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Fasteners Modeling for MSC.Nastran Finite Element Analysis

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ABSTRACT

The distribution of loads between the components of a structural assembly depends not only on their dimensions and material properties but also on the stiffness of fasteners connecting the components. So, the accuracy of the finite element analysis is influenced much by the fastener representation in the model.

This paper describes an approach designed specifically for joints with connected plates modeled by shell elements located at plates mid planes. The procedure is based on definition of independent components of a fastener joint flexibility, analysis of each component, and their assembly to represent a complete plate-fastener system of the joint.

The proposed modeling technique differs from the traditional approach where all the connected plates are modeled coplanar. The traditional approach is based on calculating a single spring rate for a particular combination of fastener and plate properties. The application of this approach is limited by single shear joint of two plates or symmetric double shear joint of three plates. It cannot be used for other joint configurations and for joints with larger number of connected plates. The proposed procedure is free of those limitations.

Considering each fastener requires the creation of additional nodes and elements, it is obvious the manual use of this procedure is practically impossible for large models of aircraft structures that could have thousands of fasteners. A new MSC.Patran utility that automates the fasteners modeling was written and is described in the paper. It takes advantage of the CBUSH element formulation in MSC.Nastran and provides a user friendly and efficient tool that creates fasteners connecting a selected group of nodes.

INTRODUCTION

The common practice in aircraft structural analysis is the creation of large finite element models with a coarse mesh with further extraction of separate parts along with applied loads for hand analysis or for preparation of more detailed models. As a rule, these parts are connected in large models rigidly, i.e. they share the common grid points. However, the distribution of loads between structural parts depends not only on the parts dimensions and mechanical properties of selected materials, but also on the stiffness of connecting elements, such as bolts and rivets.

With increase of computers speed along with the volume of available memory, the trend for creation of more detailed models has arisen. These models more realistically represent not only structural parts but also their interaction including fastener joints.

The widely used method of fastener joints modeling is the joining of co-linear or co-planar finite elements of connected structural parts with elastic elements representing fasteners. The stiffness of these elastic elements, or springs, is calculated using formulae developed by empirical or semi-empirical methods. As a rule, these formulae consider the combination of mechanical and geometric properties of a fastener and joined plates. Their application is usually limited to single shear and double shear symmetric joints.

With developing models more closely representing structures but still consisting of plate elements, the joined elements are no longer located in the same plane. In this case, the single elastic element cannot fully reflect the work of a fastener joint.

The procedure for modeling of fastener joints for detailed finite element models with non-coplanar joined parts was described in the paper presented at the First MSC Conference for Aerospace Users [1]. However, the practical use of this method showed some of its disadvantages, which will be discussed later.

The approach to 3-dimensional modeling of fastener joints is based on definition of each deformation component contributing to a joint flexibility and modeling them by corresponding finite elements. Combination of these elements represents the complete work of a fastener joint. Some relative displacements in the model of a fastener joint were limited to ensure the compatibility of deformations.

This paper presents an updated method for the finite element modeling of fastener joint for MSC.Nastran and an example of a model with fasteners. It also describes a new MSC.Patran utility for fastener joints modeling. The method does not consider the effect of fastener pretension and fit. Following the aerospace industry common analysis practice, the friction between joint parts was not taken into account.

STIFFNESS OF FASTENER JOINT

In a fastener joint (Figure 1) the following stiffness components are considered:

- translational plate bearing stiffness;
- translational fastener bearing stiffness;
- rotational plate bearing stiffness;
- rotational fastener bearing stiffness;
- fastener shear stiffness;
- fastener bending stiffness.

Under load, the plates slide relative to each other. This causes the translational bearing deformations of joined plates and a fastener. The translational bearing flexibility of plate *i* is:

$$C_{btp_i} = \frac{1}{E_{cp_i} t_{p_i}}$$

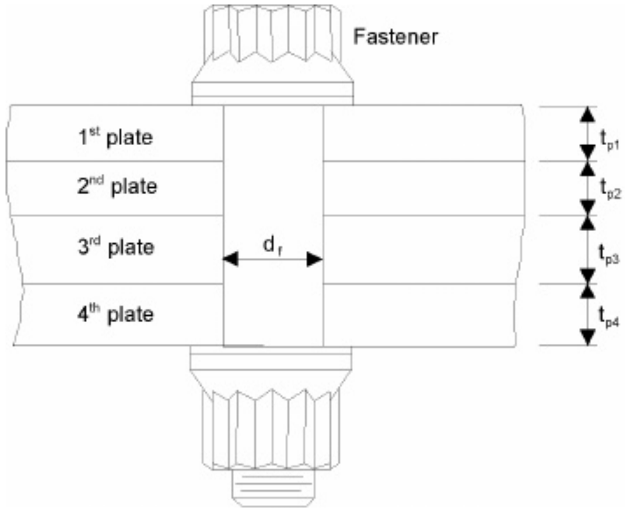

Figure 1. Fastener joint.

where E_{cp_i} - compression modulus of plate *i* material;

t_{p_i} - thickness of plate *i*.

The fastener translational bearing flexibility at plate *i*

$$C_{btf_i} = \frac{1}{E_{cf} t_{p_i}}$$

where E_{cf} - compression modulus of fastener material .

Combined fastener and plate translational bearing flexibility at plate *i*

$$C_{bt_i} = C_{btp_i} + C_{btf_i}$$

Combined translational bearing stiffness at plate *i*

$$S_{bt_i} = \frac{1}{C_{bt_i}}$$

The relative rotation of the plate and fastener creates a moment in the plate-fastener interaction (Figure 2). The bearing deformations caused by this relative rotation are assumed distributed linearly along the plate thickness

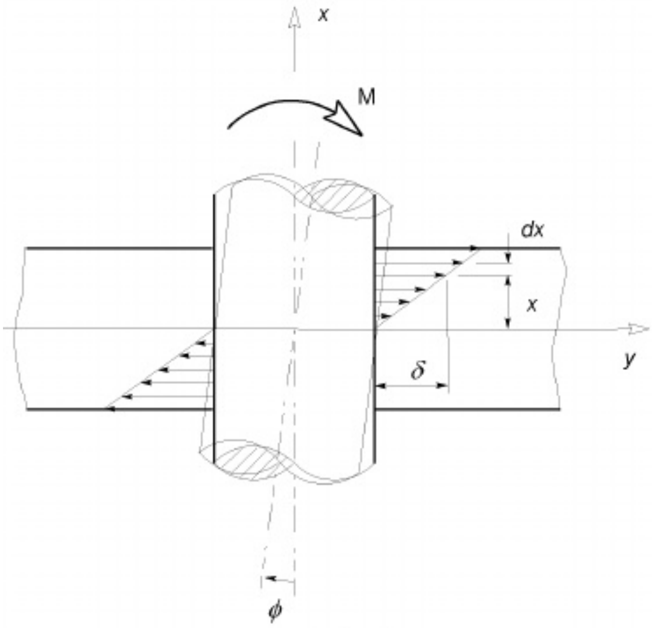

Figure 2. Rotational bearing stiffness definition.

$$\delta = x\varphi$$

where x - coordinate along the plate thickness;
φ - angle of relative rotation of the plate and fastener.

