National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, MD 20771

Reply to Attn of: 542.1 July 28, 1999

TO: 542/FEMCI

FROM: 542.1/Farhad Tahmasebi

SUBJECT: Software Tools for Analysis of Bonded Joints

Introduction

Linear and non-linear springs have been used to model adhesives in bonded joints. The modeling process involves the following steps:

1. A fine mesh of grids is created in the mid-plane of the bonded joint.
2. For every grid in the mid-plane mesh, an initially-coincident grid is created.
3. Three springs are placed between each pair of initially-coincident grids. These springs act in the X, Y, and Z directions; where the X and Y axes are parallel to the overlap plane of the bonded joint, and the Z axis is defined by the right-hand-rule.
4. Rigid elements are used to connect the mid-plane grids to the corner grids of the plate elements which represent the adherends.

The spring stiffness values are determined from the adhesive stress-strain curve. The Finite Element model of a typical bonded joint is shown in Figure 1.

If forces and/or moments are applied to a bonded joint, such as the one shown in Figure 1, spring forces and deformations can be used to determine the stresses and strains in the adhesive.

This memo describes two FORTRAN programs which obtain stresses and strains in bonded joints. For a given bonded joint model, these programs read the corresponding NASTRAN input and output files, use the spring forces or deformations to obtain the adhesive stresses or strains at the mid-plane grid points, sort the stresses and strains in descending order, and generate Mathematica plot files for 3D visualization of the stress and strain fields.

Note that **the grids and springs can be numbered in any order.** *The programs determine the pairs of grids which are initially-coincident, and the spring triplets which correspond to such grid pairs.* In the earlier attempts at NASA/GSFC to model adhesives in bonded joints, the analyst had to number the grids and/or springs in specific orders so that the XYZ spring triplets acting between pairs of initially-coincident adhesive grids could be identified. Such ordering of grids and/or springs can be very time-consuming.

Description of the Adhesive Stress Program

Given a bonded joint model, the program executes the following operations.

1. Prompts the user for the name of NASTRAN input and output files.
2. Locates and stores all of the spring ID's, the corresponding grid ID's, and the corresponding grid coordinates in the NASTRAN input file.
3. Identifies the pairs of grids which are coincident in the unloaded model.
4. Identifies the spring triplets (X, Y, and Z) for the pairs of initially-coincident grids.
5. Locates and stores the spring forces in the corresponding NASTRAN output file.
6. Assigns the stored spring forces to the appropriate springs in the triplets identified in step 4.
7. Determines adhesive shear and peel stresses at the mid-plane grids using the following equations.

$$\tau_i = \frac{\sqrt{f_{x,i}^2 + f_{y,i}^2}}{A} \tag{1}$$

$$\sigma_i = \frac{f_{z,i}}{A} \tag{2}$$

   The symbols in equations (1) and (2) are defined in Table 1.

8. Sorts the shear and peel stresses in descending order and writes them to an output file.
9. Writes the coordinates of the mid-plane grid points and their corresponding shear and peel stresses to plot files.

The plot files mentioned in step 9 are used to generate 3D representations of the shear and peel stress fields using Mathematica. Figure 2 shows the 3D shear stress field for the joint represented in Figure 1.

To efficiently execute the operations specified in steps 3, 4, and 6; the program invokes various sorting subroutines. These sorting operations and other details of the program can be found in the source code (adhsv_strs.f) which is located at http://analyst.gsfc.nasa.gov/FEMCI/adhesive.

Description of the Adhesive Strain Program

Equations (1) and (2) show that the adhesive shear and peel stresses are dependent on the area of the plate elements used to represent the adherends. For complicated joints, it may not be possible to have a uniform area for such plate elements. Therefore, as an alternative, a program was written to determine shear and peel strains which are independent of the plate element area, and dependent on the adhesive thickness which is normally uniform.

For a given bonded joint model, the program starts by executing steps 1 through 4 that the Adhesive Stress program goes through (see the previous section). Next, the program performs the following operations.

1. Locates and stores the mid-plane grid point displacements in the NASTRAN output file.

2. Calculates and stores the adhesive spring deformations from the grid point displacements obtained in the previous step.

3. Assigns the stored spring deformations to the appropriate elements in the spring triplets corresponding to the pairs of initially-coincident grids (see step 4 of the previous section).

4. Calculates adhesive shear and normal strains at the mid-plane grids using the following equations.

$$\gamma_i = \frac{\sqrt{\delta_{x,i}^2 + \delta_{y,i}^2}}{\eta} \tag{3}$$

$$\epsilon_i = \frac{\delta_{z,i}}{\eta} \tag{4}$$

   The symbols in equations (3) and (4) are defined in Table 1.

5. Sorts the shear and normal strains in descending order and writes them to an output file.

6. Writes the coordinates of the mid-plane grid points and their corresponding shear and normal strains to plot files.

The shear and normal strain plot files are read into Mathematica to generate 3D representation of the strain fields. Figure 3 shows the 3D shear strain field for the bonded joint represented in Figure 1.

