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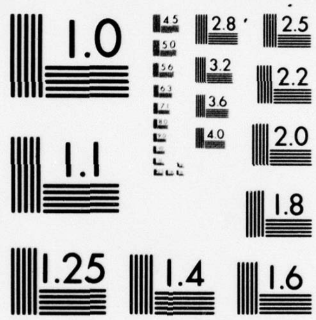

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NOVA-2S, A STIFFENED PANEL EXTENSION OF THE NOVA-2 COMPUTER PROGRAM

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William N. Lee

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Burlington, MA 01803

December 1978

Final Report

Approved for public release; distribution unlimited.

AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base, NM 87117

AFWL-TR-78-182

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This technical report has been reviewed and is approved for publication.

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A stiffened panel extension is developed into the NOVA-2S and NOVA-2LTS computer programs which replace the ~~previous~~ NOVA-2 and NOVA-2LT programs for nuclear overpressure vulnerability and analysis of aircraft. These new versions are capable of analyzing a stiffened flat or cylindrical panel in both the elastic and inelastic response regions as well as retaining the capability of analyzing stiffeners and pure panels, individually. In the stiffened panel analysis the stiffeners are treated discretely in either or

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BLOCK 20. ABSTRACT (cont'd)

both coordinate directions and are allowed various eccentric positions relative to the single-layered, multilayered and honeycomb panel skin configurations. The stiffened panel analysis is evaluated successfully by comparing the analytical solutions with experimental results from ~~three~~ 3 separate test programs that measured strains and displacement responses on stiffened panels. An evaluation of the stiffened panel analysis versus the approach of analyzing individual elements of the stiffened panel is made by comparing the two approaches on the basis of response quantities at constant range and slant ranges at constant damage level. Three stiffened panels that are very similar to those found on the B-52 aircraft ~~are used for this evaluation. It is concluded from this evaluation~~ that, in general, the individual element approach is not adequate and the stiffened panel analysis should be used for these types of stiffened panels.

A

were used and it was concluded

PREFACE

This report represents continuation of work performed by Kaman AviDyne, Burlington, Massachusetts and previously documented in AFWL TR-75-262. The current report contains a complete description of new extensions and modifications of NOVA-2. Mr. Gerald Campbell was project officer for AFWL and Mr. Lawrence J. Mente was project leader for Kaman AviDyne. This work was performed under Contract No. F29601-78-C-0019 in the Structural Mechanics Section of Kaman AviDyne headed by Mr. Emanuel S. Criscione.

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SECTION I

INTRODUCTION

The computer code NOVA-2 (Nuclear Overpressure Vulnerability Analysis, Version 2) given in reference 1 was developed to increase the level of sophistication in analyzing nuclear overpressure effects on aircraft. This program provided a technique for predicting the dynamic response of individual aircraft structural elements, such as stringers, frames, and panels, to the transient pressure loads associated with the blast wave from a nuclear burst. The NOVA-2 dynamic response analysis included both geometric and physical nonlinearities inherent in the behavior of these structural elements in the response range bounded by threshold of permanent damage and catastrophic damage. Although the NOVA-2 code represented a significant improvement over prior static solutions coupled with dynamic load factors to assess the dynamic response of the individual structural elements, the structural coupling between mutually flexible elements was ignored in analyzing the stiffened panels of an aircraft. Furthermore, in the individual element concept used in NOVA-2, the pressure loading on skin panels is assumed to be transmitted directly to adjacent stringers and frames, ignoring the panel response effects on the transmitted loads.

Stiffened panels are those skin panels of the aircraft that are stiffened by several stringers and/or frames between the more rigid boundaries represented by bulkheads, large longerons, spars and ribs. To satisfy the need for an overall stiffened panel analysis, NOVA-2 has been extended to include discrete stiffeners within the cylindrical or flat panels in both coordinate directions for both elastic and inelastic deformation regions. The extended code developed herein is designated as NOVA-2S. Similar revisions have been made to the companion NOVA-2LT code (ref. 2), which provides various general pressure loading

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1. Lee, W. N., Mente, L. J., NOVA-2 - A Digital Computer Program for Analyzing Overpressure Effects on Aircraft, Air Force Weapons Laboratory, Kirtland AFB, AFWL-TR-75-262, Parts 1 and 2, August, 1976.

2. Lee, W. N., A User's Manual for NOVA-2LT, Kaman AviDyne, Burlington, MA, KA-TM-114, January, 1978.

options for the structural elements; the extended version is designated as NOVA-2LTS. The stiffened panel capability has been developed within the analysis framework that existed in NOVA-2 and NOVA-2LT for unstiffened panels, so that the past capability for individual structural elements have been retained in NOVA-2S and NOVA-2LTS with the addition of the stiffened panel option. Thus, the stiffened panel response analysis is compatible with the existing blast, aerodynamic and criteria subroutines of NOVA-2.

Although the stiffened panel option offers a significant increase in the level of sophistication in analyzing stiffened panel structures, there are still limitations when applied to some aircraft-type structures. The boundaries of the stiffened panel must be some combination of clamped and simply supported. The geometry of the stiffened panel is limited to flat and cylindrical, although introducing initial imperfections from these shapes allows approximations for other shapes.

Section 2 of this report presents the theoretical formulation for the stiffened panel analysis. Since the analysis uses most of the unstiffened panel theory given in NOVA-2, only the additional formulation for including stiffeners is presented. To gain confidence in the stiffened panel analysis, comparisons between existing experimental dynamic response results from several stiffened-panel tests and corresponding analytically determined responses from NOVA-2LTS are presented in Section 3. The quality of the stiffened panel tests used for this comparison ranges from a very well defined laboratory experiment to a field test with several uncertainties involved. Section 4 presents an evaluation of the stiffened panel analysis versus the individual element analysis using NOVA-2S to compare the two approaches based on response characteristics and slant range. This evaluation used selected stiffened panels similar to those found in the B-52 aircraft and subjected them to a simulated, nominal nuclear encounter. Response levels corresponding to threshold of permanent damage and catastrophic damage were considered using the criteria as given in NOVA-2 and NOVA-2S. Section 5 contains the computer program description changes made to NOVA-2 to incorporate the stiffened panel option. A sample problem is also given in Section 5.

SECTION II

STIFFENED PANEL THEORETICAL FORMULATION

The addition of stiffeners to the panel skin is accomplished within the theoretical framework of DEPROP which is a response routine contained in NOVA-2 (ref. 1). The stiffeners in NOVA-2S are treated discretely in the analysis and are not smeared out over the stiffener spacing. Thus, the stiffened panel analysis handles as few as one intermediate stiffener or as many stiffeners spaced over the panel as the computer program dimensions allow. The stiffeners must be oriented parallel to either or both spatial coordinate directions of the flat or cylindrical panel, and stiffener locations are restricted to coincide with spatial integration grid lines. The stiffeners in the circumferential coordinate direction can have variable cross sections.

The eccentricity of the stiffeners either above or below the panel skin is taken into account in the analysis. Both bending and membrane deformations causing normal strains and stresses in the stiffener's coordinate direction are included, but lateral bending of the stiffener is ignored. Thus, in the analysis the stiffener is assumed symmetrical about the plane of bending. The torsional stiffnesses of the stiffeners are included in a limited manner by assuming that the twisting is always elastic. Therefore, the shear stress associated with torsion of the stiffener is assumed small compared to the normal stresses and is neglected in the elastic-plastic formulation.

The theoretical development for the stiffened panel analysis is an extension of the virtual work theory used to establish the equations of motion for the unstiffened or pure panel in Section 4.2 of reference 1. Thus, the internal work of the stiffeners undergoing infinitesimal virtual displacements is added to that of the skin portion of the panel in the formulation. While the spatial integration for the pure panel is a surface integral, the integration for the stiffeners are line integrals taken over the length of the stiffeners in the appropriate coordinate direction. The position of the coordinate surface for the flat or cylindrical stiffened panel is defined in the same manner as for the pure panel in Section 4.2.3 of reference 1. This coordinate surface is shown in figure 37 of reference 1. Thus, the membrane elongation and shear strains and the change of curvature quantities defined by the strain-displacement relations in Section 4.2.2 of reference 1 are based on this coordinate surface for the stiffened panel.

The geometry of the stiffened panel is illustrated in figure 1 and depicts discrete integral stiffeners located along various integration grid lines in both of the nondimensional γ and β coordinate directions. Figure 2 illustrates the various types of skin-stiffener configurations that are treated by the analysis. The analysis accommodates stiffeners with any shape whose cross section can be represented as a series of connected rectangular segments. Since lateral bending of the stiffeners is ignored, stiffeners such as channels and z-sections are treated symmetrically as I-sections. Configurations A and B of figure 2 show the stiffener attached to the outer and inner surfaces, respectively, of any panel skin construction designated in NOVA-2, i.e., single-layered, multilayered and sandwich (honeycomb). Configuration C shows the stiffener located in the interior of a sandwich panel and configuration D shows the stiffener attached to the inner surface of a sandwich panel that has been crimped for connection purposes.

In the stiffened panel analysis, the segmented stiffener is treated as a multilayered configuration with variable widths for each segment. These segments are referenced to the selected coordinate surface located within the panel skin in the same manner as was done for a multilayered skin. The depths of these stiffener segments, defined by h_i in figure 2, are referenced to the inner skin surface which is also the reference surface used for the multilayered skin. The manner by which these segment depths are specified for the various stiffener configurations are discussed and illustrated in more detail in Section 5. The provision for a gap between the skin and stiffener is included; a stiffener which

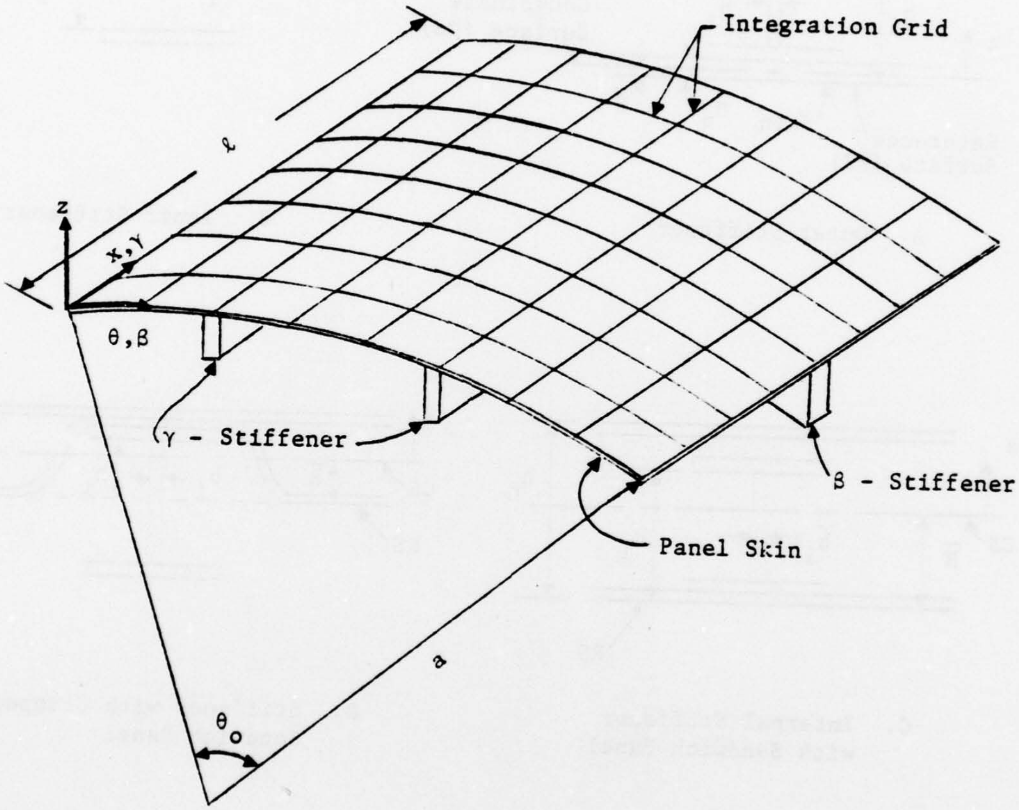
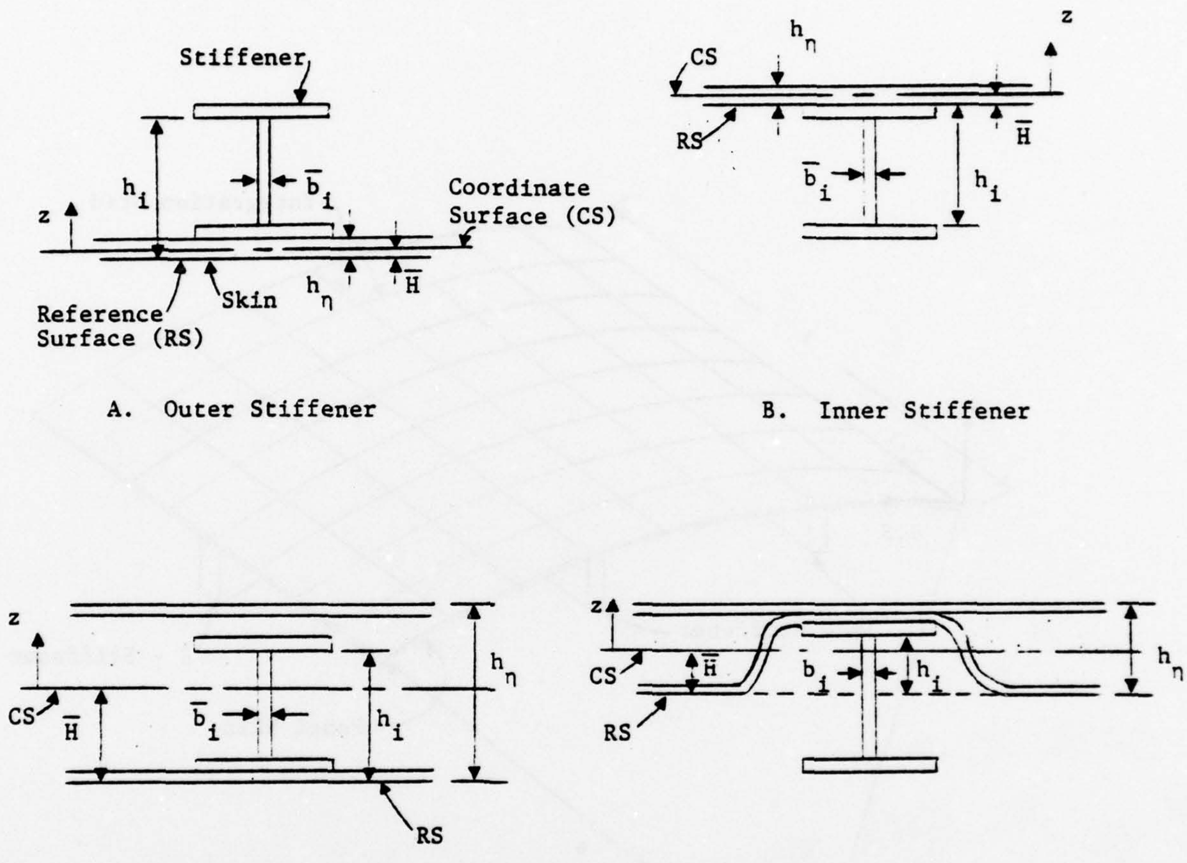


Figure 1. Stiffened Panel Geometry



A. Outer Stiffener

B. Inner Stiffener

C. Internal Stiffener with Sandwich Panel

D. Stiffener with Crimped Sandwich Panel

Figure 2. Stiffener Configurations

is not directly attached to the skin is still assumed to be acting integrally with the panel skin. This gap parameter provides a means of defining stiffeners which are attached to the stiffened panel through orthogonal stiffeners that are in direct contact with the skin or stiffeners which are attached only to the interior surface of the upper face sheet of a sandwich panel. The variable cross section option in the β-direction is accomplished by allowing a varying cross sectional definition at each integration point along the stiffener.

2.1 ELASTIC RELATIONS FOR STIFFENERS

For the elastic solution, additional membrane, bending, cross coupling and torsional stiffness coefficients are determined for the stiffeners and added to the corresponding panel skin stiffness coefficients (equation 114, ref. 1) at all spatial integration points at which stiffeners are located. Since the stiffness coefficients for the panel skin are used in a surface integration, the stiffness coefficients for the stiffeners which use a line integration require a correction factor when combined together. When the center of gravity of the stiffener is above that of the skin, the stiffener configuration is defined as "outer" and when below it is defined as "inner". Whether the stiffener is "outer" or "inner" requires some sign changes in the stiffness coefficients. The stiffness coefficients for stiffeners in the γ and β directions are given by

For γ-stiffeners:

$$C^*_{11} = \frac{3(\bar{N}-1)\bar{E}_\gamma}{a\theta_o H_k} \sum_{i=1}^{NSEG} \bar{b}_i\left(h_i - h_{i-1}\right)$$

$$F^*_{11} = \pm \frac{3(\bar{N}-1)\bar{E}_\gamma}{2a\theta_o H_k} \sum_{i=1}^{NSEG} \bar{b}_i\left[h_i^{\,2} - h_{i-1}^{\,2} \mp 2\bar{H}\left(h_i - h_{i-1}\right)\right] \qquad (1)$$

$$D^*_{11} = \frac{(\bar{N}-1)\bar{E}_\gamma}{a\theta_o H_k} \sum_{i=1}^{NSEG} \bar{b}_i\left[\left(h_i^{\,3} - h_{i-1}^{\,3}\right) \mp 3\bar{H}\left(h_i^{\,2} - h_{i-1}^{\,2}\right) + 3\bar{H}^2\left(h_i - h_{i-1}\right)\right]$$

For β-stiffeners:

$$C^*_{22} = \frac{3(\bar{M}-1)\bar{E}_\beta}{\ell H_j} \sum_{i=1}^{NSEG} \bar{b}_i \left(h_i - h_{i-1}\right)$$

$$F^*_{22} = \pm \frac{3(\bar{M}-1)\bar{E}_\beta}{2\ell H_j} \sum_{i=1}^{NSEG} \bar{b}_i \left[h_i^{\,2} - h_{i-1}^{\,2} \mp 2\bar{H}\left(h_i - h_{i-1}\right)\right] \tag{2}$$

$$D^*_{22} = \frac{(\bar{M}-1)\bar{E}_\beta}{\ell H_j} \sum_{i=1}^{NSEG} \bar{b}_i \left[\left(h_i^{\,3} - h_{i-1}^{\,3}\right) \mp 3\bar{H}\left(h_i^{\,2} - h_{i-1}^{\,2}\right)\right.$$

$$\left. + 3\bar{H}^2\left(h_i - h_{i-1}\right)\right]$$

For both γ and β stiffeners:

$$D^*_{33} = \frac{1}{4}\left[\frac{3(\bar{N}-1)}{a\theta_o H_k} \bar{G}_\gamma J_\gamma + \frac{3(\bar{M}-1)}{\ell H_j} \bar{G}_\beta J_\beta\right] \tag{3}$$

where

$\bar{E}_\gamma$, $\bar{E}_\beta$ are the moduli of elasticity for the γ and β stiffeners, respectively

$a\theta_o$ is the arc length of the cylindrical panel and for a flat panel is replaced by width b

ℓ is the length of the panel

$\bar{M}$, $\bar{N}$ are the number of spatial integration points in the γ and β directions, respectively

H_j, H_k are the weighting values for Simpson's quadrature formula in the γ and β directions, respectively

$\bar{b}_i$ is the width of the i^{th} stiffener segment

h_i is the distance from the inner panel skin surface to the furthest edge of the i^{th} stiffener segment

$\bar{H}$ is the distance from the inner panel skin surface to the coordinate surface (defined by equations 115 and 116 of ref. 1)

NSEG is the total number of stiffener segments

$\overline{G}_\gamma$, $\overline{G}_\beta$ are the shear moduli for the γ and β stiffeners, respectively

J_γ, J_β are the torsional constants for the γ and β stiffeners, respectively

Where double signs ($\pm$ or $\mp$) are indicated in equations 1 and 2, the upper sign is used for "outer" stiffeners and the lower sign is used for "inner" stiffeners. The strains and stresses in the stiffeners are determined from

$$\begin{aligned} \tilde{\varepsilon}_{xx} &= \varepsilon_{xx} + z\kappa_{xx} \text{ and } \sigma_{xx} = \overline{E}_\gamma \tilde{\varepsilon}_{xx} \quad (\gamma\text{-stiffener}) \\ \tilde{\varepsilon}_{\theta\theta} &= \varepsilon_{\theta\theta} + z\kappa_{\theta\theta} \text{ and } \sigma_{\theta\theta} = \overline{E}_\beta \tilde{\varepsilon}_{\theta\theta} \quad (\beta\text{-stiffener}) \end{aligned} \tag{4}$$

where z is the distance from the coordinate surface to a designated position on the stiffener.

2.2 ELASTIC-PLASTIC RELATIONS FOR STIFFENERS

The elastic-plastic solution applies to stiffened single-layered and sandwich skin panels. In NOVA-2 the sandwich panel was approximated by an equivalent single-layered panel, but in this current version the inelastic response is determined directly using the two thin face sheets of the sandwich panel. For the elastic-plastic solution, the stiffeners are divided into a sufficient number of segments so that the stress distribution across the cross section is accurately represented. In NOVA-2S and NOVA-2LTS the selection of this segmentation of the stiffeners is left to the discretion of the user. Figure 3 gives an illustration of the segmentation used for elastic and elastic-plastic solution of a typical stiffener. The elastic solution required only three segments for this stiffener while for the elastic-plastic solution six segments are selected to give a reasonable representation of the stress distribution. The constitutive relations for the stiffener's material are based on those used for the skin panel in reference 1, except they are reduced to the uni-axial case.

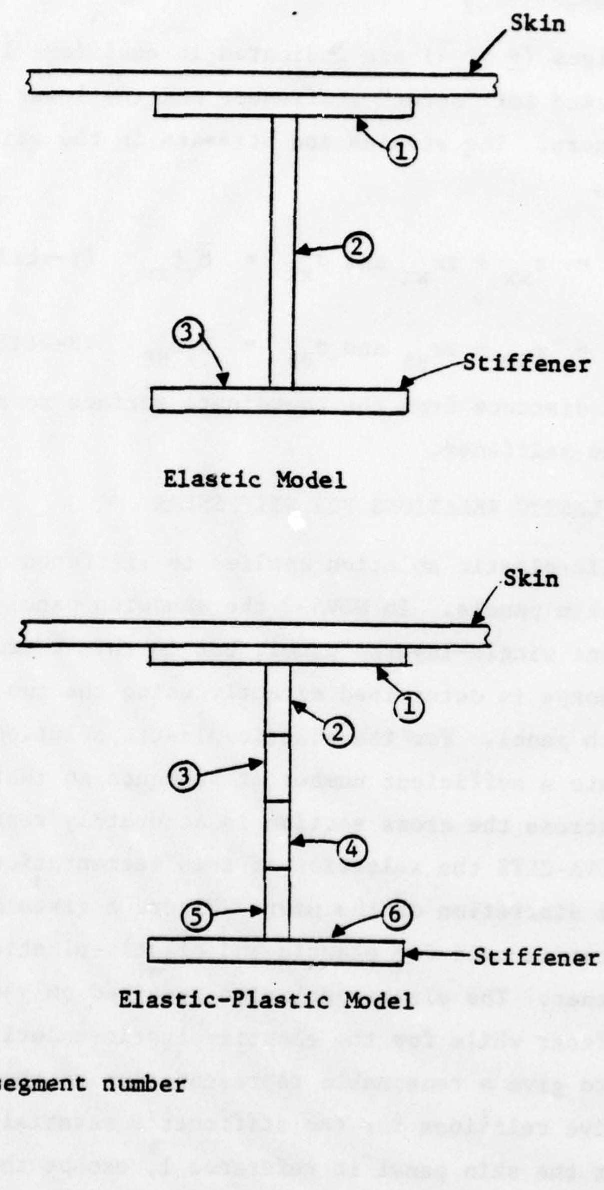


Figure 3. Example Segmentation of Stiffener

For the stiffeners the secant modulus is defined by

$$\overline{E}_s = \frac{\overline{\sigma}}{\overline{\varepsilon}} = \frac{\sigma_o + \overline{E}_t(\overline{\varepsilon}-\varepsilon_o)}{\overline{\varepsilon}} \tag{5}$$

where

σ_o, ε_o are the yield stress and strain of the stiffener, respectively, and $\sigma_o = \overline{E}\varepsilon_o$

$\overline{E}_t$ is the strain hardening slope of the stiffener

For stiffeners in the γ-direction,

$$\begin{aligned} \overline{\sigma} &= |\sigma_{xx} - \tilde{\alpha}^r_{xx}| \\ \overline{\varepsilon} &= |\tilde{\varepsilon}_{xx} - \tilde{\beta}^r_{xx}| \end{aligned} \tag{6}$$

and for stiffeners in the β-direction,

$$\begin{aligned} \overline{\sigma} &= |\sigma_{\theta\theta} - \tilde{\alpha}^r_{\theta\theta}| \\ \overline{\varepsilon} &= |\tilde{\varepsilon}_{\theta\theta} - \tilde{\beta}^r_{\theta\theta}| \end{aligned} \tag{7}$$

where

$\tilde{\alpha}^r_{ij}$, $\tilde{\beta}^r_{ij}$ are defined by equation 110 in reference 1

The general stress-strain relations for stiffeners are given by

$$\begin{aligned} \sigma_{xx} &= \tilde{\alpha}^r_{xx} + \overline{E}_s\,(\tilde{\varepsilon}_{xx} - \tilde{\beta}^r_{xx}) \quad \text{(for } \gamma\text{-stiffeners)} \\ \sigma_{\theta\theta} &= \tilde{\alpha}^r_{\theta\theta} + \overline{E}_s\,(\tilde{\varepsilon}_{\theta\theta} - \tilde{\beta}^r_{\theta\theta}) \quad \text{(for } \beta\text{-stiffeners)} \end{aligned} \tag{8}$$

The initial elastic, initial plastic, elastic unloading and reyielding regions of response are defined the same as given in equation 113 of reference 1. The integrand quantities for the stiffener are given by

$$f^{\gamma} = \sigma_{xx} \frac{\partial \varepsilon_{xx}}{\partial W_{mn}} + \frac{\overline{z}_i}{a} \sigma_{xx} \frac{\partial K_{xx}}{\partial W_{mn}} \quad \text{(for } \gamma\text{-stiffeners)}$$

$$f^{\beta} = \sigma_{\theta\theta} \frac{\partial \varepsilon_{\theta\theta}}{\partial W_{mn}} + \frac{\overline{z}_i}{a} \sigma_{\theta\theta} \frac{\partial K_{\theta\theta}}{\partial W_{mn}} \quad \text{(for } \beta\text{-stiffeners)} \tag{9}$$

where $\overline{z}_i$ is the distance from the coordinate surface to the center of the i^{th} stiffener segment and is expressed as $\overline{z}_i = \pm \frac{1}{2}(h_i + h_{i-1}) - \overline{H}$ where the plus sign is used for "outer" stiffeners and the minus sign for "inner" stiffeners. The trapezoidal rule is used for the numerical integration through the depth of a stiffener in the equation of motion.

2.3 INERTIAL COUPLING MATRICES

In the spatial surface integration of the kinetic energy the addition of the line integrals in the γ and β directions to include the mass of the stiffeners leads to inertial coupling of the modes. The M_{pq} coefficients associated with the w-equations of motion of the inertial coupling matrix [M] are determined from

$$M_{pq} = k_{\gamma} k_{\beta} \overline{\rho} \delta_{mr} \delta_{ns} + \frac{k_b^{\gamma} \delta_{mr}}{a\theta_o h_{\eta}} \sum_{i=1}^{NSG} \rho_s^i A_s^i \phi_n^w \left(\beta_k\right) \phi_s^w \left(\beta_k\right)$$

$$+ \frac{k_b^{\beta} \delta_{ns}}{\ell h_{\eta}} \sum_{i=1}^{NSB} \rho_s^i A_s^i \phi_m^w \left(\gamma_j\right) \phi_r^w \left(\gamma_j\right) \tag{10}$$

where

- pq extends over all the modal combinations selected for the solution
- $\overline{\rho}$ is the mass density of the panel skin

ρ_s^i is the mass density of the i^{th} stiffener

A_s^i is the area of the i^{th} stiffener

h_η is the total thickness of the panel skin

δ_{mr}, δ_{ns} are Kronecker deltas

$k_b^\gamma = \sqrt{2}k_\gamma$, where k_γ is defined in equation 120 of reference 1

$k_b^\beta = \sqrt{2}k_\beta$, where k_β is defined in equation 120 of reference 1

r,s are particular values of m and n, respectively

ϕ_m^w, ϕ_n^w are given in equations 118 and 119 of reference 1

γ_j, β_k are defined in equation 124 of reference 1

NSG, NSB are the number of γ and β stiffeners, respectively

In general matrix form the w-equations of motion are given by

$$\ell^2[M]\left\{\ddot{W}_{rs}\right\} = -\left\{f_{rs}\right\} \tag{11}$$

For the solution of these equations in NOVA-2S, equation 11 is placed in the form

$$\left\{\ddot{W}_{rs}\right\} = -\frac{1}{\ell^2}[M]^{-1}\left\{f_{rs}\right\} \tag{12}$$

It should be noted from equation 12 that the inertial coupling matrix has been inverted. In order to accomplish this operation, a matrix inversion subroutine has been placed in the new NOVA-2S and NOVA-2LTS programs. Although the above derivation is only demonstrated for the normal motion of the stiffened panel, similar inertial coupling matrices have been established in the program for the inplane motions of the panel (u and v-equations of motion).

2.4 EQUATIONS OF MOTION FOR STIFFENED PANELS

The inclusion of the stiffeners necessitated modifications of the equations of motion for the pure panel in reference 1. These modifications required the line integrals from the stiffeners be integrated with the surface integral of the panel skin. For the elastic case the form of the equations of motion were not altered since the stiffness coefficients of the stiffeners were integrated directly with the stiffness coefficients of the panel skin. However, for the elastic-plastic solution of a stiffened single-layered panel the equations of motion given in equation 124 of reference 1 are modified into the form:

$$k_\gamma k_\beta [M] \ell^2 \ddot{W}_{mn} + \frac{\pi^2}{9(\overline{M}-1)(\overline{N}-1)} \sum_{j=1}^{\overline{M}} \sum_{k=1}^{\overline{N}} H_j H_k \Bigg\{ L^2 \sum_{i=1}^{\overline{L}} H_i \Big[f_i^m (\gamma_j, \beta_k)$$

$$+ \frac{1}{2R} \xi_i f_i^b (\gamma_j, \beta_k) \Big] + \frac{6L^2}{h} \Bigg[\frac{(\overline{N}-1)}{H_k a \theta_o} \sum_{i=1}^{NSEG} \overline{b}_i (h_i - h_{i-1}) f_i^\gamma (\gamma_j, \beta_k)$$

$$+ \frac{(\overline{M}-1)}{H_j \ell} \sum_{i=1}^{NSEG} \overline{b}_i (h_i - h_{i-1}) f_i^\beta (\gamma_j, \beta_k) \Bigg]$$

$$+ 2L^2 R \frac{D_{33}^*}{a^3} K_{x\theta} \frac{\partial K_{x\theta}}{\partial W_{mn}} - \tilde{Q}_w (\gamma_j, \beta_k) \Bigg\} = 0 \qquad (13)$$

where the nomenclature has been given in equation 124 of reference 1 and in Section 2 of this report.

In NOVA-2 the elastic-plastic response of sandwich (honeycomb) panels was handled by an equivalent single-layered panel. It was apparent that the same technique used to include stiffeners into the elastic-plastic solution could be used to solve the inelastic response of the honeycomb panels without reducing the three-layered panel section to an equivalent single-layered panel. It is assumed the core of the sandwich or honeycomb always remains undamaged and the normal stresses are carried just by the face sheets. It is further assumed that the stress across each face sheet is constant. Figure 4 shows the nomenclature for the sandwich section. In the equations of motion given by equation 13, the single layered expression in the first brackets (associated with the first summation over i) is replaced for the sandwich panel by

$$\frac{2L^2}{h_3} \sum_{i=}^{1\&3} (h_i - h_{i-1}) \left[f_i^m (\gamma_j, \beta_k) + \frac{z_i}{a} f_i^b (\gamma_j, \beta_k) \right] \qquad (14)$$

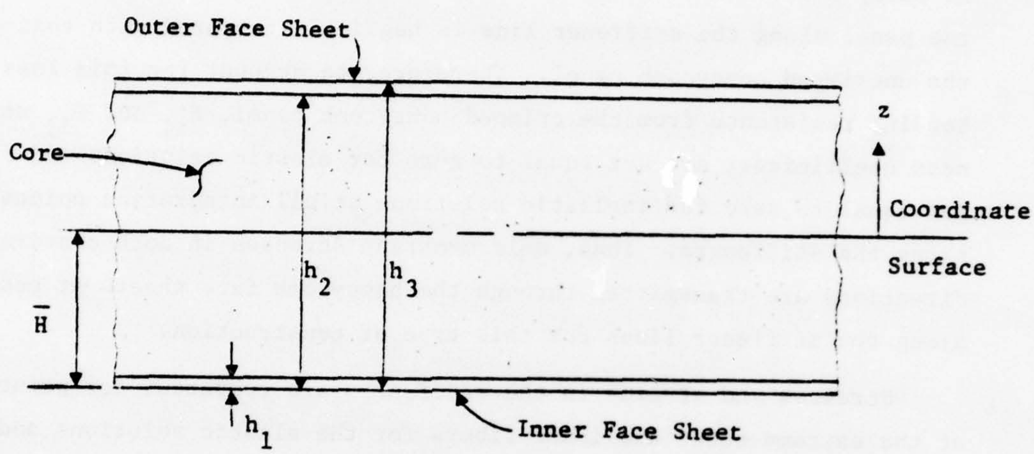


Figure 4. Sandwich (Honeycomb) Cross Section

where

f_i^m, f_i^b are defined in equation 123 of reference 1

$$z_1 = \frac{1}{2}h_1 - \overline{H}$$

$$z_3 = \frac{1}{2}(h_3 + h_2) - \overline{H}$$

In stiffened honeycomb panels the honeycomb core is often crimped where the panel skin intersects the various stiffeners for attachment purposes (see configuration D of figure 2). It is assumed that the core is fully removed over the stiffener, so that the bending resistance of the panel along the stiffener line is negliable compared with that of the uncrimped honeycomb panel. Therefore, to account for this loss of bending resistance from the crimped honeycomb panel, F_{ij} and D_{ij} stiffness coefficients are set equal to zero for elastic solutions and f_i^b is set equal to zero for inelastic solutions at all integration points along the stiffeners. Thus, only membrane stresses in both coordinate directions are transmitted through the honeycomb face sheets at positions along the stiffener lines for this type of construction.

Stresses and strains in the stiffeners are computed, for printout, at the extreme outer and inner fibers for the elastic solutions and in the center of the first and last segments for the inelastic solutions.

SECTION III

COMPARISON OF STIFFENED PANEL SOLUTIONS WITH EXISTING EXPERIMENTAL RESULTS

To evaluate the stiffened panel option contained in NOVA-2S and NOVA-2LTS, comparison of calculated displacement and strain time histories are made with existing experimental results from tests performed on stiffened panels. In this initial evaluation of the stiffened panel program, three stiffened panels are analyzed, each from a different test program. The sources for the three stiffened panels are from tests performed by the MIT Aeroelastic and Structures Research Laboratory (ref. 3), Boeing-Wichita in their Structural Response to Simulated Nuclear Overpressure (STRESNO) test program (ref. 4) and the Naval Weapons Evaluation Facility tests on A-4C aircraft in the DICE THROW event (ref. 5).

These three test sources represent a wide range in the overall quality of the test results from the standpoint of definitions of both structure and loading. The test in reference 3 represents a well controlled laboratory test in which the geometry and boundary conditions of the stiffened panel were well defined and the implusive loading with a known spatial distribution was carefully calibrated for magnitude. The test selected from reference 4 was conducted in a large shock tube in which

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3. Witner, E. A., Wu, R. W-H. and Merlis, F., Experimental Transient and Permanent Deformation Studies of Impulsively-Loaded Rings and Cylindrical Panels, Both Stiffened and Unstiffened, Aeroelastic and Structures Research Laboratory, Mass. Inst. of Tech., ASRL TR171-3 (AMMRC CTR 74-29), April 1974.

4. Syring, R. P. and Pierson, W. D., Structural Response to Simulated Nuclear Overpressure (STRESNO): A Test Program Establishing a Data Base for Evaluating Present and Future Analytical Techniques, Defense Nuclear Agency, Washington, D.C., DNA4278F-1 & 2, March 1977.

5. Friedberg, R. and Hughes, P. S., Experimental Study of Aircraft Structural Response to Blast, Naval Weapons Evaluation Facility, Albuquerque, NM, NWEF Report 1145, Volumes 1 and 2, December 1977.

the pressure was measured at one position on the panel and the boundary conditions of the panel had some uncertainties. The test on the A-4C aircraft was a field test in which pressures were measured outside the test panel area and some uncertainties also existed in the geometry of the stiffened panel.

In the following subsections, comparisons are made between measured displacements and strain time histories from the three selected stiffened panel tests and the corresponding analytical response obtained using the NOVA-2LTS stiffened panel code. In order to obtain better accuracy, the normal dimensions of NOVA-2LTS were expanded to accommodate more integration points to cover the large areas of the stiffened test panels.

3.1 ANALYTICAL AND EXPERIMENTAL COMPARISONS FOR THE MIT CYLINDRICAL STIFFENED PANEL

In reference 3 well-defined response tests were performed on stiffened cylindrical panels with clamped edges. To assure reliable structural geometry and clamped-edge boundary conditions, the test specimens were machined from solid blocks of 6061-T6 aluminum. Figure 5 shows a sketch of the test specimen which is nominally a 60-degree cylindrical panel, 0.1 inch thick, 6.0 inches long and 6.0 inches in radius. The boundaries of the specimen are thick and massive to simulate an ideally-clamped edge and, furthermore, they are attached by bolts to a thick steel plate. The integral inner stiffener in the circumferential direction is located in the center of the panel and is nominally 0.1 inch thick and 0.4 inch deep. All boundary edges of the cylindrical panel and the curved edges where the stiffener intersects the panel were machined with 1/8-inch filets to reduce the threat of premature cracking due to stress concentrations. All dimensions of this panel were carefully measured to determine the actual geometric properties after fabrication. These actual average dimensions were used for the NOVA-2LTS analytical model.