Stiffness of a dx thick slice of plate i is:

$$dS_{btp_i} = E_{cp_i} dx$$

Load on dx thick slice of plate i caused by the plate bearing deformation

$$dF = \delta dS_{btp_i} = x\varphi E_{cp_i} dx$$

Moment of dF force about the plate i center line

$$dM = xdF = E_{cp_i} \varphi x^2 dx$$

Moment in the plate-fastener contact caused by the plate deformation

$$M = E_{cp_i} \varphi \int_{-\frac{t_{p_i}}{2}}^{\frac{t_{p_i}}{2}} x^2 dx = E_{cp_i} \varphi \frac{t_{p_i}^3}{12}$$

The rotational bearing flexibility of plate i

$$C_{brp_i} = \frac{\varphi}{M} = \frac{12}{E_{cp_i} t_{p_i}^3}$$

The fastener rotational bearing flexibility at plate i

$$C_{brf_i} = \frac{12}{E_{cf} t_{p_i}^3}$$

Combined fastener and plate rotational bearing flexibility at plate i

$$C_{br_i} = C_{brp_i} + C_{brf_i}$$

Combined rotational bearing stiffness at plate i

$$S_{br_i} = \frac{1}{C_{br_i}}$$

The bearing stiffness is modeled by elastic elements. The shear and bending stiffness of a fastener are represented by a beam element.

MODELING OF A FASTENER JOINT

Modeling of a fastener joint is illustrated here using MSC.Nastran.

REPRESENTATION OF A FASTENER JOINT

Idealization of a plate-fastener system includes the following:

- Elastic bearing stiffness of a plate and fastener at contact surface;
- Bending and shear stiffness of a fastener shank;
- Compatibility of displacements of a fastener and connected plates at the joint.

The presented method creates the plate-fastener system illustrated in Figure 3.

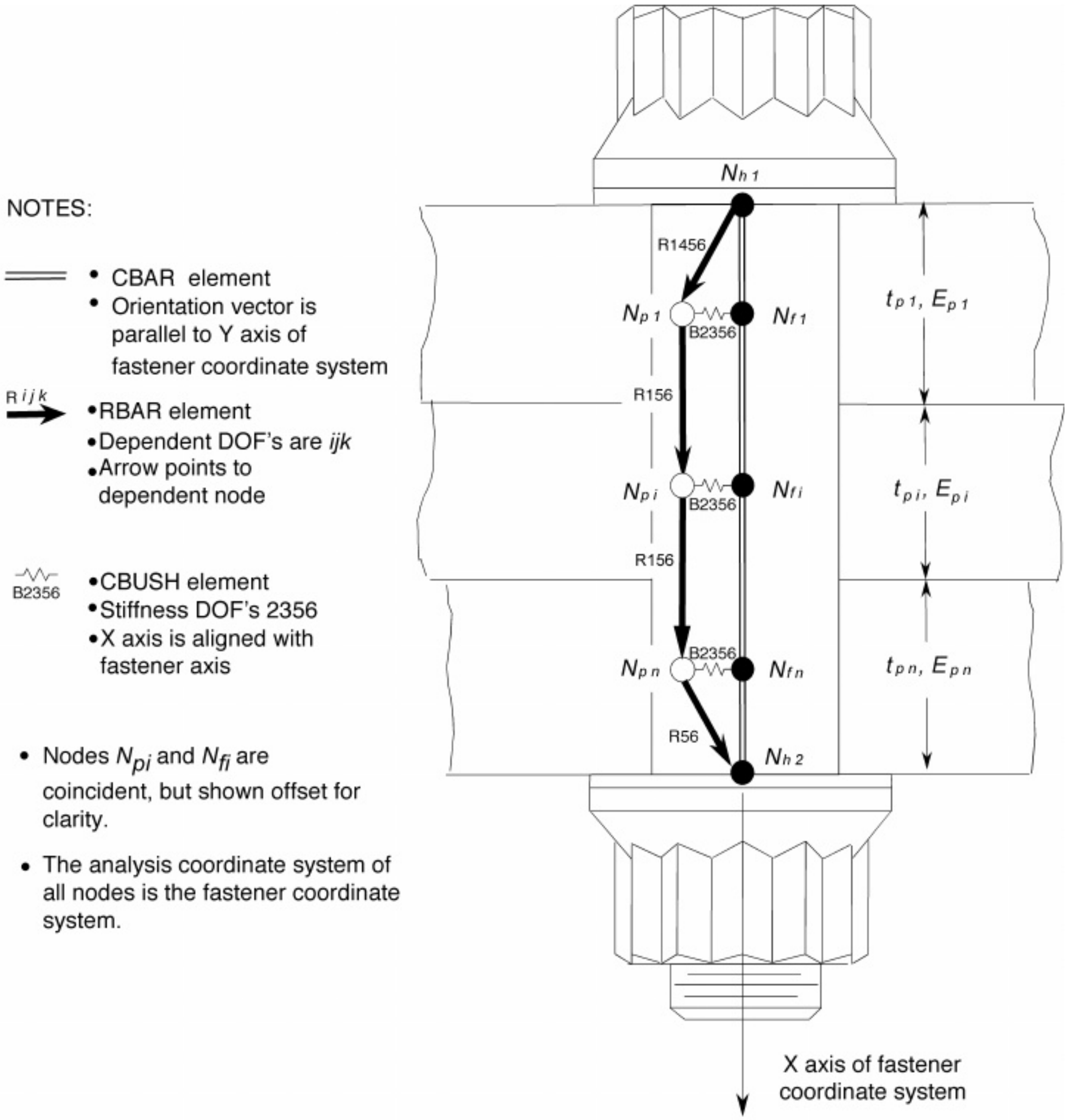

Figure 3. Fastener joint modeling.

FASTENER MODELING

A fastener is modeled by CBAR or CBEAM elements [2] with corresponding PBAR or PBEAM cards for properties definition. For the CBAR or CBEAM elements connectivity, a separate set of grid points coincidental with corresponding plate grid points (Figure 3) is created. This set also includes grid points located on intersection of the fastener axis and outer surfaces of the first and last connected plates.

All CBAR or CBEAM elements representing the same fastener reference the same PBAR or PBEAM card [2] with following properties:

- MID to reference the fastener material properties.
- Fastener cross-sectional area

$$A = \frac{\pi d_f^2}{4}$$

where d_f - fastener diameter.

- Moments of inertia of the fastener cross section

$$I_1 = I_2 = \frac{\pi d_f^4}{64}$$

- Torsional constant

$$J = \frac{\pi d_f^4}{32}$$

- Area factors for shear of circular section

$$K_1 = K_2 = 0.9$$

An example of CBAR element and its properties definition for .375" dia. fastener is shown in Table 1. An alternative form of CBAR properties definition is presented in Table 2.

