

# COMPUTER AIDED MODELING AND POST PROCESSING

## WITH NASTRAN ANALYSIS

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### SUMMARY

Computer aided engineering systems have become invaluable tools in performing NASTRAN finite element analysis at Gates Learjet. These techniques have been implemented in both the pre-processing and post-processing phases of the NASTRAN analysis. The finite element model development, or pre-processing phase, has been automated with a computer aided modeling program called Supertab, and the review and interpretation of the results of the NASTRAN analysis, or post-processing phase, has been automated with a computer aided plotting program called Output Display. An intermediate program, Nasplot, which was developed in-house, has also helped to cut down on the model checkout time and reduce errors in the model. An interface has been established between the finite element computer aided engineering (CAE) system and the Learjet computer aided design (CAD) system whereby data can be transferred back and forth between the two. These systems have significantly improved productivity and the ability to perform NASTRAN analysis in response to product development requests.

### INTRODUCTION

When finite element analysis programs first began to be widely used in the late 1960's and early 1970's, there were generally many limitations on the size of the problem that could be run on many computers available in those days. Even some of the early virtual memory computers could be easily overwhelmed by the size of many finite element problems. Consequently, the effort required to obtain a single satisfactory run frequently involved a good deal of skill and persistence, and often times the process of obtaining a completed analysis became a real struggle. Thus, when the finite element solution was finally obtained, there normally was a good deal of satisfaction in terms of having an internal loads and stress distribution definition which was not available previously with this amount of accuracy and detail. However, as the years went by, larger and faster computers became available, and the turn-around time for finite element jobs decreased significantly. These new machines with expanded memories and the associated peripheral devices such as the disk drives had improved to the point where a large portion of the analyst's time was no longer spent solving system problems and trying to schedule enough computer resources to obtain a satisfactory run. As the improvements in computer hardware precipitated faster turn-around for finite element jobs, the demand for finite element analysis expanded to a wider range of projects and proposed structural configurations. Information was requested not only about the structural characteristics of a particular installation, but also about the trade-offs between various alternatives and modifications. This demand for more information put a stronger emphasis on compressing the input/output phases of finite element analysis. The input data for the finite element analysis needed to be prepared faster, and the results from the analysis then needed to be interpreted quickly to obtain a description of the configuration's structural characteristics. If the initial analysis generated questions that needed answers from

additional computer runs, then the process needed to be repeated quickly and efficiently to obtain the necessary data. As a result of these types of demands, an investigation was initiated at Learjet to find the tools and/or methods that would permit a more efficient generation and management of the finite element data base and allow the structures analyst to respond to requests faster.

## BACKGROUND

One of the first alternatives explored to improve the productivity of the finite element input/output process at Learjet was a system of batch programs to generate NASTRAN bulk data and a max./min. search routine to identify highly stressed areas in the structure from the NASTRAN output. Automated data input batch programs were written to generate NASTRAN grid point, connectivity and property cards. These programs were used to create a large amount of data for many models over a period of about four or five years, but there were obvious areas for productivity improvements even in these routines. However, the development of interactive computer graphics hardware and software during the 1970's was a technology that appeared to offer many more significant advantages for further improvements in finite element input/output productivity than enhancement of existing batch programs. Consequently, Learjet began to emphasize interactive techniques for data base management as opposed to batch job techniques. The initial thrust into computer graphics began in 1975 with the development of an in-house program for NASTRAN model checkout. In 1977 consideration was given to expanding this routine to a complete computer aided modeling program, but at that time the resources and manpower were not available within the company to proceed with a project of this size. A search outside the company was then initiated that same year for an interactive graphics package for finite element modeling and post processing.

## SYSTEM EVALUATION AND SELECTION

Two different approaches were evaluated as possible solutions to improving productivity in the input and output phases of NASTRAN analysis using interactive computer graphics. The first alternative was to access a computer aided modeling and post processing program on a service bureau computer using a telephone line connected to a graphics terminal at Learjet's engineering facility. The second alternative was to license or lease the software, and install this program on an in-house computer. Discussions were held with many service bureaus, software vendors and hardware manufacturers over a two year period. The main objective of this investigation was to find the right combination of hardware and software that would meet Learjet's analytical requirements and provide a significantly improved level of productivity. Some of the guidelines used in this selection process were as follows:

- Interface with NASTRAN
- Three dimensional geometry
- Mesh a cubic or higher order surface
- Control over node and element numbering
- Label integer size of at least 10,000,000
- Operation on a variety of computers
- Operation on a variety of terminals
- Maintenance and enhancement support
- Transmission and display rate of at least 9600 baud

Each graphics program and supporting hardware system evaluated usually had one or more unique characteristic. Some of these features were beneficial to improved productivity and flexibility while others were restrictive and limited the application of that particular system. After evaluating several computer aided systems, one major fact became obvious about all of these packages, and that fact was the relative infancy of this technology. The potential of computer graphics was immense compared to the capabilities that were reviewed during the evaluation period. Consequently, for a short period of time the best approach appeared to be to wait for these computer aided systems to mature. However, the initial results of the evaluation also indicated that the productivity advantages were available with many of the existing systems at that time, and many of these systems had a dedicated maintenance and enhancement staff that was incorporating corrections and improvements to the code regularly. Another important consideration was that a delay at this time in adopting this technology may have more severe consequences in the future when there may be more difficult problems to overcome. So the search continued for an interactive computer aided modeling and post processing system.

Another important fact evolved from this investigation, and this fact was that productivity appeared to be generally influenced by three major factors. These factors were the computer's capability in terms of size and speed, the magnification of human effort through the unique features in the software, and the speed at which a picture could be displayed on the graphics terminal screen. There may be some subdivisions of these categories, but these items were considered to be the main factors that most influenced computer graphic's productivity by Learjet. Since the modeling and post processing were to be basically interactive functions, a computer system was needed that could best provide quick responses to interactive commands. This meant that the computer could not be loaded with users and/or batch jobs to the point where response times became unacceptable. The interactive method of central processor unit (CPU) utilization was evolving, and this concept was very much incompatible with the existing philosophy of loading the CPU with as many time share jobs as possible to lower the unit costs. Some hardware manufacturers offered a solution to this problem by providing small low cost computers which could be located in the individual work areas. The interactive work was performed on the small work station, and then, if these data needed to be run on a large batch processor, the job could be transferred to a large machine for the analysis work. This type of system generally provided a very fast terminal display rate which some of the other systems could not always match. If several of these work stations were connected to the large computer and possibly even to one another, this system was referred to as distributed computing.