The stress-strain curves in tension and compression were determined experimentally for this particular 6061-T6 aluminum and the data are given in reference 3. The impulsive loading was obtained by placing a

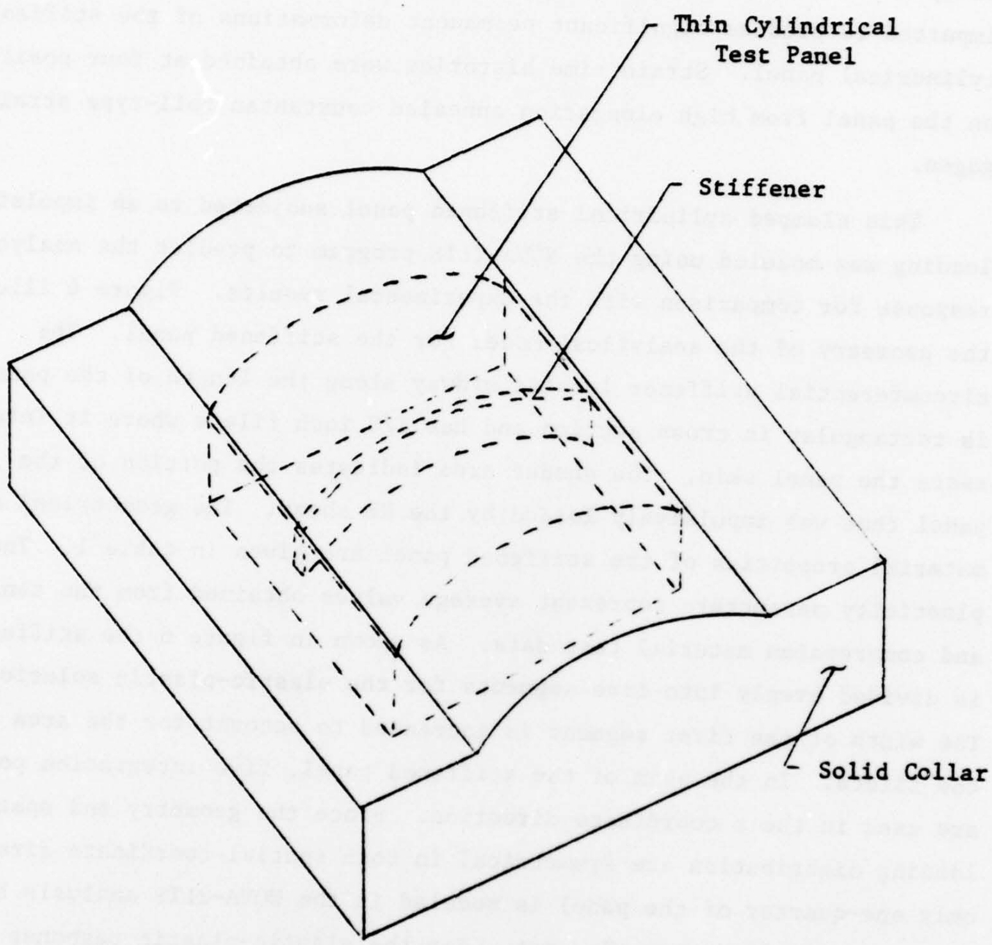


Figure 5. Schematic of the MIT Integrally Stiffened Clamped Cylindrical Panel

high explosive (HE) sheet with a foam buffer over a prescribed area of the panel. The impulse imparted to the panel by the HE sheet was carefully calibrated from experimental test data. A sufficient impulse was imparted to produce significant permanent deformations of the stiffened cylindrical panel. Strain time histories were obtained at four positions on the panel from high elongation annealed constantan foil-type strain gages.

This clamped cylindrical stiffened panel subjected to an impulsive loading was modeled using the NOVA-2LTS program to predict the analytical response for comparison with the experimental results. Figure 6 illustrates the geometry of the analytical model for the stiffened panel. The circumferential stiffener located midway along the length of the panel is rectangular in cross section and has 1/8 inch filets where it intersects the panel skin. The shaded area indicates the portion of the panel that was impulsively loaded by the HE sheet. The geometrical and material properties of the stiffened panel are given in table 1. The plasticity parameters represent average values obtained from the tension and compression material test data. As shown in figure 6 the stiffener is divided evenly into five segments for the elastic-plastic solution. The width of the first segment is increased to account for the area of the filets. In the skin of the stiffened panel, five integration points are used in the z coordinate direction. Since the geometry and spatial loading distribution are symmetrical in both spatial coordinate directions, only one-quarter of the panel is modeled in the NOVA-2LTS analysis by using a 21 by 21 integration net. For the elastic-plastic response solution of the stiffened panel, 28 modes are used. For the temporal numerical integration a 0.5 microsecond time step is used.

The magnitude, I, of the impulsive loading applied to the panel is 0.162067 psi-sec. Through load option 3 in NOVA-2LTS this loading is applied as a triangular pressure load over the first time step. The peak pressure (p_m) is given by $\frac{2I}{\Delta t}$ and is equal to 648268.0 psi. Spatially on the quarter panel, the loading is zero for x = 0 to 1.35225 inches and θ = 0 to 13.4235 degrees and defined by p_m for x = 1.65275 inches

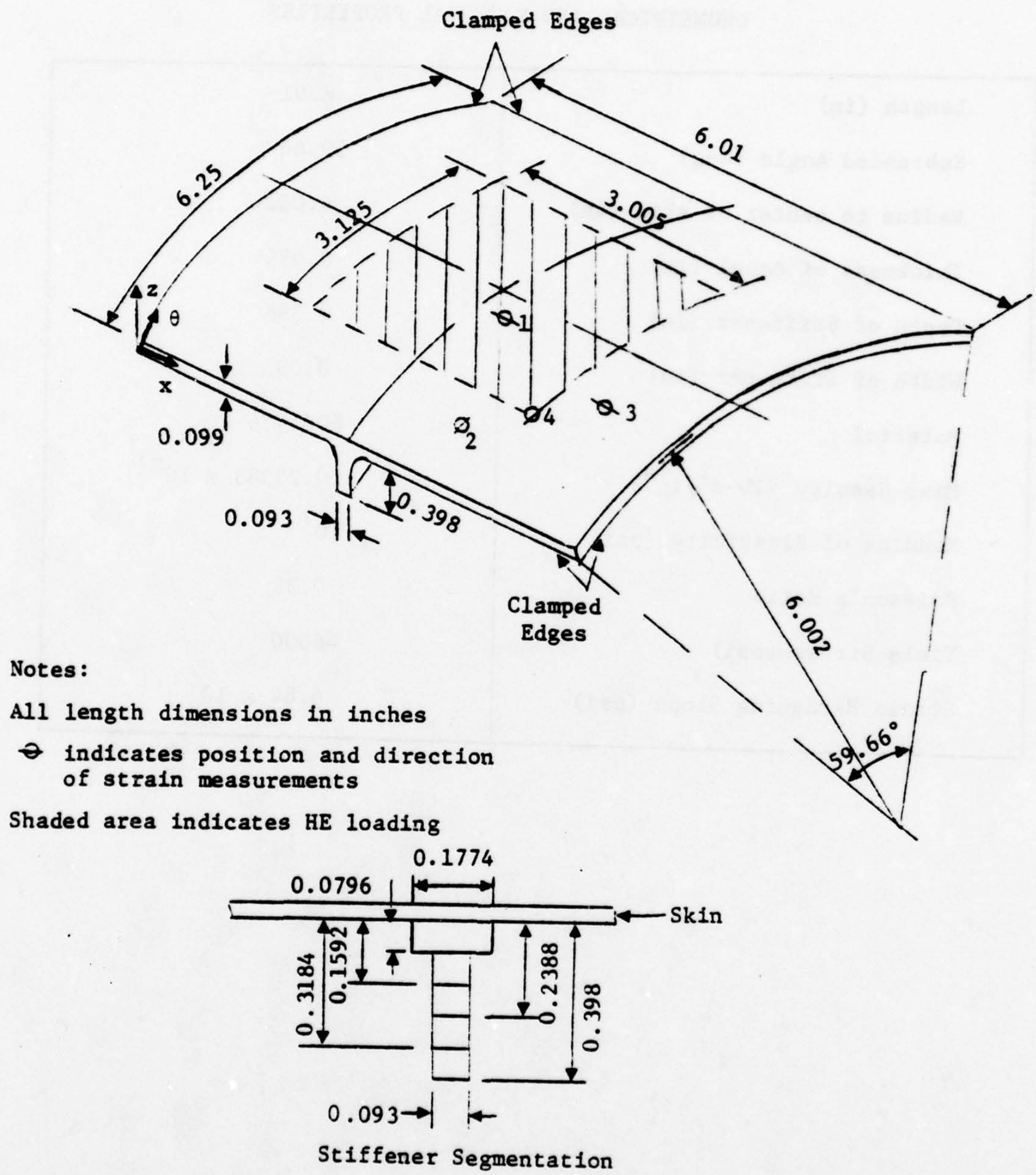


Figure 6. MIT Cylindrical Stiffened Panel Model

TABLE 1

GEOMETRICAL AND MATERIAL PROPERTIES

Length (in)	6.01
Subtended Angle (deg)	59.66
Radius to center of skin (in)	6.002
Thickness of panel (in)	0.099
Depth of Stiffener (in)	0.398
Width of Stiffener (in)	0.093
Material	6061-T6
Mass Density ($lb\text{-}s^2/in^4$)	0.25383×10^{-3}
Modulus of Elasticity (psi)	10^7
Poisson's Ratio	0.33
Yield Stress (psi)	46000
Strain Hardening Slope (psi)	6.84×10^4

to 3.005 inches and θ = 16.4065 to 29.83 degrees. Thus, the edges of the HE sheet are smeared out over two grid spacings as an approximation in the loading distribution.

Comparisons between analytical and experimental results for the MIT stiffened cylindrical panel are made for the four measured inner surface strain time histories and two permanent-set displacement measurements. The approximate spatial locations of these strain measurements are indicated in figure 6 by small circles. For the strain measurement the small straight line segments indicate whether the orientation was axially or circumferentially. Figures 7 and 8 show the comparisons for the four strain positions where the solid lines are analytically determined from NOVA-2LTS and the dashed lines are experimentally measured. At position 1 the experimental strain trace terminated just after reaching the peak and at position 3 the strain trace briefly went out of recording range during the peak portion of the response. The comparisons were very good for the two larger strain responses at positions 1 and 2 given in figure 7. The two lower level strain responses at positions 3 and 4 in figure 8 show reasonable comparison, particularly in phasing, but the analytical responses are higher than the experimental. This stiffened panel underwent large plastic deformations throughout the panel skin and the stiffener. Figure 9 illustrates the analytically determined displacement time histories at two positions on the panel. The measured permanent set values at these positions are compared to the level of oscillation near the end of the analytical time histories. The projected analytical permanent sets are slightly lower than the measured values. This might be expected since the stiffener exhibited plastic lateral buckling over a small region near the ends of the stiffener which can not be represented in the analytical model. This plastic lateral buckling occurred approximately between 2.5 to 9.2 degrees from each end and would have the tendency to retard the displacement recovery of the panel. The analytical strain results confirmed the severity of deformations of the stiffener in this region. In fact, the maximum analytical compressive strain in the stiffener occurs at 9 degrees at a magnitude of 0.19 in/in.

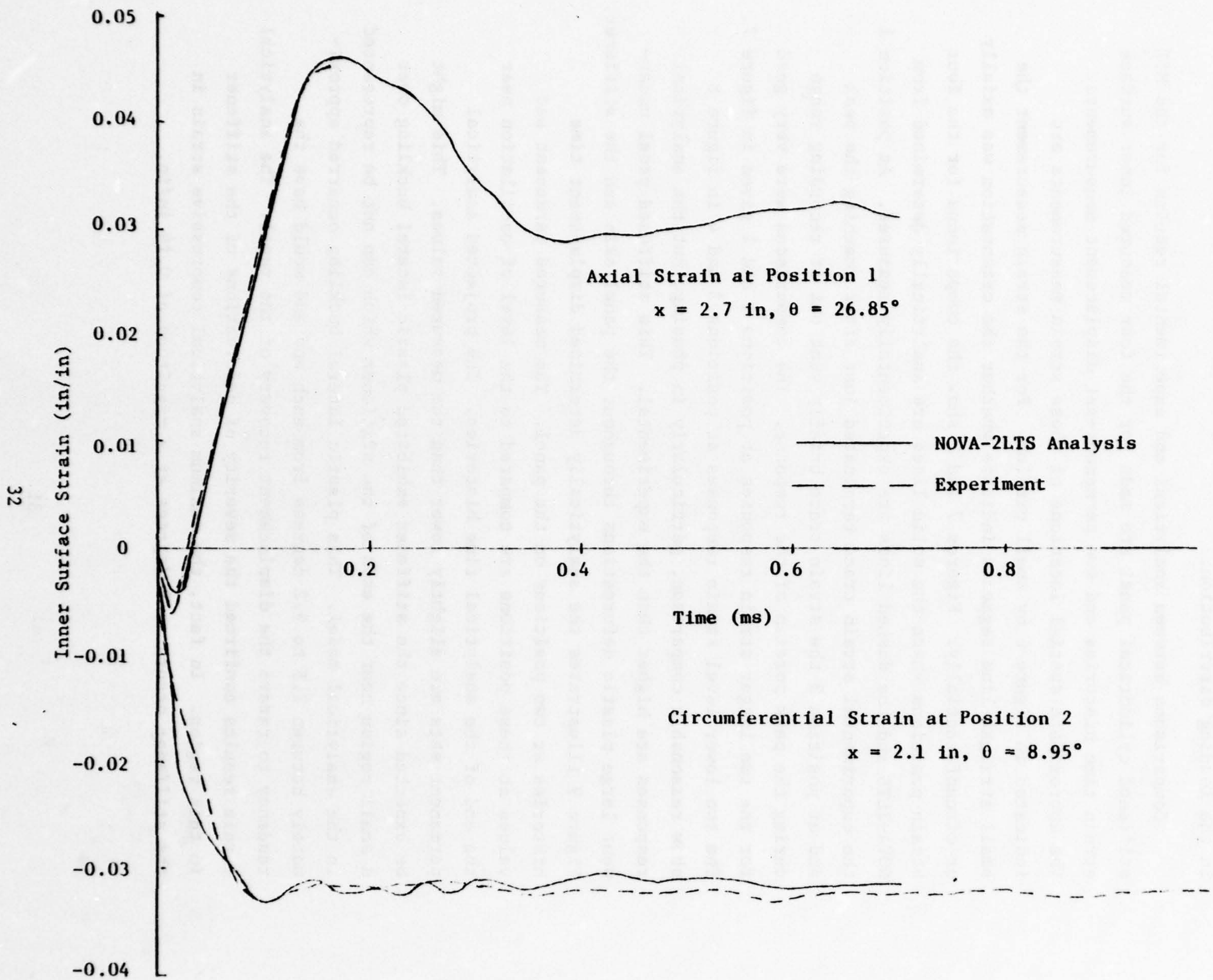


Figure 7. Strain Time Histories for the MIT Cylindrical Stiffened Panel at Positions 1 and 2

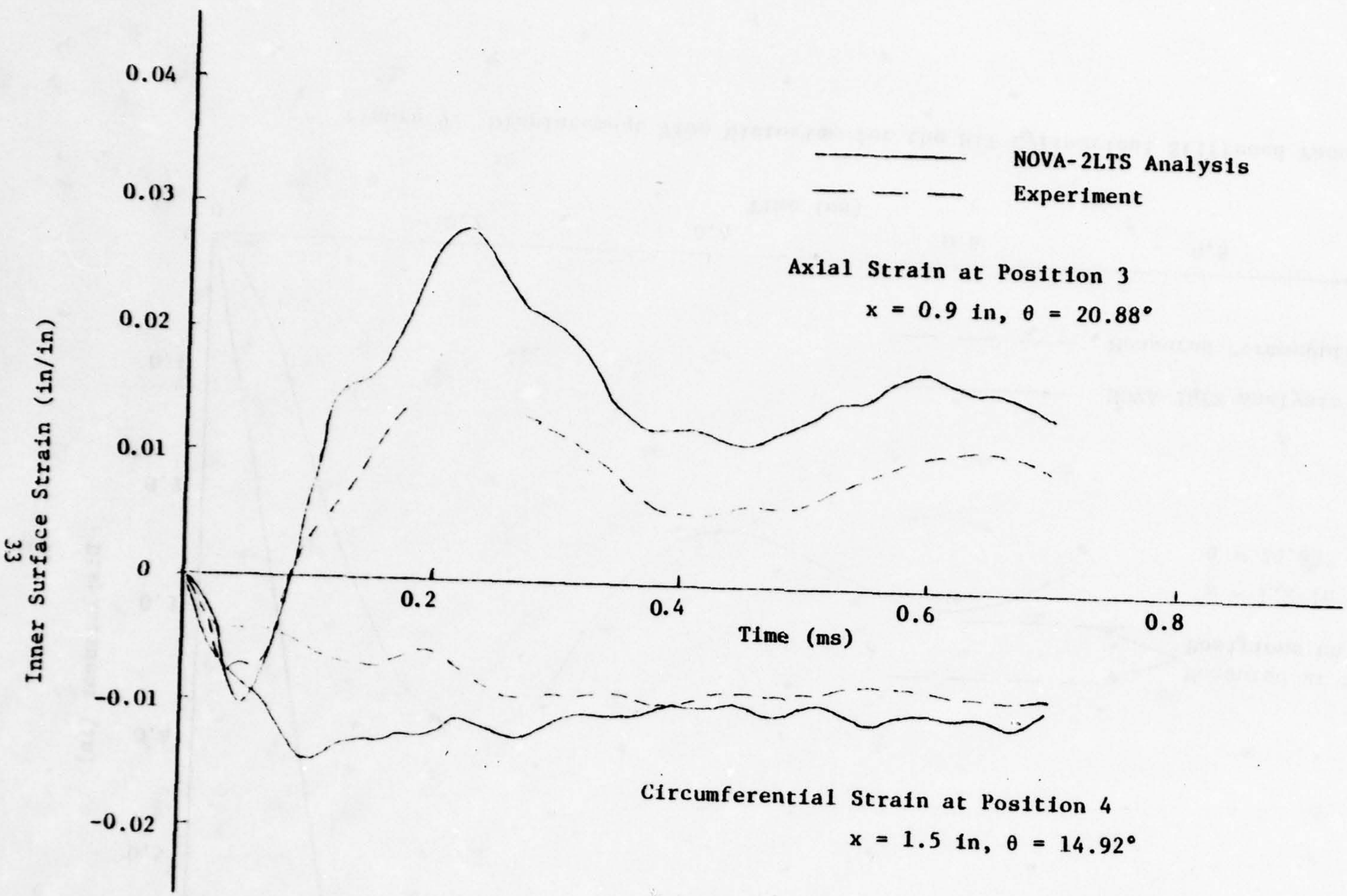


Figure 8. Strain Time Histories for the MIT Cylindrical Stiffened Panel at Positions 3 and 4

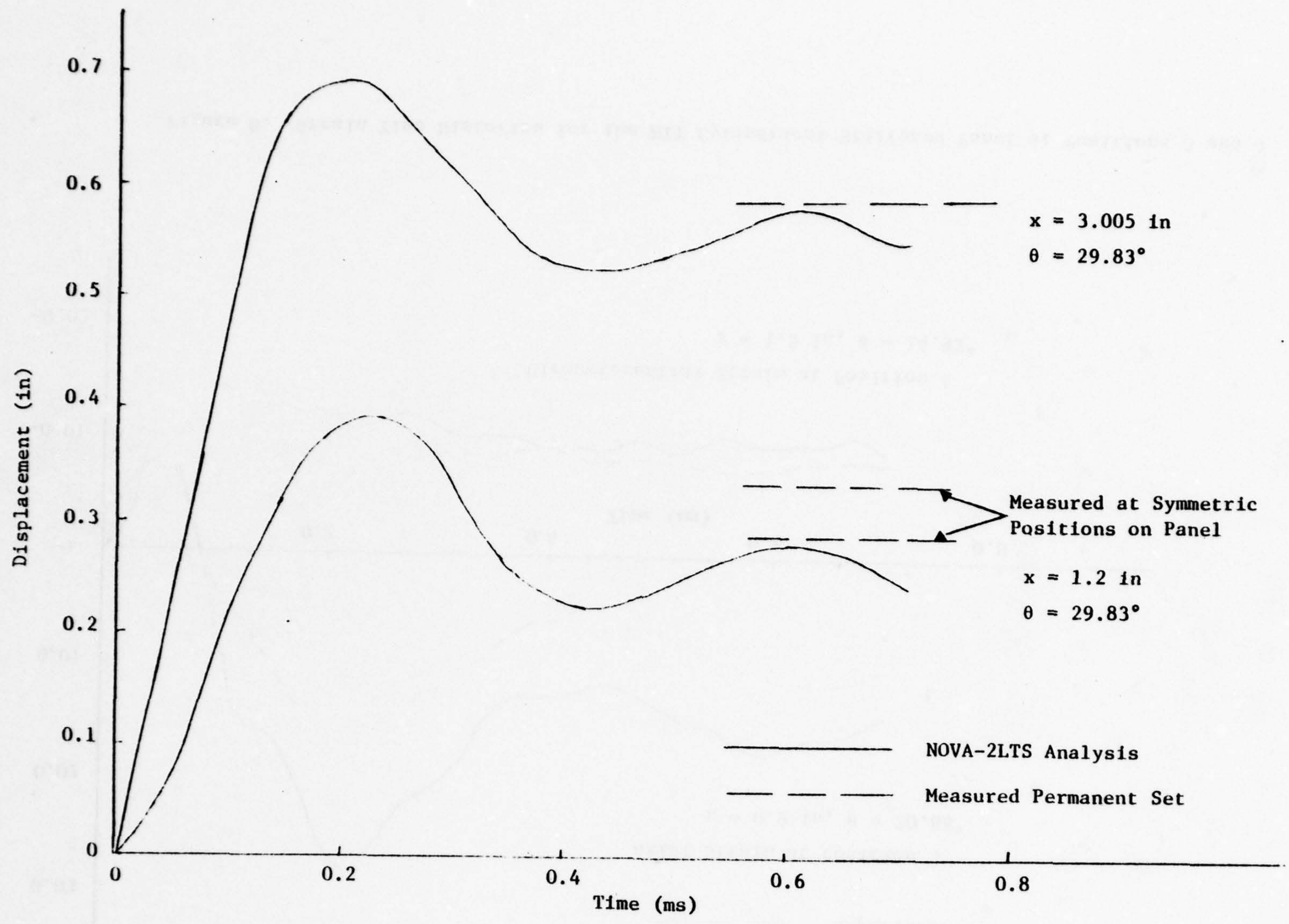
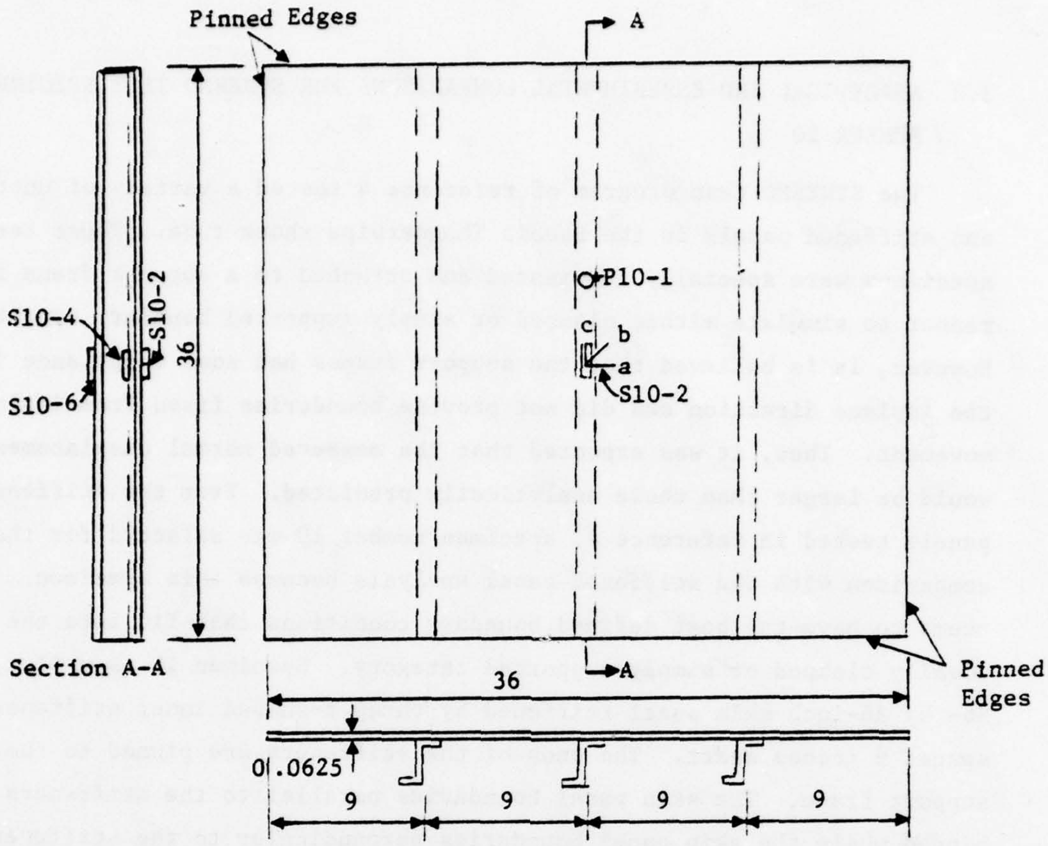


Figure 9. Displacement Time Histories for the MIT Cylindrical Stiffened Panel

3.2 ANALYTICAL AND EXPERIMENTAL COMPARISONS FOR STRESNO TEST SPECIMEN NUMBER 10

The STRESNO test program of reference 4 tested a variety of unstiffened and stiffened panels in the Sandia Thunderpipe shock tube. These test specimens were specially fabricated and attached to a support frame in a manner to simulate either clamped or simply supported boundary conditions. However, it is believed that the support frames had some compliance in the inplane direction and did not provide boundaries fixed from inplane movement. Thus, it was expected that the measured normal displacements would be larger than those analytically predicted. From the stiffened panels tested in reference 4, specimen number 10 was selected for the comparison with the stiffened panel analysis because this specimen seems to have the best defined boundary conditions that fit into the ideally clamped or simply supported category. Specimen 10 is a flat 36- by 36-inch skin panel stiffened by three z-shaped inner stiffeners spaced 9 inches apart. The ends of the stiffeners are pinned to the support frame. The skin panel boundaries parallel to the stiffeners are hinged while the skin panel boundaries perpendicular to the stiffeners are unattached except for being riveted to the stiffeners at their three locations. Figure 10 illustrates the geometry of the stiffened panel and the locations of the strain and pressure measurements. The displacement time history was also measured at the center of the stiffened panel. The dimensions of the cross section of the stiffeners are also given on figure 10. The material of the 0.0625-inch panel skin is 2024-T3 aluminum while the material of the stiffeners is 2024-T3511 aluminum. The general geometric and material properties are given in table 2.

Analytical and experimental comparison were made for shots 4 and 5 on specimen number 10. Shot 4 was a purely elastic response while shot 5 was at a level of response in the threshold of yielding region. The outer surface reflected pressure time histories for shots 4 and 5 are given in figure 11 in which the approximated pressure time histories

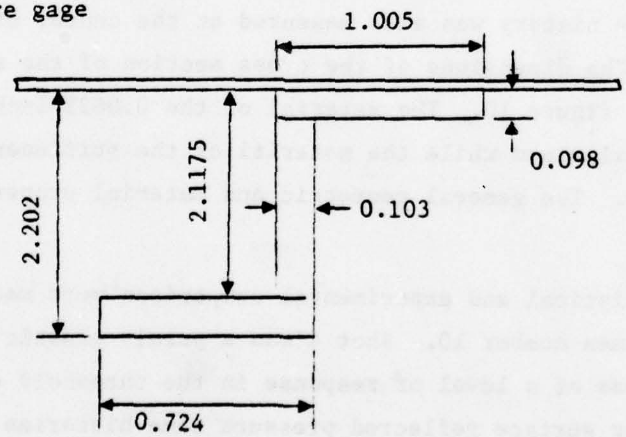


Notes:

All length dimensions in inches

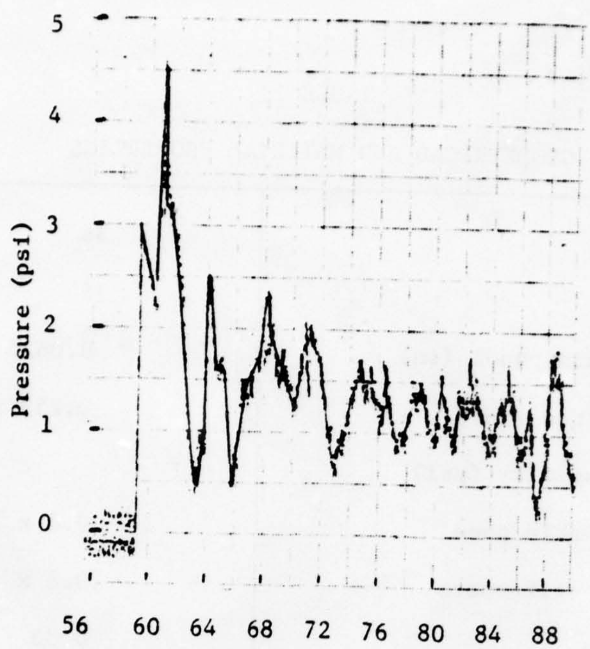
S indicates strain gage

P indicates pressure gage

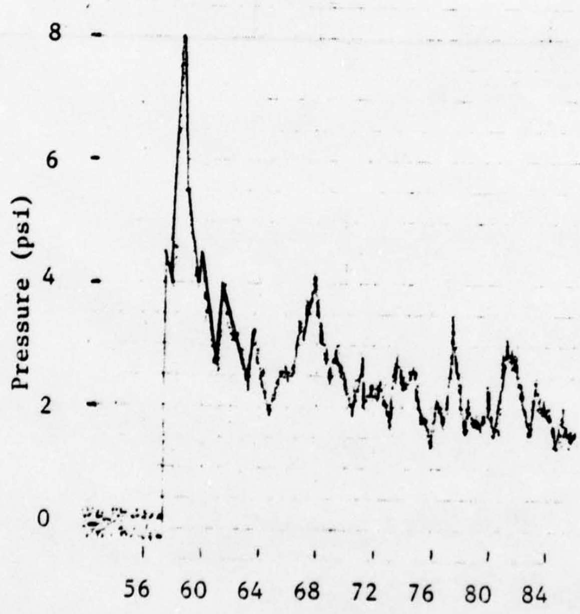


Stiffener Cross Section

Figure 10. Flat Stiffened Panel Model for STRESNO Test Specimen No. 10



Shot No. 4



Shot No. 5

Figure 11. Reflected Pressure Time Histories for Shots 4 and 5 on Specimen No. 10

TABLE 2

GEOMETRICAL AND MATERIAL PROPERTIES

Length (in)	36
Width (in)	36
Thickness of skin panel (in)	0.0625
Mass Density ($lb\text{-}s^2/in^4$)	0.259×10^{-3}
Modulus of Elasticity (psi)	
skin panel	9.8×10^6
stiffeners	10.8×10^6
Poisson's Ratio	0.33
Yield Stress (psi)	50000
Strain Hardening Slope (psi)	2.2×10^5

are shown by solid straight line segments. Table 3 gives the values of the pressure model for shots 4 and 5, corrected for the slight internal pressure generated by the panel response within the enclosed support frame box. The spatial distribution of the pressure is assumed to be uniform and is inputted into the NOVA-2LTS program by pressure option 2.

Since the geometry and spatial loading distribution are symmetrical in both spatial coordinate directions, only one-quarter of the stiffened panel is modeled. The stiffeners are oriented in the γ-direction and all edges of the stiffened panel are assumed to be simply supported. A 15-by-23 spatial integration grid and a 4-microsecond time step in the temporal integration are used in the analysis. For the elastic-plastic response in shot 5, five integration points through the thickness of the panel skin are used and the webs of the stiffeners are divided evenly into 4 segments. For the analytical solutions of the two shots, 36 modes were selected out of a 5 by 9 matrix of symmetric modes.

Comparisons between analytical and experimental strain and displacement time histories are made for the various response locations published in reference 4. Strain responses at the center of the stiffener are compared at the lower surface of the lower flange (S10-6) and lower surface of the upper flange (S10-4). Strains on the panel skin at the center of the stiffened panel are compared at the upper skin surface in the γ-direction (S10-2c) and in the β-direction (S10-2a). Normal displacements are compared at the center of the stiffened panel. Figures 12-15 show these comparisons for shot 4 and figures 16-19 for shot 5 where the solid trace is the analytical results and the dashed trace is the measured results.

The largest strains occurred on the lower flange of the stiffener as shown in figures 12 and 16, respectively for shots 4 and 5. For this strain the comparison in magnitude and phasing are good. The strains in the upper flange of the stiffener and the upper surface of the panel skin are shown in figures 13 and 17, respectively, for shots 4 and 5. For these strains, which are much lower than those on the lower flange,

TABLE 3

PRESSURE MODELS FOR SPECIMEN 10

Shot 4		Shot 5	
Time (ms)	p (psi)	Time (ms)	p (psi)
0.0	3.0	0.0	4.5
1.1	2.0	0.5	4.0
1.4	2.87	1.2	7.75
1.6	4.2	1.6	5.2
2.0	2.8	2.4	3.3
2.7	2.3	2.6	3.7
4.0	0.1	3.6	2.05
4.7	0.75	4.0	3.5
4.8	2.25	5.8	2.2
5.3	1.45	6.3	3.25
6.0	1.6		

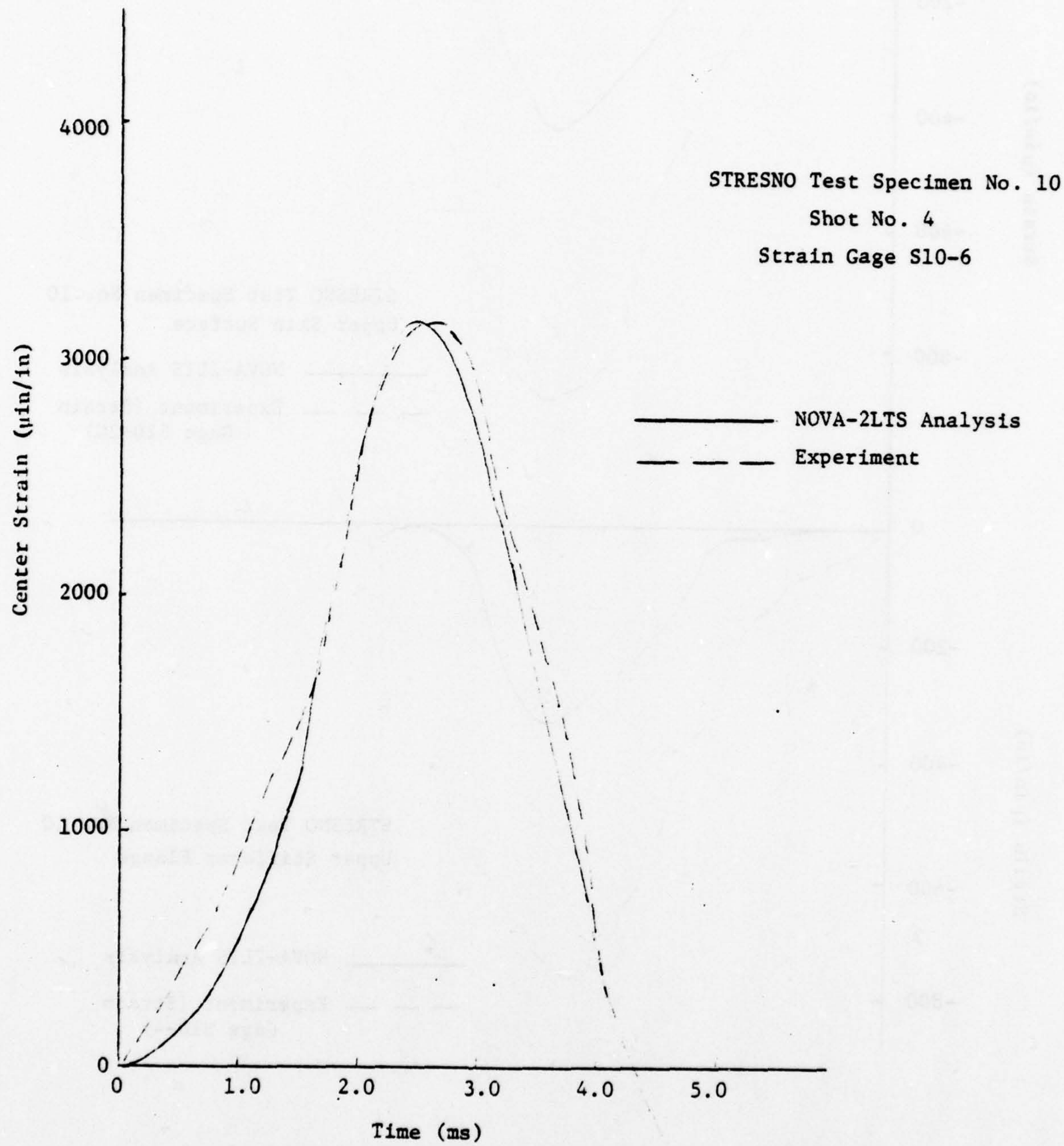


Figure 12. Center Strain Time Histories on Lower Flange of Stiffener for Shot No. 4