Definition of a fastener using CBEAM and PBEAM cards is similar to that shown in Table 2 for CBAR and PBAR with small differences described in Reference [2].

MODELING OF INTERACTION BETWEEN FASTENER AND JOINED PLATES

The interaction between a fastener and plate results in bearing deformation of all parts of the joint on their surfaces of contact. The bearing stiffness of a fastener and connected plates is defined in Section "Stiffness of fastener joint". The bearing stiffness is presented as translational stiffness in direction of axes normal to the fastener axis and defining the fastener shear plane and rotational stiffness about the same axes.

For the modeling of the bearing stiffness, two sets of coincident grid points mentioned above are used. Each pair of coincident grid points, i.e. the plate node and corresponding fastener node, is connected by CBUSH element [2] or combination of CELAS2 elements with equal translational stiffness along the axes normal to the fastener axis and equal rotational stiffness about the same axes. The connectivity card CBUSH must be accompanied by PBUSH card defining the stiffness. The CELAS2 card accomplishes both functions, but 4 CELAS2 elements are required to replace one CBUSH element. However it is difficult to interpret CELAS2 element forces.

For correct definition of a fastener shear plane and its axial direction, a coordinate system with one of its axis parallel to the fastener axis must be defined in the bulk data. This coordinate system must be used as analysis coordinate system for both sets of grid points.

An example of the bearing stiffness modeling using the CBUSH and PBUSH cards is given in Table 3. It is assumed in the example that the fastener axis is parallel to x-axis of corresponding coordinate system. An alternative method for the bearing stiffness modeling using CELAS2 elements is shown in Table 4.

COMPATIBILITY OF DISPLACEMENTS IN THE JOINT

The fastener joint model was designed under the following assumptions:

- The plates are incompressible in transverse direction;
- The plates mid planes stay parallel to each other under the load;
- Planes under the fastener heads stay parallel to the plate mid planes under the load.

These goals are reached by using RBAR elements.

An example of a group of RBAR elements satisfying the above compatibility conditions is given in Table 5. It is also assumed in this example (Figure 3) that the fastener axis is parallel to the x-axis of the corresponding coordinate system.

The first RBAR card forces the plane under the fastener head to stay parallel to the first plate mid plane under the load. It also prevents the fastener movement as a rigid body. The middle RBAR cards support the first two assumptions. They keep the constant distance between the plate mid planes, i.e. assume that plates are incompressible. They also guarantee zero relative rotation of plates keeping them parallel to each other. The last card forces the plane under the other head of the fastener to stay parallel to the last plate mid plane.

CBAR	EID	PID	GA	GB	X1	X2	X3		
CBAR	21	206	1011	2011	1.0	0.0	0.0		

PBAR	PID	MID	A	I1	I2	J	NSM		
PBAR	206	2	.11	9.7E-4					
	C1	C2	D1	D2	E1	E2	F1	F2	
	0.0	0.0							
	K1	K2	I12						
	0.9	0.9							

Table 1. Example CBAR and PBAR cards.

PBARL	PID	MID	GROUP	TYPE					
PBARL	206	2		ROD					
	DIM1	NSM							
	.375								

Table 2. Example PBARL card.

CBUSH	EID	PID	GA	GB	G0/X1	X2	X3	CID	
CBUSH	210	12	1005	2005				0	

PBUSH	PID	"K"	K1	K2	K3	K4	K5	K6	
PBUSH	12	K		1.6E7	1.6E7		5.2E3	5.2E3	

Table 3. Example CBUSH and PBUSH cards.

CELAS2	EID	K	G1	C1	G2	C2			
CELAS2	210	1.6E7	1005	2	2005	2			
CELAS2	211	1.6E7	1005	3	2005	3			
CELAS2	212	5.2E3	1005	5	2005	5			
CELAS2	213	5.2E3	1005	6	2005	6			

Table 4. Example CELAS2 cards.

RBAR	EID	GA	GB	CNA	CNB	CMA	CMB		
RBAR	310	905	1005	123456			1456		
RBAR	311	1005	2005	123456			156		
… … …	… … …	… … …	… … …	… … …			… … …		
RBAR	314	5005	6005	123456			156		
RBAR	315	6005	915	123456			56		

Table 5. Example RBAR cards for compatibility of displacements in the joint.

MODELING EXAMPLE

A symmetric double shear joint was modeled as an example (Figure 4). The modeled structure consists of three aluminum plates and two titanium fasteners. The thickness is 0.15" for outer plates and 0.2" for inner plate. The fastener diameter is 0.25". The inner plate is loaded by a distributed load of 5000 pound/in. The model is constrained at outer plates. The bulk data file is given in Appendix.

Figure 5 presents the analysis results. The displacements at a fastener location consist of the fastener movement as a rigid body, the combined plates and fastener bearing deformations, and the fastener bending and shear deformation. The results of analysis are in good agreement with the expected behavior of the joint under load.

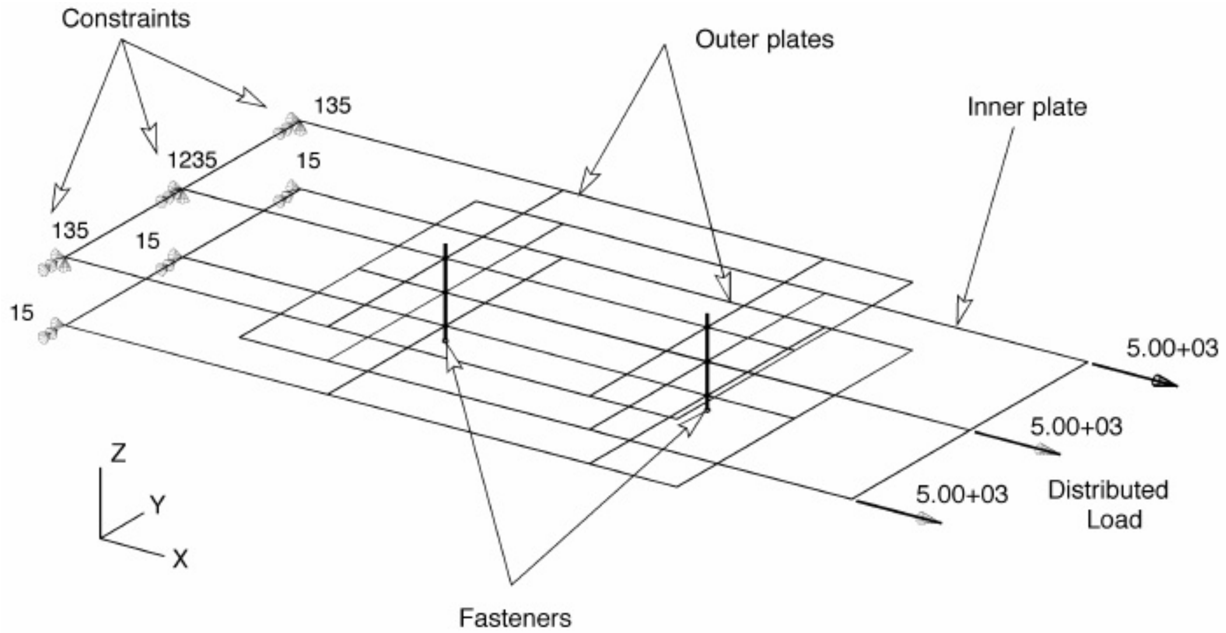

Figure 4. Example of finite element model with fasteners.

