Development of an Automated, Free-Body Forces Constructor for C-2A(R) Airframe Structural Analysis

Authors: Kris Wadolkowski, Technical Director, Aerostructures, Inc.
Leigh-Ann Waughtel, Naval Aviation Depot, North Island

1999 MSC Aerospace Users' Conference
June 7 - 10, 1999

Abstract

In carrying out their responsibilities for providing maintenance support for the C-2A(R) Carrier On-Board Delivery (COD) aircraft, the Navy's Research and Engineering Office was faced with the problem of determining proper boundary conditions for their detailed stress models. A commonly used method involves extracting the boundary conditions for a local area from a larger loads-model and it was this approach that was adopted for the development of an automated procedure. In preparation for this effort, an MSC/NASTRAN loads-model of the C-2A(R) airframe was developed from Grumman's ASTRAL model and an interrogable database of internal forces was created. A Windows-based program, with an MSC/NASTRAN for Windows interface feature, was developed to access this database and generate boundary forces for the user-specified region. Output from this program is in MSC/NASTRAN format card images and includes a "starter" file for the detailed stress model.

Introduction

In Naval aviation, the longevity of an airframe in service was initially driven by technology, with new aircraft rendering the older ones obsolete, or in time of war, the longevity was driven by attrition. The role of engineering was to repair damage by restoring "original strength." This method simply replaced material lost or removed by an equivalent amount of material fastened in its place. With the rapidly increasing cost and development time of new airframes, the factor that determined the longevity gradually shifted to the economic life of the aircraft. The factors that degraded the economic life were typically corrosion and fatigue. The earliest attempts to specify some form of economic life appeared in the early 50's such as the requirement in the A-3 specification that "The service life of the airplane shall be 500,000 statute miles!" (Reference 1). With this shift, the role of engineering evolved to address the problems of predicting economic life, specifically, fatigue life. As part of this effort, finite element loads models were either built or obtained from the manufacturers to provide the internal forces necessary to conduct detailed stress analyses. Figure 1 shows one of our first models specifically developed for this purpose: the A-3 model was built late in the life of the aircraft but was necessary to address the structural integrity issues faced by the program. Another example is the Aerostructures' developed P-3C model (figure 2).

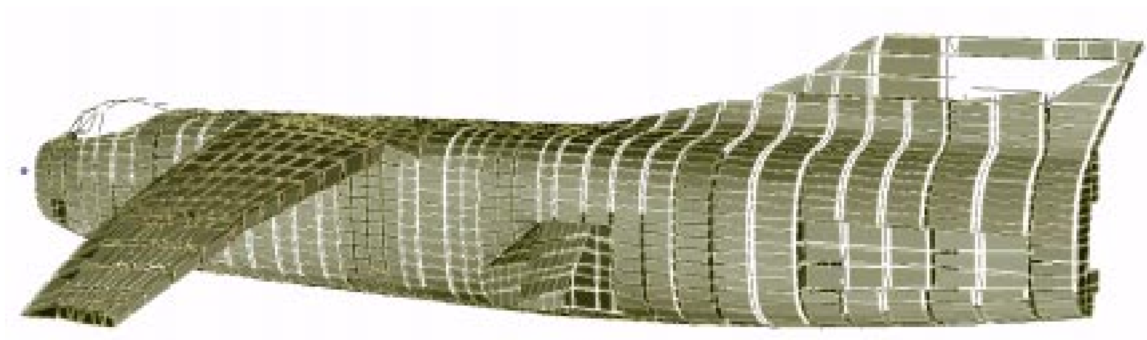

Figure 1: Loads Model of the EA-3B

With these models, the stress analyst was able to generate suitable boundary conditions for the detailed stress models. While the tools for generating the detailed stress models made it a relatively simple task, the process of determining the appropriate boundary conditions from the loads models was not as simple. Clearly, there was a need for a method of determining boundary conditions that matched the ease of use and efficiency of the modeling programs. This paper discusses the development of such a system, designed to meet the needs of the Navy's engineering office and one that reflects the increasing use of desktop computers for engineering analysis. The development emphasis was on MSC/NASTRAN for Windows and Windows applications.