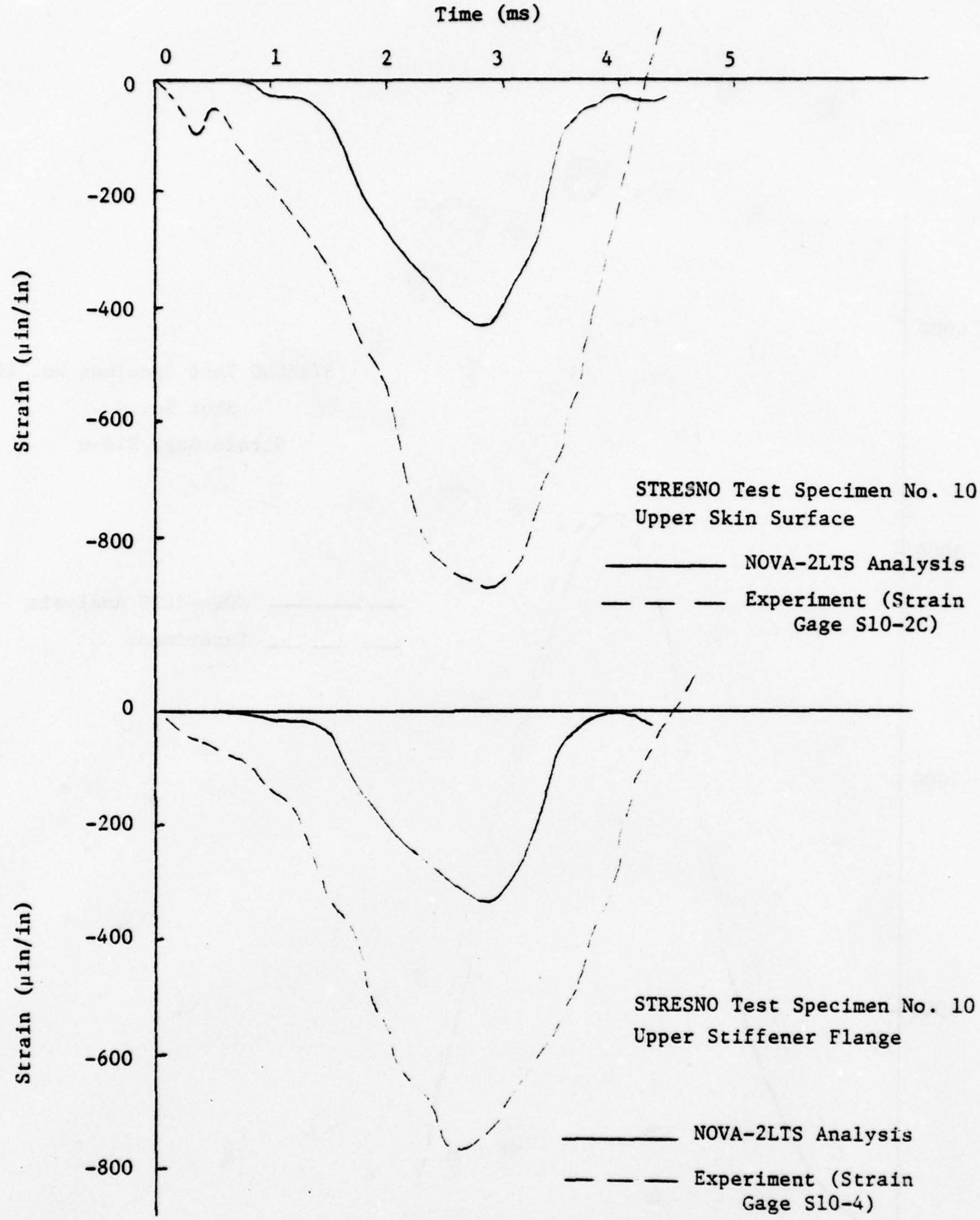


Figure 13. Center Strain Time Histories on Upper Panel Surface for Shot No. 4

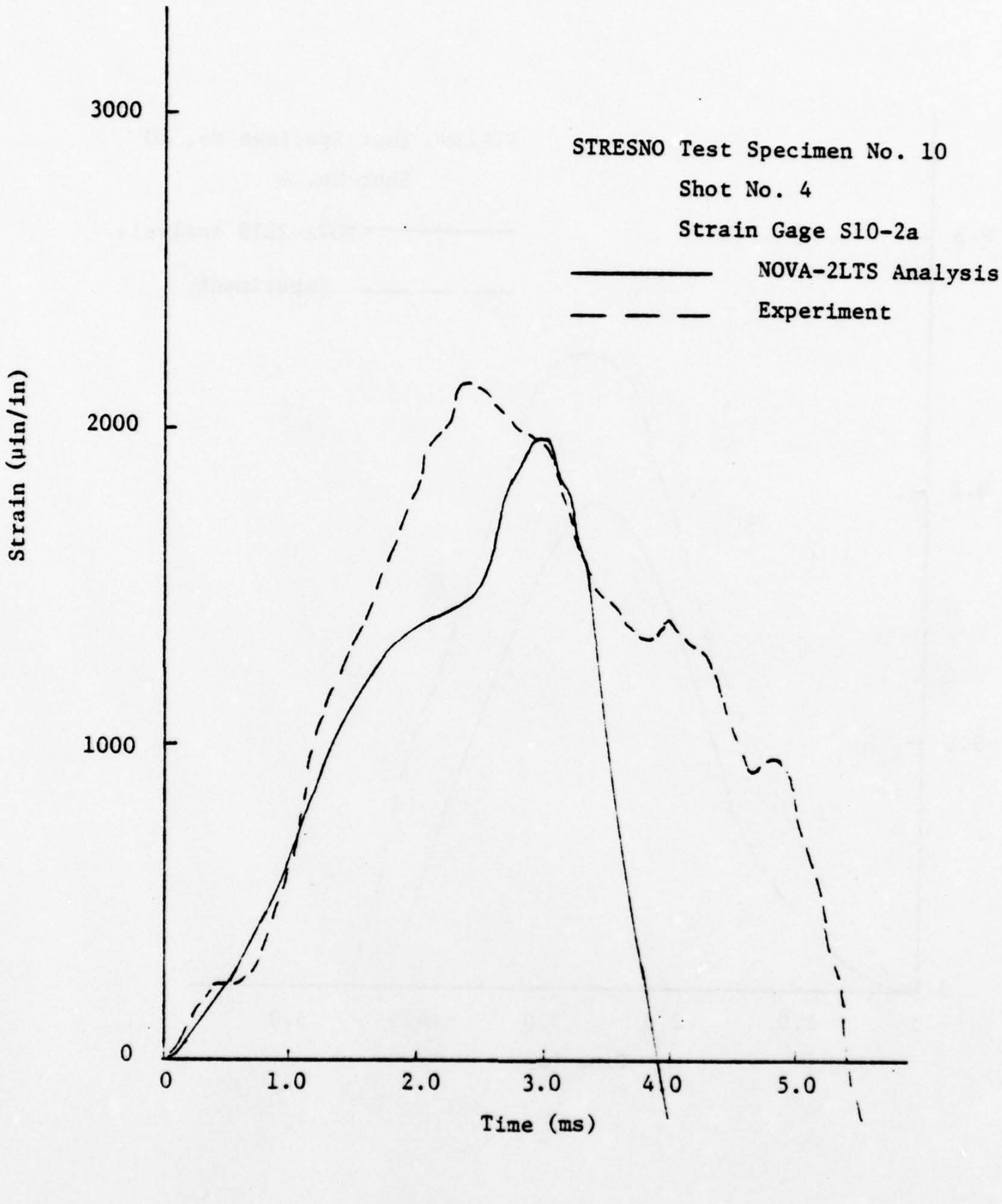


Figure 14. Center Strain Time Histories on Edge of Panel Skin for Shot No. 4

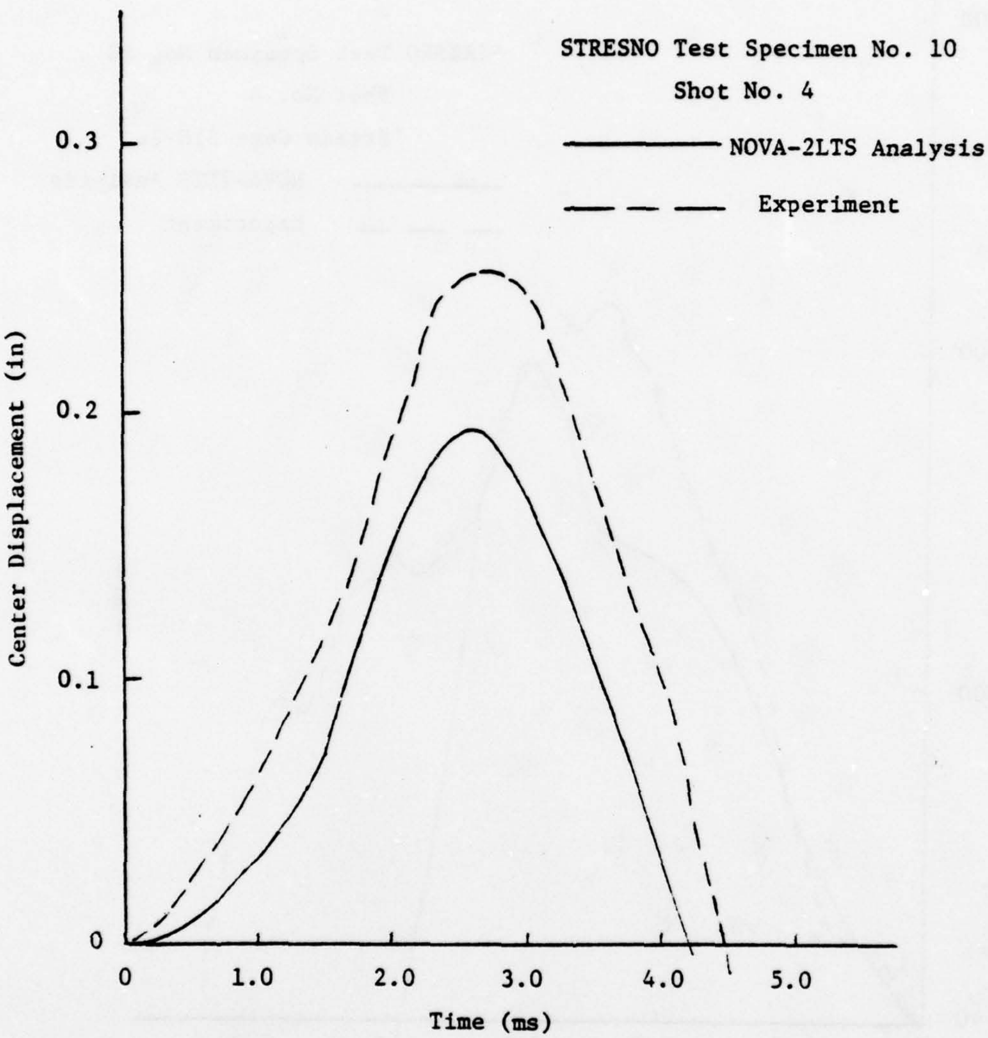


Figure 15. Center Displacement Time Histories of the Stiffened Panel for Shot No. 4

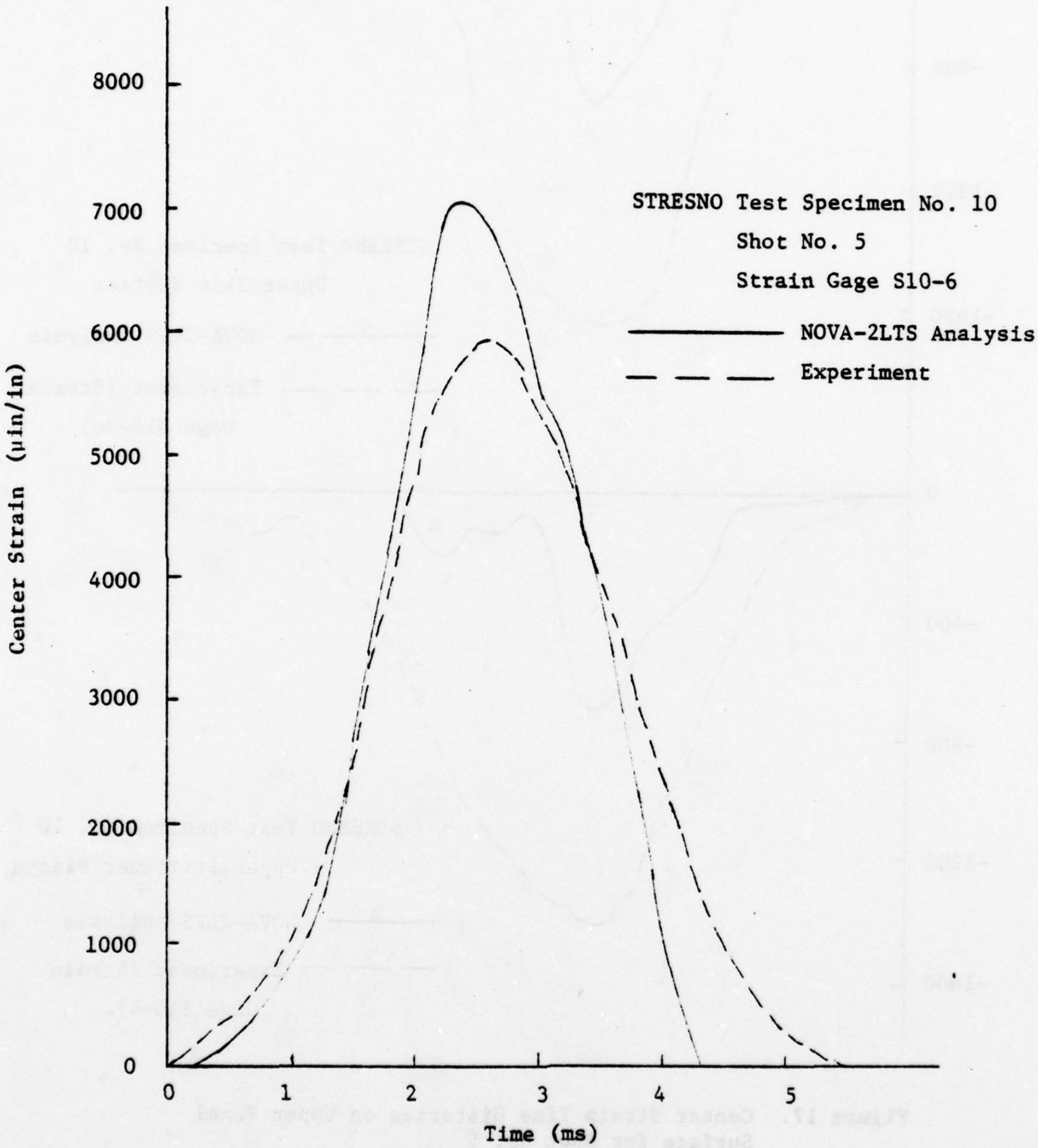


Figure 16. Center Strain Time Histories on Lower Flange of Stiffener for Shot No. 5

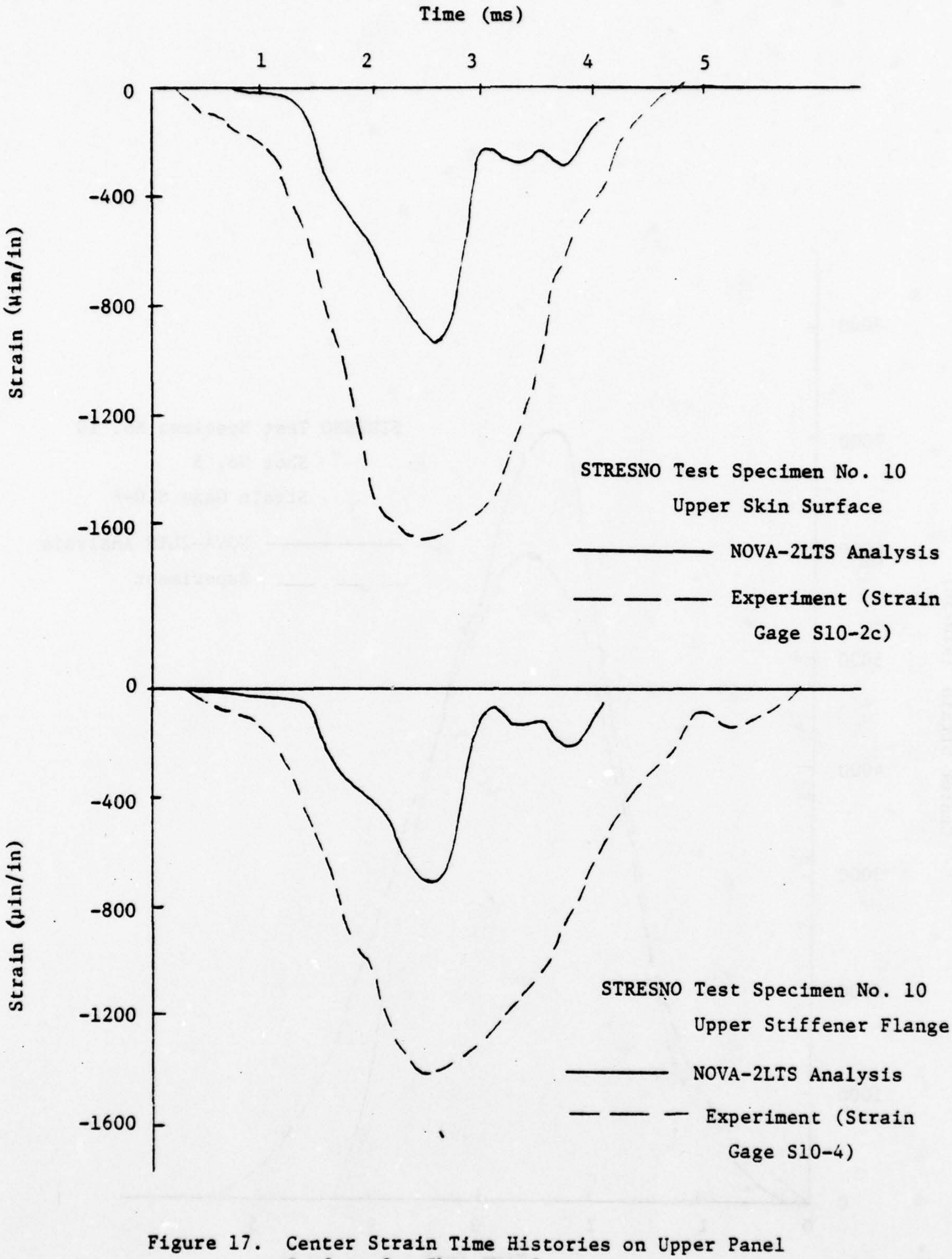


Figure 17. Center Strain Time Histories on Upper Panel Surface for Shot No. 5

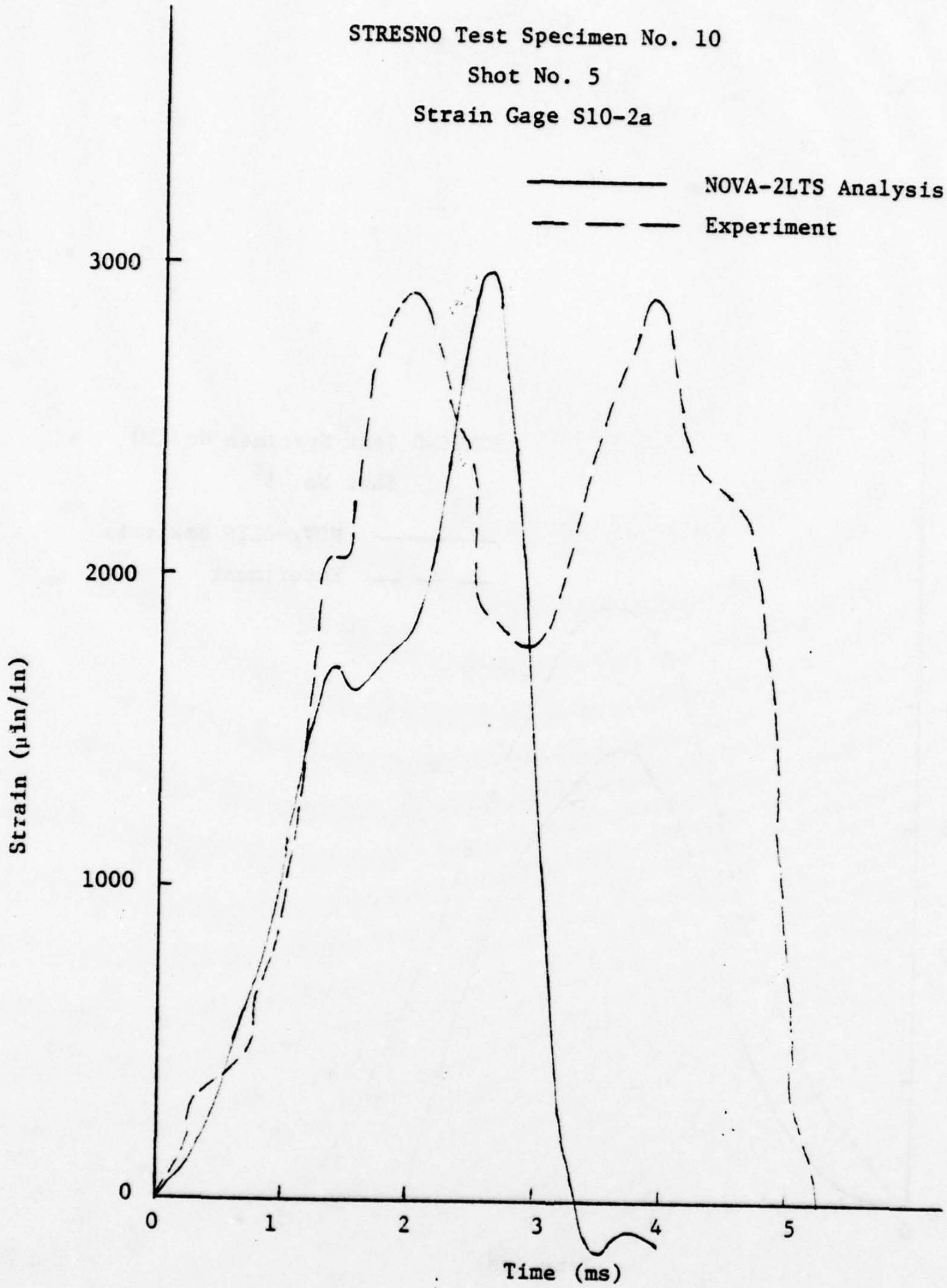


Figure 18. Center Strain Time Histories on Edge of Panel Skin for Shot No. 5

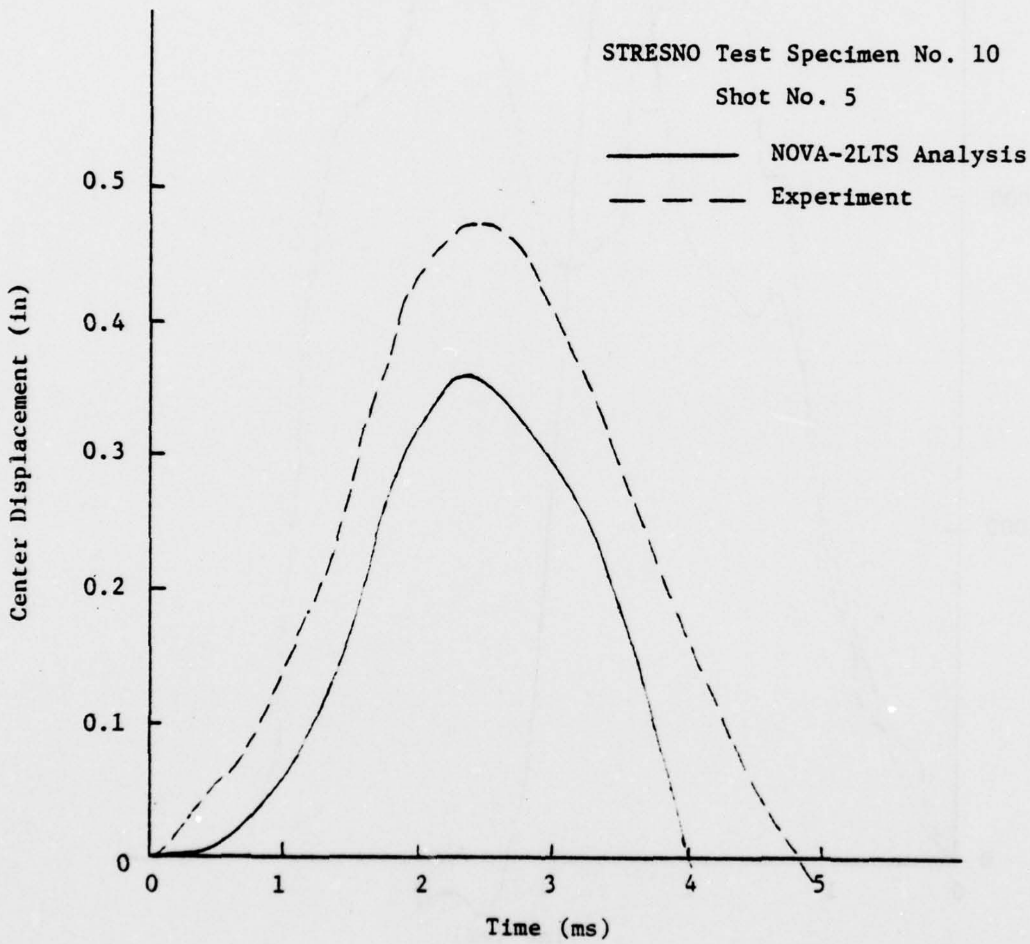


Figure 19. Center Displacement Time Histories of the Stiffened Panel for Shot No. 5

the phasing is good, but the magnitude of the measured strain is approximately double that of the analytical strain. This difference is misleading in that the distribution of the strains across the cross section is pretty good if the strain distribution is represented by the combination of pure bending and membrane strains. For example, if the extreme inner and outer strains are 3000 and 400 μin/in analytically and 3000 and 800 μin/in experimentally, the corresponding pure bending and membrane strains on the cross section are ±1700 and 1300 μin/in, analytically and ±1900 and 1100 μin/in, experimentally. Thus, the overall comparison for the strain distribution on the cross section is pretty good, even though the smaller analytical and experimented strains at the outer position differ by a factor of two.

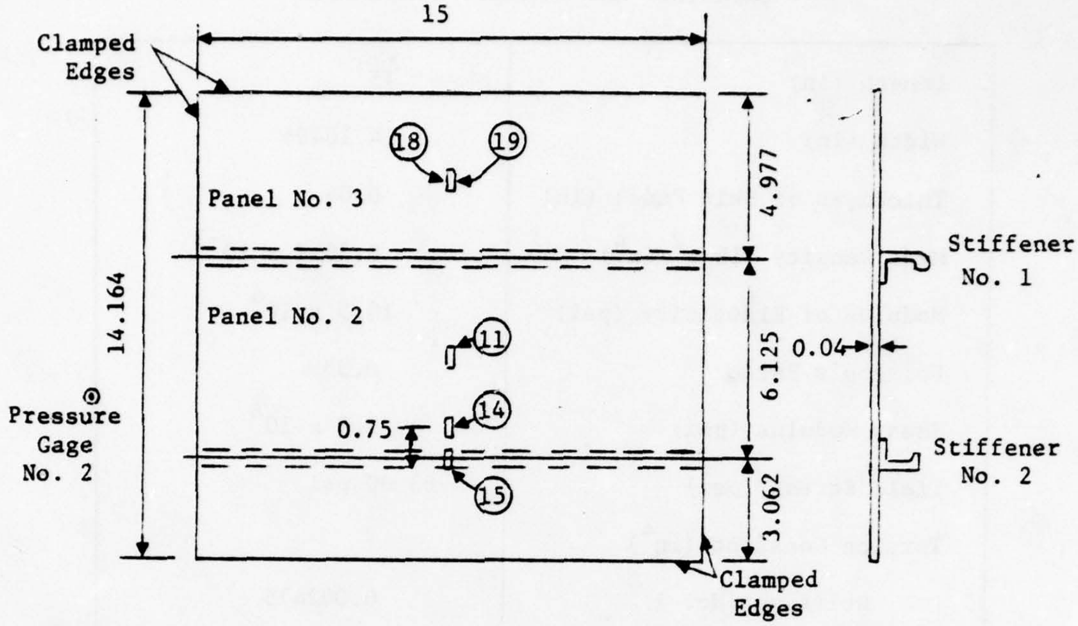
Figures 14 and 18 show the comparison of the edge strains at the upper skin surface of the local panel between stiffeners, respectively, for shots 4 and 5. The strain comparisons are good in peak magnitude but the phasing does not compare as well. Figures 15 and 19 illustrate the comparisons of the center displacement time histories, respectively, for shots 4 and 5. Although the phasing of the analytical and experimental displacement responses are good the experimental displacements are larger than the analytical ones. This is expected since it is believed the support system for the stiffened panel did not provide enough rigidity to prevent inplane movement of the boundaries. This inplane movement is magnified into significant additional normal displacements of the panel.

3.3 ANALYTICAL AND EXPERIMENTAL COMPARISONS FOR THE STIFFENED FIN PANEL OF THE A-4C AIRCRAFT

An instrumented A-4C aircraft was blast tested in the DICE THROW project at an approximate free-field overpressure level of 6 psi. The results of this test are reported in reference 5. Two areas of the vehicle were instrumented where the construction was of the stiffened panel type, namely, a nearly flat stiffened panel on the vertical fin and a curved stiffened panel on the aft fuselage. The curved fuselage panel, which contains the upper longerons as stiffeners, was eliminated from consideration due to uncertainties in its initial geometry and probable presence of coupling between the direct overpressure loading and the overall bending of the fuselage. The assumed flat panel on the vertical fin, which contains two intermediate stiffeners separating three panel bays, was the better defined structure from which to establish an analytical model.

The boundaries of this stiffened panel are supported by ribs and bulkheads which are continuous through the fin. These boundaries are assumed to be clamped in the analytical model. The geometry of the stiffened fin panel is shown in figure 20 along with the approximate cross sections of the stiffeners. The actual stiffened panels are only approximately rectangular but the analytical model is assumed rectangular. The material of the skin panel and stiffeners are 7075-T6. There were three experimental pressure time histories taken on the fin outside this panel area, but in the vicinity of the stiffened panel. Pressure gage number 2 was selected to represent the assumed uniform pressure load. Strains were measured only on the skin panel at the approximate locations indicated in figure 20 for panels designated as 2 and 3. The general geometric and material properties of the analytical model are given in table 4 and the pressure model is given in table 5 as determined from the pressure time history in figure 21. The structural response to this pressure load remains in the elastic range. Loading option 2 is used in NOVA-2LTS to input the segmented pressure time history.

The two inner stiffeners are oriented in the γ-direction and the actual dimensions of the panel are changed slightly to achieve the desired stiffener spacing within the selected integration grid in the β-direction. Since there is only symmetry in the γ-direction, half the stiffened panel is modeled for the analysis. All edges of the stiffened panel are assumed clamped. A 15-by-38 spatial integration grid and a 2.25-microsecond time step in the temporal integration are used in the analysis. From a 5 by 7 matrix of symmetric modes, 34 modes were used in the solution.

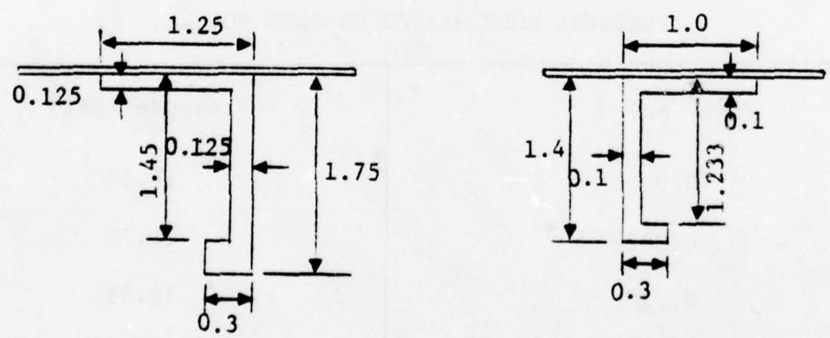


Notes:

All length dimensions in inches

◎ indicates location of pressure gage

▯ indicates locations of strain gages



Stiffener No. 1

Stiffener No. 2

Stiffener Cross Sections

Figure 20. A-4C Aircraft Fin Stiffened Panel Model

TABLE 4

GEOMETRIC AND MATERIAL PROPERTIES

Length (in)	15
Width (in)	14.16406
Thickness of Skin Panel (in)	0.04
Mass Density ($lb\text{-}s^2/in^4$)	0.2617×10^{-3}
Modulus of Elasticity (psi)	10.5×10^6
Poisson's Ratio	0.33
Shear Modulus (psi)	3.9×10^6
Yield Stress (psi)	68500 psi
Torsion Constant (in^4)	
Stiffener No. 1	0.002475
Stiffener No. 2	0.00103

TABLE 5

PRESSURE MODEL BASED ON GAGE NO. 2

Time (ms)	Pressure (psi)
0.0	16.58
0.3623	21.75
0.725	16.58
5.0	8.56
7.25	7.92
9.05	6.99

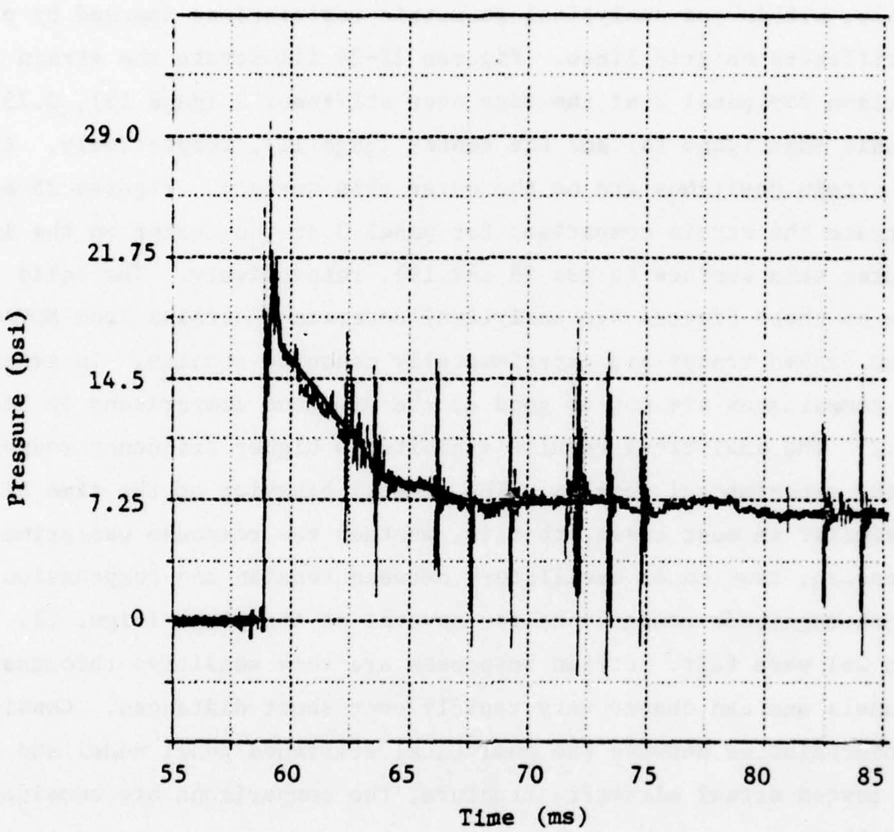


Figure 21. Reflected Pressure Time History for Pressure Gage No. 2

Comparisons between analytical and experimental strain time histories are made for measurements at gages 11, 14, 15, 18 and 19 as shown in figure 20. All these strain measurements are in the β-direction and are at or very close to the center of the panel in the γ-direction. Because of the slight distortion of the panel dimensions in the β-direction and the evenly spaced integration points, the analytical strain positions do not exactly coincide with the measured positions, but are as close as possible, within the analytical geometric restrictions imposed by placing the stiffeners on grid lines. Figures 22-24 illustrate the strain comparison for panel 2 at the edge over stiffener 2 (gage 15), 0.75 inches from this edge (gage 14) and the center (gage 11), respectively. All these strain positions are on the outer skin surface. Figures 25 and 26 illustrate the strain comparison for panel 3 at the center on the inner and outer skin surface (gages 18 and 19), respectively. The solid traces on these figures are analytical determined strains from NOVA-2LTS and the dashed traces are experimentally measured strains. In general, these comparisons are not as good as the previous comparisons in Sections 3.1 and 3.2. The analytical results exhibited a higher frequency response than the experimental results. The general behavior of the time history were similar in most cases, that is, whether the response was primarily compression, tension or oscillatory between tension and compression. The peak magnitude comparisons for several of the plots (figs. 22, 23 and 26) were fair. Strain responses are very sensitive throughout the panels and can change very rapidly over short distances. Considering the uncertainties between the analytical stiffened panel model and a field tested actual aircraft structure, the comparisons are considered reasonable.

