITE(6,35) K
35 FORMAT(/,' INPUT THICKNESS OF PLATE NO',I5)
   READ(5,*) H(K)
   GO TO 302
25 CONTINUE
   WRITE(6,260) K
260 FORMAT(/,' INPUT PLY THICKNESS IN PLATE NO',I5)
   READ(5,*) H(K)
302 CONTINUE
   DO 303 K=1,NLIM
      IF(CM(K).EQ.CMC) GO TO 45
   303 CONTINUE
   WRITE(6,207) K
207 FORMAT(/,' INPUT NUMBER OF DISTINCT PLY ORIENTATIONS ',/)
   * IN PLATE NO',I5)
   READ(5,*) NUMPLY(K)
303 CONTINUE
   DO 304 K=1,NLIM
      IF(CM(K).EQ.CMC) GO TO 55
   304 CONTINUE
   WRITE(6,387) K
387 FORMAT(/,' FOR PLATE NUMBER ',I5,' ',/)
   * NUMPLY(K) ')
   READ(5,*) ANG(L,K)
55 CONTINUE
   WRITE(6,210) K
210 FORMAT(/,' INPUT ORIENTATION OF PLY TYPE ',I5)
   READ(5,*) ANG(L,K)
210 FORMAT(' INPUT TYPE OF PLY IN PLATE NO',15,' FROM TOP',/,
      15,' TO BOTTOM') 0001760
211 FORMAT(' PLY TYPE',15,'ORIENTATION') 0001770
N=NUMPLY(Y) 0001780
DO 212 I=1,N 0001790
WRITE(6,711) L,ANG(L,K) 0001800
213 CONTINUE 0001810
WRITE(6,711) 0001820
711 FORMAT(' PLY TYPE',/,' ORIENTATION') 0001830
N=NUMPLY(Y) 0001840
DO 215 I=1,N 0001850
WRITE(6,714) I 0001860
214 FORMAT(' INPUT TYPE OF PLY FOR PLY NO',15) 0001870
READ(5,*) IPLY(I,K) 0001880
215 CONTINUE 0001890
305 CONTINUE 0001900
DO 306 K=1,NPLM 0001910
WRITE(6,216) K 0001920
216 FORMAT(' INPUT THE ENGINEERING PROPERTIES OF PLATE NO',15) 0001930
IF(CM(K).EQ.CMC) GO TO 35 0001940
WRITE(6,35) 0001950
95 FORMAT(' INPUT YOUNG'S MODULUS AND POISSON'S RATIO') 0001960
READ(5,*) E1(K),G12(K) 0001970
E2(K)=E1(K) 0001980
V12(K)=G12(K)/((2.+G12(K)))* ((1.+G12(K))/(2.*G12(K))) 0001990
GO TO 36 0002000
85 CONTINUE 0002010
WRITE(6,217) 0002020
217 FORMAT(' INPUT YOUNG'S MODULI, E1 AND E2') 0002030
READ(5,*) E1(K),E2(K) 0002040
WRITE(6,218) 0002050
218 FORMAT(' INPUT THE SHEAR MODULUS AND MAJOR POISSON'S RATIO') 0002060
READ(5,*) G12(K),V12(K) 0002070
V21(K)=V12(K)*E2(K)/E1(K) 0002080
306 CONTINUE 0002090
IF(EPR. NE.1.0) GO TO 930 0002100
WRITE(6,250) 0002110
844 FORMAT(' INPUT HOLE DIAMETER') 0002120
READ(5,*) FASD 0002130
GO TO 360 0002140
930 CONTINUE 0002150
WRITE(6,250) 0002160
250 FORMAT(' INPUT MATERIAL DESCRIPTION FOR FASTENER') 0002170
READ(5,251) (MTL(J,1),J=1,15) 0002180
251 FORMAT(15A) 0002190
WRITE(6,252) 0002200
252 FORMAT(' INPUT YOUNG'S MODULUS AND POISSON'S RATIO FOR FASTENER') 0002210
* THE FASTENER') 0002220
READ(5,*) FASE,FASV 0002230
WRITE(6,253) 0002240
253 FORMAT(' INPUT THE DIAMETER OF THE FASTENER') 0002250
READ(5,*) FASD 0002260
WRITE(6,888) 0002270
888 FORMAT(' FASTENER TYPE') 0002280
* ENTER: 1 FOR PROTRUDING HEAD, 2 FOR COUNTERSUNK HEAD') 0002290
READ(5,*) NFYP 0002300
R(1)=1.0D10 0002310
R(2)=1.0..J
IF(NF.TYP.EQ.1) GO TO 360
WRITE(6,889)
889 FORMAT(/, 'ENTER PLATE WHICH CONTAINS THE COUNTERSUNK HEAD (OPPOSITE PLATE ASSUMES THE NUT HEAD) 1 FOR TOP PLATE 2 FOR BOTTOM PLATE')
READ(5,8) N
R(N)=0.000
360 CONTINUE
READ IN GEOMETRY AND BOUNDARY DATA
4X=FA5D/2.000
BXAX
WRITE(6,856)
856 FORMAT(/, 'PLATE GEOMETRIES ARE SPECIFIED BY ',/,'INPUTTING THE COORDINATES OF THE CORNER VERTICES. NOTE: THE ORIGIN IS AT THE FASTENER CENTER; INPUT COORDINATES ACCORDINGLY',/,'HOLE CENTROID V1',/,'APPLIED LOAD CONVENTION: ',/,'FOR PLATE NO 1 (TOP) NORMAL LOADS ARE APPLIED BETWEEN V3 AND V4',/,'FOR PLATE NO 2 (BOTTOM) NORMAL LOADS ARE APPLIED BETWEEN V1 AND V2')
DO 400 K=1,NLIM
WRITE(6,734) K
734 FORMAT(' FOR PLATE NUMBER ',IS1,' ',IS2)
DO 110 I=1,4
WRITE(6,290) I
290 FORMAT(/, 'ENTER X,Y COORDINATES OF V',I4)
READ(5,1) XL(K,I),YC(K,I)
110 CONTINUE
IF(K.EQ.2) GO TO 841
A1=XC(1,1)
B1=YC(1,1)
A2=XC(1,2)
B2=YC(1,2)
XC(1,1)=XC(1,4)
YC(1,1)=YC(1,4)
XC(1,2)=XC(1,3)
YC(1,2)=YC(1,3)
XC(1,4)=A1
YC(1,4)=B1
XC(1,3)=A2
YC(1,3)=B2
841 CONTINUE
WTH=YC(K,2)-YC(K,1)
680 CONTINUE
IF(BPR.EQ.0.0 OR BP.EQ.1.0) GO TO 567
WRITE(6,741)
741 CONTINUE
SELECT FAILURE CRITERION:
1 ENTER 1 FOR POINT STRESS CRITERION
2 ENTER 2 FOR AVERAGE STRESS CRITERION
READ(5,6) NPT
IF(NOPT.EQ.1) NOPT4=2
IF(NOPT.EQ.2) NOPT4=4
GO TO 601
567 CONTINUE
WRITE(6,220)
220 FORMAT(' SELECT FAILURE CRITERION : /',/  * ENTER 1 FOR HOFFMAN/TSAI-HILL CRITERION , / * ENTER 2 FOR POINT STRESS CRITERION , / * ENTER 3 FOR MAXIMUM STRAIN CRITERION , / * ENTER 4 FOR AVERAGE STRESS CRITERION'),/ READ(5,5) NOPT4
601 CONTINUE
IF(NOPT4.EQ.2.OR.NOPT4.EQ.4) GO TO 221
DO 412 K=1,NLIM
WRITE(6,222) K
222 FORMAT(' FOR PLATE NUMBER ',10,' ENTER RADIUS OF ,/ * CHARACTERISTIC CIRCLE AT WHICH STRESSES ARE ,/ * TO BE COMPUTED TO PREDICT FAILURE'),/ READ(5,A) RCA(K) RCB(K)=RCA(K) NRCDOUT(K)=50 IF(NOPT4.EQ.3) GO TO 591 WRITE(6,834) 834 FORMAT(' ENTER THE FAILURE INDEXES FOR THE ',/ * HOFFMAN/TSAI-HILL CRITERIA ,/ * NOTE: FOR USING TSAI-HILL SET EQUAL THE COMPRESSION ',/ * AND TENSION ULTIMATES IN SIGMA X AND ',/ * ENTER: SIGMA X ULTIMATE-COMPRESSION ',/ * SIGMA X ULTIMATE-TENSION ',/ * SIGMA Y ULTIMATE-COMPRESSION ',/ * SIGMA Y ULTIMATE-TENSION ',/ * SIGMA XY ULTIMATE '),/ READ(5,C)(HFMC(I,K),I=1,5) GO TO 412
591 CONTINUE
WRITE(6,395) K
395 FORMAT(' ENTER THE FAILURE INDEXES FOR ',/ * PLATE NUMBER ',17,' (UNITS: IN/IN)'),/ READ(5,A) SALOW(K)
12 CONTINUE
IF(NOPT4.EQ.3) GO TO 17;91
IF(NOPT4.EQ.1) GO TO 591
GO TO 262
221 CONTINUE
IF(NOPT4.EQ.2) WRITE(6,555)
IF(NOPT4.EQ.4) WRITE(6,556)
555 FORMAT(' AVERAGE STRESS CRITERION '),/ 556 FORMAT(' POINT STRESS CRITERION '),/ AO IS THE CHARACTERISTIC DISTANCE OVER WHICH',/ STRESSES ARE AVERAGED AND COMPARED WITH UNNOTCHED',/ STRENGTHS TO PREDICT FAILURE'),/ DO 226 K=1,NLIM
IF(BPR.NE.0.0.AND.BPR.NE.1.0) GO TO 531 WRITE(6,225) K
225 FORMAT(' INPUT AO FOR EACH OF THE THREE PLY FAILURE',/ * MODES OF PLATE NO',15,' '),/ AOINT = NET SECTION ',/ AOBR = BEARING ',/ AOSO = SHEAR OUT ',/ N=NUMPLY(K)
WRITE(6,532)
531 FORMAT(' ENTER AO VALUES CORRESPONDING TO THE THREE FAILURE MODES IN PLATE NO.15,')
532 FORMAT(' AONT,AOBR,AOSO')
533 CONTINUE
WRITE(6,533)
534 FORMAT(' TO AVOID LENGTHY RUN TIMES DUE TO STRESS FIELD RECOMPUTATION SPECIFY THE NUMBER OF ULTIMATE PLY FAILURES AFTER WHICH JOINT FAILURE WILL BE PREDICTED')
535 READ(5,N) NULTF
226 CONTINUE
291 CONTINUE
670 CONTINUE
WRITE(6,228)
228 FORMAT(' FOR PLATE NO.15, ENTER THE THREE STRENGTHS')
229 CONTINUE
672 WRITE(6,674)
227 FORMAT(' INPUT AONT, AOBR, AND AOSO')
531 CONTINUE
WRITE(6,532)
532 FORMAT(' ENTER AO VALUES CORRESPONDING TO THE THREE FAILURE MODES IN PLATE NO.15,')
533 FORMAT(' AONT, AOBR, AOSO')
534 FORMAT(' TO AVOID LENGTHY RUN TIMES DUE TO STRESS FIELD RECOMPUTATION SPECIFY THE NUMBER OF ULTIMATE PLY FAILURES AFTER WHICH JOINT FAILURE WILL BE PREDICTED')
535 READ(5,N) NULTF
226 CONTINUE
291 CONTINUE
670 CONTINUE
WRITE(6,228)
228 FORMAT(' FOR PLATE NO.15, ENTER THE THREE STRENGTHS')
229 CONTINUE
672 WRITE(6,674)
227 FORMAT(' INPUT AONT, AOBR, AND AOSO')
531 CONTINUE
WRITE(6,532)
532 FORMAT(' ENTER AO VALUES CORRESPONDING TO THE THREE FAILURE MODES IN PLATE NO.15,')
533 FORMAT(' AONT, AOBR, AOSO')
534 FORMAT(' TO AVOID LENGTHY RUN TIMES DUE TO STRESS FIELD RECOMPUTATION SPECIFY THE NUMBER OF ULTIMATE PLY FAILURES AFTER WHICH JOINT FAILURE WILL BE PREDICTED')
535 READ(5,N) NULTF
226 CONTINUE
291 CONTINUE
670 CONTINUE
WRITE(6,228)
228 FORMAT(' FOR PLATE NO.15, ENTER THE THREE STRENGTHS')
229 CONTINUE
672 WRITE(6,674)
CONTINUE
IF(NGT(4,NE.4)) GO TO 261
DO 319 K=1,NLIM
N=NUMPILY(K)
WRITE(6,330) K
320 FORMAT(17) SASCJ ASSUMES A BILINEAR PLY BEHAVIOR. THE '...
* INITIAL MODULUS, K1, IS COMPUTED BY THE CODE; '...
* THE REDUCED MODULUS, K2, FOR INITIAL FAILURE; '...
* IN NET SECTION, SHEAROUT OR BEARING IS COMPUTED; '...
* BY THE FORMULA K2=ALPHAK1,'...
* FOR PLATE NUMBER 135, 'INPUT ALPHA VALUES FOR '...
* NET SECTION, SHEAROUT AND BEARING FAILURE ';...
READ(5,*), AF1,AF2,AF3
DO 321 I=1,N
DEL(I,K)=AF1
CMK(I,K)=AF2
DEL(I,K)=AF3
321 CONTINUE
WRITE(6,389)
389 FORMAT(17) INPUT SCALE FACTORS FOR P ULTIMATE '...
* CALCULATION SUCH THAT P(ULT)BETA4(INITIAL) '...
* INPUT DETAIL FOR NET SECTION ULTIMATE '...
* BETA3 FOR BEARING ULTIMATE '...
* BETA3 FOR SHEAROUT ULTIMATE ')
READ(5,*) PALT(3,K),PALT(2,K),PALT(1,K)
319 CONTINUE
391 CONTINUE
IF(BPR.EQ.0.0) GO TO 262
do dlim(K)=10.0
CMK(K)=CMCJ I=1,312
WRITE(6,231) K
231 FORMAT(17) INPUT THE APPROXIMATE INTERLAMINAR SHEAR STRAIN '...
* ULTIMATE FOR DELAMINATION PREDICTION IN PLATE NO.'...
* (UNIT: IN/IN ')
READ(5,*) GAMMK(1)
312 CONTINUE
262 CONTINUE
CASE HEADING
WRITE(6,145)
143 FORMAT(17) 'PROGRAM SASCJ' ')
IF(NSDL.EQ.1.AND.BPR.EQ.1) WRITE(6,633)
IF(NSDL.EQ.2.AND.BPR.EQ.1) WRITE(6,634)
633 FORMAT(2X,'A SINGLE LAP SHEAR JOINT WILL BE ANALYZED’ /)
634 FORMAT(2X,'A DOUBLE LAP SPEAR JOINT WILL BE ANALYZED’ /)
IF(BPR.EQ.0.0) WRITE(6,683)
IF(BPR.EQ.1.0) WRITE(6,682)
IF(BPR.EQ.0.0.AND.BPR.EQ.1.0) WRITE(6,683) BPR
881 FORMAT(2X,'WITH A LOADED HOLE' /)
882 FORMAT(2X,'WITH AN OPEN HOLE' /)
558 FORMAT(2X, 'AN AVERAGE STRESS CRITERION WILL BE USED',/)
       DO 631 I=1,NLIM
           WRITE(6,632) I
  632 FORMAT(2X, 'PLATE NUMBER',I5,/)
       N=NUMPLY(1)
           WRITE(6,633)
  633 FORMAT(2X, 'LAMINATE STRENGTH',/)
           WRITE(6,677) (PST[i]=1.1), LL=1.4)
  677 FORMAT(2X, 'NET SECTION ULTIMATE (COMP) = ', D9.5, ' PSI',/)
       * NET SECTION ULTIMATE (COMP) = D9.5, PSI',/)
       #2X, 'BEARING ULTIMATE = ', D9.5, PSI',/)
       #2X, 'SHEAROUT ULTIMATE = ', D9.5, PSI',/)
           WRITE(6,644)
  644 FORMAT(2X, 'PLATE NUMBER', I5/
           WRITE(6,645) DONT(I), DOBR(I), DOSO(I)
  645 FORMAT(2X, 'DONT = ', D9.5, ' INCHES',/)
       #2X, 'DOBR = ', D9.5, ' INCHES',/)
       #2X, 'DOSO = ', D9.5, ' INCHES',/)
           WRITE(6,646)
  646 FORMAT(2X, 'MAXIMUM STRAIN CRITERION WILL BE USED',/)
           WRITE(6,857) I
  857 FORMAT(2X, 'PLATE NUMBER', I5,/)
           WRITE(6,825) SALOM(II)
  825 FORMAT(2X, 'CHARACTERISTIC RADIUS = ', D9.5, ' IN/IN',/)
           WRITE(6,653)
  653 FORMAT(2X, 'CONTINUE', GO TO 627)
  627 CONTINUE
           WRITE(6,656)
  656 FORMAT(2X, 'CONTINUE', GO TO 631)
           WRITE(6,659)
  659 FORMAT(2X, 'CONTINUE', GO TO 644)
        END

581 IF(LLP.NE.0.AND.BPR.NE.I.0)
           DO 600 I=1,10
  600 WRITE(6,662) DONT(I), DOBR(I), DOSO(I)
  662 FORMAT(2X, 'PLATE NUMBER ', I5/,)
           WRITE(6,665) DONT(I), DOBR(I), DOSO(I)
  665 FORMAT(2X, 'DONT = ', D9.5, ' INCHES',/)
       #2X, 'DOBR = ', D9.5, ' INCHES',/)
       #2X, 'DOSO = ', D9.5, ' INCHES',/)
           WRITE(6,666)
  666 FORMAT(2X, 'CONTINUE', GO TO 631)

610 IF(LOB.GT.1)
           END

561 IF(IIBP.EQ.1)
           DO 22 IL=1,15P
  22 CONTINUE

427 CONTINUE

CALCULATE THE PLY FOUNDATION MODULI AND
FAILURE LOADS

130 IF(NP.NE.0.0.AND.BPR.NE.1.0) HBP=2
       IF(NP.EQ.1) NLIM=2
       GO TO 71 LOP=1.NLIM2
       DU 22 IL=1,NBP
       DU 20 K=1.NLIM

170 INITIALIZE PARAMETERS FOR COLLOCATION

210 NT=7
       NOUT=50
       NCOL=10
       NH=4*NHCL
       CONTINUE CASE HEADING
       IF(LOM.GT.1) GO TO 23

120
IF (IL.EQ.J) GO TO 23
WRITE (6, 871) K
871 FORMAT (9X, 'OOGYMETRY OF PLATE NO ', I5..."
872 FORMAT (9X, 'COORDINATES OF CORNER VERTEXES ')
IF (K.EQ.1) WRITE (6, 873) XCK(1), YCK(1), XCK(2), YCK(2)
873 FORMAT (9X, 'X...'
874 FORMAT (9X, 'X...'
AXD(*AXD.
875 FORMAT (9X, 'FASTENER HOLE DIAMETER = ', 2X, F7.3, 4X)
ED = DBE(XCCK, 1)/AXD
879 FORMAT (9X, 'W/H D RATIO = ', 2X, F7.3, 4X)
WRITE (6, 879) HD
23 CONTINUE
PROCESS INPUT DATA ON PLATE GEOMETRIES
WTH = YCCK(2) - YCCK(1)
LM1 = LOM
CALL POLY(JK, XCJ, YCJ, ASJ, MCOL, LTNCM, BPR, IL)
CALL CIRCCH(A3T, JK, LTNCM, BPR, IL)
WRITE (6, 876) EQ, 1 OR NOPT4.EQ.3) CALL RCON(K)
IF (NOPT4.EQ.2) CALL PSTR53(K, LTNCM, BPR, IL)
IF (NOPT4.EQ.4) CALL AVSTRS(K, LTNCM, NVD, BPR, IL)
PERFORM FINITE GEOMETRY ANALYSIS FOR STRESS/DISPLACEMENT
STATE, COMPUTE FOUNDATION MODULI AND FAILURE VALUES
CALL FDEOMKH(K, NOPT4, ITT)
IF (BPR.NE.0) AND (BPR.NE.1) AND (IL.EQ.1) GO TO 21
IF (BPR.NE.1) AND (LM1.NE.1) CALL FBOLT(AMOK, K, NOPT1, LM1)
21 CONTINUE
20 CONTINUE
22 CONTINUE
IF (BPR.EQ.1) GO TO 410
PREPARE INPUT FOR SEQUENTIAL PLY FAILURE PREDICTION
IF (LM1.NE.1) GO TO 61
N = NPILY(I)
30 PLYK(I) = ANG(M, 1)
31 CONTINUE
CALCULATION OF FASTENER STIFFNESSES.
C 00006560
FA30+FASV/(2.*1.+FASV))
FASLAM+3.*1.+FASV)/(7.+5.*FASV)
FASR=FASR/2.
FAS=ACOS(-1.)*FASR*X2
FASI=ACOS(-1.)*FASR*X4/4.
FASSS=FASLAM+FAS0+FASA
FASBS=FASEMFA5I

INITIALIZATION
IFCLOM.GT.1) GO TO 72
ITT=0
NTFL*0
JNT=1
P=0.
DELP=1000.
JO 5012 I=1,100
NPNI(I,1)=1
NPNI(I,2)=I+NPNI(I,1)
UNI(I)=0.
GAMNI(I)=0.
MDAM(I)=0.
MDAM(I)=0.
PNI(I)=0.
MARK(I)=0.
3012 BARU(I)=0.
72 CONTINUE
INCREMENTAL LOADS TO PLY FAILURE, PLY FAILURE
MODES, AND FRACTIONAL STIFFNESS LOSSES ARE
CALCULATED FOR EACH PLY FROM TOP TO BOTTOM
UNTIL FINAL JOINT FAILURE
90 CONTINUE
ITT=ITT+1
CALL CENTER(R,H,FAS5,FASBS,P,DELP,ITT)
CALL SOLVE(U,H,P,DELP,MSOL,ITT)
CALL FAIL(GAMDL,.,H,P,DELP,SPR,AST,MT,PFAl,ANCl,NT,
IMOUT,HP,NTFL,JO,ITT,NTFL)
CALL PRINT(U,P,DELP,PFAl,ANCl,SPR,NODE,IOUKT,NT,
MPS,MSOL,ITT)
IF(JNT.EQ.90) GO TO 410
IF(JNT.EQ.0) GO TO 90
IF(JNTFL.EQ.0.AND..LIM2.GT.1) GO TO 90
71 CONTINUE
410 STOP
END

SUBROUTINE STRTH(H,ES1,ES3,ESS,AFl,AF2,AF4,K)
IMPLICIT REAL(A-H,O-Z)
DIMENSION AIV(3,3),AVH(3),MD(1),NV(3)
DIMENSION NPLY(2),NUMPL(2),AND(5,2),IPLY(100,2)
DIMENSION NV(25),PSM(3),SOI(3),E32(2),ESS(2)
DIMENSION E1(2),E2(2),O12(2),V12(2),V21(2)
COMM/HYP,PLY,NUMP,Y,ANG,PLY
COMM/MCO1,E1,E2,012,V12,V21
COMM/MHA1,A
COMPUTE LAMINATE FAILURE LOADS BASED ON MAXIMUM FIBER STRAINS FOR EACH FAILURE MODE.

CALL AMATRIX(H,K)

IF(1) = 4

CALL LINVERSE(A,H,IA,AINV,IODT,HW,IER)

DO 10 KK = 1,3

DO 20 II = 1,3

NV(II) = 0

10 AVN(II) = 0.0D0

IF(KK.EQ.1) NV(1) = 1

IF(KK.EQ.2) NV(2) = -1

IF(KK.EQ.3) NV(3) = 1

DO 13 II = 1,3

DO 15 JJ = 1,3

AVN(IJ) = AVN(II) * AINV(II,JJ) * NV(JJ)

15 CONTINUE

NP = NUMPLY(K)

SMX = 0.0D0

RAD = DARCOS(-1.0D0/180.0D0)

DO 25 II = 1, NP

TH = ANG(II,K) * RAD

E11 = DCSIN(TH) * (2 * AVN(1) + AVN(2) * DCSIN(TH) + 2 * DCSIN(TH) * DCSIN(TH))

IF(KK.NE.1) GO TO 65

EPRT = E11 / ES2(K)

65 EPRT = E11 / ES1(K)

DO 30 60 TO 75

EPRT = E11 / ES2(K)

75 EPRT = E11 / ES1(K)

CONTINUE

IF(DABS(SMX).LT.DABS(EPRT)) SMX = EPRT

25 CONTINUE

IF(DABS(SMX).LT.1.0D0-10) GO TO 555

PSMX(KK) = ES(K) * W012(K)

DO 100 10 TO 100

555 CONTINUE

PSMX(KK) = DABS(1.0D0/SMX)

100 CONTINUE

AF1 = PSMX(1)

AF2 = PSMX(2)

AF3 = PSMX(3)

RETURN

END

SUBROUTINE POLY(J,K,XC,YC,WC,HST,NCOL,LTNCH,BPR,IL)

IMPLICIT REAL*(A-H,O-Z)

DIMENSION XC(2,3),YC(2,3),A1(400),A2(400),XB(400)

DIMENSION YB(400),T(400),A1A(4),A2A(4)

CALL LH/CHT/XB,YB,A1,A2,T

ARRAY COLLOCATION POINTS AROUND EXTERIOR BOUNDARY AND APPLY STRESS BOUNDARY CONDITIONS.
DO 120 I=1,4
A1(I)=0.
A2A(I)=0.
120 CONTINUE
M=DABS(YC(K,2)-YC(K,1))
IF(LTNCH.EQ.1) A1A(I)+=1000.0
IF(LTNCH.EQ.2) A1A(I)+=-1000.0
IF(BPR,NE.0.0) A1A(I)+=A1A(I)
IF(LTLE.EQ.0) A1A(I)+=0.0
A1+DABS(A1A(I))
J=0
XC(K,3)=XC(K,1)
YC(K,5)=YC(K,1)
PI=DARCS(1.000)
DAT=P/NCOL
DO 10 I=1,4
X=XCC(K,I)-XC(K,1)
Y=YCC(K,I)-YC(K,1)
IF(X.EQ.0.) X=1.0D-6
IF(Y.EQ.0.) Y=1.0D-6
TH=DAT*10.0
THB=TH+(U/DARCOS(1.0D1))
DX=(XCC(K,I)-XC(K,1))/NCOL)
DY=(YCC(K,I)-YC(K,1))/NCOL)
DO 20 II=1,NCOL
J=J+1
IF(I.EQ.1.OR.I.EQ.1) GO TO 23
YB(J)+YCC(K,I)
XB(J)=XCC(K,I)+DX*(II+1.0)
IF(II.EQ.1) XB(J)+XCC(K,II+1.0D2.)
GO TO 24
23 CONTINUE
IF(XCC(K,3).NE.0.0) .GO TO 26
IF(I.EQ.3) GO TO 24
ADT=DAT*100
XB(J)+YCC(K,3)*DCCOS(1.0D1)*ADT)
YB(J)+YCC(K,3)*USIN(1.0D1)*ADT)
THB=(PI/2.0)*ADT-T=
GO TO 24
26 CONTINUE
YB(J)+(K,1)+(YB(I)+)*(1.0D2.)
IF(II.EQ.1) YB(J)+C(K,1)+*(DY/2.)
XB(J)+XCC(K,1)
24 T(J)=14
A1(J)=A1A(I)
A2(J)=A2A(I)
20 CONTINUE
10 CONTINUE
RETURN
END

SUBROUTINE CIRC(W,A3T,JK,LTNCH,BPR,IL)
IMPLICIT REAL*8(A-H,O-Z)
DIMENSION X(400),Y(400),THETA(400),A1(400),A2(400)
DIMENSION X8(400),Y8(400)
COMMON/FB1,BSTR,XSTR
COMMON/CMT1/XB,YB,A1,A2,THETA
COMMON/CMT2/X,Y,HPST,HAST

124
COMMON/EL./A.B.N
ARRAY COLLOCATION POINTS AROUND INNER BOUNDARY AND APPLY BEARING STRESS IN A COSINUSOIDAL DISTRIBUTION

CON=1.0
XSTR=AST
BSTR=(2.*XSTR*YSTR)/(DARCOS(CON)*2)
IF(SPR.NE.0.0.AND.SPR.NE.1.0.AND.IL.EQ.1) BSTR=0.0
IF(3*PR.EQ.1.0) BSTR=0.
N4=N4+4
NQ=NQ+4
DO 20 I=1,N
JK=JK+1
TH=(TH-I)*180/CON
Y(I)=DSIN(TH)
Y(I)=BDSIN(TH)
CS=X(I)*Y(I)/BDSIN(Y(I))
IF(Y(I).GT.0) THTA=TH+DARCOS(CON)/2.
TH(TA(JK)+DARCOS(CON)/2.
THTA(JK)=THTA(JK)+180./DARCOS(CON)
IF(T(HM.EQ.2) GOTO 25
IF(I.GT.(NQ+1).AND.I.LT.(N-NQ)) GOTO 204
GOTO 30
20 CONTINUE
A1(JK)=Q.
A2(JK)=Q.
X(JK)=X(I)
Y(JK)=Y(I)
GOTO 40
204 CONTINUE
RETURN
END

COMMON/RCDUT(K).

COMMON/ELPA.X,NOUT
RAD=DARCOS(-0.1D1)/180.
N1=NRC(K)
DO 40 I=1,N1
TINCR=360./NRC(K)
THIA(I-1)=TIHCRNRAD
C=DCOS(THETA)
S=DSIN(THETA)
SUBROUTINE PSTR5(K,NCS,BPR,IL)

Specifies discrete coordinates of points at which stresses are required for the point stress criterion.

IMPLICIT REAL*8(A-H,O-Z)

DIMENSION X(400),Y(400),DONT(2),DOBR(2)

DIMENSION DOSO(2),NPLY(2),NUMPLY(2),ANG(5,2)

DIMENSION IPLY(100,2),AONT(2,2),AOSR(2,2),AOSO(2,2)

COMMON/CMT/X,Y,NPST,NAST
COMMM/PST/DONT,DOBR,DOSO

COMMON/LPLY,NPLY,NUMPLY,ANG,IPLY

COMMON/ADV/AONT,AOSR,AOSO

 Continue
RETURN

END

SUBROUTINE ASTR(K,NCS,ADV,BPR,IL)

Specify coordinates of points along which stresses will be averaged for the average stress criterion.

IMPLICIT REAL*8(A-H,O-Z)

DIMENSION X(400),Y(400),DONT(2),DOBR(2)

DIMENSION DOSO(2),NPLY(2),NUMPLY(2),ANG(5,2)

DIMENSION IPLY(100,2),AONT(2,2),AOSR(2,2),AOSO(2,2)

COMMON/ADV/AONT,AOSR,AOSO
COMMON/EL, AX, BX, NOUT 00009560
COMMON/CMTZ/X, Y, NPST, NAST 00009570
COMMON/PSCI, DONT, DDBR, DOSO 00009580
COMMON/LYP/NPLY, NUMPLY, ANG, IPLY 00009590
ANT+DONT(K) 00009600
ABR+DDBR(K) 00009610
ASO+DOSO(K) 00009620
IF(BPR.EQ.0.0 OR BPR.EQ.1.0) GO TO 23 00009630
ANT+DONT(1L,K) 00009640
ABR+DDBR(1L,K) 00009650
ASO+DOSO(1L,K) 00009660
25 CONTINUE 00009670
L+NOUT 00009680
SO=1.0 00009690
IF(NCS.EQ.1) SO=-1.0 00009700
ANDO=ANT/FLOAT(NAVD) 00009710
DO 20 I=1, NAVD 00009720
L=L+1 00009730
K=0.0 00009740
20 Y(L)=BX+ANDO/(I-1)*ANDO 00009750
ANSO=ASO/FLOAT(NAVD) 00009760
DO 30 I=1, NAVD 00009770
L=L+1 00009780
X(L)=X(BX+ANSO/(I-1)*ANSO) 00009790
30 Y(L)=BX 00009800
ANBR=ABR/FLOAT(NAVD) 00009810
DO 40 I=1, NAVD 00009820
L=L+1 00009830
X(L)=X(BX+ANBR/(I-1)*ANBR) 00009840
40 Y(L)=0.0 00009850
NAST=3*NAVD 00009860
N1=NOUT+1 00009870
N2=N1+NAST 00009880
HN=NOUT+3*NAVD 00009890
RETURN 00009900
END 00009910

SUBROUTINE FIGEOM(KJ,NOPT4,ITT) 00009920
FIGEOM PERFORMS A FINITE GEOMETRY ANALYSIS 00009930
USING THE BOUNDARY COLLOCATION TECHNIQUE 00009940
IMPLICIT REAL(A-H,O-Z) 00009950
DIMENSION A(3,3), AI(3,3), AZ(5), WKK(121), BC(400) 00009960
DIMENSION CM(4), H(2) 00010000
COMPLEX*16 GRS(122) 00010010
COMPLEX*16 CM(196,124), CMG(196,121), CMCTCM(121,121), RHS(121) 00010020
COMMON/ROOTS/R1, R2 00010030
COMMON/TERMS/P1, Q1, P2, Q2 00010040
COMMON/ELP, AX, BX, NOUT 00010050
COMMON/RTM, NT, NB 00010060
COMMON/ANM/A 00010070
COMPLEX*16 Z(4), Z1, Z2, Q1, Q2, P1, P2, R1, R2, HA(1488) 00010080
C 00010090
127
AMATRIX calculates the laminate 'A' matrix

CALL AMATRIX(H,KJ)

I = 3
.DGT=4
.A = 3

I INVF inverts the 'A' matrix

CALL INVF(A,H.KJ,IER)

°DEG=4

AZ(1)=AI(1,1)/AI(2,2)
AZ(2)=(2.*AI(1,1)+AI(3,3))/AI(2,2)
AZ(4)=2.*AI(1,2)/AI(2,2)
AZ(5)=1.000

ZRPOLY finds the roots of the characteristic equation

CALL ZRPOLY(AZ,NDEGZ,IER)

Z(2) and Z(4) are the complex conjugates of Z(1)
AND Z(5) respectively

R1=Z(1);
R2=Z(5);

The two roots must be checked for a unitary component
in either the real or imaginary part; such an
occurrence signifies a quasi-isotropic layup and
the value must be perturbed slightly in order to
avoid a singular matrix

CH(1)=R1
CH(2)=(0.0,-1.0)*R1
CH(3)=R2
CH(4)=(0.0,-1.0)*R2
DO 10 IJK=1,4
IF(DABS(CH(IJK)).LT.1.0D-10) CH(IJK)=1.0D-10
10 CONTINUE

R1=CCMPLX(CH(1),CH(2))
R2=CCMPLX(CH(3),CH(4))

Constants P1,P2,Q1,Q2 are needed for stress calculations

P1=AI(1,1).*R1**2+AI(1,2).*AI(1,3).*R1
P2=AI(1,1).*R2**2+AI(1,2).*AI(1,3).*R2
Q1=AI(2,2).*R1+AI(1,2).*AI(2,3)
Q2=AI(2,2).*R2+AI(1,2).*AI(2,3)

Inputs AIN1(I),AIN2(I) etc. refer to boundary conditions

NT=4*NT
NT=8*NT

128
SUBROUTINE AMATRX(H, K)

ASSEMBLE THE A MATRIX

IMPLICIT REAL*8(A-H,O-Z)
DIMENSION A(3,3), ANG(5,2), H(2), NPLY(2), NUMPLY(2)
DIMENSION E1(2), E2(2), QI2(2), VI2(2), VZ2(2)
DIMENSION IPLY(100)
COMMON/HGD/E1, E2, QI2, VI2, VZ2
COMMON/LYP/ NPLY, NUMPLY, ANG, IPLY
COMMON/AMT/A
THKNES=NPLY(K)*K)
DENO=1.-E1(K)*V12(K)*E2(K)
Q11=E1(K)/DENO
Q12=Q12*K)
DO 10 I=1,3
DO 20 J=1,3
A(I,J)=0.
A(I,J)=(Q11-Q12-2.*Q33)*M3*(Q12-Q22+2.*Q33)*M3)*M3)*M3)
DO 53 I=1,3
DO 55 J=1,3
A(I,J)=A(I,J)+THKNES
CONTINUE
RETURN
END

SUBROUTINE CMATBC, CMCTCM, CMC, CM, RHS, GRHS, NT4, NT8, NT8P4, NT6P2.

