

# LOCAL ANALYSIS OF FASTENER HOLES USING THE LINEAR GAP TECHNOLOGY OF MSC/NASTRAN

by

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Presented at the 1999 MSC Aerospace Users' Conference

## **Abstract (Review Copy 16-Apr-99):**

Local analysis of bearing stresses at fastener locations in helicopters provides the information needed to prevent cracks which could lead to catastrophic failures. The analysis has typically been done using nonlinear methods, which can lead to excessive run times. The "linear gap" technology introduced in MSC/NASTRAN V70.5 linear static solution (SOL 101) can be used to assess the bearing stress regions of the skin in an efficient manner. This paper will introduce the methodology and strategies of implementing linear gaps to solve bearing stress problems.

## Introduction:

MSC/NASTRAN Version 70.5 introduced a new method for analyzing gaps in a linear static (SOL 101) solution. The linear gap can be thought of as a contact element in its simplest form: either open or closed with no friction. This paper will describe the theory behind the linear gap technology, introduce an MSC/PATRAN interface to efficiently generate the gaps, and finally, apply the new technology to real world engineering problems. The linear gap technology provides an alternative to the nonlinear gap elements in SOL 106.

With the advent of SOL 101 linear gaps, we can redefine the usefulness of MSC/NASTRAN for aircraft structural analysis. Although improvements in computer hardware performance continue at a steady pace, reducing solve times and allowing more DOF's than ever before, the implementation remains largely unchanged. In the aircraft structures community, we regularly take advantage of our access to significantly faster computers to build and solve entire airframe models with enough detail to resolve true hot spots.

Most airframe structure tends to include skins, spars, ribs, frames, bulkheads, stringers, longerons, as well as the fittings that tie various parts together. These parts usually consist of thin plate or sheet metal, or a graphite laminate. They often have large panels, webs or bays which require discreet or generalized stiffening to resist buckling or crippling. As in all models of structural components, generating the proper boundary conditions can be critical to the success of the analysis.

Previous efforts to determine the true heel-toe interaction of structural models have included "temp rod" solutions or nonlinear solutions with actual GAP elements. The "temp rod" solution requires that the analyst use rods or springs in a linear solution, turning off those in tension while keeping those in compression, iterating until equilibrium is achieved. This is often a time consuming method, but can produce good results. Using gap elements in nonlinear has its own set of challenges, not the least of which are debugging and extended solve times.

The SOL 101 linear gap method essentially combines the "temp rod" solution with a nonlinear gap solution. The linear gaps combine the best of both analysis approaches with far fewer headaches and significantly less solve time. Essentially, this tool accomplishes what the "temp rod" method does, except that MPC's are employed instead of rods or springs, and the CLOSE/OPEN iterations are performed automatically.

Therefore, we should keep in mind that, at best, this is still a linear solution, but one which, if used properly, can provide realistic part to part interface loads or boundary conditions.

The example in Section 4 illustrates how the linear gaps can be used in a large structural assembly to determine fastener loads and heel-toe contact forces for every structural component in the model. The results of the heel-toe contact can be used to construct a Free Body Diagram of any part in the assembly using MSC/PATRAN. These forces can then be used as applied loads for a sub model that can be solved as a stand alone model

containing the necessary refinements to produce accurate local stresses at the edges of a loaded fastener hole.

## 1. Theory

Linear gaps are implemented in SOL 101 by using explicit Multi-Point Constraints (MPCs) to define the gaps. Because MPCs are used, there is no gap stiffness; adjacent grids are either “welded” or ‘free” in the user specified degrees of freedom. The linear gaps provide for contact, or compressive, forces only. Because of the implementation, friction is not available, but a large class of problems can be solved efficiently. The MPCs are satisfied by an iterative technique that is built into SOL 101. The solution converges when there is no penetration of MPCs (i.e. gap deflection  $\geq 0.0$ ) and there are no tensile forces.

### DEFINING THE MPC.

Consider 2 Grids A, and B which are separated by an initial opening of 0.05 inches in the X direction:



**Figure 1. Grids A and B used to define MPC.**

The gap displacement is defined as:

$$U_{X_{gap}} = U_{X_A} - U_{X_B} + U_{X_{init}} \quad \text{(Eq 1)}$$

Rearranging terms to fit an MPC equation:

$$U_{X_{gap}} - U_{X_A} + U_{X_B} - U_{X_{init}} = 0 \quad \text{(Eq 2)}$$

Since the gap displacement is iterated on in the MSC/NASTRAN R-set, it cannot be dependant, and the initial gap opening will be in the S-set; either  $U_{X_A}$ , or  $U_{X_B}$  must be dependant. We will choose  $U_{X_B}$  to be dependent for this paper. Rewriting once more, putting the dependant term first:

$$U_{X_B} - U_{X_A} + U_{X_{gap}} - U_{X_{init}} = 0 \quad \text{(Eq 3)}$$

Assigning Grid A = 84 and Grid B = 21, the MSC/NASTRAN bulk data entries for defining this gap are:

```
$gap between grid 84 dof 1 and grid 21 dof 1 init opening = 0.05
SPOINT 10001 10002
SUPPORT 10001 0
SPC 101106 10002 0 0.050000
MPC 101106 21 1 1. 84 1 -1.
      10001 0 1. 10002 0 -1.
```

**Listing 1.**

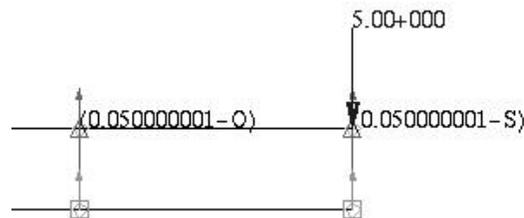
- SPOINT 10001 is used to define the gap opening.
- The SUPPORT entry places SPOINT 10001 in the MSC/NASTRAN R-set.
- SPOINT 10002 is used as the initial gap dof
- The SPC entry for SPOINT 10002 defines the initial opening of .05 inches.
- The MPC is written in the form of Equation 3.

Related MSC/NASTRAN Bulk Data entries are:

- PARAM, CDITER (integer) maximum number of iterations to determine open/closed
- PARAM, CDPRT (yes/no) print iteration history of constraint violations
- PARAM, CDPCH(yes/no) punches DMIG,CDSHUT entries for final solutions
- DMIG, CDSHUT Input vector of initial open/closed state of gaps (default=all closed)

## 2. MSC/PATRAN Interface

An MSC/PATRAN PCL utility was written as part of this paper to aid the engineer in defining the gaps. Details of using the MSC/PATRAN interface are included in Appendix A. All features of the linear gap element creation are supported. However, since MSC/PATRAN does not currently support SPOINTs, a minor edit of the MSC/NASTRAN file is required. Of particular note is the “proximity” option which can be used to generate multiple linear gap MPC’s quickly. This option allows the user to generate linear gaps for all nodes in a list which lie within a user specified distance, relieving the tedium of generating individual gaps.