One arrangement which was found to have a very difficult time achieving high transmission rates was operation with a terminal connected to a computer located many miles from the user site. Sometimes these computers were extremely fast and had a great deal of memory and disk space, but the top speed over long distance telephone lines using modems generally restricted response times at the terminal. Eventually, technological improvements in modems and long distance communications may overcome this problem, but with the existing systems higher productivity has been restricted by the speed of data transmission. Consequently, Learjet concentrated on evaluating systems that could be installed on in-house computers and could achieve transmission and display rates of at least 9600 baud. This rate was established after working with other interactive systems and discovering that speeds lower than this value many times resulted in the user waiting unneces-

sarily for the system to return to a ready state.

Learjet was also seeking a program that could work easily with geometry defined by cubic or higher order equations. Many of the surfaces in aircraft structures have been defined by aerodynamic computer programs, wind tunnel testing or a combination of the two. Surface contours frequently are generated using spline fitting routines which define a higher order curve or equation using a series of points. A computer aided modeling program needed to have a great deal of flexibility in meshing complex surfaces and offer a large amount of user control over the grid point and element generation. Large amounts of data needed to be handled by the system without becoming unnecessarily awkward or being limited by system size restrictions.

Discussions along these lines were initiated with Structural Dynamics Research Corporation (SDRC) in the fall of 1978 in regard to the Supertab computer aided modeling program. This program seemed to fill many of Learjet's requirements, and an in-house evaluation of this program was negotiated in the first quarter of 1979 with a ninety day evaluation to be conducted in the second quarter of that year. The software was installed on a Digital Equipment Corporation (DEC) PDP 11/70 during the evaluation period basically due to the availability and easy access to this machine. A small storage tube graphics terminal was attached to the computer using a 9600 baud transmission line.

Many different problems were exercised with this system to determine the capabilities and limitations of the Supertab program. All of the trial cases tested on the system yielded results which generally met Learjet's requirements and expectations for a computer aided modeling program. Shortly after the completion of this ninety day in-house evaluation, Supertab was selected as the computer aided modeling program to be used by Learjet for NASTRAN finite element model generation, and negotiations were initiated with SDRC for the acquisition of this software.

#### HARDWARE ACQUISITION

One of the reasons that Supertab was selected for Learjet's computer aided modeling tasks was due to the support provided for several different computers and a wide range of terminal configurations. Since Learjet's analytical needs could be expected to change in future years, the company wanted a system that had the product support that would contend with these changes. Also hardware manufacturers frequently bring out new products with enhanced capability that make older equipment obsolete, and software maintenance was necessary to keep pace with the evolution of these new systems.

Although the in-house evaluation of Supertab was performed on a 16 bit PDP 11/70 mini computer, a larger 32 bit computer was planned for the permanent installation site. The 32 bit machine was decided upon over the 16 bit machine due to the limitation of the single precision integer size, or in other words, the grid point label and element label size on the small computer. An in-house IBM 370-158 was originally designated to be the host computer for this software, but this designation was changed when a VAX 11/780 was chosen as the system to replace the PDP 11/70.

During the ninety day evaluation of Supertab, limitations of the small storage type terminal became obvious. The most notable of these restrictions were the

small screen size and lack of hard copy and digitizing capability. If the full potential of this new system were to be realized, a terminal was needed with a larger screen and enhanced graphics capability. This terminal also needed to have a large bus for adding desired options to the system, such as, a hard copy unit and digitizer tablet. Consequently, a review of terminals available on the open market was conducted to determine what units would satisfy the company's requirements. During this review period which was basically most of 1979, there were no satisfactory refresh graphics terminals available, and effort was concentrated on finding a storage type cathode ray tube (CRT) terminal that would perform the desired functions and access various devices. Consequently, the selection process narrowed down to Tektronix equipment such as the 4014 and a new terminal called the MEG 121. The MEG 121 was very similar to the 4014, but many features that were optional on the 4014 were standard on the MEG 121. Also, the MEG 121 could be upgraded to a distributed system with the addition of a mini computer. Thus, the Tektronix MEG 121 was selected as the terminal device for access to Supertab, and the unit was installed in the first quarter of 1980. The lead time for the VAX 11/780 installation was somewhat longer than that for the MEG 121, and the installation of this machine was not scheduled until the second quarter of 1981.

### SOFTWARE ACQUISITION AND DEVELOPMENT

Since there was a time frame of over a year between the installation of the MEG 121 graphics terminal and the VAX 11/780 computer, other alternatives were considered as temporary solutions to utilizing Supertab until the new computer installation could be completed and the engineering department was moved into a larger building. The most viable alternative appeared to be installation of Supertab on the PDP 11/70 mini computer until the VAX became available. This option would limit the size of model that could be generated on that system, and consequently restrict the projects which could benefit from this software, but the training and familiarization process could be completed and work could begin on some limited projects.

Arrangements were made for the installation and on-site training, and Supertab was installed on Learjet's PDP 11/70 mini computer. On-site training was accomplished using class room lectures supported by demonstrations on the MEG 121 terminal. Familiarization with Supertab then continued for the next several weeks on an individual basis, and shortly thereafter work started on the first project using Supertab for the computer aided modeling of a structure to be analyzed with NASTRAN.

The VAX 11/780 was installed on schedule and was operational within a few weeks. The engineering department moved into the larger building that same month, and the Supertab data base was transferred from the PDP 11/70 to the VAX 11/780. The move and data base conversion occurred in the period of just a few days, and within a week finite element modeling had resumed on the VAX 11/780 with only minor problems having to be overcome.

Shortly after the completion of the Supertab evaluation on the Learjet PDP 11/70 mini computer, SDRC announced a new computer aided post processing program for finite element analysis called Output Display. This program would use the results from a finite element analysis, such as displacements and stresses, and plot these data using the finite element model as the basis for the display. Displacements were added to nodal coordinates of the finite element model to

provide a deflected shape for a static analysis or a mode shape for a vibration or dynamic analysis. Stresses were plotted in contour form on the surface of a group of membrane or plate elements to provide a stress contour distribution on any desired structural surface. These stress contour plots could be created for both static analysis as well as dynamic analysis.

Since NASTRAN runs were being made more frequently and many models were becoming larger with more voluminous outputs, Learjet was very much interested in an efficient method for reviewing the results of a NASTRAN analysis and effectively managing the resulting data base. Output Display appeared to provide a solution to this problem. This program was directly compatible with Supertab and was integrated into the same program menu structure. Routines in the Supertab and Output Display program structures were modularized so that the user could actually transfer from one program to the other without leaving the main command stream.