3.4 CONCLUSIONS

The stiffened panel analysis using NOVA-2LTS has been compared to experiments on stiffened panels that varied in the quality of the testing techniques employed. The NOVA-2LTS stiffened panel analysis comparisons with the well defined laboratory tests are, generally, very good. Comparisons are good for the lesser controlled large shock tube

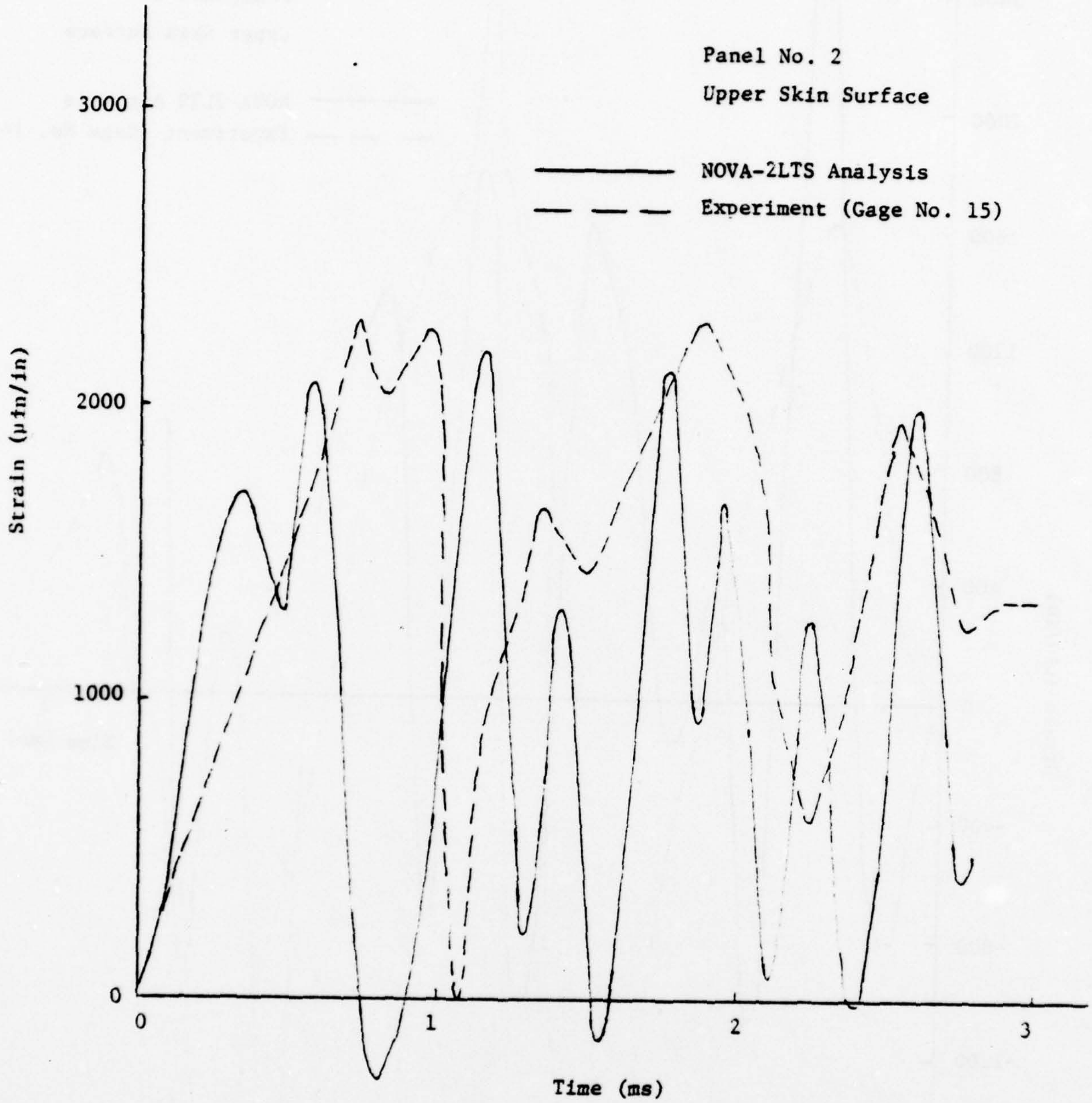


Figure 22. Edge Strain Time Histories of the A-4C Aircraft Fin Stiffened Panel

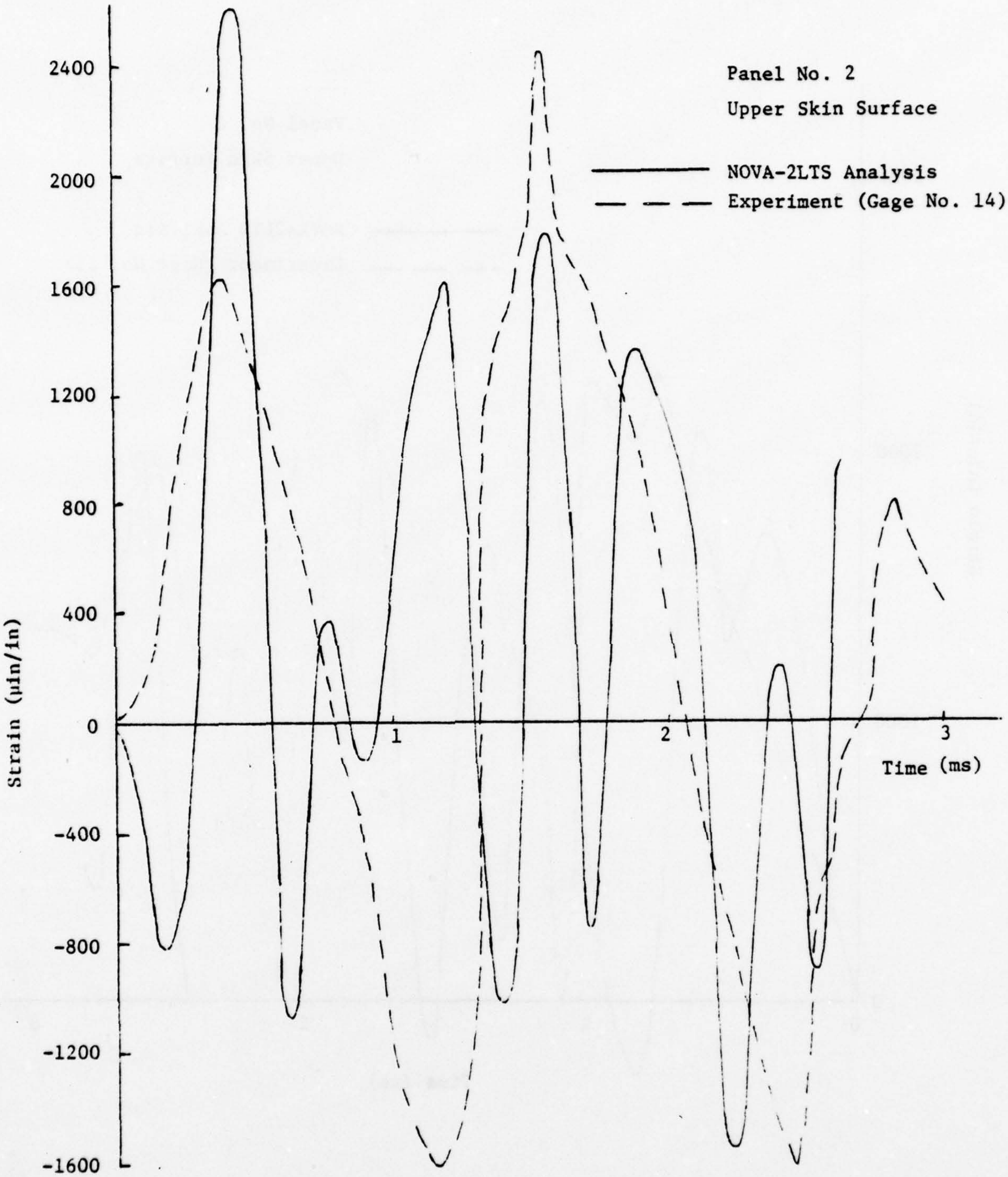


Figure 23. Strain Time Histories 0.75 in from Edge of the A-4C Aircraft Fin Stiffened Panel

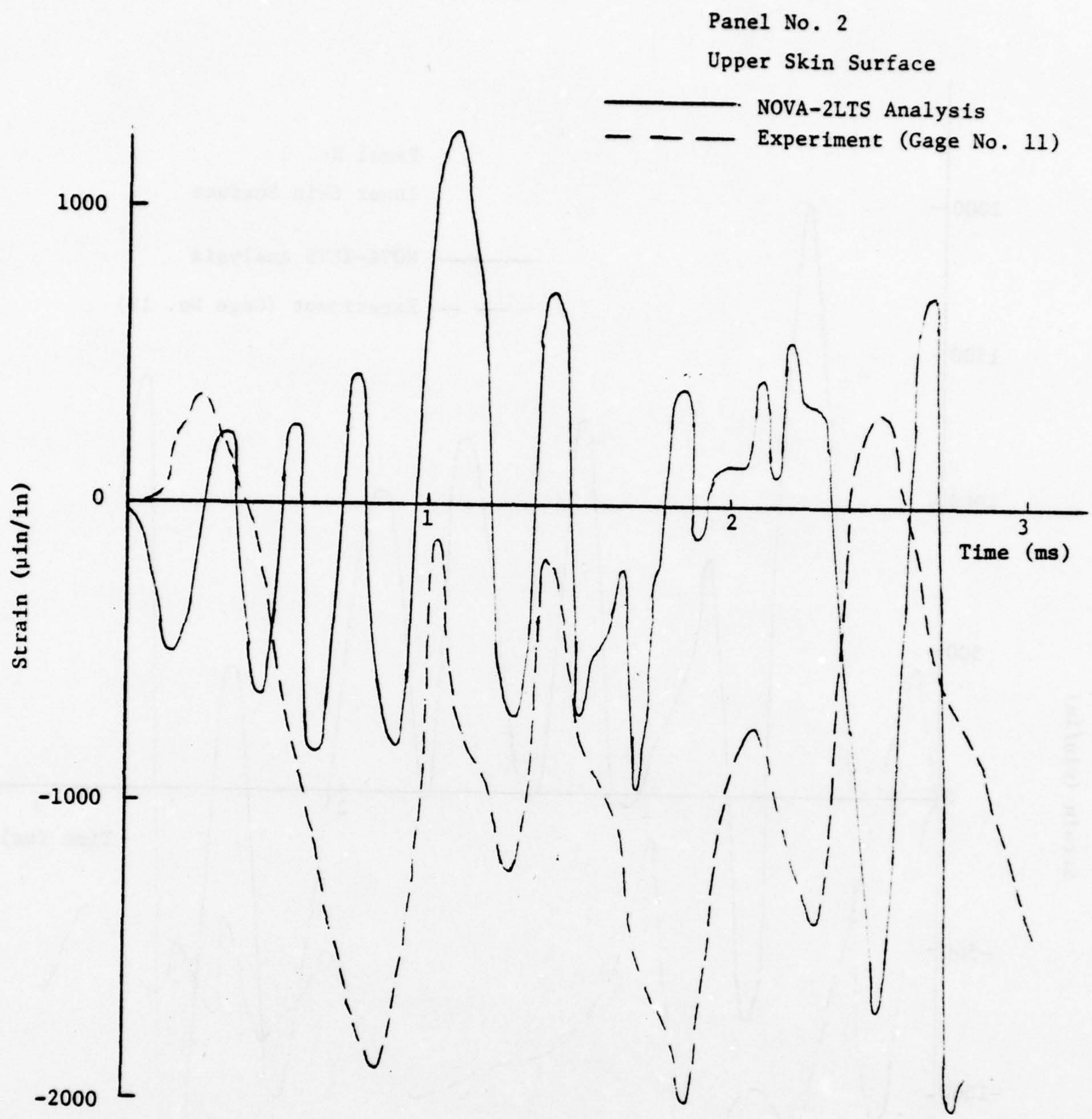


Figure 24. Center Strain Time Histories in Panel No. 2 of the A-4C Aircraft Fin Stiffened Panel

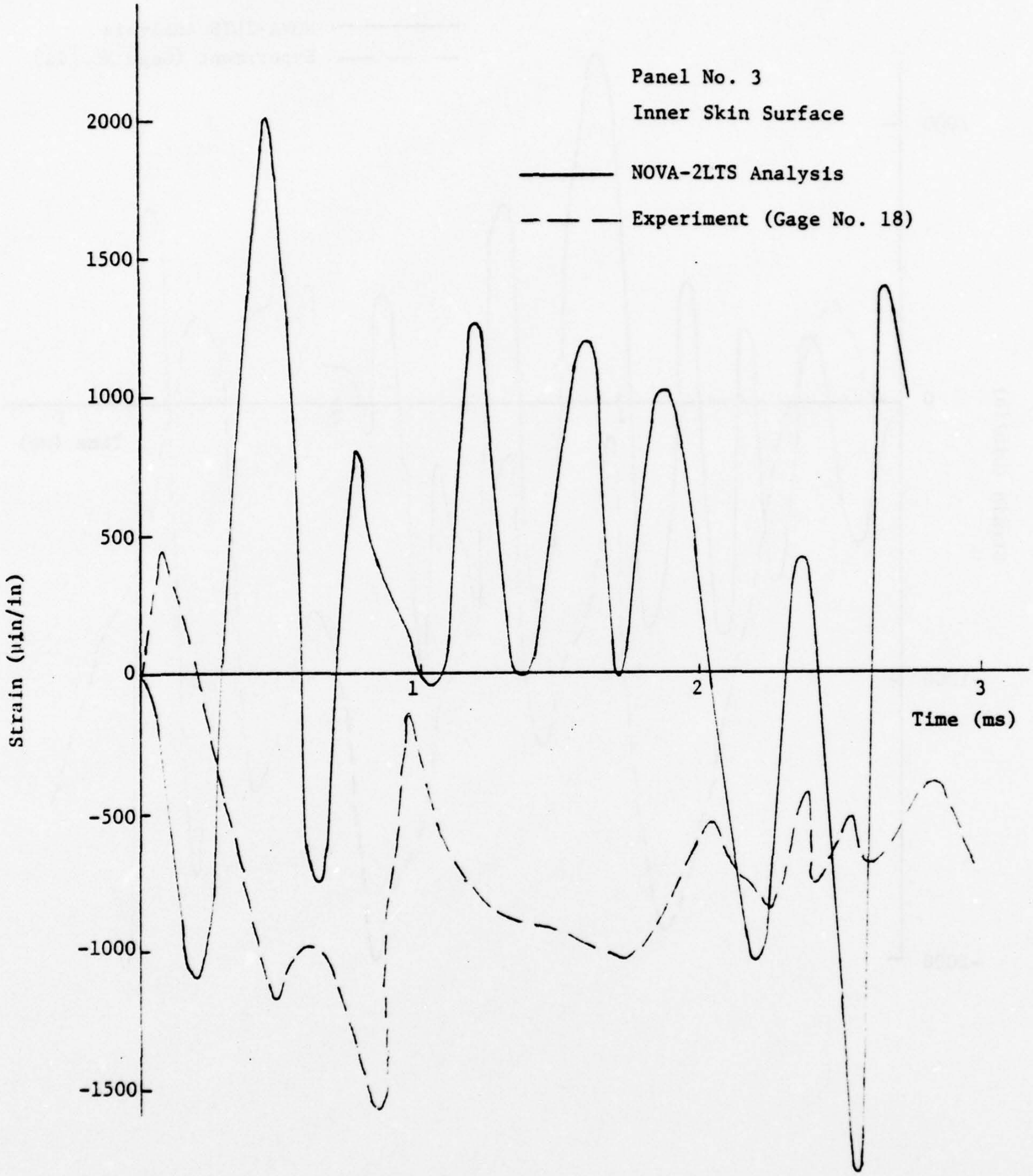


Figure 25. Center Inner Surface Strain Time Histories in Panel No. 3 of the A-4C Aircraft Fin Stiffened Panel

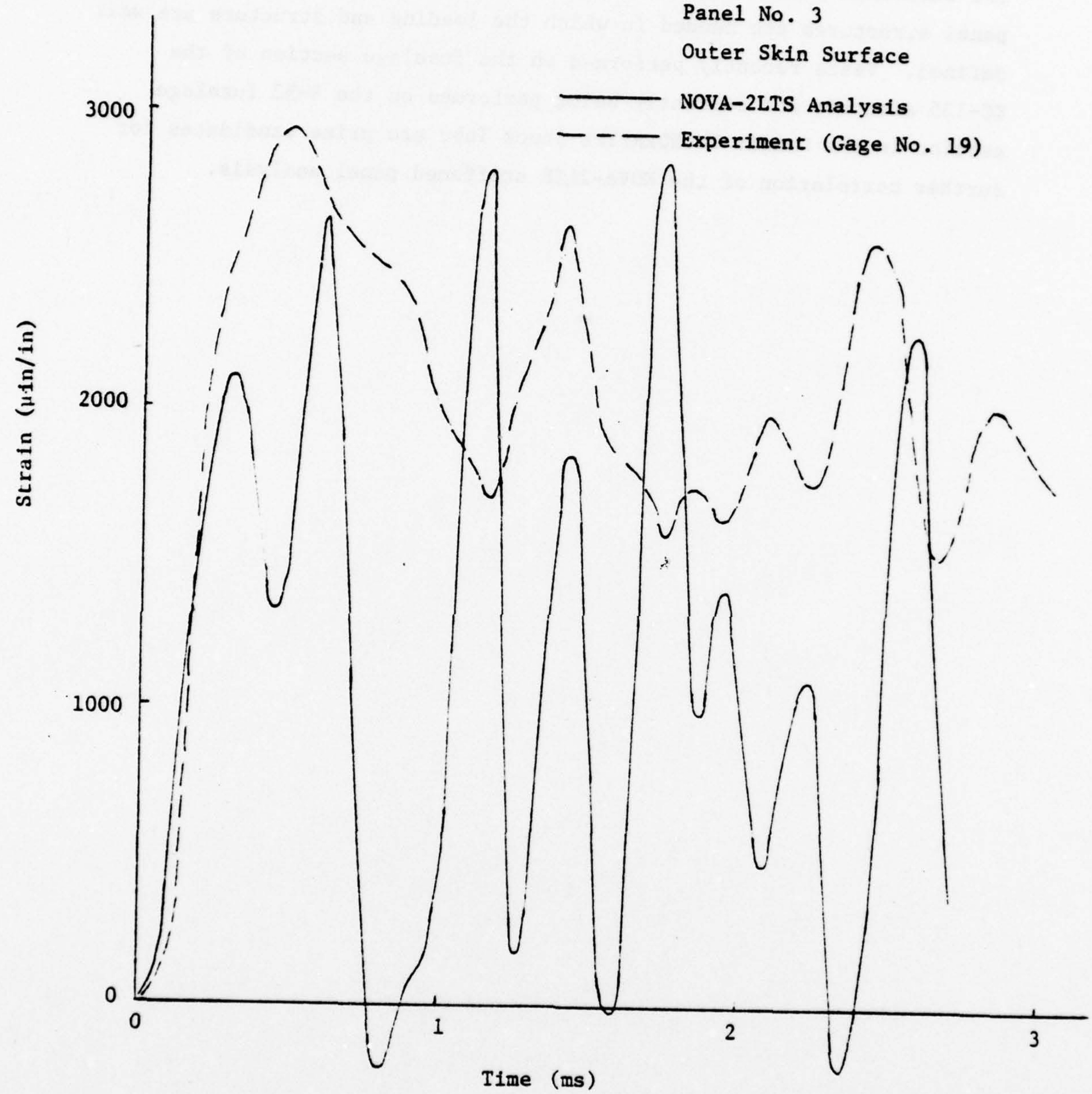


Figure 26. Center Outer Surface Strain Time Histories in Panel No. 3 of the A-4C Aircraft Fin Stiffened Panel

tests on special structural models and are at best fair for the least controlled field test of an actual aircraft. More comparisons between the stiffened panel analysis and tests on actual aircraft stiffened panel structures are needed in which the loading and structure are well defined. Tests recently performed on the fuselage section of the KC-135 aircraft and currently being performed on the B-52 fuselage section in the Sandia THUNDERPIPE Shock Tube are prime candidates for further correlation of the NOVA-2LTS stiffened panel analysis.

SECTION IV

EVALUATION OF THE STIFFENED PANEL ANALYSIS VERSUS INDIVIDUAL COMPONENT ANALYSIS

The stiffened panel analysis option of NOVA-2S is evaluated relative to the analyses of individual components of the stiffened panel (stiffener and panel between stiffeners) using the beam and pure panel options of NOVA-2S which have been retained from the original NOVA-2. Three stiffened panel configurations have been selected from the B-52 aircraft structure in this evaluation and subjected to the overpressure loading from a nominal nuclear encounter with the B-52 aircraft. The evaluation is based on the two levels of damage considered in NOVA-2S, namely, threshold of permanent damage and catastrophic damage. Analyses are performed using the response-only option in NOVA-2S for the entire stiffened panel, the individual stiffener, and the pure panel between stiffeners at the same load level (equal ranges). The ranges at which the response comparisons are to be made are determined by the weakest structure reaching the two damage levels. For this response evaluation, comparisons of the critical response levels are made for the three structures. Secondly, analyses are performed using the iteration option in NOVA-2S to determine the critical slant range at which threshold of permanent damage and catastrophic damage occurs for the stiffened panel and the governing individual structural component or element. Comparisons of the slant ranges are made for this evaluation. The objective of the response and range evaluations is to show the degree of error introduced by analyzing the components of a stiffened panel individually as is done in the beam and panel options of NOVA-2 rather than analyzing the entire stiffened panel by NOVA-2S. If individual structural components analyses are acceptable compared with the complete stiffened structure analysis, there is, generally, an advantage of less computer cost using the individual component analyses.

Three stiffened panels were selected for analysis from the B-52 aircraft structure which exhibit skin-stringer-frame type of construction. These three stiffened panels were selected from reference 6 and are generally described as follows:

1) a three bay skin-stringer panel in the vertical fin bounded between rudder stations 2 and 44 and between the aft auxilary spar and closure beam (see figs. 19 and 20 of ref. 6);

2) a twelve bay skin-frame panel in the aft fuselage bounded between the upper and lower longerons and between stations 1357 and 1477 (see figs. 8 and 11 of ref. 6); and

3) an eighteen bay skin-stringer panel in the upper wing surface bounded between the front and rear spars and between WS402 and 372 (see fig. 31 of ref. 6).

The purpose of the models selected is only to serve as example structures to evaluate the stiffened panel analysis versus individual component analysis and not to analyze the vulnerability of the B-52 aircraft. Therefore, the model geometry and loading distributions will be idealized to produce symmetry in both coordinate directions in order to obtain more accurate solutions for the stiffened panels with the available integration points and modes for comparison with the individual component solutions.

The general information required by NOVA-2S involving the principal dimensions of the B-52 aircraft are given in reference 6. Location dimensions of the selected stiffened panels are also given in reference 6. The nuclear burst orientation relative to the aircraft for the vertical fin and fuselage panels is from the side at orientation number 15 while for the wing panel the orientation is from above at orientation number 9. The pressure loadings on these panels were assumed to be uniform.

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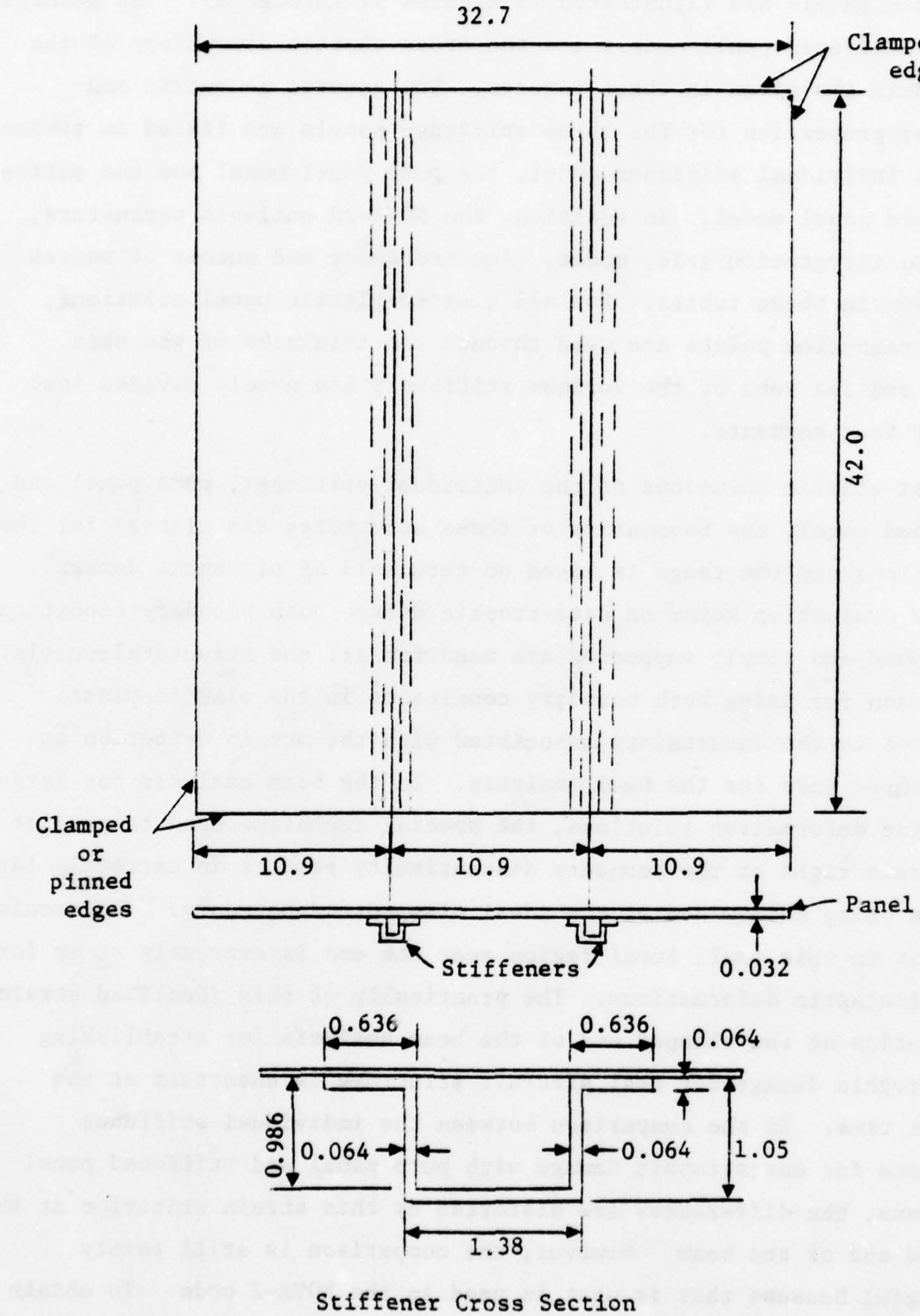
6. Leang, L. T. and Swaney, T. G., Analytical Models for the B-52H, EC-135A and 747-200B Aircraft, Air Force Weapons Laboratory, Kirtland AFB, AFWL-TR-72-197, Vol. XI (B-52H Aircraft), July 1974.

The idealized structural models for the fin, fuselage and wing stiffened panels are illustrated in figures 27 through 29. The geometry of the stiffened panel models and the cross section dimensions of the stiffeners are given in these figures. The general geometric and material properties for the three stiffened panels are listed in tables 6-8 for the individual stiffener model, the pure panel model and the entire stiffened panel model. In addition, the NOVA-2S analysis parameters, such as, integration grid, modes, time increment and number of masses are given in these tables. For all elastic-plastic panel solutions, five integration points are used through the thickness of the skin panel, and the webs of the various stiffeners are evenly divided into usually four segments.

For elastic solutions of the individual stiffener, pure panel and stiffened panel, the boundaries of these structures are clamped for the evaluations and the range is keyed on threshold of permanent damage. For the evaluation keyed on catastrophic damage both boundary conditions of clamped and simply supported are used for all the structural models. The reason for using both boundary conditions in the elastic-plastic solutions is the uncertainty associated with the strain criterion at the clamped ends for the beam analysis. In the beam analysis for large inelastic deformation solutions, the special technique used to predict the strain right at the boundary discontinuity results in extremely large strains being determined at the ideal clamped end boundary. The strain gradient in this small local region near the end is extremely steep for large inelastic deformations. The practically of this idealized strain calculation at the clamped end of the beam analysis for establishing catastrophic damage for real aircraft structure is uncertain at the present time. In the comparison between the individual stiffener solutions for catastrophic damage with pure panel and stiffened panel solutions, the differences are distorted by this strain criterion at the clamped end of the beam. However, the comparison is still partly meaningful because that is what is used in the NOVA-2 code. To obtain a



Note: All length dimensions in inches

Figure 27. Vertical Fin Stiffened Panel Model

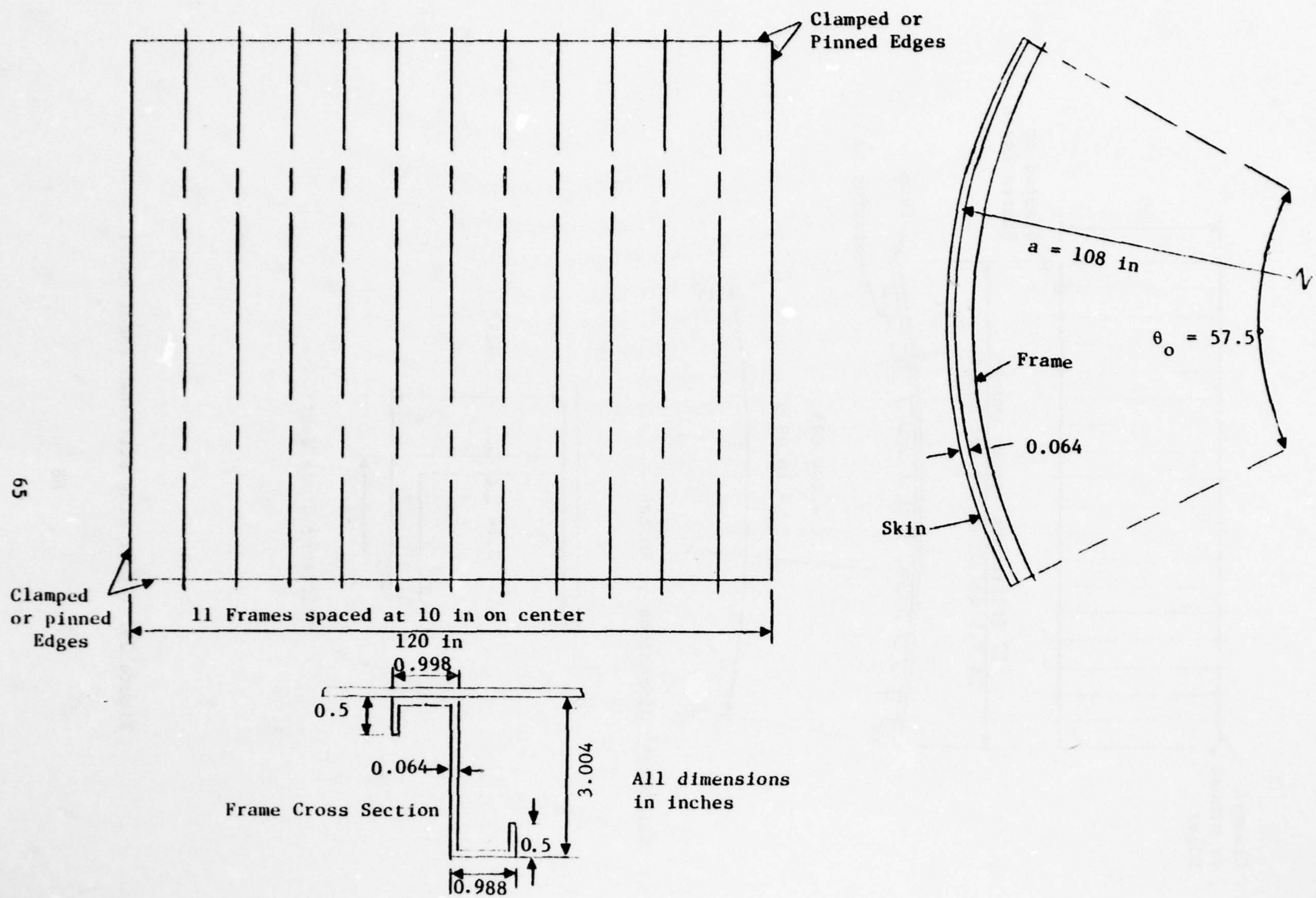
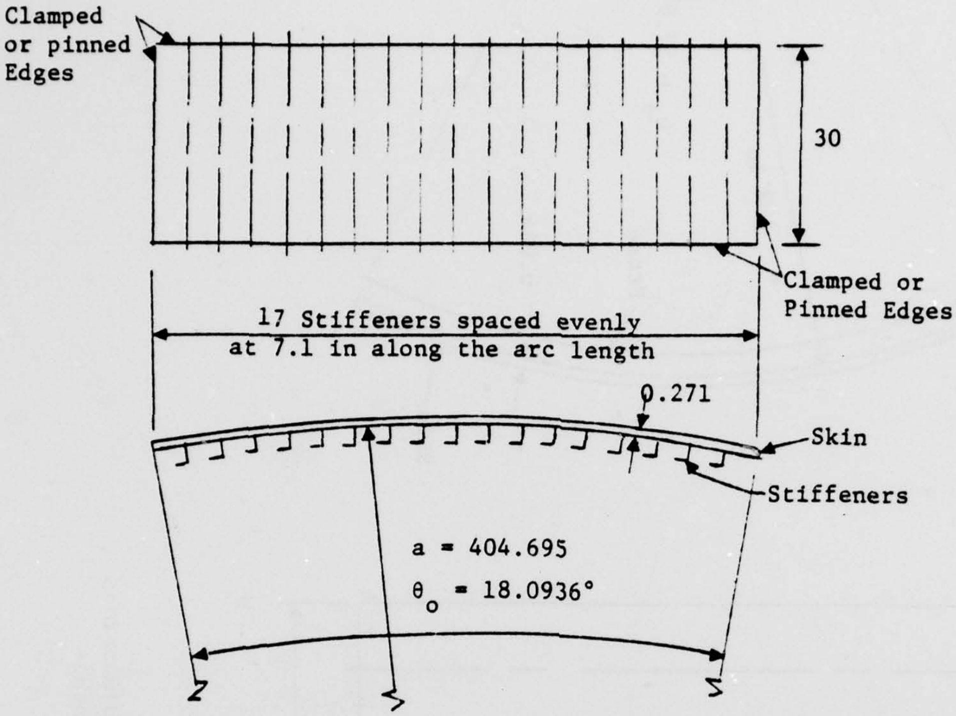
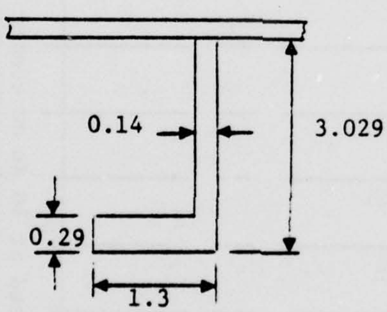


Figure 28. Aft Fuselage Stiffened Panel Model



Note: All length dimensions in inches



Stiffener Cross Section

Figure 29. Upper Wing Stiffened Panel Model

TABLE 6

GEOMETRIC AND MATERIAL PROPERTIES OF THE VERTICAL FIN PANEL

	Individual Stiffener	Pure Panel	Stiffened Panel
Length (in)	42.0	42.0	42.0
Width (in)	-	10.9	32.7
Stiffener Spacing (in)	10.9	-	10.9
Thickness of Skin Panel (in)	0.032	0.032	0.032
Effective Skin Width (in)	3.2	-	-
Mass Density ($lb\text{-}s^2/in^4$)	0.259×10^{-3}	0.259×10^{-3}	0.259×10^{-3}
Torsional Constant (in^4)	-	-	0.393×10^{-3}
Number of Masses	10	-	-
Integration Grid	-	19 x 19	19 x 19
Number of Modes	-	30	30
Time Increment (s)	9×10^{-6}	2×10^{-6}	4×10^{-6}

	Skin Panel Material (2024-T3 AL)	Stiffener Material (7075-T6 AL)
Modulus of Elasticity (psi)	10.5×10^6	10.4×10^6
Shear Modulus (psi)	4.0×10^6	4.0×10^6
Poisson's Ratio	0.33	0.33
Yield Stress (psi)	50000	70500
Strain Hardening Slope (psi)	1.24×10^5	5.9×10^4
Ultimate Strain (in/in)	0.15	0.1

TABLE 7

GEOMETRIC AND MATERIAL PROPERTIES OF THE AFT FUSELAGE PANEL

	Individual Stiffener	Pure Panel	Stiffened Panel
Length (in)	-	10.0	120.0
Subtended Angle (deg)	57.5	57.5	57.5
Radius (in)	106.5	108.0	108.0
Stiffener Spacing (in)	10.0	-	10.0
Thickness of Skin Panel (in)	0.064	0.064	0.064
Effective Skin Width (in)	1.92	-	-
Mass Density ($lb\text{-}s^2/in^4$)	0.259×10^{-3}	0.259×10^{-3}	0.259×10^{-3}
Torsional Constant (in^4)	-	-	0.959×10^{-3}
Number of Masses	15	-	-
Integration Grid	-	15 x 23	19 x 19
Number of Modes	-	26	30
Time Increment (s)	10×10^{-6}	2×10^{-6}	8×10^{-6}
	Skin Panel and Stiffener Material (7075-T6 AL)		
Modulus of Elasticity (psi)	10.4×10^6		
Shear Modulus (psi)	4×10^6		
Poisson's Ratio	0.33		
Yield Stress (psi)	70500		
Strain Hardening Slope (psi)	5.9×10^4		
Ultimate Strain (in/in)	0.1		

TABLE 8

GEOMETRIC AND MATERIAL PROPERTIES OF THE UPPER WING PANEL

	Individual Stiffener	Pure Panel	Stiffened Panel
Length (in)	30.0	30.0	30.0
Subtended Angle (deg)	-	1.005201	18.093624
Radius (in)	-	404.695	404.695
Stiffener Spacing (in)	7.1	-	7.1
Thickness of Skin Panel (in)	0.271	0.271	0.271
Effective Skin Width (in)	5.6	-	-
Mass Density (lb-s^2 in^4)	0.259×10^{-3}	0.259×10^{-3}	0.259×10^{-3}
Torsional Constant (in^4)			0.0131
Number of Masses	15	-	-
Integration Grid	-	19 x 15	15 x 28
Number of Modes	-	28	28
Time Increment (s)	2×10^{-6}	1.5×10^{-6}	4×10^{-6}

	Skin Panel and Stiffener Material (7075-T6 AL)
Modulus of Elasticity (psi)	10.4×10^6
Shear Modulus (psi)	4×10^6
Poisson's Ratio	0.33
Yield Stress (psi)	70500
Strain Hardening Slope (psi)	5.9×10^4
Ultimate Strain (in/in)	0.1

more valid comparison which is not shadowed by uncertainty in the critical strain criteria, the beam, pure panel and stiffened panel models also are used with simply supported boundary conditions which shifts the critical strain location away from the boundaries. With the simply supported boundaries all three structural models used in the evaluation are compatible on a criteria basis.

The results of this evaluation based on response and slant range comparisons are given in tables 9 and 10, respectively. Table 9 gives elastic and inelastic response comparisons at constant slant range (equal loading) between the individual structural elements and the stiffened panel analysis for the three structural configurations. The evaluation is based on the comparison of the CRIT values determined at the range at which CRIT is approximately unity for the weakest structure. CRIT is the ratio of the critical stress or strain response parameter in the structure to the yield stress value for threshold of permanent damage or ultimate strain value for catastrophic damage.

In all cases considered in this evaluation, the individual stiffener was the weakest structure. Therefore, the range (or loading) which produced yielding for the elastic response or fracturing for the elastic-plastic response in the individual stiffener is used as the basis for the comparison between the individual element analysis approach and the stiffened panel analysis. The percentage difference tabulated in table 9 indicates the error introduced by using the individual element approach instead of the more correct stiffened panel analysis.