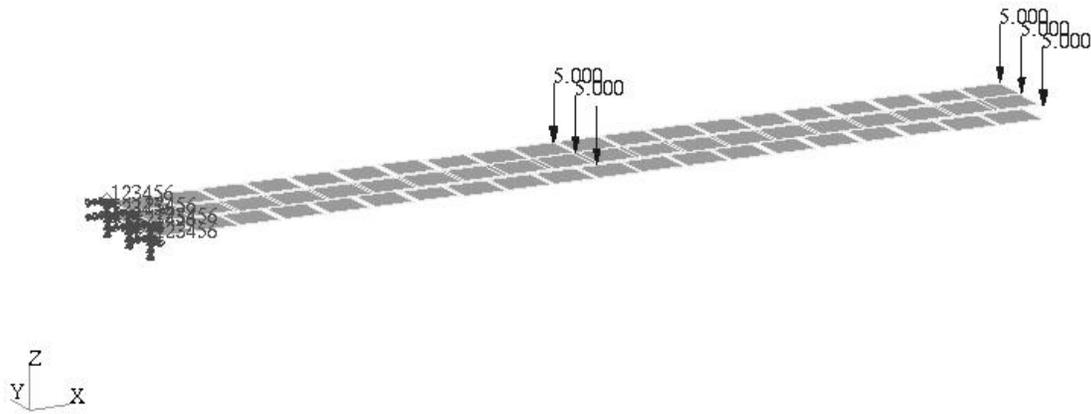


**Figure 2. Sample display of linear gaps in MSC/PATRAN**

Figure 2 shows a sample of how the linear gaps can be shown with the interface. Note that the initial opening is shown, an “S” or an “O” indicates initially shut or open, and arrows show the direction of the gap. These useful display items can be turned on or off depending on the users needs.

## 3. Simple Model

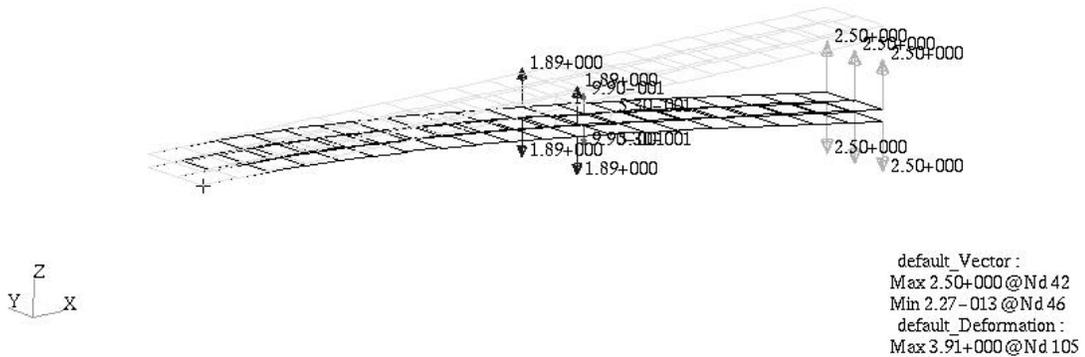
Consider two cantilevered plates with a .05 inch initial space between them. The plates are 10.0 inches long, 1.0 inches wide and .10 inches thick with generic Aluminum properties. Only the top plate is loaded with 15 pounds at the mid-span, and 15 pounds at the end. The model is meshed with 0.5 inch square CQUAD4 elements. The MSC/PATRAN interface was used to generate linear gaps between the plates. The initial opening was set to 0.05 inches, and the gaps directly beneath the loads were assumed to be initially closed, all others were assumed to be initially open.



**Figure 3. Cantilevered Plate Example—2 Plates Separated by .05” Gap**

MSC/NASTRAN solved this problem with 10 iterations. MSC/PATRAN can be used to graphically review the results. The MPC forces and displacements are shown in Figure 4. The results are as expected: the gaps under the far end are all closed, the gaps at mid-span indicate a parabolic type distribution caused by Poisson’s effects. Review of the center gaps indicates that a more refined mesh may be necessary in this area, but for the purposes of a demonstration model, no further analysis was performed. This is also a large deformation problem, but this was ignored for the sake of demonstration.

Vector: Default, Static Subcase, MPC Constraint Forces, Translational, (NON-LAYERED)  
 Deform: Default, Static Subcase, Displacements, Translational, (NON-LAYERED)



**Figure 4. Cantilevered Plate Results**

## 4. Wing Torque Box Assembly Model

The BA609 is a commercial version of the V22 Tiltrotor military aircraft. Figure 5 shows pictures of the V22 and a simulated wing torque box section of the BA609. To avoid revealing any proprietary data associated with a Bell Helicopter TEXTRON product, the torque box assembly model was generated using geometry that resembles the BA609 wing. It should be noted that the procedure outlined in this paper was used on the actual BA609 wing.