The data interface between a finite element program and Output Display was accomplished through a conversion routine called the Data Loader. This program took finite element results that had been written to a disk file and converted these data to a universal file which was suitable for input to the Output Display program. Since there were several finite element programs supported by SDRC on a wide range of computers, SDRC was involved in writing a Data Loader program for each machine that was supported by a given finite element package. Some finite element programs had completed Data Loader routines available, but the Data Loader routine for Cosmic NASTRAN had not yet been written, and the status of this project was in a state of flux. After discussing this situation with SDRC, an agreement was reached where Learjet was designated as a development site for the Cosmic NASTRAN Data Loader project. SDRC provided Learjet with a copy of the Output Display program and a copy of the Data Loader source code for a similar finite element routine. Learjet agreed to acquire the Output Display program if a satisfactory Data Loader Interface could be developed between Cosmic NASTRAN and Output Display, and the Output Display program met Learjet's graphics requirements.

Development of a Data Loader for Cosmic NASTRAN began on a time available basis. There were quite a few major projects in work at that time and only a limited amount of manpower available. The Data Loader for Cosmic NASTRAN was to be developed by extensively modifying the template type Data Loader routine furnished by SDRC. A portion of this work was done in conjunction with the Bendix Corporation which was also working on the development of interfaces between SDRC programs and Cosmic NASTRAN. All the modifications and checkout was completed within a few months. The Output Display program performed up to expectations, and this module was then added to the computer aided engineering system with Supertab. A more detail discussion of the activities involved in this project has been described in the next section of this paper.

## IMPLEMENTATION

Once the modeling has been completed, Supertab offered a great deal of flexibility in the way a finite element model can be transformed from the Supertab data base to the NASTRAN or finite element data base. The analyst can output the model using a table format, or the transformation can be accomplished with the Data Formatter module which permits output using a Fortran format. This user oriented approach allows the operator to establish mnemonics, field locations, field sizes, labels, integer values, real values or floating point values for the finite element data. Other features include grid point sequencing on the

connectivity card, batch job control card input, executive and case control card input, loads data input, property card and material card input and constraint card image generation. This routine is adaptable to the point where almost any finite element deck format could be generated using this approach. Output from Supertab through the Data Formatter module is defined by a command file which specifies the grid point connectivity card image format as well as other data that can be copied into the finite element file. If all the parameters and data have been defined by the Data Formatter for the NASTRAN executive control deck, case control deck, and bulk data deck, this file as output from the Data Formatter could be submitted directly for a NASTRAN batch job execution.

At Learjet a NASTRAN file generated by the Data Formatter module has generally not been submitted to the batch computer immediately after the transformation from Supertab. Since there is a possibility for error in the user written command file, a thorough check has normally been performed before going further with the new NASTRAN file. A major portion of this cross check has been accomplished using the NASPLOT graphics program which has been developed by Learjet over the years to support NASTRAN analysis. NASPLOT does not have as many of the sophisticated modules that Supertab utilizes, but this program can provide a very good check on grid point locations and element connectivity by plotting the NASTRAN bulk data deck. This program has currently been made operational on the VAX 11/780 computer and has been able to handle bulk data decks of Learjet's largest models without any major problems.

NASPLOT has a full NASTRAN library of elements and can also handle multiple, stacked local coordinate systems. NASTRAN files can be plotted interactively on the Tektronix MEG 121 terminal and hard copy plots can be obtained by using a screen image plotter (see Figure 1) or by spooling the plot files to a Versatec plotter. This program utilizes the refresh buffer on the MEG 121 for menu selection much as does Supertab. The master menu and sub menus can be scanned and parameters selected without erasing or having to repaint the screen. Large NASTRAN files can be plotted easily by identifying groups with a limited number of elements, and these groups can then be constrained to produce even smaller groups so local areas can be viewed more clearly (see Figure 2). If too many elements were eliminated in the constrained group, other elements can be added to the group to expand the viewing range. This type of approach allows the user to view a very complex model without having detail areas obscured by large numbers of adjacent grid points and elements. Also, the analyst does not have to divide the model into smaller substructures to fit the plot routine size restrictions and then be required to reassemble the model, if changes have been made in the substructure. If the changes are not complex or extensive, the modifications can be made directly in the NASTRAN bulk data deck using the VAX edit routine, and verification of the changes can be accomplished with the NASPLOT routine. The NASPLOT program does not have the extensive computer aided model generation capabilities of Supertab, but this package has served as a valuable checkout tool for NASTRAN bulk data decks before a file has been submitted for batch computing.

Another program developed at Learjet to provide an interface between existing NASTRAN bulk data decks and Supertab was a program called NASUPER. This routine was written basically to convert an existing NASTRAN bulk data deck to a Supertab universal file. Input to NASUPER consisted of a NASTRAN bulk data deck, and the output from NASUPER was a Supertab universal file which included coordinate system data, grid point data, and element connectivity data. The universal file generated by NASUPER could then be loaded into a Supertab permanent data base

where extensive modifications or additions could be incorporated in the model. Upon completing the changes to the existing model with the aid of Supertab, these data could then be transformed to a NASTRAN file again using the Data Formatter routine or the table output module. If there was a significant amount of the model unchanged from the original configuration, this portion of the model remaining in the Supertab data base could be recovered from the original bulk data deck with all the associated property cards, material cards, forces and constraints. This can be accomplished through another module in the NASUPER system where the modified NASTRAN model output from Supertab was compared to the original bulk data deck. Those original members remaining after the Supertab modification were sorted into the new file which contains all the data cards for a NASTRAN analysis with the exception of the property and material cards for any newly added or modified structural members.

When Learjet acquired the Supertab package, the Output Display program which plots finite element displacements and stresses had only been available for a short time, and a Data Loader interface had not yet been developed for Cosmic NASTRAN. As indicated in the previous section of this paper an agreement was reached on the development of a Data Loader where SDRC would provide Learjet with a Data Loader package for a similar finite element code and Learjet would modify and enhance the program so that Output Display would accept Cosmic NASTRAN data.

The first task in this project was to generate the model displacement and stress data using the OUTPUT2 unit in NASTRAN. A set of DMAP alter cards were inserted into the executive control deck of a NASTRAN test deck, but after several attempts there were no data coming through this port for any of the runs. A telephone call was made to Cosmic describing this problem. The support personnel at Cosmic indicated that some updates had not been implemented in the OUTPUT2 module, and this caused the unit not to pass data. Cosmic promptly indicated the necessary corrections to the OUTPUT2 module and offered to provide any additional assistance necessary. These changes were made in the Learjet source code, and the modified routine was compiled and linked into the NASTRAN executable code on Learjet's IBM 3033. The test NASTRAN model was resubmitted with the same DMAP alter cards (see Figure 3), and data began to flow from the OUTPUT2 port. This problem occurred in NASTRAN level 17.7 and the later releases now have corrected this problem.