The program invokes various sorting subroutines to efficiently execute some of the steps specified above. These sorting operations and other details of the program can be found in the source code (adhsv_strn.f) which is located at http://analyst.gsfc.nasa.gov/FEMCI/adhesive. ■

The results of both programs have been verified by hand-calculating stresses and strains at various adhesive grid points. If you have any questions or comments, call me at 301-286-5203 or send an e-mail to farhad.tahmasebi@gsfc.nasa.gov.

2 Enclosures
1. Table 1
2. Figures 1 - 3

Table 1: Nomenclature

Symbol	**Definition**
i	grid number
τ_i	shear stress at grid i
σ_i	peel stress at grid i
$f_{x,i}$	X spring force at grid i
$f_{y,i}$	Y spring force at grid i
$f_{z,i}$	Z spring force at grid i
A	area of plate elements used to model adherends
γ_i	shear strain at grid i
ϵ_i	normal strain at grid i
$\delta_{x,i}$	X spring deformation at grid i
$\delta_{y,i}$	Y spring deformation at grid i
$\delta_{z,i}$	Z spring deformation at grid i
η	thickness of adhesive

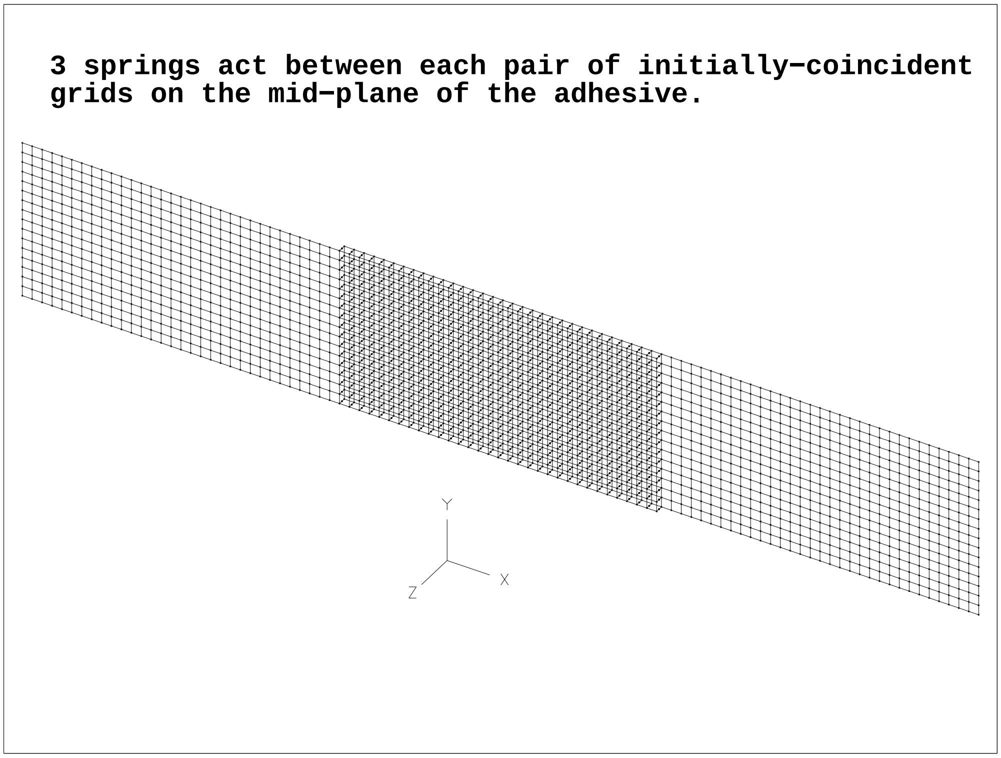

Figure 1: Finite Element model of a bonded joint.