To further illustrate the differences in the structural response for the two analysis approaches under the same loading, figures 30-40 show selected comparisons for displacement, stress, and strain time histories. For elastic solutions, comparisons were made for the center displacement response on the central stiffener, the end stress or strain response of the central stiffener, and the stress or strain response at some position on the skin panel adjacent to the central stiffener. It should be noted that skin panel comparisons are also influenced by

TABLE 9

RESPONSE COMPARISON AT CONSTANT SLANT RANGE

Vertical Fin Panel						
Type of Response	Elastic		Elastic-Plastic		Elastic-Plastic	
Boundary Condition	Clamped		Clamped		Simply Supported	
Analysis Approach	CRIT	% Diff.	CRIT	% Diff.	CRIT	% Diff.
Individual Elements		18.7		822		227
a) Stiffener	1.0		1.005		0.99	
b) Panel	0.781		0.0486		0.0986	
Stiffened Panel	0.843		0.109		0.31	
Aft Fuselage Panel						
Analysis Approach	CRIT	% Diff.	CRIT	% Diff.	CRIT	% Diff.
Individual Elements		51.4		1187		2094
a) Stiffener	0.952		1.03		1.108	
b) Panel	0.794		0.117		0.0623	
Stiffened Panel	0.629		0.08		0.0505	
Upper Wing Panel						
Analysis Approach	CRIT	% Diff.	CRIT	% Diff.	CRIT	% Diff.
Individual Elements		-10.5		321		891
a) Stiffener	0.98		0.94		1.03	
b) Panel	0.81		0.275		0.074	
Stiffened Panel	1.095		0.223		0.104	

TABLE 10

DIFFERENCE IN SLANT RANGE BETWEEN INDIVIDUAL ELEMENT APPROACH AND STIFFENED PANEL ANALYSIS

Damage Criteria	TPD	CD	CD
Boundary Condition	Clamped	Clamped	Simply Supported
Structural Configuration	Percentage Difference		
Vertical Fin Panel	15.9	138	32.7
Aft Fuselage Panel	24.3	44.1	34.4
Upper Wing Panel	-4.04	11.1	56.6

TPD denotes threshold of permanent damage

CD denotes catastrophic damage

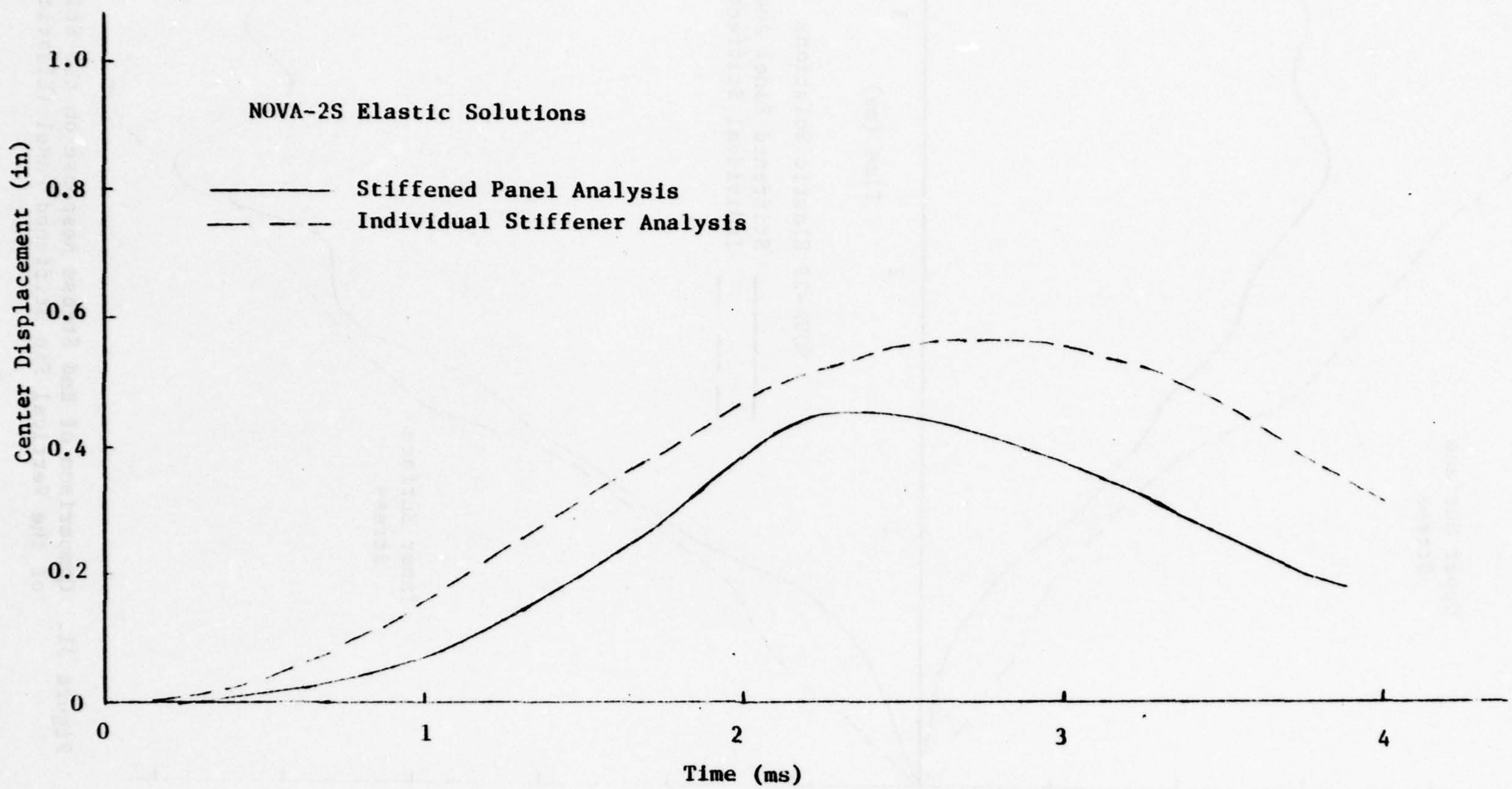


Figure 30. Comparison of Center Displacement Response on the Stiffener of the Vertical Fin Stiffened Panel (Elastic Solution)

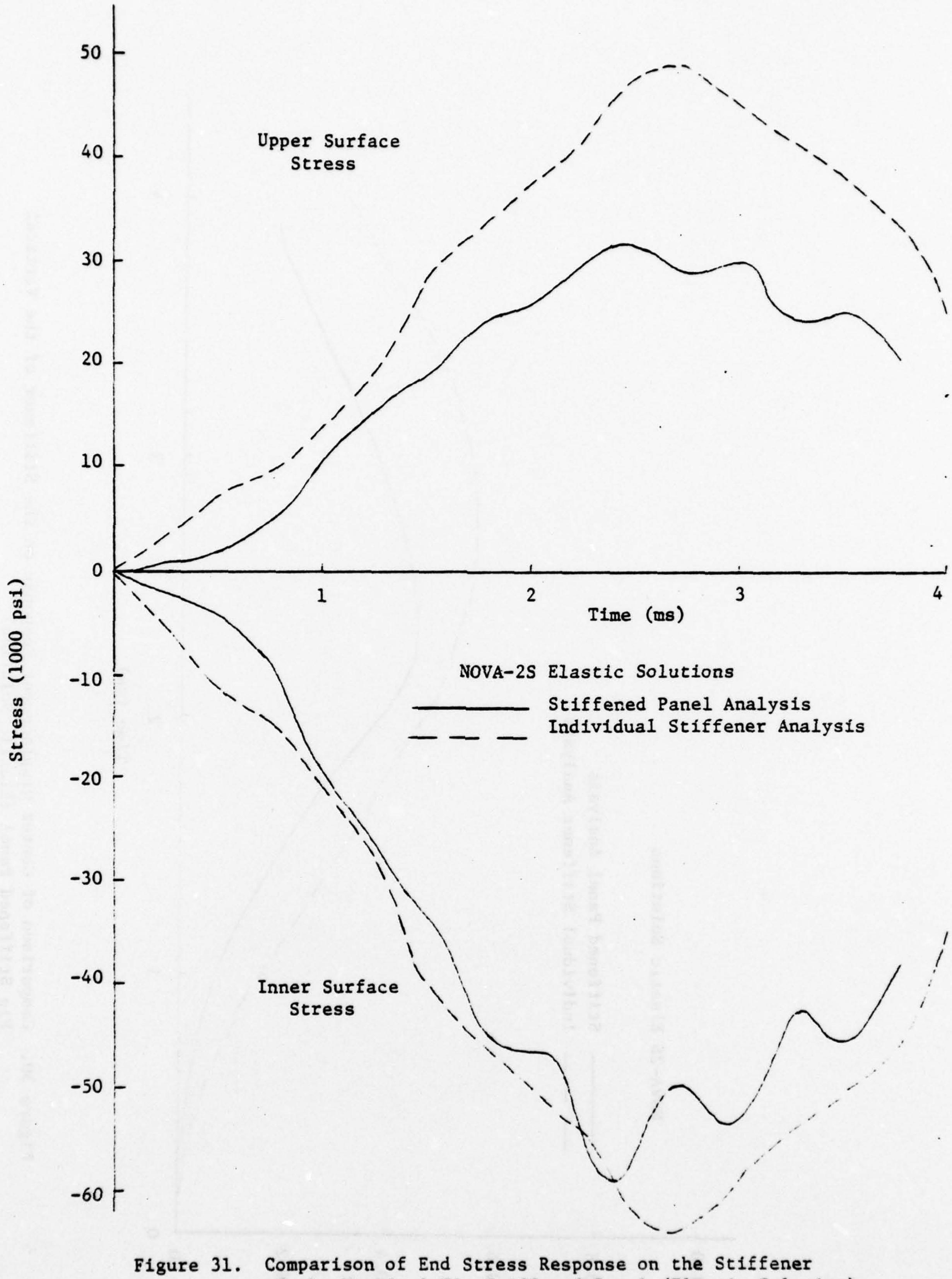


Figure 31. Comparison of End Stress Response on the Stiffener of the Vertical Fin Stiffened Panel (Elastic Solution)

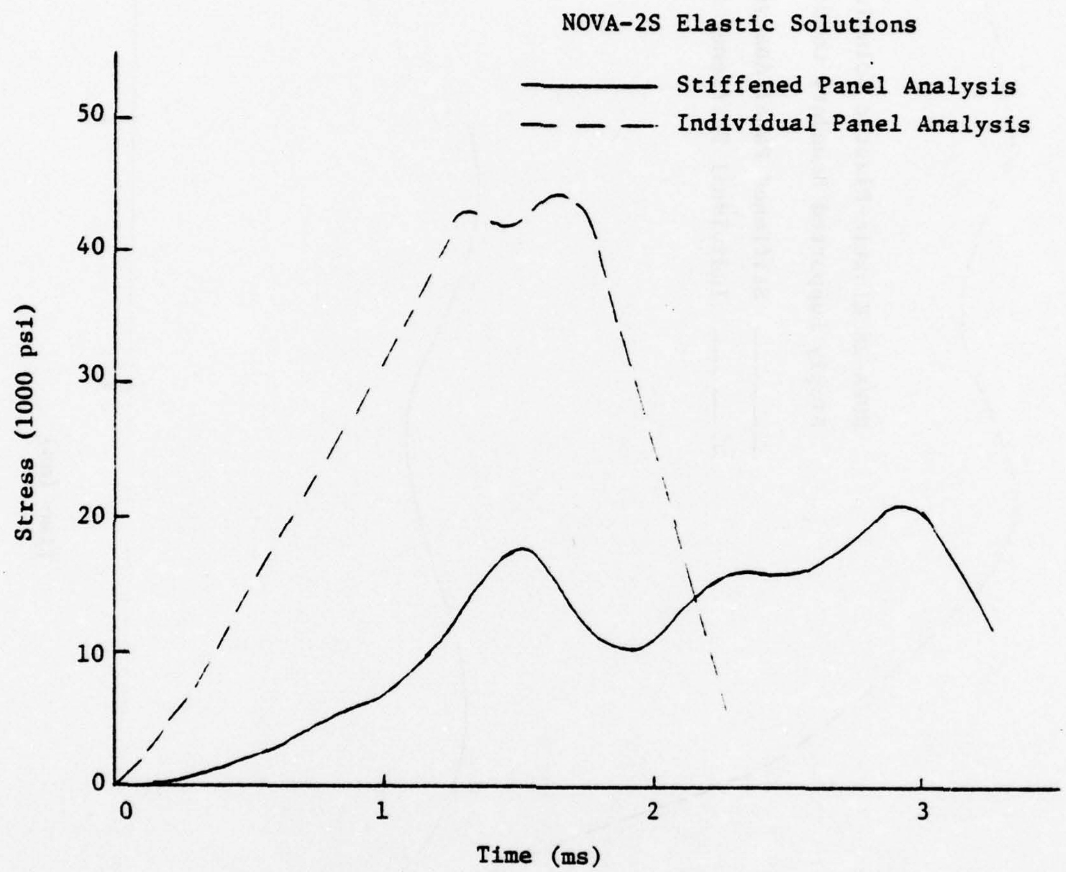


Figure 32. Comparison of Outer Surface Edge Stress Response on the Panel Skin of the Vertical Fin Stiffened Panel (Elastic Solution)

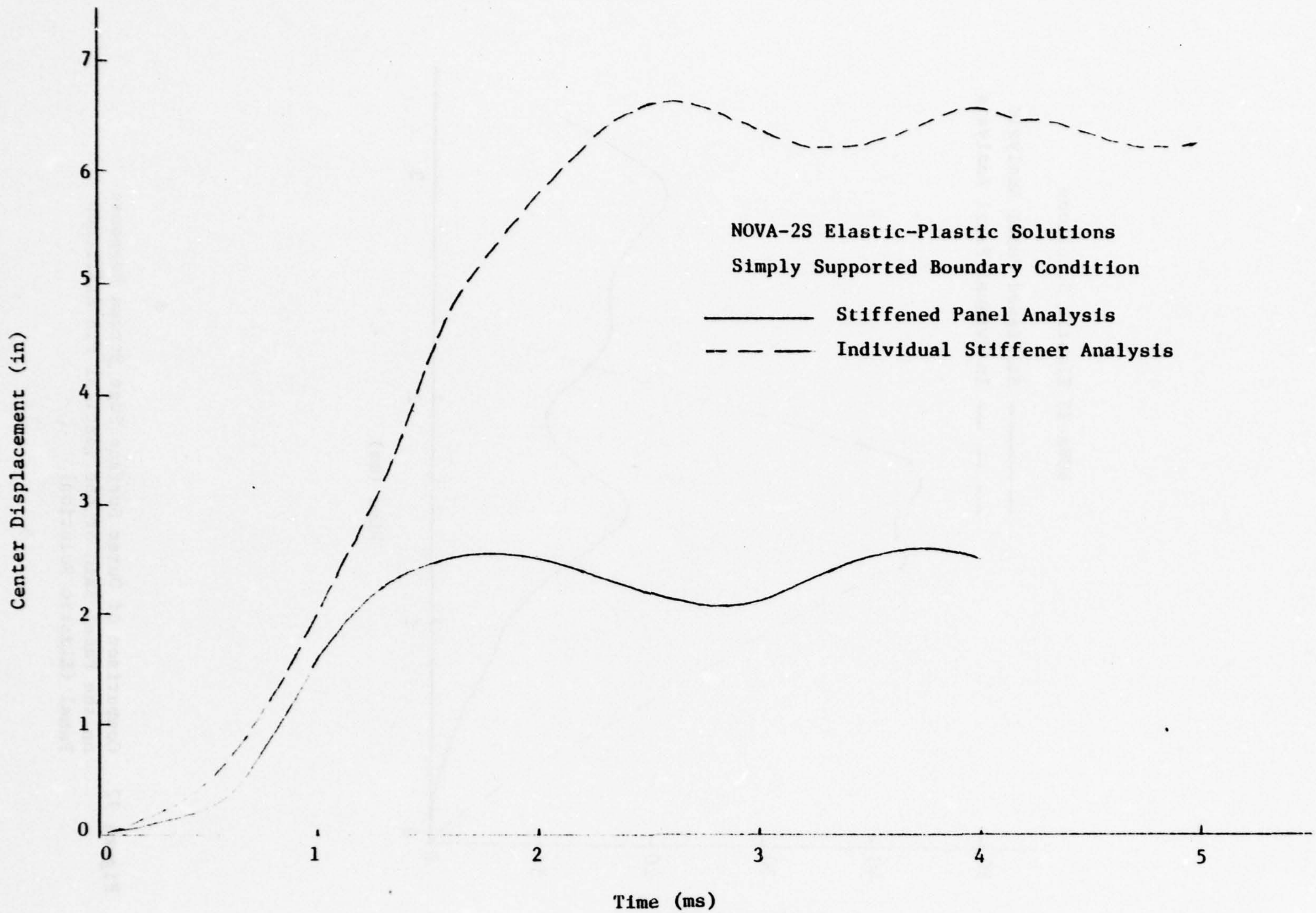


Figure 33. Comparison of Center Displacement Response on the Stiffener of the Vertical Fin Stiffened Panel (Elastic-Plastic Solution)

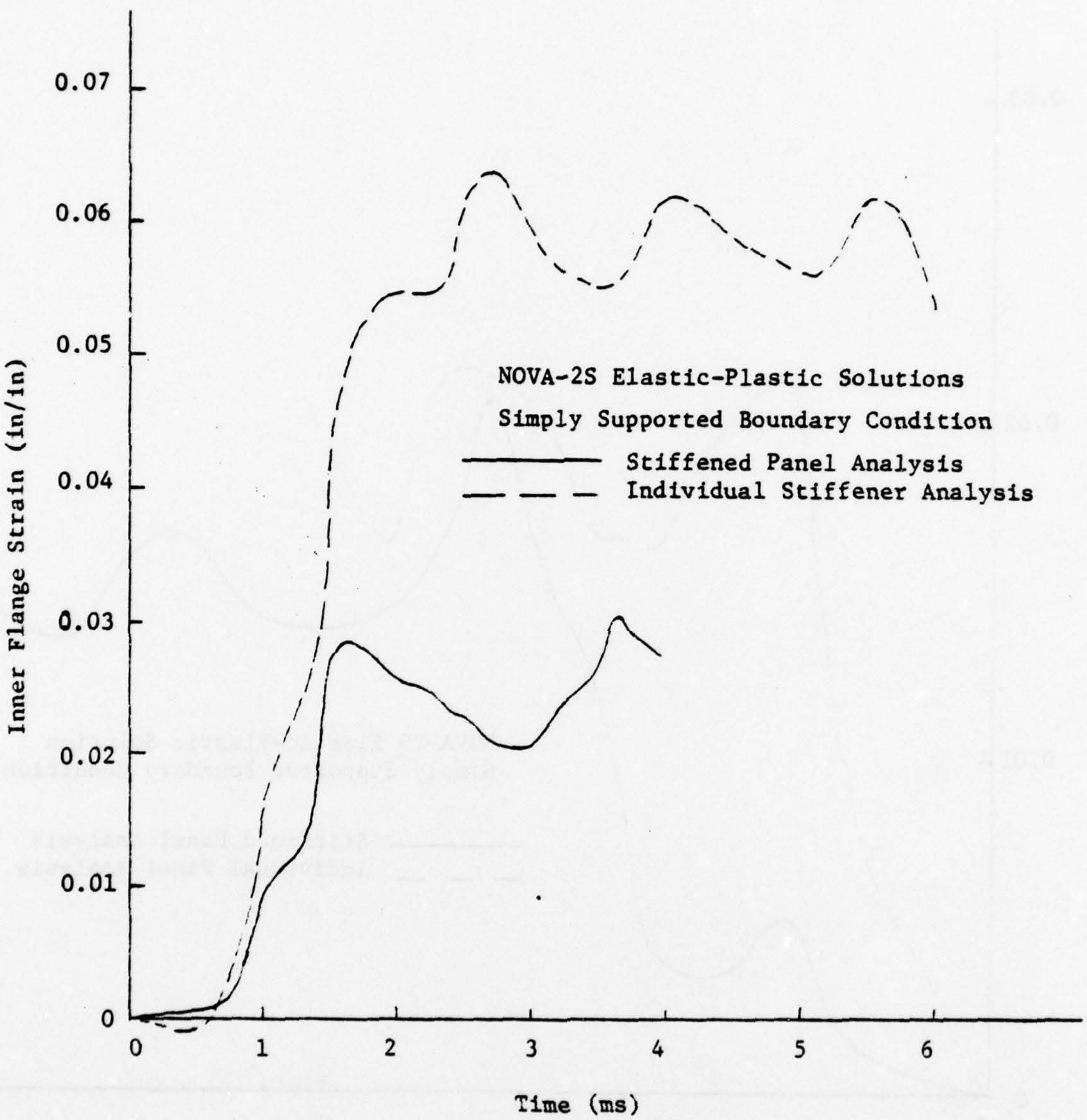


Figure 34. Comparison of Center Strain Response on the Stiffener of the Vertical Fin Stiffened Panel (Elastic-Plastic Solution)

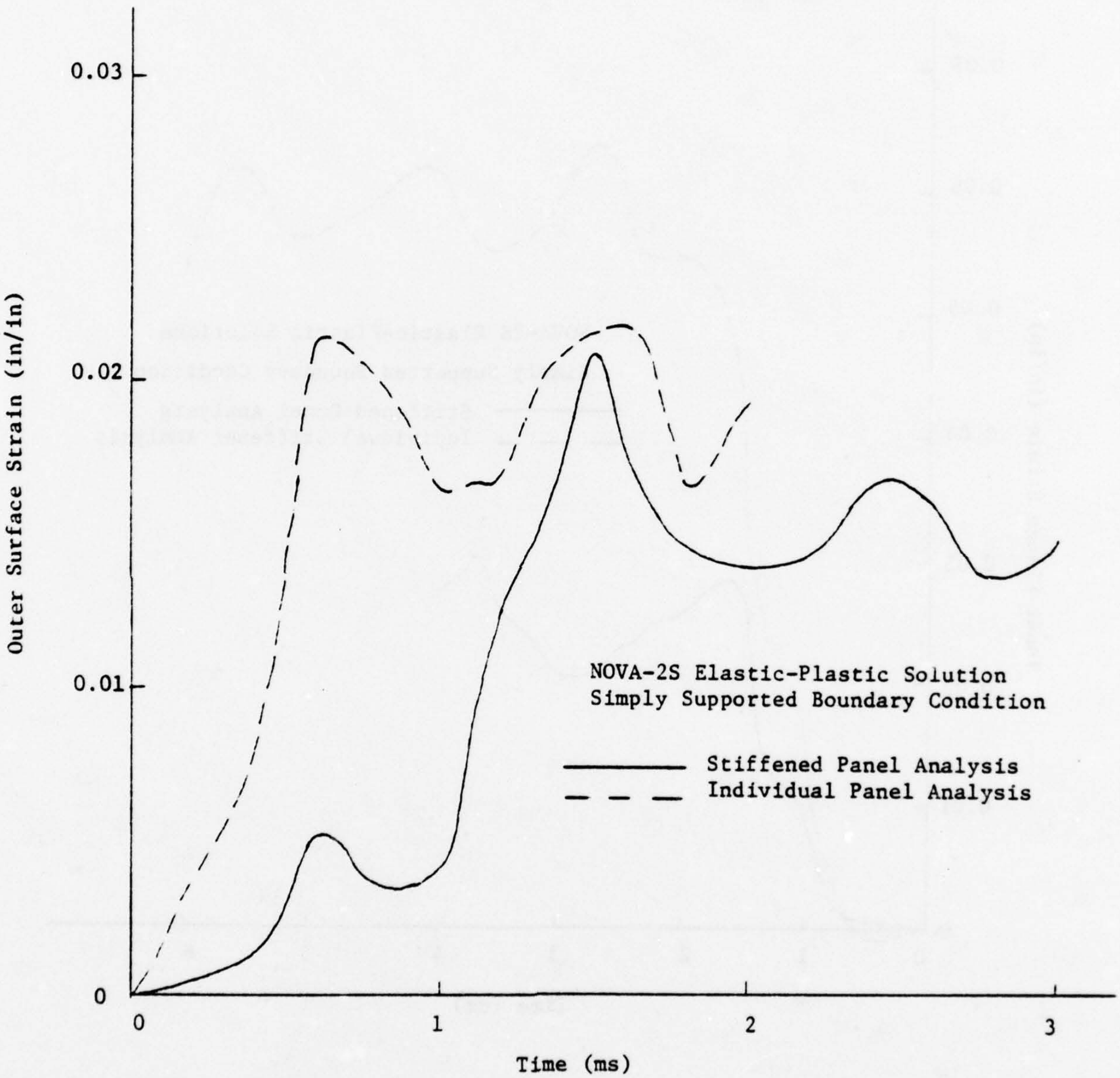


Figure 35. Comparison of the Edge Strain Response on the Panel Skin of the Vertical Fin Stiffened Panel (Elastic-Plastic Solution)

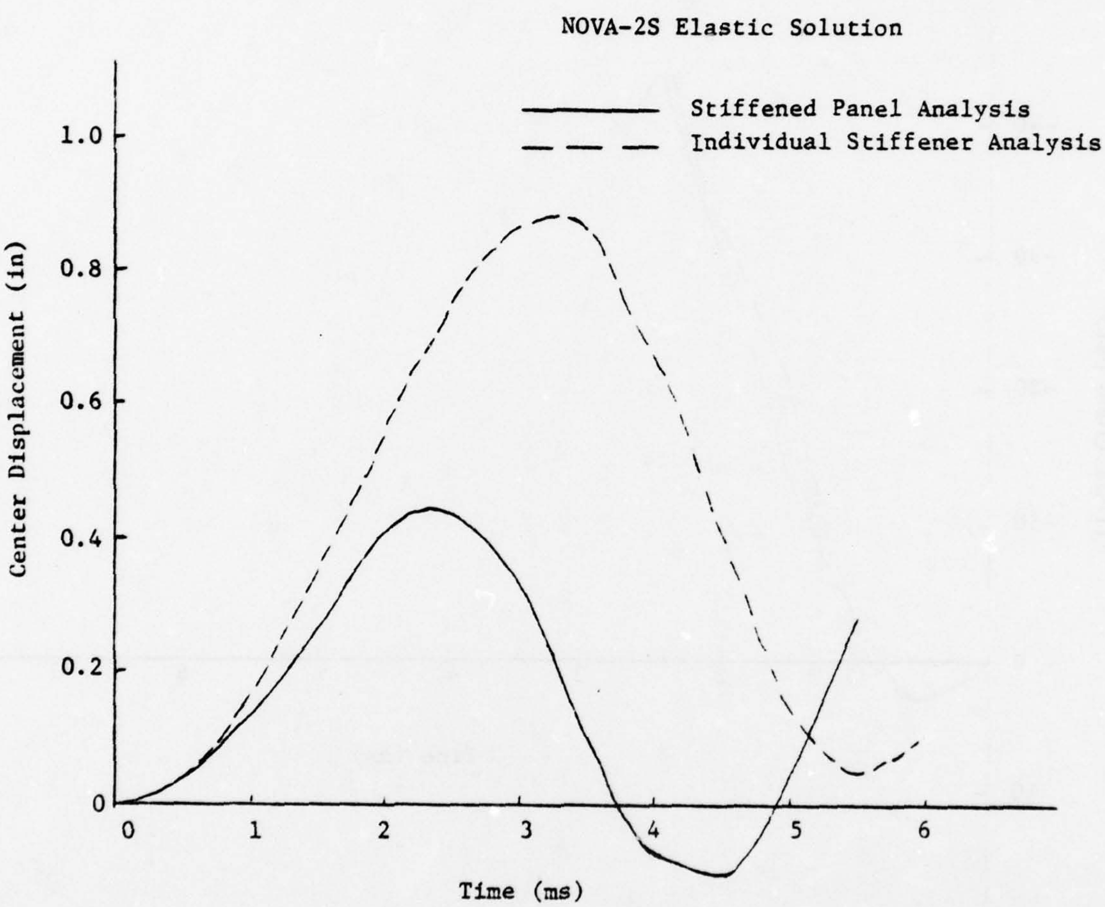


Figure 36. Comparison of Center Displacement Response on the Stiffener of the Aft Fuselage Stiffened Panel

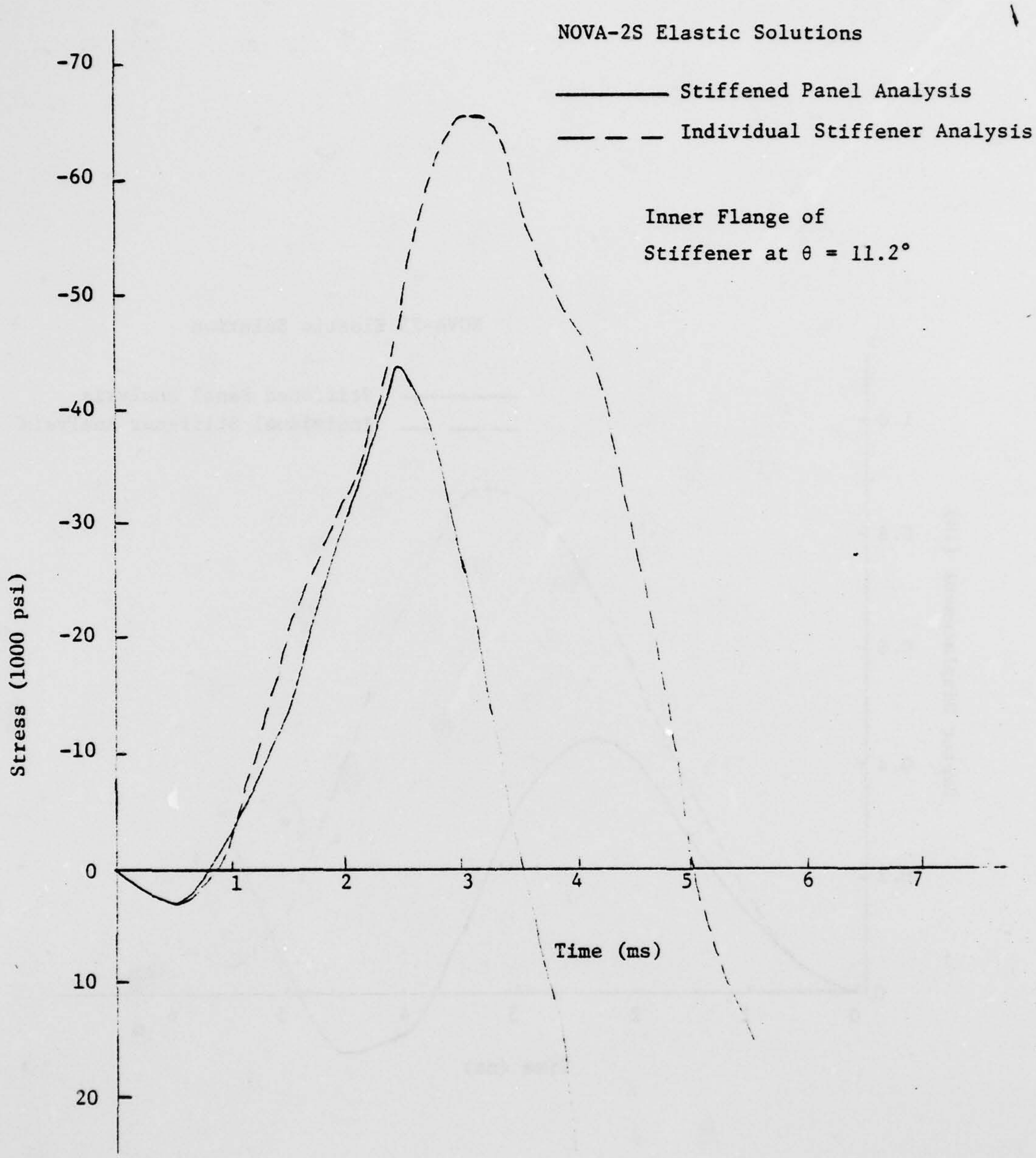


Figure 37. Comparison of Maximum Stress Response on the Stiffener of the Aft Fuselage Stiffened Panel

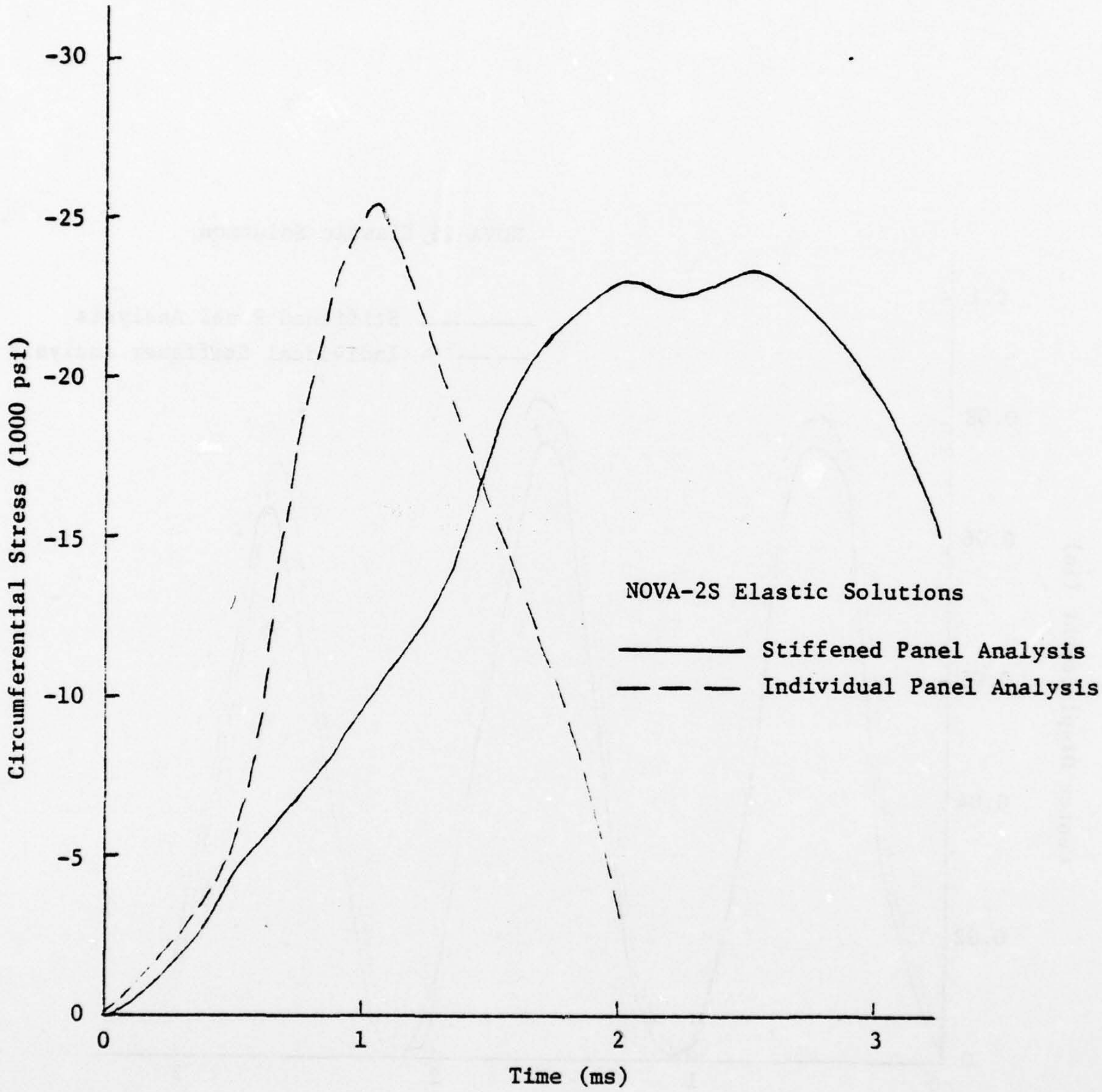


Figure 38. Comparison of Outer Surface Center Stress on the Panel Skin of the Aft Fuselage Stiffened Panel

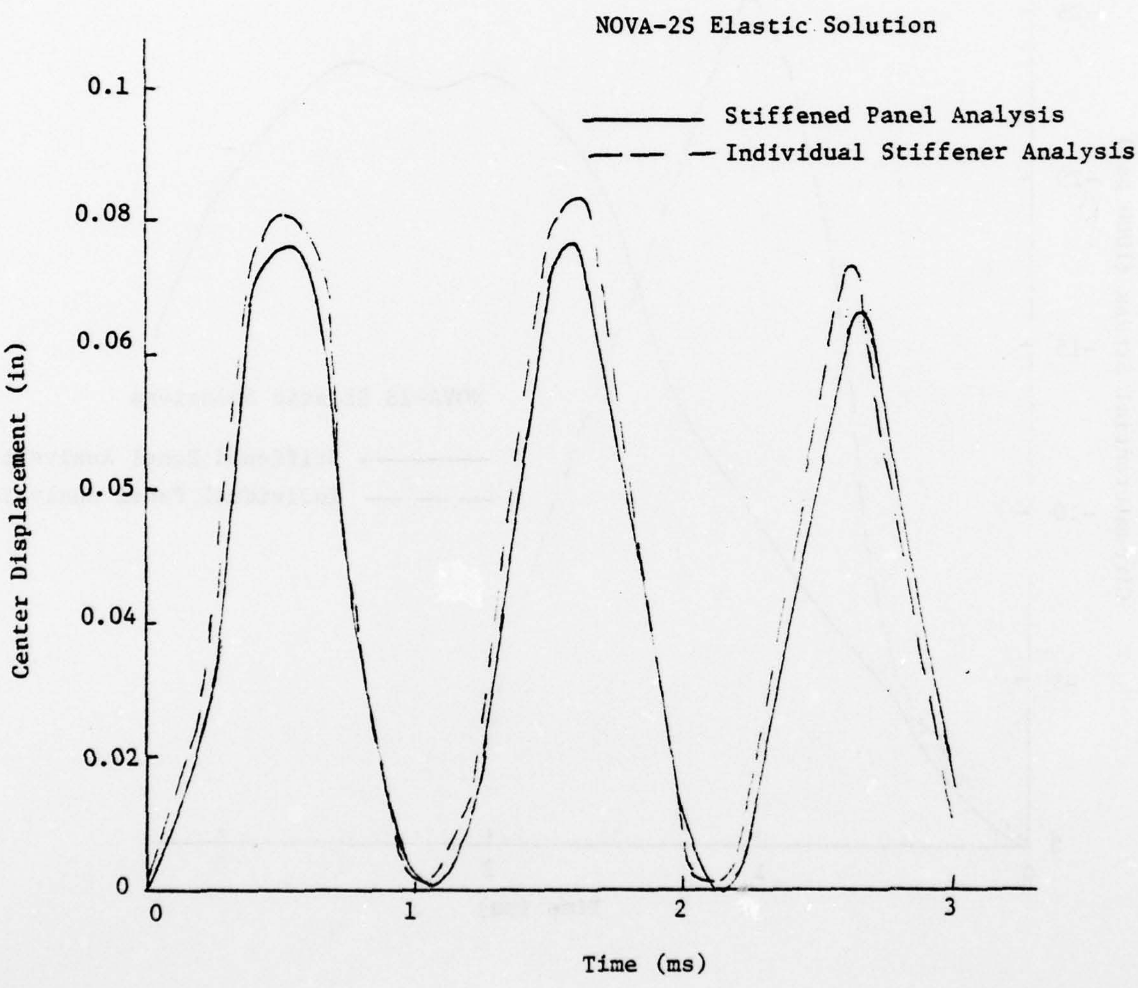


Figure 39. Comparison of Center Displacement Response on the Stiffener of the Upper Wing Stiffened Panel

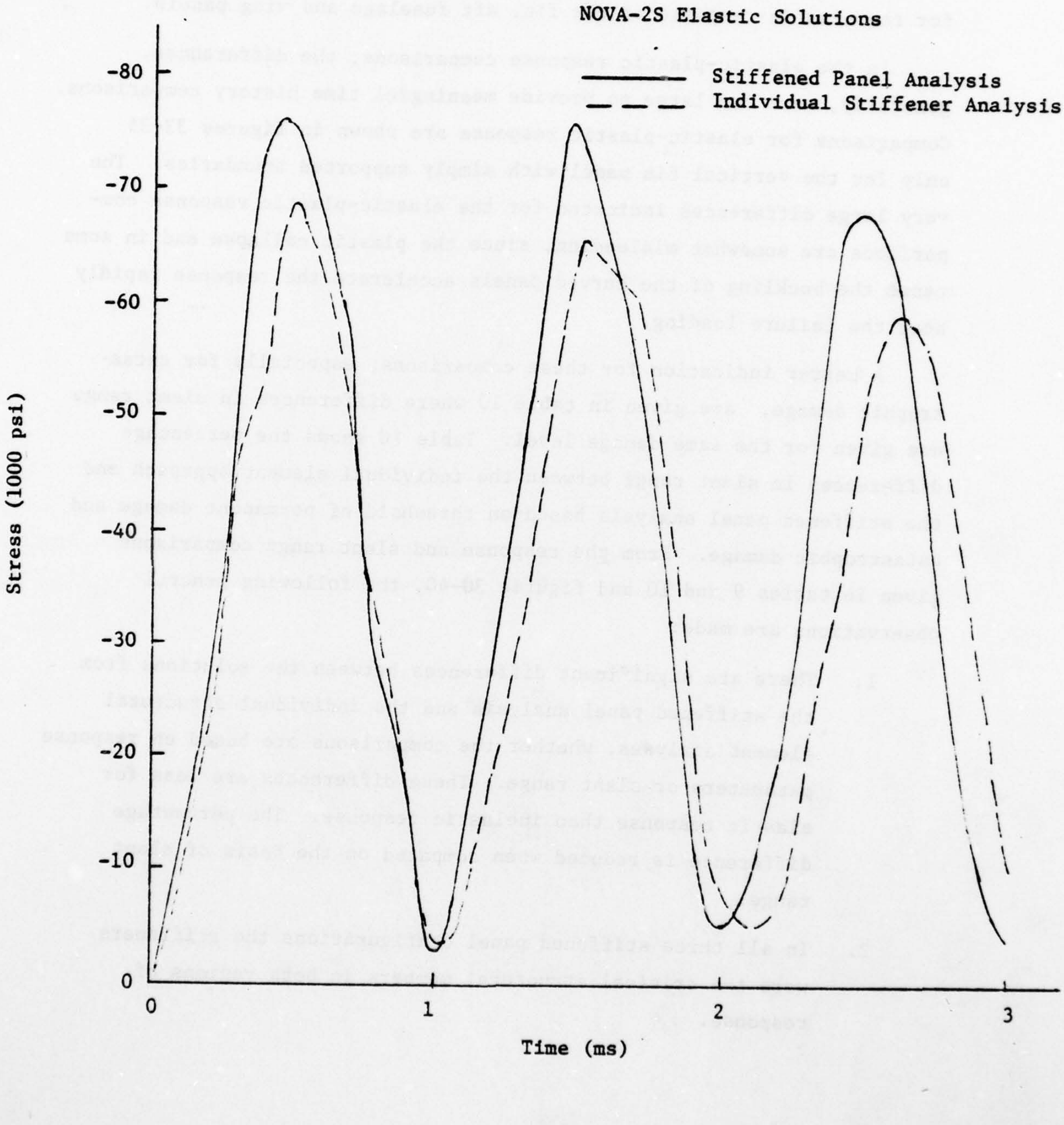


Figure 40. Comparison of Inner Flange Strain at the End of the Stiffener of the Upper Wing Stiffened Panel

solution accuracies, since, for the multi-bay models, only a few integration points are available within each panel bay compared to solutions for individual panels. These figures show response comparisons mainly for the elastic response of the fin, aft fuselage and wing panels.

In the elastic-plastic response comparisons, the differences, generally, were too large to provide meaningful time history comparisons. Comparisons for elastic-plastic response are shown in figures 33-35 only for the vertical fin panel with simply supported boundaries. The very large differences indicated for the elastic-plastic response comparisons are somewhat misleading, since the plastic collapse and in some cases the buckling of the curved panels accelerate the response rapidly near the failure loading.