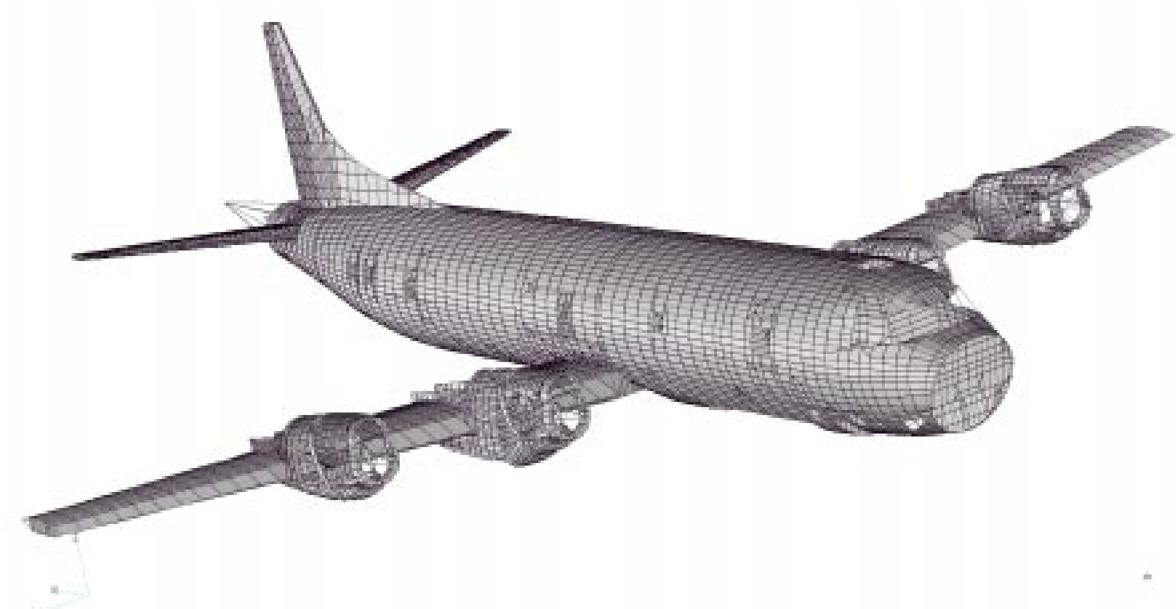

Figure 2: Loads Model of the P-3C (MSC/NASTRAN)

Problem Definition

The requirement for fatigue analysis means that if the detailed stresses for fatigue conditions are to be computed directly, all spectrum building block load cases need to be run. For the C-2A(R) this amounts to a very large number of load cases: The table below describes the spectrum building block loading conditions. Each of these conditions is further broken down into symmetrical and anti-symmetrical conditions and divided between positive bending and negative bending models. The total number of individual load cases comes to 709.

Table 1: Breakdown of C-2A(R) Loading Conditions

Type of Loading	Number of Loading Conditions
Landing Approach	3
Rolling Pullout (RPO)	90
Symmetric Flight	2
Lateral Gust	1
RPO (Cargo Ramp Open)	36
Symmetric Flight (Cargo Ramp Open)	2
CV Landing	47
Field Carrier Landing Practice (FCLP) Landing	46
CVQ Landing	48
Catapult Increments	21
Pressurization	1
Arresting Conditions	4
Ground Relaxation	2
Reversed Conditions	15
Unit Loads	21

Analysis

The boundary conditions for a detailed stress model may be applied either as enforced displacements (see reference 2 for example), or as a set of forces. Each method has advantages and disadvantages:

The enforced displacement method is straightforward and easy to automate and easy to apply. Constraint of the model is automatic and the users need only concern themselves with the applied external forces, which must be added separately. Because nodal displacements are very small, double-width fields are required to maintain accuracy.

The force method uses the force contributions at the boundary nodes from whatever source, be they externally applied forces or forces from adjacent elements, to create a boundary force. The method is more complex than the enforced displacement method and requires a much larger volume of reference data. It does however, result in a true free-body representation of the structure being analyzed. This has the potential for giving the analyst a more intuitive physical interpretation of the problem. Since the model has still has to be constrained against rigid body motion, the resulting forces of constraint provide an indirect check on the accuracy of the model's overall stiffness. Finally, so long as the boundary nodes also include any loads-model nodes internal to the detailed model, the resulting forces completely describe both boundary conditions and applied loads. For these reasons the force method was chosen.

The ability of this system to write all the boundary forces for the stress model makes it a "free-body forces constructor."

The system was developed specifically for the C-2A(R) program and the description that follows pertains to the C-2 – specific application. The method may, however, be adapted to any structure by using a suitable database of internal forces.

The underlying model used for this system was the Northrop Grumman developed C-2A(R) airframe loads-model. It was built using the proprietary ASTRAL finite element code. The loading for this model was developed as part of the Service Life Extension Program (SLEP). The SLEP program re-evaluated the operating spectrum and developed a set of loads to define the current and expected future usage of the aircraft.

To develop the internal forces database, we translated the Grumman model into MSC/NASTRAN (figure 3). The model utilized structural symmetry and used two separate configurations to model positive and negative fuselage bending behavior. Another feature of this model was the handling of cargo ramp configurations. The aircraft occasionally is required to fly with the ramp open during such operations as the deployment of Navy SEALs. The configuration of the ramp was controlled through a set of MPC equations that defined the hinges, latches and the so-called "dragon-tooth" snubbers that together attach the ramp to the fuselage. The ramp open and closed configurations could then be controlled by specifying the corresponding MPC set.