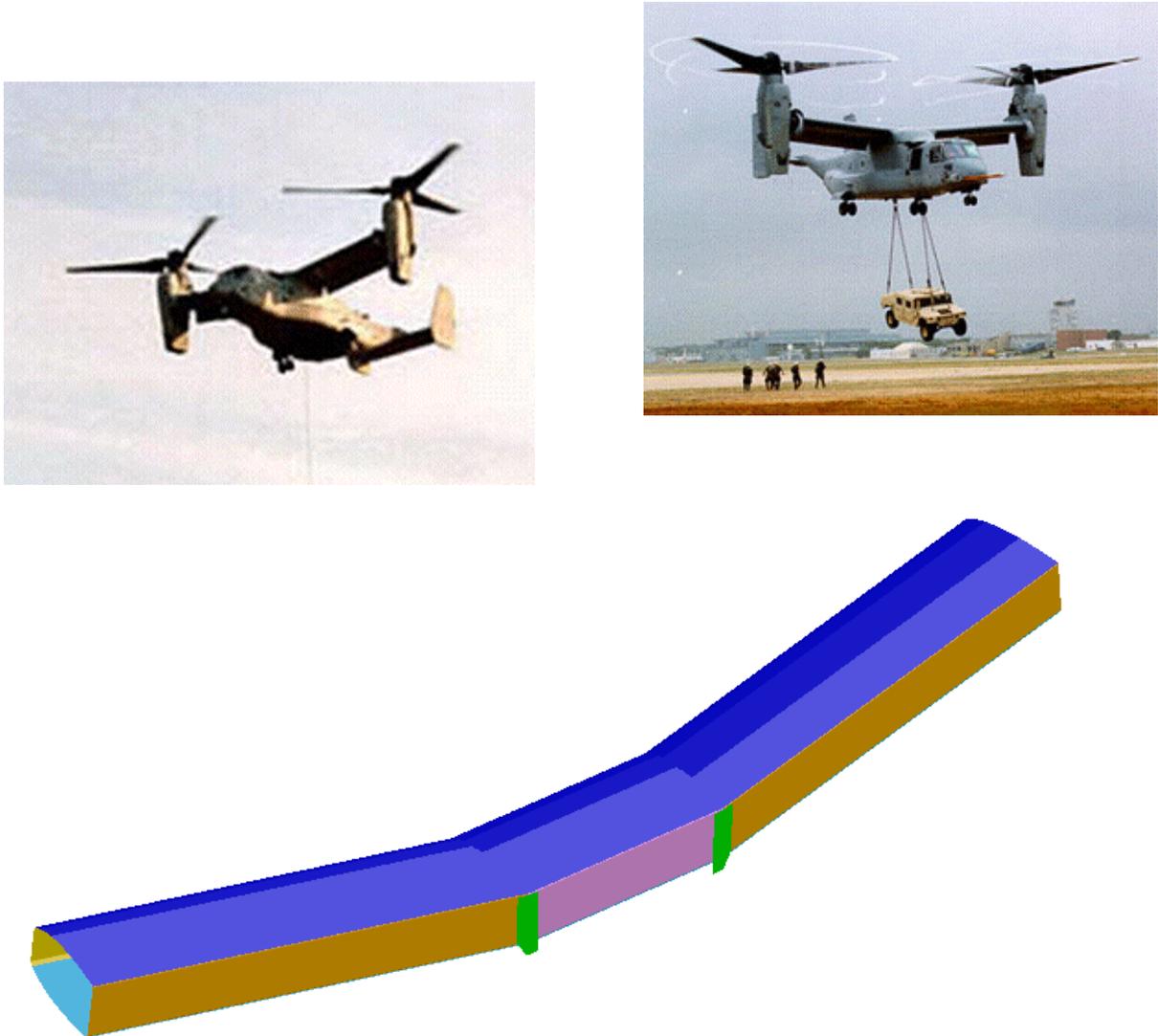


Figure 5. V22 Photos; Simulated FEM of Single Cell Wing Torque Box

The simulated torque box wing consists of:

- A forward C-Section spar, flanged aft, and discontinuous at the kick plane
- An aft C-Section spar, flanged forward, and discontinuous at the kick plane
- An upper and lower skin which are continuous across the kick plane
- Ribs at the kick plane which are tied directly into the upper and lower skins as well as into the webs of the splice fittings
- Forward and aft splice fittings at each kick plane which are just inside the torque box
- Forward and aft load fittings at each kick plane which are fastened to the spars

Note that the load fittings and splice fittings work together to splice the forward and aft spars across the kick planes. The LH forward and aft load fittings react vertical as well as lateral loads while the RH forward and aft load fittings react vertical loads only. All fore/aft drag loads are reacted along the line of nodes connecting the lower skin to the kick plane ribs. All fasteners were represented as bar elements with properties determined by the stiffness and geometry of each fastener and plate stack-up.

In contrast to a typical composite wing, the simulated wing torque box components were represented as monolithic plates, using 0.100 inch thick aluminum. Stiffeners and material thickness variations normally present in any real wing structure were not included to maintain simplicity.

Linear gaps (lin-gaps) for SOL 101 were placed between all sets of aligned nodes which lie adjacent to any fastener to characterize heel-toe interactions at the fastener locations.

### **Model Summary:**

The simulated wing model contains 26,124 elements (plates and bars), 25687 nodes (154122 DOF), 2 RBE2's to introduce applied forces at the wing tips, and 3368 lin-gaps. Loadcase 1003 is comprised of a symmetric shear of  $F_z = +5000\text{lb}$  and symmetric moment of  $M_x = -15000\text{ in-lb}$  applied to each wing tip. The model was solved on an IBM RS6000 model 595 in approximately 70 CPU minutes. There were a total of 7 iterations required to resolve the 3368 lin-gaps.

## Model Details:

The purpose of the large simulated wing torque box model is to approximate elastic wing deflection as closely as possible without the overhead of nonlinear solutions. To this end, sufficient detail of the mechanically fastened joints was included, while less detail of the large spans between joints was provided. This reduces the overall DOF's and assumes that a more coarse mesh will not adversely affect the quality of the joint loads. In this example, every structural fastener in the torque box assembly was represented and lin-gaps were included at each set of adjacent nodes to attempt to capture any heel-toe forces needed to carry moment through the joint. In fact, to emphasize the presence of the lin-gaps, all spar flange to skin joints were represented with a single row of .25 dia fasteners, with a parallel row of contact elements .5 inches fwd and .5 inches aft of the fasteners. Although this is an unconventional joint configuration for modern aircraft, it has adequate shear capability, and the lin-gaps provide the very real moment capability such a joint would possess. If significant out-of-plane loads were applied to this model, such as air pressures or fuel pressures, the heel-toe contact forces in these joints would be more significant.

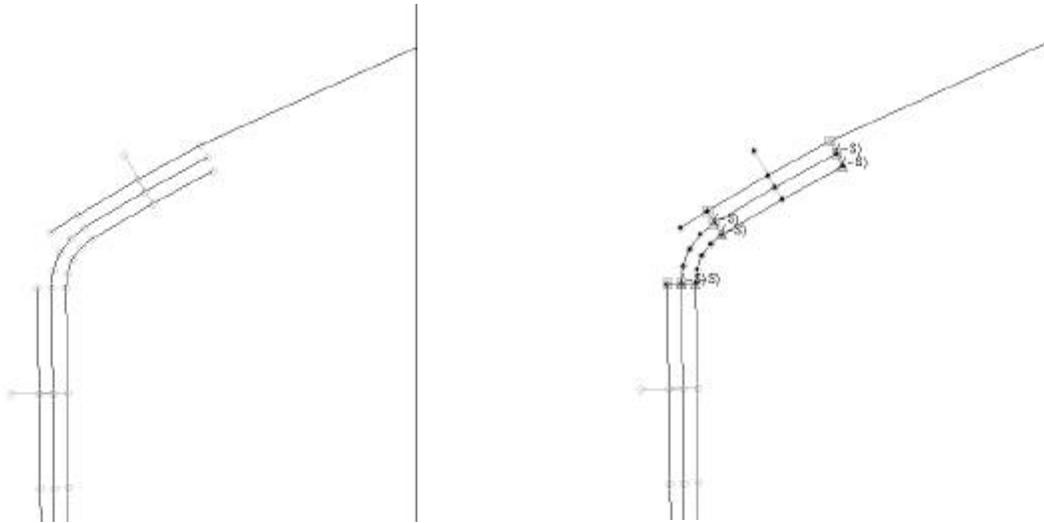


Figure 6. Spar Splice Joint With and Without Linear Gaps

As it is, the bar elements which represent the fasteners do carry some moment, and the contact forces which were produced at some of the lin-gaps were due to the linear warping caused by load path eccentricity. Note that the nodes of all plate elements were placed at the proper centroid, one part offset from the next by a distance equal to  $(t_1 + t_2)/2$ .