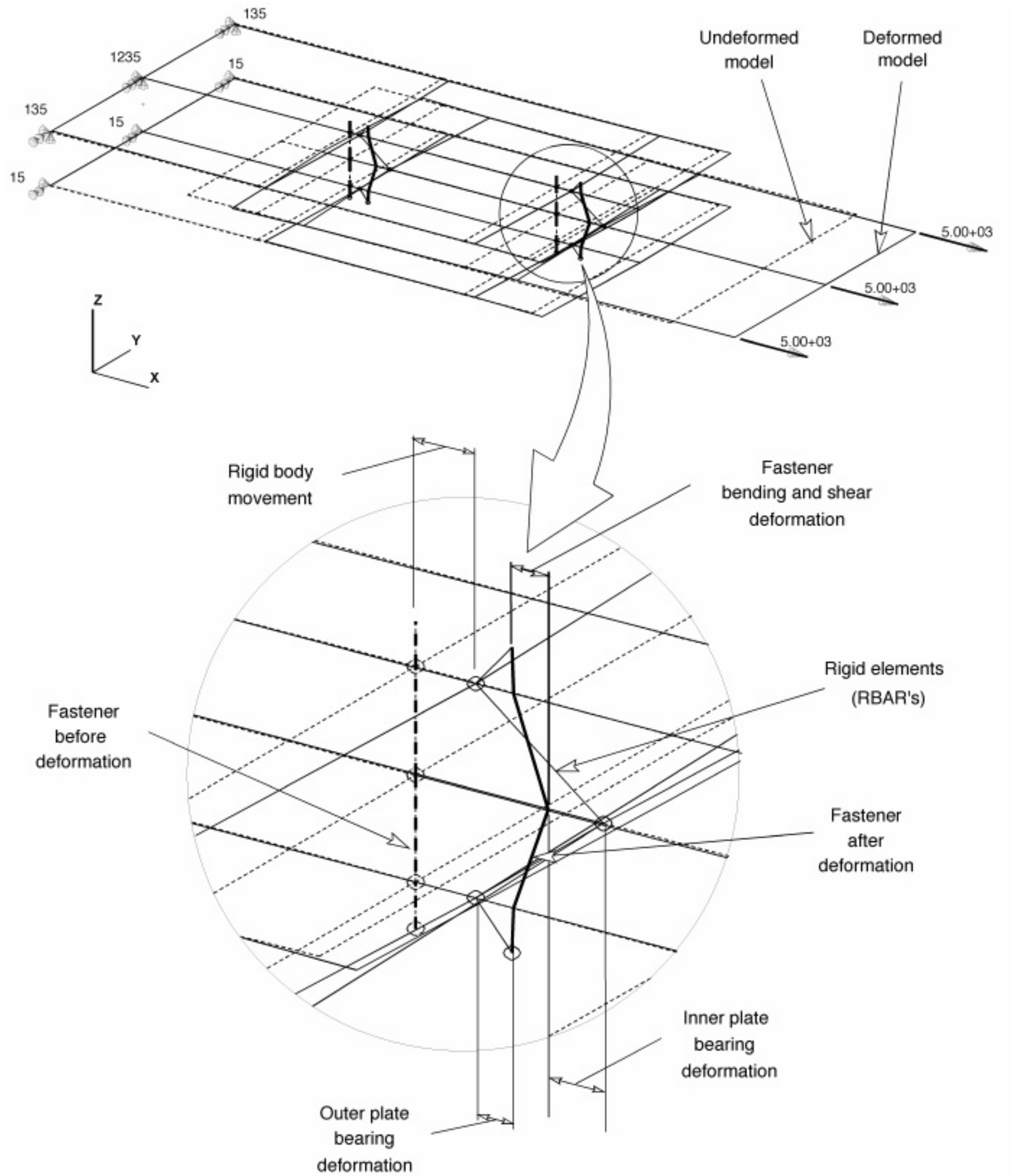

Figure 5. Displacements of example finite element model.

COMPARISON OF MODELING TECHNIQUES

To compare the modeling technique described in this paper with one developed in Reference [1] the finite element model with fine mesh was created (Figure 6). This model is the same example model presented in previous section with the only difference in mesh density. The fine mesh was employed to show deformation of fasteners and particularly the joined plates.

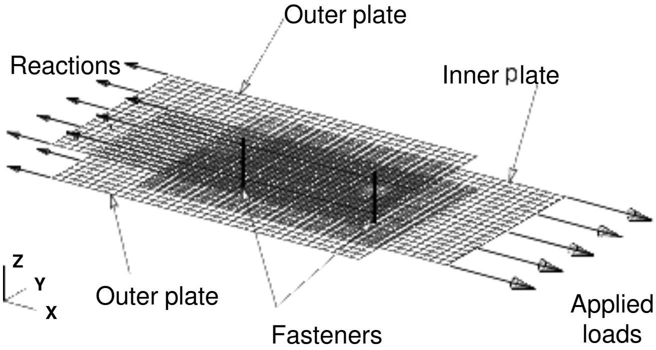

Figure 6. Fine mesh finite element model for comparison of modeling techniques.

Under the load, the joined plates slide along each other due to combined plates and fastener translational bearing deformation and the fastener bending and shear deformation. The fastener deformation causes change of angle between fastener and plate or in other words their relative rotation. This relative rotation results in non-uniform distribution of bearing stress through the plate thickness. The resultant load transferred through the contact area between the fastener and plate consists of a force in the plate mid plane and out-of-plane moment. In the structure, the moment is reacted by loads on the plate contact surfaces and does not cause the plates local bending.

The proposed modeling technique takes this phenomenon into account ensuring the plates mid planes stay parallel to each other under load. This is reached by use of rigid elements RBAR's connecting the plate nodes at the fastener location and forcing them to keep the same angle of rotation during the deformation.

The modeling technique presented in Reference [1] assumes that plates follow locally the fastener deformation. It means the fastener guides the connected plates and it results in bending of plates and interference between them. The plates bending moments in the fastener-plate contact are distributed through the model structural parts and causes additional stresses not existing in real structure.

Figure 7 illustrates the behavior of a fastener joint modeled using the both discussed techniques. Plates in the joint modeled using the proposed technique have only in-plane deformations. If the Reference [1] technique is employed, plates have clear out-of-plane deformations.