Initial data extracted from the OUTPUT2 module in NASTRAN was from a solution 1.0 statics analysis. The prototype Data Loader was modified and enhanced using these data as an initial checkout tool, and then data from a dynamics analysis solution 3.0 was used to facilitate a vibration analysis checkout. The prototype Data Loader had an element library which recognized some basic finite element members, but this library had to be modified and expanded to accept elements from Cosmic NASTRAN. This conversion was the second task of the Data Loader project. The conversion was accomplished by adding the new elements to the element table and also adding a subroutine for each new element to write the NASTRAN data to a universal file. The third task in this project was to modify the Data Loader to read and identify data from the OUTPUT2 file, and this part of the development took the most time. Source code in the Data Loader had to be modified and/or have lines added to read the NASTRAN data in the proper format, identify the type of data, and convert these data properly for input into Output Display.

Since the DMAP alters had already specified the sequence in which the data was to be output from NASTRAN, this arrangement of data in the OUTPUT2 file



helped to organize the direction of the modification of the Data Loader into related modules and subroutines within the main program. The first series of modules converted were related to the grid point and element definition in the base model. The second series of subroutines modified were related to displacements, and the third series of modules were related to the stress data. Once these corrections and enhancements had been incorporated, the checkout of test problems proceeded with very little difficulty. Eventually larger problems were tested using the Output Display program, and the dimensions on the data loader had to be increased, but no other changes than these have been incorporated, since completion of the original modification and enhancement effort. Once the checkout was completed for static analysis problems, a dynamics analysis was performed on a test model using the FEER (see Ref. 1) method in NASTRAN. Data from NASTRAN was run through the Data Loader without any problems, and mode shapes and stress contours for each mode were plotted quickly with Output Display. Since the completion of the Data Loader modification, this program has been used successfully with the updated and enhanced releases of both NASTRAN and Output Display without any problems.

### CAD SYSTEM INTERFACE

Geometry definition for a NASTRAN model prior to the acquisition of Supertab was accomplished generally by manually measuring loft drawings. These data were then either key punched on to NASTRAN grid cards, or a small Fortran computer program was written to generate intermediate points between two cross sections using linear interpolation. With Supertab, input of geometry data has been very flexible and could be accomplished using one of several methods. Data could be input directly from the keyboard into the Supertab data base, or several key geometry points could be entered and other points could be generated by interpolating between the established points. If there were areas of uniformity or symmetry in the structure, grid points could be generated using copy or reflection techniques. Supertab also has the capability to accept data from a small or large digitizer tablet. Learjet installed a large digitizer tablet with the MEG 121 terminal, and data from existing drawings has been entered into the Supertab data base for some of the preliminary and conceptual NASTRAN models.

About the same time that the Supertab CAE system was installed for finite element analysis at Learjet, a computer aided design (CAD) system was also being acquired in Learjet's design department. This CAD system was the Unigraphics software package which operates on a Digital PDP 11/70 mini computer. Unigraphics was developed by McDonnell Douglas Automation Company, a division of McDonnell Douglas Corporation, commonly called McAuto. The number of trained users on this system and the number of drawings in the data base has grown significantly in recent years. The drawings in this system have generally been more accurate and required fewer manhours to produce than previous drawings. The CAD data base has grown to the extent that several NASTRAN finite element models have been generated by transferring CAD geometry to the Supertab system. Access to this type of information has further compressed the time required to develop finite element models, and in some situations has permitted the generation of a NASTRAN model that would have been impractical or very time consuming using manual techniques.

Development of a Supertab/Unigraphics interface has evolved over a period of months and years, since these systems first began operation. Many discussions have been held with the Unigraphic's users as to the best methods of transferring

data between these two units, and meetings have been continuing in an attempt to improve existing techniques. The method of data transfer currently in use at this time involves a Unigraphics support program called GRIP. The GRIP system allows Unigraphic's users to write small routines or command files which transform the CAD data into any format desired by the user. These data have then been transferred to the VAX 11/780 where the files can be copied into a Supertab data base. Since the file format can be defined in the GRIP routine, geometry data has normally been written as NASTRAN grid points and local coordinate systems have been defined in CORD2C, CORD2R, or CORD2S (Ref. 1) formats. The use of this type of format saves a significant amount of time in the model generation using Supertab. This approach allows the user to skip the geometry definition routine which basically creates points, lines, arcs, curves, and surfaces.

Other methods have been investigated in transferring data between Unigraphics and Supertab, and in the future one of these alternatives may replace the current method. One technique presently under consideration is the IGES, or Initial Graphics Exchange System, format devised by the National Bureau of Standards. Supertab has the capability to extract geometric data from an IGES file and use these data for finite element model development. However, the details of generating these types of data on the Unigraphics system still have to be worked out. Another alternative being considered for speeding up the transfer of data between the two systems has been to connect the PDP 11/70 and VAX 11/780 computers using the DECNET computer network system developed by Digital Equipment Corporation.

### PROJECT APPLICATIONS

Since Supertab and Output Display were installed at Learjet, many projects have benefitted from the usage of these packages. One of the first projects to use Supertab for finite element model development was a composite spoiler project. This spoiler was fabricated from graphite epoxy, fiberglass, and nomex honeycomb with three aluminum hinges located along the spoiler leading edge. These hinges attached the spoiler to the rear spar of the Learjet wing, and the center hinge also served as the actuator point for raising and lowering the spoiler (see Figure 4). Although at first glance the mesh may appear uniform along the span, the grid point definitions actually conform to the location of several layered doublers at the three fitting locations as well as to the geometry of these aluminum fittings. Layout of this mesh was defined before ever sitting down at the terminal to begin work, and then when modeling did begin using Supertab, the grid point and element generation went quickly with very few areas that required correction.

The grid points and element connectivity were transformed from the Supertab format to NASTRAN bulk data format using the Data Formatter module in Supertab. This transformation consisted of writing a command file which defined the NASTRAN format. Section properties, material properties, loads and constraints were added to this file, and then a NASTRAN analysis was performed by submitting the file as a batch job on Learjet's IBM 3033. After the Output Display module was made accessible by the development of the Cosmic NASTRAN Data Loader routine, a second NASTRAN analysis was performed with the appropriate DMAP alter commands in the executive control deck (see Figure 3) for extracting data from the OUTPUT2 unit in NASTRAN. These data were processed through the Data Loader into a universal file format and input to the Output Display program. An example of a static deformation plot and stress contour plot from this analysis can be seen in Figures 5 and 6, respectively.