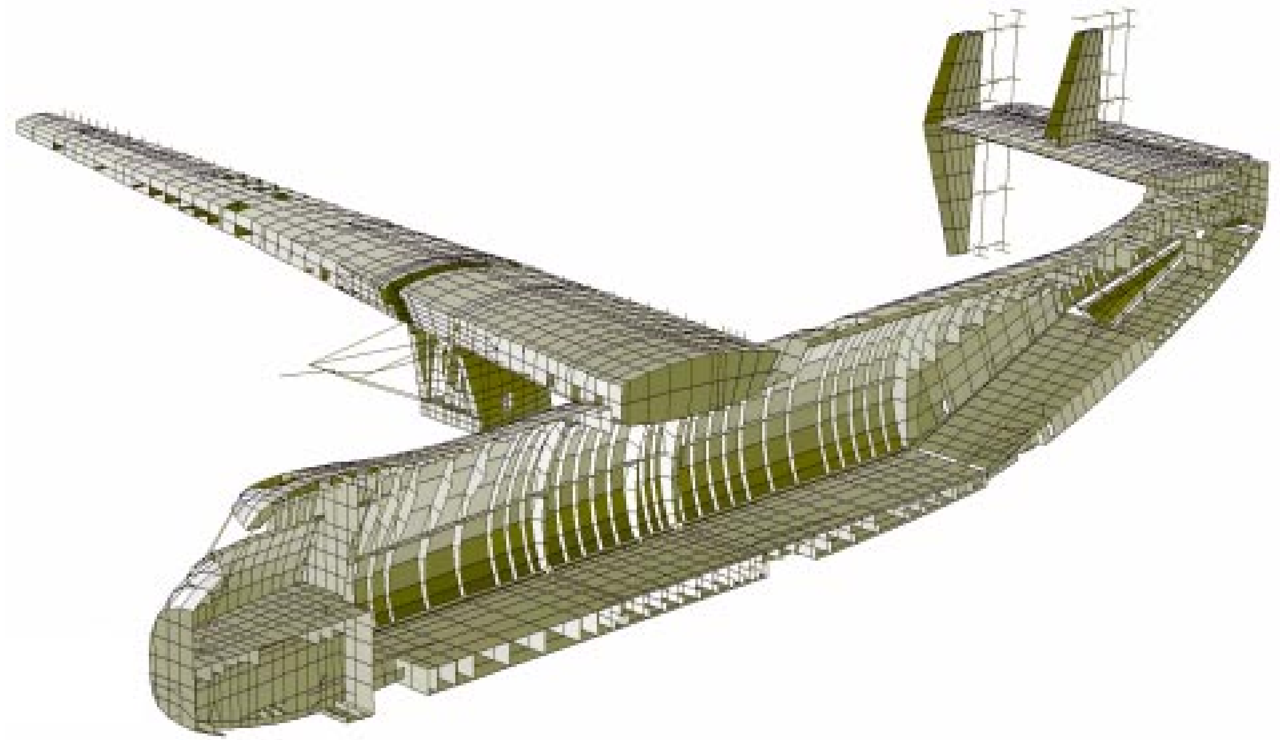

Figure 3: C-2A(R) Loads Model (MSC/NASTRAN)

This model was run on a PC for all load cases using the linear-statics solution in MSC/NASTRAN for Windows V2.1 (reference 3). Grid point forces punch file output was saved. The punch file data was further processed by re-sequencing by grid point vice load case, grouping by location and writing in binary format. This arrangement allowed the entire internal forces data to be stored on a set of six CD-ROMs each representing a separate part of the airframe (table 2).

Table 2: Disk Data

Disk 1	Forward Fuselage
Disk 2	Center Section
Disk 3	Aft Fuselage
Disk 4	Empennage
Disk 5	Wing Center Section
Disk 6	Outer Wing Panel

The Free-Body Forces Application

The extraction of the force data from the CD-ROM database is carried out using a Windows application “Free-Body Forces,” written specifically for this purpose. The program was designed to act as an interface between the user and the internal forces database by automating as many of the free-body force creation functions as possible. It also provides an interface capability with MSC/NASTRAN for Windows through the list file feature.

Defining the Free Body

The user defines the structure for detailed analysis by "cutting" it out from the C-2A(R) MSC/NASTRAN loads-model. This is done at the user's computer running MSC/NASTRAN for Windows. Since both positive and negative bending models use the same node and element IDs, it does not matter which is used for defining the cutout. The Free-Body Forces application will accept the data interactively through its list-boxes or by reading an MSC/NASTRAN for Windows generated list-file. The user identifies the nodes on the boundary of the cutout and all the nodes contained within that boundary. (This allows any external forces applied to these nodes to be included in the data.) Next, the user identifies the elements that will be removed from the cutout. To enter the data manually, the user inputs the data into the list boxes: "Boundary Nodes" and "Remove Bounded Elements." The list boxes provide a clear list to the user of the nodes and elements that have been selected.