## **Data Recovery:**

Once the simulated wing torque box model was solved successfully and the results scrutinized to a level that produced a reasonable level of confidence, additional loadcases could be run. Since the detail of this model lies in the mechanical joints, little information of value can necessarily be gleaned from the large unsupported spans of the major structural components. It is the interface loads themselves that are of value. A data recovery set of all nodes which are connected to any bar elements representing structural fasteners and any of the lin-gaps in the model was generated. Grid Point Force (GPFORCE) output, written to an XDB file, was then requested for this node set for all loadcases which were subsequently solved. Although solving this model is a significant computational task, the only critical output are these GPFORCEs, which are contained in a relatively small .XDB data file. This data can thus be maintained “online” indefinitely for use in other applications.

## **Application of the GPFORCEs:**

The first application of the wing model results is simply to use the fastener freebody forces to perform classical bearing bypass analysis. A simple max/min sort of these fastener loads for each unique joint configuration can be employed to obtain the critical bearing margins of safety.

An important distinction should be made between these fastener loads and those obtained through traditional methods. The inclusion of lin-gaps to capture heel-toe forces which couple out joint moments has the benefit of calculating the associated out of plane forces at the fastener. The analysis of a given fastener can thus be more comprehensive by including “pull through” loads along with the shear loads. Fastener pull through is often treated as a secondary load, and traditional methods of approximating this out of plane force are tedious and conservative.

An added feature of this first application of the GPFORCEs has to do with the Material Review (MR) process. The MR engineer often has to decide whether a part or assembly can or should be repaired, or simply used as is. Critical loads for parts under review are usually available through either the stress report or at least in the analyst’s stress notes. While this information can be sufficient to make a rough assessment, knowledge of the critical loads for a given fastener could save considerable time and effort. Examples of this might include repairs with oversized fasteners which end up with short edge distance, or evaluating the effect of eliminating a given fastener altogether.

The second application is to perform an eigenvalue (SOL 105) or a nonlinear (SOL 106) analysis of one of the structural regions which has a large enough span to be stability critical. This requires that a freebody for the component be produced for all loadcases which are determined to be reasonable candidates for stability analysis.

A stand alone sub model of the component to be checked must be created. This model should be based upon the representation of that part found in the assembly model, since proper loading requires that the interface nodes match up to those from which the freebodies were produced. It is certainly possible to create a new model for this purpose that would maintain the interface load node ID's, but it should not be necessary.

In either case, the sub model of this component must have sufficient resolution in the region considered stability critical to allow MSC/NASTRAN to adequately predict buckling mode shapes. If refinement is required, care must be taken to avoid changing the freebody load interfaces to prevent improper loading.

Finally, in utilizing this second application of the GPFORCES, it must be clear that since the interface loads have been calculated using a linear model, the part represented by the sub model must NOT be allowed to redistribute its applied loads following an elastic instability. Doing so violates the assumption of linearity which determined the applied loads. Therefore, this method is an excellent way to CHECK stability of a component on a local level, provided that the results of this analysis support the criteria that the part in question remain buckling resistant up to the load limits, including your safety factor.

The third application of the GPFORCES from the generic wing assembly model is similar to the second. The goal, in this case, is to apply freebody forces for a given component to a sub model of that part as applied loads to capture local stresses at a fastener hole which has been locally refined for this purpose. Again it is best, but not absolutely necessary, to start with the part representation found in the assembly model and work from there.

While the lin-gaps were employed at the outset to better represent part interaction at all the major joints, detail around a given bolt was not considered. The lin-gaps are used again, however, in this third application, as a means to distribute fastener bearing forces of the bolt shank against the hole in the plate of the part under examination.

The first step in this process is to determine which fasteners in a given part merit this level of analysis. In this example, the Forward LH Load Fitting of the generic wing was found to be an excellent part, with several fasteners standing out with higher bearing and bypass stresses than most of their neighbors. Figure 7 shows the fitting with the associated freebody loads. A series of "postage stamp" very fine grid models (sub models) of fastener/hole was generated for various diameters and ID ranges. For example,

- ¼ inch diameter      004,104,204,304,404,504,604,704,804,904
- 5/16 inch diameter    005,105,205,305,405,505,605,705,805,905
- 3/8 inch diameter     006,106,206,306,406,506,606,706,806,906

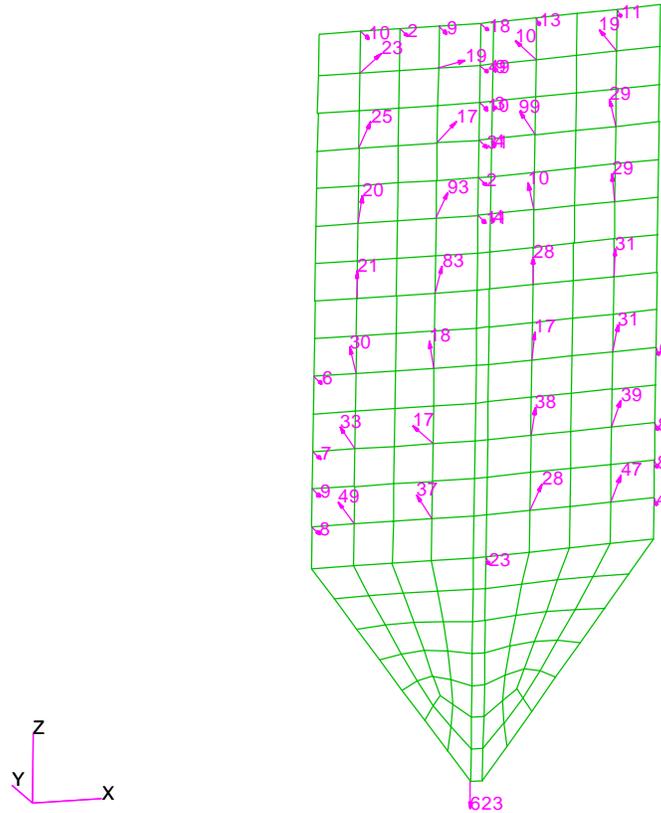
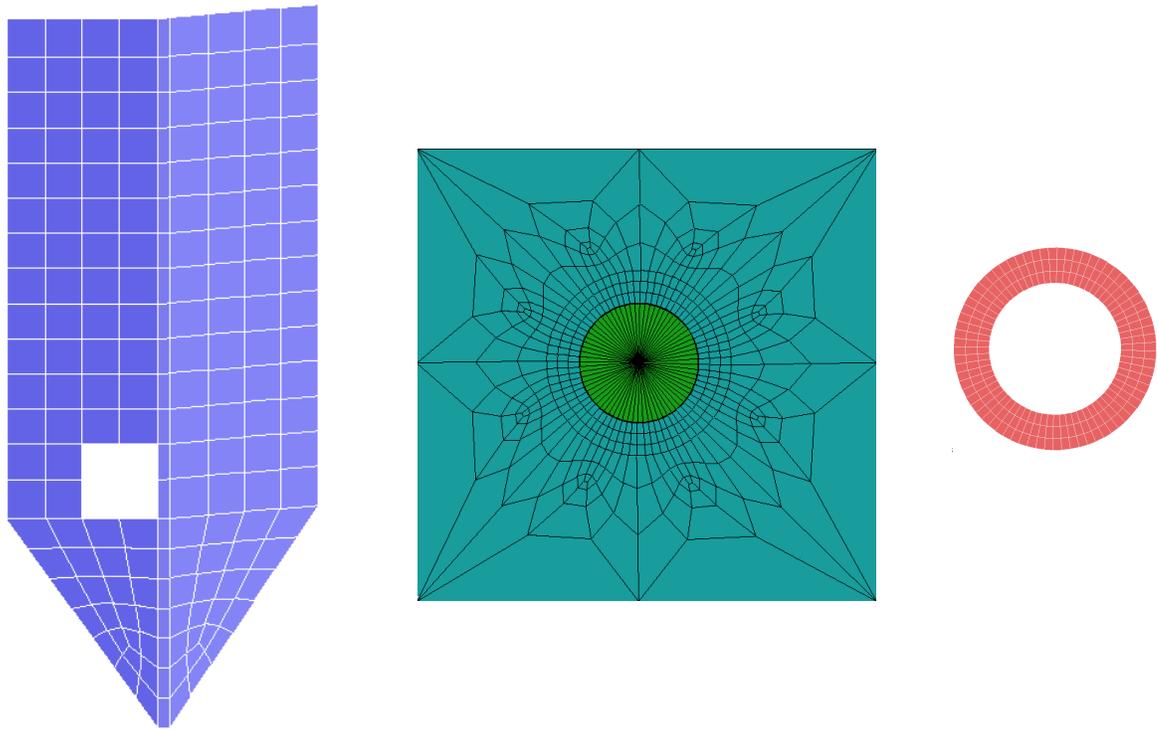