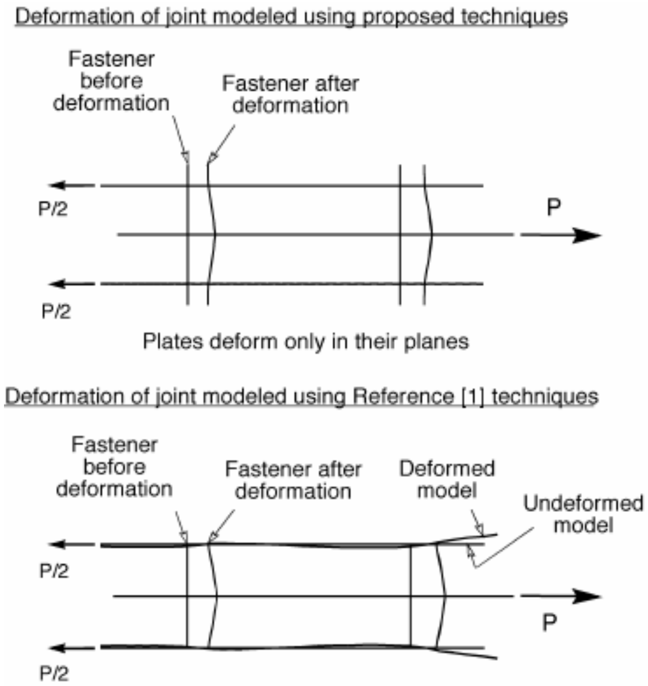

Figure 7. Comparison of results obtained by two modeling techniques.

MSC.PATRAN UTILITY

This section presents the algorithm of the newly developed MSC.Patran utility, the data input forms (Graphical User Interface) and an example of fastener joint modeling using this utility.

UTILITY DESCRIPTION

Extraction of plate nodes for connection by fastener

The MSC.Patran utility for modeling of fastener joints is applied to a group of nodes selected by user in the model area where the group of fastener joints must be created.

The program extracts sub-groups of nodes from the entire group. Each sub-group is associated with one fastener. The criterion for node subgroups creation: the distance between any two nodes of the subgroup must be smaller than or equal to the fastener length supplied by user. The fastener length chosen by user should be bigger than the longest fastener but smaller than the distance from any of subgroup nodes to grid points not belonging to the subgroup to avoid creation of undesirable elements. This condition can influence not only the user's definition of fastener length but also the selection of initial group of nodes.

The procedure assumes that fasteners in considered group have the same diameter and material. Fasteners with different diameters or material cannot be combined in one group. In this case separate groups of nodes must be selected.

Plate properties

Thickness and material properties of plate elements using a subgroup node for connectivity are extracted from the MSC.Patran database and do not require the user's input.

If connected structural parts include tapered plates, the thickness of plate elements adjacent to the fastener can be different. Moduli of elasticity for those elements can also differ if the influence of temperature distribution along the structure is considered in the analysis. To take these phenomena into account the thickness and modulus of elasticity for bearing stiffness analysis are calculated as weighted average of plates adjacent to node N_{Pi} :

$$t_{p_i} = \frac{\sum_{k=1}^{n_i} t_k^i \dfrac{1}{R_k^i}}{\sum_{k=1}^{n_i} \dfrac{1}{R_k^i}} \qquad E_{p_i} = \frac{\sum_{k=1}^{n_i} E_k^i \dfrac{1}{R_k^i}}{\sum_{k=1}^{n_i} \dfrac{1}{R_k^i}}$$

where t_{Pi} - average plate thickness at node N_{Pi};
E_{Pi} - average plate modulus at node N_{Pi};
t_k^i - thickness of element k adjacent to node N_{Pi};
R_k^i - distance between centroid of element k and node N_{Pi} ;
E_k^i - modulus of element k adjacent to node N_{Pi} ;
n_i - number of plates adjacent to node N_{Pi} .

Fastener Coordinate System

Two options of the fastener coordinate system definition are available to the user: manual and automatic.

If the user selects the manual option the program requires ID of one of previously defined coordinate systems and ID of coordinate axis parallel to the fastener axis. This coordinate axis will be addressed as reference axis of the fastener coordinate system.

If the automatic option is chosen, the program either selects one of previously defined coordinate systems or creates a new one. With the automatic option, the X-axis of the fastener coordinate system is always directed along the fastener axis. The direction of X-axis of the fastener coordinate system is defined as weighted average of normals of all elements adjacent to the fastener nodes:

$$\vec{X} = \frac{\sum_{i=1}^{n}\sum_{k=1}^{n_i} \dfrac{\vec{N}_k^i}{\left|\vec{N}_k^i\right| R_k^i}}{\sum_{i=1}^{n}\sum_{k=1}^{n_i} \dfrac{1}{R_k^i}}$$

where $\vec{X}$ - X-axis vector;
R_i - distance from node N_{Pi} to centroid of element i adjacent to node N_{Pi} ;
$\vec{N}_k^i$ - normal of element i ;
$\left|\vec{N}_k^i\right|$ - length of vector $\vec{N}_k^i$;
n - number of plate nodes N_{Pi}.

The program performs an alignment check before computing the direction of the X-axis. If the angle between normal of element k adjacent to node i and normal of element 1 adjacent to node 1 is greater than 90^0, then direction of normal of element k is reversed for computational purposes.

To reduce the number of coordinate systems in the model, the program checks the MSC.Patran database for existing coordinate systems that could be used to define the orientation of the current fastener with the following test:

$$\frac{\left|\overrightarrow{X_j} \times \overrightarrow{X}\right|}{\left|\overrightarrow{X_j}\right|\left|\overrightarrow{X}\right|} \leq \sin\alpha$$

where $\overrightarrow{X_j}$ - X axis vector of existing coordinate system CID_j;

$\overrightarrow{X_j} \times \overrightarrow{X}$ - vector product of $\overrightarrow{X_j}$ and $\overrightarrow{X}$;

α - tolerance angle, default value 1^0 .

If an existing coordinate system satisfying the above test is found, the program uses it to define the axis of the current fastener. Otherwise a new coordinate system is created and committed to the database. Coordinates of the new coordinate system origin are

$$X_0 = \frac{\sum_{i=1}^{n} X_i}{n} \qquad Y_0 = \frac{\sum_{i=1}^{n} Y_i}{n} \qquad Z_0 = \frac{\sum_{i=1}^{n} Z_i}{n}$$

where X_i, Y_i, Z_i - coordinates of plate nodes N_{Pi} .

Two other axes of the fastener coordinate system must be in plane normal to the fastener axis.

<u>Alignment of plate nodes</u>

When different structural parts are modeled separately and sometimes by different modelers, it is possible that some plate nodes, which should be connected by a single fastener, are not collinear. If the maximum deviation of those nodes normally to the fastener direction is smaller than the tolerance established by user, the program defines the fastener axis as passing through point (X_o, Y_o, Z_o) parallel to the reference axis of the fastener coordinate system. If the deviation of plate nodes exceeds the established tolerance, program stops and the corresponding message is displayed.