Alternatively, the user may choose to use the MSC/NASTRAN for Windows list-file function. After selecting a list-file destination within MSC/NASTRAN for Windows, all subsequent requests to list are written to this file. By listing the nodes and elements of the cutout, the ID of each is written to this file.

The list file can be read directly by the application "Free-Body Forces." It scans the listed entities and adds all the nodes and elements that it finds to the cutout definition.

If the cutout includes elements whose properties are dependent on the bending direction of the fuselage, shown below in red, in figure 4, then "Free-Body Forces" will issue a warning message. Separate detailed models must be built using positive and negative bending properties to reflect the different stiffnesses associated with the effectiveness of the skin. The positive and negative bending models would be run separately with their corresponding load cases.

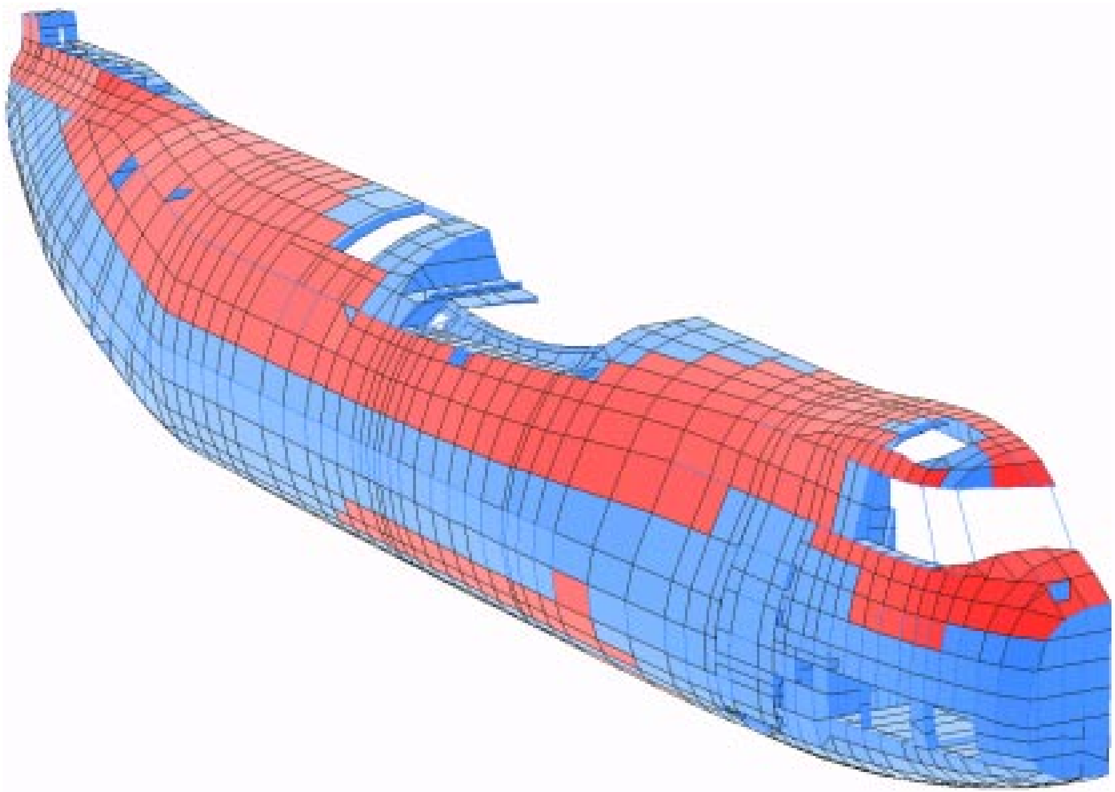

Figure 4: Bending-Shape Dependent Elements

"Free-Body Forces" Output

Free-Body Forces are written in the form of force/moment cards in MSC/NASTRAN format. A provision is made to allow an alternative format to accommodate specific users at the Navy. Destination of these files is specified by the user through a standard "save-file" dialog box. In addition to the load data cards, the application writes a case control deck, listing all of the load cases that were written and a nodes file containing the nodes defining the cutout, that can be used as a "starter" file for the stress model. The node file also contains local coordinate system definitions:

Application Features

- The application employs features that are typical of Windows applications. They include:
- A messages window at the bottom of the application window that lets the user know what the program is doing and prompts the user if there is a problem such as trying to run the program without first defining the cutouts.
- A progress bar that shows the percentage of forces data that has been processed.
- Comprehensive warning and error windows.