Another application of Supertab and Output Display to NASTRAN analysis was the modification of a conventional Learjet tip tank (see Figure 7) to a special missions tip tank configuration. The major difference between the special mission tip tank and the conventional tip tank was the addition of a radar unit in the nose of the new tip tank. This structural change basically involved making the diameter of the forward portion of the tip tank larger and installing a fuel tight bulkhead aft of the new radar unit.

A NASTRAN model of the conventional tip tank was already in existence at the beginning of this project, and one of the major tasks for the finite element analysis was to modify this tip tank to the special mission configuration. The bulk data deck for the conventional tip tank was converted to a Supertab universal file format by processing the data through the NASUPER routine. Once these data were in the Supertab data base, conversion to the new configuration took only a few hours (see Figure 8). The modified tip tank was output from Supertab and incorporated in the NASTRAN wing model replacing the conventional tip tank, and new loads were added to the file to reflect the changed configuration. A NASTRAN analysis was performed on this updated model, and the deflection and stress data were output through the OUTPUT2 unit and transformed by the Data Loader for review with Output Display. Plots of the stress contour data can be seen in Figure 9.

A third application of Supertab to NASTRAN finite element model development was the generation of a composite outboard main landing gear door model. This structure was fabricated using laminated graphite epoxy on the inner and outer surfaces with a nomex honeycomb core. The geometry of this installation was quite complex, since the contours had to reflect the curvature of the wing, the fairing of the door around the tire, and the fairing around the actuator support point on the landing gear trunion. Loft data specifying the contour of the inner and outer surfaces were defined using the Unigraphics computer aided design system. These data were then transferred to the Supertab data base utilizing the GRIP routine discussed earlier.

Layout of the gear door model was defined before any work began at the graphics terminal. Consequently, when the Supertab modeling did commence, the time required to complete the finite element definition was less than a week. Data in the Supertab data base were then transformed to a NASTRAN bulk data deck format using the Data Formatter module. Section properties, material properties, loads and constraints were added to the file along with an appropriate set of batch run JCL. A statics solution 1.0 NASTRAN analysis was performed on these data, and the results were plotted using the Output Display module. The deflection and stress contour plots can be seen in Figures 10 and 11. A vibration analysis was also performed on the door model using NASTRAN solution 3.0 with the FEER method of eigenvalue extraction. A plot of one of these mode shapes has been shown in Figure 12.

#### CONCLUDING REMARKS

Computer aided modeling and post processing has significantly improved the ability to perform NASTRAN finite element analysis at Learjet. These techniques have reduced the time required to prepare NASTRAN models and review and interpret the data from a NASTRAN analysis. This improvement in productivity has permitted a faster response to product development questions and has allowed a wider range of configurations to be investigated during preliminary design exercises. Conse-

quently, the structural characteristics of a given configuration can be identified in more detail sooner than was ever possible using manual methods.

#### REFERENCES

1. The NASTRAN User's Manual (Level 17.5), NASA SP-222(05), Washington, DC, December 1978.

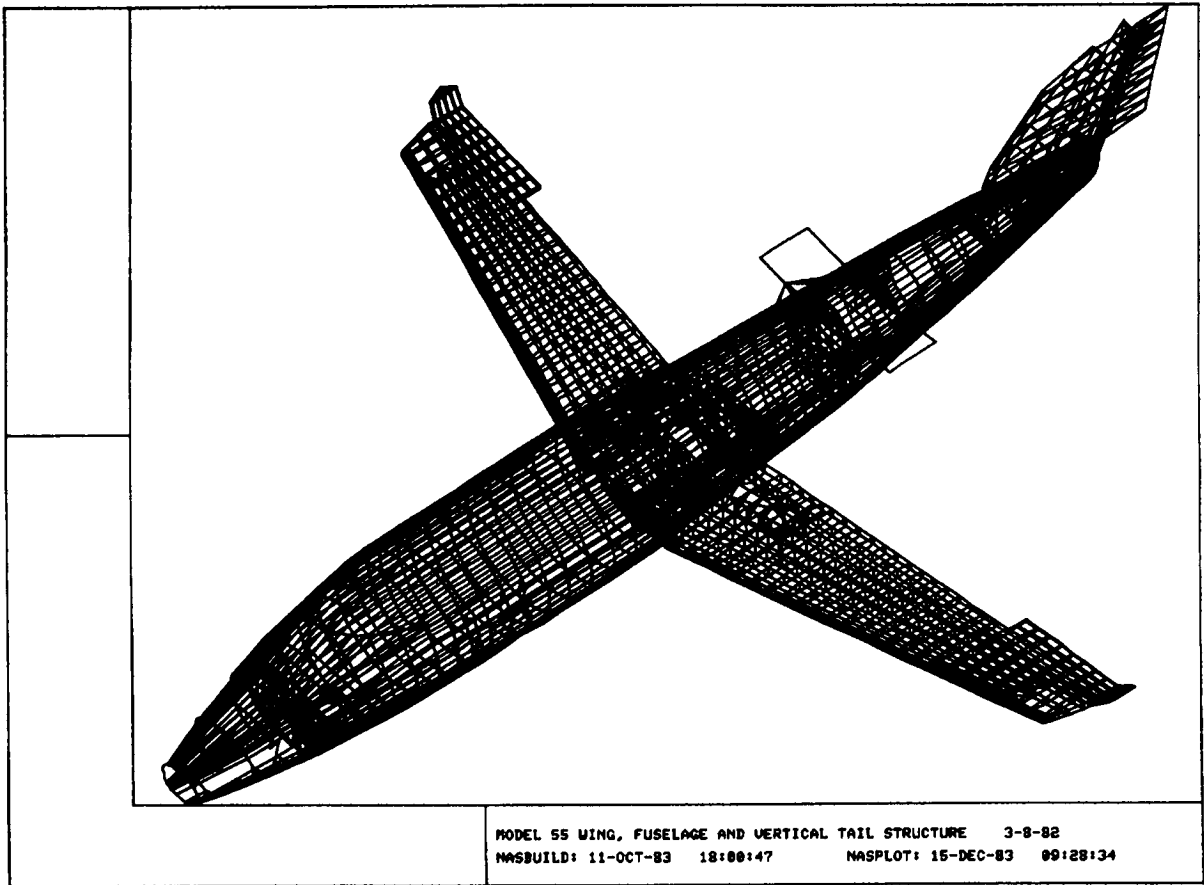


FIGURE 1 - NASPLOT SCREEN IMAGE

MODEL 55 WING, FUSELAGE AND VERTICAL TAIL STRUCTURE 3-8-82  
ALPHA = 45.0 DEG. BETA = 180.0 DEG. GAMMA = -135.0 DEG.  
NASBUILD: 11-OCT-83 18:00:47 NASPLOT: 16-JAN-84 10:59:41