MAT OUTPUTS STRESSES, STRAINS, AND DISPLACEMENTS AT SPECIFIED COORDINATES

IMPLICIT REAL*(A-H,O-Z)
DIMENSION RAC(2),RBC(2),NRCOUT(2)
DIMENSION ASX(400),ASXY(400)
COMMON/XXY/ASX,ASXY
COMMON/ROOTS/R1,R2
COMMON/TERMS/Q1,Q2
COMMON/CMT1/X,Y,AIN1,AIN2,THTA
COMMON/CMT2/XOUT,YOUT,HTST,NAST
COMMON/RBC2/FUR,FTHT,FSMR
COMMON/QMT/RHT,REPX,REPY,REPX
COMMON/RC/RCA,RBC,NRCOUT
COMMON/ELP/AX,BX,HOUT
COMMON/SERV/NT,NB
DIMENSION THTA(400),X(400),Y(400),AMAT(3,3)
DIMENSION AIN1(400),AIN2(400),BC(NB2)
DIMENSION XOOUT(400),YOOUT(400),NWK(NT&8P1)
DIMENSION FUR(400),FTHT(400),FSMR(400)
DIMENSION RTHT(400),REPX(400),REPY(400)
COMPLEX*16 CMCTCM(NT&8P1,NT&8P1),RHS(NT&8P1),PH1D,PH1D,XETA1,XETA2
COMPLEX*16 CMN8B(NT&8P4),CMC(NB2,NT&8P1),Z1,Z2,Z11,Z12,Z11,R1,P2
COMPLEX*16 T11,T12,T21,T22,P1,P2,P12,P21,P22
COMPLEX*16 P1,P2,Q1,Q2,DCMPLX,C0,CSUM,GRHS(NT&8P2)
COMPLEX*16 PH1DP,PH1DP,PH1DNP,PH1DNP
COMPLEX*16 PH1P,PH1DP,PM11,PM12,PM11,PH12
COMPLEX*16 SV11,SV12,SV21,SV22,RB11,RB21,RB21,RB21
COMPLEX*16 R11,R21,P11,P12,P21,P22,WKH(WKH)
A=AX
B=BX
C0*(0,0,1,0)
R11=(Q1-P1*R1)/(A COM*R1
R21=(Q2-P2*R2)/(A COM*R2
REALR1=R1
REALR2=R2
REALP1=P1
REALP2=P2
REALQ1=Q1
REALQ2=Q2
RR11=RB11
RR21=RB21
AIMR1=COMR1
AIMR2=COMR2
AIMQ1=COMQ1
AIMQ2=COMQ2
ARB11=COMRB1
ARB21=COMRB2
R1B=DCMPLX(REALR1,AIMR1)
R2B=DCMPLX(REALR2,AIMR2)
P1B=DCMPLX(REALP1,AIMQ1)
P2B=DCMPLX(REALP2,AIMQ2)
Q1B=DCMPLX(REALQ1,AIMQ1)
Q2B=DCMPLX(REALQ2,AIMQ2)

130
REAL1=DCOS(THETA1)
REAL2=DCOS(THETA2)

CM(J,1)=REAL1=0.0000
CM(J,2)=REAL2=0.0000

IF(CDABS(REAL1).LE.1.D-16)REAL1=0.0000
IF(CDABS(REAL2).LE.1.D-16)REAL2=0.0000

normal & tangential stress boundary conditions are imposed
CONTINUE 00012570
DO 195 I=1,HB2
DO 196 J=1,NT9
REAL1=CM(I,J)
AIMO1=CM(I,J)
IFDCABS(REAL1).LE.1.D-16)REAL1=0.0D0
IFDCABS(AIMO1).LE.1.D-16)AIMO1=0.0D0
CM(I,J)=CMPLX(REAL1,AIMO1)
AIMO2=AIMO1
CM(I,NT4+J)=CMPLX(REAL1,AIMO2)
CONTINUE 00012560
196 CONTINUE
199 CONTINUE
DO 295 I=1,HB2
DO 296 J=1,2
REAL1=CM(I,NT8+J)
AIMO1=CM(I,NT8+J)
IFDCABS(REAL1).LE.1.D-16)REAL1=0.0D0
IFDCABS(AIMO1).LE.1.D-16)AIMO1=0.0D0
CM(I,NT2+J)=CMPLX(REAL1,AIMO1)
AIMO2=AIMO1
CM(I,NT3+2+J)=CMPLX(REAL1,AIMO2)
CONTINUE 00012559
296 CONTINUE
SV11=(P2*X1B-Q2*X2B)/(Q1*X2B-Q2*X1B)
SV12=(-P2*X2B-Q2*X1B)/(Q1*X2B-Q2*X1B)
SV21=(Q1*X1B-Q1*X2B)/(Q1*X2B-Q2*X1B)
SV22=(Q1*X1B-Q2*X1B)/(Q1*X2B-Q2*X1B)
DO 139 I=1,HB2
CONTINUE 00012550
139 CONTINUE
CM(1,2NT8+1)=CM(1,1)*RB21/RB11+CM(1,2NT8+1)
CM(1,4NT8+1)=CM(1,1)*RB18/RB11+CM(1,4NT8+1)
CM(1,6NT8+1)=CM(1,1)*RB28/RB11+CM(1,6NT8+1)
CM(1,1)=(0.0,0.0)
CONTINUE 00012540
139 CONTINUE
DO 141 I=1,HB2
DO 142 J=2,HT8
CONTINUE 00012530
142 CONTINUE
CM(I,J)=CM(I,J)
CM(I,NT8+2)=CM(I,NT8+3)
CM(I,NT8+4)=CM(I,NT8+4)
CONTINUE 00012520
141 CONTINUE
DO 95 I=1,HB2
DO 96 J=1,HT8P1
REAL1=CM(I,J)
AIMO1=CM(I,J)
IFDCABS(REAL1).LE.1.D-16)REAL1=0.0D0
IFDCABS(AIMO1).LE.1.D-16)AIMO1=0.0D0
CM(I,J)=CMPLX(REAL1,AIMO1)
AIMO2=AIMO1
CONTINUE 00012510
CMC(I,J) = CMPLX(REAL1,AIMG2)
96 CONTINUE
95 CONTINUE
90 DO 120 I=1,NB
J=1+2
120 B(J-1) = AIMAG1(I)
DO 100 J=1,NT8P1
DO 100 J=1,NT8P1
CSUM + (0,0,0,0)
DO 110 K=1,N82
110 CSUM = CSUM + CM(CM(1)) + CSUM
CMCTCM(I,J) = CSUM
100 CONTINUE
DO 130 J=1,NT8P1
CSUM = (0,0,0,0)
DO 140 K=1,N82
140 CSUM = CSUM + B(J) + CSUM
130 IJOB = 0
H=1
M=1
CALL LEQC5(CMCTCM,1TBP1,NT8P1,RHS,M,NT8P1,1JOB,HA,WK,IEM)
GRHS1(J) = (RHS(2)+N1,J)+R821*RHS(4+NT)*R811+RHS(6+NT)*R821+R811
GRHS(8+NT+1) = R511*(S+NT+1)+R511*(S+NT+1)+R512
GRHS(8+NT+2) = R511*(S+NT+1)*R511*(S+NT+1)+SV21
DO 151 I=2,NT8
151 GRHS(I) = RHS(I-1)

STRESS AND STRAIN CALCULATION
NRC5=NOUT+1
IF(NOPT4.EQ.1.OR.NOPT4.EQ.3) NRCF=NOUT+NRCOUT(J)
IF(NOPT4.EQ.2) NRCF=NOUT+NPS
IF(NOPT4.EQ.4) NRCF=NOUT+NAST
DO 190 K=1,NRCF
190 Z1 = XOUT(K)+R1+YOUT(K)
Z2 = XOUT(K)+R2+YOUT(K)
Z11 = CSQRT(Z1)+A+R1+R125+R125
Z22 = CSQRT(Z2)+A+R2+R225+R225
XETA1(I) = (Z11+Z22)/(A+R1+R2+R125+R225)
IF(CDABS(XET1).LT.0.999) GO TO 400
GO TO 410
400 Z1 = -Z11
XETA1(I) = (Z11+Z22)/(A+R1+R2+R125+R225)
410 XETA2(I) = (Z11+Z22)/(A+R1+R2+R125+R225)
IF(CDABS(XETA2).LT.0.999) GO TO 420
GO TO 430
420 Z22 = Z22
XETA2(I) = (Z11+Z22)/(A+R1+R2+R125+R225)
430 CONTINUE
PH1DF + (0,0,0,0)
PH1DF = (0,0,0,0)
PH1DF = (0,0,0,0)
PH1DF = (0,0,0,0)
PH1DF = (0,0,0,0)
PH1DF = (0,0,0,0)
DO 170 N=1,NT
170 N=1,NT

133
SUBROUTINE FBOLT(ANK,W,H,K,NOPT1,1,M1)

FBOLT CALCULATES THE INDIVIDUAL PLY FOUNDATION MODULI AND THE INDIVIDUAL PLY LOADS

134
IMPLICIT REAL*(A-H,O-Z)

DIMENSION ATETAA(400), ANG(5,2), ASIGR(400), ASIGT(400), H(2)

DIMENSION ASIG1(400), ASIG2(400), ASIG6(400), UR(400), ANGK(5,2)

DIMENSION IPLY(100,2), NPLY(2), NUMPLY(2)

DIMENSION FK1(100), PLX(100)

DIMENSION E11(2), E22(2), ES(2), PMU12(2), PMU21(2)

DIMENSION RCA(2), RCB(2), HRC(2)

COMMON/STRES/ASIGR, ASIGT, ASIG1, ASIG2, ASIG6

COMMON/ELP/AX, BX, NOUT

COMMON/LYP/NPLY, ANO, IPLY

COMMON/FB2/UR, ATETAA, FSMR

COMMON/MOD/EL1.E22, ES1, PMU12, PMU21

COMMON/RC/RCA, RCB, HRC

COMMON/FCT/PLXPT

RAD* = DARCOS(-0.1D1)/130.

THETATOT=NPLY(K)*H(K)

NII=NUMPY(K)

CALCULATE DELEFF

WORK=0.

PLOADX=0.

IF(K.EQ.1) PLOAD=0.

DO 210 K=1, NOUT

TH1=ATETAA(K+1)-ATETAA(K)

TH2=(ATETAA(KK)+ATETAA(KK+1))/2.

THETA=TH2*TRAD

C=DCOS(THETA)

S=DSIN(THETA)

R=DSQRT(1.-(CM**2/AX**2+SN**2/BX**2))

FORCE=((FSMR(KK)+FSMR(KK+1))/2.*TRAD*THETATOT)

WORK=FORCE.*FORCE.*((UR(KK)+UR(KK+1))/2.)

PLOADX=PLOADX+FORCE*C

210 CONTINUE

PLOAD=PLOAD+PLOADX

DELEFF=WORK/PLOADX

CALCULATE PLY STRESSES FROM LAMINATE STRAINS

(SIGMA)K, K, RO = (Q)X(EPS)R, RO

NII=NPLY(K)

DO 100 J=1, NII

LP=IPLY(J, K)

THETA=ANG(LP, K)*TRAD

LII=1

LII=NOUT

NCAS=1

CALL QMATX(K, LII, LII, NCAS, NOPT1, RAD, THETA)

INTEGRATE AROUND CIRCULAR BOUNDARY FOR
INDIVIDUAL PLY LOADS AND COMPUTE FOUNDATION MODULI

NNN=112-1
PLoadX=0.
WK=0.
DO 70 I=LI1,NNN
TH1=(ATEAA(I+1)-ATEAA(I))/2.
TH2=(ATEAA(I)+ATEAA(I+1))/2.
THETA=TH2*RAD
C=DCOS(THETA)
S=DSIN(THETA)
FORC=(ASIGR(I)+ASIGR(I+1))/2.*RNTh*rad*H(K)
PLoadx=PLoadx*ORcrmg*FORCRTS
70 CONTINUE
FK1(I)=DAG(PLoadX*(H(K))#DEEFF))
P(I,0)=(I+1)*HNPLY(1))*PLoadX
100 CONTINUE
Ht=HNPLY(K)
NN=HNPLY(K)
DO 310 I=1,NN
DO 310 II=1,NN
IF(ILPLY(II).EQ.0 ANGK(I,K)=FKI(II)
IF(ILPLY(II).EQ.1 PLXPT(1)=PLX(II+(K-1)*NPLY(1)))
310 CONTINUE
NP=NUMPLY(K)
100 CONTINUE
COMPUTE TOTAL BEARING LOAD

IF(X.EQ.1) GO TO 611
PLXtot=0.
THM(1)*HNPLY(1)+H(2)*HNPLY(2)
BLoadX=(STRM(1)*COS(-1.000)*AXxH)/2.
Hn=HNPLY(I)+HNPLY(2)
DO 212 I=1,NN
PLXtot=PLXtot+PLX(1)
212 CONTINUE
611 CONTINUE
RETURN
END

SUBROUTINE FCrit(SALOH,H,WN5,AST,K,NOPT1,NOPT4,BPR,NAVD,IL)

FAILURE LOAD CALCULATION

IMPLICIT REAL*4(A-H,O-Z)
DIMENSION ASIO1(400),ASIO2(400),ASIO6(400),ASIGR(400)
DIMENSION VR(400),FSMR(400),ATEAA(400),ASIORT(400),NUMPLY(2)
DIMENSION ANG(5,2),ILPLY(100,2),HFMC(3,2),PLXPT(100),NPLY(2)
DIMENSION PNS(5,2),PBR(3,2),P50(3,2),PALT(3,2)
DIMENSION H(2), SALOH(2), SX(400), SXY(400), RCA(2), RCB(2), NRC(2) 00015560
DIMENSION AEPS(400), PPL(5,2), PSTC(3,3,2) 00015570
DIMENSION BPSTS(2,1,2,3) 00015580
COMMON/BP1,BPSTS 00015590
COMMON/RCA,RCA,RCB,NRC 00015600
COMMON/FRAY/RSTA,XSTR 00015610
COMMON/STRS2/AEP5 00015620
COMMON/FB2/UR, ATETA, FSMR 00015630
COMMON/FLX/FLXPT 00015640
COMMON/ELP/A.X, SX, NOUT 00015650
COMMON/HFF/HFNC 00015660
COMMON/LYP/NPLX, ANQ, IPLX 00015670
COMMON/FALS/PLR, PPT, PSJ, PALT 00015680
COMMON/PALS/PLX 00015690
COMMON/STRESS/ASIG, ASIGRT, ASIO1, ASIO2, ASIG6 00015700
COMMON/PSC2/PSTC 00015710
COMMON/PSC3/SX, SXY 00015720
IF((L.EQ.1.AND.(BPR.EQ.0.0 OR. BPR.EQ.1.0))) WRITE(6,49) K 07015740
59 FORMAT (//, 'ANALYSIS OF PLATE NO. , ') 00015750
IF(NOPT4.EQ.2) GO TO 20 00015760
IF(NOPT4.EQ.3) GO TO 40 00015770
IF(NOPT4.EQ.4) GO TO 40 00015780
HOFFMAN/TSAI-HILL CRITERIA 00015790
WRITE(6,10) 00015800
10 FORMAT (//, 'HOFFMAN/TSAI-HILL CRITERIA', /) 00015810
LI1=NOUT+1 00015820
LI2=L11+NRC(K) 00015830
NCAS+2 00015840
NN=NUMPLY(K) 00015850
DO 402 I=1,NN 00015860
THETA=ANQ(I,K)*RAD 00015900
CALL QMAT(K,LI1,LI2,NCAS,NOPT1,RAD,THETA) 00015910
PFAIL=1.0D10 00015920
NL=NRC(K) 00015930
IF(BPR.EQ.0.0) DSB=DAUBSPLXPT(I)) 00015940
IF(BPR.EQ.1.0) DSB=DAUBS(XSTR) 00015950
DO 404 J=1,NL 00015960
S1=ASIO1(J)*DSB 00015970
S2=ASIO2(J)*DSB 00015980
S6=ASIO6(J)*DSB 00015990
CALL HOFF(S1,S2,S6,A,B,K) 00016000
NN=NOUT+J 00016010
FOR EACH PLY TYPE FIND THE LOCATION AND MAGNITUDE 00016020
OF THE HIGHEST HOFFMAN/TSAI-HILL FAILURE INDEX VALUE 00016030
00016040
P1=(-B+DSGRT(BX2+4*A))/2.0A 00016050
P2=(-B+DSGRT(BX2+4*A))/2.0A 00016060
IF(P1.LT.0.D0)PF=P2 00016100
IF(P2.LT.0.D0)PF=P1 00016110
IF(P1.LT.P2.AND.P1.GT.0.D0) PF=P1 00016120
IF(P2.LT.P1.AND.P2.GT.0.D0) PF=P2 00016130
IF(DABS(PF).GT.PFAIL) GO TO 480 00016140
00016150
THE CORRESPONDING FAILURE LOAD IS OBTAINED FROM THE INDEX VALUE.

XULT = HFMC(I, K)
IF (ASIG1(LOC).LT.0.) XULT = HFMC(2, K)
IF (ASIG2(LOC).LT.0.) XULT = HFMC(4, K)
SULT = HFMC(5, K)
IF (ASIG6(LOC).LT.0.) SULT = HFMC(6, K)
SR1 = ASIG1(LOC)/XULT
SR2 = ASIG2(LOC)/XULT
SR6 = ASIG6(LOC)/SULT

IWRITE(6, 405) I, ANG(I, K), THETA, PFAIL, SR1, SR2, SR6

* THE HIGHEST FAILURE INDEX WAS FOUND AT 'D9.3,' DEGREES.

* THE CORRESPONDING FAILURE LOAD = 'D9.3,' LBS.

* THE STRESS RATIOS AT THIS LOCATION ARE:

* SIG1/XULT = 'D9.3,'/
* SIG2/XULT = 'D9.3,'/
* SIG6/SULT = 'D9.3,'/

PFL(I, K) = PFAIL

IF (BPR.EQ.0.0) GO TO 80
SFAIL = 1.0D10
DO 110 I = 1, NN
   110 IF (SFAIL.GT.PFL(I, K)) NPY = I

IWRITE(6, 771) PFL(I, K)

IF (SFAIL.GT.PFL(I, K)) WRITE(6, 50) I, ANG(I, K), THETA, PFAIL, SR1, SR2, SR6

* IS PREDICTED AT A JOINT LOAD OF 'D9.3,' LBS.

GO TO 80

POINT STRESS CRITERION

IF (IL.EQ.1.AND.(BPR.EQ.0.0.OR.BPR.EQ.1.0)) WRITE(6, 50)
50 FORMAT(//, ' POINT STRESS CRITERION', ')

HH = NUMPLY(K)
NCAS = 2
L11 = NOUT + 1
L12 = L11 + 2
IF (BPR.EQ.1.0.AND.NOPTI.EQ.2) HH = 3
DO 100 I = 1, HH
   100 THETA = ANG(I, K)*RAD
CALL QMATX(K, L11, L12, NCAS, OPTI, RAD, THETA)

IWRITE(6, 771) PFL(I, K)
IF(IL.EQ.,) FAC=BP
IF(IL.EQ.2) FAC=(1.-BP)/PLXPT(I)
BPST(K,1,IL,1)=SX(1)*FAC/(ASTMWW(K)*MNPLY(K))
BPST(K,1,IL,2)=SX(2)*FAC/(ASTMWW(K)*MNPLY(K))
BPST(K,1,IL,3)=SX(3)*FAC/(ASTMWW(K)*MNPLY(K))
GO TO 100

CONTINUE
IF(BPR.EQ.0.0) DSNI=ABS(PLXPT(I))
IF(BPR.EQ.1.0) PNT=DSN*PSTC(I1)/DABS(SX(I))
IF(SX(I).LT.0.) PNT=DSN*PSTC(2,1)/DABS(SX(I))
PSH=DSN*PSTC(4,1)/DABS(SX(3))
IF(BPR.EQ.0.0) WRITE(6,70) !ANOCZ.K),PNT
70 FORMAT(/' FOR PLY TYPE NUMBER ',13,' WITH ',/,' A PLY ORIENTATION OF ',D9.3,' DEGREES ',/,' NET SECTION FAILURE LOAD = ',D9.3,' LBS ',/,' BEARING FAILURE LOAD = ',D9.3,' LBS ',/,' SHEAR-OUT FAILURE LOAD = ',D9.3,' LBS ',/)

PSH=PNT
PB(R,I,K)=PBN
P30(I,K)=PSH
100 CONTINUE
IF(BPR.EQ.0.0) GO TO 80
N=NMPLY(K)
IF(BPR.EQ.1.0.AND.HOPT1.EQ.2) N=1
PFAIL1=1.0D10
PFAIL2=1.0D10
PFAIL3=1.0D10
GO TO 781
781 IF(PFAIL1.GT.PH(I,K)) NPY1=1
IF(PFAIL1.GT.PH(I,K)) PFAIL1=PH(I,K)
IF(PFAIL2.GT.PH(I,K)) NPY2=1
IF(PFAIL2.GT.PH(I,K)) PFAIL2=PH(I,K)
IF(PFAIL3.GT.PH(I,K)) NPY3=1
IF(PFAIL3.GT.PH(I,K)) PFAIL3=PH(I,K)
GO TO 813
IF(PFAIL1.GE.PFAIL2.OR.PFAIL1.GE.PFAIL3) GO TO 813
PFAIL1=PFAIL1*WTHH(K)*MNPLY(K)
WRITE(6,982) PFAIL1
WRITE(6,816)
GO TO 811
813 IF(PFAIL2.GE.PFAIL1.OR.PFAIL2.GE.PFAIL3) GO TO 812
PFAIL2=PFAIL2*WTHH(K)*MNPLY(K)
WRITE(6,982) PFAIL2
WRITE(6,815)
GO TO 811
812 IF(PFAIL3.GE.PFAIL1.OR.PFAIL3.GE.PFAIL2) GO TO 811
PFAIL3=PFAIL3*WTHH(K)*MNPLY(K)
WRITE(6,982) PFAIL3
WRITE(6,816)
811 CONTINUE
982 FORMAT(/' FOR THE LAMINATE WITH AN OPEN HOLE, FAILURE ',/,

' IS PREDICTED AT A JOINT LOAD OF ',D9.3,' LBS ',/)
814 FORMAT(/' PREDICTED FAILURE MODE IS NET SECTION',/)
815 FORMAT(/' PREDICTED FAILURE MODE IS BEARING FAILURE',/)
816 FORMAT(/' PREDICTED FAILURE MODE IS SHEAR-OUT FAILURE',/)
GO TO 80

AVERAGE STRESS CRITERION

139
40 CONTINUE

IF (IL.EQ.1.AND.(BPR.EQ.0.0 .OR. BPR.EQ.1.0)) WRITE(6,55)
55 FORMAT(' ' , ' AVERAGE STRESS CRITERION ' , '/', ')
L11=NOUT+1
NN=NUMPLY(K)
NCJ=2
IF (BPR.EQ.1.0 .AND. NLOPT1.EQ.2) NN=1
DO 105 I=1,NN

L12=NOUT+3

WRITE(6,55)
FORMAT(14)(AVERAGE STRESS CRITERION, A

CALL QMATX(K,L11,L12,NCAS,NLOPT1,RAD,THETA)

CALCULATE AVERAGE STRESS

SUM=0.
N1=1
N2=NAVAD
DO 200 IJ=N1,N2

200 SUM=SUM+XY(IJ)

AS1=SUM/FLOAT(NAVAD)
N1=NAVAD+1
N2=2*NAVAD
SUM=0.
DO 215 IJ=N1,N2

215 SUM=SUM+XY(IJ)

AS2=SUM/FLOAT(NAVAD)
SUM=0.
N1=2*NAVAD+1
N2=3*NAVAD
DO 220 IJ=N1,N2

220 SUM=SUM+XY(IJ)

AS3=SUM/FLOAT(NAVAD)
IF (BPR.EQ.0.0 .OR. BPR.EQ.1.0) GO TO 720
IF (IL.EQ.1) FAC=1.0
IF (IL.EQ.2) FAC=((1.0-BPR)/PLXPT(I))
BPSY(K,I,IL,1)=AS1*FAC/(AS1*TWTHMN(K)*NUMPLY(K))
BPSY(K,I,IL,2)=AS2*FAC/(AS2*TWTHMN(K)*NUMPLY(K))
BPSY(K,I,IL,3)=AS3*FAC/(AS3*TWTHMN(K)*NUMPLY(K))
GO TO 105

720 CONTINUE

IF (BPR.EQ.0.0) DSN=DABS(PLXPT(I))
IF (BPR.EQ.1.0) DSN=XSTR
PNT=DSNPSTC(I,1,K)/DABS(AS1)
PNT=DSNPSTC(I,2,K)/DABS(AS2)
PNT=DSNPSTC(I,3,K)/DABS(AS3)
PNT=DSNPSTC(I,4,K)/DABS(AS2)
IF (BPR.EQ.0.0) WRITE(6,75) I,ANG(I,K),PNT,PBN,PSH

75 FORMAT(14) FOR PLY TYPE NUMBER ' , ' WITH ' , '

A PLY ORIENTATION OF ', D.E., ' DEGREES ' , '
N ERT SECTION FAILURE LOAD = ', D9.3, ' LBS ' , '
BEARING FAILURE LOAD = ', D9.3, ' LBS ' , '
SHEAROUT FAILURE LOAD = ', D9.3, ' LBS ' , '

CONTINUE

105 IF (BPR.EQ.0.0) GO TO 80
N=NUMPLY(K)

140
IF(BPR.EQ.1.0 .AND. NOPT1.EQ.2) N=1
PFAIL1=1.0D10
PFAIL2=1.0D10
PFAIL3=1.0D10
DO 718 I=1,N
  IF(PFAIL1.GT.PNS(I,K)) PFAIL1=PNS(I,K)
  IF(PFAIL2.GT.PBR(I,K)) PFAIL2=PBR(I,K)
  IF(PFAIL3.GT.PSO(I,K)) PFAIL3=PBR(I,K)
  IF(PFAIL1.GT.PNS(I,K)) PFAIL1=PNS(I,K)
  IF(PFAIL2.GT.PBR(I,K)) PFAIL2=PBR(I,K)
  IF(PFAIL3.GT.PSO(I,K)) PFAIL3=PBR(I,K)
  IF(PFAIL1.GE.PFAIL2.OR.PFAIL2.GE.PFAIL3) N=PFAIL1
  WRITE(6,478) PFAIL1
  WRITE(6,475) PFAIL2
  WRITE(6,476) PFAIL3
  WRITE(6,475) PFAIL4
GO TO 883
883 IF(PFAIL2.GE.PFAIL1.OR.PFAIL2.GE.PFAIL3) GO TO 882
PFAIL=PFAIL2*WTH*(K)*NPLY(K)
WRITE(6,475) PFAIL2
GO TO 883
882 IF(PFAIL3.GE.PFAIL1.OR.PFAIL3.GE.PFAIL2) GO TO 881
PFAIL=PFAIL3*WTH*(K)*NPLY(K)
WRITE(6,476) PFAIL3
GO TO 882
881 CONTINUE
478 FORMAT(/,' FOR THE LAMINATE WITH THE OPEN HOLE, FAILURE',/)
  ' IS PREDICTED AT A JOINT LOAD OF ',D9.3,'LBS',/)
884 FORMAT(,' PREDICTED FAILURE MODE IS NET SECTION',/)
885 FORMAT(,' PREDICTED FAILURE MODE IS BEARING FAILURE',/)
886 FORMAT(,' PREDICTED FAILURE MODE IS SHEAR-OUT FAILURE',/)
GO TO 80
MAXIMUM STRAIN CRITERION
90 CONTINUE
NCA=NCA+1
NCAS=NCA
N=1
DO 310 I=1,NN
  NRC=NRC(K)
  DO 310 I=1,NN
    THETA=ANG(I,K)*RAD
    IF(THETA.GT.90.0) THETA=90.0
    IF(CALL QMAX(K,LI1,LI2,NCAS,NOPT1,RAD,THETA))
      STMAX=1.9D0
    IF(CALL QMAX(K,LI1,LI2,NCAS,NOPT1,RAD,THETA))
      STMAX=1.9D0
  WRITE(6,772) NOUT+1,STMAX
GO TO 310
310 N=N+1
310 CONTINUE
772 FORMAT(/,' MAXIMUM STRAIN CRITERION ',/)
    L11=HOUT+1
    L12=L11+HRC(/)
    NCAS=2
    N=1
    DO 310 I=1,NN
      NRC=NRC(K)
      DO 310 I=1,NN
        THETA=ANG(I,K)*RAD
        IF(CALL QMAX(K,LI1,LI2,NCAS,NOPT1,RAD,THETA))
          STMAX=1.9D0
        IF(CALL QMAX(K,LI1,LI2,NCAS,NOPT1,RAD,THETA))
          STMAX=1.9D0
      WRITE(6,772) NOUT+1,STMAX
    GO TO 310
774 FORMAT(,' FOR PLY TYPE NUMBER ',I1,' WITH ',/)
    '* A PLY ORIENTATION OF ',D9.3,' DEGREES ',/)
    '* FAILURE IS PREDICTED AT ',D9.3,' DEGREES ',/)
    '* AT A PLY LOAD OF ',D9.3,'LBS ',/)
GO TO 210
141
substr subroutine qmatx(k, li1, li2, ncas, nopt1, rad, theta)
qmatx performs basic stress and strain transformations
implicit real*8(a-h,o-z)
dimension asigr(400), asigrt(400), asig1(400), a5i02(400)
dimension atetaa, aepsx, aepsy, aepsyxy
common/xx/ asx, asxy
common/mod/ e11, e22, ess, pmu12, pmu21
common/strss/asig, asigrt, asig1, asig02, asig06
common/qnt/atetaa, aeptsx, aepsy, aepsyxy
common/psc3/sx, sxy
q11=e11(k)/((1.0-pmu12(k)*pmu21(k))
q12=(pmu21(k)*e11(k))/(1.0-pmu12(k)*pmu21(k))
q22=e22(k)/((1.0-pmu12(k)*pmu21(k))
q66=ess(k)
c=cos(theta)
s=dsninc(theta)
b011=((q11-q12+(2.*q66))+(q22(q11+k12))+(q66(q12-k12))+(q12-k12))
b016=((q11-q12-(2.*q66))+(q22(q11+k12))+(q66(q12+k12))+(q12+k12))
b021=((q11+q12)2+(2.*q66))+(q22(q11-k12))+(q66(q12-k12))+(q12-k12))
b026=((q11+q12)2-(2.*q66))+(q22(q11-k12))+(q66(q12+k12))+(q12+k12))
\do 40 i=li1,li2
j=j+1
if(ncas.eq.1) then
a=atetaa(i)*rad
c=dsninc(theta)
s=dsninc(theta)
sigx=b011*aepsy(i)+b012*aepsy(i)+b016*aepsy(i)
sigy=b016*aePTSx(i)+b022*aePTSx(i)+b026*aePTSx(i)
sigxy=b016*aePTSx(i)+b022*aePTSx(i)+b026*aePTSx(i)
sx(1)=sigx
sx(1)=sigxy
endif
end
SUBROUTINE HOFF(S1, S2, S6, A, 3, K)

IMPLICIT REAL*(A-H.O-Z)
DIMENSION HFMCCS, K)
COMON/HFF/HFMCCS

COMPUTE THE HOFFMAN/TSAI-HILL FAILURE INDEX

A = 0.000
B = 0.000
C = HFMCCS(1, K)
D = HFMCCS(2, K)
E = HFMCCS(3, K)
F = HFMCCS(4, K)
STC = HFMCCS(5, K)
A = (S1 - S2 - S6) / (C - D)
B = C / (C - D)
C = F / (F - E)
D = E / (E - D)
E = D / (D - C)
F = C / (C - B)

IF C .EQ. X. AND Y .EQ. Y)

CONTINUE

RETURN

END

SUBROUTINE CENTD(RF, HFASS, FAPS, FPEP, ITT)

IMPLICIT REAL*(A-H.O-Z)
DIMENSION PLYK(100), BARK(100), BARU(100), F(100)
DIMENSION H(2), RF(2)
DIMENSION AIM(100, 100), A(2), B(2)
COMMON/PBB/PLYK, BARK, BARU
COMMON/AFM/AIM, F
COMMON/LYP/PLYK

SET UP THE CENTRAL DIFFERENCE EQUATIONS

DO 3 I = 1, 100

AII(I, J) = 0

NECESSARY CONSTANTS ARE FORMED
DO 7 I=1,2
AI(I)=H(I)*M2/FASSE
7 B(I)=H(I)*M4/FASSE
M=H(I)/M2
A1=H(I)*M2/FASSE
A2=(I)*M2/FASSE
FP=NP(I)+NP(I)

SHEAR AT TOP OF JOINT EQUALS ZERO

AI(I,1)=1.
AI(I,2)=-2+AINPLYK(I)
AI(I,4)=2-AINPLYK(I)
AI(I,5)=1.
F(I)=0.0

MOMENT CONDITION AT TOP

IF(RF(I,GE.1.D10) GO TO 50
Z=1.
R*RF(I)
GO TO 60
50 Z=0.

60 AI(I,1)=R
AI(I,2)=2*XH(I)*FASSE+R*(I)-2+AINPLYK(I)(I)
AI(I,4)=2*XH(I)*FASSE+R*(I)+AINPLYK(I)(I)

GOVERNING EQUATIONS FOR THE TOP PLATE

N2=NP(Y(I)
DO 55 J=1,N2
IF(J+2) GO TO 56
AI(I,J+1)=1.
IF(J,EQ.1) GO TO 56
AI(I,J+1)=-4.-A(I)*PLYK(I-J-1)
GO TO 57
56 AI(I,J+1)=4.-A(I)*PLYK(I-J-1)
GO TO 62
61 AI(I,J+3)=4.-A(I)*PLYK(NP(Y(I)-1)
62 AI(I,J+4)=1.
IF(J,GE.1) GO TO 58
F(I)=A(1)*BARK(I-1)*BARU(I-1)
F(I)=A(1)*BARK(I)*BARU(I)
F+1+1)*BARK(I)*BARU(I)
GO TO 59
58 F(I)=2*HA(I)*BARK(1)*BARU(1)
GO TO 59
INTERFACE SHEAR ON TOP PLATE = P+DELP

\[ I = \text{NPLY(1)} + 3 \]
\[ J = \text{NPLY(1)} \]
\[ AII(I,J) = (2, A1NPLY(NPLY(1)-1)) \]
\[ AII(I,J) = 2 \]
\[ AII(I,J+4) = \text{NPLY(1)-1} \]
\[ F(I,J) = (-2, A1NPLY(NPLY(1)-1)) \]

SLOPE CONTINUITY

\[ I = \text{NPLY(1)} + 4 \]
\[ J = \text{NPLY(1)} \]
\[ AII(I,J) = (2, A1NPLY(NPLY(1)-1)) \]
\[ AII(I,J+5) = -H12*W3 \]
\[ AII(I,J+6) = H12*W3 \]

MOMENT CONTINUITY

\[ I = \text{NPLY(1)} + 5 \]
\[ J = \text{NPLY(1)} + 1 \]
\[ AII(I,J) = (2, A1NPLY(NPLY(1))) \]
\[ AII(I,J+2) = 1 \]
\[ AII(I,J+5) = -H12*W2 \]
\[ AII(I,J+6) = H12*W2 \]

INTERFACE SHEAR ON BOTTOM PLATE

\[ I = \text{NPLY(1)} + 6 \]
\[ J = \text{NPLY(1)} + 5 \]
\[ AII(I,J) = (2, A2NPLY(NPLY(1)+2)) \]
\[ AII(I,J+1) = -(2, A2NPLY(NPLY(1)+2)) \]
\[ AII(I,J+4) = 1 \]

GOVERNING EQUATIONS FOR THE BOTTOM PLATE

\[ M1 = \text{NPLY(1)} + 7 \]
\[ N2 = \text{NPLY(1)} + \text{NPLY(2)+6} \]
\[ DD 70 I = N1,N2 \]
\[ J = 1-2 \]
\[ AII(I,J) = 1 \]

IF(I.EQ.N1) GO TO 71
SUBROUTINE SOLVE(U,H,P,DELP,NSDLS,IT)

AII(I,J+1,J+2)=A(I,J)*H(I,J+1)*A(J+1,J)*H(J,J)
GO TO 72
72 AII(I,J+2)=A(I,J+1,J+2)*H(I,J+1)*A(J+1,J)*H(J,J)
IF(I.EQ.N2) GO TO 75
AII(I,J+3)=A(I,J+2)*H(I,J+2)*A(J+2,J)*H(J,J)
GO TO 76
75 AII(I,J+3)=A(I,J+2)*H(I,J+2)*A(J+2,J)*H(J,J)
76 AII(I,J+4)=1.
IF(I.EQ.N1) GO TO 73
IF(I.EQ.N2) GO TO 77
F(I)*A(K)*BARK(J-5)*BARK(J-5)
K=(2.*A(K)*B(J)+B(2))*BARK(J-5)*BARK(J-4)
B(R)*A(K)*BARK(J-3)*BARK(J-3)
GO TO 74
73 F(I)*A(K)*BARK(NPLY(1)+2)*BARK(NPLY(1)+2)
K=(2.*A(K)*B(J)+B(2))*BARK(J-4)*BARK(J-4)
GO TO 74
77 F(I)*A(K)*BARK(J-5)*BARK(J-5)
K=(2.*A(K)*B(J)+B(2))*BARK(J-4)*BARK(J-4)
GO TO 74
74 CONTINUE
70 CONTINUE

SHEAR ON BOTTOM PLATE EQUALS ZERO

NP=NPLY(1)+NPLY(2)
I*NP+7
J*NP+4
AII(I,J)=-1.
AII(I,J+1)=(2.*A2*NPLY(NP-1))
AII(I,J+3)=(2.*A2*NPLY(NP-1))
AII(I,J+4)=1.
F(I)=0.

MOMENT BOUNDARY CONDITION ON BOTTOM PLATE

I*NP+8
IF(RF(2).LE.1.D10) GO TO 85
Z=1.
R=RF(2)
GO TO 95
85 Z=0.
R=1.
95 AII(I,J)=R
AII(I,J+1)=Z*(2.*H(J)*A2)*FASST+S*(2.*A2*NPLY(NP-1))
AII(I,J+2)=Z*(4.*H(J)*A2)*FASST+2.*H(J)*A2*NPLY(NP)
AII(I,J+3)=Z*(2.*H(J)*A2)*FASST+2.*H(J)*A2*NPLY(NP-1)
AII(I,J+4)=Z*(2.*H(J)*A2)*FASST
F(I)=Z*(2.*H(J)*A2)*BARK(NP)*BARK(NP)
RETURN
END
IMPLICIT C(ALPHA-A-Z)
DIMENSION A(100,100),B(100),NPLY(2),U(100),F(100)
DIMENSION SX(100),PLYK(100),H(2)
COMMON/LYP,NPLY
COMMON/AFMA,F
COMMON/PBY,PLYK,BARK,BARU

SOLUTION OF THE SYSTEM: 9AICU)=B)
NP=NPLY(1)+NPLY(2)+8
DO 444 I=1,NP
  B(I)=F(I)

APPLYING JUASSIAN ELIMINATION TO THE
MATRIX OF COEFFICIENTS
DO 2001 I=1,NP
  IR=I
  IF(A(IR,I),NE.0.) GO TO 20042
  IR=IR+1
  IF(IR.GT.NP) GO TO 2001
  GO TO 2042
20041 DO 2002 L=NN,NP
  IF(DABS(A(L,I)).GT.1.D-30) GO TO 2009
  A(L,I)=0.
  GO TO 2002
2009 CF=-A(IR,I)/A(L,I)
  DO 2003 J=I,NP
  A(L,J)=A(L,J)*CF+A(IR,J)
  IF(DABS(A(L,J)).LT.1.D-30) A(L,J)=0.
  A(L,I)=CF
  CONTINUE
2002 CONTINUE
2001 CONTINUE

BACK SUBSTITUTION
DO 2112 L=NP+1,I
  SUM=0.
  IF(A(L,L).EQ.0.) GO TO 2112
  N=L+1
  IF(N.GT.NP) GO TO 2113
  DO 2113 J=N,NP
    SUM=SUM-A(L,J)*SX(J)
  2113 CONTINUE
  SX(L)=SUM/A(L,L)
  GO TO 2111
2112 CONTINUE
2111 CONTINUE

EQUILIDRIUM CHECK
NPTS=NPLY(1)+NPLY(2)+8
SUBROUTINE FAIL(OAMDL, bU, M, PDELPDPRA3TH, PFAIL, ANOIE, NODEP, NORT, NULT, ITNTFL)

IMPLICIT REAL*8(A-H,O-Z)

DIMENSION NiPLY(2), MDAMP(100), HC(2), PLYKC(100), S(100)
DIMENSION BARK(100), BARU(100)
DIMENSION PNC, MDAMIC(100), OAMDL(2), OAMN(I00)
DIMENSION DELNS(5), DELBR(5), DELSO(5), DELT(5)
DIMENSION UN(100), PPL(5,2), P5TC(5,2)
DIMENSION IPL(100,2), ANO(5,2), NUMPLYC(2)
DIMENSION PNS(5,2), P5RC(5,2), PSO(5,2), PALT(3,2)
DIMENSION BPST(2,100,2)
DIMENSION NPNM(100)
COMMON /COUNT.*NPNM/
COMMON /PI/B PSTS/
COMMON /FALI/PNS, PBR, P30, PALT/
COMMON /FALS/DELNS, DELBR, DELSO/
COMMON /FAL4/UN, OAMN, MDAMP, MDAMIC, PNC/
COMMON /FAL 5/PF/
COMMON /PSbs/PLYK, BARK, BARU/
COMMON /PRT./NDAM, INPLY, ANO, IPLY/

C
C 148
FAIL INCREMENTS THE POINT LOAD TO EACH SUCCESSIVE
PLY AND INTERFACE FAILURE UNTIL FINAL JOINT FAILURE
TAKES PLACE.

FULL BEARING FAILURE ANALYSIS

IF(BPR.NE.0.0) GO TO 400
IOUT=1

LOOP OVER ALL PLIES TO FIND LOAD, LOCATION, AND MODE OF
NEXT PLY FAILURE

100 IF(DELP.EQ.0.) GO TO 10
PPF=1.0010
GO TO 13
10 PPF=10.0.
19 MODER=0
DELP=0.0

IF(PLY HAS ALREADY LOST STIFFNESS, GO
ON TO THE NEXT PLY)

1F(MDAMP(I).EQ.10) GO TO 20

DETERMINE WHICH PLATE THIS PLY IN IN...