<u>Creation of fastener nodes</u>

The new fastener nodes N_{Fi} are created as duplicates of corresponding plate nodes N_{Pi}. In addition to these nodes, the program creates the fastener head node N_{H1} at distance $t_{P1} / 2$ from node N_{F1} and fastener node N_{H2} at distance t_{Pn} from node N_{Fn} along the fastener axis, as shown in Figure 3. The analysis coordinate system of all fastener nodes is the fastener coordinate system.

<u>Model symmetry</u>

The symmetry coefficient η is used to scale the properties of fasteners located on symmetry planes.

If the structure has one symmetry plane and only half of the structure is modeled, $\eta = 0.5$ for the fasteners located on the symmetry plane.

For structures with two symmetry planes, when only quarter of the structure is modeled, a fastener located on the intersection of the two symmetry planes has $\eta = 0.25$. For other fasteners located on symmetry planes, $\eta = 0.5$ is used.

For fasteners not located on symmetry planes, $\eta = 1.0$.

<u>Modeling of fasteners</u>

Each fastener is represented by a group of CBAR elements. The program creates CBAR elements between nodes N_{H1}, N_{F1}, ... , N_{Fn}, N_{H2} (see Figure 3). The orientation vector of the CBAR elements is given by one of axes normal to the reference axis of the fastener coordinate system. Calculation of CBAR elements section properties is described in Section “Modeling of a fastener joint”. Area, moments of inertia, and torsional constant of fasteners located on symmetry planes are multiplied by coefficient η.

If a PBAR property card with same data already exists, the program associates the current CBAR to the existing property. Otherwise a new PBAR record is created.

<u>Fastener-plate interface</u>

CBUSH elements created between plate nodes N_{Pi} and their corresponding fastener nodes N_{Fi} represent fastener-plate interface. An example of expressions for the CBUSH stiffness coefficients when the fastener axis is parallel to X-axis of the fastener coordinate system:

$$S1 = 0 \qquad S2 = S3 = \frac{\eta\, t_{p_i}}{\frac{1}{E_{cp_i}} + \frac{1}{E_{cf}}}$$

$$S4 = 0 \qquad S5 = S6 = \frac{\eta\, t_{p_i}^3}{12\left(\frac{1}{E_{cp_i}} + \frac{1}{E_{cf}}\right)}$$

Where *S1-6* - CBUSH stiffness coefficients (Reference [2])

The program then checks the MSC.Patran database for existence of a property card PBUSH with the same data. If such PBUSH record is found, then the current CBUSH element is associated with the existing property. Otherwise a new PBUSH record is created.

Compatibility of displacements

Compatibility of displacements in the fastener joint is enforced by RBAR elements. The RBAR elements are created as shown in Figure 3. If the fastener is on a symmetry plane, the degrees of freedom already constrained by symmetry are eliminated from the dependant set of the RBAR elements.

MSC.PATRAN INPUT PANEL

Figure 8 shows the input form for the MSC.Patran utility. The starting ID of the new nodes and elements can be selected, as it is usually done in majority of input forms. On the symmetry coefficient panel the user has three choices:

- 1.0 - for fasteners not located on symmetry planes (Figure 8);
- 0.5 – for fasteners belonging to one plane of symmetry (Figure 9);
- 0.25 – for fasteners located on the intersection of symmetry planes (Figure 10).

If the fasteners are on a symmetry plane (Figure 9), the user must identify the coordinate system with one of coordinate planes coplanar with the symmetry plane. This coordinate plane is indicated by perpendicular to its coordinate axis.

When the fastener axis is on the intersection of two symmetry planes (Figure 10), the user must to identify the coordinate system with one axis collinear wit intersection line. Two other axes are in symmetry planes.

The fastener diameter and material are self-explanatory. The fastener material listbox (Figure 8) contains all the materials currently defined in the MSC.Patran database. The fastener material must be created before this utility is executed.

The user has two options for the fastener coordinate system definition: manual and automatic. If the manual method has been chosen, the user is required not only identify the existing coordinate system as a fastener coordinate system but also to tell the program which axis of the system is parallel to the fastener axis. When the automatic option was selected, the user is not required to supply any additional information. In this case, the program either selects an existing coordinate system according to established criterion or creates a new one. When the fastener is on intersection of two symmetry planes identification of coordinate system is not required and the fastener axis selection panel is dimmed (Figure 10).

The user has to identify the region where fasteners will be created by giving the program the list of plate nodes. It is not necessarily the program will use all this nodes for connection by fasteners. The fasteners will be created only between nodes located not further from each other than the established by user maximum fastener length.

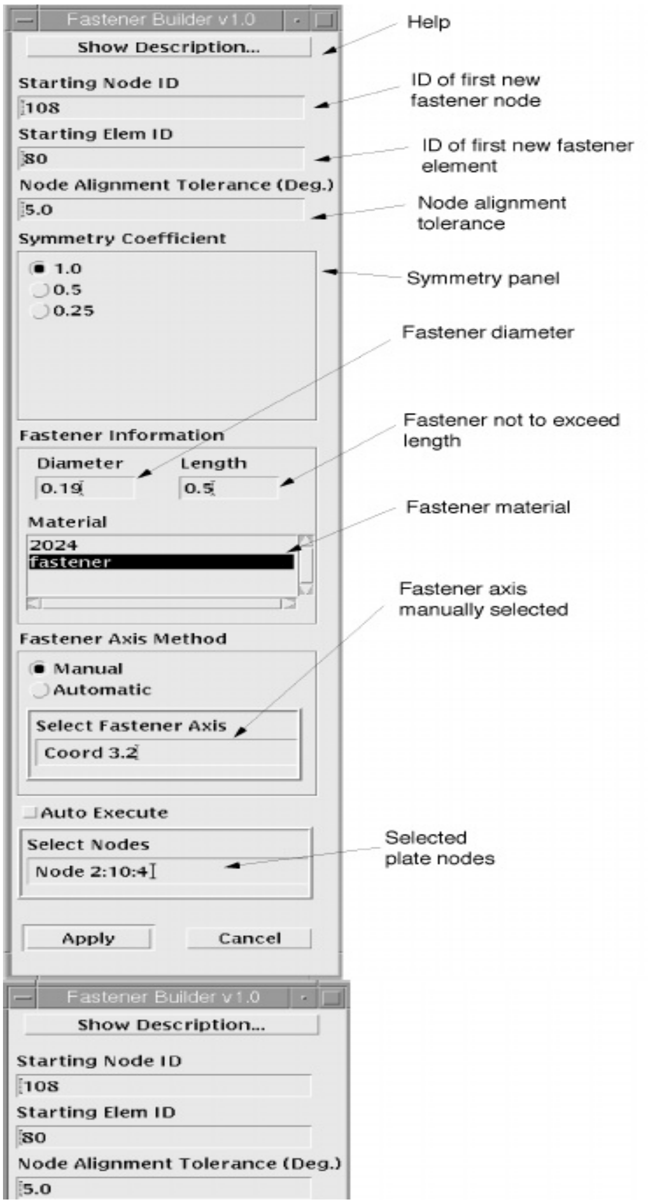

Figure 8. MSC.Patran utility input panel when fasteners are not on symmetry plane.