Figure 7. Forward Left Hand Load Fitting Freebody Resultant Forces

Figure xx shows a plot of the original load fitting with the four quads surrounding the critical fastener removed and a “postage stamp” representation of the bolt and surrounding structure to the right. This submodel includes the 006 location described above. The ring of 3 rows of quad elements is the plate of the Forward LH Load Fitting under the head of the most critical fastener in the part. The inner diameter is actually the maximum hole diameter as prescribed by the hole preparation specification associated with this fastener. The outer diameter is the maximum diameter of the head of this fastener. The circle has been segmented into 72 units, a 5 degree arc from the fastener centerline to each element face. The remaining elements of this postage stamp fastener model are in line with this pattern.

The diameter of the shank is the minimum value shown in the fastener specification. Although there is a visible gap shown in this plot, the lin-gaps that are used to connect these parts have been assigned an initial value of 0.000 inches, which suggests that the fastener and the hole are in intimate mathematical contact.



**Figure 8. Load Fitting, Sub Model with Bolt, and Model Details Near Bolt**

Bolt clamp-up forces are an important issue. If these clamp-up is ignored then the out-of-plane loads will cause unrealistically high stresses due to bending. Thus, the bolt clamp-up is accounted for by enforcing consistent slope under the head of the bolt. This is accomplished by creating a duplicate set of quad elements above the load fitting and MPCing the 2 plates together in the out-of-plane direction only (i.e no shear from friction). Many methods to account for clamp up have been attempted, and their virtues and failings will not be discussed in this article. Suffice it to say that by using these two sets of plates, both fixed to the shank elements and each connected to the Forward LH Load Fitting plate by means of Multi Point Constraints acting in the direction parallel to the centerline of the fastener, an accounting for fastener clamp up is accomplished. This does not in any way presume to be THE correct approach to dealing with this issue. It can be said, however, that this method is conservative in that it ignores the composite plate effect that friction forces due to bolt pre load can produce, while reducing the free edge rotation which unrealistically exaggerates local stresses about the edges of the hole due to imparting out of plane freebody forces to a single member of the stack up.

This approach is an effort to determine local stresses about the hole of a given fastener. This sub mesh has been treated as a “postage stamp” fastener model, which implies fast implementation at a reasonable cost. If one considers that a thorough review of the preliminary results from the assembly model should suggest a few critical fastener locations, then only a few “postage stamp” fastener models need be included in the stand alone model.

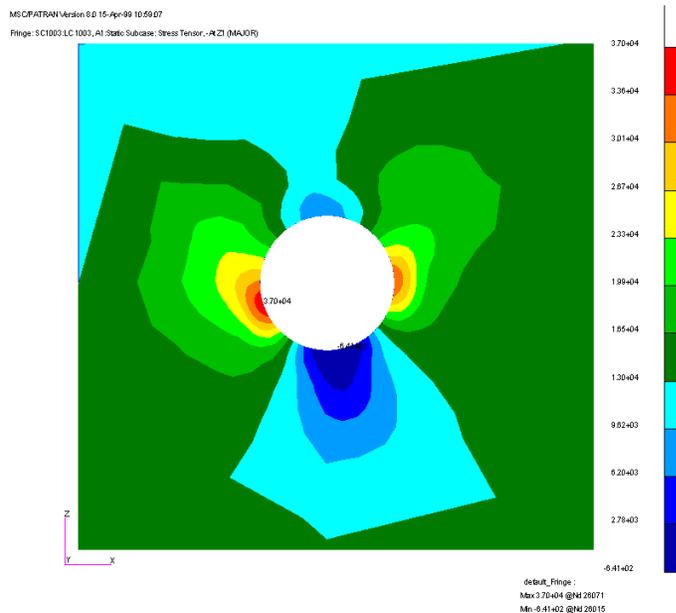
Since the ground work has already been laid by setting up a series of core “postage stamp” fastener models (006, 106, etc.), then the only real task is to choose a critical

fastener location or two, hang one of the core models in place, use your preprocessor to help generate a transition mesh, and equivalence the shared grids. Along with the core “postage stamp” fastener models should be an associated series of lin-gap .BDF files which contain all of the MPC, SUPORT, and SPOINT cards necessary to accommodate the fastener to plate interaction. In terms of efficiency, these “postage stamp” fastener models contain fewer than 1000 elements and should not significantly increase the solution time, provided too many are not attempted at one time.