K=1
IF(I.GT.NPLY(I)) K=2
CALCULATE THE LOAD ON PLY FOR CURRENT JOINT LOAD

IF(PL.LT.0..AND.K.EQ.1) GO TO 20
IF(PL.LT.0..AND.K.EQ.2) GO TO 20

Determine ply load necessary to cause next

FAILURES AND ITS MODE

IF(NOPT4.NE.1.AND.NOPT4.NE.3) GO TO 200

MODE=8
IN=-(K-1)*NPLY(I)
NPY=IPLY(IN.K)
PF=PFL(NPY.K)

IF PL>PF AT CURRENT JOINT LOAD
PREDICT FAILURE

NCC=0
IF(DELS.NE.0.0) GO TO 210
IF(DABS(PL).LT.DABS(PF)) GO TO 210

HCC=0
INPLY=1
MODEF=MODF
NCC=1
GO TO 140
200
IF(IOT.NPLY(I)) NNM=I-NPLY(I)
NX=IPLY(NMN,K)
IF(PBR(NX,K).LT.PSD(NX,K).OR.PNS(NX,K).LT.PSD(NX,K)) GO TO 700
MODE=1
PF=PSD(NX,K)
IF(MDAMP(I).EQ.1) MODE=5
IF(MDAMP(I).EQ.1) PF=PALT(1,K)*PF
GO TO 25
700 IF(PNS(NX,K).LT.PBR(NX,K)) GO TO 710
MODE=2
PF=PBR(NX,K)
IF(MDAMP(I).EQ.2) MODE=6
IF(MDAMP(I).EQ.2) PF=PALT(2,K)*PF
GO TO 25
710 MODE=3
PF=PNS(NX,K)
IF(MDAMP(I).EQ.3) MODE=7
IF(MDAMP(I).EQ.3) PF=PALT(3,K)*PF
25 CONTINUE
NCC=0
IF(DELPF.EQ.0) GO TO 210
IF(DABS(PF).LT.DABS(PF)) GO TO 210
IFPLY=I
"DEF=MODE
NCC=1
GO TO 1212
210 CONTINUE
DETERMINE INCREMENTAL JOINT LOAD TO CAUSE
PLY FAILURE
IF(ITT.LE.1) GO TO 21
IF(DABS(DABS(U(1)/UN(1)-1.).LT.1.0D-10) GO TO 20
21 CONTINUE
DELPF=(PF-DABS(PN(I)))/1000./DABS(PF)-DABS(PN(I)))
A NEGATIVE VALUE OF DELPF INDICATES UNLOADING
IN A PLY, THIS NODE IS THEN SKIPPED
IF(DELPF.LT.0.) GO TO 20
RECORD LOWEST JOINT FAILURE LOAD INCREMENT,
PLY IN WHICH IT OCCURS, AND MODE
PF2=PF
IF(DELPF.EQ.0) PF2=1.
IF(DELPF.GT.PF2) GO TO 20
PF+DELPF
IFPLY=I
MODE=MODE
20 CONTINUE
LOOP OVER ALL INTERFACES TO FIND LOAD
AND LOCATION OF NEXT DELAMINATION
NN=NPLY(I)+NPLY(J)-2
DO 30 J=1,NN
  IF (INTERFACE HAS ALREADY FAILED) GO TO NEXT
  IF (NDAM(I,J).EQ.1) GO TO 50
  DETERMINE WHICH INTERFACE IS IN
  K=1
  IF (J.GE.NPLY(I)) K=2
  CALCULATE INTERFACE SHEAR STRAIN FOR CURRENT
  JOINT LOAD
  GAMJ=U(J+K)-U(J+K)/H(J)
  DETERMINE INCREMENTAL JOINT LOAD TO CAUSE
  INTERFACE FAILURE
  IF (DAM(I,J).EQ.1) GO TO 47
  IF (DABS(DABS(GAMJ)/GAMJ)-1.,LT.1.00E-10) GO TO 50
  DETERMINE INCREMENTAL JOINT LOAD TO CAUSE
  INTERFACE FAILURE
  IF (DAM(I,J).EQ.1) GO TO 47
  CONTINUE
  DELPF*GAMJ(DA3L(K)-DABS(GAMJ))/DABS(GAMJ)-DABS(GAMJ))\iota000.
  IF (DELPF.LT.0.) GO TO 50
  CONTINUE
  RECORD LOWEST JOINT FAILURE LOAD INCREMENT,
  PLY OF INTERFACE IN WHICH IT OCCURS, AND MODE
  PFPK*DELPF
  IF (DELPF.GT.PFPK) PFPK=1.
  IF (DELPF.GT.PFPK) PFPK=1.
  PFPK=DELPF
  IF (MODEF.EQ.0) GO TO 325.
  CONTINUE
  DETERMINE VALUES AT END OF INCREMENT
  JOINT LOAD AT FAILURE
  IF (MODEF.GE.0) GO TO 325.
  PFPK=DELP/1000.
  CONTINUE
  NODAL DISPLACEMENTS AND PLY LOADS
  NN=NPLY(I)+NPLY(J)
  DO 55 I=1,NN
  UN(I)=UN(I)+(U(I)-UN(I))*PFPK/1000.
  CONTINUE
  UPDATE UN
  IF (NCC.EQ.1) UN(I)=U(I)
  K=1
  IF (I.GT.NPLY(I)) K=2
  PHN(I)-H(K)*(PLYK(I)+UN(I))+BAR(I)+BARU(I))
  55 CONTINUE
INTERFACk SHEAR STRAINS

NN=NPLY(1)+NPLY(2)-2
DG 60 J=1,NN
K=1
IF(J.GE.NPLY(1)) K=2
GAM(N,J)=UN(J+1-1)-UN(J+K)/K(K)

60 CONTINUE
1212 CONTINUE

PLY STIFFNESS, DAMAGE STATES, AND NEXT_LOAD INCREMENT

K=1
IF(INPLY.GT.NPLY(1)) K=2
NM=NPLY
IF(INPLY.GT.NPLY(1)) NM=NPLY-NPLY(1)
NX=NPLY(NMN,K)
IF(MODEF.NE.0) GO TO 70
DELP=1000.
NDAM=1
GO TO 65

70 IF(MODEF.NE.1) GO TO 80
IF(INPLY.EQ.1.AND.MDAM(INPLY).EQ.1) GO TO 75
IF(INPLY.EQ.NPLY(1).AND.MDAM(INPLY-1).EQ.1) GO TO 75
IF(INPLY.EQ.(NPLY(1)+1).AND.MDAM(INPLY-1).EQ.1) GO TO 73
IF(INPLY.EQ.(NPLY(1)+NPLY(2)).AND.MDAM(INPLY(1)+NPLY(2)
1-2).EQ.1) GO TO 75
K=1
IF(INPLY.GT.NPLY(1)) KK=1
IF(MDAM(INPLY-KK-1).EQ.1.AND.MDAM(INPLY-KK).EQ.1) GO TO 75
MDAM(INPLY)=1
TEMPK=INPLY
PLYK(INPLY)-DELS0(NX,K)*PLYK(INPLY)
BARK(INPLY)=1.-DELS0(NX,K))TEMPK.
BARU(INPLY)=UN(INPLY)
DELP=0.
NDAM=2
GO TO 65

75 PLYK(INPLY)=0.0
BARK(INPLY)=0.
BARU(INPLY)=UN(INPLY)
MDAM(INPLY)=10
DELP=0.
NDAM=2
GO TO 65

80 IF(MODEF.NE.2) GO TO 85
TEMPK=PLYK(INPLY)
PLYK(INPLY)=DELS0(NX,K)*TEMPK
BARK(INPLY)=1.-DELS0(NX,K))TEMPK
BARU(INPLY)=UN(INPLY)
MDAM(INPLY)=2
DELP=0.
NDAM=6
GO TO 65

85 IF(MODEF.NE.3) GO TO 90
TEMPK=PLYK(INPLY)
PLYK(INPLY)=DELS0(NX,K)*TEMPK
BARK(INPLY)=1.-DELS0(NX,K))TEMPK
BARU(INPLY)=UN(INPLY)

152
MDAMP(INPLY)=3
DELP=0.
NDAM=5
GO TO 65
90 IF(MODEF.NE.4) GO TO 140
PLYK(INPLY)=0.0
BARK(INPLY)=0.
BARU(INPLY)=UN(INPLY)
MDAMP(INPLY)=10
DELP=0.
NDAM=6
GO TO 65
140 IF(MODEF.NE.5) GO TO 110
PLYK(INPLY)=0.
BARK(INPLY)=0.
BARU(INPLY)=UN(INPLY)
MDAMP(INPLY)=10
DELP=0.
NDAM=6
GO TO 65
110 IF(MODEF.NE.6) GO TO 115
PLYK(INPLY)=0.0
BARK(INPLY)=0.0
BARU(INPLY)=UN(INPLY)
MDAMP(INPLY)=10
DELP=0.
NDAM=7
GO TO 65
115 IF(MODEF.NE.7) GO TO 120
PLYK(INPLY)=0.
BARK(INPLY)=0.
BARU(INPLY)=UN(INPLY)
MDAMP(INPLY)=10
DELP=0.
NDAM=8
GO TO 65
120 IF(MODEF.NE.8) GO TO 125
PLYK(INPLY)=0.
BARK(INPLY)=0.
BARU(INPLY)=UN(INPLY)
MDAMP(INPLY)=10
DELP=0.
GO TO 65
125 IF(MODEF.NE.9) GO TO 65
DELP=100.
MDAMP(INPLY)=1
NDAM=10
GO TO 65
600 CONTINUE

PARTIAL BEARING FAILURE ANALYSIS

IROUT=2
NPL*INPLY(1)*INPLY(2)
AJFLNS=1.0D10
AJFLSR=1.0D10
AJFLOS=1.0D10
GO 550 1=1,NPL
K=1

00025700
IF (I.GT.NL) K = 2
PL = -K(K+1)XPL(I)+BAR(K)*BARU(I)
PL = PL + PL + L + K.EQ.1) GO TO 350
PL = DABS (PL) X N PLY(K) X N PLY(K)/1000.
I = 1
IF ((NPLY(I)).NPLY(I)) UPLU(NPLY(I))
IF (PL.LT.OAND.K.EQ.1) GO TO 550
IF (PL.LT.0AND.K.EQ.2) GO TO 550
IF (NPLY(I) .NPLY(I) X IJ = IJ-NPLY(I))
IF (PLPLY(I,K)) N PLY(I,K)
I = 1
IF (PST3(K,IP,2,1).LT.O) NT = 2
FI = DABS (PST3(I,IP,K))/PST3(K,IP,1,1)+PLMPST3(K,IP,2,1)
F2 = DABS (PST3(K,IP,1)/PLMPST3(K,IP,2,1))
F3 = DABS (PST3(4,4,K))/PST3(K,IP,1,3)+PLMPST3(K,IP,2,3)
IF (MDAMP(I).EQ.3) F1 = PALT(3,K)*F1
IF (MDAMP(I).EQ.4) F2 = PALT(2,K)*F2
IF (AJFNLSP.OT.F1) NF1 = 1
IF (AJFNLSP.OT.F1) AJFNLSP = F1
IF (AJFLBR.OT.F2) NF2 = 1
IF (AJFLS0.OT.F3) NF3 = 1
IF (AJFLS0.OT.F3) AJFLS0 = F3
550 CONTINUE
IF (AJFNLSP.OT.AJFLBR.OT.AJFNLSP.OT.AJFNLSP.OT.AJFNLSP.OT.AJFLS0) GO TO 360
INPLY = NPLY
551 NDAM = 5
IF (MDAMP(INPLY).EQ.2) GO TO 371
IF (MDAMP(INPLY).EQ.3) GO TO 361
IF (MDAMP(INPLY).EQ.4) NDAM = 6
MDAMP(INPLY) = NDAM
PAFIL = AJFNLSP
GO TO 64
560 IF (AJFLBR.OT.AJFNLSP.OT.AJFLBR.OT.AJFNLSP) GO TO 371
INPLY = NF2
561 NDAM = 4
IF (MDAMP(INPLY).EQ.2) GO TO 391
IF (MDAMP(INPLY).EQ.3) GO TO 361
IF (MDAMP(INPLY).EQ.4) NDAM = 7
MDAMP(INPLY) = NDAM
PAFIL = AJFLBR
GO TO 64
570 IF (AJFLS0.OT.AJFNLSP.OT.AJFLS0.OT.AJFLS0.OT.AJFLBR) GO TO 64
INPLY = NPLY
571 NDAM = 3
IF (MDAMP(INPLY).EQ.2) GO TO 391
IF (MDAMP(INPLY).EQ.3) GO TO 361
IF (MDAMP(INPLY).EQ.4) NDAM = 6
MDAMP(INPLY) = NDAM
PAFIL = AJFLS0
GO TO 64
64 CONTINUE
K = 1
IF (INPLY.OT.NPLY(I)) K = 2
INPLY = NPLY
IF (IPL.OT.NPLY(I)) IPL = IPL-NPLY(I)
IPL = IPL(INPL,K)
ANGLE = ANG1(IPL,K)
NODE = NPMH(INPL,K)
IF (MDAMP(INPLY).GE.6) GO TO 107
IF (MDAMP(INPLY).EQ.5) AR = DCLNS(IPL,K)
IF (MDAMP(INPLY).EQ.4) AR = DELBR(IPL,K)
0025760
0025770
0025760
0025790
0025800
0025810
0025820
0025830
0025840
0025850
0025860
0025870
0025880
0025890
0025900
0025910
0025920
0025930
0025940
0025950
0025960
0025970
0025980
0025990
0026000
0026010
0026020
0026030
0026040
0026050
0026060
0026070
0026080
0026090
0026100
0026110
0026120
0026130
0026140
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0026210
0026220
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0026300
0026310
0026320
0026330
0026340
0026350
0025760
0025770
0025760
0025790
0025800
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0025900
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0025990
0026000
0026010
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0026090
0026100
0026110
0026120
0026130
0026140
0026150
0026160
0026170
0026180
0026190
0026200
0026210
0026220
0026230
0026240
0026250
0026260
0026270
0026280
0026290
0026300
0026310
0026320
0026330
0026340
0026350
IF(IYPL>0.EQ.0) AR=DELSQ(IPLP.K)
TEMPK=IPLY(IN IPL)
IPLY(IN IPL)=0.0*TEMPK
ARK(IN IPL)+(1.-AR)*TEMPK
BARU(IN IPL)=U(IN IPL)
IYPL=IPLY(IPLP.K)
NTFL=0
GO TO 103

107 CONTINUE
IF(K.EQ.1) NPLY(1)=NPLY(1)-1
IF(K.EQ.2) NPLY(2)=NPLY(2)-1
NP=NPLY
IF(K.EQ.2) NP=NPLY-NPLY(1)
N=NPLY(K)-NP+2
IYP=IPLY(NP,K)
DO 101 I=1,N
IPLY(NP+1.K)=IPLY(NP+1.K)
101 CONTINUE
N=NPLY-1
DO 102 I=1,N
MDAMP(IN IPLY+I-1)=MDAMP(IN IPLY+I)
PLYK(IN IPLY+I-1)=PLYK(IN IPLY+I)
ARK(IN IPLY+I-1)=ARK(IN IPLY+I)
102 CONTINUE
BARU(IN IPLY+I-1)=ARU(IN IPLY+I)
NTFL=1
NULTF=NULTF-1
IF(NULTF.EQ.0) JNT=0
IF(NPLY(1).EQ.2.OR.NPLY(2).EQ.2) JNT=0
103 CONTINUE
RETURN

65 CONTINUE
INCREMENT LOAD IF JOINT HAS NOT FAILED
T1=0.
T2=0.
N1=NPLY(1)
N2=NPLY(2)
DO 135 I=1,N1
135 T1=T1+PLYK(I)
DO 126 I=1,N2
126 T2=T2+PLYK(N)
IF(T1.EQ.0.0.OR.T2.EQ.0.0) GO TO 130
RETURN

130 JNT=0
RETURN
END

SUBROUTINE PRINT(U,P,DELP,PFAIL,ANGLE,BPR,NODE,IROUT,JNT,
*NP,HSDLS,ITT)
IMPLICIT REAL*8(A-H,O-Z)
DIMENSION U(100),PLYK(100)
DIMENSION NPLY(2),NUMPPLY(2),ANG(5,2),IPLY(100,2)
DIMENSION BARK(100),BARU(100)

155
DIMENSION MPNM(100,2)
COMMON/COUNT/NPNM
COMMON/MPY/MPX,MPY,NSP,ANG,PLY
COMMON/PBX/PKY,BP,BAR
COMMON/PR/DAD,INPL,ITYP

PRINT VALUES AT END OF INCREMENT...

IF(ITT.EQ.1) WRITE(6,10)
10 FORMAT(/,10X,'FAILURE MODE ABBREVIATIONS:',/10X,'NPNM','00026970')
   00026980
   00026990
   00027000
   00027010
   00027020
   00027030
   00027040
   00027050
   00027060
   00027070
   00027080
   00027090
   00027100
   00027110
   00027120
   00027130
   00027140
   00027150
   00027160
   00027170
   00027180
   00027190
   00027200
   00027210
   00027220
   00027230
   00027240
   00027250
   00027260
   00027270
   00027280
   00027290
   00027300
   00027310
   00027320
   00027330
   00027340
   00027350
   00027360
   00027370
   00027380
   00027390
   00027400
   00027410
   00027420
   00027430
   00027440
   00027450
   00027460
   00027470
   00027480
   00027490
   00027500
   00027510
   00027520
   00027530
   00027540
   00027550
220 CONTINUE
   WRITE(6,240) PFAILP
240 FORMAT(/,10X,'THE PREDICTED JOINT FAILURE',/10X,'NO. ',/10X,'PLY TYP',/10X,'NPNM','00026970')
   00026980
   00026990
   00027000
   00027010
   00027020
   00027030
   00027040
   00027050
   00027060
   00027070
   00027080
   00027090
   00027100
   00027110
   00027120
   00027130
   00027140
   00027150
   00027160
   00027170
   00027180
   00027190
   00027200
   00027210
   00027220
   00027230
   00027240
   00027250
   00027260
   00027270
   00027280
   00027290
   00027300
   00027310
   00027320
   00027330
   00027340
   00027350
   00027360
   00027370
   00027380
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   00027400
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   00027430
   00027440
   00027450
   00027460
   00027470
   00027480
   00027490
   00027500
   00027510
   00027520
   00027530
   00027540
   00027550
SUBROUTINE LINV2F (A,N,IA,AINV,IDGT,WKAREA,IER)
DOUBLE PRECISION A(AA,N),AINV(AA,N),WKAREA(1),ZERO,ONE
DATA IER=0
FIRST EXECUTABLE STATEMENT
INITIALIZE IER
IER=0
DO 10 I = 1,N
   DO 5 J = 1,N
      AINV(I,J) = ZERO
      5 CONTINUE
     10 CONTINUE
COMPUTE THE INVERSE OF A
CALL LEQT2F (A,N,IA,AINV,IDGT,WKAREA,IER)
IF (IER.EQ.0) GO TO 9005
9000 CONTINUE
CALL UERTST (IER,6HLINV2F)
9005 RETURN
END

SUBROUTINE LEQT2F (A,N,IA,B,IDGT,WKAREA,IER)
DIMENSION A(AA,1),B(AA,1),WKAREA(1)
DOUBLE PRECISION A,B,WKAREA,D1,DZ,WA
FIRST EXECUTABLE STATEMENT
INITIALIZE IER
IER=0
J = N+1
K = J+N
MM = K+N
KK = 0
MM1 = MM-1
JJ = 1
DO 5 I = 1,N
   DO 5 J = 1,N
      WKAREA(JJ) = A(I,1)
      JJ = JJ+1
   5 CONTINUE
DECOMPOSE A
CALL LUDATN (WKAREA,N,N,IA,IDGT,DI,D2,WKAREA(K),
*         WA,IER)
IF (IER.GT.126) GO TO 25
IF (IDGT .EQ. 0 .OR. IER .NE. 0) KK = 1
DO 15 I = 1,M
PERFORMS THE ELIMINATION PART OF
CALL LUELMN (A,IA,N,B(1,1),WKAREA(1),WKAREA(MM))
REFINEMENT OF SOLUTION TO AX = B
IF (KK .NE. 0) THEN
  CALL LUREFN (WKAREA, N, N, A(I, I), IDOT, WKAREA(J), WKAREA(MM),
               WKAREA(K), WKAREA(K), JER).
  DO 10 II = 1, N
      B00 II,I = WKAREA(MM+II)
  10 CONTINUE
  IF (JER .NE. 0) GO TO 20
  GO TO 25
  20 IER = 131
  25 JJ = 1
  DO 30 J = 1, N
      ACX, J = WKAREA(JJ)
      JJ = JJ + 1
  30 CONTINUE
  IF (IER .EQ. 0) GO TO 9005
  CONTINUE
  CALL VERTST (IER, 6M6EQ2F).
  9005 CONTINUE
END

SUBROUTINE LUDATF (A, LU, N, IA, IDOT, DI, D2, IPVT, EQUIL, MA, IER)
DIMENSION A(IA, 1), LU(IA, 1), IPVT(1), EQUIL(1)
DOUBLE PRECISION A, LU, DI, D2, EQUIL, MA, ZERO, ONE, FOUR, SIXTH, SIXTH, RN, WREL, BIGA, BIG, P, SUM, AI, WI, TEST, Q
DATA ZERO, ONE, FOUR, SIXTH, SIXTH / 0.0D0, 1.0D0, 4.0D0,
16.D0, 1625.D0/
FIRST EXECUTABLE STATEMENT
INITIALIZATION
IER = 0
RN = N
WREL = ZERO
DI = ONE
D2 = ZERO
BIGA = ZERO
DO 10 II = 1, N
BIG = ZERO
DO 5 J = 1, N
P = ACX, J
P = DABS(P)
IF (P .GT. BIG) BIG = P
  5 CONTINUE
IF (BIG .GT. BIGA) BIGA = BIG
IF (BIG .EQ. ZERO) GO TO 110
EQUIL(I) = ONE / BIG
  10 CONTINUE
DO 105 J = 1, N
  JMI = J - 1
  IF (JMI .LE. 1) GO TO 40
  COMPUTE UIJ, I = 1, ..., J - 1
  105 CONTINUE
  WITH ACCURACY TEST
AI = DABS(SUM)  
WI = ZERO  
IF (JMI .LT. 1) GO TO 20  
DO 15 K = 1, JMI  
T = LU(I, K) * LU(K, J)  
SUM = SUM + T  
WI = WI + DABS(T)  
15 CONTINUE  
IF (C .EQ. ZERO) C = BIGA  
TEST = WI/AI  
IF (TEST .LT. WREL) WREL = TEST  
GO TO 35  
C  
25 IF (JMI .LT. 1) GO TO 35  
DO 30 K = 1, JMI  
SUM = SUM - LU(I, K) * LU(K, J)  
30 CONTINUE  
LU(I, J) = SUM  
35 CONTINUE  
40 P = ZERO  
DO 70 I = J+1, N  
SUM = LU(I, J)  
IF (IDOT .EQ. 0) GO TO 55  
C  
45 CONTINUE  
LU(I, J) = SUM  
50 WI = WI + DABS(SUM)  
IF (AI .EQ. ZERO) AI = BIGA  
TEST = WI/AI  
IF (TEST .LT. WREL) WREL = TEST  
GO TO 65  
C  
55 IF (JMI .LT. 1) GO TO 65  
DO 60 K = 1, JMI  
SUM = SUM - LU(I, K) * LU(K, J)  
60 CONTINUE  
LU(I, J) = SUM  
65 Q = EQUIV(I) * DABS(SUM)  
IF (P .GE. Q) GO TO 70  
P = Q  
IMAX = I  
70 CONTINUE  
C  
70 CONTINUE  
IF (RTH + P .EQ. KN) GO TO 110  
IF (J .EQ. IMAX) GO TO 80  
C  
81 D1 = -D1  
DO 75 K = 1, N  
P = LU(IMAX, K)  
LU(IMAX, K) = LU(J, K)  
75 CONTINUE  
C  
159
LU(j,k) = P

75 CONTINUE

EQUIL(IMAX) = EQUIL(J)

80 IF (IPV{T(J)} = IMAX)

85 IF (DABS(D1) .LE. ONE) GO TO 90

D1 = D1 * L{U(J,J)}

D2 = D2 + L{FOUR}

GO TO 85

90 IF (DABS(D1) .GE. SIXTH) GO TO 95

D1 = D1 * SIXTH

D2 = D2 - L{FOUR}

GO TO 90

95 CONTINUE

JP{1} = J+1

IF (JP{1} .GT. N) GO TO 105

C

P = L{U(J,J)}

DO 100 I = JP{1}, N

L{U(I,J)} = L{U(I,J)} / P

100 CONTINUE

105 CONTINUE

PERFORM ACCURACY TEST

C

IF (IDOT .EQ. 0) GO TO 9005

P = 3 * N + 1

WA = PWMREL

IF (WA + 10.0 * N + (-IDOT) .NE. WA) GO TO 9005

IER = 34

GO TO 9000

C

ALGORITHMIC SINGULARITY

IER = 129

D1 = ZERO

D2 = ZERO

9000 CONTINUE

PRINT ERROR

9005 RETURN

C

SUBROUTINE LUEL{MN} (A, IA, N, B, APVT, X)

DIMENSION A(IA, 1), B(1), APVT(1), X(1)

DOUBLE PRECISION A, B, X, SUM, APVT

FIRST EXECUTABLE STATEMENT

SOLVE LY = B FOR Y

DO 5 I = 1, N

5 X(I) = B(I)

IH = 0

DO 20 I = 1, N

IP = APVT(I)

SUM = X(IP)

X(IP) = X(I)

IF (IN .EQ. 0) GO TO 15

IM{1} = 1 - IH

DO 10 J = IH, IM{1}

SUM = SUM - A(I, J) * X(J)

10 CONTINUE

GO TO 20

15 IF (SUM .NE. 0.00) IH = I

0029360

0029370

0029380

0029390

0029400

0029410

0029420

0029430

0029440

0029450

0029460

0029470

0029480

0029490

0029500

0029510

0029520

0029530

0029540

0029550

0029560

0029570

0029580

0029590

0029600

0029610

0029620

0029630

0029640

0029650

0029660

0029670

0029680

0029690

0029700

0029710

0029720

0029730

0029740

0029750

0029760

0029770

0029780

0029790

0029800

0029810

0029820

0029830

0029840

0029850

0029860

0029870

0029880

0029890

0029900

0029910

0029920

0029930

0029940

160
C

SOLVE UX = Y FOR X

DO 30 IB=1,N
   I = N+1-IB
   IP1 = I+1
   SUM = X(I)
   IF (IP1 .GT. N) GO TO 30
   DO 25 J=IP1,N
      SUM = SUM - A(I,J) * X(J)
   25 CONTINUE
30   X(I) = SUM / A(I,I)

RETURN
END

SUBROUTINE LURFN (A, IA, N, UL, IUL, B, IDOT, APVT, X, RES, DX, IER)

DIMENSION A(IA), UL(IUL,1), B(1), X(1), RES(1), DX(1)
DIMENSION APVT(1)
DIMENSION ACCXT(2)
DOUBLE PRECISION A, ACCXT, B, UL, X, RES, DX, ZERO, XNORM, DXNORM, APVT
DATA ITMAX/75/, ZERO/0.00/

C FIRST EXECUTABLE STATEMENT

IF (XNORM .NE. ZERO) GO TO 20

IDOT = 50
GO TO 9005

20 DO 45 ITER = 1, ITMAX
   DO 30 I = 1, N
      ACCXT(I) = 0.00
      ACCXT(2) = 0.00
      CALL VXADD(A(I), ACCXT)
   30 CONTINUE
   CALL VXSTO(ACCXT, RES(I))
   CALL VXG(UL, IUL, N, RES, APVT, DX)
   XNORM = ZERO
   DO 35 I = 1, N
      X(I) = X(I) + DX(I)
      DXNORM = DMAX1(DXNORM, DABS(DX(I)))
   35 CONTINUE
   IF (ITER .NE. 1) GO TO 40
   IDOT = 50
   IF (DXNORM .NE. ZERO) IDOT = -DLOG10(DXNORM/XNORM)
   GO TO 9005
40 IF (XNORM + DXNORM .EQ. XNORM) GO TO 9005

ITERATION DID NOT CONVERGE

IER = 129
9005 CONTINUE
CALL VERTST(IER, 6, LURFN)
9006 RETURN
END
SUBROUTINE UERTST (IER, NAME)

SPECIFICATIONS FOR ARGUMENTS

INTEGER IER
INTEGER NAME(1)

SPECIFICATIONS FOR LOCAL VARIABLES

INTEGER IIEQ, IEQDF, IOUNIT, LLEVOLD, NAMEQ(6),
    NAMSET(6), NAMUPK(6), MIN, NMT
DATA NAMEQ/6NLH
DATA LEVEL/4/1IEQDF/0-%IEQ/1Nu'

C UNPACK NAME INTO NAMUPK
C EXECUTABLE STATEMENT.
CALL USPKD (NAME, 6, NAMUPK, NMT)

C GET OUTPUT UNIT NUMBER
CALL UOETIG (1, NIN, IOUNIT)

C CHECK IER
IF (IER.0T.999) GO TO 25
IF (IER.LT.-52) GO TO 55
IF (IER.LE.128) GO TO 5
IF (LEVEL.LT.1) GO TO 30
C PRINT TERMINAL MESSAGE
IF (IEQDF.ZQ.1) WRITE(IOUNIT,33) IER, NAMEQ, IEQ, NAMUPK
IF (IEQDF.EQ.0) WRITE(IOUNIT,33) IER, NAMUPK
GO TO 30

C PRINT WARNING WITH FIX MESSAGE
IF (IEQDF.EQ.1) WRITE(IOUNIT,40) IERNAMEQ, IEQ, NAMUPK
IF (IEQDF.EQ.0) WRITE(IOUNIT,40) IER, NAMUPK
GO TO 30

C PRINT NON-DEFINED MESSAGE
IF (IEQDF.EQ.1) WRITE(IOUNIT,50) IER, NAMEQ, IEQ, NAMUPK
IF (IEQDF.EQ.0) WRITE(IOUNIT,50) IER, NAMUPK
RETURN

FORMAT(19H ! ! ! TERMINAL ERROR, 16X, 7H IER = , I3,)
1 I, 20H FROM IMSL ROUTINE .6A1 .A1 .6A1)
20 FORMAT(27H ! ! ! WARNING WITH FIX ERROR, 16X, 7H IER = , I3,)
30 I, 162
1 20H FROM IMSL ROUTINE .6A1,A1,6A1)
45 FORMAT(18H WARNING,11X,7H(IER = ,15,
20H) FROM IMSL ROUTINE .6A1,A1,6A1)
50 FORMAT(20H UNDEFIN ED ERROR,9X,7HIER = ,15,
1 20H) FROM IMSL ROUTINE .6A1,A1,6A1)
        SAVE P FOR P = R CASE
        P IS THE PAGE NAME PK
        R IS THE ROUTINE NAME PK
55 IEQDF = 1
56 DO 1,6,1
57 NAMEQ(I) = NAMEPK(I)
59 RETURN
END

SUBROUTINE UGETC(IOPT,NIN,NOUT)
        SPECIFICATIONS FOR ARGUMENTS
        INTEGER IOPT,NIN,NOUT
        SPECIFICATIONS FOR LOCAL VARIABLES
        INTEGER NIND,NOUTD
        DATA NIND/5/,NOUTD/6/
        FIRST EXECUTABLE STATEMENT
        IF (IOPT.EQ.3) GO TO 10
        IF (IOPT.EQ.2) GO TO 5
        IF (IOPT.NE.1) GO TO 9005
        NIN = NIND
        NOUT = NOUTD
        GO TO 9005
        5 NIND = NIN
        GO TO 9005
        10 NOUTD = NOUT
        9005 RETURN
END

SUBROUTINE VXADD(A,ACC)
        SPECIFICATIONS FOR ARGUMENTS
        DOUBLE PRECISION A,ACC(2)
        SPECIFICATIONS FOR LOCAL VARIABLES
        DOUBLE PRECISION X,Y,Z,ZZ
        FIRST EXECUTABLE STATEMENT
        X = ACC(1)
        Y = A
        IF (DABS(ACC(1)).GE.DABS(A)) GO TO 1
        X = A
        Y = ACC(1)
        1 Z = X+Y
        ZZ = (X-Z)+Y
        COMPUTE Z+ZZ = ACC(1)+A EXACTLY
        COMPUTE ZZ+ACC(2) USING DOUBLE
        PRECISION ARITHMETIC
        ZZ = ZZ+ACC(2)
        COMPUTE ACC(1)+ACC(2) = Z+ZZ EXACTLY
        ACC(1) = Z+ZZ
        ACC(2) = (Z-ACC(1))+ZZ
        RETURN

163
SUBROUTINE VXMUL (A,B,ACC)

DOUBLE PRECISION A,B,ACC(2)

DOUBLE PRECISION X,MA,TA,HB,TB

INTEGER IX(2),I

EQUIVALENCE (X,IX(1)),(I,IX(1))

DATA I/0/

SPLIT A = HA+TA

FIRST EXECUTABLE STATEMENT

X = A
LX(4) = LX(5)
IX(2) = 0
I = (I/16)*16
LX(5) = LI(4)

HA = X
TA = A-HA
X = B
LI(4) = LX(5)
IX(2) = 0
I = (I/16)*16
LX(5) = LI(4)

TB = B-HB

COMPUTE HAMS,HAHS,TAMS, AND TARTS

AND CALL VXADD TO ACCUMULATE THE SUM

CALL VXADD(X,ACC)

CALL VXADD(X,ACC)

CALL VXADD(X,ACC)

CALL VXADD(X,ACC)

RETURN

END

SUBROUTINE VXSTO (ACC,D)

DOUBLE PRECISION ACC(2),D

D = ACC(1)+ACC(2)

RETURN

END

SUBROUTINE ZRPOLY (A,NDEG,Z,IER)

INTEGER NDEG,IER

DOUBLE PRECISION A(1),Z(1)
C SPECIFICATIONS FOR LOCAL VARIABLES

INTEGER N, NN, J, JJ, I, NMI, ICONT, N2, L, M, MP
REAL ETA, RHRE, RINFP, REPSP, RADIX, RLO, XX, YY, SINSR, C0
1 COSR, RHMR, RHNX, X, SC, XM, P, DX, DF, BND, XXX, ARE
REAL PT(101), P(101), QP(101), RK(101), QK(101), N00
DOUBLE PRECISION TEMP(101), P(101), QP(101), RK(101), QK(101).
LOGICAL ZEROK


DATA RINFP=2777777777/ 00032680
DATA REPSP=201000000/ 00032690
DATA RADIX=16./ 00032700
DATA RSR=1/ 00032710
DATA ZER0=0.000/ 00032720
DATA 
ZRPOLY USES SINGLE PRECISION CALCULATIONS FOR SCALING, BOUNDS AND ERROR CALCULATIONS.
FIRST EXECUTABLE STATEMENT
IER = 0
IF (NDEO .GT. 100 OR. NDEO .LT. 1) GO TO 165
IER = 0
ETA = REPSP
ARE = ETA
RHRE = ETA
RLO = REPSP/ETA
INITIALIZATION OF CONSTANTS FOR SHIFT ROTATION
IF (A(1).NE.ZERO) GO TO 3
IER = 130
GO TO 9000

165
C REMOVE TH! ZEROS AT THE ORIGIN =
C ANY
C
5 IF (CNH) .NE. ZERO) GO TO 10
J = NDEG-N+1
JJ = J+NDEG
Z(J) = ZERO
Z(JJ) = ZERO
N = N-1
IF (NN.EQ.1) GO TO 9005
GO TO 5
C
10 DO 15 I=1,NN
P(I) = A(I)
15 CONTINUE
C MAKE A COPY OF THE COEFFICIENTS
C
20 IF (N .GT. 2) GO TO 30
IF (N .LT. 1) GO TO 9005
C START THE ALGORITHM FOR ONE ZERO
C
IF (N .EQ. 2) GO TO 25
Z(NDEG) = -P(2)/P(1)
Z(NDEG+NDEG) = ZERO
GO TO 145
25 CALL ZRPOLI (P(1),P(2),P(3),Z(NDEG-1),Z(NDEG+NDEG-1),Z(NDEG))
GO TO 145
C
30 RMAX = 0.
RMN = RINFP
DO 35 I=1,NN
K = ABS(SHNL(P(I)))
IF (K .GT. RMAX) RMAX = K
IF (K .LT. RMAX+RMIN) RMIN = K
35 CONTINUE
C SCALE IF THERE ARE LARGE OR VERY SMALL COEFFICIENTS COMPUTES A SCALE FACTOR TO MULTIPLY THE COEFFICIENTS OF THE POLYNOMIAL. THE SCALING IS DONE TO AVOID OVERFLOW AND TO AVOID UNDETECTED UNDERFLOW INTERFERING WITH THE CONVERGENCE CRITERION. THE FACTOR IS A POWER OF THE BASE
SC = RLO/RMIN
IF (SC .GT. 1.0) GO TO 40
IF (RMAX .LT. 1.0) GO TO 55
IF (SC .EQ. 0.0) SC = REPS*RADIX*RADIX
GO TO 45
40 IF (RINFP/SC .LT. RMAX) GO TO 55
45 L = ALG0(SC)/ALOG(RADIX)+.5
IF (L .EQ. 0) GO TO 55
FACTOR = DBLE(RADIX)**L
DO 50 I=1,NN
50 P(I) = FACTOR*P(I)
55 CONTINUE
C COMPUTE LOWER BOUND ON MODULI OF ZEROS.
C
DO 60 I=1,NN
PT(I) = ABS(SHNL(P(I)))
60 CONTINUE
C
166
PT(NN) = PT(NN)

C COMPUTE UPPER ESTIMATE OF BOUND

X = EXP((ALOGC - PT(NN)) - ALOG(PT(I)) / N)

IF (PT(N).EQ.0.) GO TO 63

C IF NEWTON STEP AT THE ORIGIN IS BETTER, USE IT.

XM = -PT(NN) / PT(N)

IF (XM.LT.X) X = XM

C CHOP THE INTERVAL (0, X) UNTIL FF.LE.0

DO 65 2, NN

70 IF (FF.LE.0.) GO TO 75

75 DX = X

DO 80 100

C DO NEWTON ITERATION UNTIL X CONVERGES TO TWO DECIMAL PLACES

C COMPUTE THE DERIVATIVE AS THE INITIAL K POLYNOMIAL AND DO 5 STEPS WITH NO SHIFT

HH = NN - 1

DO 95 10, NN

95 RK(I) = (NN-I) * P(I) * FN

RK(I) = P(I)

AA = P(NN)

BB = P(N)

ZEROK = RK(N).EQ.ZERO

DO 115 20, NN

CC = RK(N)

IF (ZEROK) GO TO 105

USE SCALED FORM OF RECURRENCE IF VALUE OF K AT 0 IS NONZERO

T = -AA / CC

DO 100 50, NN

100 RK(J) = T * RK(J-1) + P(J)

CONTINUE

RK(I) = P(I)

ZEROK = DABS(RK(N)).EQ.DABS(BB) * ETA / 10.