A better indication for these comparisons, especially for catastrophic damage, are given in table 10 where differences in slant range are given for the same damage level. Table 10 shows the percentage differences in slant range between the individual element approach and the stiffened panel analysis based on threshold of permanent damage and catastrophic damage. From the response and slant range comparisons given in tables 9 and 10 and figures 30-40, the following general observations are made:

1. There are significant differences between the solutions from the stiffened panel analysis and the individual structural element analyses, whether the comparisons are based on response parameters or slant range. These differences are less for elastic response than inelastic response. The percentage difference is reduced when compared on the basis of slant range.

2. In all three stiffened panel configurations the stiffeners were the critical structural members in both regions of response.

3. The individual stiffener structural model was always weaker than the stiffened panel model, except for the elastic solutions of upper wing panel configuration. This exception occurred because the skin of the panel is very thick, so that the computed effective width of the skin produced a significant skin segment in the individual stiffener model.

4. From figures 30-38, which show selected comparisons for the fin and aft fuselage panels, the response time histories indicate that the time of peak response is less for the stiffened panel models. Thus, as might be expected, the stiffened structured models are higher frequency than the corresponding individual stiffener models.

5. In the use of NOVA-2S, the slant range is the more important parameter on which to draw a conclusion from this evaluation of stiffened panel analysis versus individual element analysis. From table 10 the percentage difference in slant range are between 4 percent and 24 percent for threshold of permanent damage and between 11 percent and 138 percent for catastrophic damage. These differences are significant and become even more significant in terms of a volume envelope. It is therefore concluded that the stiffened panel analysis should be used instead of the individual element technique for stiffened panels as described in this report. The individual element technique is still useful for many aircraft structures, such as pure panels bounded by ribs, spars or bulkheads, ribs analyzed for buckling, and configurations with free or spring supported boundary conditions.

SECTION V

COMPUTER PROGRAM DESCRIPTION

This section outlines the changes made in the computer program, including dimension changes and preparation of the input data. The user is referred to reference 1 for full documentation of the NOVA-2 computer code.

The postscript "S" in NOVA-2S refers to the addition of discrete stiffeners in the DEPROP model, as described earlier. Although the most significant change, this was not the only modification. A brief summary of the changes follows:

In the NOVA routines, a fuselage loading option was added to permit either a circumferentially uniform or nonuniform blast load for beam or panel elements. Previously only frames and radome elements received the nonuniform load. The change necessitated modifying the NOVA input slightly.

In DEPROB, the maximum *allowable flanges* in the cross-sectional model (NLK) was increased from 20 to 21 in order to provide better representation of certain elements.

The summary output for DEPROB and DEPROP iterative runs was modified to indicate the type of damage corresponding to the CRIT used. For example, threshold-of-damage criteria for a frame can be either tensile or compressive yielding of the material, or a compressive buckling of the outstanding leg.

Several major changes were made in DEPROP. The most significant was the addition of stiffeners in either coordinate direction in the panel model. These stiffeners must be located at the grid lines in the spatial integration model, but can be located either on the inside or outside of a multilayered panel and in the interior of a sandwich panel. The cross section is modelled in a manner similar to the DEPROB models.

The cross section can vary along the length of the beta (β) stiffeners (stiffeners running parallel to the beta axis), but not for gamma (γ) stiffeners (see figure 1). Stiffeners can be of different construction and material, but are assumed to be attached at each grid point in the system.

The inner and outer flanges are monitored for maximum CRIT at each grid point and the results printed out at the conclusion of the run. The criteria used are the same as for stringer elements in the DEPROB models.

In general, the stiffeners introduce coupling in the mass matrix and this capability was added. It was made optional, however, because the matrix algebra requires considerable storage and computer time, and may not be significant for all problems. By rejecting the option, only the diagonal terms of the mass matrix are included.

In addition to including stiffeners, the modal representation of the panel response was expanded to include non-symmetric mode shapes. Thus, either a non-symmetric panel or a panel subjected to a non-symmetric load can be analyzed. This change necessitated changing the numbering system of the modes, since the even-numbered modes had been automatically excluded in the old system.

Printout of the stresses, strains and displacements at user-selected spatial locations has been added, whereas before, the program automatically printed out every third spatial point in both coordinate directions and the points along the boundaries and lines of symmetry. The user now has complete control over the printout, making for more efficient use of output. For maximum CRIT, however, the program continues to automatically check <u>every</u> spatial location.

A formulation similar to that employed to treat the discrete stiffeners was used to replace the "equivalent layer" treatment of honeycomb metal panels undergoing catastrophic damage (KTYPE=3, KDAM=1 or 101). This method involves two integration points through the thickness (LBAR=2), one in each face sheet.

The deck structure of DEPROP was modified somewhat with the addition of three routines associated with the stiffeners, MATXIN, SIGMAB, and STIFF. Separately, the routine DERV2 was broken down into two routines, DERV1 and DERV2. Several common blocks were also changed in DEPROP.

Subsection 5.5 of this report deals with a special version of NOVA-2S called NOVA-2LTS. The blast and aerodynamic subroutines have been replaced by analytical and tape-supplied pressure data to permit correlation with experimentation.

The final subsection documents an example problem intended to provide the user with both an example of program input and modelling, and a check on the computer program.

5.1 SUBROUTINES AND COMMON BLOCKS

Three new routines were added to DEPROP: MATXIN, SIGMAB and STIFF. Subroutine STIFF sets up all the constants associated with stiffened panels. If the inertia coupling is included, it calls MATXIN which inverts the mass matrix. SIGMAB calculates the inelastic stresses for option NDERV=2 associated with the stiffeners.

Subroutine DERV2 was separated into two routines, DERV1 and DERV2, because of the length of the original routine and the logical differences which exist. DERV1 calculates displacements, strains, and stresses; DERV2 calculates accelerations.

Table 11 lists the 107 routines of NOVA-2S and table 12 lists all the associated common blocks. Common block IFIRST was added so that the first storage location (101) contains an integer variable monotonically increasing in value as long as the program is running normally. This can be checked by the operator.

Two versions of NOVA-2S, representing different dimensions for the program DEPROP, are documented. The smaller version can be run on the Control Data Corporation (CDC) 6600; the larger version can only be run using LCM on the CDC 176, or an equivalent system.

TABLE 11

LIST OF SUBPROGRAMS OF NOVA-2S

NOVA		DEPROP	DEPROB
NOVA	WFDZR	DEPROP	DEPROB
BLOCK	WELL	BOLT	COMP1
IODUM	WFPRMT	DERV1	COMP2
SEC	WFVZR	DERV2	COMSET
NIN	WFVRMT	DSET1	CYCLE
NEWSL	AIR	DSET2	DAB
NOVSUM	WFPKOP	DSET3	DEFORM
RITC	REFRA	DTSTEP	DPUR
RITER	OPT1	HIM	EQUILP
CSETUP	OPT2	LEGEND	EQUILX
INTP	OPT3	LIST1	FB
PINIT	ADVANC	LIST2	FBCTL
SOLVE	BISH	MATXIN	FBSET
BLAST	READ	RELAXP	FINAL
XBLAST	POSTAP	SIGMA	FSOL
HYDRA	SKIP	SIGMAB	PRINT1
IOPT1	FPRES	STIFF	READ1
IOPT2	INTSLO		RESD
IOPT3	PFUSE		RESET
ATMOS	PJUMP		RLAXB
MATM62	POSTW1		RLAXF
SHOCK	POSTW2		SLAY
TPINT	POSTW3		STRESS
INT1	POSTW4		STRESX
INT2	POSTW5		STRN1
WFZR	POSTW6		STRN2
WFPKOD	POSTW7		STSET
WFPR	PRESS		TSTEP
WFPKV	PREW		VCS
WFDRMT	SETW		
	WPRES		

TABLE 12

COMMON BLOCKS AND SUBPROGRAMS USING THEM IN NOVA-2S

Common Block	Length (Decimal)		Subprograms
	CDC 6600	CDC 176	
FIRST	1	1	NOVA*, DEPROP, DEPROB, DEFORM
CNOVA	546	605	NOVA, NIN, NEWSL, NOVSUM, RITC, CSETUP, BLAST, XBLAST, PINIT, FPRES, PRESS, PREW, WPRES, DEPROP, DSET1, DSET2, DSET3, DERV1, DERV2, DTSTEP, LIST1, LIST2, SIGMA, STIFF, DEPROB, COMP1, COMP2, COMSET, CYCLE, DEFORM, EQUILP, EQUILX, FB, FINAL, PRINT1, READ1, STRESS, TSTEP
DNOVA	2858	2858	NOVA, BLOCK, NIN, NEWSL, NOVSUM, RITC, BLAST, XBLAST, PINIT, FPRES, POSTW1, POSTW2, POSTW3, POSTW4, POSTW5, POSTW6, POSTW7, PRESS, PREW, SETW, WPRES
CTLX	2	2	NOVA, BLAST, REFRA, FPRES, WPRES
CONSTC	15	15	HYDRA, IOPT1, IOPT2, IOPT3
SCALEC	5	5	HYDRA, IOPT1, IOPT2, IOPT3, SHOCK
WFRT	13	13	SHOCK, WFPKOD, WFPR, WFPKV, WFDRMT, WELL, WFPRMT, WFVRMT
REFRAC	7495	7495	REFRA, OPT1, OPT2, ADVANC, READ, SKIP
PW1	23	23	POSTW1, POSTW2, POSTW3, POSTW4, POSTW5, POSTW6, POSTW7, SETW, WPRES
CBLK1	894	1159	DEPROP, BOLT, DSET1, DSET2, DSET3, DERV1, DERV2, DTSTEP, LEGEND, LIST1, LIST2, SIGMA, SIGMAB, STIFF
CBLK2	4547	5487	DEPROP, BOLT, DSET1, DSET2, DSET3, DERV1, DERV2, DTSTEP, STIFF

*Underlined routine in each group owns that common block in segmentation setup.

TABLE 12 (Continued)

Common Block	Length (Decimal)		Subprograms
	6600	176	
CBLK3	12	12	DEPROP, DSET1, DSET2, DSET3, DERV2, LEGEND, SIGMA
CBLK4	589	589	DEPROP, DSET1, DSET2, DSET3, DERV1, DERV2, SIGMA
CBLK5	1185	1185	DEPROP, DSET1, DSET2, DSET3, STIFF
CBLK6*	25270	29400	SIGMA
CBLK7	23	23	DEPROP, DSET1, DSET2, DSET3, LIST2, SIGMA, SIGMAB, STIFF
CBLK8	148	148	DEPROP, HIM
CBLK9	163	184	DEPROP, DSET1, DSET2, DSET3, LIST1, LIST2
CBLK10	5415	6300	DEPROP, DSET1, DSET2, DSET3, DERV1, DERV2, LIST1, LIST2
CBLK11	12	12	DEPROP, DSET1, DSET2, DSET3, DERV1
CBLK12	22638	22638	RELAXP
CBLK13	9	9	DEPROP, DSET1, DSET2, DSET3, DTSTEP, STIFF
CBLK15	5755	10547	DEPROP, DERV1, DERV2, DSET1, LIST1, LIST2, SIGMAB, STIFF
CBLK16*	2944	5376	SIGMAB
CBLK17*	7203	7203	DEPROP, DERV2, STIFF
CBLANK*	14259	16501	DEPROP, DERV1, DERV2, DSET1, DSET2, DSET3, LIST1, LIST2, SIGMA, SIGMAB, STIFF

*Assigned to Level 2 storage on CDC 176.

TABLE 12 (Concluded)

Common Block	Length (Decimal)		Subprograms
	6600	176	
BLK2	12717	12717	DEPROB, COMP1, COMP2, COMSET, CYCLE, DAB, DEFORM, DPUR, EQUILP, EQUILX, FB, FBCTL, FBSET, FINAL, FSOL, PRINT1, READ1, RESD, RESET, SLAY, STRESS, STRESX, STRN1, STRN2, STSET, TSTEP, VCS
BLK3	466	466	DAB, DEFORM, DPUR, FSOL, RESD, RESET, STSET
BLK4*	7216	7216	RLAXB
BLK5	21	21	RLAXF
BLK6	2369	2369	COMP1, COMP2, COMSET, DEFORM, FB, FBSET, PRINT1, STRESS, STRN1, STRN2

*Assigned to Level 2 storage on CDC 176.

5.2 MAXIMUM PROGRAM DIMENSIONS

Nearly all of the dimensioned variables appear in labelled common, and the current maximum dimensions are indicated in tables 13 through 15. The variable associated with each dimension is listed in case the user should want to change program dimensions. These tables should also be consulted when making up input for the program to be sure the dimensions are not exceeded.

There are a few other changes to be made when the dimensions are changed, and these are listed in table 16. The new integer variables which represent maximum dimensions, along with the list of dimensions of the new program variables, make up table 17.

5.3 PROGRAM INPUT

Input instructions remain the same (reference 1), except for two minor changes in the NOVA input, and a complete overhaul of DEPROP.

Groups 10, 27 and 28 of the NOVA data change (see the new instructions in tables 18 and 19). Group 20 permits the user to make a response run, yet still receive output indicating maximum response, or CRIT. For KDAM = 100 (or 101) the program executes as if KDAM = 0 (or 1), except that only one iterative trial is permitted; otherwise there is no difference. For KDAM = 2, a response run without any iterative information is made.

An extra input parameter, NU, is added to Group 27. This parameter gives the user the choice of either a uniform load or a circumferentially varying load on certain fuselage elements. Table 20 lists the new options. Previously, radomes and frame elements received the varying load; panels, stringers and longerons received a uniform load.

The parameter NFP locates the element longitudinally on the aircraft, while THETAR (θ_R) locates the element circumferentially. Both parameters should correspond to the center of the structural element, or that point on the structure at which the loading is desired. See figure 19 of reference 1 for the definition of θ_R in the Aircraft Axis System (AAS), and note that the DEPROB coordinates (V, W) in the

AD-A066 038 KAMAN AVIDYNE BURLINGTON MASS F/G 1/3
NOVA-2S, A STIFFENED PANEL EXTENSION OF THE NOVA-2 COMPUTER PRO--ETC(U)
DEC 78 L J MENTE, W N LEE F29601-78-C-0019
UNCLASSIFIED KA-TR-153 AFWL-TR-78-182 NL

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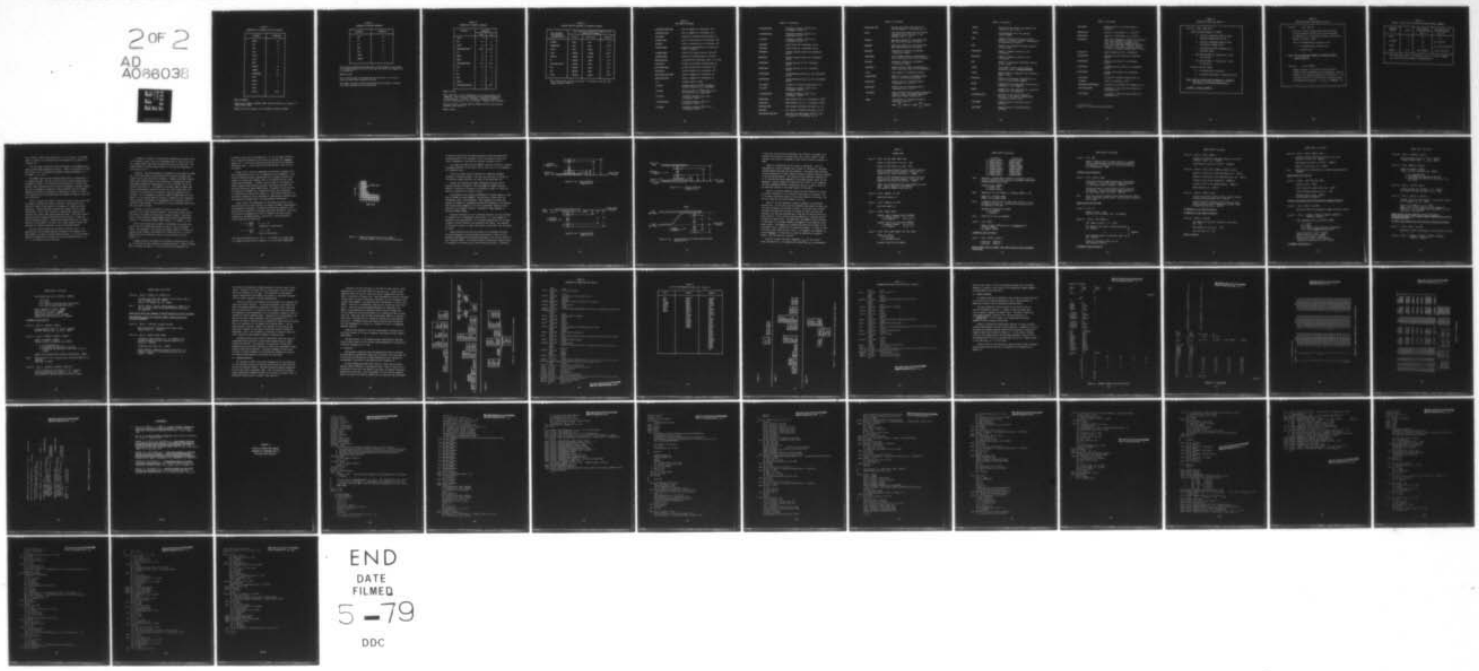

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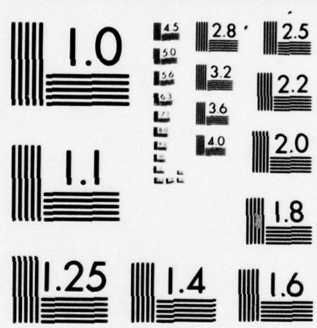

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TABLE 13

DIMENSIONS OF VARIABLES FOR NOVA ROUTINE

VARIABLE	DIMENSION
MMAS[1]	28
NEL	20
NFS	20
NLE[2]	5
NLEHT	5
NLEVT	5
NLEW	5
NMASS[3]	40
NORMAX	30
NORMAX*NEL	100
NTE[2]	5
NTEHT	5
NTEVT	5
NTEW	5
NTP1+1	1000

[1] MBAR in DEPROP

[2] NLE must be largest of NLEHT, NLEVT, NLEW and NTE must be largest of NTEHT, NTEVT, NTEW

[3] NMASS must be the largest of N in DEPROB and NBAR in DEPROP

TABLE 14

DIMENSION OF DEPROB VARIABLES

VARIABLE	DIMENSION
NX[1]	10
N[2]	40
NL[3]	8
NLK	21
NSL	5
NSSC[4]	5
NSSCT[4]	5

[1]The program automatically assigns NX or fewer flanges to each layer, so NX should usually be four or six since the sum of all flanges must not exceed NLK

[2]NMASS in NOVA

[3]For a uniform beam, the program may add one layer, so the actual limit on input would ordinarily be seven

[4]The number of distinct slopes defined by NSSC and NSSCT, excluding zero slope segments, must not exceed NSL

TABLE 15

DIMENSIONS OF DEPROP VARIABLES

VARIABLE	DIMENSION	
	6600	176
LBAR	6	6
MB	13	13
MBAR[1]	23	28
MBAR*NBAR*LBAR[2]	1805	2100
MG	13	13
MGMB[3]	49	49
NBAR[4]	23	28
NGNBT=MBAR*NBAR	361	420
NKP	46	46
NL	8	8
NSG	4	9
NSB	4	6
NSMAX	8	8
NSG*MBAR+NSB*NBAR	92	168

[1] MMASS in NOVA

[2] This constraint is only significant for an elastic-plastic run (NDERV=2). Four possible combinations using maximum dimensions on the 6600 are: (17x17x6), (19x19x5), (23x15x5), (15x23x5). Possible combinations on the 176 include: (28x15x5) and (18x18x6).

[3] The total number of modes selected (MGMB) from the total possible (MB*MG) cannot exceed 49

[4] NMASS in NOVA

TABLE 16

PROGRAM CHANGES REQUIRED BY DIMENSION CHANGES

When Changing the Dimensions Corresponding to:	Also Change the Fixed-Point Number in the Indicated Statement		
	Routine	Subroutine	Location[1]
NORMAX	NOVA	NOVA	5^{-1}
NORMAX*NEL	NOVA	NOVA	570^{+6}
NTP1+1	NOVA	WPRES	43^{-2}
LBAR	DEPROP	LEGEND	300^{-11}
MG*MB*3	DEPROP	RELAXP	20^{+1}
NL	DEPROB	COMP1	50^{-7}
NSL*NLK*2*(N+1)	DEPROB	COMP1	50^{-6}
NLK	DEPROB	COMP1	50^{-5}
NSL	DEPROB	COMP1	50^{-4}
N*2+2	DEPROB	RLAXB	40^{+3}

[1]The location code is read as follows: s^{+n} refers to the nth line after statement number s.

TABLE 17

NEW DEPROP VARIABLES

AASB(NSEGB,NBAR,NSB)	Area of segment in β-stiffener, in^2.
AASG(NSEGG,NSG)	Area of segment in γ-stiffener, in^2.
ALX(LXMAX)	Storage for stiffener stress-strain, $\overline{\alpha}$.
ASB(NBAR,NSB)	Area of cross-section in β-stiffener, in^2.
ASG(NSG)	Area of cross-section in γ-stiffener, in^2.
AU(MGMB,MGMB)	Inverse of inertia matrix in u-direction, $[-M]^{-1}$, $in^4/lb\text{-}s^2$.
AV(MGMB,MGMB)	Inverse of V-inertia matrix, $in^4/lb\text{-}s^2$.
AW(MGMB,MGMB)	Inverse of W-inertia matrix, $in^4/lb\text{-}s^2$.
*BETC(NBAR,NSB)	β-position for β-stiffener input, in or deg.
BEX(LXMAX)	Storage for stiffener stress-strain, $\overline{\beta}$.
*BIGJB(NBAR,NSB)	Torsion constant for β-stiffener, in^4.
*BIGJG(NSG)	Torsion constant for γ-stiffener, in^4.
*BSTB(NSEGB,NBAR,NSB)	Width of segment in β-stiffener, in.
*BSTG(NSEGG,NSG)	Width of segment in γ-stiffener, in.
CA1	Constant equal to $2L^2R$.
CA2(NSG)	Constant equal to $6L^2(\overline{N}-1)/a\theta_o hH_K$ at the k^{th} β-position of a γ-stiffener.
CA3(NSB)	Constant equal to $6L^2(\overline{M}-1)/\ell hH_j$ at the jth γ-position of a β-stiffener.
C11G(NSG)	Stiffness constant, C_{11}^*/a, for a γ-stiffener, lb/in^2.
C22B(NBAR,NSB)	Stiffness constant, C_{22}^*/a for a β-stiffener, lb/in^2.
D11G(NSG)	Stiffness constant, D_{11}^*/a^3, for a γ-stiffener, lb/in^2.

TABLE 17 (Continued)

D22B(NBAR,NSB)	Stiffness constant, D^*_{22}/a^3, for a β-stiffener, lb/in^2.
D33B(NBAR,NSB)	Stiffness constant, D^*_{33}/a^3, for a β-stiffener, lb/in^2.
D33G(NSG)	Stiffness constant, D^*_{33}/a^3 for a γ-stiffener, lb/in^2.
EPOB(NSB)	Yield strain for β-stiffener, in/in.
EPOG(NSG)	Yield strain for γ-stiffener, in/in.
*EPSB(NSB)	Ultimate tensile strain for β-stiffener, in/in.
*EPSG(NSG)	Ultimate tensile strain for γ-stiffener, in/in.
*ESTRB(NSB)	Elastic modulus, $\overline{E}$, for β-stiffener, lb/in^2.
*ESTRG(NSG)	Elastic modulus, $\overline{E}$, for γ-stiffener, lb/in^2.
*ETSTRB(NSB)	Strain-hardening slope, $\overline{E}_t$, for β-stiffener, lb/in^2.
*ETSTRG(NSG)	Strain-hardening slope, $\overline{E}_t$, for γ-stiffener, lb/in^2.
EX1(LXMAX)	Storage for stiffener stress-strain, $\overline{\varepsilon}_1$.
F11G(NSG)	Stiffeners constant, F^*_{11}/a^2, for a γ-stiffener, lb/in^2.
F22B(NBAR,NSB)	Stiffness constant, F^*_{22}/a^2, for a β-stiffener, lb/in^2.
*GBARB(NSB)	Shear modulus, $\overline{G}$, for a β-stiffener, lb/in^2.
*GBARG(NSG)	Shear modulus, $\overline{G}$, for a γ-stiffener, lb/in^2.
*HOB(NBAR,NSB)	Gap between β-stiffener and panel, h_o, in.
*HOG(NSG)	Gap between γ-stiffener and panel, h_o, in.
*HSTB(NSEGB,NBAR,NSB)	Distance from inner panel surface to the ℓ^{th} segment of β-stiffener, h_o, in.

TABLE 17 (Continued)

*HSTG(NSEGG,NSG)	Distance from inner panel surface to the ℓ^{th} segment of γ-stiffener, h_{α}, in.
*KCOUP	Code indicating whether the full inertia coupling is to be included: 0, only diagonal terms; 1, yes.
*KPB(NKP)	Mesh-point number (β), when paired with KPG, specifies printout locations.
*KPG(NKP)	Mesh-point number (γ), when paired with KPB, specifies printout locations.
*KSB(NSB)	Gamma-point location of β-stiffener (γ grid-point number).
KSBX(MBAR)	Beta-stiffener number corresponding to each γ grid point (zero for no stiffener).
*KSG(NSG)	Beta-point location of γ-stiffener (β grid-point number).
KSGX(NBAR)	Gamma-stiffener number corresponding to each β grid point (zero for no stiffeners).
KSTIF	Total number of stiffeners in model.
KSUMB(NSGMB)	Number of z points in stiffeners which have not yielded during response.
*KSUPB(NSB)	Support code for outstanding leg of β-stiffener (0, 1, or 2).
*KSUPG(NSG)	Support code for outstanding leg of γ-stiffener (0, 1, or 2).
KYX(LXMAX)	Code in elastic-plastic response indicating number of times a stiffener integration point has yielded, unloaded, etc.
LXMAX	Total number of integration points in stiffeners, equal to $\mathrm{MBAR} \cdot \sum_{I=1}^{NSG} \mathrm{NSEGG(I)} + \mathrm{NBAR} \cdot \sum_{J=1}^{NSB} \mathrm{NSEGB(J)}$

TABLE 17 (Continued)

MFIRST	Code indicating whether any stiffener has yielded (0, no; 1, yes).
NFIRST	Code indicating first pass through routine SIGMAB.
*NKP	Number of spatial grid points for which printout of strains, stresses, displacements, and pressures is required.
*NSB	Number of β-stiffeners (stiffener parallel to the β-axis).
*NSEGB(NSB)	Number of segments (layers) in the β-stiffener.
*NSEGG(NSG)	Number of segments (layers) in the γ-stiffener.
*NSG	Number of γ-stiffeners (stiffeners parallel to the γ-axis).
NSGMB	Total number of grid points involving stiffeners, equal to NSG*MBAR+NSB*NBAR.
NSMAX	Maximum number of segments in any stiffener - gamma or beta.
*NSTB(NSB)	Number of β-stiffeners which define cross-section for β-stiffener ($\leq$NBAR).
*NSYMB	Symmetry code for panel model in β-direction: 0-symmetric; 1-not symmetric.
*NSYMG	Symmetry code for panel model in γ-direction: 0-symmetric; 1-not symmetric.
NUSE(NBAR,MBAR)	Use-code for the spatial integration stations: 0-not used; 1-printout only; 2-integration only; 3-both.
PRLU(MGMB)	Diagonal terms of u-stiffness matrix, $in^4/lb\text{-}s^2$.
PRLV(MGMB)	Diagonal terms of v-stiffness matrix, $in^4/lb\text{-}s^2$.

TABLE 17 (Concluded)

PRLW(MGMB)	Diagonal terms of w-stiffness matrix, $in^4/lb\text{-}s^2$.
*RHOSTB(NSB)	Density of β-stiffeners, ρ_s, $lb\text{-}s^2/in^4$.
*RHOSTG(NSG)	Density of γ-stiffeners, ρ_s, $lb\text{-}s^2/in^4$.
*SIDEB(NSB)	Input code designating location of β-stiffener: -1.0, inner (exterior to panel); +1.0, outer; +2.0, internal (honeycomb only); +3.0, inner with panel crimped at stiffener locations. After input, variable takes on a value of 1.0 unless crimped, when it is 0.0.
*SIDEG(NSG)	Same as SIDEB, only for γ-stiffeners.
*SIGOBC(NSB)	Compressive yield stress for β-stiffener, lb/in^2.
*SIGOBT(NSB)	Tensile yield stress for β-stiffener, lb/in^2.
*SIGOGC(NSG)	Compressive yield stress for γ-stiffeners, lb/in^2.
*SIGOGT(NSG)	Tensile yield stress for γ-stiffeners, lb/in^2.
SIX1(LXMAX)	Storage for stiffener stress-strain, $\bar{\sigma}_1$.
SX(LXMAX)	Stress in stiffeners, lb/in^2.
ZFB(NSMAX,NSG+NSB*NBAR)	z-position in stiffener for integration, in.
ZSTB(2,NBAR,NSB)	z-position on inner and outer surfaces of β-stiffener, in.
ZSTG(2,NSG)	z-position on inner and outer surfaces of γ-stiffener, in.

Asterik (*) indicates an input variable.

TABLE 18

REVISION OF NOVA DATA GROUP 10

Group 10: (2I12) KDAM, KALT

Range iteration/damage code (KDAM)

0, iterate to determine range at which permanent damage first occurs.

1, iterate to determine range at which catastrophic damage occurs.

2, determine structural response only at specified range.

100, same as KDAM = 0, except only 1 trial in iteration.

101, same as KDAM = 1, except only 1 trial in iteration.

Constant altitude (KALT)

0, no restriction on iteration.

1, iteration restricted to constant altitude.

Note: KALT is not necessary for KDAM = 2. Otherwise KALT must be 1 if both KB and KGRD are 1.

If KDAM = 3, skip to GROUP 12.

TABLE 19

REVISION OF NOVA DATA GROUPS 27 AND 28

Group 27: (2I12) NFP, NU

The number of the fuselage section (from the table of values supplied in Group 24) at which pressures are desired, i.e., the section at which the structural element if located. (NFP)

Code for circumferential variation of load:

0 - circumferentially varying load.

1 - uniform load.

Note: If the structural element is a radome (KTYPE>7), skip to GROUP 29.

Group 28: (F12.1) THETAR

Angular location of the center of the structural element on the circumference of the equivalent, circular section for the fuselage (figure 19 of reference 1). For a uniform load (NU = 1) this locates the point at which the pressures are applied. $(-\pi \leq \theta_R \leq \pi)$ (THETAR), rad.

TABLE 20

GROUPS 27 AND 28 DATA OPTIONS FOR LOADING FUSELAGE ELEMENTS

Fuselage Element	KTYPE	Group 28 data for Uniform Load (NU = 1)	Group 28 data for non-uniform Load (NU = 0)
Panel	≤ 5	θ_R	θ_R
Stringer	6	θ_R	Not possible
Frame	7	θ_R	θ_R can be anything*
Radome	8,9	Not possible	θ_R not inputted*

*For these cases, the V, W coordinates (or θ_1, θ_2) (LAS) in DEPROB must locate the beam elements circumferentially.

Local Aircraft System (LAS) align with (y, z) in the AAS. The DEPROB angle θ, though, is not defined in the same manner as θ_R (page 274 of reference 1).

The only input instruction which is modified in the DEPROB section deals with the KSUP parameters of Group 1. KSUP is not needed for cases where there is not a threshold-of-permanent change requirement; i.e., for KDAM = 1, 2 or 101.

The DEPROP input has been changed significantly, although much of it remains the same. Even so, the entire set of input instructions is documented in table 21 to facilitate the preparation of an input deck. Specific input instructions follow several paragraphs of general remarks. The user is reminded to compare all input variables with the maximum dimension provided in the program, as delineated in table 15. This is very important since the program does not attempt to check the input for such violations.

Group 1 contains the number of modes to be used in the solution and the number of integration points to be used. The accuracy of the solution is based on the degree of convergence of stress and strain quantities. These quantities converge less rapidly than the radial displacement. Also, cases involving a clamped edge condition will converge less rapidly than simply-supported cases. Since both computer time and accuracy increase with more modes and points, a trade-off usually becomes necessary. Although the program allows up to 13 gamma modes and 13 beta modes to be used, only a small number of modal combinations are normally required, as will be discussed shortly.

The actual mode numbers are specified in Groups 2 and 3. The maximum value that the mode numbers can assume in the program is 19. When symmetry is taken in either direction (Group 4, or if the pressure loading is symmetrically oriented, only the odd numbered modes (1, 3, 5, ...) are required in that direction.

In general, a minimum of sixteen modal combinations should be used for a symmetric panel, and it is recommended that at least 25 be used for clamped panels where edge stresses and strains are important. The maximum number of combinations permitted is 49 (see the discussion of data groups 6 and 7).

Spatially, the optimum number of integration points (MBAR and NBAR) for a full panel should be approximately two times the maximum mode number used in that direction, plus three. However, when NBN or MGM is large, this condition may not be satisfied for nonsymmetrical panels, since MBAR and NBAR are dimensioned at 23 (28 on the CDC 176) in the program (see table 15). For symmetric solutions, MBAR (or NBAR) need only be approximately one-half the value for a full panel since only one-half (or one quarter) of the panel is actually analyzed in the solution. For a nonsymmetric condition, MBAR (or NBAR) must be an odd number. For an elastic-plastic solution, a minimum of four integration points through the thickness is recommended, and a maximum of six is provided in the program. The exception is a metal honeycomb panel where only two points are used.

In Group 5, the user is given the option of a purely elastic solution, or an elastic-plastic solution. The elastic-plastic option will tend to be slower and require more computer memory. The second option (elastic-plastic) <u>must be used</u> for metal panel solutions which iterate to a catastrophic damage level (KTYPE = 1, 3; KDAM = 1, 101).

Group 5 also specifies the number of stiffeners in the model and whether the full coupled mass matrix is used, or only the diagonal terms. The advantage of only using the diagonal terms is to reduce the computer time; however, the savings is not that much and it is recommended that the full matrix be used for a more accurate solution (KCOUP = 1).

A gamma stiffener is defined as a stiffener running parallel to the (x, γ) axis and the beta stiffener is defined similarly. These stiffeners must be located on either a γ or β grid line and are assumed to be

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attached at each grid line intersection. If all the gamma stiffeners are of identical construction, NSG should be inputted as a <u>negative</u> number (i.e., -3 for three identical stiffeners) which will eliminate unnecessary input. And the same instruction applies to NSB for beta stiffeners.

Groups 6 and 7 provide a mechanism for selecting a maximum of 49 modal combinations from a 13 by 13 combination array (MG=MB=13). Thus, the more significant modal combinations for an optimal solution with respect to accuracy and computer time can be selected and the other combinations eliminated. A general rule of thumb is to eliminate the higher frequency modes which are usually associated with modal combinations having the larger MG+MB values. An example of this would be the selection of MG=MB=7 for a symmetric problem, but eliminating 24 combinations as indicated in figure 41. The relative importance of each modal combination can be evaluated by examining the response output and comparing the magnitudes of the displacement coefficients.

Groups 8 and 9 are responsible for selecting the points in the integration grid for which printout of strains, stresses, displacements, and pressures is required. Strains and stresses are computed at the inner and outer surfaces of the panel layers and stiffeners. Each point in the grid is designated by a pair of integers, the first integer referring to the gamma-position, the second to the beta-position. Actual positions are found from

$$x = \frac{\ell}{2} \frac{(I-1)}{(\bar{M}-1)} \qquad I = 1,\ldots,\bar{M}$$

(symmetric in x-direction)

$$x = \ell \frac{(I-1)}{\bar{M}-1} \qquad I = 1,\ldots,\bar{M}$$

(full in x-direction)

and similar expressions for y (or θ). For example, the corner point in a symmetric panel would be numbered (1,1); the center (MBAR,NBAR).

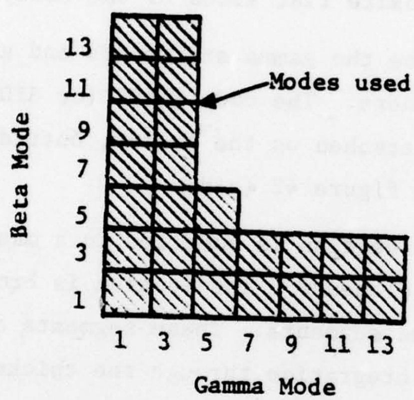

Figure 41. Example of Modal Selection for a Panel Exibiting Symmetry in both Coordinate Directions

It should be noted that the maximum response values associated with determining CRIT for an iterative run are calculated at every grid point, independent of the printout selected in groups 8 and 9.

The length and width (XLP and THETAO) selected in Group 11 represent the total dimensions of the panel, even if only 1/2 or 1/4 is analyzed in a symmetric case.

Group 15 provides the data required for computing allowable stresses for honeycomb panels. The core cell size (DC) is defined as the distance between opposite flat sides of the honeycomb cell.

Groups 18-23 describe the gamma stiffeners and groups 24-29 describe the beta stiffeners. The code SIDEG (or SIDEB) indicates whether a stiffener is attached on the inside, outside, or within the panel, as illustrated in figure 42 (a-d).

The stiffener cross section is modelled in a manner similar to that used in DEPROB for beam elements. The section is broken down into rectangular layers called segments. These segments also serve the purpose of flanges for integration through the thickness, so the analyst must assign enough segments to be able to adequately model the cross section for an inelastic problem. A maximum of eight segments is permitted (NSEGG, NSEGB).

Although stiffeners can be of different material, any one stiffener is assumed to be of homogeneous construction; i.e., each segment is composed of the same material. It is further assumed that if the panel is made of plastic material, the stiffeners are plastic, and similarly if the panel is metal (or metal face sheets on honeycomb), the stiffeners are metal.

Gamma stiffeners also must be uniform in the spanwise direction, but beta stiffeners can have variable cross section. This is accomplished by specifying the cross-sectional shape at one or more arbitrary beta locations (BETC). The program linearly interpolates between points, if necessary, to provide data at every spatial grid point. Obviously,

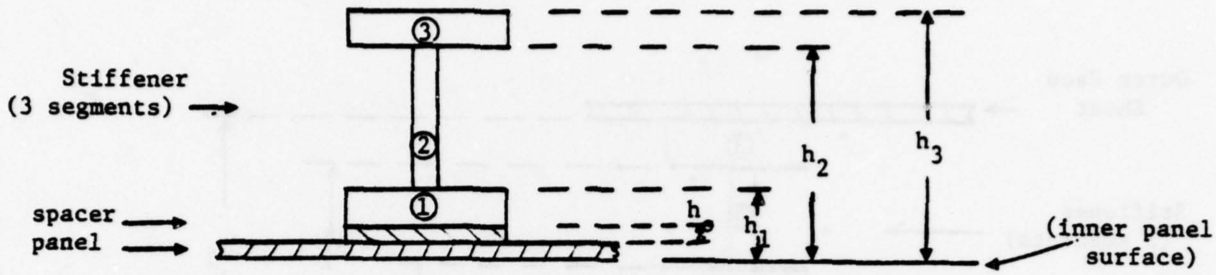

Figure 42 (a). Outer Stiffener.
(SIDEG(B)=+1.0).