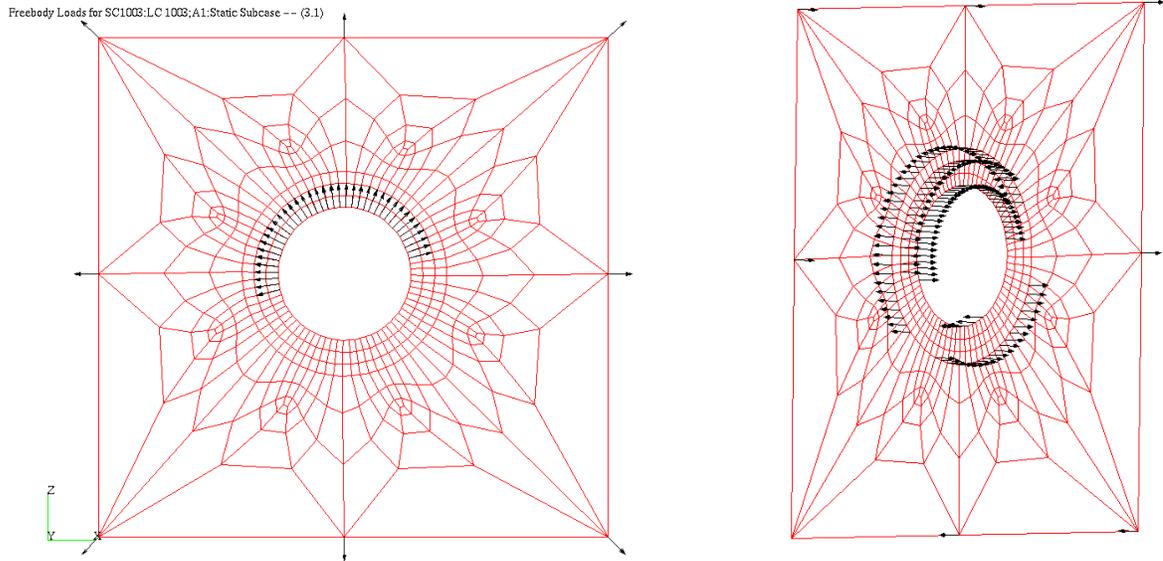
Since the applied loads are always in balance, and the original mesh density of these fittings was not overly coarse, the desire to check many or all of the fasteners for local stresses can easily be accomplished by creating several versions of the stand alone model, each perhaps containing a different zone or cluster of “postage stamp” fastener models. Finally, due to the fact that the applied forces used to load up the stand alone model will never be perfectly in balance, even though they were produced using freebodies, it is recommended that several CBUSH translational springs with small spring rates (to ground) be tied to the extreme corner grids of the part to prevent “drift”. In addition, a rotational CBUSH spring to ground with small spring rate must be included at each bolt center grid of every “postage stamp” fastener model in the stand-alone model to prevent it from spinning about the fastener centerline.

## RESULTS

Due to the experience of finding some level of bending gradients through the plate in the vicinity of a critical fastener, corner stresses were requested for the first three rows of elements about the fastener hole. Where multiple loadcases were solved, a max/min sorter was employed to search through the output2 file and find the critical values/cases.



**Figure 9. Fringe Plot of Local Stresses**



**Figure 10. Freebody Results – Radial and Out of Plane**

#### COMPARISONS WITH TEST RESULTS OR OTHER METHODS

Since this process begins with a higher fidelity, newly configured “coarse grid” or internal loads model, and ends with a very refined mesh used to describe a single fastener, it is difficult to compare these results with other math models used in this organization. While it is certainly possible to construct several models of this same structure based upon various classical methods, this has yet to be accomplished.

As for test results, it would likely be instructive to make use of some reasonably good data from previous tests to construct a series of models based on this approach. One key difficulty, however, will inevitably be to find a test which can accurately address local fastener hole edge stresses of loaded fasteners which would likely preclude data recovery in the critical zone. Comparisons could certainly be drawn between test and analytical methods using the reduced intensity stresses in areas of a plate adjacent to a fastener head where instrumentation could be installed.

#### CONCLUSIONS

This paper has explained the theory used by MSC/NASTRAN to implement simple contact using an iterative method in an otherwise linear solution. There is also an MSC/PATRAN graphical interface introduced to help define the gaps. A relatively complicated Tiltrotor wing torque box was analyzed to determine the heel-toe interaction at fastener locations. These heel-toe results were then used as input to determine local bearing stresses using the linear gaps. The process outlined above can significantly reduce the time required to predict critical local stresses in airframe parts, with perhaps greater resolution/accuracy than has previously been possible.

## A. Appendix A – Details of MSC/PATRAN Linear Gap Interface

The purpose of the MSC/PATRAN Linear Gap Interface is to fully support the MSC/NASTRAN V70.5 linear gaps in SOL 101. The supported features include automatic generation of gaps, parameters and DMIG entries necessary for MSC/NASTRAN.

Primary Features:

- Specify initial gap—Several options
  - Automatically calculated based on nodal distance
  - Automatically calculated nodal distance projected into displacement c.s.
  - Explicitly defined (user input)
- Specify initial condition (shut/open)
- Graphically identify displacement (analysis) dof direction to ensure proper definition
- Generate graphical representation of gaps
  - Identify independent vs. dependent dof
  - Draw a line between gap nodes
- Automatically reorder MPC equation if MSC/NASTRAN set conflicts are detected (i.e. dependent dof can only be specified 1 time, dependent dof cannot be spc'd)
- Automatically generate gaps for nodes within a user specified proximity
- Delete unwanted gaps
- Graphical verifications
  - Initial conditions (open/shut)
  - Initial gap opening
  - Independent/dependent dof colors/marker identification
  - Displacement vector to show closing direction of gaps
- Write bulk data entries for PARAMeters, SUPORTs, SPCs, MPCs, SPOINTS, and DMIGs
- Read bulk data entries associated with linear gaps.

### Creating Gaps

There are 2 methods to create the linear gaps: individually selecting nodes and choosing a group of nodes to match based on proximity (model distance.) The creation form is shown for both methods:

Linear Gap Elements

Option

Type

Gap Input Method

- Nodal Distance
- Enter Value

Option

Initial Gap Opening

Initial Position (DMIG CDSHUT)

- Shut
- Open

Auto Execute

Node 1 DOF:

- Ux
- Uy
- Uz

Show Disp. CS

Select Node:

Node 2 DOF:

- Ux
- Uy
- Uz

Show Disp. CS

Select Node:

If Coinc. Node

- Higher
- Lower

Proximity Threshold

Linear Gap Elements

Option

Type

Gap Input Method

- Nodal Distance
- Enter Value

Option

Initial Gap Opening

Initial Position (DMIG CDSHUT)

- Shut
- Open

Auto Execute

Node 1 DOF:

- Ux
- Uy
- Uz

Show Disp. CS

Select Node:

Node 2 DOF:

- Ux
- Uy
- Uz

Show Disp. CS

Select Node:

If Coinc. Node

- Higher
- Lower

Proximity Threshold

Gap Input Method

- Nodal Distance
- Enter Value

Option

Initial Gap Opening

Initial Position (DMIG CDSHUT)

- Shut
- Open

Auto Execute

Node 1 DOF:

- Ux
- Uy
- Uz

Show Disp. CS

Select Node:

Node 2 DOF:

- Ux
- Uy
- Uz

Show Disp. CS

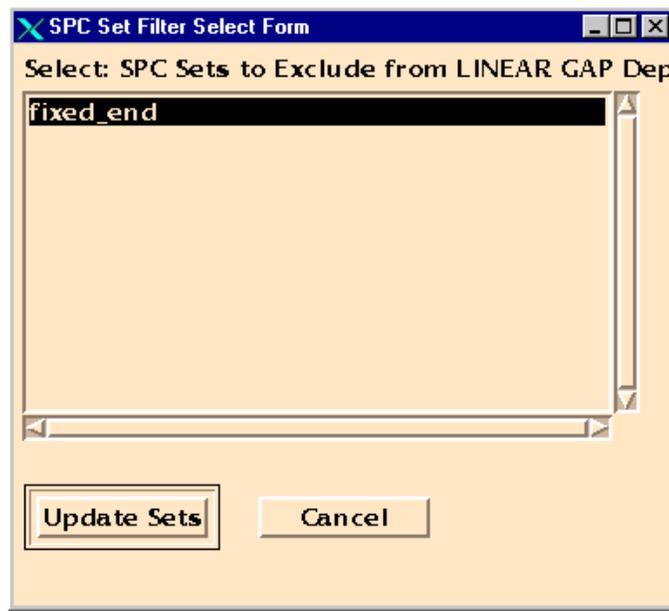
Select Node:

If Coinc. Node

- Higher
- Lower

Proximity Threshold

Several valuable checks are performed when creating a gap. MSC/NASTRAN set definitions are enforced when writing the MPC equation. Specifically, the MSC/PATRAN database is searched for dof which are part of the S-set and M-set. The S-set is the Single Point Constraint (SPC) set, which cannot be specified as a dependent dof. The MSC/PATRAN database is searched for any nodes which have displacement constraints (S-set), and the MPC equation will be automatically rewritten if S-set dof is chosen as dependent. A form is used to “filter” the displacement constraints used in this check. By default all displacements constraints will be searched. The MPC equations on the MSC/PATRAN database are also interrogated to ensure that a dependant dof isn’t specified more than 1 time.



### CREATION by SELECT NODES:

By default, the Node 1 will be the independent node in the MPC equation, and the equation will be written in the format shown in **EQ 3**. Note that the user must determine which node to select first.

- For non-coincident nodes, Node 1 should be the node which has the higher coordinate value in the dof selected. (I.e. choose node with coordinates [1.01, 0.0, 0.0] as Node 1, and [1.00, 0.0, 0.0] as Node 2 for a gap in the X direction). There is no check by the program to ensure compliance; the equation will be written as **EQ 3**.

- For coincident nodes, Node 1 should belong to the object or model component which is “above” the other object. An example of this would be a table sitting on the floor. Assume that the Z-axis is pointing up from the floor. Then the coincident nodes at the table leg/floor interface should be chosen with Node 1 belonging to the table leg and Node 2 belonging to the floor.

## **CREATION by PROXIMITY**

A far more valuable tool provided by the graphical interface is creation by proximity. Here, a group of nodes is compared to another group of nodes. If the nodes fall within a specified tolerance (10 times model tolerance), then a gap is created between them. The program will automatically determine the MPC equation based on the nodal coordinates. If two nodes are coincident, then Node 1 will be based on the “Higher” or “Lower” toggle above the proximity threshold input box. *The proximity method is preferred for creating linear gaps.*

### **CREATION: Gap Input Method**

The creation form allows several methods of determining the initial gap opening. “Nodal Distance” will calculate the magnitude of the distance between the two nodes for use in the initial opening. This is useful for models with solid interfaces, but should be used with caution for plate or beam interfaces because the actual gap may be different than the nodal distance. The “Nodal Distance” “Option” is either Magnitude, or a projection of the magnitude into one of the analysis coordinate systems of one of the nodes. “Enter Value” allows the user to specify the initial gap distance.

### **CREATION: Initial Position**

The initial position can be specified as “Shut” or “Open.” The MSC/NASTRAN default is “Shut” for all gaps. If any of the gaps are created with an initial “Open,” then the appropriate DMIG CDSHUT entries will be written to the MSC/NASTRAN input file. *Careful selection of initial position can greatly improve the solution iteration time.*

### **CREATION: Node 1 DOF and Node 2 DOF**

Since an explicit MPC is written for each linear gap, the dof must be specified to define the MPC properly. As an aid to the user, an arrow is drawn in the analysis coordinate system (displacement coordinate system) of the node when it is selected. The analysis coordinate system direction is calculated using the analysis coordinate frame of the node. The graphical interface will automatically resolve any coordinate system transformations and display the appropriate arrow. Rectangular, cylindrical, and spherical coordinate systems are all displayed appropriately. A toggle is provided if the user doesn’t wish to see the displacement coordinate systems when selecting nodes. The “Auto Execute” will automatically toggle between the Node 1 and Node 2 selections.

## CREATION: Delete Last Gap

Since there is no “Undo” for the creation, a “Delete Last Gap” button is included on the form. This will delete the last gap entry. This can be used multiple times to delete as many gaps as necessary, always deleting the most recently created gap. There is an option to delete gaps which can be used for more extensive deletion.

## CREATION: Proximity Threshold

This is explained in “CREATION by PROXIMITY” above.

## Displaying Gaps

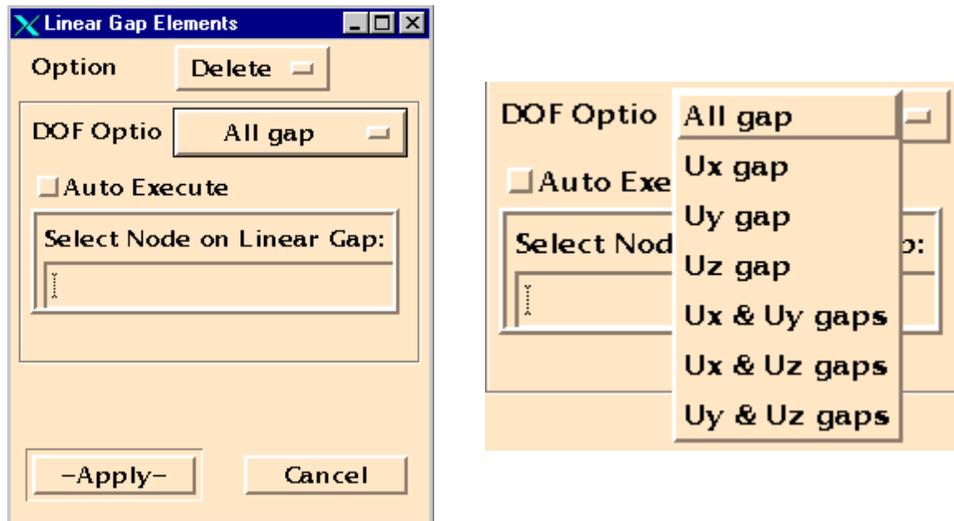
The “Display” option allows the user to modify the display attributes of the gap. This form requires no further explanation.