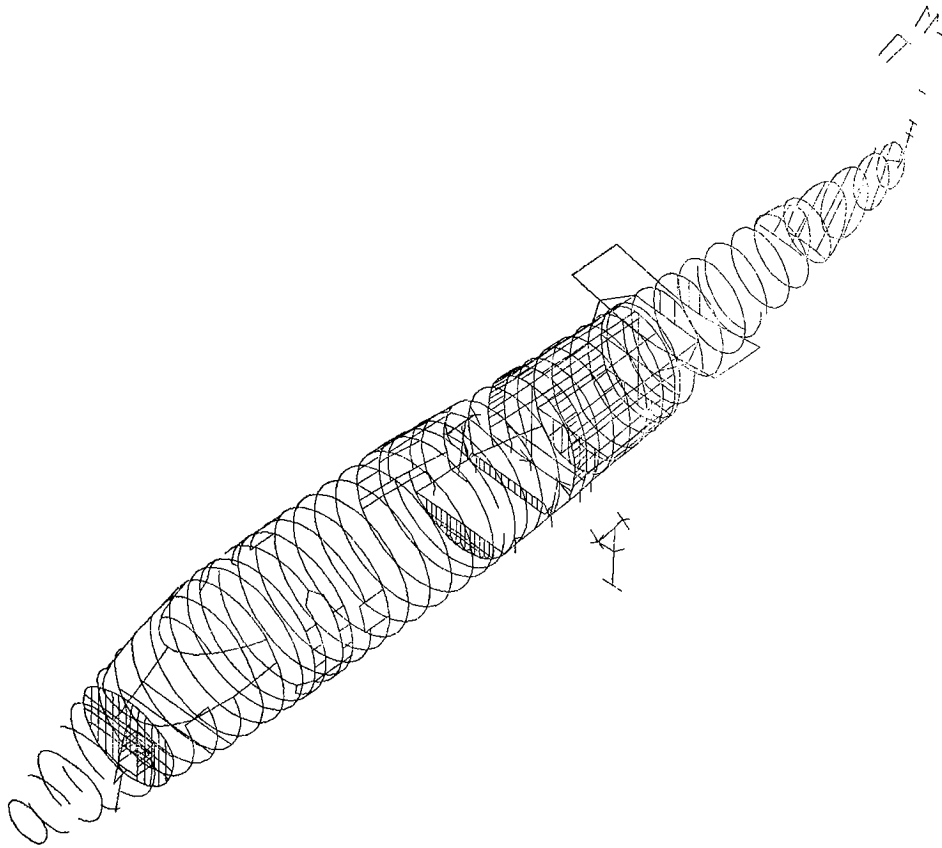


FIGURE 2 - NASPLOT CONSTRAINED ELEMENT GROUP

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ID NASTRAN USER
APP DISP
SOL 1,3
DIAG 14
ALTER 106
OUTPUT2  CSTM,GPL,GPDT,GEOM2, //Ø $
OUTPUT2  OUGV1,OES1,,, //Ø $
OUTPUT2  ,,,, //-9// $
ENDALTER
TIME 180
CEND
```

FIGURE 3 - NASTRAN DMAP ALTER CARDS

COMPOSITE SPOILER ANALYSIS 8-12-83  
ALPHA = 60.0 DEG. BETA = -20.0 DEG. GAMMA = 60.0 DEG.  
NASBUILD: 17-DEC-83 17:46:04 NASPLOT: 23-DEC-83 14:10:15