GO TO 115

USE UNSCALED FORM OF RECURRENCE

DO 110 50, NN

110 RK(J) = RK(J-1)

CONTINUE
I = 

ZERO 00034160

ZEROK 00034170

RK(I).EQ.ZERO 00034180

CONTINUE 00034190

DO 120 I=1,N 00034200

TEMP(I) = RK(I) 00034210

LOOP TO SELECT THE QUADRATIC CORRESPONDING TO EACH NEW SHIFT 00034220

QUADRATIC CORRESPONDS TO A DOUBLE SHIFT TO A NON-REAL POINT AND ITS COMPLEX CONJUGATE. THE POINT HAS MODULUS BND AND AMPLITUDE ROTATED BY 94 DEGREES FROM THE PREVIOUS SHIFT...... 00034240

XX = COSRMXX-SINRMYY 00n34250

YY = SINRMXX+COSRMYY 00034260

XX = XXX 00034270

SR = BNDXX 00034280

SI = BNDYY 00034290

U = -SR-SR 00034300

V = BND*BND 00034310

SECOND STAGE CALCULATION, FIXED QUADRATIC 00034320

CALL ZRPQLB (20,MNTNZ) 00034330

IF (NZ.EQ.0) GO TO 130 00034340

THE SECOND STAGE JUMPS DIRECTLY TO ONE OF THE THIRD STAGE ITERATIONS AND RETURNS HERE IF SUCCESSFUL. DEFLATE THE POLYNOMIAL, STORE THE ZERO OR ZEROS AND RETURN TO THE MAIN ALGORITHM. 00034350

J = NDEO-N+1 00034360

JJ = J+NDEO 00034370

ZC(J+1) = RLZR 00034380

ZC(J+1) = RLZI 00034390

IF THE ITERATION IS UNSUCCESSFUL, ANOTHER QUADRATIC IS CHOSEN AFTER RESTORING K 00034400

125 DO 125 I=1,NN 00034410

PP(I) = QP(I) 00034420

IF (NZ.EQ.1) GO TO 20 00034430

ZC(J+1) = RLZR 00034440

ZC(J+1) = RLZI 00034450

GO TO 20 00034460

RETURN WITH FAILURE IF NO CONVERGENCE WITH 20 SHIFTS 00034470

130 DO 135 I=1,N 00034480

135 RX(I) = TEMPI(I) 00034490

140 CONTINUE 00034500

IER = 131 00034510

143 DO 150 I=1,NDEO - 00034520

NPI = NDEO+I 00034530

P(I) = Z(NPI) 00034540

150 CONTINUE 00034550

NZ = NDEO+NDEO 00034560

J = NDEO 00034570

168
DO 155 I=1,NDEQ
Z(N2-1) = Z(J)
Z(N2) = P(J)
N2 = N2-2
J = J-1
155 CONTINUE
IF (IER .EQ. 0) GO TO 9005
SET UNFOUND ROOTS TO MACHINE INFINITY
C
N2 = 2*(NDEQ-NN)+3
DO 160 I=1,N
Z(N2) = RINFP
Z(N2+1) = RINFP
N2 = N2+2
160 CONTINUE
GO TO 9000
165 IER = 129
CONTINUE
CALL UERTST (IER,6HZRPOLY)
9005 RETURN
END
C
SUBROUTINE ZRPQLB (L2,NZ)
C SPECIFICATIONS FOR ARGUMENTS
INTEGER L2,NZ
INTEGER N,NN,J,ITYPE,IFLAG
REAL AKE,BETAS,BETAV,ETA,OSS,OTS,OTV,OVV,RAHE,SS,
TS,TSS,TV,TVW,VV
DOUBLE PRECISION P(101),QP(101),RK(101),QK(101),SVK(101)
DOUBLE PRECISION SR,SI,U,V,RA,RB,C,D,A1,A2,A3,
A6,A7,E,F,G,H,SZ,RZI,RLZI,
SVU,SVV,UI,VI,VS,VSZ
LOGICAL VPASS,SPASS,TTRY,STRY
COMMON /ZRPQLJ/
P,QP,RK,QK,SVK,SR,SI,U,V,RA,RB,C,D,A1,A2,A3,A6
DATA ZERO/O,000/
FIRST EXECUTABLE STATEMENT
NZ = 0
COMPUTES UP TO L2 FIXED SHIFT K-POLYNOMIALS. TESTING FOR
X-POLYNOMIALS. TESTING FOR
CONVERGENCE IN THE LINEAR OR
QUADRATIC CASE. INITIATES ONE OF
THE VARIABLE SHIFT ITERATIONS AND
RETURNS WITH THE NUMBER OF ZEROS FOUND.
L2 - LIMIT OF FIXED SHIFT STEPS
NZ - NUMBER OF ZEROS FOUND
BETAV = .25
BETAS = .25
OSS = SR
Ovv = V
CALL ZRPQH (NN,U,V,P,QP,RA,RB)
CALL ZRPQLE (ITYPE)
DO 40 J=1,L2
CALL NEXT K POLYNOMIAL AND
ESTIMATE V
CALL LRQLF (ITYPE) 00035360
CALL ZRPQLE (ITYPE) 00035370
CALL ZRPQLG (ITYPE, UI, VI) 00035380

VVI = VI 00035390
SS = 0. 00035400
TF = 1. 00035410
TS = 1. 00035420

IF (J.EQ.1.OR.ITYPE.EQ.3) GO TO 15 00035430

CALL ZRPQLE (ITYPE) 00035460
CALL ZRPQLG (ITYPE, UI, VI) 00035470

IF (VV.NE.0.) TV = ABS(LVV-OVV)/VV 00035480
IF (SS.NE.0.) TS = ABS(SS-SS)/SS 00035490

IF DECREASING, MULTIPLY TWO MOST RECENT CONVERGENCE MEASURES

TV = 1. 00035500
IF (TV.LT.OVV) TVV = TV*OVV 00035510
IF (TS.LT.OSS) TSS = TSS*OSS 00035520

COMPARE WITH CONVERGENCE CRITERIA

VPASS = TVV.LT.BETAV 00035530
SPASS = TSS.LT.BETAS 00035540

IF (.NOT.(SPASS.OR.VPASS)) GO TO 15 00035550

AT LEAST ONE SEQUENCE HAS PASSED THE CONVERGENCE TEST. STORE VARIABLES BEFORE IITRATING

SVU = U 00035560
SVV = V 00035570
DO 5 I=1,N 00035580
5 SVK(I) = RK(I) 00035590
S = SS 00035600

CHOOSE IITRATION ACCORDING TO THE FASTEST CONVERGING SEQUENCE

VTRY = .FALSE. 00035610
STRY = .FALSE. 00035620
IF (SPASS.AND.(.NOT.VPASS).OR.TSS.LT.TVV)) GO TO 20 00035630

CALL ZRPQLC (UI, VI, NZ) 00035640
IF (NZ.GT.0) RETURN 00035650

QUADRATIC ITERATION HAS FAILED. FLAG THAT IT HAS BEEN TRIED AND DECREASE THE CONVERGENCE CRITERION.

STRY = TRUE. 00035660
BETAV = BETAV*.25 00035670

TRY LINEAR ITERATION IF IT HAS NOT BEEN TRIED AND THE S SEQUENCE IS CONVERGING

IF (STRY.OR.(.NOT.SPASS)) GO TO 25 00035680

DO 15 I=1,N 00035690
15 WW(I) = SVK(I) 00035700

CALL ZRPQMD (S, NZ, IFLAG) 00035710
IF (NZ.GT.0) RETURN 00035720

LINEAR ITERATION HAS FAILED. FLAG THAT IT HAS BEEN TRIED AND DECREASE THE CONVERGENCE CRITERION.

STRY = TRUE. 00035730
BETAS = BETAS*.25 00035740
IF (IFLAG.EQ.0) GO TO 25 00035750

IF LINEAR ITERATION SIGNALS AN

170
ALMOST DOUBLE REAL ZERO ATTEND.
QUADRATIC INTERATION

UI = -(S+S)

VI = SW

GO TO 10

v = SW

DO 30 I = 1, N

30 PK(I) = .K(I)

TRY QUADRATIC ITERATION IF IT HAS NOT BEEN TRIED AND THE V SEQUENCE IS CONVERGING

IF (VPASS AND (.NOT.VTRY)) GO TO 10

RECOMPUTE OP AND SCALAR VALUES TO CONTINUE THE SECOND STAGE

CALL ZRPLQH (NN, U, V, P, Q, RA, RB)

CALL ZRPLQ (ITYPE)

CONTINUE

RETURN

END

SUBROUTINE ZRPLQ (U, V, NZ)

SPECIFICATIONS FOR ARGUMENTS

INTEGER NZ

DOUBLE PRECISION U, V

SPECIFICATIONS FOR LOCAL VARIABLES

INTEGER NN, J, I, ITYPE

REAL ARE, ETA, OMP, RELSTP, RMP, RMRK, T, ZM

DOUBLE PRECISION P(101), Q(101), RK(101), S(QK(101))

DOUBLE PRECISION SR, SI, U, V, RA, RB, C, D, A1, A2, A3


DOUBLE PRECISION UI, VI, ZERO, PT01, ONE

LOGICAL TRIED


DATA ZERO, PT01, ONE / 0.000, 0.000, 0.0100, 0.1000/

FIRST EXECUTABLE STATEMENT

VARIABLE-SHIFT K-POLYNOMIAL

ITERATION FOR A QUADRATIC FACTOR CONVERGES ONLY IF THE ZEROS ARE EQUIMODULAR OR NEARLY SO

U, V - COEFFICIENTS OF STARTING QUADRATIC

NZ - NUMBER OF ZERO FOUND

TRIED = .FALSE.

U = U

V = V

J = 0

CALL ZRPLQ (ONE, U, V, NZ)

RETURN IF ROOTS OF THE QUADRATIC ARE REAL AND NOT CLOSE TO MULTIPLE OR
C NEARLY EQUAL AND OF OPPOSITE SIGN RETURN
C EVALUATE POLYNOMIAL BY QUADRATIC SYNTHETIC DIVISION
C COMPUTE A RIGOROUS BOUND ON THE ROUNING ERROR IN EVALUATING P

DO 10 I=2,N
10 EE = EE*2*ABS(SIN(LCV))

EE = (S,RMRE+2,ARE)*EE-(5,RE+2,ARE)*ABS(SINL(RA)+T)+2,ARE*ABS(T)

ITERATION HAS CONVERGED SUFFICIENTLY IF THE POLYNOMIAL VALUE IS LESS THAN 20 TIMES THIS BOUND

IF (RMP.GT.20.*EE) GO TO 15

STOP ITERATION AFTER 20 STEPS IF (J.GT.20) RETURN

A CLUSTER APPEARS TO BE STALLING THE CONVERGENCE. FIVE FIXEN SHIFT STEPS ARE TAKEN WITH A U,V CLOSE TO THE CLUSTER

IF (RELSTP.LT.ETA) RELSTP = ETA

U = U-UMRELSTP
V = V+VMRELSTP

CALL ZRPQLM (HNU,V,P,OP,RA,RB)

CALL ZRPQLE (ITYPE)

CALL ZRPQLF (ITYPE)

CALL ZRPQLO (ITYPE,UI,VI)

CALCULATE NEXT K POLYNOMIAL AND NEW U AND V

IF VI IS ZERO THE ITERATION IS NOT CONVERGING

IF (VI.EQ.ZERO) RETURN

RELSTP = DABS((VI-V)/VI)
U = UI
V = VI
GO TO 5

END
SUBROUTINE ZRPQDL (SSS,NZ,IFLAG)

C SPECIFICATIONS FOR ARGUMENTS
NZ,IFLAG:
INTEGER
SSS:
DOUBLE PRECISION

C SPECIFICATIONS FOR LOCAL VARIABLES
N,NJ,I
ARX,EE,ETA,OMP,RMP,WM,RE,MRB
P(101),Q(101),WK(101),QK(101),SVK(101)
SR,SI,U,VA,R8,RA,A,2,A,3
A0,A7,E,F,G,H,SZ,R,SZ1,RLZ,RLZI,
A0,A7,E,F,G,H,SR,SZ1,RLZ,RLZI,ETA,ARE,REM,NN
ZERO/0.0000/,P(101)/0.001D0/

COMMON /ZRPQLJ/
   DATA ZERO/O.0DO/,PTO01/0.001D0/

C VARIABLE-SHIFT H POLYNOMIAL
C ITERATION FOR A REAL ZERO SSS
C STARTING ITERATE
C HZ - NUMBER OF ZERO FOUND
C IFLAG - FLAG TO INDICATE A PAIR OF
C ZEROS NEAR REAL AXIS
C FIRST EXECUTABLE STATEMENT
C MAIN LOOP
C EVALUATE P AT S
C COMPUTE A RIGOROUS BOUND ON THE
C EREZ IN EVALUATING P
C ITERATION HAS CONVERGED SUFFICIENTLY
C IF THE POLYNOMIAL VALUE IS LESS
C THAN 20 TIMES THIS BOUND
C STOP ITERATION AFTER 10 STEPS
C A CLUSTER OF ZEROS NEAR THE REAL
C AXES HAS BEEN ENCOUNTERED RETURN
C WITH IFLAG SET TO INITIATE A
C QUADRATIC ITERATION
C
IFLAG = 1
SSS = S
RETURN
RETURN IF THE POLYNOMIAL VALUE has INCREASED SIGNIFICANTLY

COMPUTE T, THE NEXT POLYNOMIAL, AND THE NEW ITERATE

RETURN IF THE POLYNOMIAL VALUE increased significantly

To compute the next polynomial, and the new iterate

IF (DABS(RKV).LE.DABS(RK(N))) N10.META) GO TO 40

USE THE SCALED FORM OF THE RECURRENCE IF THE VALUE OF K AT S IS NONZERO

T = -PV/RKV
RK(1) = QP(1)
DO 35 I=2,N
RK(I) = TKQK(I-1)+QP(I)
GO TO 50

USE UNSCALED FORM

RK(1) = ZERO
DO 45 I=2,N
RK(I) = RK(I-1)
GO TO 50

IF (DABS(RKV).GT.DABS(RK(N))) N10.META) T = -PV/RKV
S = S+T
GO TO 5

END

IMSL ROUTINE NAME - ZRPQLE

COMPUTER - IBM/DOUBLE

LATEST REVISION - JANUARY 1, 1978

SUBROUTINE ZRPQLE (ITYPE)

INTEGER ITYPE

SPECIFICATIONS FOR ARGUMENTS

INTEGER N,NN

SPECIFICATIONS FOR LOCAL VARIABLES

REAL ARE,ETA,RMRE

DOUBLE PRECISION P(101),QP,101),RK(101),QK(101),SVK(101)

1


A6.A7,E,F,G,H,SZ,51,RLZI,RLZI,ETA,ARE,REP,NN

THIS ROUTINE CALCULATES SCALAR QUANTITIES USED TO COMPUTE THE NEXT POLYNOMIAL AND NEW ESTIMATES OF THE QUADRATIC COEFFICIENTS

ITYPE - INTEGER VARIABLE SET HERE

-----------------------------------------------------------------------

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INDICATING HOW THE CALCULATIONS ARE NORMALIZED TO AVOID OVERFLOW
SYNTHETIC DIVISION OF K BY THE QUADRATIC 1,U,V

CALL ZRPQLM (N,U,V,RK,GK,D)
IF (DABS(C).GT.DABS(RK(N))*100,META) GO TO 5
IF (DABS(D).GT.DABS(RK(N-1))*100,META) GO TO 5
ITYPE = 3
TYPE=3 INDICATES THE QUADRATIC IS ALMOST A FACTOR OF K
RETURN
5 IF (DABS(D).LT.DABS(C)) GO TO 10
ITYPE = 2
TYPE=2 INDICATES THAT ALL FORMULAS ARE DIVIDED BY D
E = RA/D
F = C/D
G = UVRB
H = VVRB
A5 = (RA+G)*E+H*N*(RB/D)
A1 = RBM-R0
A7 = (F+U)*RA+H
RETURN
10 ITYPE = 1
TYPE=1 INDICATES THAT ALL FORMULAS ARE DIVIDED BY C
E = RA/C
F = D/C
G = U/E
H = VVRB
A5 = RA*(H/C)+G*N*(RB)
A1 = RB-RA*(D/C)
A7 = RA+G*D+H*M
RETURN
END

SUBROUTINE ZRPQLF (ITYPE)

INTEGER ITYPE

INTEGER N,NN,1
REAL ARE,ETA,ROM\,
DOUBLE PRECISION P(101),OP(101),RK(101),QK(101),SVK(101)
DOUBLE PRECISION SR,SI,UV,RA,RB,C,D,A1,A2,A3,
COMMON /ZRPQL/ PQP,RK,QK,SVK,SR,SI,UV,RA,RB,C,D,A1,A2,A3,A6,
DATA ZERO/O.ODO/

IF (ITYPE.EQ.3) GO TO 20
TEMP = RA
IF (ITYPE.EQ.1) TEMP = RB
IF (DABS(A1).GT.DABS(TEMP)*META)10.) GO TO 10
IF A1 IS NEARLY ZERO THEN USE A SPECIAL FORM OF THE RECURRENC
SUBROUTINE ZRPQLG (ITYPE, UU, VV)

INTEGER ITYPE
DOUBLE PRECISION UU, VV

INTEGER N, NN
REAL ARE, ETA, RMRE

DOUBLE PRECISION P(101), QP(101), RK(101), QK(101), SVK(101)

COMMON /ZRPQLG/ P, QP, RK, QK, SVK, SR, SI, U, VR, AR, RB, C, D, A1, A2, A3,
A4, A5, B1, B2, C1, C2, C3, C4, TEMP, ZERO

DATA ZERO/O.0D0/

COMPUTE NEW ESTIMATES OF THE QUADRATIC COEFFICIENTS USING THE SCALARS COMPUTED IN ZRPQLE
USE FORMULAS APPROPRIATE TO SETTING OF TYPE
FIRST EXECUTABLE STATEMENT

IF (ITYPE.EQ.3) GO TO 15
IF (ITYPE.EQ.2) GO TO 5
A4 = RA+UXRB+M+H
A5 = C*(U+V+MXK+D)
GO TO 10

EVALUATE NEW QUADRATIC COEFFICIENTS.
10 B1 = -RK(N)/P(NN)
B2 = -(RK(N-1)+B1*M(N))/P(NN)
C1 = V*K2/MA1
C2 = B1/MA7
C3 = B1*K1/MA3
C4 = C1-C2-C3
TEMP = A5+B1*A4-C4
IF (TEMP.EQ.ZERO) GO TO 15
UU = U-(U*K(C3+C2)+V*(B1*A1+B2*A7))/TEMP
VV = V*(1+C9/TEMP)
RETURN
15 IF TYPE=3 THE QUADRATIC IS ZERED
UU = ZERO
VV = ZERO
RETURN
END

SUBROUTINE ZRPOHL (NN, U, V, P, Q, RA, RB)

INTEOER NN
DOUBLE PRECISION P(NN), Q(NN), U, V, RA, RB

SPECIFICATIONS FOR LOCAL VARIABLES
INTEGER I
DOUBLE PRECISION C

DIVIDES P BY THE QUADRATIC U, V
PLACING THE QUOTIENT IN Q AND THE
REMAINDER IN A, B
FIRST EXECUTABLE STATEMENT
RB = P(1)
Q(1) = RB
RA = P(2)-U*RB
DO 5 I=3, NN
C = P(I)-U*RA-V*RB
Q(I) = C
RB = RA
RA = C
5 CONTINUE
RETURN
END

IMSL ROUTINE NAME - ZRPOHL

SUBROUTINE ZRPQLI (RA, B1, C, SR, SI, LRL, RLI)

DOUBLE PRECISION RA, B1, C, SR, SI, LRL, RLI

SPECIFICATIONS FOR LOCAL VARIABLES
DATA ZERO, ONE, TWO/0.000, 1.000, 2.000/

COMPUTER - IBM/DOUBLE
LATEST REVISION - JANUARY 1, 1978
CALCULATE THE ZEROS OF THE QUADRATIC
\[ \text{AM} \times 2 + B \text{IM} + C \text{ MM} 0 \text{ TIMES} \]
FORMULA, MODIFIED TO AVOID OVERFLOW, IS USED TO FIND THE LARGER ZERO IF THE ZEROS ARE REAL AND BOTH ZEROS ARE COMPLEX.
THE SMALLER REAL ZERO IS FOUND DIRECTLY FROM THE PRODUCT OF THE ZEROS C/A.

FIRST EXECUTABLE STATEMENT
IF (RA.NE.ZERO) GO TO 10
SR = ZERO
IF (BI.NE.ZERO) SR = -C/B1
RLR = ZERO
5 SI = ZERO
RL = ZERO
RETURN
10 IF (C.NE.ZERO) GO TO 15
SR = ZERO
RLR = -B/RA
GO TO 5

COMPUTE DISCRIMINANT AVOIDING OVERFLOW
15 RB = B1/THQ
IF (DABS(RB).LT.DABS(C)) GO TO 20
E = ONE-(RA/RA*B1*C/RB)
D = DSQRT(DABS(E))*DABS(RB)
GO TO 25
20 E = RA
IF (C.LT.ZERO) E = -RA
E = RBW(RB/DABS(C))-E
D = DSQRT(DABS(E))*DSQRT(DABS(C))
25 IF (E.LT.ZERO) GO TO 30
REAL ZEROS
IF (RB.GE.ZERO) D = -D
RLR = (-RB+D)/RA
SR = ZERO
IF (RLR.NE.ZERO) SR = (C/RLR)/RA
GO TO 5

COMPLEX CONJUGATE ZEROS
10 SR = -RB/RA
RLR = SR
SI = DABS(D/RA)
RL = -SI
RETURN END

SUBROUTINE LEQ2C (A,N,IA,BM,MB,JS,WA,WK,IER)
COMPLEX*16 A(IA,1),B(1,1),NACHI,1,TMETHA,TMPP,TMPB,TMPC
DOUBLE PRECISION AR,AK,BR,CK,CI,UXNORM,XNORMZERO
DOUBLE PRECISION ACC(2)
EQUIVALENCE (TAC1),AR),(TB(2),AI),(TB(2),BR),(TB(2),DI)
(Data ZERO/0.00D)
(Data ITMAX/50)

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C
IER = 0
N1 = N+1
N2 = N+2
IF (IJOB .EQ. 2) GO TO 15
SAVE MATRIX A
DO 10 I = 1, N
DO 5 J = 1, N
W(A(I,J)) = A(I,J)
5 CONTINUE
10 CONTINUE
CALL LEQTIC(WA, N, N, NB, MIZ8DNK, ZER)
IF (ZER.NE.0) GO TO 9000
IF (IJOB .EQ. 1) GO TO 9003
SAVE THE RIGHT HAND SIDES
DO 65 J = 1, M
DO 20 I = 1, N
WA(I,N1) = B(I,J)
20 CONTINUE
OBTAIN A SOLUTION
CALL LEQTIC(WA, N, WA(1,N1), 1, N, 2, WK, IER)
XNORM = ZERO
DO 25 I = 1, N
TEMPA = WA(1,N1)
XNORM = DMAX1(XNORM, DABS(AR), DABS(AI))
25 CONTINUE
IF (XNORM.EQ.0) GO TO 65
COMPUTE THE NORM OF THE SOLUTION
DO 40 I = 1, N
TEMP = B(I,J)
ACCI = 0.0D0
ACCS = 0.0D0
CALL VXADD(B, ACC)
DO 30 JJ = 1, N
TEMPA = A(I, JJ)
TEMP = WA(JJ,N1)
CALL VXADD(-AR, BR, ACC)
CALL VXADD(-AI, BI, ACC)
30 CONTINUE
CALL VXSTO(ACC, CR)
TEMP = B(I,J)
ACCI = 0.0D0
ACCS = 0.0D0
CALL VXADD(BI, ACC)
DO 55 JJ = 1, N
TEMPA = A(I, JJ)
TEMP = WA(JJ,N1)
CALL VXADD(-AR, BI, ACC)
CALL VXADD(-BR, AI, ACC)
55 CONTINUE
CALL VXSTO(ACC, C)
WA(1,N2) = TEMPC
CALL LEQTIC(WA, N, WA(1,N2), 1, N, 2, WK, IER)
DXNORM = ZERO
DO 45 I = 1, N
UPDATE THE SOLUTION
45 CONTINUE
..(I,N1) = WA(I,N1)+WA(I,N2)
        TEMP = WA(I,N2)
        DXNORM = DMAX1(DXNORM, DABS(AR), DABS(AI))
        45 CONTINUE
        IF (XNORM+DXNORM .EQ. XNORM) GO TO 50
        CONTINUE
        IER = 130
        STORE THE SOLUTION
        50 CONTINUE
        IF (IER .NE. 0) GO TO 9000
        GO TO 9000
        9000 CONTINUE
        CALL UERTSTIER, AMLEQ2C )
        9005 RETURN
        END

        SUBROUTINE LEQTIC (A,N,IA,B,M,IB, IJOB, WA, IER)
        SPECIFICATIONS FOR ARGUMENTS
        INTEGER N, IA, M, IB, IJOB, IER
        COMPLEX*16 A (IA, N), B(IB, M)
        DOUBLE PRECISION WA(N)
        SPECIFICATIONS FOR LOCAL VARIABLES
        DOUBLE PRECISION P, Q, ZERO, ONE, T(2), RN, BIG
        COMPLEX*16 SUM, TEMP
        INTEGER I, J, JM1, IM1, K, IMAX, JP1, IM, N
        EQUIVALENCE (SUM(1)),...
        DATA ZERO, 0.0, 0.0
        C INITIALIZATION
        C FIRST EXECUTABLE STATEMENT
        C
        IER = 0
        IF ( IJOB .EQ. 2) G0 TO 75
        RN = N
        FIND EQUILIBRATION FACTORS
        DO 10 I = 1, N
            BIG = ZERO
            DO 5 J = 1, N
                TEMP = A(I, J)
                P = CDABS(TEMP)
                IF (P .GT. BIG) BIG = P
            5 CONTINUE
            IF (BIG .EQ. ZERO) GO TO 105
            WA(I) = ONE/BIG
        10 CONTINUE
        L-U DECOMPOSITION
        DO 70 J = 1, N
            JM1 = J-1
            IF (JM1 .LT. 1) GO TO 25
            COMPUTE U(I, J), I=1,...,J-1
        70 CONTINUE
        DO 20 I=1, JM1
            SUM = A(I, J)
            IM1 = I-1
            IF (IM1 .LT. 1) GO TO 20
            DO 15 K=1, IM1
                SUM = SUM-A(I, K)*WA(K, J)
            15 CONTINUE
        20 CONTINUE
A(I,J) = SUM

CONTINUE

P = ZERO

SUM = 0

DO 45 I=J,N

SUM = A(I,J)

IF (J .LT. 1) GO TO 40

DO 35 K=1,J-1

SUM = SUM - A(I,K)*X(K)

CONTINUE

A(I,J) = SUM

40 CONTINUE

IF (P .GE. Q) GO TO 45

P = Q

IMAX = I

CONTINUE

TEST FOR ALGORITHMIC SINGULARITY

Q = RN

IF (J.EQ. RN) GO TO 105

IF (J .EQ. IMAX) GO TO 60

DO 50 K=1,N

IF (A(I,K) .EQ. 0) GO TO 55

A(I,K) = A(I,M)

CONTINUE

INTERCHANGE ROWS J AND IMAX

DO 60 K=1,J-1

A(I,K) = A(I,K)*TEMP

CONTINUE

DIVIDE BY PIVOT ELEMENT U(J,J)

DO 65 I=J+1,N

A(I,J) = A(I,J)/TEMP

CONTINUE

DO 70 J=1,I-1

SUM = SUM - A(I,J)*X(J)

CONTINUE

IF (I+1 .EQ. 1) GO TO 90

DO 103 K=1,M

IH = 0

DO 90 I=J,N

IMAX = I

SUM = B(I,M)

B(I,M) = B(I,K)

IF (I .EQ. 0) GO TO 85

IM1 = I-1

DO 80 J=I,IM1

SUM = SUM - A(I,J)*B(J,M)

CONTINUE

GO TO 88

IF (T(I) .NE. ZERO .OR. T(2) .NE. ZERO) IH = I

85 CONTINUE

88 B(I,K) = SUM

CONTINUE

SOLVE UY = B FOR Y

DO 100 I=J,N

IF (J+1 .GT. N) GO TO 98

IH = 1

DO 103 J=1,I-1

SUM = B(I,J)

IF (J+1 .GT. N) GO TO 98

103 CONTINUE

SOLVE LY = B FOR Y

DO 100 I=J,N

END
DO 95 J = JPI, N
   SUM = SUM - A(I, J)*B(J, K)
95   CONTINUE
98   B(I, K) = SUM / A(I, I)
100  CONTINUE
105  CONTINUE
      GO TO 9005
C 105 IER = 129
   9000 CONTINUE
C   CALL UERTST(IER, 6HLEGTC)
   9005 RETURN
END
APPENDIX B
SAMCJ Program Listing
~00000010
~'~i

CNNNNNWNK~~V'~
V
CNN NNNNMNMNNI
f i gNNNNNNNNNNNMN~NNKNNNNNNNNNMNNN
N

CNN

CNN

PROGRAM SAMCJ

CNN
CNA

STRENGTH ANALYS:S OF MULTI-FASTENER COMPOSITE JOINTS

c

L;
c
C
C

NNM

NN
N
:NNNNNNNNWWNVMNNWdNANNNMNNNNNNMNNKNNNNNMNNNNNNNNNN
MNN~WW~fMNNNNN~AWKI~NNNN
4NNNMMNNMNMNNNNNNMNNMNNNN
C.

CNN

C

N

SAMCJ COMPUTES ';,ELUAD DISTFIDUTION AMONG FASTENERS IN
A MULTI-FASTEflEb (:,`MPOSITý/ METALLIC JOINT, AND PREDICTS
THE JOINT FAILURE P.AD, FAILURE MODE, AND FAILURE LOCATION.
THE FASTElJER LOAD iLý,rRIBUTION 13 DETERMINED BY A
FINITE EIL MENIT MET00t) WITH THr- USE OF SPECIAL FINITE
FLEMENTS. THE SUBSE'QUElir FAIL'S:' ANALYSIS IS BASED
ilil ANlAVERAGE STRE55 FAILURE Cp..TERION
C
IMPLICIT REAth8CA-1W OiZ
DIMENSION NPLY(2).klASHD(2),STM(3)
DTM~nt1i ON IIEF( 2). I.X( 2). IOH( 2), NPL (2)
oimctlS!OtN NOfEK(L.T.0.1ObNIGLH(2.10,10),NOOH(2,13,10)
DIMENSTI'iI N4UPLC24O0.10).NUMEF(2,10),NUMLH(2,10)
DIVEFN3SI'JN IlkMOH( 2, 10), NUMPL( 2, 10)
DIME115101I NELO0R D (2,?A, 25 ) #NELD15(5 0, 5 ,2)
DIMEhS IoNl ELLoADf50PC)IPSMXC!0,4),NZER0(50),NBDARY(25)
0 1IrlFI 51Oil X0UTC600).'IOUT(600),PLYK(100).AARKC100),BARUC100)
Cr10Ell' 10N ELSrFFC'jo.10,10),ELSTSS(5a,50,olO
D1IM1E1NSI ON SSX(20).G..SN4(20).ANR(200),RHS(2O0).PDCC200)
DIMENSI ON GLSTFF(2U0,200),ASQM(200.200) .ANR2(200)
DIMEtlSIOil RDSTPFF'50.Z)IWOHT(500),ERO(50)
D'.MF.NSIOII NELPLS(Z.,50 ) oNELPTZ2.50, 50)
DTMENtION0
EL THK 0 ) , ELC0N( 50 ,6 ) ,1ELCNAC 50, 6
DIMENIS!ONl GCUORDC150.2),PLYTHKC2,2.5),N4ELFAS(25,3)
DIMIIlS I Oil NELF :A Cý5. 3)
DIMENlSION ELWf)IH ( 511) . t0RI D (15 0,LYP N (5 0
1,1M ENSI
1 i FSCD(50, !LtIlELTYP(50)
DINENIWON MTL(3, 1'),R(2)
D 1rI
rtlS 0 11 AllOK(5.C.1,'UMPLYC2).CM(2)
0 I- it j1111 AlJ3
t15C -" I PL Y( 10 0. 2 )
D111F1451SOil E(2),E2C2), ý2(2).V12(2)AV21(2),H(2)
D 11. - a)'iJJ1 3TvL~ke
DIN IFtS 10N )fC;( 5) , '-C(5)
DIMEN3SION AUNTC?).,AUBRIZI ,AOSOCZ)
DimriisION ELFATL(50.3)
rý0tit 10 11/A0V/ AO0ItT -A rR , A0 3O
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COMMON/L.Aff/El. FAT 1
C0Mr10ll/F7'%-FA3E, FA5V, rAsI)

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COMMON/R7/R
COMMON/MFS/FSCD
COMMON/NTP/NELYP
COMMON/HPT/HOPT6,HOPT7,HOPT8
COMMON/MD/E1,E2,E12,E121,E122
COMMON/ELP/NUMPLY,ANG,IPLY
COMMON/ELP/AX,EX,NOUT,NSTS
COMMON/FCC/ELNDTH,ELTHK,ELLOAD
COMMON/KST/NCASE,NATYPE
COMMON/DISP/ANR2
COMMON/P5B/PLYKBARKBARKBARU
COMMON/ELS/ELSTFF,ELSTSS
COMMON/CMT2/XOUT,YOUT
COMMON/SER/NT,N5
DATA Y/Y/
DATA CM/CM/

READ IN REQUIRED INPUT DATA

WRITE(6,876)
876 FORMAT(//,10X,'PROGRAM SANCJ',//)

WRITE(6,900)
900 FORMAT(//,8X,'PROGRAM SANCJ PREDICTS THE FAILURE LOAD, FAILURE ',/)

WRITE(6,911)
911 FORMAT(/' IS THE TOP PLATE A COMPOSITE OR A METAL?'/)

WRITE(6,203)
203 FORMAT(' ENTER MATERIAL DESCRIPTION OF THIS PLATE '/)

WRITE(6,754)
754 FORMAT(//' METALLIC PLATE IS MODELED AS A 30 PLY',//)

WRITE(6,794)
794 FORMAT(//' LAMINATE OF 7 DEGREE PLIES WITH ISOTROPIC',//)

WRITE(6,796)
796 FORMAT(//' MATERIAL PROPERTIES',//)

READ(5,N) NSDLS
WRITE(6,912)
912 FORMAT(' IS THE TOP PLATE A COMPOSITE OR A METAL?'/)

WRITE(6,913)
913 FORMAT(' IS THE BOTTOM PLATE A COMPOSITE OR A METAL?'/)

WRITE(6,914)
914 FORMAT(' ENTER C OR M IN THE FIRST FIELD'/)

WRITE(5,204) CM(K)
204 FORMAT(' ENTER MATERIAL DESCRIPTION OF THIS PLATE '/)

WRITE(5,106) CM(K)
106 FORMAT(//)

CONTINUE
DO 300 K=1,2
IF(K.EQ.1) WRITE(6,912)
IF(K.EQ.2) WRITE(6,913)

CONTINUE
DO 300 K=1,2
IF(K.EQ.1) WRITE(6,912)
IF(K.EQ.2) WRITE(6,913)
DO 306 K=1,2
   IF(K.EQ.1) WRITE(6,216)
   IF(K.EQ.2) WRITE(6,555)
 216 FORMAT(' INPUT THE ENGINEERING PROPERTIES OF THE TOP PLATE')
   WRITE(6,931) CC(K),CMC
   IF(CC(K).EQ.CMC) GO TO 85
   WRITE(6,702) CC(K)
   931 FORMAT(' INPUT YOUNG'S MODULUS AND POISSON'S RATIO')
   READ(5,21) E1(K),V12(K)
   G12(K)=E1(K)/(2.0D0*V12(K))
   V21(K)=V12(K)*E2(K)/E1(K)
   GO TO 306
85 CONTINUE
217 FORMAT(' INPUT YOUNG'S MODULUS, E1 AND E2')
   READ(5,21) E1(K),E2(K)
   WRITE(6,213)
 218 FORMAT(' INPUT THE SHEAR MODULUS AND MAJOR POISSON'S RATIO')
   READ(5,21) G12(K),V12(K)
   V21(K)=V12(K)*E2(K)/E1(K)
   WRITE(6,217)
306 CONTINUE
290 CONTINUE
   DO 303 K=1,2
      IF(K.EQ.1) WRITE(6,931) CC(K),CMC
      IF(K.EQ.2) WRITE(6,931) CC(K)
      GO TO 306
   43 CONTINUE
   IF(K.EQ.1) WRITE(6,207)
   207 FORMAT(' INPUT TOTAL NUMBER OF DISTINCT PLY ORIENTATIONS IN THE TOP PLATE')
   702 FORMAT(' INPUT TOTAL NUMBER OF DISTINCT PLY ORIENTATIONS IN THE BOTTOM PLATE')
   209 CONTINUE
   DO 303 K=1,2
      IF(K.EQ.1) WRITE(6,702) CC(K)
      IF(K.EQ.2) WRITE(6,702) CC(K)
      GO TO 306
303 CONTINUE
   DO 209 L=1,11
      READ(5,14) ANG(L,K)
      WRITE(6,206) L
   209 CONTINUE
   WRITE(6,1823)
1823 FORMAT(' THICKNESS VARIATIONS MAY BE APPROXIMATED',/)
NELPLS(I,J) = 30
DO 892 III = 1, 30
892 HELPT(I, I, III) = 1
GO TO 811
891 CONTINUE
   IF(I.EQ.1) WRITE(6, 812)
   IF(I.EQ.2) WRITE(6, 813)
812 FORMAT(/' ENTER NUMBER OF DIFFERENT LAYUPS IN THE ',/,' TOP PLATE'/)
813 FORMAT(/' ENTER NUMBER OF DIFFERENT LAYUPS IN THE ',/,' BOTTOM PLATE'/)
   READ(5, X) NL
   DO 814 J = 1, NL
   WRITE(6, 815) J
   815 FORMAT(' ENTER NUMBER OF PLIES IN LAYUP #',/,'X')
   READ(5, X) NELPLS(I, J)
   WRITE(6, 816)
   816 FORMAT(' ENTER PLY THICKNESS FOR THIS LAYUP')
   READ(5, X) PLYTHK(I, J)
   NN = NELPLS(I, J)
   WRITE(6, 818)
   818 FORMAT(' ENTER SEQUENCE OF PLY TYPES FROM TOP TO BOTTOM'/)
   DO 817 K = 1, NN
   READ(5, N) NELPT(I, J, K)
   817 CONTINUE
   814 CONTINUE
   WRITE(6, 53)
   53 FORMAT(/' FASTENER DESCRIPTION'/)
   WRITE(6, 250)
   250 FORMAT(' INPUT MATERIAL DESCRIPTION FOR FASTENER')
   READ(5, I) MTL(3, I)
   WRITE(6, 251)
   251 FORMAT(15A4)
   WRITE(6, 252)
   252 FORMAT(' INPUT YOUNG'S MODULUS AND POISSON'S RATIO FOR',/,' THE FASTENER')
   READ(5, F) EAS, FASV
   WRITE(6, 253)
   253 FORMAT(/' INPUT THE DIAMETER OF THE FASTENER'/)
   READ(5, S) FASD
   WRITE(6, 888)
   888 FORMAT(/' FASTENER TYPE '/, /,' ENTER 1 FOR PROTRUDING HEAD',/,' 2 FOR COUNTERSUNK HEAD'/)
   IF(NFTYP.EQ.1) GO TO 360
   WRITE(6, 889)
   889 FORMAT(/' ENTER PLATE WHICH CONTAINS THE COUNTERSUNK',/,' HEAD (OPPOSITE PLATE ASSUMES THE NUT HEAD)/',/,' ENTER 1 FOR TOP PLATE',/,' 2 FOR BOTTOM PLATE'/)
   READ(5, X) N
   RR(I) = 0.0D10
   IF(NFYP.EQ.1) GO TO 360
   WRITE(6, 6477)
   6477 FORMAT(/' GRID LAYOUT'/)
   WRITE(6, 6477)
   477 FORMAT(/' GRID LAYOUT'/)
   C INPUT ORIG'S, ELEMENT CONNECTIVITY AND PROPERTIES
TOP PLATE

WRITE(6,689)
689 FORMAT(' ENTER NUMBER OF GRIDS IN TOP PLATE')
READ(5,N) NQP1
WRITE(6,571) NQP1
371 FORMAT(' ENTER ','GRID POINTS ','

DO 603 I=1,NQP1
WRITE(6,371) NQP1
READ(5,N) NORID(I),GCOORD(I,1),GCOORD(I,2)
603 CONTINUE

BOTTOM PLATE

WRITE(6,683)
683 FORMAT(' ENTER NUMBER OF GRIDS IN BOTTOM PLATE')
READ(5,N) NQP2
NOTOT=NQP1+NQP2
WRITE(6,371) NQP2
NPI=NQP1+1
DO 604 I=NPI,NOTOT
WRITE(5,N) NORID(I),GCOORD(I,1),GCOORD(I,2)
604 CONTINUE

WRITE(6,399)
399 FORMAT(' PLANAR ELEMENT ARE NUMBERED ','

N2 N3
N1 N4

ELEMENT TYPES ARE DESIGNATED AS FOLLOWS:

4 NODE PLAIN ELEMENT TYPE NO. 1
5 NODE LOADED HOLE ELEMENT TYPE NO. 2
4 NODE OPEN HOLE ELEMENT TYPE NO. 3

(NOTE: ENTER N5=0 FOR FOUR NODE ELEMENTS)

WRITE(6,191)
191 FORMAT(' ENTER NUMBER OF ELEMENTS IN TOP PLATE')
READ(5,N) HELI
DO 597 I=1,HELI
WRITE(6,388) I
388 FORMAT(' FOR ELEMENT NO.15',

HELI(I,1)=HELI(I,1)
DO 592 KLP1,NQP1
IF(HELI(I,IL).EQ.NORID(KLP1)) IC=1
IF(HELI(I,IL).EQ.NORID(KLP2)) NELCHI(I,IL)=KLP1
592 CONTINUE
591 CONTINUE
IF(CM(1).EQ.CMC) GO TO 627
IF(NELTYP(I).NE.1) GO TO 721
WRITE(6,1721)
1721 FORMAT(' ENTER ELEMENT THICKNESS')
READ(5,NM) ATH
IF(NELTYP(I).NE.2) GO TO 722
WRITE(6,723)
723 FORMAT(' ENTER ELEMENT THICKNESS')
READ(5,NM) ATH
FSCD(I,1)=GCOORD(NELCHAI,6,1)
FSCD(I,2)=GCOORD(NELCHAI,6,2)
FSCD(I,3)=FASD/2.000
722 IF(NELTYP(I).NE.3) GO TO 724
WRITE(6,725)
725 FORMAT(' ENTER ELEMENT THICKNESS, X AND Y COORDINATES')
IF(NELTYP(I).NE.1) GO TO 726
WRITE(6,727)
726 FORMAT(' ENTER OPEN HOLE AND HOLE RADIUS')
READ(5,NM) LYPN(I)
IF(NELTYP(I).NE.2) GO TO 728
WRITE(6,729)
729 FORMAT(' ENTER ELEMENT LAYUP NO')
READ(5,NM) LYPN(I)
FSCD(I,1)=ATH/30.000
PLYTHK(I,1)=ATH/30.000
LYPN(I)=1
627 CONTINUE
IF(NELTYP(I).NE.1) GO TO 726
WRITE(6,727)
727 FORMAT(' ENTER ELEMENT LAYUP NO')
READ(5,NM) LYPN(I)
IF(NELTYP(I).NE.2) GO TO 726
WRITE(6,727)
728 FORMAT(' ENTER ELEMENT LAYUP NUMBER')
READ(5,NM) LYPN(I)
FSCD(I,1)=FASD/2.000
628 CONTINUE
WRITE(6,688)
688 FORMAT(' ENTER NUMBER OF ELEMENTS IN BOTTOM PLATE')
READ(5,NM) HLPN(I)
NELT=NEL1+NEL2
HNP1=NEL+1
DO 593 I=1,HNP1,NELT
WRITE(6,689) I
593 CONTINUE
800 FORMAT(' FOR ELEMENT NO,IS')
READ(5,NM) NELCON(I,J),J=1,5
NELCON(I,1)=NELCON(I,1)
NIN=NIN+1
DO 594 K=0,NIN,NELTOT
IF(NELCON(I,IL).EQ.NGRID(KL)) IC=1
IF(NELCON(I,IL).EQ.NGRID(KL)) NELCHAI,IL)=KL
IF(NELCON(I,IL).EQ.NGRID(KL)) NELNA(I,IL)=KL
594 CONTINUE
593 CONTINUE
  IF(CM(2).EQ.CMC) GO TO 927
  IF(NELTYP(I).NE.1) GO TO 921
  WRITE(6,1921)
  1921 FORMAT(' ENTER ELEMENT THICKNESS')
  READ(5,*) ATH
  921 IF(NELTYP(I).NE.2) GO TO 922
  WRITE(6,1923)
  1923 FORMAT(' ENTER ELEMENT THICKNESS')
  READ(5,*) ATH
  FSCD(I,1)=COORD(NELCNA(I,6),1)
  FSCD(I,2)=COORD(NELCNA(I,6),2)
  FSCD(I,3)=FASD/2.000
  WRITE(6,3443) I,NELCNA(I,6),FSCD(I,1),FSCD(I,2)
  3443 FORMAT(' C I NELCNA FSCD12',15.2X,5(D9.3,2X))
  922 IF(NELTYP(I).NE.3) GO TO 924
  WRITE(6,925)
  925 CONTINUE
  IF(NELTYP(I).NE.1) GO TO 926
  WRITE(6,1927)
  1927 FORMAT(' ENTER ELEMENT LAYUP NO')
  READ(5,*) LYPN(I)
  926 IF(NELTYP(I).NE.2) GO TO 928
  WRITE(6,929)
  929 CONTINUE
  IF(NELTYP(I).NE.3) GO TO 930
  WRITE(6,1711)
  1711 FORMAT(' ENTER NUMBER OF FASTENERS IN JOINT')
  READ(5,*) NUMF
  WRITE(6,1716)
  1716 FORMAT(' *) EFFECTIVE FASTENER ELEMENTS ARE
  *) EFFECTIVE FASTENER ELEMENTS ARE
  *) NUMBERED AS SHOWN
  *) N1 (TOP PLATE)
  *) N2 (BOTTOM PLATE)
WHERE N1 AND N2 CORRESPOND TO THE CENTRAL NODES IN LOADED HOLE ELEMENTS.