The screenshot shows a dialog box titled "Linear Gap Elements". It has a title bar with standard window controls. The main content is organized into several sections:

- Option:** A button labeled "Display".
- Independant Node:**
  - Shape:** A dropdown menu set to "triangle".
  - A color swatch showing a green square.
  - A value "10" positioned between "1" and "25".
  - A horizontal slider labeled "Size of Marker".
- Dependant Node:**
  - Shape:** A dropdown menu set to "square".
  - A color swatch showing a magenta square.
  - A value "10" positioned between "1" and "25".
  - A horizontal slider labeled "Size of Marker".
- Three checkboxes:
  - Label Gap Size
  - Indicate CDSHUT?
  - Show directions
- At the bottom, there are two buttons: "-Apply-" and "Cancel".

## Deleting Gaps

In addition to “Delete Last Gap” on the Create form, there is a more general delete gap form. Simply choose a node to which a gap is connected to delete the gap. The “DOF Option” can be used to limit the number of gaps deleted. For instance, if a node is connected with linear gaps in all 3 dof, the user may only want to eliminate one of the gaps.



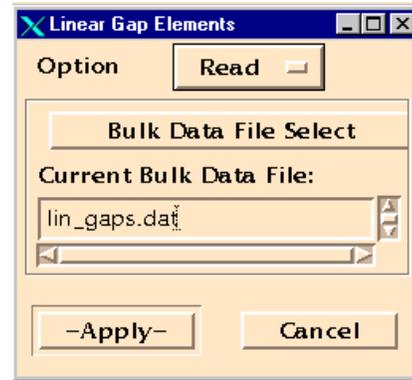
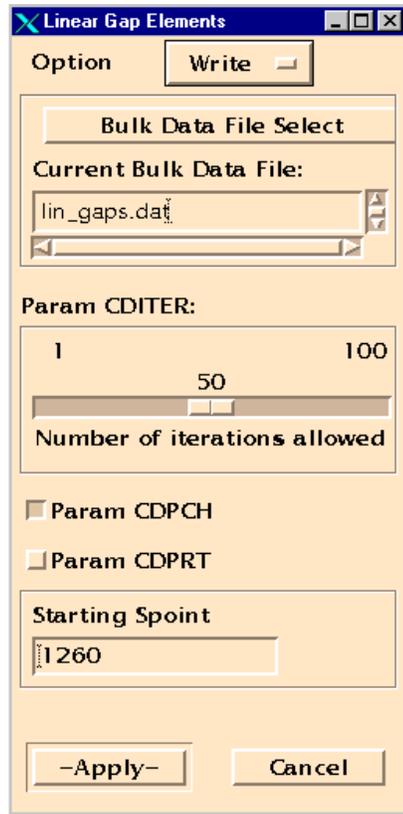
## Writing Gaps

The “Write” option allows the user to write an MSC/NASTRAN input file for the linear gaps. The user must select a file to write to. In addition, the PARAMeters required by MSC/NASTRAN can be specified on the form. See section 1 for an explanation of the parameters.

Since MSC/PATRAN does not normally handle SPOINTs, this form requires the input of the starting SPOINT id. By default, the “Starting Spoint” will be set to 10 times the maximum model node id. Note that 2 SPOINTs are used for each linear gap (one for the actual gap opening, and one for the initial opening). The maximum legal SPOINT id allowed in MSC/NASTRAN is 1,000,000.

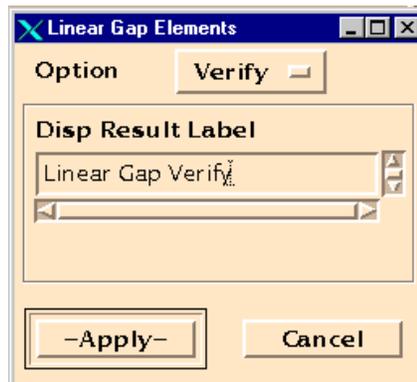
## Reading Gaps

The graphical interface can also be used to read the linear gaps. It requires that both the SPC and MPC ids be 101106 for the linear gap elements. Free- or fixed-format are supported.



## Verifying Gaps

To verify the gaps, a displacement result case is created. This result case will create a negative unit (-1.0) displacement for the node which will move in the “closing” direction of the gap. All other nodes have no displacement. The user can then use the normal MSC/PATRAN “Results” to plot the closing direction of the gap to provide a visual verification of the gap closing directions. See also “Displaying Gaps” above.



## Modifying the MSC/NASTRAN Input Deck

After creating, verifying, and writing the linear gaps, an MSC/NASTRAN input deck can be created with MSC/PATRAN as with an ordinary static analysis. Be sure to create an analysis deck only and don't submit the run until the following edits to the input file are performed:

- 1) In the case control section: add "MPC = 101106" prior to the 1<sup>st</sup> SUBCASE
- 2) After "BEGIN BULK" add "INLCUDE 'lin\_gap\_filename.dat'"
- 3) Modify the "SPCADD" entry to include spc set 101106

A sample is shown here, the modifications are denoted in bold:

```
...
...
MAXLINES = 999999999
$ Direct Text Input for Global Case Control Data
mpc=101106
SUBCASE 1
$ Subcase name : Default
  SUBTITLE=Default
  SPC = 2
...
...
BEGIN BULK
include 'plate_gaps.dat'
PARAM      POST      -1
PARAM      PATVER    3.
...
...
$ Loads for Load Case : Default
SPCADD    2          1          101106
...
...
```

## Usage Notes

- The preferred way to generate the gaps is with the "Proximity" option.
- The user is urged to use the "Display" and "Verify" forms to determine if the gaps were generated correctly.

- If the user wants to modify a gap, he can simply re-create the gap with the new values (i.e. initial opening or initial position).
- For existing MSC/NASTRAN bulk data files, the model can be read into MSC/PATRAN and the gaps created and written to another file.
- The user must remember to request MPC FORCES in the case control output requests.
- It is strongly recommended to use PARAM CDPCH to generate DMIG CDSHUT entries on the MSC/NASTRAN punch file. These can be used in subsequent analyses as a refined starting point (initial condition).

## Limitations

Because MSC/PATRAN does not recognize SPOINTs, the user must modify the MSC/NASTRAN input file. There are precisely 3 modifications which should take the average user less than 1 minute to perform. When MSC/PATRAN recognizes SPOINTs, this limitation can be avoided.

The MPC and SPC set ids generated for the linear gaps are each 101106. If, by Murphy's Law, the user has an existing input file which uses these set ids, the user will have to modify the set ids manually. This should be a relatively simple step of performing a global replace of 101106 in the file generated by the graphical interface. The MSC/NASTRAN input file modifications will have to be modified accordingly.