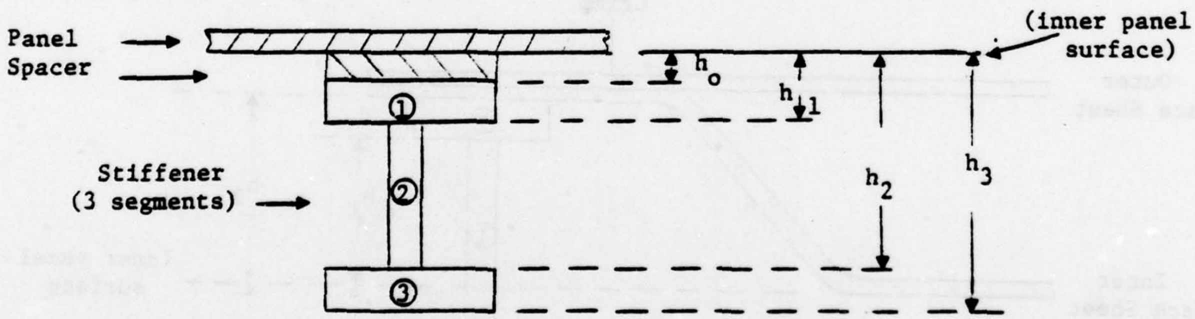

Figure 42 (b). Inner Stiffener.
(SIDEG(B)=-1.0).

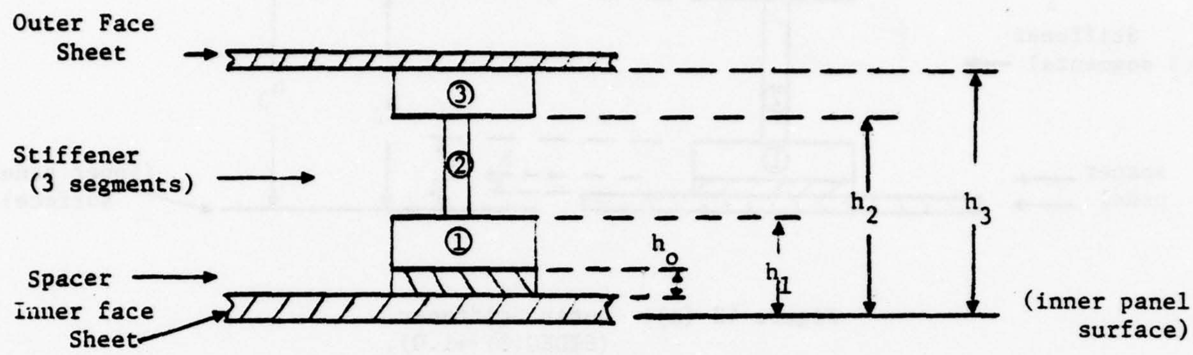

Figure 42 (c). Internal Stiffener.
(SIDEG(B)=+2.0).

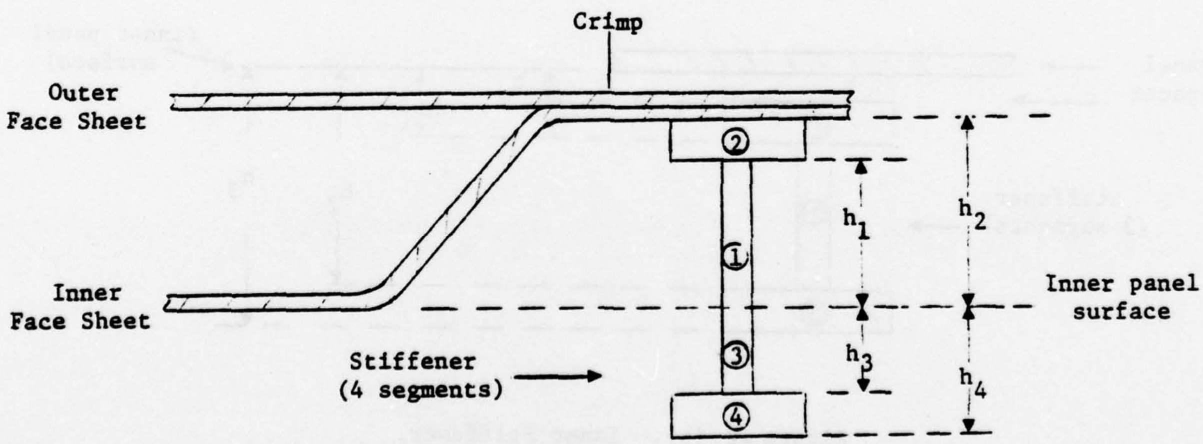

Figure 42 (d). Inner Stiffener with Crimped Sandwich Panel.
(SIDEG(B)=+3.0).

if only one cross section is specified, the stiffener is assumed to be uniform and it makes no difference what beta location (BETC) is used. Constant cross section is assumed for beta points outside the domain of BETC.

Figure 42 illustrates the four types of stiffeners. Case (a) represents an "outer" stiffener with a spacer of thickness h_o (HOG,HOB) located between the panel and the stiffener. This space might represent insulating material or a gap created by another stiffener running orthogonal to the one being modelled. For simplicity the stiffener is modelled as an "I" section with three segments; in an elastic-plastic model the web (segment 2) should probably be broken down into three or four segments. The input parameters HSTG(B) correspond to the h_1, h_2 and h_3 shown and are measured relative to the inner surface of the panel.

Case (b) is nearly identical, except that the stiffener is called an "inner" stiffener as it is located on the inside of the panel. The h_ℓ are again referenced relative to the inner surface of the panel, and are also inputted as positive numbers, as is h_o.

Cases (c) and (d) represent a panel of sandwich (or honeycomb) construction. In the first case the stiffener lies within the panel and the input parameters are defined as before. The second case, however, considers the case when the panel is crimped in order to attach the stiffener, and thus the stiffener may or may not lie totally within the panel section. If not, the h_ℓ's must be defined in a different manner, as shown in figure 42 (d). To begin with, the segments must be defined so that there is a division between two segments at the imaginary inner panel surface. The segments are ordered from that point outward as far as possible until a switch over is required, as shown. In order to flag this switch over, which occurs at the $\ell = L^{th}$ segment, the parameter h_L is made <u>negative</u>. In this case, h_3 would be inputted as a negative number - all the others are positive.

Group 30 contains the modal components, δ_{mn}, for the initial radial imperfections. The analyst must compute the δ_{mn}'s from measured

TABLE 21

DEPROP INPUT

Group 1: (5I12) MG, MB, MBAR, NBAR, LBAR

Number of gamma modes to be used. (MG)

Number of beta modes to be used. (MB)

Number of gamma integration points actually used over the portion of the panel analyzed. Must be an odd number for full panel (see Group 4). (MBAR)

Number of beta integration points actually used over the portion of the panel analyzed. Must be an odd number for full panel (see Group 4). (NBAR)

Number of z integration points used through the thickness. (LBAR) Should be 2 for KTYPE=3. [Not needed for NDERV=1 (see Group 5)]

Group 2: (6I12) (MGM(I), I=1, MG)

Gamma mode numbers, m.

Group 3: (6I12) (NBN(I), I=1, MB)

Beta mode numbers, n.

Group 4: (2I12) NSYMG, NSYMB

Symmetry code in gamma direction (NSYMG):
0, symmetry assumed $(0 \leq \gamma \leq \pi/2)$
1, no symmetry $(0 \leq \gamma \leq \pi)$

Symmetry code in beta direction (NSYMB):
0, symmetry assumed $(0 \leq \beta \leq \pi/2)$
1, no symmetry $(0 \leq \beta \leq \pi)$

Group 5: (6I12) NPLT, NBND, NDERV, NSG, NSB, KCOUP

Panel type (NPLT):
0, flat panel
1, cylindrical panel

Boundary condition code (NBND):

DEPROP INPUT (Continued)

γ-direction	β-direction
1, clamped-clamped	clamped-clamped
2, simple-simple;	simple-simple
3, clamped-clamped;	simple-simple
4, simple-simple	clamped-clamped
5, clamped-simple;	clamped-clamped
6, clamped-clamped;	clamped-simple
7, clamped-simple;	simple-simple
8, simple-simple;	clamped-simple
9, clamped-simple;	clamped-simple

Note: Whenever a clamped-simple condition is selected, the full panel is analyzed in that direction, and NSYMG, NSYMB, MBAR and NBAR should reflect this.

Response option (NDERV):
1, elastic only
2, elastic-plastic

Note: NDERV must be 2 for KTYPE=1 or 3 whenever KDAM=1 or 101.

Number of γ stringers (NSG)
Number of β stringers (NSB)

Note: A negative value for NSG (or NSB) means that all γ (or β) stringers are identical. Only one set of input data will be required in that case.

Mass-matrix coupling code (KCOUP)
0, no compiling
1, compiling

Note: KCOUP will be zero if NSG=NSB=0.

Group 6: (I12) NNOUT

Number of modal combinations to be <u>eliminated</u> from solution (NNOUT).
($0 \leq$ NNOUT < MG*MB)

<u>If NNOUT=0, skip to Group 8.</u>

Group 7: (2I12) MOUT(I), NOUT(I)

Gamma mode. (MOUT(I))
Beta mode. (NOUT(I))

<u>Repeat Group 7 for I=1, NNOUT. The cards in Group 7 may be arranged in any order.</u>

Group 8: (I12) NKP

Number of spatial points at which printout of stresses, strains, displacements, reactive forces and pressures are requested. If NKP=0, all of the above information will be suppressed. (NKP)

If NKP=0, skip to Group 10.

Group 9: (2I12) KPG(I), KPB(I)

Integration point in gamma-direction at which printout is requested. Points are ordered 1-MBAR, beginning at γ=0, and evenly spaced from there. (KPG(I))

Integration point in beta-direction at which printout is requested. Points are ordered 1-NBAR, beginning at β=0, and evenly spaced from there. (KPB(I))

Note: These two indices are taken as pairs where each pair designates a particular spatial point. The pairs may be specified in any order.

Repeat Group 9 for I=1, NKP.

Group 10: (I12) NL

Number of layers. (NL)
(NL must be 1 for KTYPE=1, and 3 for KTYPE=3)

Group 11: (3F12.1) XLP, THETAO, A

Full length of panel, ℓ, in. (XLP)

Full width of flat panel, b (short direction), in. (NPLT=0)

or

Full subtended angle of cylindrical panel, θ_0, deg. (NPLT=1)

(THETAO)

Radius of cylindrical panel, in. (A)
(Not needed for NPLT=0)

If NDERV=2, skip to Group 16.

DEPROP INPUT (Continued)

Group 12: (2F12.1) HM(I), RHOM(I)

Distance (h) from the inner panel surface to the outer surface of layer I, in. (HM(I))

Mass density of layer I, $lb\text{-}s^2/in^4$. (RHOM(I))

Group 13: (5F12.1) EX(I), ET(I), XXNU(I), THNU(I), GXT(I)

Modulus of elasticity in the x-direction, psi. (EX(I))

Modulus of elasticity in the theta-direction, psi. (ET(I))

Poisson's ratio in the x-direction. (XXNU(I))

Poisson's ratio in the theta-direction. (THNU(I))

Shear modulus, psi. (GXT(I))

Group 14: (2F12.1) SAT(I), SAC(I)

Tensile yield stress of metal panels; tensile ultimate stress for plastic panels, psi. (SAT(I))

Absolute value of compressive yield stress for metal panels; absolute value of compressive ultimate stress for plastic panels, psi. (SAC(I))

<u>If KTYPE=1,2, or 5, skip to Group 18.</u>

<u>If KDAM=1,2, or 101, skip to Group 18.</u>

Group 15: (3F12.1) EC,GC,DC

Core modulus of elasticity parallel to core depth, psi. (EC)

Shear modulus of core, psi. (GC)

Core cell size, in. (DC)

<u>Skip to Group 18.</u>

DEPROP INPUT (Continued)

Group 16: (3F12.1) HM(I), RHOM(I), EM(I)

Distance (h) from inner shell surface in the outer surface of layer I, in. (HM(I))

Mass density of layer I, $lb\text{-}s^2/in^4$. (RHOM(I))

Modulus of elasticity, psi. (EM(I))

Note: EM(2) need not be specified for a metal honeycomb material (KTYPE=3)

Repeat Group 16 for I=1, NL.

Group 17: (4F12.1) TNU, SIGO, EP, EPSIF

Poisson's ratio. (TNU)

Yield stress for a metal panel, psi. (SIGO)

Strain hardening modulus (E_t), psi. (EP)

Ultimate strain, in/in. (EPSIF)
(Not necessary for KDAM=2)

If NSG=0, skip Groups 18-23, which pertain to gamma stiffeners.

Group 18: (6I12) KSG(I), I=1,/NSG/

Beta-point number corresponding to gamma stiffener location.

Group 19: (6F12.1) SIDEG(I), ESTRG(I), GBARG(I), RHOSTG(I), SIGOGT(I), SIGOGC(I)

Code designating type of stiffener (SIDEG):

- -1.0, Inner
- +1.0, Outer
- +2.0, Internal (honeycomb panel construction)
- +3.0, Inner (crimped honeycomb panel)

Elastic modulus, $\bar{E}$, lb/in^2 (ESTRG)
Shear modulus. $\bar{G}$, lb/in^2 (GBARG)
Density, ρ_s, $lb\text{-}s^2/in^4$ (RHOSTG)
Tensile yield stress, lb/in^2 SIGOGT)
Compressive yield-stress, lb/in^2 (SIGOGC)

If NDERV=1, skip Group 20.

DEPROP INPUT (Continued)

Group 20: (2F12.1) ETSTRG(I), EPSG(I)

Strain-hardening slope, $\overline{E}_t$, lb/in^2 (ETSTRG)
Ultimate tensile strain, ε_u, in/in (EPSG)

Group 21: (2I12) NSEGG(I), KSUPG(I)

Number of segments (NSEGG)
Support code for outstanding leg (KSUPG):

0, no outstanding leg.
1, outstanding leg supported at one end.
2, outstanding leg supported at both ends or has two corners.

Group 22: (2F12.1) BIGJG(I), HOG(I)

Torsion constant for stiffener, J, in^4 (BIGJG)
Gap between stiffener and panel, h_o, in (HOG)

Group 23: (2F12.1) HSTG(L,I), BSTG(L,I)

Distance from inner panel surface to the furthest edge of the ℓ^{th} segment, h_ℓ, in. (HSTG)

Width of ℓ^{th} segment, b_ℓ, in. (BSTG)
Note - HSTG is always a positive number except for SIDEG=3, for the ℓ=L segment which causes HSTG to switch directions. See figure 42.

Repeat Group 23 for all segments in the Ith stiffener.
Unless NSG was read in as a negative number, repeat Groups 19-23 for each gamma stiffener.

If NSB=0, skip Groups 24-29, which pertain to the beta stiffeners.

Group 24: (6I12) KSB(I), I=1,/NSB/

Gamma-point number corresponding to beta stiffener location.

Group 25: (6F12.1) SIDEB(I), ESTRB(I), GBARB(I), RHOSTB(I), SIGOBT(I), SIGOBC(I)

DEPROP INPUT (Continued)

Code designating type of stiffener (SIDEB):

- -1.0, Inner
- +1.0, Outer
- +2.0, Internal (honeycomb panel construction)
- +3.0, Inner (crimped honeycomb panel)

Elastic modulus, $\overline{E}$, lb/in^2 (ESTRB)
Shear modulus, $\overline{G}$, lb/in^2 (GBARB)
Density, ρ_s, $lb\text{-}s^2/in^4$ (RHOSTB)
Tensile yield stress, lb/in^2 (SIGOBT)
Compressive yield stress, lb/in^2 (SIGOBC)

<u>If NDERV=1, skip Group 26</u>.

Group 26: (2F12.1) ETSTRB(I), EPSB(I)

Strain-hardening slope, $\overline{E}_t$, lb/in^2 (ETSTRB)
Ultimate tensile train, ε_u, in/in (EPSB)

Group 27: (3F12.1) NSEGB(I), KSUPB(I), NSTB(I)

Number of segments (NSEGB)
Support code for outstanding leg (KSUPB):

- 0, no outstanding leg
- 1, outstanding leg supported at one end.
- 2, outstanding leg supported at both ends or has two corners.

Number of β-stations used to define cross section. (NSTB)

Notes: NSTB should be 1 for a uniform cross section and BETC can be anything.
NSTB must be $\leq$ NBAR.

Group 28: (3F12.1) BIGJB(K,I), HOB(K,I), BETC(K,I)

Torsion constant for k^{th} station, J, in^4. (BIGJB)
Gap between stiffener and panel, h_o, in. (HOB)
Beta position of the k^{th} station, in or deg. (BETC)

DEPROP INPUT (Concluded)

Group 29: (2F12.1) HSTB(L,K,I), BSTB(L,K,I)

Distance from inner panel surface to the furthest edge of the ℓ^{th} segment, h_ℓ, in. (HSTB)
Width of ℓ^{th} segment, b_ℓ, in. (BSTB)

Note: HSTB is always a positive number except for SIDEB=3.0, for the ℓ=L segment, which causes HSTB to switch directions. See figure 42.

Repeat Group 29 for all segments at the k^{th} station of the I^{th} stiffener.

Unless NSB was read in as a negative number, repeat Groups 25-29 for each β-stiffener.

Group 30: (6F12.1) ((FG(N,M), N=1,MB), M=1,MG)

Modal displacement coefficients for initial radial imperfections, in. (FG(N,M))

Group 31: (3F12.1) DELTIM, TSTOP, PRINT

Integration time increment, sec. If DELTIM=0.0, the program determines the time increment required for stability. (DELTIM)

Integration stop time, sec. (TSTOP)

Print frequency (integration steps per printout). If PRINT=0.0, printout of intermediate data will be suppressed. (PRINT) data using the integration technique applied to Fourier series coefficients. Generally, such data will not be available, and zero values should be specified for the δ_{mn}'s. The capability of considering initial imperfections also enables the analyst to determine the sensitivity of panel response to initial imperfections.

Group 31 provides the integration time increment, the response stop time, and printout interval. If the user specifies a zero time increment, the program computes an appropriate Δt which in most cases will give a stable solution. It should be noted, however, that stiffeners are neglected in the computation, so it is possible a smaller Δt will be required for some stiffened panels. Because the Δt is approximate, the analyst may want to make comparable runs using different Δt's. In general, an elastic solution which is numerically stable will be accurate. Hence, the optimum Δt is the largest which remains stable. For an elastic-plastic solution, however, the accuracy of the solution may deteriorate slightly as the point at which the solution diverges is approached. Once a time increment is selected, it should be valid for other orientations and moderate changes in response level.

Although the stop time can vary a great deal, the total number of integration steps required to capture peak response will be roughly between 500 and 1500. One exception to this may be a curved panel experiencing "snap-through" buckling, in which case considerably larger response times may be required. A printout frequency of once every 20 steps is usually adequate for monitoring the response time history. The program checks response values every ten time steps.

5.4 PROGRAM OPERATION

Two versions of NOVA-2S have been assembled due to the difference in core allocation between the Control Data Corporation (CDC) 6600 and the CDC 176 computer systems. The 6600 version has smaller dimensions and only uses small core memory (SCM). The 176 version has somewhat larger dimensions in DEPROP and makes use of large core memory (LCM) by assigning 6 common blocks to LEVEL 2 (see table 12).

Otherwise, the deck structure is the same for each version, using segmentation as in the past (figure 43 and table 22). Logical files TAPE5 and TAPE6 are used for input and output, respectively, and file TAPE1 is reserved for internal use. When the REFRA near-ground reflection (blast) model is selected and ground reflection is to be included in the analysis (KB=1,KGRD=1), the REFRA data must be available on logical file TAPE10. This data is unformatted (binary) with record type S and block type C. This record-type-blocking combination is compatible with SCOPE 3.3 and possesses the important feature that the system copy utility COPYBF can be used with SCOPE 3.4 to transfer the data to disk, tape, etc. When used with the NOVA program under SCOPE 3.4, however, a FILE card is required prior to loading to specify the record type and block type. The REFRA routine will usually operate more efficiently when the information is on disk, so a transfer to disk is recommended whenever possible.

Using the FTN compiler on the 176, approximately $60{,}000_8$ cells of SCM and 15 seconds of CP time is required, specifying the fast compile mode (OPT=1).

The 6600 version of the program requires approximately $260{,}000_8$ cells of SCM to load; the 176 version needs approximately $172{,}000_8$ cells of SCM and $255{,}000_8$ cells of LCM.

5.5 NOVA-2LTS

This special version includes the modifications made in previous versions NOVA-2L and NOVA-2LT, where the "L" refers to the fact that all of the blast and aeronautical loading routines have been replaced by user-generated functions or tape-supplied data (reference 2).

No other changes were made here, except to adapt the up-to-date response codes in NOVA-2S to this special deck. Table 23 lists all the subroutines in the deck, and figure 44 and table 24 document the proper segmentation directives. Core requirements for this deck are approximately the same as for NOVA-2S, except for an additional LCM requirement

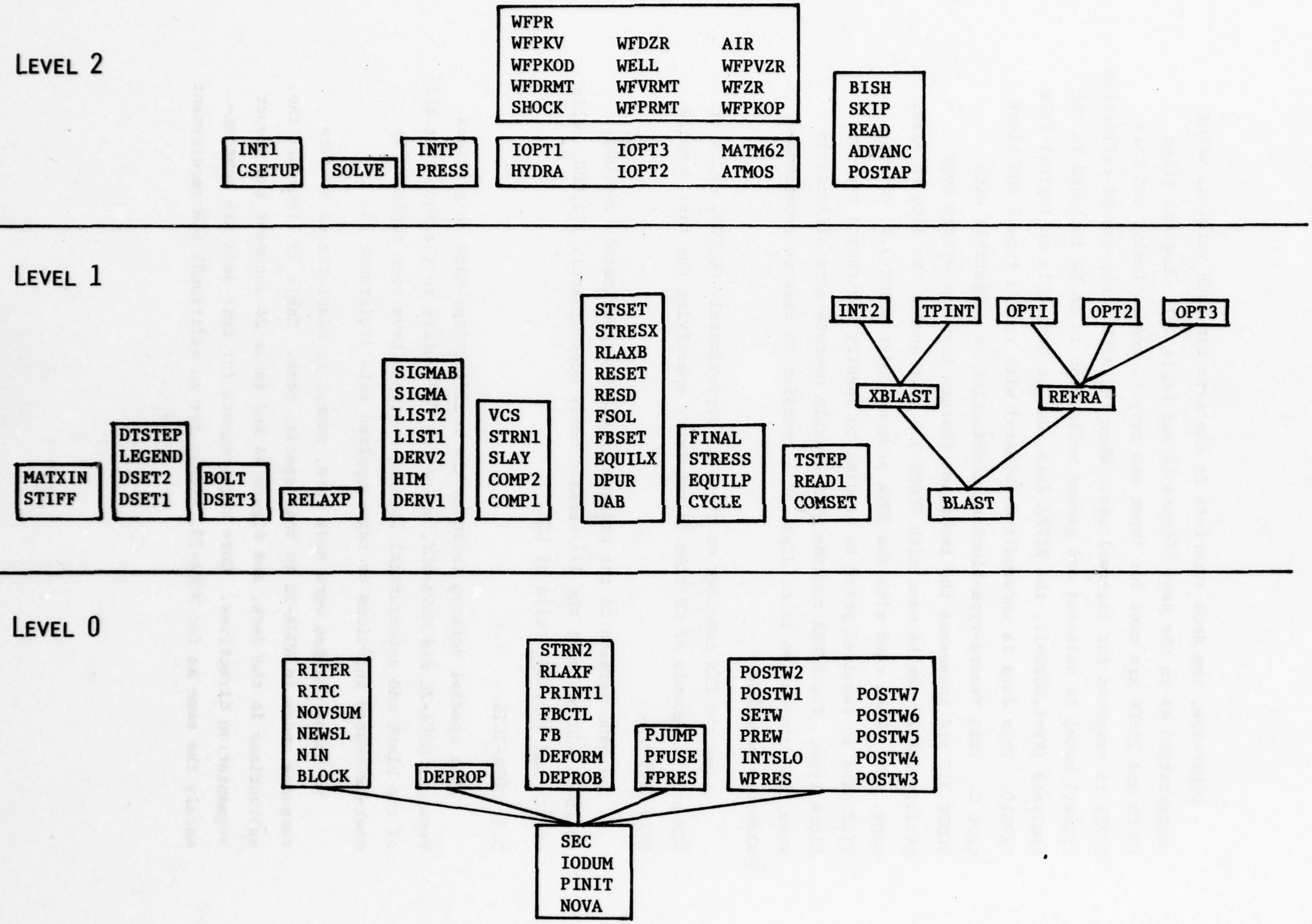

Figure 43. Segmentation Tree Structure of NOVA-2S

TABLE 22

SEGMENTATION DIRECTIVES FOR NOVA-2S

```
         TREE        NOVA
NOVA     INCLUDE     PINIT,IODUM,SEC
         LEVEL
         TREE        BLOCK
BLOCK    INCLUDE     NIN,NEWSL,NOVSUM,RITC,RITER
         TREE        DEPROP
         TREE        DEPROB
DEPROB   INCLUDE     DEFORM,FB,FBCTL,PRINT1,RLAXF,STRN2
         TREE        FPRES
FPRES    INCLUDE     PFUSE,PJUMP
         TREE        WPRES
WPRES    INCLUDE     INTSLO,PREW,SETW,POSTW1,POSTW2,POSTW3,POSTW4,POSTW5,P
,OSTW6,POSTW7
         LEVEL
         TREE        DSET1
DSET1    INCLUDE     DSET2,LEGEND,DTSTEP
         TREE        DSET3
DSET3    INCLUDE     BOLT
         TREE        STIFF
STIFF    INCLUDE     MATXIN
         TREE        DERV1
DERV1    INCLUDE     SIGMA,SIGMAB,HIM,DERV2,LIST1,LIST2
         TREE        RELAXP
         TREE        COMP1
COMP1    INCLUDE     COMP2,SLAY,STRN1,VCS
         TREE        DAB
DAB      INCLUDE     DPOR,EQUILX,FBSET,FSOL,RESD,RESET,RLAXB,STRESX,STSET
         TREE        CYCLE
CYCLE    INCLUDE     EQUILP,STRESS,FINAL
         TREE        COMSET
COMSET   INCLUDE     READ1,TSTEP
         TREE        BLAST-(XBLAST-(INT2,TPINT),REFRA-(OPT1,OPT2,OPT3))
         LEVEL
         TREE        CSETUP
CSETUP   INCLUDE     INT1
         TREE        SOLVE
         TREE        PRESS
PRESS    INCLUDE     INTP
         TREE        HYDRA
HYDRA    INCLUDE     MATM62,IOPT1,IOPT2,IOPT3,WELL,WFDRMT,WFDZR,WFPKOP,WFP
,KOD,AIR,WFPKV,WFPR,WFZR,WFPRMT,WFVRMT,WFVZR,SHOCK,ATMOS
         TREE        POSTAP
POSTAP   INCLUDE     ADVANC,READ,SKIP,BISH
NOVA     GLOBAL      FIRST,CNOVA,DNOVA,CTLX-SAVE
HYDRA    GLOBAL      CONSTC,SCALEC
WPRES    GLOBAL      PW1-SAVE
REFRA    GLOBAL      REFRAC-SAVE
DEPROB   GLOBAL      BLK2,BLK3,BLK6-SAVE
DEPROP   GLOBAL      CBLK1,CBLK2,CBLK3,CBLK4,CBLK5,CBLK7,CBLK8,CBLK9,CBLK1
,0,CBLK11,CBLK13,CBLK15,CBLK17,CBLANK-SAVE
DERV1    GLOBAL      CBLK6,CBLK16-SAVE
RELAXP   GLOBAL      CBLK12-SAVE
         END         NOVA
```

TABLE 23

LIST OF SUBPROGRAMS FOR NOVA-2LTS (NOVA-2L)

NOVA	DEPROP	DEPROB
NOVA	DEPROP	DEPROB
SEC	BOLT	COMP1
RITER	DERV1	COMP2
CSETUP	DERV2	COMSET
PINIT	DSET1	CYCLE
SOLVE	DSET2	DAB
INT1	DSET3	DEFORM
PRESS	DTSTEP	DPUR
	HIM	EQUILP
	LEGEND	EQUILX
	LIST1	FB
	LIST2	FBCTL
	MATXIN	FBSET
	RELAXP	FINAL
	SIGMA	FSOL
	SIGMAB	PRINT1
	STIFF	READ1
		RESD
		RESET
		RLAXB
		RLAXF
		SLAY
		STRESS
		STRESX
		STRN1
		STRN2
		STSET
		TSTEP
		VCS

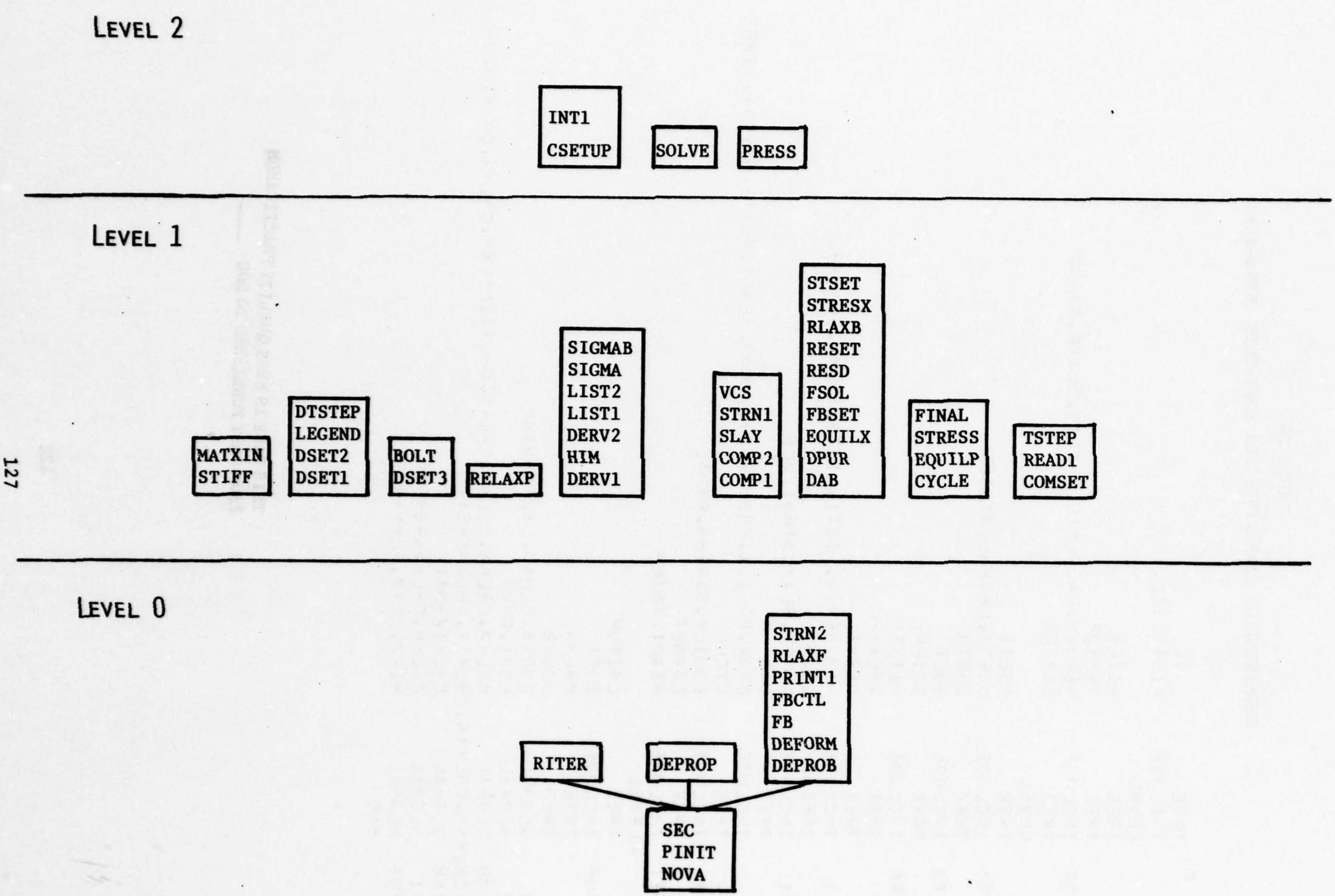

Figure 44. Segmentation Tree Structure of Modified NOVA-2LTS (NOVA-2L)

TABLE 24

SEGMENTATION DIRECTIVES FOR NOVA-2LTS (NOVA-2L)

```
          TREE        NOVA
NOVA      INCLUDE     PINTT,SEC,IODUM
          LEVEL
          TREE        RITER
          TREE        DEPROB
DEPROB    INCLUDE     DEFORM,FB,FBCTL,PRINT1,RLAXF,STRN2
          TREE        DEPROP
          LEVEL
          TREE        DSET1
 DSET1    INCLUDE     DSET2,LEGEND,DTSTEP
          TREE        DSET3
 DSET3    INCLUDE     BOLT
          TREE        STIFF
 STIFF    INCLUDE     MATXIN
          TREE        RELAXP
          TREE        DERV1
DERV1     INCLUDE     HIM,DERV2,LIST1,LIST2,SIGMA,SIGMAB
          TREE        COMP1
COMP1     INCLUDE     COMP2,SLAY,STRN1,VCS
          TREE        DAB
DAB       INCLUDE     DPUR,EQUILX,FBSET,FSOL,RESD,RESET,RLAXB,STRESX,STSET
          TREE        CYCLE
CYCLE     INCLUDE     EQUILP,STRESS,FINAL
          TREE        COMSET
COMSET    INCLUDE     READ1,TSTEP
          LEVEL
          TREE        CSETUP
CSETUP    INCLUDE     INT1
          TREE        PRESS
          TREE        SOLVE
NOVA      GLOBAL      CNOVA,CLOAD,CBLK1-SAVE
NOVA      GLOBAL      COM1,COM2
DEPROP    GLOBAL      CBLK2,CBLK3,CBLK4,CBLK5,CBLK7,CBLK8,CBLK9,CBLK10,CBLK
,11,CBLK13,CBLK15,CBLK17,CBLANK-SAVE
RELAXP    GLOBAL      CBLK12-SAVE
DERV1     GLOBAL      CBLK6,CBLK16-SAVE
DEPROB    GLOBAL      BLK2,BLK3,BLK6-SAVE
          END
```

when the tape option is used for supplying pressure data, as before. Appendix A contains a card listing of the appropriate UPDATE changes to transform NOVA-2S into NOVA-2LTS.

5.6 EXAMPLE PROBLEM

An example problem is presented in this section to provide the user with a test case for exercising NOVA-2S, and to also indicate the modelling technique used in analyzing stiffened panels.

The panel modelled is the fin panel on the vertical tail of the B-52 discussed in section 4. Figure 45 lists the input data for an inelastic response run (KDAM = 101). The model contains one inner gamma stiffener located at the 13th beta position, or $y = \frac{(13-1)\ (32.7)}{(19-1)\ (2)} = 10.9$ inches, of a clamped panel exibiting symmetry in both coordinate directions.

Figure 46 contains the time-history printout at time 1.75 milliseconds, approximately the time of peak response. A summary of the run, including the maximum response compared with allowables, follows the response output and is shown in figure 47. In this case, a tensile strain at the clamped edge of the stiffener produced a CRIT of 0.539. The maximum CRIT of 0.445 in the panel was also due to a tensile strain at the same edge, at y = 11.81 inches.