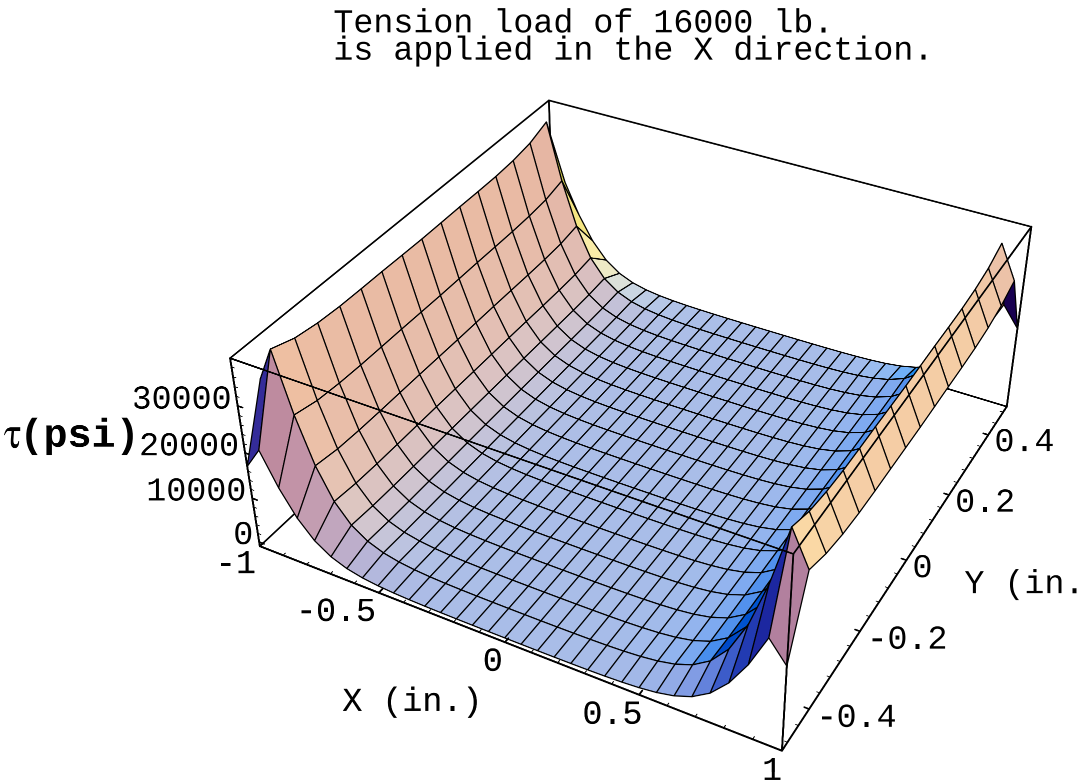

Figure 2: Shear stress in a bonded joint.

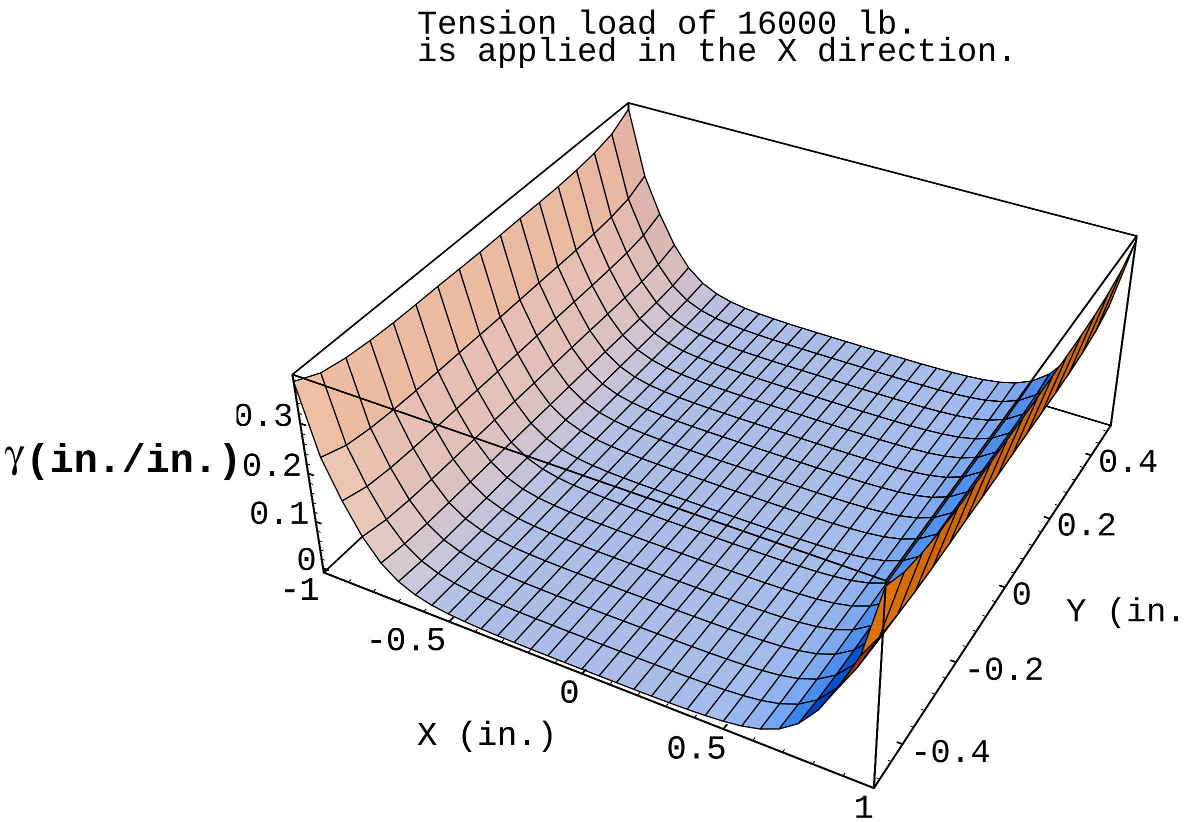

Figure 3: Shear strain in a bonded joint.