DO 717 I=1,NUMF
WRITE(6,711) I

711 FORMAT(' ENTER ELEMENT NO.',I5)
READ(5,W) (NELFAS(I,J),J=1,3)

CONTINUE

DETERMINE GRID STORAGE LOCATIONS FOR ELEMENT NODES:

DO 612 I=1,NEL1
  N=6
  IF(NELTP(I),NE.2) N=5
  NELCNA(I,1)=NELCON(I,1)
  DO 613 J=2,N
    IC=0
    DO 614 K=1,NOP1
      IF(NELCON(I,J).EQ.NORID(K)) IC=1
      IF(NELCON(I,J).EQ.NORID(K)) NELCNA(I,J)=K
    IF(IC.EQ.1) GO TO 613
    CONTINUE
  614 CONTINUE

613 CONTINUE

612 CONTINUE

NPL1=NEL1+1

DO 395 I=NPL1,NELTOT
  N=6
  IF(NELTP(I),NE.2) N=5
  NELCNA(I,1)=NELCON(I,1)
  DO 616 J=2,N
    IC=0
    NIN*NOP1+1
    DO 617 K=NIN,NORDT
      IF(NELCON(I,J).EQ.NORID(K)) IC=1
      IF(NELCON(I,J).EQ.NORID(K)) NELCNA(I,J)=K
      IF(IC.EQ.1) GO TO 616
    CONTINUE
  617 CONTINUE

616 CONTINUE

395 CONTINUE

DO 741 J=1,NUMF
  N=2
  NELFAS(I,1)=NELFAS(I,1)
  DO 242 J=1,N
    IC=0
    DD 243 K=1,NGTOT
      IF(NELFAS(I,J+1).EQ.NORID(K)) IC=1
      IF(NELFAS(I,J+1).EQ.NORID(K)) NELFAS(I,J+1)=K
      IF(IC.EQ.1) GO TO 242
    CONTINUE

242 CONTINUE

741 CONTINUE

C COMPUTE ELEMENT WIDTHS:

DO 239 I=1,NELTOT
  ELWTH(I)=DABS(GCOORD(NELCNA(I,1),2)-GCOORD(NELCNA(I,2),2))

239 CONTINUE

C
GROUP ELEMENTS TO AVOID THE DUPLICATE
CALCULATION OF IDENTICAL STIFFNESS
MATRICES

WRITE(6,3000)
3000 FORMAT(1X,' TO REDUCE RUN TIMES, ELEMENTS MAY BE ',/,'GROUPED INTO SETS WHICH WILL BE ASSIGNED',/,'IDENTICAL STIFFNESS MATRICIES ',/,' ENTER 1 TO USE THIS OPTION ',/,' 2 OTHERWISE ')
READ(S.W.) NOPT
IF(NOPT.EQ.1) GO TO 3001
N1=0
N2=0
N3=0
DO 3002 I=1,NEL1
IF(NELTYPE(I).EQ.1) N1=N1+1
IF(NELTYPE(I).EQ.2) N2=N2+1
3002 IF(NELTYPE(I).EQ.3) N3=N3+1
NEF(I)=NUMF
NLM(1)=N2
NOM(1)=N3
NPL(I)=N1
N=NUMF
DO 3003 I=1,N
3003 HOFF(I,I)=NELFAS(I,1)
IC=0
DO 3004 I=1,NEL1
IF(NELTYPE(I).EQ.1) IC=IC+1
IF(NELTYPE(I).EQ.2) NGLM(I,1,IC)=NELCON(I,1)
3004 CONTINUE
IC=0
DO 3005 I=1,NEL1
IF(NELTYPE(I).EQ.3) IC=IC+1
3005 CONTINUE
IC=0
DO 3006 I=1,NEL1
IF(NELTYPE(I).EQ.1) IC=IC+1
3006 CONTINUE
N=NEL1+1
N1=0
N2=0
N3=0
DO 3007 I=1,NELTO1
IF(NELTYPE(I).EQ.1) N1=N1+1
3007 IF(NELTYPE(I).EQ.3) N3=N3+1
NEF(I)=NUMF
NLM(2)=N2
NOM(2)=N3
NPL(2)=N1
N=NUMF
DO 3008 I=1,N
3008 HGEF(I,1,1)=NELFAS(I,1)
IC=0
N=NEL+1
DO 3010 I=N, NELTOT
1F(NELTYP(I).EQ.1) IC=IC+1
1F(NELTYP(I).EQ.2) NGLH(2,IC,1)=NELCON(I,1)
1F(NELTYP(I).EQ.2) NUMLH(2,IC)=1
3010 CONTINUE
IC=0
N=NEL+1
DO 3011 I=N, NELTOT
1F(NELTYP(I).EQ.1) IC=IC+1
1F(104NLTYP(I).EQ.1) NUML(2,IC,1)=NELCON(I,1)
1F(104NLTYP(I).EQ.1) NUMPL(2,IC)=1
3011 CONTINUE
IC=0
N=NEL+1
DO 3012 I=N, NELTOT
1F(NELTYP(I).EQ.3) IC=IC+1
1F(NELTYP(I).EQ.3) NUMOH(2,IC,1)=NELCON(I,1)
1F(NELTYP(I).EQ.3) NUMOH(2,IC)=1
3012 CONTINUE
GO TO 3013
3013 CONTINUE
WRITE(6, 3019)
3015 FORMAT(7, 'FOR THE TOP PLATE INPUT NUMBER OF GROUPS',/)
* FOR THE EFFECTIVE FASTENER, LOADED HOLE, UNLOADED',/)
* HOLE AND PLAIN ELLMENT ',/)
READ(S, *) NHEF(I), NLH(I), NOH(I), NPL(I)
WRITE(6, 3016)
3016 FORMAT(' GROUPING OF EFFECTIVE FASTENER ELEMENTS:')
N=NHEF(I)
DO 3017 I=1,N
WRITE(6, 3018) I
3018 FORMAT(' ENTER NUMBER OF ELEMENTS IN GROUP NUMBER',/)
READ(S, *) NUMLH(I)
NL=NUMLH(I,1)
WRITE(6, 3019) NL
3019 FORMAT(7, ' ENTER '18, ' ELEMENT IDS')
READ(S, *) (NHEF(I,1,J), J=1, NL)
3017 CONTINUE
WRITE(6, 3020)
3017 FORMAT(' GROUPING OF LOADED HOLE ELEMENTS:')
N=NLH(I)
DO 3021 J=1,NL
WRITE(6, 3021) J
3021 FORMAT(' ENTER NUMBER OF ELEMENTS IN GROUP NUMBER',/)
READ(S, *) NUMLH(I)
NL=NUMLH(I,1)
WRITE(6, 3022) NL
3022 FORMAT(7, ' ENTER '18, ' ELEMENT IDS')
READ(S, *) (NHEF(I,1,J,1,NL)
3017 CONTINUE
WRITE(6, 3023)
3017 FORMAT(' GROUPING OF UNLOADED HOLE ELEMENTS:')
N=NOH(I)
DO 3024 J=1,N
WRITE(6, 3024) J
3024 FORMAT(7, ' ENTER NUMBER OF ELEMENTS IN GROUP NUMBER',/)
READ(S, *) NUMOH(I)
3017 CONTINUE
WRITE(6, 3025)
3025 FORMAT(' ENTER '18, ' ELEMENT IDS')
READ(S, *) (NHEF(I,1,J,1,NL)
3017 CONTINUE
N1=NUMOH(1,1)
WRITE(6,3026) N1
3026 FORMAT(' ENTER',1B,' ELEMENT IDS')
READ(5,*) (NGOH(I,1,J),J=1,N1)
3024 CONTINUE
4071 IF(NPL(1).EQ.0) GO TO 4072
WRITE(6,3027)
3027 FORMAT(' GROUPING OF PLAIN ELEMENTS:')
N=NPL(1)
DO 3031 I=1,N
3032 FORMAT(' ENTER NUMBER OF ELEMENTS IN GROUP NUMBER',I8)
READ(5,*) NPL(I,1)
N1=NPL(I,1)
WRITE(6,3033) N1
3033 FORMAT(' ENTER',1B,' ELEMENT IDS')
READ(5,*) (NGP(1,I,J),J=1,N1)
3031 CONTINUE
4072 CONTINUE
4015 FORMAT(' FOR THE BOTTOM PLATE INPUT NUMBER OF GROUPS',/)
* FOR THE LOADED HOLE, UNLOADED HOLE, AND PLAIN */
* ELEMENTS */
* (INPUT 0 IF AN ELEMENT TYPE IS NOT USED) */
READ(5,*) NML(2),NOM(2),NPL(2)
HEP(2)=HEP(1)
N=HEP(1)
DO 4017 I=1,N
4017 FORMAT(' ENTER NUMBER OF ELEMENTS IN GROUP NUMBER',I8)
READ(5,*) NPL(2,I)
N1=NML(2)
DO 4019 J=1,N1
4019 FORMAT(' ENTER ELEMENT IDS')
READ(5,*,) (NML(2,I,J),J=1,N1)
4018 CONTINUE
WRITE(6,4015)
4016 FORMAT(' FOR THE LOADED HOLE, UNLOADED HOLE, AND PLAIN */
* ELEMENTS */
* (INPUT 0 IF AN ELEMENT TYPE IS NOT USED) */
READ(5,*) NML(2),NOM(2),NPL(2)
HEP(2)=HEP(1)
N=HEP(1)
DO 4022 I=1,N
4022 FORMAT(' ENTER NUMBER OF ELEMENTS IN GROUP NUMBER',I8)
READ(5,*) NML(2),NOM(2),NPL(2)
HEP(2)=HEP(1)
N=HEP(1)
DO 4025 J=1,N1
4025 FORMAT(' ENTER ELEMENT IDS')
READ(5,*,) (NML(2,I,J),J=1,N1)
4024 CONTINUE
4073 IF(NPL(2).EQ.0) GO TO 4074
WRITE(6,4023)
4023 FORMAT(' GROUPING OF UNLOADED HOLE ELEMENTS')
N=NML(2)
DO 4026 I=1,N
4026 FORMAT(' ENTER NUMBER OF ELEMENTS IN GROUP NUMBER',I8)
READ(5,*) NML(2),NOM(2),NPL(2)
HEP(2)=HEP(1)
N=HEP(1)
DO 4029 J=1,N1
4029 FORMAT(' ENTER ELEMENT IDS')
READ(5,*,) (NML(2,I,J),J=1,N1)
4028 CONTINUE
4074 IF(NPL(2).EQ.0) GO TO 4075
WRITE(6,4024)
4027 FORMAT(' GROUPING OF PLAIN ELEMENTS:') 00006540
        M=NPL(2)
        DO 4031 I=1,N
        WRITE(6,4032) I
        WRITE(6,4033) N1
        READ(5,C) NUMPL(2,I)
        WRITE(6,4034) 1:
        4032 FORMAT(' ENTER NUMBER OF ELEMENTS IN GROUP NUMBER',I8)
        READ(5,C) NUMPL(2,I)
        WRITE(6,4035) 1:
        4033 FORMAT(' ENTER ELEMENT IDS')
        READ(5,M) (NGPL(I,J),J=1,N1)
        4031 CONTINUE
        4074 CONTINUE
        3013 CONTINUE
        3737 FORMAT(///,' INPUT DATA FOR FAILURE ANALYSIS',//)
        DO 2226 K=1,2
        IF(CM(K).NE.CMC) GO TO 2226
        WRITE(6,3739) K
        532 FORMAT(' ENTER FIBER ULTIMATE STRAIN VALUES ',//,
                  Epsilon ult in compression',//,
                  Epsilon ult in tension',//,
                  Gamma ult in shear ',//)
        READ(5,X) (JULT(I,K),I=1,3)
        GO TO 2227
        2226 CONTINUE
        2229 FORMAT(///,' METALLIC STRENGTHS',//)
                  Tensile strength',//,
                  Compressive strength',//,
                  Shear strength ',//)
        READ(5,X) STM(1),STM(2),STM(3)
        2227 CONTINUE
        4054 FORMAT(///,' AN AVERAGE STRESS CRITERIA IS USED TO ',//,
                  Predict failure, au values are required as ',//,
                  Characteristic distances over which stresses',//,
                  Are to be averaged and compared to unnotched',//,
                  Laminate strengths to predict failure',//)
        WRITE(6,4052) K
        5432 FORMAT(' ENTER AO VALUES FOR STRESS AVERAGING',//,
                  For each failure mode in plate no',I5',//,
                  Aont = net section',//,
                  Adnr = bearing',//,
                  Aoso = shearout ')
        READ(5,X) (AONIT(K),AOPR(K),AOSO(K))
        226 CONTINUE
        143 FORMAT(///,' PROGRESS REPORT',//)
        IF(NSLSDS.EQ.1) WRITE(6,6133)
        IF(NSLSDS.EQ.2) WRITE(6,6134)
        613 FORMAT(' A SINGLE LAP SHEAR PANEL WILL BE ANALYZED',//)
        614 FORMAT(' A DOUBLE LAP SHEAR PANEL WILL BE ANALYZED',//)
        IF(LTCHM.EQ.1) WRITE(6,823)
        IF(LTCHM.EQ.2) WRITE(6,824)
        823 FORMAT(' LOADED IN STATIC TENSION ',//)
        824 FORMAT(' LOADED IN STATIC COMPRESSION',//)
DO 241 I=1.2
WRITE(6,600) I
600 FORMAT(10X,'PLATE NO '*,I5,*,*:*/)
WRITE(6,601) (MTLC(I,J),J=1,15)
601 FORMAT(2X,15A4,*)
   HT=HELPSCI,1,XPILYTHK(I,1)
WRITE(6,602) E1(I),E2(I),G12(I),V12(I),V21(I)
602 FORMAT(600)
I=1.2
WRITE(6,603) X,601)
   #10X,'E1 = ',D9.3, ' PSI'*,*/
   #10X,'G12 = ',D9.3, ' PSI'*,*/
   #10X,'NU12 = ',D9.3, '*/
   #10X,'NU21 = ',D9.3, '*/
241 CONTINUE
WRITE(6,606)
606 FORMAT(10X,'FASTENER DESCRIPTION:*/)
WRITE(6,607) (MTLC(J),J=1,15)
607 FORMAT(2X,15A4,*)
   WRITE(6,477) 'FAST DESCRIPTION:*/
477 FORMAT(2X,15A4,*)
   WRITE(6,609) 'MATERIAL PROPERTIES:*/
609 FORMAT(600)
   #10X,'E = ',D9.3, ' PSI'*,*/
   #10X,'H = ',D9.3, '*/
708 CONTINUE
WRITE(6,923)
923 FORMAT(10X,'FAILURE ANALYSIS:*/)
WRITE(6,558)
558 FORMAT(10X,'H AVERAGE STRESS CRITERION WILL BE USED:*/)
DO 631 I=1:
WRITE(6,632) I
632 FORMAT(10X,'PLATE NUMBER '*,I5,*)
   N=HNUMPL(I)
   IF(N N=999) GO TO 3112
WRITE(6,712)
712 FORMAT(600)
   WRITE(6,633) I
633 FORMAT(10X,'FIBER STRAIN ULTIMATES:*/
713 FORMAT(2X,15A4,*)
   WRITE(6,677) CSTUL(1),LL=1,13)
677 FORMAT(2X,15A4,*)
   WRITE(6,678) EPSUL(ULT COMP = ',D9.3, '*/
   #2X,'EPUL(ULT TEN = ',D9.3, '*/
   #2X,'EPUL(ULT SHEAR = ',D9.3, '*/
   GO TO 713
3112 CONTINUE
WRITE(6,314)
314 FORMAT(10X,'METALLIC STRENGTHS:*/
WRITE(6,315) STM(1),STM(2),STM(3)
315 FORMAT(600)
   WRITE(6,316) 'TENSILE STRENGTH = ',D9.3, '*/
   #2X,'COMPR UREN STRENGTH = ',D9.3, '*/
   #4X,'HEAT STRENGTH = ',D9.3, '*/
3115 CONTINUE
WRITE(6,153)
153 FORMAT(10X,'CHARACTERISTIC DISTANCES:*/
WRITE(6,154) AQNT(I),AQBR(I),AQSD(I)
154 FORMAT(600)
   #864 'AQNT = ',D9.3, ' INCHES'*/
   #864 'AQBR = ',D9.3, ' INCHES'*/
   #52 'AQSD = ',D9.3, ' INCHES'*/
631 CONTINUE
THE JOINT LOAD DISTRIBUTION IS CALCULATED USING THE
FINITE ELEMENT METHOD WITH SPECIAL PROBLEM-ADAPTED
ELEMENTS WHICH EFFECTIVELY REPRESENT THE STIFFNESS
00007750
PROPERTIES OF FASTENERS, LOADED HOLES, AND OPEN HOLE REGIONS IN THE JOINT

INTERNAL APPLIED LOAD SET TO 1 KIP

PROPERTIES OF FASTENERS, LOADED HOLES, AND OPEN HOLE REGIONS IN THE JOINT
IIOUT-57

XSCD(INTOP,3) 00008400

DO 570 L=1,2

PHL=0.000

IF(L.EQ.2) PHI=90.00

DO 530 K=1,2

NTB=NTOP

IF(K.EQ.2) NTB=NGOT

ELEMENT VERTEXES ARE INTERNALLY NUMBERED AS:

3 2

1 4

FX=(GCOORD(NELCHA(NTB,5),1)+GCOORD(NELCHA(NTB,2),1))/2.000
FY=(GCOORD(NELCHA(NTB,3),2)+GCOORD(NELCHA(NTB,2),2))/2.000

DO 128 CONTINUE

XC(JJ)=GCOORD(NELCHA(NTB,6-JJ),1)-FSCD(NTB,1)

YC(JJ)=GCOORD(NELCHA(NTB,6-JJ),2)-FSCD(NTB,2)

128 CONTINUE

XC(5)=XC(1)

YC(5)=YC(1)

W=ELWDTH(NTB)

AGT=1000.0

CALL PPLY(W,AST,JK,K,NCLL,LTNCM)

CALL CIRC(W,AST,JK,K,LTNCM)

NOPT=1

NCAS=1

NCASE=1

NTYPE=HELTYPE(NEL)

CALL FIGEOM(H,PHI,K,NOPT4,NCLL)

CALL FBOLT(ANOK,H,PHI,K)

580 CONTINUE

H=HPLY(1)

U 30 II=1,N

U=HPLY(U.I.I)

30 PLYK(II)=ANOK(M,II)

H=HPLY(2)

DO 61 II=1,N

H+II+HPLY(1)

N=HPLY(II.2)

61 PLYK(N)=ANOK(N2,2)

580 CONTINUE

CALCULATION OF FASTENER PROPERTIES

FA50=FA50/(2.*M(1+FA5V))

FASLM=5.*M(1.0+FA5V)/(7.46.*FA5V)

FA5R=FA5D/2.

FASA=ACOS(1.*FA5R)*2

FAS1=ACOS(-1.)*FA5R*2

FASG=FA5AM*ACOS(FA5A

FASBS=FA5FAS

P=1000.

CALL CONTD(H,FASS,FASBS,P)

CALL SOLVE(H,F,U,U*)

IF(L.EQ.2) GO TO 666
570 CONTINUE
IF(NUMEF(1,1).EQ.1) GO TO 444
N=NUMEF(1,1)
DO 524 K=2,N
DO 524 L=1,NUMF
524 IF(NGEF(1,K).EQ.NELFAS(L,1)) IEL2=L
RSTFF(IEL2,1)=RSTFF(IEL,1)
RSTFF(IEL2,2)=RSTFF(IEL,2)
570 CONTINUE
444 CONTINUE
584 CONTINUE

CALCULATION OF LOADED HOLE AND UNLOADED HOLE ELEMENT STIFFNESS MATRICIES

INITIALIZE GAUSSIAN QUADRATURE POINTS AND WEIGHTS

NQP=5
GSX(1)=-0.9739065285
GSX(2)=-0.8630633666
GSX(3)=-0.7594095682
GSX(4)=-0.646845935641
GSX(5)=-0.534282384586
GSX(NP)=0.2955442247
DO 588 I=1,NQP
GSX(I+NQP)=GSX(NQP+I+1)
GSSW(I+NQP)=GSSW(NQP+I+1)
588 CONTINUE

NAV=10
DO 420 KJ=1,2
ISLM=1
ISPL=1
NLOOP=NLH(KJ)+NOM(KJ)+NPL(KJ)
NCLH=0
NCDH=0
NCPL=0
DO 400 L=1,NLOOP
IF(NCLH.EQ.NLH(KJ)) ISLM=0
IF(NCLH.EQ.NLH(KJ)) GO TO 6010
NCLH=NCLH+1
IEL=NLH(KJ,NCLH,1)
GO TO 6011
6010 IF(NCDH.EQ.NOM(KJ)) ISLM=0
IF(NCDH.EQ.NOM(KJ)) GO TO 6020
NCDH=NCDH+1
IEL=NLH(KJ,NCDH,1)
GO TO 6011
6020 IF(NCPL.EQ.NPL(KJ)) ISPL=0
IF(NCPL.EQ.NPL(KJ)) GO TO 6040
NCPL=NCPL+1
IEL=NCPL(KJ,NCPL,1)
GO TO 6040

420 CONTINUE

200
6011 CONTINUE
DO 6030 KK=1,NELTOT
6030 IF (IEL2.EQ.NELCDM(KK,1)) IEL=KK
K(KJ)=ELTHK(IEL)
MPY(KJ)=HEPL5(KJ,LYPH(IEL))
DO 919 JJJ=1,50
MPY(JJJ,KJ)=HELPT(KJ,LYPH(IEL),JJJ)
919 CONTINUE
IF (NELTYP(IEL).EQ.2) NRNK=7
INTERNAL NUMBERING OF ELEMENT VERTICES:

\begin{align*}
\begin{array}{cc}
3 & 2 \\
4 & 1 \\
\end{array}
\end{align*}

SFY=(GCOORD(NELCHA(IEL,5),1)+GCOORD(NELCHA(IEL,2),1))/2.0DD
SFY=(GCOORD(NELCHA(IEL,3),2)+GCOORD(NELCHA(IEL,2),2))/2.0DD
DO 440 K=1,6
XC(K)=GCOORD(NELCHA(IEL,6-K),1)-FSCD(IEL,1)
YC(K)=GCOORD(NELCHA(IEL,6-K),2)-FSCD(IEL,2)
440 CONTINUE

DO 6030 K=1,NCPT
DO 15 JJ=1,NCPT
XOUT(JJ)=((-AX-XC(JJ))/2.)*GSSX(IJ)+(-AX+XC(3))/2.
YOUT(JJ)=((-YC(JJ)-YC(4))/2.)*GSSY(JJ)+(YC(3)+YC(4))/2.
END

Determine coordinates at which stresses and displacements are to be computed. Element natural flexibility matrices are computed by integrating stresses for each load case in the natural mode method. The elements are divided into four regions and the Gaussian points are scaled to each region size.

REGION 1
DO 15 II=1,NCPT
DO 15 JJ=1,NCPT
IC=IC+1
XOUT(IC)=((-AX-XC(JJ))/2.)*GSSX(JJ)+(-AX+XC(3))/2.
YOUT(IC)=((-YC(JJ)-YC(4))/2.)*GSSY(JJ)+(YC(3)+YC(4))/2.
15 CONTINUE

REGION 2
DO 16 II=1,NCPT
   DO 16 JJ=1,NCPT
   IC=IC+1
   XOUT(IC)=AX*QSSX(JJ)
   YI=DSRT((AXX+2-XOUT(IC))*W2)
   YOUT(IC)=((YC(2)-YI)/2.*QSSX(JJ)+((YC(2)+YI)/2.)*QSSX(JJ))*XOUT(IC)
   WOUT(IC)=QSSW(JJ)*QSSX(JJ)*((YC(2)-YI)*AX/2.0D0
   16 CONTINUE

REGION 3
   DO 17 II=1,NCPT
   DO 17 JJ=1,NCPT
   IC=IC+1
   XOUT(IC)=AX*QSSX(JJ)
   YOUT(IC)=((YC(2)-YC(1))/2.)*QSSX(JJ)*((YC(2)+YC(1))/2.)*QSSX(JJ)*XOUT(IC)
   WOUT(IC)=QSSW(JJ)*QSSX(JJ)*((YC(2)-YC(1))/AX/2.0D0
   17 CONTINUE

REGION 4
   DO 18 II=1,NCPT
   DO 18 JJ=1,NCPT
   IC=IC+1
   XOUT(IC)=((XC(2)-AX)/2.)*QSSX(JJ)+((XC(1)+AX)/2.)*QSSX(JJ)
   YOUT(IC)=((YC(2)-YC(1))/2.)*QSSX(JJ)*((YC(2)+YC(1))/2.)*QSSX(JJ)*XOUT(IC)
   WOUT(IC)=QSSW(JJ)*QSSX(JJ)*((YC(2)-YC(1))/AX)/4.0D0
   18 CONTINUE

ADD COORDINATES ALONG WHICH STRESSES WILL BE AVERAGED
   ANT=AONT(KJ)
   ABR=ABR(KJ)
   ASO=AOSO(KJ)
   SG=1.0
   IF(LHCM.EQ.2.0) SG=-1.0
   IF(K.J.EQ.2) SG=-SG

NET SECTON
   ANDO=ANT/FLOAT(NAVD)
   DO 21 II=1,NAVD
   IC=IC+1
   XOUT(IC)=0.0D0
   YOUT(IC)=IX+ANDO/2.+(II-1)*ANDO
   21 CONTINUE

SHEAROUT
   ANSO=ASO/FLOAT(NAVD)
   DO 31 II=1,NAVD
   IC=IC+1
   XOUT(IC)=SGX(IX+ANSO/2.+(II-1)*ANSO)
   YOUT(IC)=IX
   31 CONTINUE
BEARING

ANBR=ABR/FLOAT(NAVD)
DO 41 II=1,NAVD
IC=IC+1
YOUT(IC)=30K(AX+ANBR/2.+(II-1)*ANBR)
YOUT(IC)=0.
41 CONTINUE

ADD COORDINATES ALONG WHICH ELEMENT LOAD RECOVERY WILL BE COMPUTED
DO 3332 III=1,10
IC=IC+1
IF(KJ.EQ.1) XOUT(IC)=YC(3)+0.1MAX
IF(KJ.EQ.2) XOUT(IC)=YC(1)-0.1MAX
YOUT(IC)=((YC(2)-YC(1))/2.0DD*XSSX(III)+(YC(2)+YC(1))/2.0DD

STRESSES ARE SINGULAR AT THETA = 180 DEG OR Y = 0
IF(DABS(YOUT(IC)).LT.0.01) YOUT(IC)=YOUT(IC-1)
3332 CONTINUE
4891 CONTINUE
NSTS=4*NAVD
NOUT=4*(NQAUSS*2)

CALCULATION OF LOADED HOLE, UNLOADED HOLE, AND PLAIN ELEMENT STIFFNESS MATRICIES
THN=0.00
NN=IEL
DO 410 J=1,MRNK
NOUT=4*(NQAUSS*2)

CALCULATE ELEMENT FAILURE VALUES BASED ON MAXIMUM FIBER STRAIN ALLOWABLES
HT=H(KJ)*NPLY(KJ)
IF(NELTYP(IEL).EQ.2) CALL SMAX(HT,KJ,IEL)
IF(NELTYP(IEL).EQ.3) CALL SMAX(HT,KJ)
IF(ISLT.0) GO TO 6040
NL=NUMH(KJ,1CLL)
IF(NL.EQ.1) GO TO 400
DO 6041 K=2,NL
6042 IF(NLXL(KJ,1CLL,K).EQ.0) IEL2=LL
DO 6043 ILM=1,10
6043 ELSTFF(IEL2, ILM, ILK) = ELSTFF(IEL, ILM, ILK)
DO 6044 KK=1,4
6044 PSMX(IEL2, KK) = PSMX(IEL, KK)
NNN=4*NAVD
DO 6045 ILM=1, NNN
DO 6045 ILK=1,10
6045 ELSTSS(IEL2, ILM, ILK) = ELSTSS(IEL, ILM, ILK)
6045 CONTINUE
GO TO 400
6040 IF(ISOM.EQ.0) GO TO 6046
NL=NUMON(KJ, NCOL)
IF(NL.EQ.1) GO TO 400
DO 6047 K=2, NL
DO 6048 ILM=1, NELTOT
6048 IF(NOON(KJ, NCOL, K).EQ.NCON(LL, 1)) IEL2=LL
DO 6049 ILM=1,10
DO 6049 ILK=1,10
6049 ELSTFF(IEL2, ILM, ILK) = ELSTFF(IEL, ILM, ILK)
DO 6050 KK=1,4
6050 PSMX(IEL2, KK) = PSMX(IEL, KK)
NNN=4*NAVD
DO 6051 ILM=1, NNN
DO 6051 ILK=1,10
6051 ELSTSS(IEL2, ILM, ILK) = ELSTSS(IEL, ILM, ILK)
6047 CONTINUE
GO TO 400
6046 IF(ISPL.EQ.0) GO TO 6046
NL=NUMPL(KJ, NCPL)
IF(NL.EQ.1) GO TO 400
DO 6053 K=2, NL
DO 6054 ILM=1, NELTOT
6054 IF(NOPL(KJ, NCPL, K).EQ.NELCON(LL, 1)) IEL2=LL
DO 6055 ILM=1,10
DO 6055 ILK=1,10
6055 ELSTFF(IEL2, ILM, ILK) = ELSTFF(IEL, ILM, ILK)
DO 6056 KK=1,4
6056 PSMX(IEL2, KK) = PSMX(IEL, KK)
NNN=4*NAVD
DO 6057 ILM=1, NNN
DO 6057 ILK=1,10
6057 ELSTSS(IEL2, ILM, ILK) = ELSTSS(IEL, ILM, ILK)
6053 CONTINUE
GO TO 400
400 CONTINUE
420 CONTINUE
C
C DETERMINE ELEMENT ARRANGEMENT IN TOP
C AND BOTTOM PLATES
C
DO 651 KJ=1,2
IF(KJ.EQ.2) GO TO 501
L1=1
L2=NOPL+1
L3=1
L4=IEL1
GO TO 502
501 L1=NOPL+1
L2=NOPL+1
L3=IEL1+1

204
502 CONTINUE
AXMIN=1.D10
AYMIN=1.D10
DO 503 I=1,1,2
IF(AXMIN.GT.GCOORD(I,1)) AXMIN=GCOORD(I,1)
IF(AYMIN.GT.GCOORD(I,2)) AYMIN=GCOORD(I,2)
IF(AXMIN.EQ.GCOORD(I,1) .AND. AYMIN.EQ.GCOORD(I,2)) NC=I
503 CONTINUE
DO 574 K=1,3,4
574 IF(NELCON(K,2).EQ.NGRID(NC)) IEL=I
NELORD(KJ,1,1)=IEL
DO 504 I=1,23
DO 505 J=1,23
IF(I=0) GO TO 505
DO 506 K=1,3,4
506 IF(NELCON(K,2).EQ.NGRID(NC)) IEL=K
NELORD(KJ,1,1)=IEL
IF(I=0) GO TO 506
CONTINUE
507 CONTINUE
IF(KJ.EQ.1) NROW1=J
IF(KJ.EQ.2) NROW2=J
IEL=0
DO 508 K=1,3,4
508 IF(NELCON(K,2).EQ.NGRID(NC)) IEL=K
NELORD(KJ,1,1)=IEL
IF(I=0) GO TO 508
CONTINUE
509 CONTINUE
IF(KJ.EQ.1) NCOL1=I
IF(KJ.EQ.2) NCOL2=I
681 CONTINUE

COMPUTE NODAL DEGREES OF FREEDOM

IC=0
DO 540 KJ=1,2
IF(KJ.EQ.1) NR=NROW1
IF(KJ.EQ.1) NC=NCOL1
IF(KJ.EQ.2) NR=NROW2
IF(KJ.EQ.2) NC=NCOL2
NELDIS(NELORD(KJ,1,1),1,1)=IC+1
NELDIS(NELORD(KJ,1,1),1,2)=IC+2
NELDIS(NELORD(KJ,1,1),2,1)=IC+3
NELDIS(NELORD(KJ,1,1),2,2)=IC+4
IC=IC+4
IF(NR.EQ.1) GO TO 549
DO 541 I=1,2,NR
NELDIS(NELORD(KJ,1,1),1,1)=NELDIS(NELORD(KJ,1,1),1,1)
NELDIS(NELORD(KJ,1,1),1,2)=NELDIS(NELORD(KJ,1,1),1,2)
NELDIS(NELORD(KJ,1,1),2,1)=NELDIS(NELORD(KJ,1,1),2,1)
NELDIS(NELORD(KJ,1,1),2,2)=NELDIS(NELORD(KJ,1,1),2,2)
IC=IC+4
IF(NR.EQ.1) GO TO 549
DO 541 I=2,2,ITR
NELDIS(NELORD(KJ,1,1),1,1)=NELDIS(NELORD(KJ,1,1),1,1)
NELDIS(NELORD(KJ,1,1),1,2)=NELDIS(NELORD(KJ,1,1),1,2)
NELDIS(NELORD(KJ,1,1),2,1)=NELDIS(NELORD(KJ,1,1),2,1)
NELDIS(NELORD(KJ,1,1),2,2)=NELDIS(NELORD(KJ,1,1),2,2)
IC=IC+4
541 CONTINUE
549 CONTINUE
DO 542 I=1,NC

205
DO 543 J=1, NR
   IF(I.EQ.1) GO TO 544
   NELDIS(NELORD(KJ,J,I),1,1)=NELDIS(NELORD(KJ,J,I-1),4,1)
   NELDIS(NELORD(KJ,J,I),1,2)=NELDIS(NELORD(KJ,J,I-1),4,2)
   NELDIS(NELORD(KJ,J,I),2,1)=NELDIS(NELORD(KJ,J,I-1),3,1)
   NELDIS(NELORD(KJ,J,I),2,2)=NELDIS(NELORD(KJ,J,I-1),3,2)
544 CONTINUE
   IF(J.EQ.1) GO TO 561
   NELDIS(NELORD(KJ,J,I),4,1)=IC+1
   NELDIS(NELORD(KJ,J,I),4,2)=IC+2
561 CONTINUE
   IF(NELDIS(NELORD(KJ,J,I)),NE,2) GO TO 545
   NELDIS(NELORD(KJ,J,I),5,1)=IC+1
   NELDIS(NELORD(KJ,J,I),5,2)=IC+2
   IC=IC+2
545 CONTINUE
   NELDIS(NELORD(KJ,J,I),3,1)=IC+1
   NELDIS(NELORD(KJ,J,I),3,2)=IC+2
   IC=IC+2
543 CONTINUE
542 CONTINUE
541 CONTINUE

DETERMINE BOUNDARY NODES AND VALUES

   NRD=2*(NGP1+NGP2)
   DO 165 I=1, NRD
       165 PBC(I)=0.