Documenting the Work

"Free-Body Forces" writes a report that lists the cutout definition and the filenames chosen for the output. The report may be saved and/or printed:

The report has the format shown below in figure 5:

```
C-2A(R)FEM Free-Body Forces Program
            Generated on 7/22/98
NASTRAN loads data written to file: C:\C-2_FEM\Data\NLG_Web.DAT
NASTRAN nodes data written to file: C:\C-2_FEM\Data\ NLG_Web.NOD
NASTRAN case control data written to file: C:\C-2_FEM\Data\ NLG_Web.CAS
The following nodes define the cutout:
210055
210073
210075
210163
260157
The following elements are removed from the cutout:
2100095
2100161
2106126
2106235
2108054
2601161
2602158
```

Figure 5: Sample report

The following figures (6 through 11) illustrate the use of the application in a typical sequence.

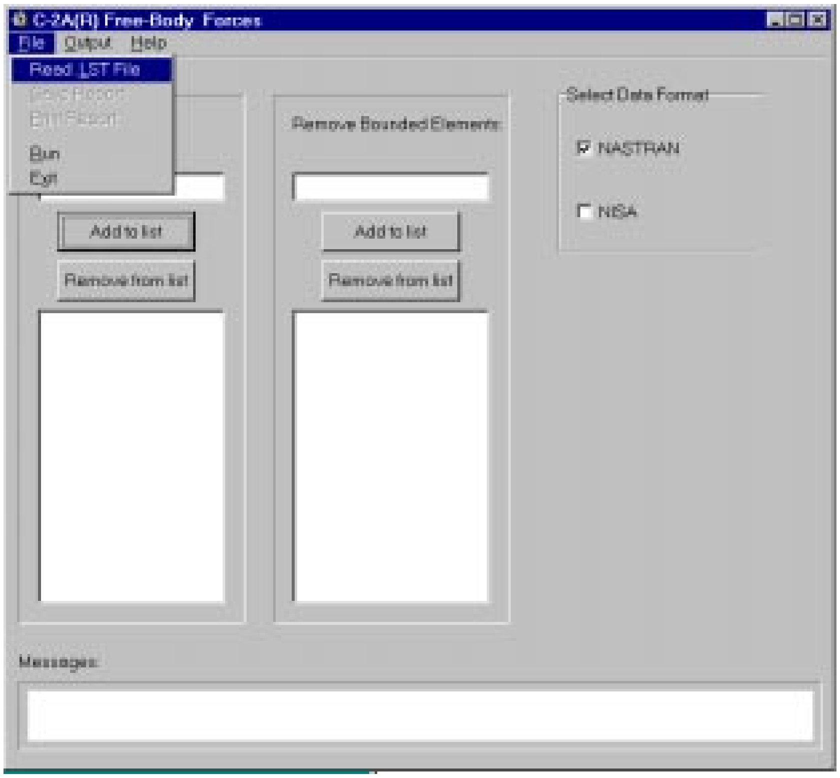

Figure 6:Input Using MSC/NASTRAN for Windows List File

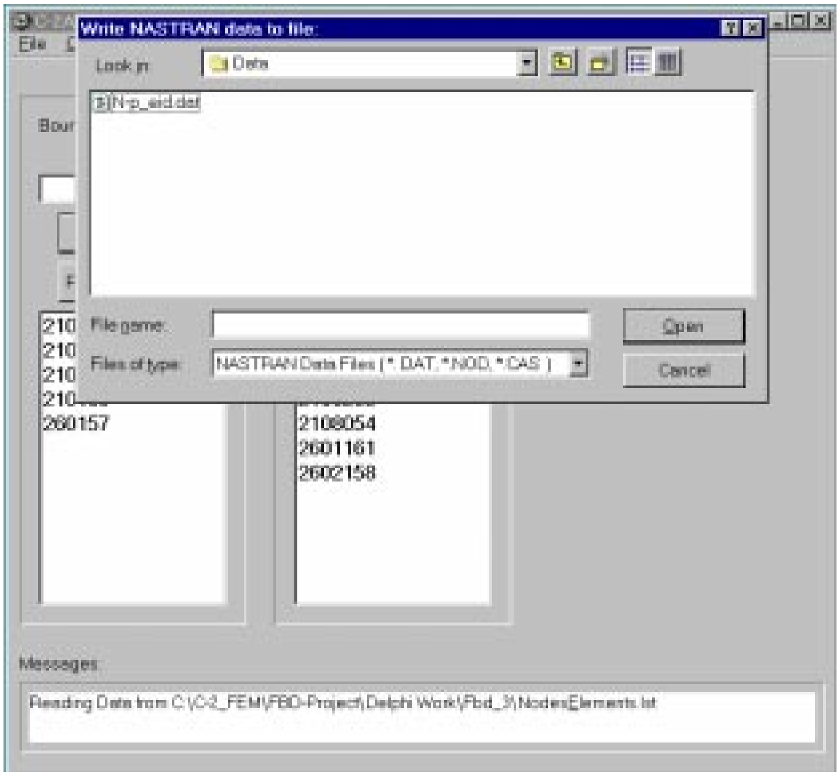

Figure 7: Selecting Output Destination

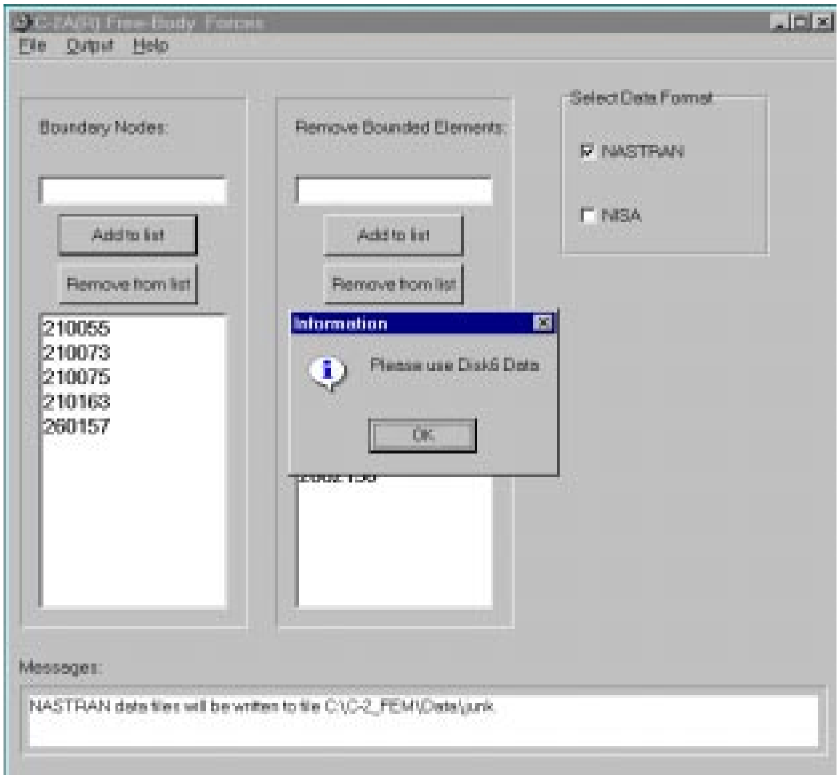

Figure 8:Automatic Prompt for Correct Data Disk