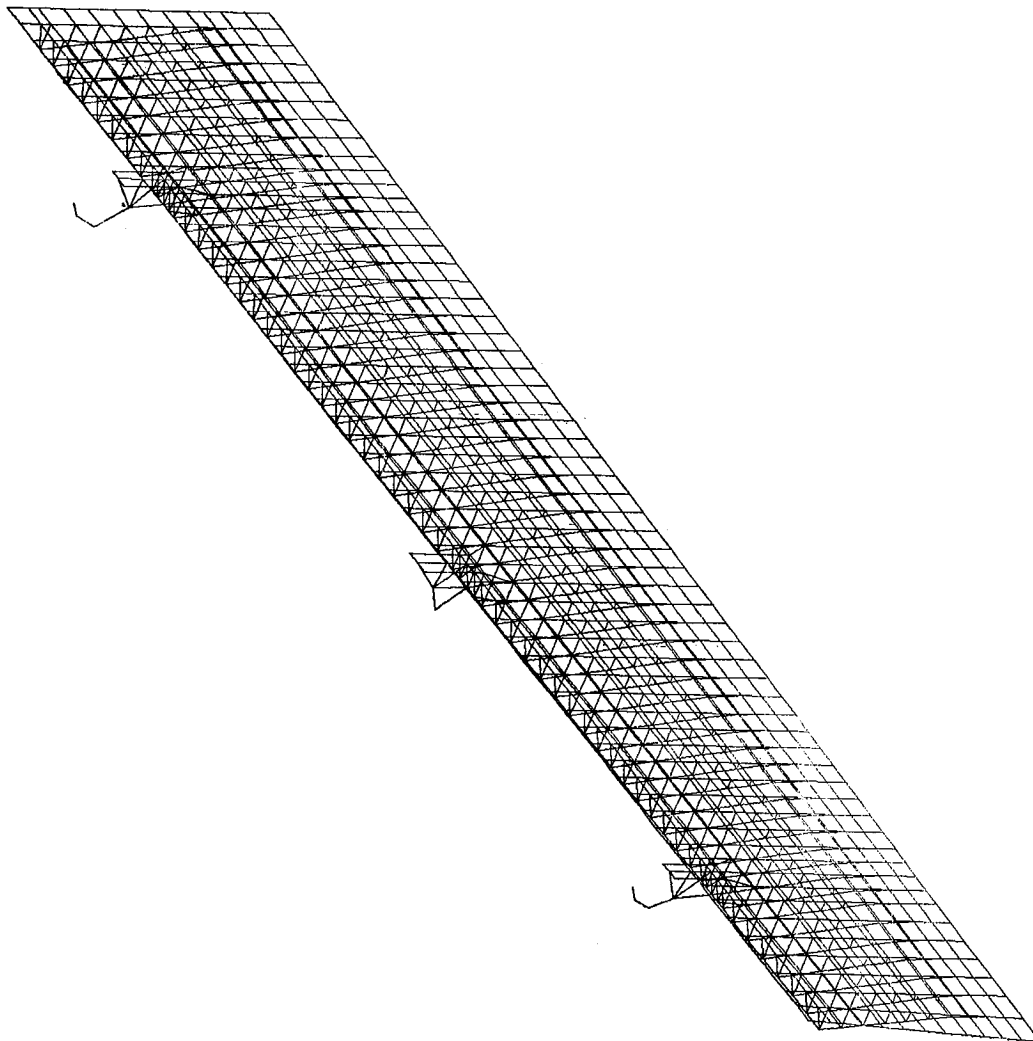


FIGURE 4 - COMPOSITE SPOILER NASTRAN MODEL



SDRC/OUTPUT DISPLAY 3.11 11-OCT-82 12:24:15  
COMPOSITE SPOILER REDESIGN (133( ULT DWN LOAD) 1-23-82  
STATIC DISPLACEMENTS

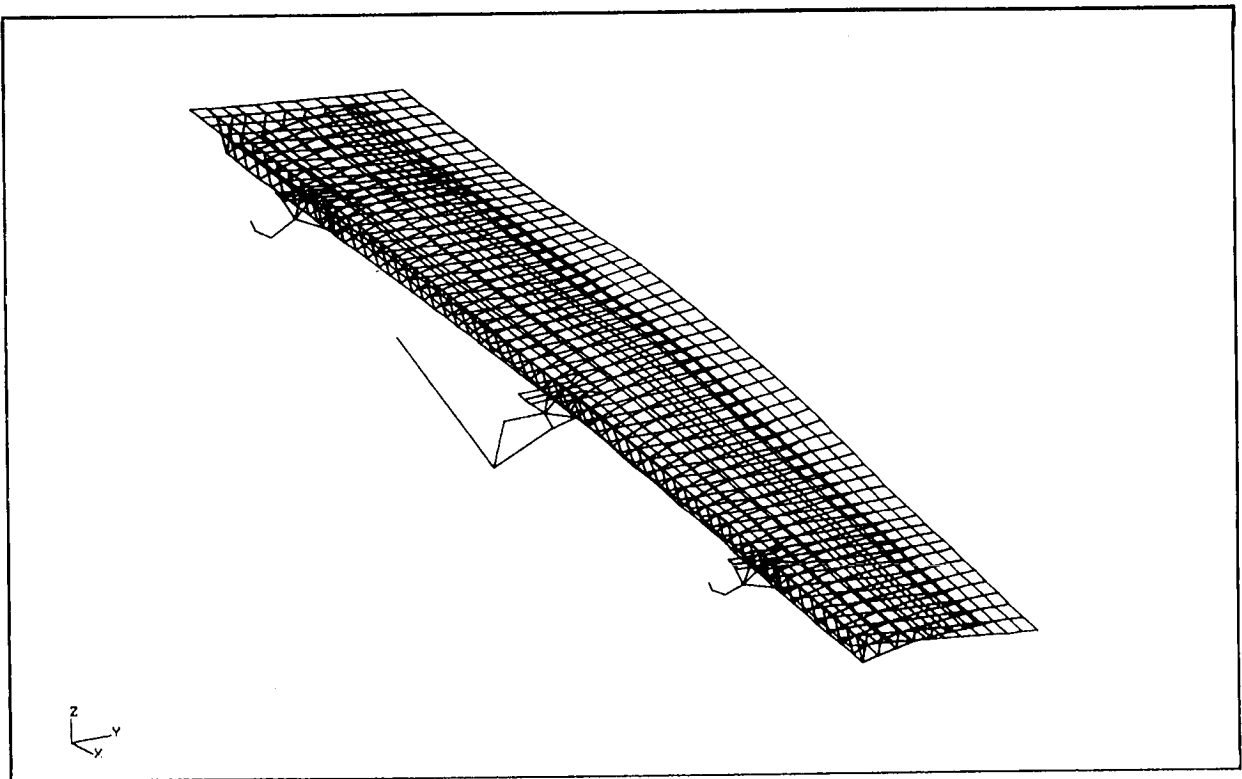


FIGURE 5 - COMPOSITE SPOILER STATIC DEFORMED SHAPE

SDRC/OUTPUT DISPLAY 3.11 15-SEP-82 15:18:29  
COMPOSITE SPOILER REDESIGN (133( ULT DWN LOAD) 1-23-82  
MAXIMUM PRINCIPAL STRESS TOP SURFACE

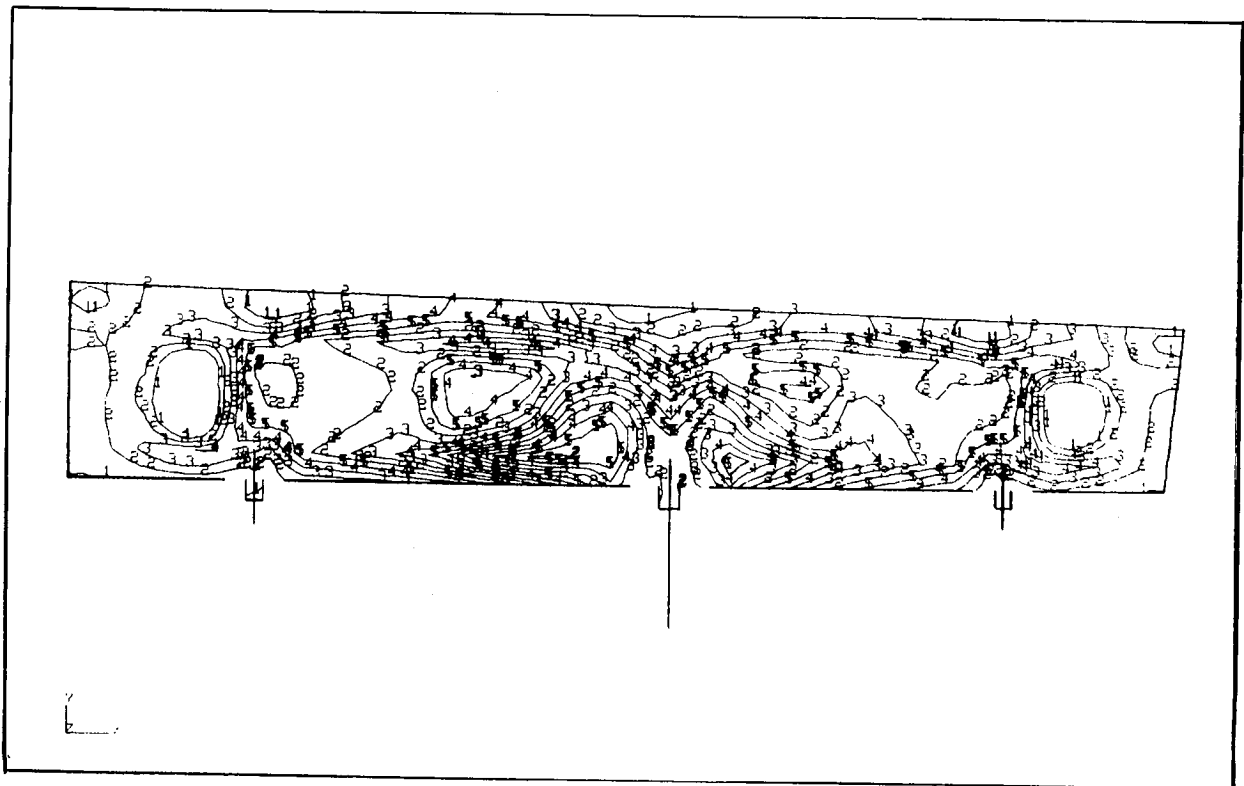
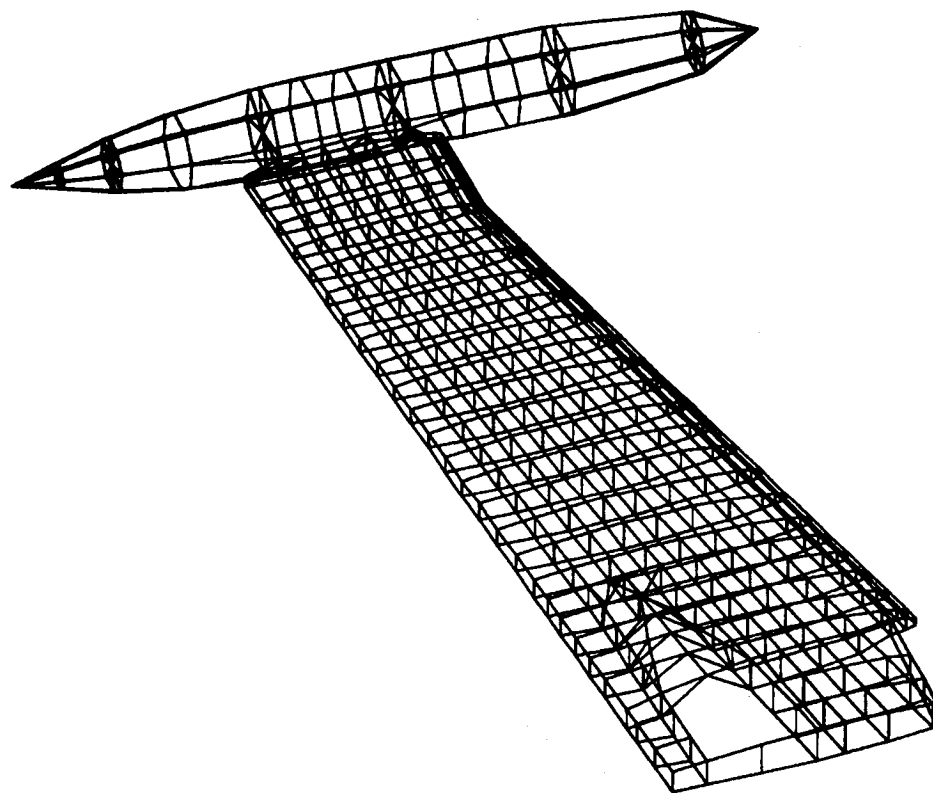