DISTRIBUTE APPLIED LOAD

   ATOT=GCOORD(NELORD(1,NRD,1),3,2)
   M=GCOORD(NELORD(1,1,1),2,2)
   APL=APP/ATOT
   SG=1.0
   IF(LTLCM.EQ.1) SG=-1.0
   DO 176 I=1, NRD
       176 A=COORD(NELORD(I),1),3,2)
   M=GCOORD(NELORD(1,1,1),1,1)
   M1=NELDIS(NELORD(1,1,1),1,1)
   M2=NELDIS(NELORD(1,1,1),2,1)
   PBC(M1)=-PBC(M1)+SG(0.5*DABS(APLMA1))
   PBC(M2)=-PBC(M2)+SG(0.5*DABS(APLMA1))
178 CONTINUE
1119 CONTINUE

ASSEMBLE GLOBAL STIFFNESS MATRIX

   DO 220 M1=1, NELTOT
       IR=M1
       IF(NELTY.EQ.1,NE,2) IR=4
TOP AND BOTTOM PLATE LOADED HOLE AND UNLOADED HOLE ELEMENTS

IC1=0
DO 425 N2=1,IR
DO 429 N3=1,2
ML=NELDIS(N1,N2,N3)
IC1=IC1+1
IC2=0
DO 425 N4=1,IR
DO 425 N3=1,2
NL=NELDIS(N1,N4,N5)
IC2=IC2+1
OLSTFF(M1,M2)=OLSTFF(M1,M2)+ELSTFF(N1,IC1,IC2)
425 CONTINUE
429 CONTINUE

ADD EFFECTIVE FASTENER ELEMENTS

DO 260 I=2,NUMF
DO 1561 J=1,NEL1
IF(NELFAS(I,2).EQ.NELCON(J,6)) H=J
NL=NELDIS(N,J,1)
NL=NELDI5(N,J,2)
DO 1562 J=NL,NELTOT
IF(NELFAS(I,3).EQ.NELCON(J,6)) H=J
NL=NELDIS(N,J,1)
NL=NELDI5(N,J,2)
OLSTFF(N1,N1)=OLSTFF(N1,N1)+RDSTFF(I,1)
OLSTFF(N2,N3)=OLSTFF(N2,N3)-RDSTFF(I,1)
OLSTFF(N2,N3)=OLSTFF(N2,N3)+RDSTFF(I,2)
OLSTFF(N2,N4)=OLSTFF(N2,N4)-RDSTFF(I,2)
OLSTFF(N3,N1)=OLSTFF(N3,N1)-RDSTFF(I,1)
OLSTFF(N3,N1)=OLSTFF(N3,N1)+RDSTFF(I,2)
OLSTFF(N4,N4)=OLSTFF(N4,N4)-RDSTFF(I,2)
OLSTFF(N4,N4)=OLSTFF(N4,N4)+RDSTFF(I,2)
260 CONTINUE

GLOBAL BOUNDARY CONDITIONS

DO 415 I=1,NP
RHS(I)=PBCCI(I)
415 CONTINUE

IC=1
NZE\(IC)=NELDIS(NELORD(2,1,NCOL2),4,1)
DO 437 I=1,NCOL2
IC=IC+1
NZE\(IC)=NELDIS(NELORD(2,1,NCOL2),5,1)
437 CONTINUE

RESTORE REDUCED STIFFNESS MATRIX

IC'=0
DO 655 I=1,NP
DO 655 K=1,NUMZ
IF(I.EQ.NZEROC(K)) GO TO 655
665 CONTINUE
ICR=ICR+1
RHS(ICR)*RHS(I)
ICC=0
DO 670 J=1,NP
DO 680 K=1,NUMZ
IF(J.EQ.NZEROC(K)) GO TO 670
680 CONTINUE
ICC=ICC+1
ASQM(ICR,ICC)=OLSTFF(I,J)
670 CONTINUE
655 CONTINUE
NP=NP+NUMZ
685 CONTINUE
DO 695 I=1,NP
DO 695 J=1,NP
695 OLSTFF(I,J)=ASQM(I,J)
APPLYING QUASSIAN ELIMINATION TO THE
MATRIX OF COEFFICIENTS
DO 2001 I=1,NP
IR=I
2042 IF(DABS(ASQM(IR,I)).GT.1.0D-10) GO TO 2041
IR=IR+1
IF(IR.GT.NP) GO TO 2001
GO TO 2042
2041 NN=IR+1
DO 2002 L=NN,NP
IF(DABS(ASQM(L,I)).GT.1.0D-10) GO TO 2009
ASQM(L,I)=0.
GO TO 2002
2009 CF=ASQM(IR,I)/ASQM(L,I)
CF1=1.0D0
IF(DABS(CF).GT.1.0) CF1=1.0D0/CF
IF(DABS(CF).GT.1.0) CF1=1.0D0
DO 2003 J=1,NP
ASQM(L,J)=ASQM(L,J)*CF+ASQM(IR,J)*CF1
IF(DABS(ASQM(L,J)).LT.1.0D-10) ASQM(L,J)=0.0
2003 CONTINUE
RHS(L)=RHS(L)*CF+RHS(I)*CF1
2002 CONTINUE
2001 CONTINUE
BACK SUBSTITUTION
DO 2112 I=1,NP
L=NP+1-I
SUM=0.
IF(ASQM(L,L).EQ.0.) GO TO 2112
2112 CONTINUE
IF(NOT.NP) GO TO 213
DO 213 J=1,NP
SUM=SUM+ASQM(L,J)*ANR(J)
213 CONTINUE
ANR(L)=(PI4S(L)+SUM)/ASQM(L,L)
GO TO 2011
2112 CONTINUE
ANR(I) = 0.
2011 CONTINUE

CALCULATE NODAL LOADS
IC = 0
DO 54 I = 1, NRD
DO 54 J = 1, NUMZ
IF (I .NE. ZERO(J)) GO TO 54
ANR(I) = 0.000
GO TO 44
54 CONTINUE
IC = IC + 1
ANR(IC) = ANR(IC)
44 CONTINUE
WRITE (6, 3712)
3712 FORMAT (/10X, 'ELEMENT FORCES', /*)
DO 500 K = 1, NELTGR
NID = NELCD(K, 1)
WRITE (6, 3947) NID
5947 FORMAT (/9X, 'ELEMENT ID', I8, /*,
   &6X, 'GRID', 9X, 'FX', 9X, 'FY', /*)
IR = 5
KL = K
IF (KL .GT. NEI) KL = K - NEI
IF (NEI .EQ. 2) IR = 6
DO 510 I = 1, IR
SUMU = 0.
SUMV = 0.
N = 2**I - 1
DO 520 J = 1, IR
N1 = HELDIS(K, J, 1)
N2 = HELDIS(K, J, 2)
SUMU = SUMU + ELSTFF(K, N, (2*J - 1)) * ANR2(N1) +
   & ELSTFF(K, N, (2*J)) * ANR2(N2)
520 CONTINUE
N = 2**I - 1
DO 530 J = 1, IR
N1 = HELDIS(K, J, 1)
N2 = HELDIS(K, J, 2)
SUMV = SUMV + ELSTFF(K, N, (2*J - 1)) * ANR2(N1) +
   & ELSTFF(K, N, (2*J)) * ANR2(N2)
530 CONTINUE
510 CONTINUE

STORE ELEMENT LOADS FOR CHECK ON ELEMENT
LOAD RECOVERY
IF (K .LE. NEL1 AND (.NOT. (I .EQ. 1 OR I .EQ. 2))) ELLOAD(K, I) = SUMU
IF (K .GT. NEL1 AND (.NOT. (I .EQ. 3 OR I .EQ. 4))) ELLOAD(K, I - 2) = SUMU
NID = NELCD(K, I + 1)
WRITE (6, 3239) NID, SUMU, SUMV
3239 FORMAT (2X, I8, 3X, 2(D9.3, 2X))
510 CONTINUE
500 CONTINUE

COMPUTE ELEMENT FAILURE LOADS AND DETERMINE CRITICAL ELEMENT TO CALCULATE JOINT FAILURE
LOAD
CALL FCRT(C,APP,NEL1,NEL2,NDAM,IN,LTNCH,NAVDC)
FAILV=DABS(ELFAIL(IN,NDAM))
IF(NDLS.EQ.0.OR.FAILV.EQ.2.XFAILV)
FAILV=ELFAIL(IN,NDAM))
WRITE(6,5555) ND,FAILV
5555 FORMAT(1X,"FAILURE IS PREDICTED TO OCCUR IN ELEMENT ",
1X,'NUMBER',1X,' AT AN APPLIED JOINT LOAD VALUE ',
1X,'OF ',1.14.7," LBS,")
IF(NDAM.EQ.1)
WRITE(6,5555)
IF(NDAM.EQ.2)
WRITE(6,5555)
IF(NDAM.EQ.3)
WRITE(6,5555)
5556 FORMAT(C THE PREDICTED FAILURE MODE IS NET SECTION")
5557 FORMAT(C THE PREDICTED FAILURE MODE IS SHEAR-OUT")
5558 FORMAT(C THE PREDICTED FAILURE MODE IS BEARING")
STOP
END

SUBROUTINE M30D(HT,H,AST,J,IN,KJ,NEL,NCL)
IMPLICIT REAL*8(A-H,O-Z)
DIMENSION A1A(4),A2A(4)
DIMENSION X1(200),Y1(200),A1(200),A2(200)
DIMENSION NELTYP(30),HTA(200)
DIMENSION XC(5),YC(5)
COMMON/CM1/X1,Y1,A1,A2,HTA
COMMON/XC/YC
COMMON/NTP/HELT/P
Determine exterior collocation points and stress boundary conditions corresponding
to the natural load cases
NCS=5
IF(NELTYP(IN).NE.2) NCS=3
JX=0
DO 15 I=1,4
15 A1A(I)=0.
15 A2A(I)=0.
15 A(YC(I)-YC(I-1))=HT
B=(XC(I)-XC(I-1))=HT
IF(J.EQ.1) A1A(1)=1.000/A
IF(J.EQ.1.AND.NELTYP(IN).NE.2) A1A(1)=1.000/A
IF(J.EQ.2) A1A(2)=1.000/D
IF(J.EQ.2.AND.NELTYP(IN).NE.2) A1A(2)=1.000/B
IF(J.EQ.3) A1A(1)=1.000/A
IF(J.EQ.3.AND.NELTYP(IN).NE.2) A1A(1)=1.000/B
IF(J.EQ.4) A1A(2)=1.000/D
IF(J.EQ.4) A1A(2)=1.000/B
IF(J.EQ.1.OR.J.EQ.3) AST=1.000/A
IF(J.EQ.2.OR.J.EQ.4) AST=1.000/B
CONTINUE
IF(J.EQ.1.OR.J.EQ.3.OR.J.EQ.6) W=YC(2)-YC(1)
DO 10 I=1,4
X=XC(I)-XC(I-1)
10 Y=YC(I)-YC(I-1)
IF(X.EQ.0.) X=1.D-6
IF(Y.EQ.0.) Y=1.D-6

210
TH = DATTAN2(X,Y) 00015560
TH = 180. / DARCOS(-0.1D1) 00015570
DX = (XC(I+1)-XC(I))/ (NCL+1) 00015580
DY = (YC(I+1)-YC(I))/(NCL+1) 00015590
GO TO 20 00015600
II = 1, NCL 00015610
JK = JK+1 00015620
IF I.EQ.1 OR I.EQ.3 GO TO 23 00015630
YB(JK) = YC(I) 00015640
XB(JK) = XC(I) + DX*(II + 5) 00015650
IF II.EQ.1 XB(JK) = XC(I) + (DX/2.) 00015660
GO TO 24 00015670
23 00015680
YB(JK) = YC(I) + DY*(II + 5) 00015690
IF (II.EQ.1) YB(JK) = YC(I) + (DY/2.) 00015700
XB(JK) = XC(I) 00015710
24 00015720
INTA(JK) = TM 00015730
A1(JK) = A1(AI) 00015740
A2(JK) = A2(A2I) 00015750
IF J.EQ.1.I OR. I.EQ.3) AI(JK) = (YB(JK) / W) * (3.0D0/A) 00015760
IF J.EQ.1.I OR. I.EQ.4) AI(JK) = (YB(JK) / W) * (0.5) 00015770
CONTINUE 00015800
CONTINUE 00015810
RETURN 00015820
END 00015830
SUBROUTINE MCIR(W,AST, I, J, NCL) 00015840
IMPLICIT REAL*8(A-H, O-Z) 00015850
DIMENSION X(200), Y(200), A1(200), A2(200) 00015860
DIMENSION THTA(200), NELTYP(50) 00015870
COMMON/CH1/XB, YB, A1, A2, THTA 00015880
COMMON/NT/NELTYP 00015890
COMMON/ELP/AX, DX 00015900
COMMON/AS/0.0F0 00015910
RA = DARCOS(CON)/180. 00015920
RAD = DARCOS(CON)/180. 00015930
STH = DBSG((2.0*STH)/(DARCOS(CON)*AX)) 00015940
IF NELTYP(I).NE.2) BSTR = 0.0D0 00015950
IF NELTYP(I).EQ.2.AND. I.GT.5) BSTR = 0.0D0 00015960
C4 = + NCL 00015970
Determine interior collocation points and
SIRECS boundary conditions 00015980
NB1 = 52 00015990
NB1 = NB2 00016000
DO 10 K = 1, 4 00016010
CR = (4-K)*DARCOS(CON)/2. 00016020
DO 20 KI = 1, NB1 00016030
IC = IC + 1 00016040
THINC = DARCOS(CON)/2./FLOAT(NBI) 00016050
A11C = 0. 00016060
A21C = 0. 00016100
THINC = THINC/2. 00016110
THINC = MINC2*(KI-1)*THINC + CR 00016120
XB(1) = AX*DARCOS(TH) 00016130
20 00016140
21 00016150
SUBROUTINE INFLN(WHT,H:HRN,K,J,K,l,NOPT)

IMPLICIT REAL*8(A-H,O-Z)
DIMENSION ELSF(F50,10,10),WHT(500),WK(150)
DIMENSION ELST:F(50,50,10),STSV(50),STSA(50,10)
DIMENSION AJ(10,7),UVOUT(20)
DIMENSION PHF(3,7,400),STINF(10,10),AOF(10,3)
DIMENSION FNFN(10,10),SINF(10,10),AIMV(10,3)
DIMENSION APSX(500),APSY(500),APSXY(500)
DIMENSION H(2),XC(5),YC(5),PLVY(2)
DIMENSION IC(10)
DIMENSION A(10,10),ATEMP(10,10)
COMMON/U\\/UVOUT
COMMON/XC/S/XC,WC
COMMON/ELP/AH,B/NDU,STS
COMMON/ELST/ELSTF,ELSTG
COMMON/STSV/STSV
COMMON/INF/APSX,APSY,APSXY
COMMON/YP/PLVY
COMMON/PV/AIVN

COMPUTE ELEMENT STIFFNESS COEFFICIENTS

IF(J.GT.1)GO TO 20
IF(J.EQ.1.AND.(K.EQ.1.OR.K.EQ.4))A1CIC)=
*BSY#DAS(DCOS(TH))
IF(J.EQ.2.AND.(K.EQ.3.OR.K.EQ.4))A1CIC)=
*BSY#DAS(DSIN(TH))
IF(J.EQ.3.AND.(K.EQ.2.OR.K.EQ.5))A1CIC)=
*BSY#DAS(DCOS(TH))
IF(J.EQ.4.AND.(K.EQ.1.OR.K.EQ.2))A1CIC)=
*BSY#DAS(DSIN(TH))
40 CONTINUE
20 CONTINUE
10 CONTINUE
RETURN
END
FINF(IN1,IN2)=0.000
200 CONTINUE
STRESSES AND DISPLACEMENTS ARE STORED FOR EACH LOAD CASE
DO 2107 KLK=1,8
2107 AN(KL,K,J)*UVOUT(KLK)
IF(NRNK.EQ.4) GO TO 2221
IF(J.EQ.1) UVOUT(5)+UVOUT(9)
IF(J.EQ.2) UVOUT(7)+UVOUT(9)
IF(J.EQ.3) UVOUT(7)+UVOUT(9)
IF(J.EQ.4) UVOUT(7)+UVOUT(9)
IF(J.EQ.5) UVOUT(7)+UVOUT(9)
IF(J.EQ.6) UVOUT(7)+UVOUT(9)
IF(J.EQ.7) UVOUT(7)+UVOUT(9)
IF(J.EQ.8) UVOUT(7)+UVOUT(9)
2221 CONTINUE
IF(NRNK.EQ.7.AND.J.LT.5) GO TO 371
AN(9,J)=(UVOUT(9)+UVOUT(13))/2.
AN(10,J)=(UVOUT(12)+UVOUT(16))/2.
GO TO 372
371 AN(9,J)=UVOUT(?+2WJ)
AN(10,J)=UVOUT(?+2WJ)
372 CONTINUE
DO 15 IS=1,NSTS
15 STSA(IS,J)=STSV(IS)
DO 10 IS=1,NGPT
PHIC(J,IS)=APSX(IS)
10 CONTINUE
DO 20 IS=1,NGPT
PHIC2(J,IS)=APSY(IS)
20 CONTINUE
IF(J.LT.*P4N) RETURN
INTEGRATION OF STRESSES
DO 1010 III=1,10
1010 CONTINUE
NTR=NRNK+3
DO 45 IK=1,NTR
DO 44 JK=1,NTR
45 FINF(\*K,KJ)=0.
HI=HI+X(J)*NPLY(KJ)
DO 50 LI=1,NGPT
DO 50 LJ=1,1
50 CONTINUE
DO 50 LI=1,NGPT
DO 60 LK=1,NRK
SUM=0.
DO 60 LK=1,1
60 CONTINUE
SUM=SUM+X(AINV(LJ,LI)*PHI(LJ,KI,LI))
70 CONTINUE
STEP=(LJ,KI)-SUM
60 CONTINUE
DO 50 LK=1,NRK
DO 50 LJ=1,1
SUM=0.
DO 60 LJ=1,1
60 CONTINUE

SUM=SUM+PHI(IL,LK,LI)*STEMP(IL,LJ)
90 CONTINUE
FINF(LK,LJ)=FINF(LK,LJ)+SUM*NGHT(LI)
80 CONTINUE
50 CONTINUE
DO 90 II=1,NRNK
DO 90 JJ=1,NRNK
51 STEMPC=FINF(I,II,JJ)+FINF(JJ,JJ)/2.0DO
DO 91 II=1,NRNK
DO 91 JJ=1,NRNK
52 FINF(I,II,JJ)=-STEMP(I,II,JJ)
CALL LIN2F(FINF,NN,KK,10,SINF,4,WK,IER)
DO 410 IA=1,NTR
A0(IA,2)=0.5+0.5*(IA-IA+1)
A0(IA,2)=0.5+0.5*(IA+IA)
410 A0(IA,3)=0.00
A0(1,1)=DABS(YC(1))
A0(1,2)=DABS(XC(1))
A0(1,3)=DABS(YC(2))
A0(2,1)=DABS(YC(1))
A0(2,2)=DABS(YC(2))
A0(2,3)=DABS(XC(1))
A0(3,3)=DABS(YC(2))
A0(4,3)=DABS(XC(2))
A0(5,3)=DABS(YC(3))
A0(6,3)=DABS(XC(3))
A0(7,3)=DABS(YC(4))
A0(8,3)=DABS(XC(4))
A0(9,3)=DABS(YC(5))
A0(10,3)=DABS(XC(5))
DO 420 KK=1,NRNK
DO 420 LL=1,NRNK
SUM=0.0DO
DO 430 JJ=1,NRNK
SUM=SUM+AN(KK,LL)*SINF(JJ,LL)
420 STEMPC=SUM
DO 440 KK=1,NRNK
NI=NTR-2
DO 440 KK=1,NRNK
430 STEMPC=AC(KK,JK-NRNK)
CALL LIN2F(STEMP,NN,NN,FINF,4,WK,ILK)
DO 450 II=1,NTR
DO 450 JJ=1,NTR
SUM=0.0DO
DO 460 KK=1,NRNK
SUM=SUM+FINF(I,II)*FINF(K,JK)
440 STEMPC=SUM
DO 470 II=1,NTR
DO 470 JJ=1,NTR
SUM=0.0DO
DO 480 KK=1,NRNK
SUM=SUM+FINF(KK,II)*STEMP(KK,JK)
ELUFF(II,JK)=SUM
A(II,JK)=SUM
470 CONTINUE
DO 500 II=1,NRNK
DO 500 JJ=1,NRNK
SUM=0.0DO
DO 510 KK=1,NRNK
560 SUM=SUM+SINF(I,II)*FINF(KK,JK)
550 STEMPC=SUM
DO 570 II=1,NTR
DO 570 JJ=1,NTR
SUM=0.0DO
DO 580 KK=1,NRNK
580 SUM=SUM+A(II,II)*STEMP(KK,JK)
SUBROUTINE SMAX(II,KJ,1)
IMPLICIT REAL*(A-H,O-Z)
DIMENSION AINV(3,3),STULT(3,2),AVN(3)
DIMENSION HV(3)
DIMENSION PSMX(50,4),STM(3),CM(3)
DIMENSION UIPY(2),NUMPLY(5,2),IPLY(100,2)
DIMENSION EI(2),E2(2),G12(2),V12(2),V21(2)
COMMON//MOD/1.2,G12,V12,V2I
COMMON//LMP/IPLY,NUMPLY,APG,IPLY
COMMON//STM/STM.CH
COMMON//NV/AVN
COMMON//SMX/PSMX
COMMON//STULT
DATA CM/CV,
FCH(KJ),E1,CM//GO TO 222
PSMX(I,1)+STM(I)
PSMX(I,2)+STM(2)
PSMX(I,4)+STM(2)
RETURN
222 CONTINUE

COMPUTE LAMINATE FAILURE LOADS BASED ON MAXIMUM
FIBER STRAINS FOR EACH FAILURE MODE

DO 100 K=1,3
DO 10 J=1,3
NV(II) = 0
10 AVN(II)+0.000
IF(K.EQ.1) NV(1)+1
IF(K.EQ.2) NV(1)+1
IF(K.EQ.3) NV(1)+1
DO 15 JJ=1,3
15 NV(JJ)+AVN(JJ)+AVN(JJ)
CONTINUE
NP=NUMPLY(KJ)
SMX=0.000
IF(J.EQ.1) NP=
DO 25 JJ=1,16
25 NP=NP+DSIN(TJ)*AVN(JJ)*AVN(JJ)
DO 25 JJ=1,16
25 NP=NP+DSIN(TJ)*AVN(JJ)*AVN(JJ)
IF(K.NE.1) GO TO 65
EPRT=EII/STULT(2,KJ)
GO TO 50
65 IF(K.NE.2) GO TO 75
EPRT=EII/STULT(1,KJ)
GO TO 50
75 EPRT=EII/STULT(2,KJ)
CONTINUE
IF(DABS(SMX).LT.DABS(EPRT)) SMX=EPRT
25 CONTINUE
IF(DABS(SMX).GT.1.0D-10) GO TO 553

219
PSMX(I,K)=STULT(S,KJ)*012(KJ)
GO TO 100
555 CONTINUE
PSMX(I,K)=DABS(1.0D0/SMX)
100 CONTINUE
PSMX(I,4)=PSMX(1,2)
RETURN
END

SUBROUTINE POLY(W,AST,J,K,NCOL,LTNCM)
IMPLICIT REAL*8(A-M,O-Z)
DIMENSION XC(5),YC(5),AI(200),A2(200),X(200)
DIMENSION YB(200),T(200),A1(4),A2A(4)
COMMON/CMT1/XB,YB,41,42,7
COMMON/XYC/XC,YC

ARRAY COLLOCATION POINTS AROUND EXTERIOR
BOUNDARY AND APPLY STRESS BOUNDARY CONDITION

DO 120 I=1,4
A1A(I)=0.0
A2A(I)=0.0
120 CONTINUE
IF(LTNCM.EQ.1) A1A(I)=AST
IF(LTNCM.EQ.2) A1A(I)=-AST
J=0
XC(5)=XC(1)
YC(5)=YC(1)
DO 10 I=1,4
X=XC(I+1)-XC(I)
Y=YC(I+1)-YC(I)
IF(X.EQ.0.) X=1.0D-6
IF(Y.EQ.0.) Y=1.0D-6
TH=DATAN2(X,Y)
TH=TH*1.80./DARCS(-0.1D1)
DX=XC(I+1)-XC(I)/(NCOL+1)
DY=YC(I+1)-YC(I)/(NCOL+1)
DO 20 K=1,NCOL
J=J+1
IF(J.EQ.1.OR.J.EQ.3) GO TO 23
YB(J)=YC(I)
XB(J)=XC(I)+DX*(J+4.5)
IF(J.EQ.1) XB(J)=XC(I)+(DX/2.)
GO TO 24
23 CONTINUE
YB(J)=YC(I)+DY*(J+4.9)
IF(J.EQ.1) YB(J)=YC(I)+DY/2.
XB(J)=XC(I)
24 CONTINUE
RETURN
END
SUBROUTINE CIRC(NDASTJK,K,LTNC)

ARRAY COLLOCATION POINTS AROUND INNER BOUNDARY AND APPLY BEARING LOAD IN A COSINUSOIDAL DISTRIBUTION

IMPLICIT REALS(A-N,0-Z)
DIMENSION X(600),Y(600),THTA(200),A1(200),A2(200)
COMMON/FB1/XTSTR,XSTR
COMMON/GHT1,XB,YB,A1,A2,THTA
COMMON/LT2/K,Y
COMMON/ELP/K.B,N
COMMON/XSTR

XSTR=AST

BSTR=(2.0*XSTR)/(DARCSX(CON)+B)

IM$4=1-4

IQ=00

DO 20 I=1,N

JK=JK+1

TH=((I-1)*XI2+1)*DARCSX(CON)/N

X(I)=XSTR+DARCSX(CON)

Y(I)=YSTR+DARCSX(CON)

IF(Y(I).GT.0.)THTA(I)=DARCSX(CON)+2.

IF(Y(I).LT.0.)THTA(I)=DARCSX(CON)-2.

THTA(I)=THTA(I)+THTA(JK)*LICE(JK)/DARCSX(CON)

IF(LTNC.EQ.2.0.)GO TO 25

IF(1.0.X(I).LT.1.0.X(NQ-1)) GO TO 204

GO TO 30

25 CONTINUE

20 A1(K)=0.

A2(K)=0.

YB(K)=X(I)

YB(K)=Y(I)

204 CONTINUE

RETURN

END

SUBROUTINE FIGEO(N,PHS,NJ,HOPT4,NCLL)

AN ANALYSIS FORM FOR SIMPLE GEOMETRIC ANALYSIS BY A

TER MIN COLLOCATION TECHNIQUE

SUB
IMPLICIT REAL*8(A-H,O-Z)

DIMENSION A(3,3),MK(25),AX(3,3),AZ(5),MKK(121),BC(300)

DIMENSION CH(4),H(7)

COMMON/ROTS/R1,R2

COMMON/AMT/A

COMMON/TERMS/P1,P2,P2,P2,P2,P2,R1,R2,MA(14883)

COMMON/INV/A

COMPLEX*16 ORHS(100)

COMPLEX CMCS(90,90),CMCS(300,90),CMCTCM(90,90),RHS(90)

AMATRIX CALCULATES THE LAMINATE 'A' MATRIX

CALL AMATRX(H,PH5,KJ)

LINV2F INVERTS THE 'A' MATRIX

CALL LINV2F(A,N,IA,A1,IDOT,WK,IER)

AZDEG=4

N=5

1A=3

ZRPOLY FINDS THE ROOTS OF THE CHARACTERISTIC EQUATION

CALL ZRPOLY(AZ,NDEG,Z,IER)

Z(2) AND Z(4) ARE THE COMPLEX CONJUGATES OF Z(1)

AND Z(3) RESPECTIVELY

THE TWO ROOTS MUST BE CHECKED FOR A UNITARY COMPONENT

IN EITHER THE REAL OR IMAGINARY PART; SUCH AN OCCURRENCE SIGNIFIES A QUASI-ISOTROPIC LAYUP AND

THE VALUE MUST BE PERTURBED SLIGHTLY IN ORDER TO

AVOID A SINGULAR MATRIX

CH(1)=R1

CH(2)=(0.0,-1.0)*R1

CH(3)=R2

CH(4)=(0.0,-1.0)*R2

DO 50 IJK=1,4

AR=DBSG(CH(IJK))

IF(AR.LT.1.0) GO TO 51

GO TO 52

51 IF((1.0-AR).LT.0.02) CH(IJK)=0.98

GO TO 50

52 IF((AR-1.0).LT.0.02) CH(IJK)=1.02

CONTINUE

R1=CNHPLX(CH(1),CH(2))

R2=CNHPLX(CH(3),CH(4))
CONSTANTS P1, P2, Q1, Q2 ARE NEEDED FOR STRESS CALCULATIONS

P1 = A11(1, 1) * R1 + A12(1, 2) * R1
P2 = A11(1, 1) * R2 + A12(1, 2) * R2
Q1 = A11(2, 2) * R1 + A12(2, 2) * R2
Q2 = A11(2, 2) * R2 + A12(2, 2) * R2

INPUTS A11(I), A12(I) ETC. REFER TO BOUNDARY CONDITIONS

NT4 = NNT
NT8 = NNT
NT8P4 = NNT + 4
NT8P2 = NNT + 2
NT8P1 = NNT + 1
11N = NT8P4 * (NT8P1 + 2)

CALL CHAT(BC, CHK, KMC, CMR, RHS, ORHS, NT4, NT8, NT8P4, NT8P2, 1NTP1, NEZ, HHK, WNK, HHK, NPTK, KJ, NCKL)
RETURN

END

SUBROUTINE AMATRIX(H, PHS, K)

IMPLICIT REAL*8(A-H,O-Z)

DIMENSION A(3, 3), ANO(5, 2), H(2), NPLY(2), HUMPLY(2)

DIMENSION IPLY(100, 2)

COMMON/MOD/E1, E2, G12, V12, V21

COMMON/MP/A

COMMON/LYP/HUMPLY, ANO, IPLY

COMMON/NPLY(100, 2)

COMMON/HK, THK(1), THK(K)

COMMON/MD/1, E2(K) * V12(K) * V21(K)

DO 10 I = 1, 3
DO 20 J = 1, 3

10 A(I, J) = 0.0

20 NN = NPLY(K)

THAI = ANO(1, K) * PP(0) * DARCOS(-1.0) / 180.0

C = COS(THAI)
S = SIN(THAI)

A(1, 1) = (Q11 * HNW + 2.0 * NW3) * NWCM * NWMS * NWQ2 * NWMP * NT + A(1, 1)
A(2, 2) = (Q12 * HNW + 2.0 * NW3) * NWCM * NWMS * NWQ2 * NWMP * NT + A(2, 2)
A(1, 2) = (Q11 * HNW + 2.0 * NW3) * NWCM * NWMS * NWQ2 * NWMP * NT + A(1, 2)
A(2, 1) = A(1, 2)
A(3, 3) = (Q11 * HNW + 2.0 * NW3) * NWCM * NWMS * NWQ3 * NWMP * NT + A(3, 3)
A(1, 3) = (Q11 * HNW + 2.0 * NW3) * NWCM * NWMS * NWQ3 * NWMP * NT + A(1, 3)
A(2, 3) = A(1, 3)
A(3, 1) = A(1, 3)
A(3, 2) = A(1, 3)

RETURN
A(1,1)=A(1,3)
20 CONTINUE
DO 33 I=1,3
DO 33 J=1,3
A(1,J)=A(1,J)/THKNES
33 CONTINUE
RETURN
END

SUBROUTINE CMAT(CMCTCM,CMC,CMRHNS,QHQX,NT4,NT5,NT8P4,NT8P2,
1NT8P1,NB2,NHK,HA,WKK,NOPT4,KJ,NCOL)

CMAT OUTPUTS STRESSES, STRAINS, AND DISPLACEMENTS
AT SPECIFIED COORDINATES

IMPLICIT REAL*(A-H,O-Z)
DIMENSION ASX(400),ASXY(400),UVOUT(20)
DIMENSION XCC(5),YCC(5)
DIMENSION THTA(200),X(200),Y(200),AMAT(3,3)
DIMENSION AIN1(200),AIN2(200),BCN(B2)
DIMENSION WKK(NT8P1),WORK(700)
DIMENSION XOUT(500),YOUT(500),STSU(50)
DIMENSION FUR(400),FTHT(400),FSMR(400)
DIMENSION RTHY(400),REPX(400),REPY(400),REPSY(400)
DIMENSION APX(500),APSY(500),APXY(500)
COMPLEXM16 CMCTCM(NT8P1,NT8P1),RHNS(NT8P1),PH1D,PH12D,XETA1,XETA2
COMPLEXM16 ACMC(25,25),ACD(25,25),ACM(25)
COMPLEXM16 VOUT,VO
COMLEXM16 CM(NB2,NT8P4),CMC(NB2,NT8P1),Z1,Z2,Z11,Z22,R1,R2
COMPLEXM16 T11,T12,T21,T22,P11,P12,P21,P22
COMPLEXM16 P1,P2,Q1,Q2,DCMPLX,CD,CSTNM,GRHS(NT8P2)
COMPLEXM16 PH1D,PH12D,PH1DN,PH12DN
COMPLEXM16 PH1P,PH12P,PH11P,PH12P,PH11N,PH21N
COMPLEXM16 PHIN,PH13P,PH14P,PH13N,PH14N
COMPLEXM16 SV11,SV12,SV21,SV22,R11,R12,R21,R22,R21B
COMPLEXM16 R1B,R2B,P1B,P2B,Q1B,Q2B,HA(NWK)
COMMON/INFL/APSX,APSY,APXY
COMMON/XCYC,XC,YC
COMMON/HCS/NCASE,NTYPE
COMMON/XXY1/ASX,ASXY
COMMON/STCSTRV
COMMON/UOU/UVOUT
COMMON/ROUS/R1,R2
COMMON/TERMS,P1,P2,Q2
COMMON/CMT1/X,Y,A1N1,A1N2,THTA
COMMON/CMT2/XOUT,YOUT
COMMON/FUR,FTHT,FSMR
COMMON/OUT/RTHT,REPX,REPY
COMMON/ELP/AX,BX,HOUT,STST
COMMON/SER/NT,NB
COMMON/HNV/AMAT
IF(NOPT4.EQ.9.AND.NCASE.GT.1) GO TO 3335
DO 6666 III=1,NT8P1
DO 6666 INH=1,NT8P1
6666 CMCTCM(III,INH)=(0.0DO,0.0DO)
A=AX
REAL: R1, R2, P1, P2, Q1, Q2, R1B, R2D, P1B, P2B, Q1R, Q2R, R1D, R2D

R1 = (Q1-P1)/R1
R2 = (Q2-P2)/R2
P1 = 1
P2 = 2
Q1 = 3
Q2 = 4
R1B = R1
R2D = R2
P1B = P1
P2B = P2
Q1R = Q1
Q2R = Q2
R1D = R1
R2D = R2

IF (DABS(R1).LE.1.D-16) R1 = 0.0
IF (DABS(R2).LE.1.D-16) R2 = 0.0
IF (DABS(P1).LE.1.D-16) P1 = 0.0
IF (DABS(P2).LE.1.D-16) P2 = 0.0
IF (DABS(Q1).LE.1.D-16) Q1 = 0.0
IF (DABS(Q2).LE.1.D-16) Q2 = 0.0
IF (DABS(R1B).LE.1.D-16) R1B = 0.0
IF (DABS(R2D).LE.1.D-16) R2D = 0.0
IF (DABS(P1B).LE.1.D-16) P1B = 0.0
IF (DABS(P2B).LE.1.D-16) P2B = 0.0
IF (DABS(Q1R).LE.1.D-16) Q1R = 0.0
IF (DABS(Q2R).LE.1.D-16) Q2R = 0.0
IF (DABS(R1D).LE.1.D-16) R1D = 0.0
IF (DABS(R2D).LE.1.D-16) R2D = 0.0
NORMAL & TANGENTIAL STRESS BOUNDARY CONDITIONS ARE IMPOSED

DO 310 H=1,NT

CM(J-1,N)*CM*CM(J,N)=CM(J,1)*CM(J,N)+CM(J,N-1)*CM(J,1)
CM(J,N)*CM*CM(J,N)=CM(J,N-1)*CM(J,N)+CM(J,1)*CM(J,N)
CM(J-1,N-1)*CM*CM(J-1,N)=CM(J,N)*CM(J-1,N-1)+CM(J-1,1)*CM(J,N)
CM(J,N-1)*CM*CM(J,N-1)=CM(J-1,N)*CM(J,N-1)+CM(J-1,1)*CM(J,N-1)

CONTINUE

DO 100 J=1,NT

REAL1=CM(I,J)
AIM0=AIM0+CM(I,N)*AIM0
IF(DABS(REAL1) .LT. 1.D-16)REAL1=0.0D0
IF(DABS(AIM0) .LT. 1.D-16)AIM0=0.0D0
CM(I,J)=CM(J,N)*CM*CM(I,J)
AIM0=AIM0+CM(I,J)
CM(I,J)=CM(J,N)*CM*CM(I,J)

CONTINUE

DO 220 I=1,NT

REAL1=CM(I,J)
AIM0=AIM0+CM(I,N)*AIM0
IF(DABS(REAL1) .LT. 1.D-16)REAL1=0.0D0
IF(DABS(AIM0) .LT. 1.D-16)AIM0=0.0D0
CM(I,J)=CM(J,N)*CM*CM(I,J)
AIM0=AIM0+CM(I,J)
CM(I,J)=CM(J,N)*CM*CM(I,J)

CONTINUE

DO 222 I=1,NT

REAL1=CM(I,J)
AIM0=AIM0+CM(I,N)*AIM0
IF(DABS(REAL1) .LT. 1.D-16)REAL1=0.0D0
IF(DABS(AIM0) .LT. 1.D-16)AIM0=0.0D0
CM(I,J)=CM(J,N)*CM*CM(I,J)
AIM0=AIM0+CM(I,J)
CM(I,J)=CM(J,N)*CM*CM(I,J)

CONTINUE

CONTINUE

IMPOSE RIGID BODY ROTATION CONDITION

CM(I,2*NNT+1)=CM(I,1)*RB11+CM(I,1)*CM(I,2*NNT+1)
CM(I,4*NNT+1)=CM(I,1)*RB11+CM(I,1)*CM(I,4*NNT+1)
CM(1,6+NT+1)=-CM(I,1)*RB21B/R511+CM(I,6+NT+1)
CM(I,1)=(0.0,0.0)

IMPOSE SINGLE-VALUESNESS CONDITION

CM(I,NT8+3)=CM(I,NT8+1)*SV11+CM(I,NT8+3)
CM(I,NT8+4)=CM(I,NT8+1)*SV12+CM(I,NT8+4)
CM(I,NT8+3)=CM(I,NT8+2)*SV21+CM(I,NT8+3)
CM(I,NT8+4)=CM(I,NT8+2)*SV22+CM(I,NT8+4)
CM(I,NT8+1)=(0.0,0.0)
CM(I,NT8+2)=(0.0,0.0)

139 DO 141 I=1,NB2
140 DO 142 J-1+CM(I,J)
141 CONTINUE

DO 95 I=1,NB2
95 CONTINUE

CSUM(I,1)=CSUM

C Stress and Strain Calculation
RAD=DARCOS(-1.000)/180.00
IC=1
IC=2
SUMUI=0.000
SUMVI=0.000
SUMU2=0.000
SUMV2=0.000
NADD=0
IF(NOPT.EQ.1) GO TO 1195
IF(NOPT.EQ.2.OR.NCASE.GT.4) GO TO 1196
NADD*4=IC
NOC=1
DO 197 II=1,NADD
   ICOUT(II+I)*=X(II)
   MN+ICOUT+I*NADD
   ICOUT(IN)*=AX
   YOUT(MN+I)*=AX
   YOUT(MN+2)*=AX
   XOUT(NI+3)=AX*DCOS(177.00*RAD)
   YOUT(MN+3)*=AX*DSIN(177.00*RAD)
   YOUT(MN+4)*=AX
   YOUT(MN+4)*=AX
   NADD=NADD+4
GO TO 1195
1195 CONTINUE
NADD=8
NOC=2
MN+ICOUT+I*NADD
DO 199 III=1,4
   ICM=III
   XOUT(III)*=XC(ICH)
   YOUT(III)*=Y(ICH)
199 CONTINUE
MN+IC=4
XOUT(IN+I)*=AX
   YOUT(IN+I)*=AX
   YOUT(IN+2)*=AX
   YOUT(IN+3)*=AX
   XOUT(IN+3)=AX*DCOS(177.00*RAD)
   YOUT(IN+3)*=AX*DSIN(177.00*RAD)
   XOUT(IN+4)*=AX
   YOUT(IN+4)*=AX
IF(NOPT.EQ.5) NRCF=ICOUT+I*NADD
   INC=I*NADD
   DO 190 K=1,NRCF
   Z1*XOUT(K)+R1*YOUT(K)
   Z2*XOUT(K)+R2*YOUT(K)
   Z1=CDQRT(Z1*Z1-AMA-R1*MRI*WB)
   Z2=CDQRT(Z2*Z2-AMA-R2*M2*MB)
   XEITA1=(Z1+Z1)/A-COMR1*MB
   IF(CDABS(XEITA1).LT.0.999) GO TO 400
   GO TO 410
400 Z1=-Z1
   XEITA1=(Z1+Z1)/A-COMR1*MB
   XEITA2=(Z2+Z2)/A-COMR2MB
   IF(CDABS(YEITA2).LT.0.999) GO TO 420
GO TO 430
420 Z22=-Z22
XET1=(Z2+Z22)/(A-C02*R2*B)
430 CONTINUE
PH11P=0.0,0.0)
PH12P=0.0,0.0)
PH11N=0.0,0.0)
PH12N=0.0,0.0)
PH11P=0.0,0.0)
PH12P=0.0,0.0)

DO 170 N=1,NT
NP=N
N0=-N
PH11P=PH12P=PH11N=PH12N=PH11P=PH12P=PH11N=PH12N=PH11P

170 CONTINUE
PH11D=PH11D+GRHS(3*NNT+1)/Z11
PH12D=PH12D+GRHS(8*NNT+2)/Z12
PH11N=PH12N+GRHS(3*NNT+1)/Z11
PH12N=PH12N+GRHS(8*NNT+2)/Z12

SOMAX=2.*X(R1*W)*PH11D+R2*X*PH12D
SGMAXY=-2.*X(R1*PH11D+R2*PH12D)
EPSX=AMAT(1,1)*SGMAX+AMAT(1,2)*SGMAY+AMAT(1,3)*SGMXY
EPSY=AMAT(2,1)*SGMAX+AMAT(2,2)*SGMAY+AMAT(2,3)*SGMXY
EPSXY=AMAT(3,1)*SGMAX+AMAT(3,2)*SGMAY+AMAT(3,3)*SGMXY
U=2.*X(R1*PH11D+R2*PH12D)
V=2.*X(R1*PH11D+R2*PH12D)

IF(XCUT(() .LT.0. AND. YOUT(K). LT.0.)
+TETAw=DATAN(YOUT(K)/XOUT(K))*180./PI
IF(YOUT(K). LT.0. AND. XOUT(K). LT.0.)
+TETAw=DATAN(YOUT(K)/XOUT(K))*180./PI+180.