Computer time for this relatively large structural model (30 modes and 361 spatial points) was 403 cp seconds and 2 EC seconds on the CYBER 176.

```
B-52H FIN PANEL
         1         0
1000.     525.      1000.     0.0
0.0       0.0       0.0       0.0
        15        15
7000.
                                                            (BLANK)
         2         0
       101         0
.5
         2         2
-426.     0.0
-1259.    1110.
-783.     0.0
-1407     1110.
         2         2
-1493.5   0.0
-1774.5   309.81
-1825.8   0.0
-1859.3   309.81
         2         2
-1493.5   0.0
-1731.5   278.8
-1795.5   0.0
-1851.7   278.8
         9
-45.      -1935.87
0.0       -69.1
-75.      30.
-202.3    64.4
-538.     69.1
-847.     69.1
-1207.    69.1
-1307.    66.2
-1417.    59.5
-1462.    56.71
-1646.5   44.93
         4         1         1
-1758.    0.0       35.0
0.0
         7         7        19        19         5
         1         3         5         7         9        11
        13
         1         3         5         7         9        11
        13
         0         0
         0         1         2         1         0         1
        19
         5        11
         5        13
         7         9
         7        11
         7        13
```

Figure 45. Example Problem Input Card Listing

```
            9          7
            9          9
            9         11
            9         13
           11          5
           11          7
           11          9
           11         11
           11         13
           13          5
           13          7
           13          9
           13         11
           13         13
           11
            1          7
            1         13
            1         19
            5         13
            9         13
           13         13
           17         13
           19          1
           19          7
           19         13
           19         19
            1
42.0        32.7
.032        .259      E-3 1.05    E7
.33         50000.       1.24     E5 .15
           13
-1.0        1.04      E7 4.0      E6 .259     E-3 70500.    70500.
5.9        E4 .1
           6          0
.000393     0.0
.064        1.272
.2945       .128
.525        .128
.7555       .128
.986        .128
1.05        1.38
0.0         0.0       0.0         0.0         0.0           0.0
0.0         0.0       0.0         0.0         0.0           0.0
0.0         0.0       0.0         0.0         0.0           0.0
0.0         0.0       0.0         0.0         0.0           0.0
0.0         0.0       0.0         0.0         0.0           0.0
0.0         0.0       0.0         0.0         0.0           0.0
0.0         0.0       0.0         0.0         0.0           0.0
0.0         0.0       0.0         0.0         0.0           0.0
0.0         0.0       0.0         0.0         0.0           0.0
0.0
5.        E-6 2.0     E-3 50.
                                                                  (BLANK)
```

Figure 45. (Continued)

T = .1750000E-02 SEC

GAMMA	BETA	URS	VRS	WRS
1	1	-.5230203E-02	-.1331277E+00	.1420174E+01
1	3	.4630511E-02	.2060700E-02	.2215974E+00
1	5	-.2181547E-01	-.3333915E-03	.1300624E+00
1	7	.1294750E-01	.1112352E-01	.3167696E-01
1	9	.8243200E-03	.5425165E-02	.1852758E-01
1	11	-.2834038E-02	.3302959E-02	.1710247E-01
1	13	.2995723E-02	.6203720E-02	.3419267E-02
3	1	.3874515E-01	.2699537E-01	.1843773E+00
3	3	-.8345375E-02	-.6199409E-02	.4610194E-01
3	5	-.1133315E-01	.5558203E-04	.4820834E-01
3	7	.8578999E-02	-.1508777E-02	.3389310E-02
3	9	-.1196156E-03	-.1483615E-02	.2169737E-02
3	11	-.9334082E-03	.3765060E-04	.6862618E-02
3	13	.1027097E-02	-.1252304E-02	-.6922534E-03
5	1	.1751215E-01	.1139684E-01	.5197428E-01
5	3	-.3348249E-02	-.2066051E-03	.8629721E-02
5	5	-.6686487E-02	-.1410041E-02	.2225108E-01
5	7	.4715672E-02	-.9406256E-04	-.3477148E-02
5	9	-.1257474E-02	-.5585221E-03	.2019252E-02
7	1	.1004999E-01	-.5250889E-03	.3243097E-01
7	3	-.1417402E-02	-.9099809E-03	.1514947E-01
7	5	-.3144024E-02	.1457180E-03	.1843928E-01
7	7	.2714052E-02	.1083678E-02	-.2476861E-02
9	1	.8041374E-02	.2803149E-02	.1836462E-01
9	3	-.5874269E-03	.1126768E-02	-.2616809E-02
9	5	-.1020338E-02	-.7536666E-03	.1032307E-01
11	1	.5421501E-02	.1496272E-02	.2280565E-02
11	3	-.5909510E-03	.9058207E-03	.2011152E-02
13	1	.3664895E-02	.1970065E-02	.8742892E-03
13	3	-.5975651E-03	.4531423E-03	-.1968796E-02

Figure 46. Example Problem Output at 1.75 Milliseconds

X (IN)	Y (IN)	Z (IN)	EXX (IN/IN)	EYY (IN/IN)	EXY (IN/IN)	SIGMA XX (PSI)	SIGMA YY (PSI)	SIGMA XY (PSI)	REGION
0.00	5.45	-.0160	.295326E-02	.393907E-18	.395586E-02	.[illegible]4907E+05	.128193E+05	.149643E+05	7
0.00	5.45	.0160	.721646E-02	-.393907E-18	.395566E-02	.4[illegible]1020E+05	.208978E+05	.783650E+04	9
0.00	10.90	-.0160	.531[illegible]E-01	-.143640E-17	.546614E-02	.[illegible]16073E+05	.317724E+05	.173319E+04	2
0.00	10.90	.0160	.566796E-01	.143640E-17	.546614E-02	.[illegible]11441E+05	.321136E+05	.164569E+04	2
0.00	10.90	-.0160	.531906E-01			.730324E+05			2
0.00	10.90	-1.0660	-.612921E-01			-.735104E+05			10
0.00	16.35	-.0160	.226057E-01	.167944E-18	-.337884E-16	.469365E+05	.243061E+05	-.852024E-10	5
0.00	16.35	.0160	.294676E-01	-.167944E-18	-.337884E-16	.[illegible]89916E+05	.283387E+05	-.738356E-10	3
4.67	10.90	-.0160	.264573E-02	.116155E-02	.426057E-02	.360033E+05	.248833E+05	.169097E+05	1
4.67	10.90	.0160	.266930E-02	.279578E-02	.475556E-02	.390963E+05	.402685E+05	.172967E+05	2
4.67	10.90	-.0160	.264573E-02			.272705E+05			1
4.67	10.90	-1.0660	.187229E-02			.197170E+05			1
9.33	10.90	-.0160	.867333E-03	.769309E-02	-.155733E-02	.330312E+05	.562203E+05	-.588808E+04	6
9.33	10.90	.0160	.575160E-03	.894110E-02	-.654108E-03	.385661E+05	.610512E+05	-.328460E+04	5
9.33	10.90	-.0160	.867333E-03			.120589E+05			1
9.33	10.90	-1.0660	.104542E-01			.706996E+05			4
14.00	10.90	-.0160	.256721E-02	.139[illegible]25E-01	.115472E-03	.395707E+05	.531007E+05	-.624827E+04	7
14.00	10.90	.0160	.266233E-02	.149[illegible]12E-01	.145968E-03	.364448E+05	.543735E+05	-.878270E+04	9
14.00	10.90	-.0160	.256721E-02			.319457E+05			1
14.00	10.90	-1.0660	.191334E-01			.711991E+05			4
18.67	10.90	-.0160	.549490E-02	.135459E-01	.911040E-0[illegible]	.522454E+05	.312807E+05	.137513E+03	7
18.67	10.90	.0160	.503513E-02	.140673E-01	.156635E-0[illegible]	.434885E+05	.231046E+05	-.410464E+03	9
18.67	10.90	-.0160	.549490E-02			.619287E+05			1
18.67	10.90	-1.0660	.205613E-01			.656282E+05			3
21.00	0.00	-.0160	-.716544E-18	-.331752E-02	-.903413E-1[illegible]	.537651E+04	.432751E+05	-.284314E-09	7
21.00	0.00	.0160	.716544E-18	.932534E-02	-.903413E-1[illegible]	.252827E+05	.583767E+05	-.212171E-09	4
21.00	5.45	-.0160	.107130E-02	.202250E-01	.124043E-[illegible]	.262746E+05	.109321E+05	.469314E-02	11
21.00	5.45	.0160	.135315E-02	.204034E-01	.166761E-[illegible]	.407253E+05	.205688E+05	.356264E-02	11
21.00	10.90	-.0160	.364775E-02	.140405E-01	.608356E-11	.449445E+05	.213683E+05	-.178095E-03	7
21.00	10.90	.0160	.329001E-02	.150090E-01	-.793400E-1[illegible]	.369598E+05	.862698E+04	-.328679E-03	7
21.00	10.90	-.0160	.364775E-02			.416571E+05			1
21.00	10.90	-1.0660	.153261E-01			.575819E+05			5
21.00	16.35	-.0160	.104652E-01	.309555E-01	.190816E-16	-.354901E+04	-.170346E+05	.661456E-10	7
21.00	16.35	.0160	.896761E-02	.29[illegible]364E-01	.166467E-16	.610257E+04	-.248030E+04	.103364E-09	5

X (IN)	Y (IN)	U (IN)	V (IN)	W (IN)	PRESSURE (PSI)
0.	.5450000E+01	0.	0.	.7096162E-15	.3288632E+02
0.	.1090000E+02	0.	0.	.6192740E-15	.3288632E+02
0.	.1635000E+02	0.	0.	.1008203E-14	.3288632E+02
.4666667E+01	.1090000E+02	.876[illegible]E-01	-.309221[illegible]E-02	.6220483E+00	.3288632E+02
.9333333E+01	.1090000E+02	.2569[illegible]17E-01	-.485652[illegible]E-01	.1465324E+01	.3288632E+02
.1400000E+02	.1090000E+02	-.1105[illegible]2E-01	-.997149[illegible]E-01	.2117203E+01	.3288632E+02
.1866667E+02	.1090000E+02	-.9747[illegible]E-02	-.123471[illegible]E+00	.2424577E+01	.3288632E+02
.2100000E+02	0.	0.	0.	.9541292E-15	.3288632E+02
.2100000E+02	.5450000E+01	-.67393[illegible]E-16	-.12612[illegible]E+00	.1464481E+01	.3288632E+02
.2100000E+02	.1090000E+02	-.2495[illegible]E-15	-.12247[illegible]E+00	.2456521E+01	.3288632E+02
.2100000E+02	.1635000E+02	-.6946[illegible]39E-15	-.16576[illegible]E-14	.3062507E+01	.3288632E+02

Figure 46. (Continued)

```
NORMAL DEPROP STOP CONDITION AT T, SEC =      .200500E-02

NET CP TIME FOR RESPONSE, SEC =      402.509

1673 OF1805 PANEL POINTS YIELDED
  67 OF 114 STIFFENER POINTS YIELDED

DEPROP -  RESULTS OF RANGE ITERATION    1      CASE    1

  MAXIMUM PANEL CRIT                  =            .44457099E+00
    DAMAGE MODE - TENSILE STRESS/STRAIN
    GAMMA-POINT LOCATION, IN            =   0.
    BETA-POINT LOCATION, IN OR DEG =   .118083E+02
    TIME, SEC =                         =   .180000E-02

  MAXIMUM GAMMA-STIFFENER CRIT        =            .53908081E+00
    DAMAGE MODE - TENSILE STRESS/STRAIN
    GAMMA-POINT LOCATION, IN            =   0.
    BETA-POINT LOCATION, IN OR DEG =   .109090E+02
    TIME, SEC =                         =   .180000E-02

  RANGE, FT =    .70000000E+04
  CRIT      =    .53908081E+00
```

Figure 47. Summary Output for Example Problem

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APPENDIX A

LISTING OF UPDATE CARD CHANGES NECESSARY TO TRANSFORM NOVA-2S INTO NOVA-2LTS (NOVA-2L).

```
*IDENT N2LTS
*PURDECK BLOCK
*PURDECK IODUM
*PURDECK NIN.RITC
*PURDECK INTP
*PURDECK BLAST.TPINT
*PURDECK INT2.POSTW7
*PURDECK PREW.NPRES
*PURGE BLOCK
*PURGE IODUM
*PURGE NIN.RITC
*PURGE INTP
*PURGE BLAST.TPINT
*PURGE INT2.POSTW7
*PURGE PREW.NPRES
*ADDFILE INPUT,CNOVA
*COMDECK CLOAD
      COMMON /CLOAD/ PP1,PPO,TTO,TPRIME,AA,ANN,OTT1,OTTO,AZ,
     1  JL,NTIME,NLOAD,PT(20),TT(20), KTIME(10,10), LTIME(41),ISP(40),
     2  JLB(41),NPS,TTP(6,10,10),PRT(6,10,10),NPX,NPY,XP(22),YP(22),
     3  IXI(23),JYJ(23),JLT(10,10),PRTT(10,10),DX1(23),DY1(23),
     4  NGSUM,DEL,MAXD2,MAXD,PS
*COMDECK COM1
      COMMON /COM1/ P(22,1)
      LEVEL 2, P
*COMDECK COM2
      COMMON /COM2/ Q(22,1)
      LEVEL 2, Q
*PURDECK NOVA
*PURGE NOVA
*ADDFILE INPUT,CBLANK
*DECK NOVA
      PROGRAM NOVA    (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE1=513,
     1  TAPE10)
C
C     THIS IS THE NOVA-2LTS VERSION OF NOVA.  THE AERODYNAMIC AND BLAST
C        ROUTINES ARE REPLACED BY USER-DESIGNATED PRESSURE FUNCTIONS.
C     PRIVISION HAS ALSO BEEN MADE FOR READING PRESSURE DATA FROM TAPE.
C     JUNE, 1978.
C
*CALL CLOAD
*CALL CNOVA
C
    1 FORMAT(6I12)
    2 FORMAT(6F12.1)
    3 FORMAT (20A4)
      NCASE = 0
      INOUT = 1
      RER = 1.0
      READ(5,1) NCASES
  100 READ(5,3) (TITLE(I),I=1,20)
      NCASE = NCASE + 1
      KERR = 0
      NTRIAL = 0
      READ (5,1) ICOMP,KTYPE,KDAM,KDS,NDBUG
      IF (KDS.EQ.1) KDAM = 2
```

```
      NCHPT = 0
      IF (KDAM.LT.2) NCHPT = 1
      IF (KDAM.GT.2) KDAM = KDAM - 100
      IF(KDAM.LT.2) READ (5,2) PDAM
      IF(INOUT.EQ.0) GO TO 1400
      WRITE(6,3000) (TITLE(I),I=1,20)
      IF (KTYPE.LT.6.OR.KTYPE.GT.7) ICOMP = 5
      IF (ICOMP.EQ.2) WRITE (6,5000)
      IF (NCHPT.EQ.1) WRITE (6,3100)
      IF (NCHPT.EQ.0) WRITE (6,3200)
      IF(KDAM.EQ.0) WRITE(6,3300)PDAM
      IF(KDAM.EQ.1) WRITE(6,3400)PDAM
      GO TO (300,400,500,600,700,800,900,1010,1000,1020),KTYPE
  300 WRITE(6,3500)
      GO TO 1050
  400 WRITE(6,3600)
      GO TO 1050
  500 WRITE(6,3700)
      GO TO 1050
  600 WRITE(6,3800)
      GO TO 1050
  700 WRITE(6,3900)
      GO TO 1050
  800 WRITE(6,4000)
      GO TO 1050
  900 WRITE(6,4100)
      GO TO 1050
 1000 WRITE(6,4200)
      GO TO 1050
 1010 WRITE(6,4700)
      GO TO 1050
 1020 WRITE(6,4800)
 1050 GO TO (1100,1200,1300), KDS
 1100 WRITE(6,4300)
      GO TO 1400
 1200 WRITE(6,4400)
      GO TO 1400
 1300 WRITE(6,4500)
 1400 NCALL = 2
      IF(KTYPE.GT.5) CALL DEPROB
      IF (KTYPE.LT.6) CALL DEPROP
      IF(KERR.GT.0) GO TO 1600
      NCALL = 1
      CALL PINIT(0)
      IF(KTYPE.GT.5) CALL DEPROB
      IF (KTYPE.LT.6) CALL DEPROP
      IF(KDS.EQ.1) GO TO 1600
      IF(KERR.GT.0) GO TO 1600
      NCALL = 0
      KOK = 0
      CALL PINIT(1)
      IF (KERR.GT.0) GO TO 1700
      RTRIAL(1)=1.0
 1500 NTRIAL = NTRIAL + 1
      IF(KDAM.LT.2) WRITE(6,4600) NCASE,NTRIAL,RTRIAL(1)
      IF (KTYPE.GT.5) CALL DEPROB
```

```
      IF (KTYPE.LT.6) CALL DEPROP
      IF(KERR.NE.0) GO TO 1600
      IF (NCHPT.EQ.0) GO TO 1600
      CALL RITER (CRIT,RTRIAL,NTRIAL,8,KOK)
      IF(KOK.EQ.0) GO TO 1500
 1600 IF(NCASE.LT.NCASES) GO TO 100
 1700 STOP
C
 3000 FORMAT (1H1,30X,17HV 0 V A - 2 L T S//1X,20A4)
 3100 FORMAT (14H ITERATION RUN)
 3200 FORMAT (32H RESPONSE RUN ONLY, NO ITERATION)
 3300 FORMAT (42H NO DAMAGE LEVEL, PROBABILITY OF EXCEEDING, F6.3)
 3400 FORMAT (52H CATASTROPHIC DAMAGE LEVEL, PROBABILITY OF EXCEEDING,
     1F6.3)
 3500 FORMAT (28H0SINGLE-LAYER METAL PANEL    )
 3600 FORMAT (30H0SINGLE-LAYER PLASTIC PANEL    )
 3700 FORMAT (25H0HONEYCOMB METAL PANEL    )
 3800 FORMAT (27H0HONEYCOMB PLASTIC PANEL    )
 3900 FORMAT (29H0MULTI-LAYER PLASTIC PANEL    )
 4000 FORMAT (30H0METAL STRINGER OR LONGERON    )
 4100 FORMAT (15H0METAL FRAME    )
 4200 FORMAT (16H0PLASTIC RING    )
 4300 FORMAT (21H0STATIC SOLUTION ONLY)
 4400 FORMAT (22H0DYNAMIC RESPONSE ONLY)
 4500 FORMAT (37H0STATIC SOLUTION AND DYNAMIC RESPONSE)
 4600 FORMAT (12H1CASE NUMBER I2/
     114H TRIAL NUMBER I3, 10X, 18H   RANGE FACTOR = E14.6)
 4700 FORMAT(11H0METAL RING)
 4800 FORMAT(13H0RIB BUCKLING)
 5000 FORMAT (69H0STRUCTURAL ELEMENT DOES DERIVE ADDITIONAL SUPPORT FROM
     1 FUSELAGE SKIN)
      END
```

```
*PURDECK PINIT
*PURGE PINIT
*ADDFILE INPUT,CSETUP
*DECK PINIT
      SUBROUTINE PINIT(M)
*CALL CNOVA
*CALL CLOAD
*CALL CBLK1
*CALL COM1
*CALL COM2
      DIMENSION ID(100),DD(100),AI(1004),NORDER(40)
      EQUIVALENCE (ID(1),DD(1))
      DIMENSION TTB(14,41),PRTB(14,41),SP(41),SPS(41)
      EQUIVALENCE (PRT(1,1,1),PRTB(1,1)), (TTP(1,1,1),TTB(1,1))
      DATA TRD/10HFFFFFFFFFF/
C
      IF(M.EQ.1) GO TO 200
      PS = 0.0
      IF(KDS.EQ.2) GO TO 150
C
C     STATIC
C
      READ(5,2000) PS
      WRITE(6,2200) PS
      NU=1
      PPP=PS
      IF (KTYPE.LT.6) GO TO 150
      IF (KTYPE.LT.10) GO TO 50
      DO 30 I=1,NMASS
   30 PB(I) = 0.
      GO TO 150
   50 DO 100 I=1,NMASS
  100 PB(I) = PS
  150 RETURN
C
C     DYNAMIC
C
  200 IF(KDS.EQ.1) GO TO 400
      READ (5,2050) NLOAD
      WRITE (6,2400) NLOAD
      GO TO (250,500,500,6000), NLOAD
  250 READ(5,2000) PP1,PP0,TT0,TPRIME,AA,ANN
      WRITE(6,2300) PP1,PP0,TT0,TPRIME,AA,ANN
      NU=1
      IF(TPRIME.EQ.0.0) GO TO 300
      PPRIME=PP0*(1.0 - TPRIME/TT0)**ANN
      PPRIME = PPRIME*EXP(-AA*TPRIME/TT0)
      TT1=TPRIME*PP1/(PP1-PPRIME)
      OTT1=1.0/TT1
  300 OTT0=1.0/TT0
      AZ=AA*OTT0
  400 RETURN
C
  500 READ (5,2050) NTIME
      READ (5,2100) (TT(I),PT(I),I=1,NTIME)
      WRITE (6,2500) NTIME,(TT(I),PT(I),I=1,NTIME)
```

```
      JL = 2
      RETURN
C
  800 IF (KTYPE.GT.5) GO TO 1000
C     PANELS.
      READ (5,2050) NPX,NPY
      WRITE (6,2700) NPX,NPY
      READ (5,2000) (XP(I),I=1,NPX)
      WRITE (6,3100) (XP(I),I=1,NPX)
      READ (5,2000) (YP(J),J=1,NPY)
      WRITE (6,3200) (YP(J),J=1,NPY)
      WRITE (6,3300)
      DO 820 I=1,NPX
      READ (5,2050) (KTIME(J,I),J=1,NPY)
  820 WRITE (6,2800) (KTIME(J,I),J=1,NPY)
      DO 840 I=1,NPX
      DO 840 J=1,NPY
      NTIME = KTIME(J,I)
      READ (5,2000)          (TTP(K,J,I),K=1,NTIME)
      WRITE (6,3600) I,J,(TTP(K,J,I),K=1,NTIME)
      WRITE (6,2900)
      READ (5,2000) (PRT(K,J,I),K=1,NTIME)
  840 WRITE (6,3000) (PRT(K,J,I),K=1,NTIME)
C     SPATIAL INTERPOLATION-EXTRAPOLATION.  INDICES ARE LOWER BOUND.
      DO 900 I=1,NGT
      DO 860 III = 1,NPX
      IF (XP(III).GT.XG(I)) GO TO 880
  860 CONTINUE
      III = NPX
  880 IF (III.GT.1) III = III - 1
      DX1(I) = (XG(I) - XP(III))/(XP(III+1) - XP(III))
  900 IXI(I) = III
      DO 960 J = 1,NBT
      DO 920 JJJ = 1,NPY
      IF (YP(JJJ).GT.XB(J)) GO TO 940
  920 CONTINUE
      JJJ = NPY
  940 IF (JJJ.GT.1) JJJ = JJJ - 1
      DY1(J) = (XB(J) - YP(JJJ))/(YP(JJJ+1) - YP(JJJ))
  960 JYJ(J) = JJJ
      NU = 0
      DO 980 I=1,NPX
      DO 980 J=1,NPY
  980 JLT(J,I) = 2
      RETURN
C     BEAMS.
 1000 READ (5,2050) NPS
      WRITE (6,3400) NPS
      READ (5,2000) (SP(I),I=1,NPS)
      WRITE (6,3500) (SP(I),I=1,NPS)
      WRITE (6,3300)
      READ (5,2050) (LTIME(I),I=1,NPS)
      WRITE (6,2800) (LTIME(I),I=1,NPS)
      DO 1200 I=1,NPS
      NTIME = LTIME(I)
      READ(5,2000) (TTB(K,I),K=1,NTIME)
```

```
      WRITE (6,3700) I,(ITB(K,I),K=1,NTIME)
      READ (5,2000) (PRTB(K,I),K=1,NTIME)
      WRITE (6,3800)
 1200 WRITE (6,3000) (PRTB(K,I),K=1,NTIME)
C     SPATIAL INTERPOLATION - EXTRAPOLATION.  INDICES ARE LOWER BOUND.
 1250 DO 1500 I=1,NPS
      FSP = SP(I)
      II = FSP + .00001
      DII = FSP - FLOAT(II)
      SPSX = 0.0
      IF (II.EQ.0) GO TO 1400
      DO 1300 J=1,II
 1300 SPSX = SPSX + DS00(J)
 1400 IF (II.LT.NMASS+1) SPS(I) = SPSX + DII*DS00(II+1)
 1500 CONTINUE
      DO 1600 J=2,NMASS
 1600 DS00(J) = DS00(J-1) + DS00(J)
      DO 1850 I=1,NMASS
      DO 1700 III = 1,NPS
      IF (SPS(III).GT.DS00(I)) GO TO 1800
 1700 CONTINUE
      III = NPS
 1800 IF (III.GT.1) III = III - 1
      DS00(I) = (DS00(I) - SPS(III))/(SPS(III+1) - SPS(III))
 1850 ISP(I) = III
      IF (NLOAD.EQ.4) GO TO 7100
      DO 1900 I=1,NPS
 1900 JLB(I) = 2
      RETURN
C
C     LOAD OPTION 4 - TAPE INPUT FROM TAPE10.
C     PROGRAMMED FOR 7600 ONLY.
C
 6000 MAXD = 11914
      MAXD2 = 5957
      READ (5,2000) TIM1,SKIP
      TIM2 = TIM1 + TSTOP + DELTIM
      NSKIP = SKIP + .0001
      READ (5,2050) NGAGE
      READ (5,2050) (NORDER(I),I=1,NGAGE)
      WRITE (6,3900) TIM1,NSKIP,NGAGE,(NORDER(I),I=1,NGAGE)
      NGSUM = 0
      DO 6050 I=1,NGAGE
      IF (NORDER(I).GT.0) NGSUM = NGSUM + 1
 6050 CONTINUE
      IF (KTYPE.GT.5) GO TO 7000
C     PANELS.
      READ (5,2050) NPX,NPY
      WRITE (6,2700) NPX,NPY
      IF (NPX.GT.1.AND.NPY.GT.1) GO TO 6800
      READ (5,2000) (XP(I),I=1,NPX)
      READ (5,2000) (YP(I),I=1,NPY)
      WRITE (6,3100) (XP(I),I=1,NPX)
      WRITE (6,3200) (YP(I),I=1,NPY)
      JL = 2
      NU = 1
```

```
      IF (NPX*NPY.EQ.1) GO TO 7100
      NU = 0
      IF (NPX*NPY.NE.NGSUM) GO TO 8600
      IF (NPX.EQ.1) GO TO 6600
      DO 6500 I=1,NGT
      DO 6300 III=1,NPX
      IF (XP(III).GT.XG(I)) GO TO 6400
 6300 CONTINUE
      III = NPX
 6400 IF (III.GT.1) III = III - 1
      DX1(I) = (XG(I) - XP(III))/(XP(III+1) - XP(III))
 6500 IXI(I) = III
 6600 IF (NPY.EQ.1) GO TO 7100
      DO  6900 J=1,NBT
      DO 6700 JJJ = 1,NPY
      IF (YP(JJJ).GT.XB(J)) GO TO 6800
 6700 CONTINUE
      JJJ = NPY
 6800 IF (JJJ.GT.1) JJJ = JJJ - 1
      DY1(J) = (XB(J) - YP(JJJ))/(YP(JJJ+1) - YP(JJJ))
 6900 JYJ(J) = JJJ
      GO TO 7100
C     BEAMS.
 7000 READ (5,2050) NPS
      WRITE (6,3400) NPS
      READ (5,2000) (SP(I),I=1,NPS)
      WRITE (6,3500) (SP(I),I=1,NPS)
      JL = 2
      NU = 1
      IF (NPS.EQ.1) GO TO 7100
      IF (NPS.NE.NGSUM) GO TO 8500
      NU = 0
      GO TO 1250
C
 7100 DEL = 0.
      TCV = 1.E-6
      TIM1 = TIM1/TCV
      KG = 0
      KK = 0
      KKK = 0
      NTIME = 0
      BUFFER IN (10,1) (ID(1),ID(100))
      IF (UNIT(10)) 7200,7200,8300
 7200 BUFFER IN (10,1) (ID(1),ID(100))
      IF (UNIT(10)) 7250,8100,8300
 7250 IF (ID(1).EQ.TRD) GO TO 8700
      NWORDS = ID(17)
      NPOINT = ID(18)
      LR = NWORDS*NPOINT
      NWS = NWORDS*NSKIP
      KK = KK + 1
      KG = NORDER(KK)
      IF (KG.GT.0) KKK = KKK + 1
      IL = NWORDS
 7300 BUFFER IN (10,1) (AI(1),AI(LR))
      IF (UNIT(10)) 7400,8100,8300
```

```
7400 IF (DEL.EQ.0.) DEL = (AI(1+NWORDS) - AI(1))*SKIP*TCV
C     LOCATE FIRST TIME.
      DO 7500 I=IL,LR,NWORDS
      IF (AI(I-1).GE.TIM1) GO TO 7600
7500 CONTINUE
      GO TO 7300
7600 IF (KG.GT.0) P(KG,1) = AI(I)
      T1 = AI(I-1)*TCV
      IF (NTIME.EQ.0) NTIME = (TIM2-TIM1*TCV)/DEL + 2
      IF (NTIME.GT.MAXD) GO TO 8400
      J = 1
      IF (KG.EQ.0) GO TO 7800
      IL = NWS - LR + I
      IF (IL.GT.0) GO TO 7800
      IL = I + NWS
      DO 7700 I=IL,LR,NWS
      IX = I
      J = J + 1
      IF (J.GT.NTIME) GO TO 7700
      P(KG,J) = AI(I)
7700 CONTINUE
7750 IL = NWS - LR + IX
7800 BUFFER IN (10,1) (AI(1),AI(LR))
      IF (UNIT(10)) 7900,8100,8300
7900 IF (KG.EQ.0) GO TO 7800
      IF (J.GE.NTIME) GO TO 7800
      DO 8000 I=IL,LR,NWS
      IX = I
      J = J + 1
      IF (J.GT.NTIME) GO TO 8000
      IF (J.GT.MAXD2) GO TO 7950
      P(KG,J) = AI(I)
      GO TO 8000
7950 Q(KG,J-MAXD2) = AI(I)
8000 CONTINUE
      GO TO 7750
C     END OF GAGE DATA.
```

```
8100 IF (NDBUG.GT.0) WRITE (6,4200) KK,KG,DEL,T1,NTIME,
    1  NWORDS,NPOINT,(I)(I),I=1,9)
     IF (KKK.LT.NGSUM) GO TO 7200
C    DATA READ.
8200 REWIND 10
     WRITE (6,4800) DEL,NTIME
     IF (NDBUG.LT.2) GO TO 8250
     DO 8220 I=1,NGSUM
     NT1 = MIN0(NTIME,MAXD2)
     NT2 = NTIME - MAXD2
     WRITE (6,4900) I, (P(I,J),J=1,NT1)
     IF (NT2.GT.0) WRITE (6,4900) I,(Q(I,J),J=1,NT2)
8220 CONTINUE
8250 RETURN
C
C    ERRORS.
C
8300 WRITE (6,4300)
     GO TO 8900
8400 WRITE (6,4400) NTIME,MAXD
     GO TO 8900
8500 WRITE (6,4500) NPS,NGSUM
     GO TO 8900
8600 WRITE (6,4500) NPX,NPY,NGSUM
     GO TO 8900
8700 WRITE (6,4700) KK,NGAGE
     GO TO 8900
8800 WRITE (6,4000)
C
8900 KERR = 2
     RETURN
C
2000 FORMAT(6F12.1)
2050 FORMAT (6I12)
2100 FORMAT (2F12.1)
2200 FORMAT(24H0STATIC PRESSURE, PSI = E15.6)
2300 FORMAT(23H0DYNAMIC LOAD CONSTANTS/
    1        11H  PP1    = E15.6/
    1        11H  PP0    = E15.6/
    1        11H  TT0    = E15.6/
    1        11H  TPRIME = E15.6/
    1        11H  AA     = E15.6/
    1        11H  ANN    = E15.6)
2400 FORMAT (21H0DYNAMIC LOAD OPTION I4)
2500 FORMAT (18H0NUMBER OF TIMES = I4/28H     TIME, SEC  PRESSURE, PSI/
    1  (2E15.6))
2700 FORMAT (24H0NUMBER OF LOAD STATIONS/
    1  12H    NPX    = I3/12H    NPY    = I3)
2800 FORMAT (5X,10I5)
2900 FORMAT (18H PRESSURES (PSI) =)
3000 FORMAT (5X,6E15.6)
3100 FORMAT (19H0X-POSITIONS (IN) =/(5X,5E15.6))
3200 FORMAT (26H0Y-POSITIONS (IN OR DEG) =/(5X,5E15.6))
3300 FORMAT (26H0NUMBER OF TABLE ENTRIES =)
3400 FORMAT (24H0NUMBER OF LOAD STATIONS/12H    NPS    = I3)
3500 FORMAT (25H0MEASUREMENT POSITIONS = /(5X,5E15.6))
```

```
3600 FORMAT (14HOTIMES (SEC)   ,10X,6HNPX = I3,5X,6HNPY = I3/
    1   (5X,6E15.6))
3700 FORMAT (14HOTIMES (SEC)    ,10X,2HI=I3/(5X,6E15.6))
3800 FORMAT (19H PRESSURES (SEC) = )
3900 FORMAT (9HOTAPE USE/ 34H    START TIME, SEC (TIM1)        = E15.6/
    1   34H    SKIP  FREQUENCY (NSKIP)         = I6/
    2   34H    NO. OF GAGES ON TAPE (NGAGE) = I6/
    3   25H    LOCATION ID OF GAGES = /(5X,10I4))
4000 FORMAT (33HOTAPE INPUT IS ONLY 1 DIMENSIONAL/
    1   28H EITHER NPX OR NPY MUST BE 1)
4200 FORMAT (19HODATA FOR GAGE NO. I4, 15H,  LOCATION ID  I4/
    1   14H TIME INTERVAL E15.6, 13H,  START TIME E15.6/
    2   16H NUMBER OF TIMES I6/ 26H NUMBER OF WORDS PER POINT I4/
    3   28H NUMBER OF POINTS PER RECORD I5/ 1X,9A10)
4300 FORMAT (26HOPARITY ERROR ON DATA TAPE)
4400 FORMAT (25HODATA EXCEEDS TABLE SPACE 2I5)
4500 FORMAT (32HONUMBER OF ACTIVE GAGES IS WRONG   3I4)
4700 FORMAT (12HOEND OF TAPE 2I4)
4800 FORMAT (22HOTAPE 10 HAS BEEN READ/
    1   19H    TIME INTERVAL = E15.6/18H    NO. OF TIMES = I6)
4900 FORMAT (5HO I = I3,4X,9HP (PSI) = /(1X,10E12.4))
     END
```

```
*PURDECK PRESS
*PURGE PRESS
*ADDFILE INPUT,INT1
*DECK PRESS
      SUBROUTINE PRESS
*CALL CNOVA
*CALL CLOAD
*CALL CBLK1
*CALL COM1
*CALL COM2
      DIMENSION PRTTB(41)
      DIMENSION TTB(14,41),PRTB(14,41)
      EQUIVALENCE (PRT(1,1,1),PRTB(1,1)), (TTP(1,1,1),TTB(1,1))
      EQUIVALENCE (PRTT(1,1),PRTTB(1))
C
      IF(NCALL.GT.0) GO TO 9000
      ZZ= 1.0/RTRIAL(1)
      GO TO (50,220,800,1000), NLOAD
   50 IF(TIME.GE.TPRIME) GO TO 100
      PPP=ZZ*PP1*(1.0 - TIME*OTT1)
      IF(PPP.LT.0.0) PPP=0.0
      GO TO 400
  100 IF(TIME.GE.TTO) GO TO 200
      PPP=PPO*(1.0 - TIME*OTTO)**ANN
      PPP=ZZ*PPP*EXP(-AZ*TIME)
      GO TO 400
  200 PPP=0.0
      GO TO 400
C
  220 DO 240 J=JL,NTIME
      IF (TIME.LE.TT(J)) GO TO 260
  240 CONTINUE
      JL = NTIME
      PPP = ZZ*PT(JL)
      GO TO 400
  260 JL = J
      PPP = PT(J-1) + (TIME - TT(J-1))*(PT(J) - PT(J-1))/
     1  (TT(J) - TT(J-1))
      PPP = ZZ*PPP
C
  400 PPP = PPP + PS
      IF (KTYPE.LT.6) GO TO 9000
      PX = PPP
      IF (KTYPE.EQ.10) PX = 0.
      DO 500 I=1,NMASS
  500 PR(I) = PX
      GO TO 9000
C
  800 IF (KTYPE.GT.5) GO TO 900
C     PANELS.
      DO 860 I=1,NPX
      DO 860 J=1,NPY
C     INTERPOLATE ON TIME.
      PPP = 0.0
      IF (TIME.LT.TTP(1,J,I)) GO TO 860
      JL = JLT(J,I)
```

```
      NTIME = KTIME(J,I)
      DO 820 K=JL,NTIME
      KK = K
      IF (TIME.LE.TTP(K,J,I)) GO TO 840
  820 CONTINUE
      JLT(J,I) = NTIME
      PPP = PRT(NTIME,J,I)
      GO TO 860
  840 JL = KK
      P1 = PRT(JL-1,J,I)
      T1 = TTP(JL-1,J,I)
      PPP = P1 + (TIME - T1)*(PRT(JL,J,I) - P1)/(TTP(JL,J,I) - T1)
      JLT(J,I) = JL
  860 PRTT(J,I) = PPP
C     INTERPOLATE SPATIALLY.
      K = 0
      DO 880 I=1,NGT
      II = IXI(I)
      DX = DX1(I)
      DO 880 J=1,NBT
      IF (NUSE(J,I).EQ.0) GO TO 880
      K = K + 1
      JJ = JYJ(J)
      DY = DY1(J)
      P1 = PRTT(JJ,II) + DY*(PRTT(JJ+1,II) - PRTT(JJ,II))
      P2 = PRTT(JJ,II+1) + DY*(PRTT(JJ+1,II+1) - PRTT(JJ,II+1))
      PPP = P1 + DX*(P2 - P1)
      PA(K) = PPP*ZZ + PS
  880 CONTINUE
      GO TO 9000
C     BEAMS.
  900 DO 930 I=1,NPS
      PPP = 0.0
      IF (TIME.LT.TTB(1,I)) GO TO 930
      JL = JLB(I)
      NTIME = LTIME(I)
      DO 910 K=JL,NTIME
      KK = K
      IF (TIME.LE.TTB(K,I)) GO TO 920
  910 CONTINUE
      JLB(I) = NTIME
      PPP = PRTB(NTIME,I)
      GO TO 930
  920 JL = KK
      P1 = PRTB(JL-1,I)
      T1 = TTB(JL-1,I)
      PPP = P1 + (TIME-T1)*(PRTB(JL,I) - P1)/(TTB(JL,I) - T1)
      JLB(I) = JL
  930 PRTTB(I) = PPP
      K = 0
      DO 940 I=1,NMASS
      II = ISP(I)
      DX = DSOO(I)
      PPP = PRTTB(II) + DX*(PRTTB(II+1) - PRTTB(II))
  940 PB(I) = PPP*ZZ + PS
      GO TO 9000
```

```
C
C     TAPE OPTION.
C
 1000 IF (NU.EQ.0) GO TO 1500
C     UNIFORM LOAD.
      DO 1100 K=JL,NTIME
      T1 = DEL*FLOAT(K-1)
      IF (TIME.LE.T1) GO TO 1200
 1100 CONTINUE
      JL = NTIME
      IF (NTIME.LE.MAXD2) PPP = P(1,NTIME)
      IF (NTIME.GT.MAXD2) PPP = Q(1,NTIME-MAXD2)
      GO TO 1300
 1200 JL = K
      T1 = T1 - DEL
      T1 = (TIME-T1)/DEL
      IF (JL-1.GT.MAXD2) GO TO 1220
      P1 = P(1,JL-1)
      IF (JL.GT.MAXD2) GO TO 1230
      P2 = P(1,JL)
      GO TO 1250
 1220 P1 = Q(1,JL-1-MAXD2)
 1230 P2 = Q(1,JL-MAXD2)
 1250 PPP = P1 + T1*(P2-P1)
 1300 PPP = PPP*ZZ + PS
      IF (KTYPE.LT.6) GO TO 9000
      PX = PPP
      IF (KTYPE.EQ.10) PX = 0.
      DO 1400 I=1,NMASS
 1400 PB(I) = PX
      GO TO 9000
C     NON-UNIFORM LOAD.
 1500 DO 1600 K=JL,NTIME
      T1 = DEL*FLOAT(K-1)
      IF (TIME.LE.T1) GO TO 1700
 1600 CONTINUE
      JL = NTIME
      GO TO 1800
 1700 JL = K
      T1 = T1 - DEL
      T1 = (TIME-T1)/DEL
 1800 IF (KTYPE.GT.5) GO TO 2400
C     PANELS.
      IF (JL.LT.NTIME) GO TO 1900
      DO 1850 KG = 1,NGSUM
      IF (NTIME.LE.MAXD2) PRTTB(KG) = P(KG,NTIME)
      IF (NTIME.GT.MAXD2) PRTTB(KG) = Q(KG,NTIME-MAXD2)
 1850 CONTINUE
      GO TO 2000
 1900 DO 1950 KG=1,NGSUM
      IF (JL-1.GT.MAXD2) GO TO 1920
      P1 = P(KG,JL-1)
      IF (JL.GT.MAXD2) GO TO 1930
      P2 = P(KG,JL)
      GO TO 1950
 1920 P1 = Q(KG,JL-1-MAXD2)
```

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```
 1930 P2 = Q(KG,JL-MAXD2)
 1950 PRTTB(KG) = P1 + T1*(P2 - P1)
C
 2000 K = 0
      DO 2300 I=1,NGT
      IF (NPX.EQ.1) GO TO 2050
      II = IXI(I)
      DX = DX1(I)
 2050 DO 2300 J=1,NBT
      IF (NUSE(J,I).EQ.0) GO TO 2300
      K = K + 1
      IF (NPY.EQ.1) GO TO 2100
      JJ = JYJ(J)
      DY= DY1(J)
      P1 = PRTTB(JJ)
      PPP = P1 + DY*(PRTTB(JJ+1) - P1)
      PA(K) = PPP*ZZ + PS
      GO TO 2300
 2100 IF (J.GT.1) GO TO 2200
      P1=PRTTB(II)
      PPP = (P1 + DX*(PRTTB(II+1) - P1))*ZZ
 2200 PA(K) = PPP + PS
 2300 CONTINUE
      GO TO 9000
C     BEAMS.
 2400 IF (JL.LT.NTIME) GO TO 2500
      DO 2450 KG=1,NGSUM
      IF (NTIME.LE.MAXD2) PRTTB(KG) = P(KG,NTIME)
      IF (NTIME.GT.MAXD2) PRTTB(KG) = Q(KG,NTIME-MAXD2)
 2450 CONTINUE
      GO TO 2600
 2500 DO 2550 KG=1,NGSUM
      IF (JL-1.GT.MAXD2) GO TO 2520
      P1 = P(KG,JL-1)
      IF (JL.GT.MAXD2) GO TO 2530
      P2 = P(KG,JL)
      GO TO 2550
 2520 P1 = Q(KG,JL-1-MAXD2)
 2530 P2 = Q(KG,JL-MAXD2)
 2550 PRTTB(KG) = P1 + T1*(P2-P1)
 2600 DO 2700 I=1,NMASS
      II = ISP(I)
      DX = DS00(I)
      P1 = PRTTB(II)
 2700 PB(I) = ZZ*(P1 + DX*(PRTTB(II+1) - P1)) + PS
C
 9000 RETURN
      END
```