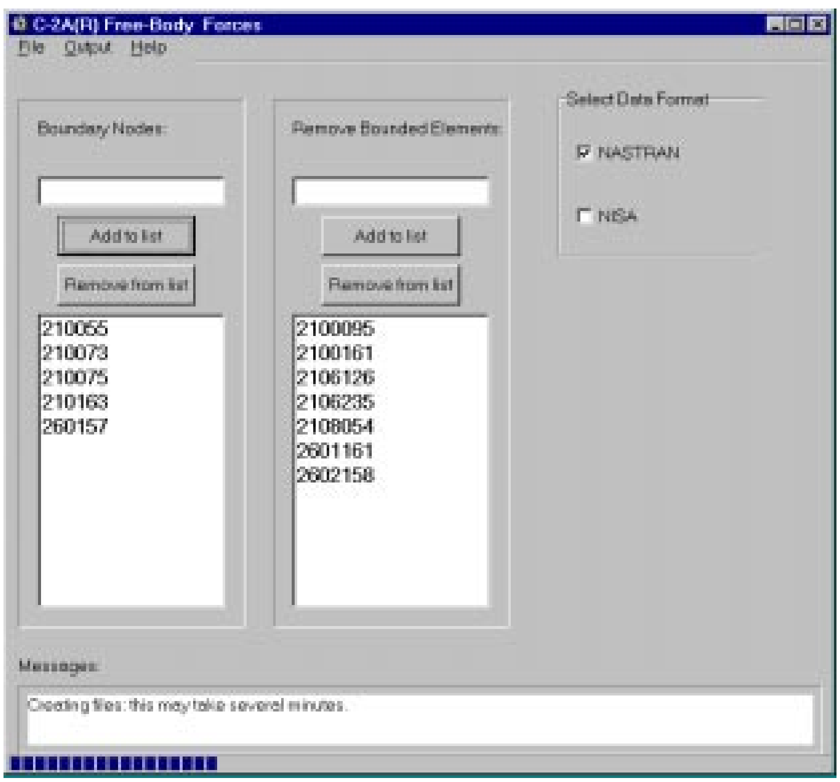

Figure 9:Progress Bar Feature

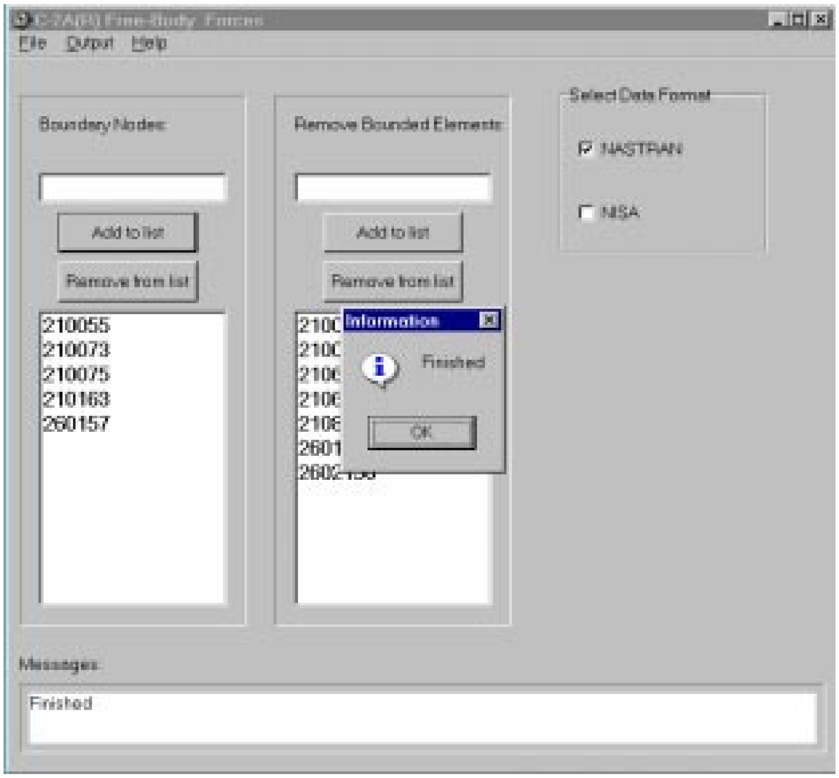

Figure 10:Typical Information Window Feature

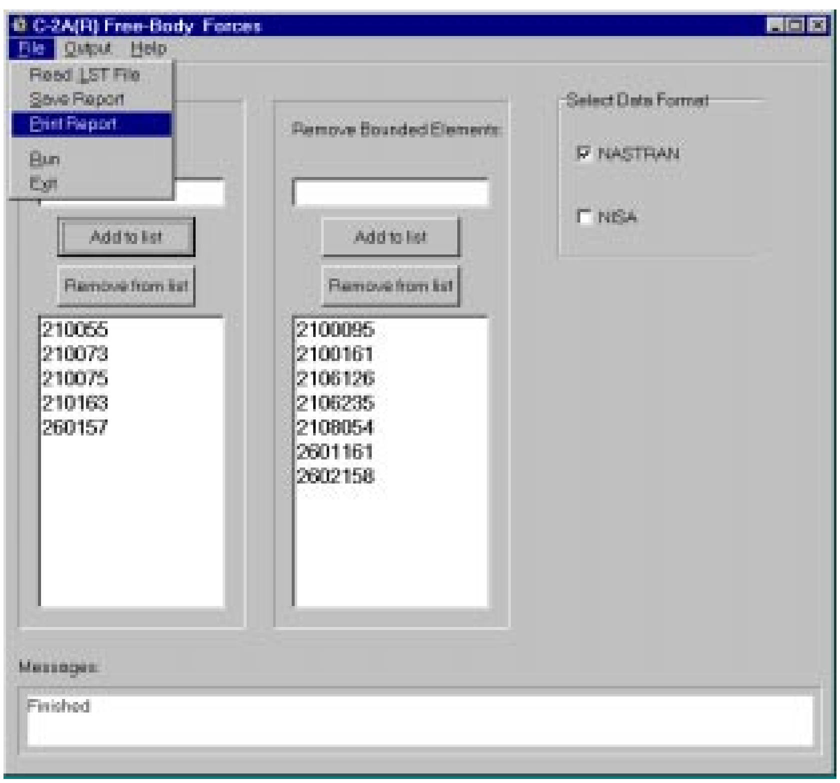

Figure 11:Reporting Feature

Illustration

In this example, we analyze the stresses in the nose-landing gear web around a newly created unreinforced access hole. Figure 12, below, shows a part of the loads-model and the area of interest is highlighted. The cutout in this case is kept to a minimum, consisting of a single shear panel.