UR=UR+V*4S
IF(NOPT4.EQ.5) GO TO 3338

225
ASXY(K) = SGMAX
FUR(K) = UR
FHT(K) = ETA
FSMR(K) = SGMA
3358 CONTINUE
IF(NOPT4.EQ.5.AND.K.GT.NOUT) GO TO 3359
APX(K) = SGMAX
APSY(K) = SGAY
APSXY(K) = SGMAX
3359 CONTINUE
IF(NOPT4.EQ.1) GO TO 190
IF(NOPT4.EQ.5.AND.K.LE.NOUT.OR.K.GT.(NOUT+NSTS)) GO TO 191
IF(C2.LE.NINC) STSV(IC2) = SGMAX
IF(C2.GT.NINC.AND.IC2.LE.(2*NINC)) STSV(IC2) = SGAY
IF(C2.GT.(2*NINC).AND.IC2.LE.(3*NINC)) STSV(IC2) = SGMAX
IC2 = IC2 + 1
GO TO 190
190 CONTINUE
IF(NIC.EQ.1) GO TO 192
IF(NIC.EQ.5.AND.X.LT.(NRCF-7)) GO TO 190
UVOUT(IC) = U
UVOUT(IC+1) = V
IC = IC + 2
GO TO 190
192 CONTINUE
HNC = NOUT + NSTS
IF(K.GT.NC.AND.K.LE.(NC+NCOL)) SUMU1 = SUMU1 + U
IF(K.GT.(NC+NCOL).AND.K.LE.(NC+2*NCOL)) SUMV1 = SUMV1 + V
IF(K.GT.(NC+2*NCOL).AND.K.LE.(NC+3*NCOL)) SUMU2 = SUMU2 + U
IF(K.GT.(NC+3*NCOL).AND.K.LE.(NC+4*NCOL)) SUMV2 = SUMV2 + V
HNC = NC+4*NCOL
IF(K.EQ.(NC+1)) UVOUT(9) = U
IF(K.EQ.(NC+2)) UVOUT(10) = V
IF(K.EQ.(NC+3)) UVOUT(11) = U
IF(K.EQ.(NC+4)) UVOUT(12) = V
IF(K.EQ.(NC+5)) UVOUT(13) = U
IF(K.EQ.(NC+6)) UVOUT(14) = V
IF(K.EQ.(NC+7)) UVOUT(15) = U
IF(K.EQ.(NC+8)) UVOUT(16) = V
190 CONTINUE
DISPLACEMENTS ARE AVERAGED OVER ELEMENT SIDES FOR CERTAIN LOAD CASES
IF(NIC.NE.1) RETURN
SUMU1 = SUMU1 / FLOAT(NCOL)
SUMV1 = SUMV1 / FLOAT(NCOL)
SUMU2 = SUMU2 / FLOAT(NCOL)
SUMV2 = SUMV2 / FLOAT(NCOL)
UVOUT(1) = SUMU2
UVOUT(2) = SUMV2
UVOUT(3) = SUMU2
UVOUT(4) = SUMV1
UVOUT(5) = SUMU1
UVOUT(6) = SUMV1
UVOUT(7) = SUMU1
UVOUT(8) = SUMV2
RETURN
END
SUBROUTINE FBOLT(ANG,K,PSH,K)

FBOLT CALCULATES THE INDIVIDUAL PLY FOUNDATION MODULI AND THE INDIVIDUAL PLY LOADS

IMPLICIT REAL*8(A-H,O-Z)
DIMENSION ATETAA(400),ANG(3,2),ASIGR(400),ASIGT(400),M(2)
DIMENSION ASIQ1(400),ASIQ2(400),ASIQ6(400),UR(400),ANGK(5,2)
DIMENSION FSMR(400),PLXPT(100)
DIMENSION IPLY(100,2),NPLY(2),NUMPLY(2)
DIMENSION FKI(100),PLX(100)
DIMENSION E11(2),E22(2),ESS(2),PMU12(2),PMU21(2)
COMMON/STRESS/ASIQ1,ASIQ2,ASIQ6
COMMON/ELP/A.X,BX,NOUT
COMMON/F31/STR,YSTR
COMMON/LYP/ICPLY,NUMPLY,ANG,ICPLY
COMMON/FB2/UR,ATETAA,FSMR
COMMON/MOD/E11,E22,ESS,PMU12,PMU21
COMMON/FCT/PLXPT

Napl=0.1D0/180.
THKTOT=HPLY(K)*N(K)
NW=NPLY(K)

CALCULATE DELEFF

WOPK=0.
PLOADX=0.
IF(K.EQ.1) PLDL=0.
DO 210 KK=1,NOUT
TH1=ATETAA(KK+1)-ATETAA(KK)
TH2=(ATETAA(KK)+ATETAA(KK+1))/2.
THETA=TH2*XRAD
C=DCOS(THETA)
S=DSIN(THETA)
R=(SQR1.0/(CM**2/AX**2+CM**2/BX**2))
FORCE=((FSMR(KK)+FSMR(KK+1))/2.)*W*TH1*XRAD*THKTOT
WORK=FORCE*5*X((UR(KK)+UR(KK+1))/2.)
PLOADX=PLoadX+FORCE*W
210 CONTINUE
PLD=PLD+PLOADX
DELEF=FORCE/PLoadX

COMPUTE PLY STRESSES FROM LAMINATE STRAINS

SIGMA(0,0,0)=Q*(EPS)R,0,0

N=nply(K)
DO 100 J=1,N
LP=ICPLY(J,K)
THETA=ANG(LP,K)+PSH*XRAD
100=1

00025160
00025170
00025180
00025190
00025200
00025210
00025220
00025230
00025240
00025250
00025260
00025270
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00025700
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00025740
00025750

227
I

INTTEGRATE AROUND CIRCULAR BOUNDARY FOR
INDIVIDUAL PLY LOADS AND COMPUTE FOUNDATION
MODULI!

\text{\texttt{\textbackslash NNN=*12-1}}
\text{\texttt{\textbackslash W\textbackslash K*0.}}
\text{\texttt{\textbackslash D\textbackslash O 70 1=II,NNN}}
\text{\texttt{\textbackslash T\textbackslash H1=\texttt{ATETAA(I-I)-ATETAA(I)}}}
\text{\texttt{\textbackslash T\textbackslash H2=(ATETAA(I)+ATETAA(I+1))/2.}}
\text{\texttt{\textbackslash T\textbackslash HET\textbackslash TA=TH2*360}}
\text{\texttt{\textbackslash C=\texttt{DSCOSTHETA)}}
\text{\texttt{\textbackslash S=\texttt{D\textbackslash INH(THET\textbackslashes)}}}
\text{\texttt{\textbackslash R=\texttt{DGRT(3/2/A*X*X+2+S*X*X*A*X*X)}}}
\text{\texttt{\textbackslash FOR\textbackslash CR=((\texttt{ASIGR(I)}+\texttt{ASIGR(I+1)})/2.)*K\textbackslash MT\textbackslash H1*XRAD\times H(K)}}
\text{\texttt{\textbackslash FOR\textbackslash CR=((\texttt{ASIGR(I)}+\texttt{ASIGR(I+1)})/2.)*K\textbackslash MT\textbackslash H1*XRAD\times H(K)}}
\text{\texttt{\textbackslash PLO\textbackslash ADX=\texttt{LOADX+FOR\textbackslash CR}}}
\text{\texttt{\textbackslash \texttt{\textbackslash C\textbackslash CONTINUE}}}
\text{\texttt{\textbackslash F\textbackslash K\textbackslash I(J)=\texttt{DABS(PL\textbackslash ADX/(\texttt{K*(I1)\times DELE\textbackslashes})}}}
\text{\texttt{\textbackslash PL\textbackslash X(J+K-1)*\textbackslash NPLY(I))=\texttt{LOADX}}}
\text{\texttt{\textbackslash 100 \textbackslash CONTINUE}}
\text{\texttt{\textbackslash N\textbackslash T=\texttt{NUM\textbackslash L(Y(K))}}}
\text{\texttt{\textbackslash N\textbackslash H=\texttt{NPLY(K)}}}
\text{\texttt{\textbackslash DO 310 I=1,NT}}
\text{\texttt{\textbackslash DO 310 II=1,NN}}
\text{\texttt{\textbackslash IF(I\texttt{PLY}(I,K).EQU.1) A\texttt{\textbackslashes(K,I,K)\textbackslashes=FK\textbackslashes(I,I)}}}
\text{\texttt{\textbackslash IF(I\texttt{PLY}(I,K).EQU.1) P\texttt{\textbackslashes=X\texttt{\textbackslashesPT(I)}=PL\texttt{\textbackslashesX(I+K-1)\texttt{\times NPLY(I))}}}
\text{\texttt{\textbackslash 310 \textbackslash CONTINUE}}
\text{\texttt{\textbackslash N\textbackslash P=\texttt{NUM\textbackslashesL(Y(K))}}}
\text{\texttt{\textbackslash DO 311 I=1,NP}}
\text{\texttt{\textbackslash A\texttt{\textbackslashes=A\texttt{\textbackslashesSIGR(I,K)}+PSH}}}
\text{\texttt{\textbackslash 311 \textbackslash CONTINUE}}
\text{\texttt{\textbackslash P\texttt{\textbackslashes=PT\texttt{\textbackslashesT+0.000}}}
\text{\texttt{\textbackslash IF(K,EQ.1) B\texttt{\textbackslashesLOAD=0.}}}
\text{\texttt{\textbackslash TH(K)\texttt{=NPLY(K)}}}
\text{\texttt{\textbackslash B\texttt{\textbackslashesLOAD=((-\texttt{BSTRMDACOS(-1.000)}\times 360*/2.+\texttt{LOAD}}}
\text{\texttt{\textbackslash IF(K,EQ.1) GO TO 611}}
\text{\texttt{\textbackslash N\texttt{\textbackslashes=\texttt{NPLY(I)+NPLY(Z)}}}
\text{\texttt{\textbackslash DO 212 I=1,NN}}
\text{\texttt{\textbackslash P\texttt{\textbackslashes=\texttt{PT\textbackslashesT+\texttt{PL\textbackslashesX(I})}
\text{\texttt{\textbackslash 212 \textbackslash CONTINUE}}
\text{\texttt{\textbackslash 611 \textbackslash CONTINUE}}
\text{\texttt{\textbackslash RETURN}}
\text{\texttt{\textbackslash END}}

\texttt{\textbackslash SUB\textbackslashesROUTINE Q\texttt{\textbackslashesMATX(RAD,TH\textbackslashesETA,K,LI1,LI2,NCAS)}}
\texttt{\textbackslashesMATX PERFORMS BASIC STRESS AND STRAIN}
\texttt{\textbackslashesTRANSFORMATIONS}
\texttt{\textbackslashesIMPLICIT REAL\&(A-H,O-Z)}
\texttt{\textbackslashesDIMENSION ASIGR(400),ASIGR(400),ASIGR(400),ASIGR(400),ASIGR(400),ASIGR(400)}
SUBROUTINE CENTD(H, FASSSFASbSP)

DIMENSION PLYK(100), BARK(100), F(100)
DIMENSION HC2(2), RF(2)
DIMENSION AIIC(100), F(100), AC2(100), B(2)
DIMENSION 14PLY(2)

COMMON/PB5/PLYK, BARK, F(100)
COMMON/ARA/To, RF

SUBROUTINE CENTD(H, FASSSFASbSP)

INTEGRAL REALS (H, D-Z) INTEGRAL DIMENSION M(2), F(2), A(2), B(2)

COMMON/PB5/PLYK, BARK, F(100), F(100)
COMMON/ARA/To, RF

CONTINUE}

RETURN
END
COMMON/LYP/NPLY
NN=NPLY(1)+NPLY(2)

SET UP THE CENTRAL DIFFERENCE EQUATIONS

DO 3 I=1,100
DO 3 J=1,100
3 AI(I,J)=0.

NECESSARY CONSTANTS ARE FORMED

DO 7 I=1..
A(I)=H(I)**2/FASSS
7 B(I)=H(I)**4/FASSS
M2=H(I)/H(2)
A1=H(I)**2/FASSS
A2=H(2)**2/FASSS
NPNL=NPLY(1)+NPLY(2)

SHEAR AT TOP OF PANEL EQUALS ZERO

AII(1,1)=1.
AII(1,2)=-(2.*AI*P(2))
AII(1,3)=2.*AI*P(2)
AII(1,5)=-1.
F(1)=0.0

MOMENT CONDITION AT TOP

IF(RF(1).OE.1.D10) GO TO 50
Z=1.
R=RF(1)
GO TO 60
50 Z=0.
R=1.
60 AII(2,1)=R
AII(2,2)=(ZM2.*H(1)*FASSS)**R*-2.*AI*P(2)+(H(1)**2
*FASSS)/FASSS)
AII(2,3)=ZM2.*H(1)*FASSS+(2*H(1)**2*NPLY(1)*H(1))
AII(2,4)=ZM2.*H(1)*FASSS+R*2.*AI*P(2)-(H(1)**2
*FASSS)/FASSS)
AII(2,5)=-R
F(2)=ZM2.*H(1)**3*BARK1*XBARU1

GOVERNING EQUATIONS FOR THE TOP PLATE

N2=NPLY(1)
DO 55 J=1,N2
1=J+2
AI(I,J)=1.
IF(J.EQ.1) GO TO 56
AII(I,J+1)=-4.-AI*P(J-1)
GO TO 57
55 AI(I,J+1)=-4.-AI*P(J-1)
56 AI(I,J+2)=6.+AI*P(J)+B(1)*NPLY(J)
IF(J.EQ.N2) GO TO 61
AII(I,J+3)=-4.-AI*P(J+1)
GO TO 63
57 AI(I,J+3)=-4.-AI*P(NPLY(1)-1)
61 AI(I,J+3)=-4.-AI*P(NPLY(1)-1)
62 Ai(i,j+4)=1
   IF(J.EQ.1) GO TO 58 
   IF(J.EQ.0) GO TO 63
   F(i)=x(i)*bark(j-1)*baru(j-1)
   F(i)=-(2.*a(i)+b(i))*bark(j)*baru(j)
   **a(i)*bark(j+1)*baru(j+1)
   GO TO 59
58 F(i)=2.*a(i)*bark(2)*baru(2)
   x(2.*a(i)+b(i))*bark(1)*baru(1)
   GO TO 59
63 F(i)=2.*a(i)*bark(nply(1)-1)*baru(nply(1)-1)
   x(2.*a(i)+b(1))*bark(j)*baru(j)
59 CONTINUE
59 CONTINUE

INTERFACE SHEAR ON TOP PLATE = P
   I=nply(1)+3 
   J=nply(1)
   Ai(i,j)=1
   Ai(i,j+1)=-(2.+a(i)*nply(nply(1)-1))
   Ai(i,j+2)=2.+a(i)*nply(nply(1)-1)
   Ai(i,j+4)=-1.
   F(i)=-(2.*x(i)+3)*x(p)/fasbs 
   SLOPE CONTINUITY
   I=nply(1)+4 
   J=nply(1)
   Ai(i,j)=1.
   Ai(i,j+1)=-(2.+a(i)*nply(nply(1)-1)-h(1)*x2*fas3/fasbs)
   Ai(i,j+3)=2.+a(i)*nply(nply(1)-1)-h(1)*x2*fas3/fasbs 
   Ai(i,j+4)=-1.
   Ai(i,j+5)=-h12*x3 
   Ai(i,j+6)=-h12*x3+(2.+a(i)*nply(nply(1)+2)-h(2)*x2*fas3/fasbs) 
   Ai(i,j+7)=-h12*x2 
   Ai(i,j+8)=-h12*x2+(2.+a(i)*nply(nply(1)+2)-h(2)*x2*fas3/fasbs) 
   Ai(i,j+9)=-h12*x3 
   F(i)=0. 
   MOMENT CONTINUITY 
   I=nply(1)+5 
   J=nply(1)+1 
   Ai(i,j)=1.
   Ai(i,j+1)=-(2.+a(i)*nply(nply(1))) 
   Ai(i,j+2)=1.
   Ai(i,j+4)=h12*x2 
   Ai(i,j+5)=h12*x2+(2.+a(i)*nply(nply(1)+1)) 
   Ai(i,j+6)=h12*x2+(2.+a(i)*nply(nply(1)+1)) 
   Ai(i,j+7)=h12*x2 
   Ai(i,j+8)=-h12*x2 
   Ai(i,j+9)=-h12*x2 
   Ai(i,j+10)=h12*x2+(2.+a(i)*nply(nply(1)+1)) 
   Ai(i,j+11)=-h12*x2 
   Ai(i,j+12)=-h12*x2+(2.+a(i)*nply(nply(1)+2)) 
   Ai(i,j+13)=h12*x2 
   Ai(i,j+14)=-h12*x2+(2.+a(i)*nply(nply(1)+1)) 
   Ai(i,j+15)=h12*x2 

INTERFACE SHEAR ON BOTTOM PLATE
   I=nply(1)+6 
   J=nply(1)+5 
   Ai(i,j)=1.
   Ai(i,j+1)=-(2.+a(i)*nply(nply(1)+2)) 
   Ai(i,j+3)=-(2.+a(i)*nply(nply(1)+2)) 
   Ai(i,j+5)=-1.

231
GOVERNING EQUATIONS FOR THE BOTTOM PLATE

\[ N1 = N P L Y(1) \]
\[ N2 = N P L Y(1) + N P L Y(2) \]

DO 70 I = N1, N2

\[ A(I, J) = \]

IF \((J - 1) > 0 \) \( A(I, J) = -4 \) \((J = 0) \)

71 \( A(I, J) = N P L Y(J) \)

72 \( A(I, J) = 6 \)

75 \( A(I, J) = 4 \)

5 \( A(I, J) = 1 \)

SHEAR ON BOTTOM PLATE EQUALS ZERO

NP = N P L Y(1) + N P L Y(2)
I = NP + 7
J = NP + 4

IF \((I - 1) = 0 \) \( I(F) = 0 \)

MOMENT BOUNDARY CONDITION ON BOTTOM PLATE

I = NP + 8
IF \((F(2, G) \ge 1.0) \) GO TO 85
Z1 = \( R(2) \)
GO TO 95

85 Z = 0.0
R = 1.0

93 \( A(I, J) = -R \)

A(I, J+1) = Z \((2, M + 2) \times F A S S \) + R \((2, M + 2) \times N P L Y(N P - 1) \)
\( N(H) \times 2 \times F A S S / F A S S \) 3

A(I, J+2) = Z \((4, M + 2) \times F A S S + 2, M + 2, N P L Y(N P) \)

A(I, J+3) = Z \((2, M + 2) \times F A S S + R \((2, M + 2) \times N P L Y(N P - 1) \)
\( N(H) \times 2 \times F A S S / F A S S \) 5

A(I, J+4) = \( R \)

232
SUBROUTINE SOLVE(H,P,U1,U2)

I*PI,IT REN4A(1-4,0-7)
DIMENSION A(100,100),B(100),HPLY(2),U(100),F(100)
DIMENSION SX(100),PLYK(100),H(2)
DIMENSION BAR(100),BARU(100)
COMMON/LYP/PLY
COMMON/PLYK,XP,Y
COMMON/PLYK,BAR,BARU

: SOLUTION OF THE SYSTEM: A(U)=B

HP=HPLY(1)*HPLY(2)+B
DO 444 I=1,HP
DO 444 3=1,444
APPLYING GAUSSIAN ELIMINATION TO THE
MATRIX OF COEFFICIENTS
DO 2001 I=1,HP
IR=I
2042 IF(A(IR,I).NE.0.) GO TO 2041
IR=IR+1
IF(IR.GT.HP) GO TO 2001
GO TO 2042
2041 NN=IR+1
DO 2002 L=NN,HP
IF(DABS(A(L,I)).GT.1.D-30) GO TO 2009
A(L,I)=0.
GO TO 2002
2009 CF=A(IR,I)/A(L,I)
DO 2005 J=1,HP
A(L,J)=A(L,J)*CF*A(IR,J)
IF(DABS(A(L,J)).LT.1.D-30) A(L,J)=0.0
2003 CONTINUE
B(L)=B(L)*CF+B(I)
2002 CONTINUE
2001 CONTINUE
BACK SUBSTITUTION
DO 2011 I=1,HP
L=HP+1-I
SUM=0.
IF(A(L,I).EQ.0.) GO TO 2112
H=I
IF(N.GT.HP) GO TO 2013
DO 2015 J=N,HP
SUM=SUM+A(L,J)*SX(J)
2013 CONTINUE
SX(L)=B(L)+SUM/A(L,I)
GO TO 444

RETURN
END
2112 CONTINUE
SX(I)=0.
2111 CONTINUE
PT=P
NI=NPLY(I)+2
NZ=NPLY(I)+7
NN=NPLY(I)+NPLY(2)+6
DO 1444 I=3,NI
I=1-2
UC(I)=SX(I)
1444 CONTINUE
DO 1555 I=NZ,NN
J=6
UC(I)=SX(I)
1555 CONTINUE
NP=NPLY(I)+NPLY(2)

COMP AV REL DISPL MT AND BTT PLTS
V1=ABS(U(I)-U(NPLY(1)))/2.
V2=ABS(U(NPLY(1)+1)-U(NPLY(1)+NPLY(2)))/2.
RETURN
END

SUBROUTINE FCRIT(APP,NEL1,NEL2,NDAM,IN,LTNCM,NAV)
IMPLICIT REAL*8(A-H,O-Z)
DIMENSION ELSTFF(50,10,10),ELSTSS(50,50,10),U(200)
DIMENSION OSSX(20),OSSW(20)
DIMENSION NELDIS(50,5,2)
DIMENSION PSMX(50,4),AVES(50,3),STRSS(50),DLT(10)
DIMENSION ELFAIL(50,3),HELTYPE(50)
DIMENSION NELCON(50,6),HELCONA(50,6),NPLY(2)
DIMENSION ELWIDTH(50),ELTHK(50),ELLOAD(50,2)
DIMENSION NELPS(2,50),LYPN(50)
COMMON/ELS/ELSTFF,ELSTSS
COMMON/PSL/NESPLPS,LYPN
COMMON/NC/NC,NC,NC,NC
COMMON/FCC/ELWIDTH,ELTHK,ELLOAD
COMMON/LAMX/ELFAIL
COMMON/DISP/U
COMMON/NTP/NELTYPE
COMMON/LYP/NPLY

DETERM ELEMENT FAIL LOADING IN NET. SEC.
SHEAROUT AND BEARING, AND LOCATE THE CRIT.
FASTENER LOCATION. JOINT STRENTH IS DETER.
FROM LOWEST ELEMENT FAIL LOAD

NELTOT=NEL1+NEL2
NS=NAV
NSTS=4*NAV
DO 10 I=1,NELTOT
NRNK=10
IF(HELTYPE(I).EQ.3) NRNK=8
KJ=I

0029360
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0029390
0029400
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0029950
IF(KJ.OT.NEL) KJ*KJ-NEL C002960
IF(NELTYPCI).EQ.1) 00 TO 10 0029970
DO 20 J=1,5 0029980
IC=IC+1 0030000
DLT(IC)=U(NELDIS(I,J,1)) 0030010
IC=IC+1 0030020
DLT(IC)=U(NELDIS(I,J,2)) 0030030
20 CONTINUE 0030040
DO 30 K=1,NSTS 0030050
SUM=0.000 0030060
DO 40 K2=1,NNK 0030070
SUM=SUM+ELSTSS(SUB2(K,K2)+DLT(K2)) 0030080
30 CONTINUE 0030090
30 STRSS(K)=SUM 0030100
SUM1=SUM+0.000 0030110
SUM2=SUM+0.000 0030120
SUM3=SUM+0.000 0030130
DO 50 J=1,NS 0030140
SUM1=SUM1+STSS(J) 0030150
SUM2=SUM2+STSS(J+1) 0030160
SUM3=SUM3+STSS(J+2) 0030170
50 CONTINUE 0030180
HH=2+NS 0030190
DO 51 II=1,NS 0030200
SUM4=SUM4+STSS(II+2+NS) 0030210
AVES(1,1)=SUM1/NS 0030220
AVES(1,2)=SUM2/NS 0030230
AVES(1,3)=SUM3/NS 0030240
51 CONTINUE 0030250
IF(J.EQ.1.AND.LTNCM.EQ.1) 0030260
THK=ELTHK(I) 0030270
IF(J.EQ.1.AND.LTNCM.EQ.2) 0030280
PRATIO=DABS((ELLOAD(I,1)+ELLOAD(I,2))/ELD) 0030290
SCALE AVERAGE STRESSES 0030300
AVES(1,1)=AVES(1,1)*PRATIO 0030310
AVES(1,2)=AVES(1,2)*PRATIO 0030320
AVES(1,3)=AVES(1,3)*PRATIO 0030330
10 CONTINUE 0030340
COMPUTE JOINT FAILURE LOADS BASED ON ELEMENT LOADS 0030350
DO 100 J=1,NELTOT 0030360
IF(NELTYPC(I).EQ.1) GO TO 100 0030370
DO 110 J=1,3 0030380
N=N+1 0030390
110 CONTINUE 0030400
ELFAIL(I,J)=DABS(ELFA(I,J)/AVES(I,J)) 0030410
100 CONTINUE 0030420
SEARCH FOR LOWEST JOINT FAILURE LOAD 0030430
INNS=0 0030440
FHS=1.000 0030450
INGO=0 0030460
356 FORMAT(1' JOINT LOAD LEVELS CORRESPONDING TO NET NS, SHAE-OUT (SO) AND BEARING (BR)'
* FAILURES AT EVERY LOADED AND UNLOADED HOLE ',/,
* ELEMENT ARE PREDICTED AS FOLLOWS ',/,
* ELEMENT NS SO BR',/)
DO 120 N=1.NELDCT
IF(HELYP(I),E)1) GO TO 120
IF(FNS.GT.DEBS(ELFAIL(I,1))) INNS=I
IF(FNS.GT.DEBS(ELFAIL(I,2))) INSD=I
IF(FSO.GT.DEBS(ELFAIL(I,2))) FSO=DEBS(ELFAIL(I,2))
IF(FBR.GT.DEBS(ELFAIL(I,3))) INBR=I
IF(FBR.GT.DEBS(ELFAIL(I,3))) FBR=DEBS(ELFAIL(I,3))
WRITE(6,222) NELCNO(I),ELFAIL(I,1),ELFAIL(I,2),ELFAIL(I,3)
222 FORMAT(2X,18,2X, 3(09.3#2X))
120 CONTINUE
IF(FNS.GT.FSO.0R.FNS.GT.FBR) GO TO 130
IN=INNS
GO TO 200
130 IF(FPSO.GT.FNS.0R.FSO.GT.FBR) GO TO 140
NDAM=I
IN=INSD
GO TO 200
140 IF(FBR.GT.FNS.0R.FBR.GT.FSO) GO TO 200
NDAM=3
IN=INBR
200 CONTINUE
RETURN
END
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00311200
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00311500

SUBROUTINE LINV2F (A,N,IA,AINV,IDOT,HKAREA,IER)
DOUBLE PRECISION A(A,N),AINV(A,N),HKAREA(N),ZERO(1),ONE
DATA ONE/1,000/,ZERO/0,000/
IER=0
SET AINV TO THE N X M IDENTITY MATRIX
DO 10 I = 1,N
D0 5 J = 1,N
AINV(I,J) = ZERO
CONTINUE
AINV(I,I) = ONE
10 CONTINUE
CALL LEQT2F (A,N,IA,AINV,IDOT,HKAREA,IER)
IF (IER EQ.0) GO TO 9005
9000 CONTINUE
CALL UERTST (IER,HLINV2F)
9005 RETURN
END
SUBROUTINE LEQTZF (A, M, N, IA, IDOT, HKAREA, IER)

DIMENSION A(IA,1), B(IA,1), HKAREA(1)
DOUBLE PRECISION A, B, HKAREA, DI, D2, WA

FIRST EXECUTABLE STATEMENT

initialize ier

IER=0
JER=0
J = N+1
K = J
MM = K+N
KK = 0
MM1 = MM-1
JJ=1
DO 5 L=1,N  
  DO 5 T=1,N
    WKAREA(JJ)=A(I,L) 
    JJ=JJ+1
5 CONTINUE

DECOMPOSE A

CALL LDATN(HKAREA,N,IA,IDOT,DI,D2,HKAREA(J),HKAREA(K))

IF (IER.EQ.128) GO TO 25
IF (IDOT.EQ.0 OR IER.NE.0) KK = 1

DO 15 I = 1,N
  HKAREA(JJ)=A(I,L) 
  JJ=JJ+1
15 CONTINUE

PERFORMS THE ELIMINATION PART OF AX = B

CALL LUELMN(A, IA, N, B(I, I), HKAREA(J), HKAREA(MM))

IF (KK.EQ.0) GO TO 25

DO 10 II=1,N
  B(II, I)= HKAREA(MM1+II)
10 CONTINUE

PERFOMS THE REFINEMENT PART OF AX = B

IF (IER.EQ.0) GO TO 25

DO 13 I = 1,N
  DO 15 J = 1,N
    A(I, J)=HKAREA(JJ)
    JJ=JJ+1
15 CONTINUE

IF (IER.EQ.0) GO TO 25

DO 10 I = 1,N
  DO 15 J = 1,N
    HKAREA(JJ)=HKAREA(JJ+1)
15 CONTINUE

9000 CONTINUE

RETURN

SUBROUTINE LUDATF (A, LU, N, IA, IDOT, DI, D2, IPVT, EQUIL, WA, IER)

DIMENSION A(IA,1), LU(IA,1), IPVT(1), EQUIL(1)
DOUBLE PRECISION A, LU, DI, D2, EQUIL, WA, ZERO, ONE, FOUR, SIXTH, SIXTH, RN, WREL, BIGA, BIGP, SUM, AI, WI, T, TEST, G
DATA ZERO, ONE, FOUR, SIXTH, SIXTH, 0.0, 1.0, 4.0, .DO, .DO, .DO, .DO, .DO, .DO

237
m:e
	n
16.D0.0625DC
FIRST EXECUTABLE STATEMENTS

111.

IFER = 0
RN = N
WREL = ZERO
DI = ONE
D2 = ZERO
BIGA = ZERO
DO 10 I=1,N
BIG = ZERO
DO 5 J=1,N
P = A(I,J)
L(I,J) = P
P = DABS(P)
IF (P.GT. BIG) DOG = P
5 CONTINUE
IF (BIG .GT. BIGA) BIGA = BIG
IF (BIG .EQ. ZERO) GO TO 110
EQU(I,J) = ONE/BIG
10 CONTINUE
DO 105 J=1,N
JMI = J-1
IF (JMI .LT. 1) GO TO 40
COMPUTE U(I,J), I=1,...,J-1
DO 35 I=1,JMI
SUM = LU(I,J)
IM1 = I-1
IF (IDOT .EQ. 0) GO TO 25
WITH ACCURACY TEST
AI = DABS(SUM)
HI = ZERO
IF (IM1 .LT. 1) GO TO 20
DO 15 K=1,IM1
T = LU(I,K)*LU(K,J)
SUM = SUM-T
HI = HI+DABS(T)
15 CONTINUE
LU(I,J) = SUM
20 HI = HI+DABS(SUM)
IF (AI .GT. ZERO) AI = BIGA
TEST = HI/AI
IF (TEST .GT. WREL) WREL = TEST
GO TO 35
WITHOUT ACCURACY
25 IF (IM1 .LT. 1) GO TO 35
DO SUM = I=1,IM1
SUM = SUM-LU(I,K)*LU(K,J)
30 CONTINUE
LU(I,J) = SUM
35 CONTINUE
40 P = ZERO
C COMPUTE U(J,J) AND L(I,J), I=J+1,...
DO 70 J=1,N
SUM = LU(I,J)
IF (IDOT .EQ. 0) GO TO 55
WITH ACCURACY TEST
AI = DABS(SUM)
HI = ZERO
IF (JMI .LT. 1) GO TO 50
C
DC AS K=1, JM1
  I = LU(I,K)*LU(K,J)
  SUM = SUM+I
  WI = WI+DABS(T)
45 CONTINUE
  LU(I,J) = SUM
  WI = WI+DABS(SUM)
  IF (AI .EQ. ZERO) AI = DIGA
  TEST = WI/AI
  IF (TEST .GT. WREL) WREL = TEST
  GO TO 65
C 55 IF (JM .LT. 1) GO TO 65
  DO 60 K=1, JM1
  SUM = SUM-LU(I,K)*LU(K,J)
60 CONTINUE
  LU(I,J) = SUM
  Q = EQUIL(I)*DABS(SUM)
  P = Q
  IMAX = I
70 CONTINUE
C 75 IF (RH+P .EQ. RH) GO TO 110
  IF (J .EQ. IMAX) GO TO 90
  D1 = -P
  DO 75 K=1, N
    P = LU(IMAX,K)
    LU(IMAX,K) = LU(J,K)
    LU(J,K) = P
75 CONTINUE
C 85 EQUIL(IMAX) = EQUIL(J)
  IPV(J) = IMAX
  D1 = D1*LU(J,J)
  D2 = D2*FOUR
  DO TO 95
  90 IF (DABS(D1) .EQ. ONE) GO TO 95
   D1 = D1*SIXTH
   D2 = D2*FOUR
   GO TO 90
95 CONTINUE
C 90 IF (JPI .GT. N) GO TO 105
C 95 IF (JPI .EQ. J) GO TO 110
  P = LU(J,J)
  DO 100 I=JPI, N
    LU(I,J) = LU(I,J)/P
100 CONTINUE
C 100 CONTINUE
C 105 CONTINUE
C 105 IF (IDOT .EQ. 0) GO TO 9005
  P = 3*N+3
  WA = P*WREL
  IF (WA+10.0EQ0.0) WA = GO TO 9005
  IER = 34
  GO TO 9000
C 239
110 IER = 12y
               D1 = ZERO
               D2 = ZERO
               9000 CONTINUE
               PRINT ERRJR
               CALL UERTST(IER,6HLUDATF)
               9905 RETURN
               END
               CALL UERTST(IER,6HLUDATF)
               SUBROUTINE LUELIX(A,A,I,N,B.,APVT,X)
               DIMENSION A(I,I),B(I),APVT(I),X(I)
               DOUBLE PRECISION A,B,X,SUM,APVT
               FIRST EXECUTABLE STATEMENT
               SOLVE LY = B FOR Y
               DO 5 I=1,N
               5 X(I) = B(I)
               IH = 0
               DO 20 I=1,N
               IP = APVT(I)
               SUM = X(IP)
               X(IP) = X(I)
               IF (IH .EQ. 0) GO TO 15
               IM1 = I-1
               DO 10 J=IH.IM1
               SUM = SUM-A(I,J)*X(J)
               10 CONTINUE
               GO TO 20
               15 IF (SUM .NE. 0.D0) IH = I
               DO 30 IP1=1,N
               I = N+1-IP1
               IP1 = I+1
               SUM = X(I)
               IF (IP1 .GT. N) GO TO 30
               DO 25 J=IP1,N
               SUM = SUM-A(I,J)*X(J)
               25 CONTINUE
               30 X(I) = SUM/A(I,I)
               RETURN
               END
               SUBROUTINE LURENF(A,A,I,N,U,L,IUL,B.,IDOT,APVT,X,RES,DX,IER)
               DIMENSION A(I,I),UL(IUL,1),B(I),X(I),RES(I),DX(I)
               DIMENSION APVT(I)
               DIMENSION ACCXT(2)
               DOUBLE PRECISION A,ACCXT,B,UL,X,RES,DX,ZERO,XNORM,DXNORM,APVT
               DATA ITMAX/75/, ZERO/0.D0/
               FIRST EXECUTABLE STATEMENT
               IER=0
               XNORM = ZERO
               DO 10 I=1,N
               XNORM = DMAX1(XNORM,DABS(X(I)))
               10 CONTINUE
               IF (XNORM .NE. ZERO) GO TO 20
               IDOT = 5
GO TO 9005

20 DO 45 IER=1,ITMAX
  DO 30 I=1,N
  ACCX(1) = 0.0DD
  ACCX(2) = 0.0DD
  CALL VXADD(B(I),ACCX)
  DO 25 J=1,N
    CALL VXML(-A(I,J),X(J),ACCX)
  25 CONTINUE
  CALL VXSTO(ACCX,RES(I))
30 CONTINUE
  CALL LUELMN(UL,UL,N,LU,AP,T,DX)
  DXNORM = ZERO
  XNORM = ZERO
  DO 35 I=1,N
    X(I) = X(I) + DX(I)
    DXNORM = DMAX1(DXNORM,DABS(DX(I)))
  XNORM = DMAX1(XNORM,DABS(X(I)))
  35 CONTINUE
  IF (ITER .NE. 1) GO TO 40
  IDT = 50
  IF (DXNORM .NE. ZERO) IDT = DLOG10(DXNORM/XNORM)
40 IF (XNORM+DXNORM .EQ. XNORM) GO TO 9005
45 CONTINUE
ITERATION DID NOT CONVERGE
IER = 129
9000 CONTINUE
CALL UERTST(IER,6HLMFEN)
9005 RETURN
END

C SUBROUTINE UERTST (IER,NAM)

C SPECIFICATIONS FOR ARGUMENTS
INTEGER IER
INTEGER NAME(1)

C SPECIFICATIONS FOR LOCAL VARIABLES
INTEGER I,EQ,EOF,IOUNIT,LEVEL,LEVOLD,NAMETH,INT/
NAMEQ/6)P1,0.0
DATA NAMEQ/6)P1H
DATA LEVEL/4/mIEQDF/0,.IEQ/1Naol
C UNPACK NAME INTO NAMUPK
C FIRST EXECUTABLE STATEMENT
CALL USPKD(NAME,6,NAMUPK,NMTB)
C GET OUTPUT UNIT NUMBER
CALL UGETIO1(NAMUPK,NMTB)
C CHECK IER
IF (IER.GT.999) GO TO 25
IF (IER.LT.-32) GO TO 55
IF (IER.EQ.128) GO TO 5
IF (LEVEL.LT.1) GO TO 30
C PRINT TERMINAL MESSAGE
IF (EOF.EQ.1) WRITE(IONUNIT,35) IER,NAM,EOQ,EQ,NAMUPK
IF (EOQ.EQ.0) WRITE(IONUNIT,35) IER,NAMUPK
GO TO 30
5 IF (IER.LE.64) GO TO 10
C PRINT WARNING WITH FIX MESSAGE
C
IF (IEQDF.EQ.1) WRITE(IOUNIT,40) IER,NAMEQ,IEQ,NAMUPK
IF (IEQDF.EQ.4) WRITE(IOUNIT,40) IER,NAMUPK
GO TO 20
10 IF (IER.LT.32) GO TO 15
   PRINT WARNING MESSAGE
15 CONTINUE
GO TO 10
10 IF (IEQDP.EQ.1) WRITE(IOUNIT,40) IER,NAMEQ,IEQ,NAMUPK
GO TO 20
IF (IEQDF.EQ.0) WRITE(IOUNIT,50) IER,NAMUPK
20 CONTINUE
GO TO 10
30 IF (IEQDF.EQ.0) WRITE(IOUNIT,50) IER,NAMUPK
RETURN
C CHECK FOR UERSET CALL
C LEVEL = LEVEL
C IER = IER
C (LEVEL.LT.0) LEVEL = 4
C (LEVEL.GT.4) LEVEL = 4
C CONTINUE
25 IF (LEVEL.GT.4) GO TO 30
C PRINT NON-DEFINED MESSAGE
IF (IEQDF.EQ.1) WRITE(IOUNIT,30) IER,NAMEQ,IEQ,NAMUPK
IF (IEQDF.EQ.0) WRITE(IOUNIT,30) IER,NAMUPK
RETURN
55 IF (IERT.EQ.1) WRITE(IOUNIT,10) IER,7H1X = ,I3,
1 20H FROM IMSL ROUTINE ,6A1,A1,6A1)
20H FORMAT(1H XXX TERMINAL ERROR,10X,7H1X = ,I3,
1 20H FROM IMSL ROUTINE ,6A1,A1,6A1)
C FIRST EXECUTABLE STATEMENT
C SPECIFICATIONS FOR ARGUMENTS
C SPECIFICATIONS FOR LOCAL VARIABLES
C FIRST EXECUTABLE STATEMENT
C SUBROUTINE UGETIO(IOPT,NIN,NOUT)
SUBROUTINE UGETIO(IOPT,NIN,NOUT)
C SPECIFICATIONS FOR ARGUMENTS
INTEGRAL IOPT,NIN,NOUT
INTEGRAL NIND,NOUTD
DATA NIND,NOUTD/6/
C FIRST EXECUTABLE STATEMENT
IF (IOPT.EQ.5) GO TO 10
IF (IOPT.EQ.2) GO TO 5
IF (IOPT.NE.1) GO TO 9005
NIND = NIND + 1
NOUTD = NOUTD + 1
GO TO 9005
55 IERT = 1
DO 60 I=1,6
55 RETURN
C P IS THE PAGE NAMEQ
C R IS THE ROUTINE NAMUPK
60 NAMEQ(I) = NAMUPK(I)
65 RETURN
END
SUBROUTINE VXADD(A,ACC)

DOUBLE PRECISION A,ACC(2)
DOUBLE PRECISION X,Y,Z,ZZ

X = ACC(1)
Y = A
IF (DABS(ACC(1)).GE.DABS(A)) GO TO 1
X = A
Y = ACC(1)

Z = X+Y
ZZ = (X-Z)+Y

ZZ = ZZ+ACC(2)
ACC(1) = Z+ZZ
ACC(2) = (Z-ACC(1))+ZZ
RETURN

SUBROUTINE VXADD(A,ACC)

DOUBLE PRECISION A,ACC(2)
DOUBLE PRECISION X,Y,Z,ZZ

X = ACC(1)
Y = A
IF (DABS(ACC(1)).GE.DABS(A)) GO TO 1
X = A
Y = ACC(1)

Z = X+Y
ZZ = (X-Z)+Y

ZZ = ZZ+ACC(2)
ACC(1) = Z+ZZ
ACC(2) = (Z-ACC(1))+ZZ
RETURN

SUBROUTINE VXADD(A,ACC)

DOUBLE PRECISION A,ACC(2)
DOUBLE PRECISION X,Y,Z,ZZ

X = ACC(1)
Y = A
IF (DABS(ACC(1)).GE.DABS(A)) GO TO 1
X = A
Y = ACC(1)

Z = X+Y
ZZ = (X-Z)+Y

ZZ = ZZ+ACC(2)
ACC(1) = Z+ZZ
ACC(2) = (Z-ACC(1))+ZZ
RETURN

SUBROUTINE VXADD(A,ACC)

DOUBLE PRECISION A,ACC(2)
DOUBLE PRECISION X,Y,Z,ZZ

X = ACC(1)
Y = A
IF (DABS(ACC(1)).GE.DABS(A)) GO TO 1
X = A
Y = ACC(1)

Z = X+Y
ZZ = (X-Z)+Y

ZZ = ZZ+ACC(2)
ACC(1) = Z+ZZ
ACC(2) = (Z-ACC(1))+ZZ
RETURN
SUBROUTINE VXSTO (ACC,D)

DOUBLE PRECISION ACC(2),D

SPECIFICATIONS FOR ARGUMENTS
FIRST EXECUTABLE STATEMENT
RETURN END

SUBROUTINE ZRPOLY (A,NDEG,Z,IER)

INTEGER NDEG,IER

INTEGER NNN,JJ,J,NNM,ICM,HI,MZ,HPF

REAL ETA,HRM,RFNFP,RPSP,RIAX,RIO,XX,YY,SNR,

COSR,RTMAX,MRN,X,SC,XM,FF,DF,BND,XX,ARE

REAL P(T1),P(101),QP(101),RP(101),KQ(101).