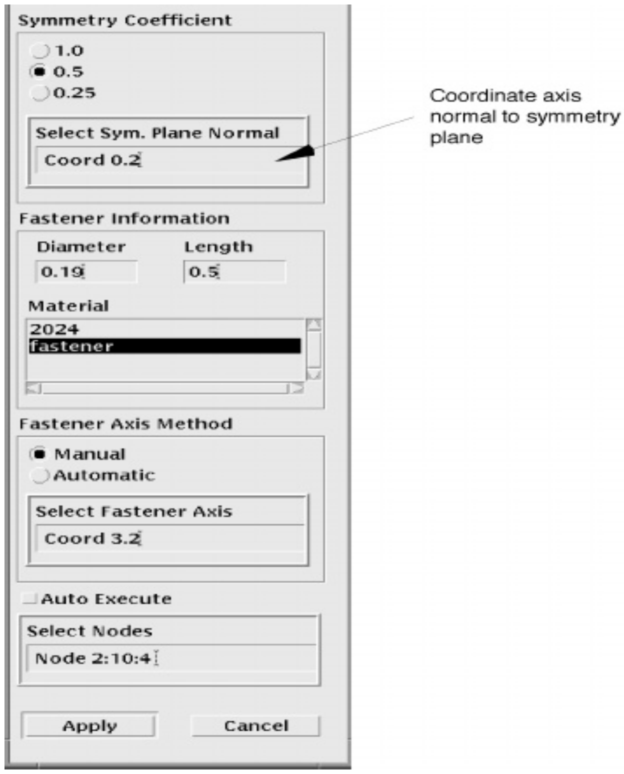

Figure 9. MSC.Patran utility panel when fasteners are on symmetry plane.

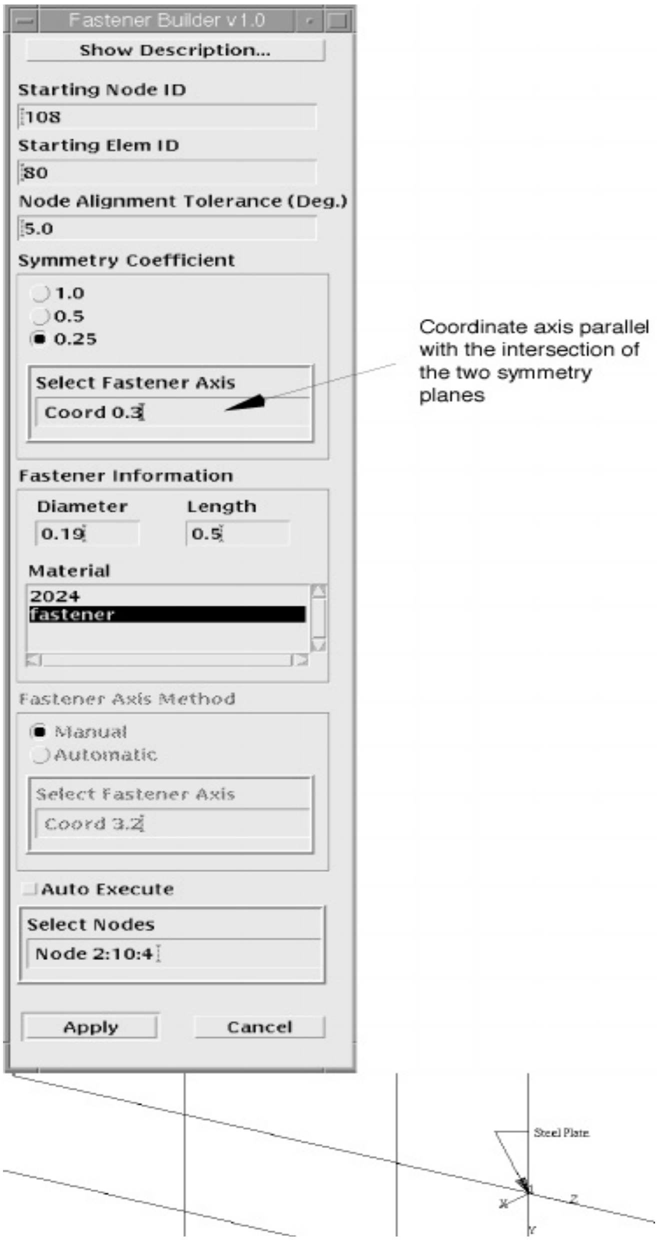

Figure 10. MSC.Patran utility panel when fasteners are on intersection of two symmetry planes.

EXAMPLE OF MSC.PATRAN UTILITY APPLICATION

Figure 11 shows a fragment of example model consisting of three plates made from different materials. The shown plate nodes were selected for connection by a fastener.

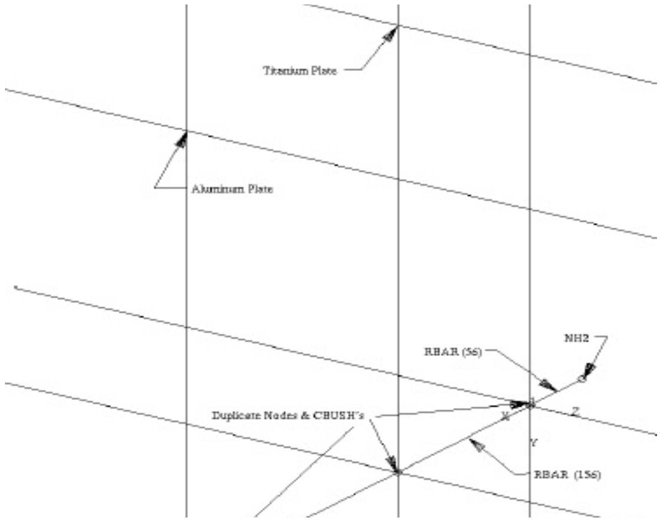

Figure 11. Example model before fastener creation.

The fastener axis is X-axis of local coordinate system 1. Figure 12 shows the fastener created between the three selected nodes. Degrees of freedom of CBUSH and RBAR elements refer to the same local coordinate system 1.

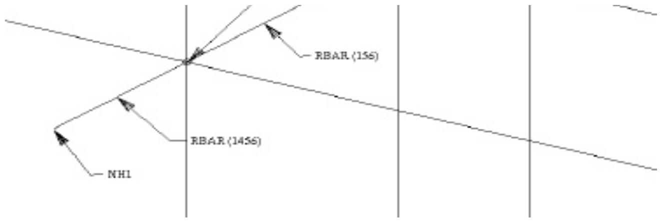

Figure 12. Example model with created fastener.