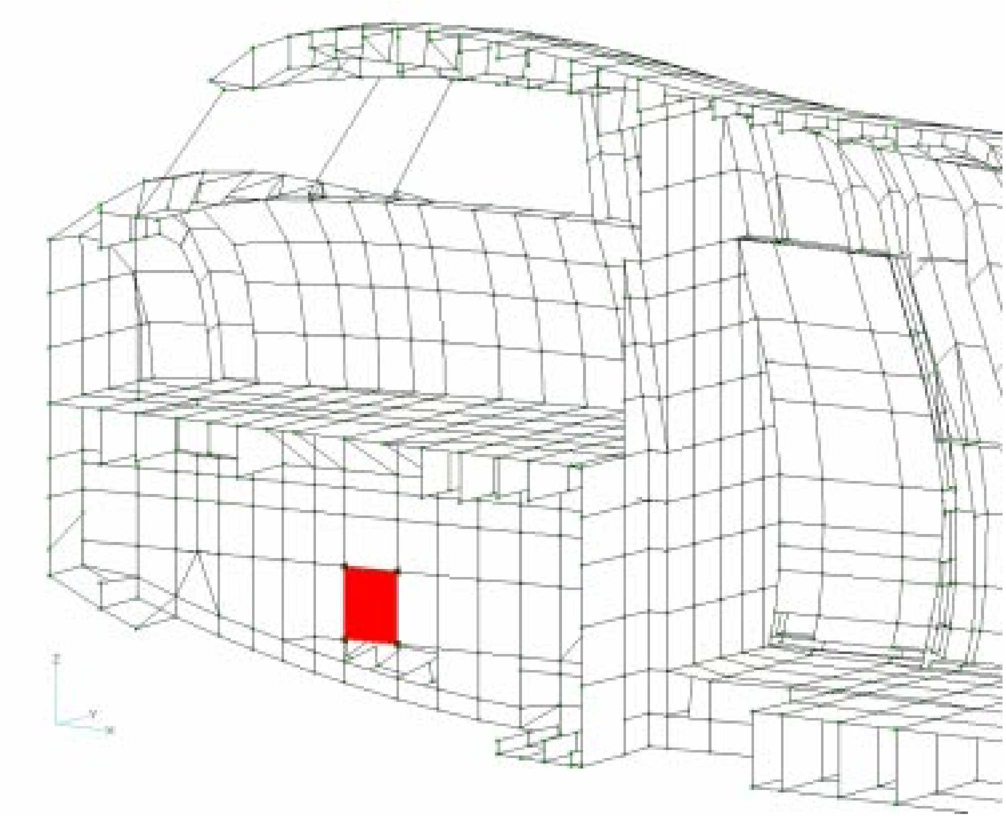

Figure 12: Selecting the Location of the Detailed Stress Model

In figure 13 we see the detailed stress model with the access hole, for one of the load cases.

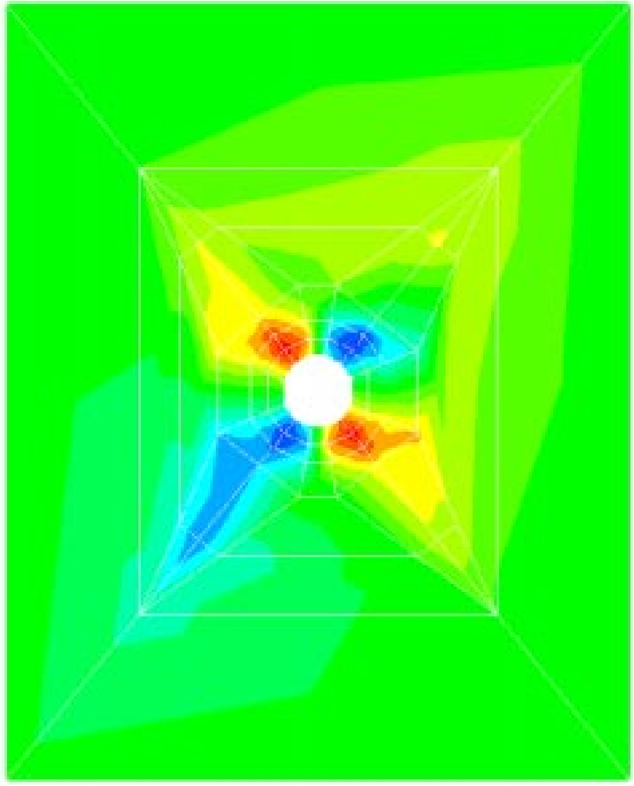

Figure 13: Average Mean Stress Distribution Around the Access Hole.

Conclusions

The work described in this paper addressed the need of the Navy's aircraft structural analysts to have a tool that enables them to quickly extract loading data from a large scale airframe loads model and apply them to a detailed stress model in a Windows PC environment. The application was designed to work with MSC/NASTRAN for Windows and complement the ease of use that that application provides. The subsequent success of the application "Free-Body Forces" has prompted the Navy to begin expanding this method to other aircraft including the F-14 and the E-2C.

References

(1) A-3 Specification, SD-501-1-1B.

(2) Klaus Otto Schwarzmeier, "Global-to_local analysis without using superelements," Proceedings, 1998 MSC Americas Users' Conference, October 1998

(3) MSC/NASTRAN for Windows vs2.1, The MacNeal-Schwendler Corporation, Loas Angeles, CA