REAL SVK(101)

DOUBLE PRECISION A(101).

DOUBLE PRECISION T.AA,5B5CCFACTDRREPSR1I.ERO.OHEDFN

LOGICAL ZEROK

COMMON /ZRPQLJ/

THE FOLLOWING STATEMENTS SET MACHINE

CONSTANTS USED IN VARIOUS PARTS OF

THE PROGRAM. THE MEANING OF THE

FOUR CONSTANTS ARE - REPSP1 THE

MAXIMUM RELATIVE REPRESENTATION

ERROR WHICH CAN BE DESCRIBED AS

THE SMALLEST POSITIVE FLOATING

POINT NUMBER SUCH THAT 1.+REPSP1 IS000.3580

LARGER THAN 1.

RINFP THE LARGEST FLOATING-POINT

NUMBER

REPS THE SMALLEST POSITIVE

FLOATING-POINT NUMBER IF THE

EXPONENT RANGE DIFFERS IN SINGLE

AND DOUBLE PRECISION THEN REPSP

AND RINFP SHOULD INDICATE THE

SMALLER RANGE
DATA RINFP/Z7FFFFFFF/
DATA REPSR/Z00100000/
DATA RE/P/1/2/0041000000000000/
DATA ZET0/0.0000000000000000/

ZRPOLY USES SINGLE PRECISION CALCULATIONS FOR SCALING, BOUNDS AND ERROR CALCULATIONS.

FIRST EXECUTABLE STATEMENT

IERR = 0
IF (NDEO .LT. 100 .OR. NDFO .LT. 1) GO TO 165
ETR = REPSR
ARE = ETA
RMRE = ETA
RLO = REPSR/ETA

INITIALIZATION OF CONSTANTS FOR SHIFT ROTATION

YY = .7071068
YY = -.7071068
SINR = .9975641
COSR = -.0075647
N = NDEO
NN = N+1

ALGORITHM FAILS IF THE LEADING COEFFICIENT IS ZERO.

IF (A(1).NE.ZERO) GO TO 5
IERR = 130
GO TO 9000

REMOVE THE ZEROS AT THE ORIGIN IF ANY

5 IF (A(NH).NE.ZERO) GO TO 10
J = NDEO-N+1
JJ = J+NDEO
Z(J) = ZERO
Z(JJ) = ZERO
NN = NN-1
N = N-1
IF (IN.EQ.1) GO TO 9005
GO TO 5

MAKE A COPY OF THE COEFFICIENTS

10 DO 15 I=1,NN
P(I) = A(I)
15 CONTINUE

START THE ALGORITHM FOR ONE ZERO

C 20 IF (N.GT.2) GO TO 30
IF (N.LT.1) GO TO 9005

CALCULATE THE FINAL ZERO OR PAIR OF ZEROS

20 IF (N.EQ.2) GO TO 25
Z(NDEO) = -P(2)/P(1)
Z(NDEO+NDEO) = ZERO
GO TO 145
25 CALL ZRPOLI (P(1),P(2),P(3),Z(NDEO-1),Z(NDEO),Z(NDEO+NDEO-1),Z(NDEO),Z(NDEO+NDEO))
GO TO 145

FIND LARGEST AND SMALLEST MODULI OF COEFFICIENTS.

30 RMAX = 0.

245
RMIN = RINFP
DO 35 I=1,NN
X = ABS(SNOL(P(I)))
IF (X.GT.RMAX .AND. X.RMIN) RMIN = X
35 CONTINUE

SCALE IF THERE ARE LARGE OR VERY SMALL COEFFICIENTS Computes A SCALE FACTOR TO MULTIPLY THE COEFFICIENTS OF THE POLYNOMIAL. THE SCALING IS DONE TO AVOID OVERFLOW AND TO AVOID UNDETECTED UNDERFLOW INTERFERING WITH THE CONVERGENCE CRITERION.

THE FACTOR IS A POWER OF THE BASE

SC = RL3/RMIN
IF (SC.GT.1.0) GO TO 40
IF (RMAX.LT.10.) GO TO 55
IF (SC.EQ.0.) SC = 1
GO TO 65
40 IF (RINFP/SC.LT.RMAX) GO TO 55
45 L = ALOG(SC)/ALOGRADIX+3
IF (L.EQ.0.) GO TO 55
FACTOR = DBLE(RADIX)**L
DO 50 I=1,NN
50 P(I) = FACTOR*P(I)

COMPUTE LOWER BOUND ON MODULI OF ZEROS.

DO 60 I=1,NN
60 PT(I) = ABS(SNOL(P(I)))
PT(NN) = -PT(NN)

COMPUTE UPPER ESTIMATE OF BOUND

X = EXP((ALOG(-PT(NN))-ALOGRADIX)/L)
IF (PT(N).EQ.0.) GO TO 65

IF NEWTON STEP AT THE ORIGIN IS BETTER, USE IT.

XM = -PT(NN)/PT(1)
IF (XM.LT.X) X = XM

CHOP THE INTERVAL (0,X) UNTIL FF.LE.0.005

DO 85 I=2,NN
70 FF = FF*X+PT(I)
IF (FF.LT.0.0) GO TO 75
X = XM
75 DX = X
85 CONTINUE

DO NEWTON ITERATION UNTIL X CONVERGES TO TWO DECIMAL PLACES
90 BND = X

COMPUTE THE DERIVATIVE AS THE INITIAL K POLYNOMIAL AND DO 3 STEPS WITH NO SHIFT

99 N1 = N-1
FN = ONE/N
DO 95 I=2,N
95 RK(I) = (NN-I)*P(N)*FN
RK(I) = P(I)
AA = P(NH)
BB = P(N)
ZEORK = RK(N).EQ.ZERO
DO 115 J=1,NM
CC = P(N)
IF(ZEORK) GO TO 105
    T = -AA/CC
    DO 100 I=1,NM
    RK(J) = T*RK(J-1)+P(J)
100 CONTINUE
    RK(J) = P(J)
    ZEORK = DABS(RK(N)).LE.DABS(BB)*METAK10.
    GO TO 113

USE SCALED FORM OF RECURRENCE IF VALUE OF K AT 0 IS NONZERO

105 DO 110 I=1,NM
    J = NN-I
    RK(J) = RK(J-1)
110 CONTINUE
    RK(J) = ZERO
    ZEORK = RK(N).EQ.ZERO
    GO TO 113

USE UNSCALED FORM OF RECURRENCE

113 CONTINUE

SAVE X FOR RESTARTS WITH NEW SHIFTS

DO 120 I=1,N
120 TEMP(I) = RK(I)

LOOK TO SELECT THE QUADRATIC CORRESPONDING TO EACH NEW SHIFT

QUADRATIC CORRESPONDS TO A DOUBLE SHIFT TO A NON-REAL POINT AND ITS COMPLEX CONJUGATE. THE POINT HAS MODULUS BND AND AMPLITUDE ROTATED BY 90 DEGREES FROM THE PREVIOUS SHIFT

XX = COSRXX-SINRYY
YY = SINRXX+COSRYY
XX = XX
SR = BND*XX
SI = BND*YY
U = -SR-SR
V = BND*BND

SECOND STAGE CALCULATION. FIXED QUADRATIC

CALL ZRPOLB(ZB*ICHT,NZ)
IF(NZ.EQ.0) GO TO 130

SECOND STAGE JUMPS DIRECTLY TO ONE OF THE THIRD STAGE ITERATIONS AND RETURNS HERE IF SUCCESSFUL DEFLATE THE POLYNOMIAL, STORE THE
ZERO OR ZEROS AND RETURN TO THE MAIN ALGORITHM.

IF THE ITERATION IS UNSUCCESSFUL

ANOTHER QUADRATIC IS CHOSEN AFTER RESTORING K

RETURN WITH FAILURE IF NO CONVERGENCE WITH 20 SHIFTS

CONVERT ZEROS (Z) IN COMPLEX FORM

SET UNFOUNDO ROOTS TO MACHINE INFINITY

SUBROUTINE ZRPQLB (L2,NZ)

INTEGER L2,NZ

SPECIFICATIONS FOR LOCAL VARIABLES

INTEGER N,NN,J,ITYPE,I,IFLAG

REAL ARE,BETAS,BETAV,ETA,OSS,OTS,OTV,OVV,RMRF,SS,
TS,TSS,TV,TVV,VV

C SPECIFICATIONS FOR ARGUMENTS

SUBROUTINE ZRPQL8 (LZ,NZ)

INTEGER LZ,NZ

C SPECIFICATIONS FOR LOCAL VARIABLES

INTEGER N,NN,J,ITYPE,I,IFLAG

REAL ARE,BETAS,BETAV,ETA,OSS,OTS,OTV,OVV,RMRF,SS,
TS,TSS,TV,TVV,VV

END
DOUBLE PRECISION P(101), QP(101), PK(101), QK(101), SVK(101)
DOUBLE PRECISION SR, SI, U, V, RA, R2, C, D, A1, A2, A3,
                   A6, A7, E, F, O, H, SIZ, SLR, RLZ, RLZI,
                   SVVR, SVV, UI, VI, S, ZERO
LOGICAL VPS, SPASS, VTRY, STRY
COMMON /ZRPQLJS/ P, QP, RK, QK, SVK, SR, SI, U, V, RA, RB, C, D, A1, A2, A3,
                   A6, A7, E, F, O, H, SIZ, SLR, RLZ, RLZI, ETA, ARE, MRE, H, NN
DATA ZERO/0.000000000000000/ COMMON ZRPQLJS

FIRST EXECUTABLE STATEMENT
 NZ = 0

COMPUTES UP TO L2 FIXED SHIFT K-POLYNOMIALS, TESTING FOR
 K-POLYNOMIALS, TESTING FOR CONVERGENCE IN THE LINEAR OR
 CONVERGENCE IN THE LINEAR OR QUADRATIC CASE. INITIATES ONE OF
 QUADRATIC CASE. INITIATES ONE OF THE VARIABLE SHIFT ITERATIONS AND
 THE VARIABLE SHIFT ITERATIONS AND RETURNS WITH THE NUMBER OF ZEROS
 RETURNS WITH THE NUMBER OF ZEROS FOUND.
 FOUND.

L2 - LIMIT OF FIXED SHIFT STEPS
NZ - NUMBER OF ZEROS FOUND

BETAV = .25
BETAS = .25
OVV = V

EVALUATE POLYNOMIAL BY SYNTHETIC DIVISION

CALL ZRPQH(NN, U, V, P, QP, RA, RB)
CALL ZRPQLE (ITYPE)
DO 40 J=1, L2

CALL ZRPQH (NN, U, V, P, QP, RA, RB)
CALL ZRPQLE (ITYPE)
CALL ZRPQLO (ITYPE, UI, VI)

DO 35 VV = VI

DO 40 J=1, L2

CALL ZRPQH (NN, U, V, P, QP, RA, RB)
CALL ZRPQLE (ITYPE)
CALL ZRPQLO (ITYPE, UI, VI)

ESTIMATE S

SS = 0.
IF (RK(N).NE.ZERO) SS = -P(NN)/RK(N)
TV = 1.
TS = 1.

IF (V.VV.NE.0.) TV = ABS((VV-OV)/VV)
IF (SS.NE.0.) TS = ABS((SS-US)/SS)

IF DECREASING, MULTIPLY TWO MOST RECENT CONVERGENCE MEASURES

TVV = 1.

IF (TV.LT.TOV) TVV = TV/TOV

IF (TS.LT.TOS) TSS = TS/TSOS

IF (.NOT.(SPASS.OR.VPASS)) GO TO 35

IF (.NOT.(SPASS.OR.VPASS)) GO TO 35

A JOINT ONE SEQUENCE HAS PASSED THE CONVERGENCE TEST. STORE VARIABLES
A JOINT ONE SEQUENCE HAS PASSED THE CONVERGENCE TEST. STORE VARIABLES

BEFORE ITERATING

BEFORE ITERATING

SVU = U
SVV = V
DO 5 I=1, N

249
5 \textit{SVK}(I) = \textit{RK}(I) \quad \textit{S} = 55

\textbf{C} \quad \textbf{CHOOSE ITERATION ACCORDING TO THE FASTEST CONVERGING SEQUENCE}

\textbf{C} \quad \textbf{VTRY} = \textbf{.FALSE.}

\textbf{C} \quad \textbf{stry} = \textbf{.FALSE.}

\textbf{C} \quad \textbf{IF} (\textbf{SPASS}.\textbf{AND}.(\textbf{.NOT.}.\textbf{VPASS}).\textbf{OR}.\textbf{TSS}.\textbf{LT}.\textbf{TVV})) \textbf{GO} \textbf{TO} \textbf{20}

\textbf{C} \quad \textbf{IF} (\textbf{NZ}.\textbf{GT}.0) \textbf{RETURN}

\textbf{C} \quad \textbf{QUADRATIC ITERATION HAS FAILED. FLAG THAT IT HAS BEEN TRIED AND DECREASE THE CONVERGENCE CRITERION.}

\textbf{C} \quad \textbf{VTRY} = \textbf{.TRUE.}

\textbf{C} \quad \textbf{BETAV} = \textbf{BETAV}.25

\textbf{C} \quad \textbf{TRY LINEAR ITERATION IF IT HAS NOT BEEN TRIED AND THE S SEQUENCE IS CONVERGING}

\textbf{C} \quad \textbf{IF} (\textbf{STRY}.\textbf{OR}(\textbf{.NOT.}.\textbf{SPASS})) \textbf{GO} \textbf{TO} \textbf{25}

\textbf{C} \quad \textbf{DO} 15 \textbf{I}=1,\textbf{N}

\textbf{C} \quad \textbf{RK}(\textbf{I}) = \textbf{SVK}(\textbf{I})

\textbf{C} \quad \textbf{RETURN}

\textbf{C} \quad \textbf{LINEAR ITERATION HAS FAILED. FLAG THAT IT HAS BEEN TRIED AND DECREASE THE CONVERGENCE CRITERION}

\textbf{C} \quad \textbf{STRY} = \textbf{.TRUE.}

\textbf{C} \quad \textbf{BETAS} = \textbf{BETAS}.25

\textbf{C} \quad \textbf{IF} (\textbf{IFLAG}.\textbf{EQ}.0) \textbf{GO} \textbf{TO} \textbf{25}

\textbf{C} \quad \textbf{UI} = -(\textbf{S}+3)

\textbf{C} \quad \textbf{VI} = \textbf{S}3\textbf{S}

\textbf{C} \quad \textbf{GO} \textbf{TO} \textbf{10}

\textbf{C} \quad \textbf{RESTORE VARIABLES}

\textbf{C} \quad \textbf{U} = \textbf{SVU}

\textbf{C} \quad \textbf{V} = \textbf{SVV}

\textbf{C} \quad \textbf{DO} 50 \textbf{I}=1,\textbf{N}

\textbf{C} \quad \textbf{RK}(\textbf{I}) = \textbf{SVK}(\textbf{I})

\textbf{C} \quad \textbf{RETURN}

\textbf{C} \quad \textbf{TRY QUADRATIC ITERATION IF IT HAS NOT BEEN TRIED AND THE V SEQUENCE IS CONVERGING}

\textbf{C} \quad \textbf{IF} (\textbf{VPASS}.\textbf{AND}(\textbf{.NOT.}.\textbf{VTRY})) \textbf{GO} \textbf{TO} \textbf{10}

\textbf{C} \quad \textbf{RECOMPUTE QP AND SCALAR VALUES TO CONTINUE THE SECOND STAGE}

\textbf{C} \quad \textbf{CALL ZRPQLH (NN,\textbf{U},\textbf{V},\textbf{P},\textbf{QP},\textbf{RA},\textbf{RB})}

\textbf{C} \quad \textbf{CALL ZRPQLC (ITYPE)}

\textbf{C} \quad \textbf{OQV} = \textbf{VV}

\textbf{C} \quad \textbf{OSS} = \textbf{SS}

\textbf{C} \quad \textbf{OUT} = \textbf{TV}

\textbf{C} \quad \textbf{OTS} = \textbf{T}3

\textbf{C} \quad \textbf{CONTINUE}

\textbf{C} \quad \textbf{RETURN}

\textbf{C} \quad \textbf{END}

\textbf{C} \quad \textbf{SUBROUTINE ZRPQLC (UU,\textbf{VV},\textbf{NZ})}

\textbf{C} \quad \textbf{SPECIFICATIONS FOR ARGUMENTS}
INTEGER NZ
DOUBLE PRECISION UU,VV

INTEGER N,NJ,ITYPE
REAL ARE,EE,ETA,DMP,RELSTP,RMP,RRME,T,ZM
DOUBLE PRECISION SR,SU,UD,UR,RA,RA,RB,SD,SA,A2,A3.
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LOGICAL /2RPLJ/

COMMON /ZRPIQL/ 
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TO THE CLUSTER

IF (RELSTP .LT. ETA) RELSTP = ETA
RELSTP = SQRT(RELSTP)
U = U - U'RELSTP
V = V - V'RELSTP
CALL ZRPQLH (NN, U, V, P, QP, RA, RB)
DO 20 I = 1, 5
   CALL ZRPQLE (ITYPE)
   CALL ZRPQLF (ITYPE)
20 CONTINUE
TRIED = .TRUE.
J = 0
25 CMP = RMP
   CALL ZRPQLE (ITYPE)
   CALL ZRPQLF (ITYPE)
   CALL ZRPQLO (ITYPE, UI, VI)
IF (VI .EQ. ZERO) RETURN
RELSTP = DABS(VI - VI) / V
U = U - U'RELSTP
V = V - V'RELSTP
GO TO 5
END

SUBROUTINE ZRPQLD (SSS, NZ, IFLA0)

REAL ARE, ETA, OMP, RMS, RMRE
DOUBLE PRECISION P(101), QP(101), RK(101), SVK(101)

COMMON /ZRPQLJ/ P, QP, RK, Q, SVK, ETA, ARE, RMRE, NN

DATA ZERO/0.0D0/, PTO01/0.0D0/  

VARIABLE-SHIFT H POLYNOMIAL
ITERATION FOR A REAL ZERO SSS -
STARTING ITERATE
NZ - NUMBER OF ZERO FOUND
IFLAG - FLAG TO INDICATE A PAIR OF
ZEROS NEAR REAL AXIS
FIRST EXECUTABLE STATEMENT

NZ = 0
S = SSS
IFLA0 = 0
J = 0

5 PV = P(1)

DO 10 I = P, NN

DO 10 I = P, NN
PV = PVWS+P(I)
QP(I) = PV
10 CONTINUE
RMP = DABS(PV)

COMPUTE A RIGOROUS BOUND ON THE
ERROR IN EVALUATING P

RMS = DABS(S)
EE = (RMRE/(ARE+RMRE))ABS(SNOLQ(P(I)))
DO 15 I=2,NH
15 EE = EE*RMS*ABS(SNOLQ(P(I)))

ITERATION HAS CONVERGED SUFFICIENTLY
IF THE POLYNOMIAL VALUE IS LESS
THAN 20 TIMES THIS BOUND

IF (RMP.GT.20.*((ARE+RMRE)*EE-RMRE*RMP)) GO TO 20
NZ = 1
SZR = S
SZI = ZERO
20 J = J+1
STOP ITERATION AFTER 10 STEPS
RETURN IF THE POLYNOMIAL VALUE HAS
INCREASED SIGNIFICANTLY

IF (J.LT.2) GO TO 25
IF (DABS(I).GT.PT01*DBS(S-T).OR.RMP.LE.OMP) GO TO 25
A CLUSTER OF ZEROS NEAR THE REAL
AXIS HAS BEEN ENCOUNTERED RETURN
WITH IFLAG SET TO INITIATE A
QUADRATIC ITERATION
IFLAG = 1
SSS = S
RETURN

RETURN IF THE POLYNOMIAL VALUE HAS
INCREASED SIGNIFICANTLY

COMPUTE Y, THE NEXT POLYNOMIAL, AND
THE NEW ITERATE

RKV = RK(1)
QK(I) = RKV
DO 30 I=2,N
RKV = RKV*WS+R(KI)
QK(I) = RKV
30 CONTINUE
IF (DABS(RKV).LE.DABS(RK(N))*.10.*ETA) GO TO 40
USE THE SCALED FORM OF THE
RECURSION IF THE VALUE OF K AT S
IS NONZERO

T = -PV/RKV
RK(I) = OP(I)
DO 35 I=2,N
35 RK(I) = TMGK(I-1)+QP(I)
GO TO 40

USE UNSCALED FORM

40 RK(I) = ZERO
DO 45 I=2,N
45 RK(I) = QK(I-1)
DO 55 I=2,N
55 RKV = RKV*WS+RK(I)
T = ZERO
IF (DABS(RKV).GT.DABS(RK(N))*.10.*ETA) T = -PV/RKV
S = S+T
IMSL ROUTINE NAME  -  ZRPQLE

COMPUTER  -  IBM/DOUBLE
LATEST REVISION  -  JANUARY 1, 1978

SUBROUTINE ZRPQLE (ITYPE)

INTEGER

REAL

DOUBLE PRECISION

COMMON /ZRPQLE/

THIS ROUTINE CALCULATES SCALAR QUANTITIES USED TO COMPUTE THE NEXT K POLYNOMIAL AND ESTIMATES OF THE QUADRATIC COEFFICIENTS.

ITYPE  -  INTEGER VARIABLE SET HERE INDICATING HOW THE CALCULATIONS ARE NORMALIZED TO AVOID OVERFLOW.

FIRST EXECUTABLE STATEMENT

CALL ZRPQLEH (N,U,V,RK,C,D)

IF (DABS(C).GT.DABS(RK(N-1))x100.ETA) GO TO 5

IF (DABS(D).GT.DABS(RK(N-1))x100.ETA) GO TO 5

ITYPE  =  3

TYPE 3 INDICATES THE QUADRATIC IS ALMOST A FACTOR OF K.

RETURN

5 IF (DABS(D).LT.DABS(C)) GO TO 10

ITYPE  =  2

TYPE 2 INDICATES THAT ALL FORMULAS ARE DIVIDED BY D.

RETURN

10 ITYPE  =  1

TYPE 1 INDICATES THAT ALL FORMULAS ARE DIVIDED BY C.

END
SUBROUTINE ZRPQLF (ITYPE)

SPECIFICATIONS FOR ARGUMENTS

INTEGER ITYPE

SPECIFICATIONS FOR LOCAL VARIABLES

INTEGER N, NN, I

REAL ARE, ETA, RMR

DOUBLE PRECISION P(101), QP(101), RK(101), QK(101), SVK(101)


DATA ZERO /0.0D0/

COMPUTES THE NEXT K POLYNOMIALS USING SCALARS COMPUTED IN ZRPQL

FIRST EXECUTABLE STATEMENT

IF (ITYPE.EQ.3) GO TO 20

TEMP = RA

IF (ITYPE.EQ.1) TEMP = RB

IF (DABS(A1).GT.DABS(TEMP)*META10.) GO TO 10

IF A1 IS NEARLY ZERO THEN USE A SPECIAL FORM OF THE RECURRENCe

RK(I) = ZERO

RK(2) = -A7*QP(1)

DO 5 I = 3, N

5 RK(I) = A3*QP(I-2)-A7*QP(I-1)

RETURN

USE SCALED FORM OF THE RECURRENCe

10 A7 = A7/A1

A3 = A3/A1

RK(1) = QP(1)

RK(2) = QP(2)-A7*QP(1)

DO 15 I = 3, N

15 RK(I) = A3*QP(I-2)-A7*QP(I-1)+QP(I)

RETURN

USE UNSCALED FORM OF THE RECURRENCe

IF TYPE IS 3

20 RK(1) = ZERO

RK(2) = ZERO

DO 25 I = 3, N

25 RK(I) = QP(I-2)

RETURN

IMSL ROUTINE NAME - ZRPQLG

COMPUTER - IBM DOUBLE

H = VHRB
A5 = RAXE+(H/C4)XRB
A1 = RB-RAX(D/C)
A7 = RA+GMD+HKF
RETURN

END
SUBROUTINE ZRPQLO (ITYPE, U, V)

SPECIFICATIONS FOR ARGUMENTS

INTEGER ITYPE
DOUBLE PRECISION U, V

SPECIFICATIONS FOR LOCAL VARIABLES

INTEGER N, NN
REAL ARE, ETA, RMRE
DOUBLE PRECISION P(I), Q(I), RK(101), QK(I), SV(101)

COMMON /ZRPQLJ/

DATA ZEROID.0/0

COMPUTE ESTIMATES OF THE QUADRATIC COEFFICIENTS USING THE SCALARS COMPUTED IN ZRPQLE

USE FORMULAS APPROPRIATE TO SETTING OF TYPE

FIRST EXECUTABLE STATEMENT

IF (ITYPE.EQ.3) GO TO 15
IF (ITYPE.EQ.2) GO TO 5

4 $A_5 = \frac{R \times (U + V)}{H \times (U + V)}$

5 $A_3 = \frac{R \times (U + V)}{H \times (U + V)}$

EVALUATE NEW QUADRATIC COEFFICIENTS.

10 $B_1 = -\frac{R \times (U + V)}{H \times (U + V)}$

15 $U = 0$

RETURN

END

SUBROUTINE ZRPQLN (N, U, V, P, Q, RA, RB)

SPECIFICATIONS FOR ARGUMENTS

INTEGER N
DOUBLE PRECISION P(N), Q(N), U, V, RA, RB

SPECIFICATIONS FOR LOCAL VARIABLES

INTEGER I
DOUBLE PRECISION C

DIVIDES P BY THE QUADRATIC 1.U.V, PLACING THE QUOTIENT IN Q AND THE REMAINDER IN A,B
SUBROUTINE ZRPQLI (RA,B1,C,SR,SI,RLR,RLI)

DOUBLE PRECISION RA,B1,C,SR,SI,RLR,RLI

DOUBLE PRECISION R8,D,E,ZERO,ONE,TWO

DATA ZERO,ONE,TWO / 0.0, 1.0, 2.0/

CALCULATE THE ZEROS OF THE QUADRATIC

AMKX**2 + BIX + C. THE QUADRATIC

FORMULA, MODIFIED TO AVOID

OVERFLOW, IS USED TO FIND THE

LARGER ZERO IF THE ZEROS ARE REAL

AND BOTH ZEROS ARE COMPLEX.

THE SMALLER REAL ZERO IS FOUND

DIRECTLY FROM THE PRODUCT OF THE

ZEROS C/A

FIRST EXECUTABLE STATEMENT

IF (RA.NE.ZERO) GO TO 10
SR = ZERO
IF (B1.NE.ZERO) SR = -C/B1
RLR = ZERO
SI = ZERO
RLI = ZERO
RETURN

IF (C.NE.ZERO) GO TO 15
SR = ZERO
RLR = -B1/RA
GO TO 5

IF (DABS(RB).LT.DABS(C)) GO TO 20
E = ONE-(RA/RB)**(C/RB)
D = DABS(DABS(E)/DABS(RB))
GO TO 25

E = RA
IF (C.LT.ZERO) E = -RA

OVERFLOW

5 CONTINUE
RETURN

END

IMSL ROUTINE NAME - ZRPQLI
E = RBW(DABS(C)) - E
D = DSORT(DABS(E)) * DSORT(DABS(C))
25 IF (E.LT.ZERO) GO TO 30
C REAL ZEROS
IF (RB,GE.ZERO) D = -D
RLR = (-RB+D)/RA
SR = ZERO
IF (RLR.NE.ZERO) SR = (C/RLR)/RA
GO TO 5
C COMPLEX CONJUGATE ZEROS
30 SR = -RB/RA
RLR = SR
SI = DABS(D/RA)
RLI = SI
RETURN
END

SUBROUTINE LEQ2C (A,IA,B,IB,IJOB,WA,WK,IER)

REAL ZEROS
IF (CRD.OE.ZERO)
D = -0
RLR = 2
C -RB+D)eRA
SR
ZERO
IF (RLR.NE.ZERO)
SR = (C/RLR).eRA
GO TO 5
C COMPLEX CONJUGATE ZEROS
SUBROUTINE LEQ2C (A,IA,B,IB,IJOB,WA,WK,IER)

DOUBLE PRECISION WK(N),TA(2),TB(2),TC(2)
DOUBLE PRECISION AR,AIBR,BI,CR,CI,DXNORM,XNORM,ZERO
DOUBLE PRECISION ACC(2)
DATA ZERO,O.ODO
DATA ITMAX,100

FIRST EXECUTABLE STATEMENT
IER = 0
N1 = N+1
N2 = N+2
IF (IJOB .EQ. 2) GO TO 15
SAVE MATRIX A
DO 10 I = 1,N
20 CONTINUE
10 CONTINUE
C FACTOR MATRIX A
CALL LEQT1C (WA,N,IA,B,IB,IJOB,WA,WK,IER)
IF (IER .NE. 0) GO TO 9000
C SAVE THE RIGHT HAND SIDES
15 DO 65 J = 1,M
5 CONTINUE
65 CONTINUE
C OBTAIN A SOLUTION
CALL LEQT1C(WA,N,WA(1,1),N,2,WK,IER)
XNORM = ZERO
DO 25 I = 1,N
25 CONTINUE
C COMPUTE RESIDUALS
IF (XNORM .EQ. ZERO) GO TO 65

258
DO 50  ITER = 1, ITMAX
DO 40  I = 1, N
TEMPB = B(I, J)
ACC(1) = 0.0D0
ACC(2) = 0.0D0
CALL VXADD(BR, ACC)
DO 30  JJ = 1, N
TEMPA = AC(I, JJ)
TEMPB = WA(JJ, N)
CALL VXADD(BI, ACC)
DO 25  JJ = 1, N
TEMPA = AC(I, JJ)
TEMPB = WA(JJ, N)
CALL VXADD(-AR, BI, ACC)
CALL VXADD(-BR, BI, ACC)
30  CONTINUE
CALL VXSTO(ACC, CR)
TEMP = B(I, J)
ACC(1) = 0.0D0
ACC(2) = 0.0D0
CALL VXADD(BI, ACC)
DO 20  JJ = 1, N
TEMPA = AC(I, JJ)
TEMPB = WA(JJ, N)
CALL VXADD(-AR, BI, ACC)
CALL VXADD(-BR, BI, ACC)
25  CONTINUE
CALL VXSTO(ACC, CI)
WA(I, N2) = TEMPC
DO 40  I = 1, N
WA(I, N1) = WA(I, N1) + WA(I, N2)
TEMPA = WA(I, N2)
DXNORM = DMAX1(DXNORM, DABS(AR), DABS(AI))
40  CONTINUE
IF (DXNORM * DXNORM .EQ. XNORM) GO TO 55
50  CONTINUE
IER = 130
STORE THE SOLUTION
DO 60  JK = 1, N
B(JK, J) = WA(JK, N1)
60  CONTINUE
IF (IER .NE. 0) GO TO 9000
DO TO 9000
9000 CONTINUE
CALL UERTST(IER, 6HLE92C )
9005 RETURN
END
C
C SUBROUTINE LEQTIC (A, N, IA, B, M, IB, IJOB, WA, IER)
SPECIFICATIONS FOR ARGUMENTS
INTEGER N, IA, M, IB, IJOB, IER
COMPLEX*16 A(IA, N), B(IB, M)
DOUBLE PRECISION WA(N)
SPECIFICATIONS FOR LOCAL VARIABLES
DOUBLE PRECISION P, Q, ZERO, ONE, T(2), RN, BIO
COMPLEX*16 SUM, TEMP
INTEGER I, J, IA, IM1, K, IMAX, JF1, IW, N1
EQUIVALENT (SUM,T(1))

C DATA ZERO/.0D0/,ONE/I.D0/

C TERN = 0
IF (IJOB .EQ. 2) GO TO 73
RN = N

C DO 10 I=1,N
   BIO = ZERO
   DO 5 J=1,N
      TEMP = A(I,J)
      P = CDABS(TEMP)
      IF (P .GT. BIO) BIO = P
   5 CONTINUE
   IF (BIO .EQ. ZERO) GO TO 105
   WA(1) = ONE/BIO

10 CONTINUE
C DO 70 J = 1,N
   JMI = J-1
   IF (JMI .LT. 1) GO TO 25
   COMPUTE U(I,J), I=1,...,J-1
   DO 20 I=1,JMI
      SUM = A(I,J)
      IMI = I-1
      IF (IMI .LT. 1) GO TO 20
      DO 15 K=1,IMI
         SUM = SUM-A(I,K)*A(K,J)
      15 CONTINUE
      A(I,J) = SUM
   20 CONTINUE
   P = ZERO
   DO 45 I=1,N
      SUM = A(I,J)
      IF (JMI .LT. 1) GO TO 40
      DO 35 K=1,JMI
         SUM = SUM-A(I,K)*A(K,J)
      35 CONTINUE
      A(I,J) = SUM
   45 CONTINUE
   Q = WA(1)*CDABS(SUM)
   IF (P .GE. Q) GO TO 45
   IF (P .EQ. 0) GO TO 105
   P = Q
   IMAX = I
   45 CONTINUE
C Q = RN+P
   IF (Q .EQ. RN) GO TO 105
   IF (J .EQ. IMAX) GO TO 60
   TEST FOR ALGORITHMIC SINGULARITY
   DO 50 K=1,N
      TEMP = A(IMAX,K)
      A(IMAX,K) = A(J,K)
      A(J,K) = TEMP
   50 CONTINUE
   WA(IMAX) = WA(J)
   WA(J) = IMAX
   JP1 = J+1
   IF (JP1 .GT. N) GO TO 70
   INTERCHANGE ROWS J AND IMAX
C 260
```
C

DIVIDE BY PIVOT ELEMENT U(I,J)

DO 65 I = JP1,N
   A(I,J) = A(I,J)/TEMP
   C
   CONTINUE
   C

65 IF (IJOB.EQ.1) GO TO 9005
   C
   DO 103 K = 1,N
   C
   JPI = I
   C
   IF (JPI.NE.0) GO TO 90
   C
   IMAX = WAK(I)
   C
   SUM = B(IMAX,K)
   C
   B(IMAX,K) = SUM
   C
   IF (SUM.EQ.0) GO TO 85
   C
   IM1 = I-1
   C
   DO 88 J = I,IM1
       C
       SUM = SUM-A(I,J)*B(J,K)
   C
   88 CONTINUE
   C
   IF (T(JPI).NE.ZERO .OR. T(JPI).NE.ZERO) IM = I
   C
   CONTINUE
   C
   CONTINUE
   C
   GO TO 9005
   C

SOLVE UX = Y FOR X

DO 90 I = 1,N
   IMAX = WAK(I)
   C
   SUM = B(IMAX,K)
   C
   B(IMAX,K) = SUM
   C
   IF (SUM.EQ.0) GO TO 85
   C
   IM1 = I-1
   C
   DO 88 J = I,IM1
       C
       SUM = SUM-A(I,J)*B(J,K)
   C
   88 CONTINUE
   C
   CONTINUE
   C
   CONTINUE
   C
   GO TO 9005
   C

C

SOLVE LY = B FOR Y

N1 = N+1
   C
   JPI = I-1
   C
   SUM = B(I,K)
   C
   IF (JPI.GT. N) GO TO 98
   C
   SUM = SUM-A(I,J)*B(J,K)
   C
   98 CONTINUE
   C
   CONTINUE
   C
   CONTINUE
   C
   GO TO 9005
   C

C

ALGORITHM SINGULARITY

C

IF (IER.EQ.129) PRINT ERROR

C

PRN CTY(SER,6HELTIC)

C

PRINT ERROR

END
```
SUBJECT: Correction to AFWAL Technical Reports, AFWAL-TR-86-3034 and 86-3035


2. Please contact the undersigned if you have any questions regarding this letter.

G. DOBEN
Chief, Scientific & Tech Info Gp
Information Services Branch

cc: AFWAL/FIBRA
    (V. Venkayya)

UNITED STATES AIR FORCE
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SEPTEMBER 18, 1947