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2. MSC.Nastran Version 70.5 Quick Reference Guide, The MacNeal-Schwendler Corporation, Los Angeles, CA 1998

CONTACT

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APPENDIX. BULK DATA FILE FOR EXAMPLE MODEL

```
$ NASTRAN input file created by the MSC MSC/NASTRAN input file
$ translator ( MSC/PATRAN Version 8.5 ) on May       26, 2000 at
$ 12:37:02.
$
ASSIGN OUTPUT2 = 'dsh_new_course.op2', UNIT = 12
$
$ Linear Static Analysis, Database
$
SOL 101
TIME 600
CEND
$
SEALL = ALL
SUPER = ALL
TITLE = MSC/NASTRAN job created on 17-Feb-00 at 17:37:42
ECHO = NONE
MAXLINES = 999999999
$
SUBCASE 1
$ Subcase name : Tension
   SUBTITLE=Tension
   SPC = 2
   LOAD = 2
   DISPLACEMENT(SORT1,REAL)=ALL
   SPCFORCES(SORT1,REAL)=ALL
   OLOAD(SORT1,REAL)=ALL
   STRESS(SORT1,REAL,VONMISES,BILIN)=ALL
   FORCE(SORT1,REAL,BILIN)=ALL
$
$
BEGIN BULK
$
$
PARAM    POST    -1
PARAM    PATVER  3.
PARAM    AUTOSPC YES
PARAM    INREL   0
PARAM    ALTRED  NO
PARAM   COUPMASS -1
PARAM    K6ROT   10.
PARAM    WTMASS  1.
PARAM,NOCOMPS,-1
PARAM   PRTMAXIM YES
$
$ Elements and Element Properties for region : pshell.1
$
PSHELL   1       1       .2      1               1
$
CQUAD4   1       1       12      11      15      14
CQUAD4   2       1       14      15      19      18
CQUAD4   3       1       18      19      23      22
CQUAD4   4       1       11      25      27      15
CQUAD4   5       1       15      27      31      19
CQUAD4   6       1       19      31      35      23
$
$ Elements and Element Properties for region : pshell.2
$
PSHELL   2       1       .15     1               1
$
CQUAD4   7       2       36      37      39      38
CQUAD4   8       2       38      39      43      42
CQUAD4   9       2       42      43      47      46
CQUAD4   10      2       37      49      51      39
CQUAD4   11      2       39      51      55      43
CQUAD4   12      2       43      55      59      47
CQUAD4   13      2       60      61      63      62
CQUAD4   14      2       62      63      67      66
CQUAD4   15      2       66      67      71      70
CQUAD4   16      2       61      73      75      63
CQUAD4   17      2       63      75      79      67
CQUAD4   18      2       67      79      83      71
$
$ Elements and Element Properties for region : pbar.4
```

```
$
PBAR     4       1       1.      1.      1.      1.
$
CBAR     27      4       22      23      11                              +       A
+       A        1
CBAR     28      4       23      35      11                              +       B
+       B        1
$
$ Elements and Element Properties for region : pbar.5
$
PBARL    5       2               ROD                                     +       C
+       C .125
$
CBAR     19      5       84      85      1.      0.      0.
CBAR     20      5       86      87      1.      0.      0.
CBAR     21      5       85      89      1.      0.      0.
CBAR     22      5       87      91      1.      0.      0.
CBAR     23      5       92      84      1.      0.      0.
CBAR     24      5       89      95      1.      0.      0.
CBAR     25      5       96      86      1.      0.      0.
CBAR     26      5       91      99      1.      0.      0.
$
$ Referenced Material Records
$
$ Material Record : aluminum
$ Description of Material : Date: 03-Feb-00           Time: 15:39:23
$
MAT1     1       1.05+7          .33
$
$ Material Record : titanium
$ Description of Material : Date: 08-Feb-00           Time: 17:45:11
$
MAT1     2       1.6+7           .3
$
$ Nodes of the Entire Model
$
GRID     11              1.      0.      0.
GRID     12              1.      1.      0.
GRID     14              1.5     1.      0.
GRID     15              1.5     0.      0.
GRID     18              3.      1.      0.
GRID     19              3.      0.      0.
GRID     22              4.5     1.      0.
GRID     23              4.5     0.      0.
GRID     25              1.     -1.      0.
GRID     27              1.5    -1.      0.
GRID     31              3.     -1.      0.
GRID     35              4.5    -1.      0.
GRID     36              0.      1.      .175
GRID     37              0.      0.      .175
GRID     38              1.5     1.      .175
GRID     39              1.5     0.      .175
GRID     42              3.      1.      .175
GRID     43              3.      0.      .175
GRID     46              3.5     1.      .175
GRID     47              3.5     0.      .175
GRID     49              0.     -1.      .175
GRID     51              1.5    -1.      .175
GRID     55              3.     -1.      .175
GRID     59              3.5    -1.      .175
GRID     60              0.      1.     -.175
GRID     61              0.      0.     -.175
GRID     62              1.5     1.     -.175
GRID     63              1.5     0.     -.175
GRID     66              3.      1.     -.175
GRID     67              3.      0.     -.175
GRID     70              3.5     1.     -.175
GRID     71              3.5     0.     -.175
GRID     73              0.     -1.     -.175
GRID     75              1.5    -1.     -.175
GRID     79              3.     -1.     -.175
GRID     83              3.5    -1.     -.175
GRID     84              1.5     0.      .175
GRID     85              1.5     0.      0.
GRID     86              3.      0.      .175
GRID     87              3.      0.      0.
```

```
GRID     89              1.5     0.     -.175
GRID     91              3.      0.     -.175
GRID     92              1.5     0.      .25
GRID     95              1.5     0.     -.25
GRID     96              3.      0.      .25
GRID     99              3.      0.     -.25
$
$ Loads for Load Case : Tension
$
SPCADD   2       1       3       4
$
LOAD     2       1.      1.      1
$
$ Displacement Constraints of Load Set : spc_2
$
SPC1     1       2       37
$
$ Displacement Constraints of Load Set : spc_1
$
SPC1     3       135     36      37      49
$
$ Displacement Constraints of Load Set : spc_3
$
SPC1     4       15      60      61      73
$
$ Distributed Loads of Load Set : Tension
$
PLOAD1   1       27      FYE     FR      0.     -5000.   1.     -5000.
PLOAD1   1       28      FYE     FR      0.     -5000.   1.     -5000.
$
$ Bearing Stiffnesses
$
PBUSH   6       K       1267925.1267925.   4226.   4226.
PBUSH   7       K        950943. 950943.   1783.   1783.
$
CBUSH   31      7       39      84                              0
CBUSH   32      6       15      85                              0
CBUSH   33      7       63      89                              0
$
CBUSH   34      7       43      86                              0
CBUSH   35      6       19      87                              0
CBUSH   36      7       67      91                              0
$
$ Compatibility Conditions
$
RBAR    41      92      39      123456                  3456
RBAR    42      39      15      123456                  345
RBAR    43      15      63      123456                  345
RBAR    44      63      95      123456                  45
$
RBAR    45      96      43      123456                  3456
RBAR    46      43      19      123456                  345
RBAR    47      19      67      123456                  345
RBAR    48      67      99      123456                  45
$
$
ENDDATA
```