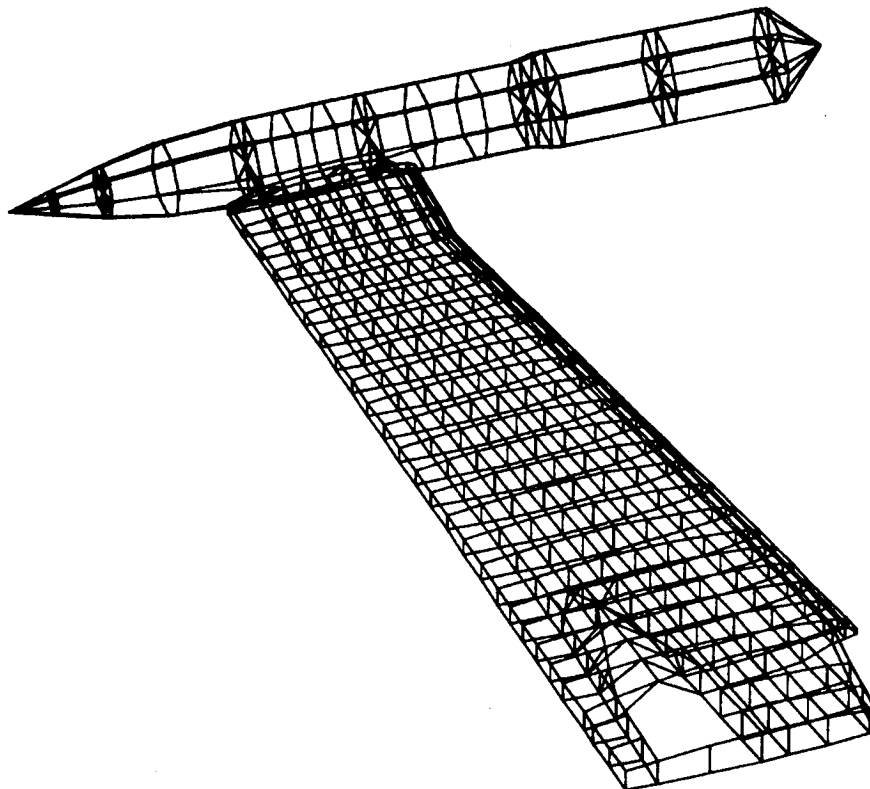


FIGURE 6 - COMPOSITE SPOILER STRESS CONTOURS



MODEL 35/36 WING STRUCTURE 10-25-78  
NASBUILD: 9-JAN-84 10:58:54 NASPLOT: 25-JAN-84 09:26:12

FIGURE 7 - M35/36 WING NASTRAN MODEL WITH CONVENTIONAL TIP TANK



M35/36 WING STRUCTURE  
NASBUILD: 9-JAN-84 17:32:20

10-15-82  
NASPLOT: 25-JAN-84 09:37:11

FIGURE 8 - M35/36 WING NASTRAN MODEL WITH SPECIAL MISSION TIP TANK

OUTPUT\_DISPLAY  
M35/36 WING STRUCTURE WITH  
MIN PRIN STRESS TOP SURFACE

7-JAN-84 15:47:16  
LOAD CASE: 0

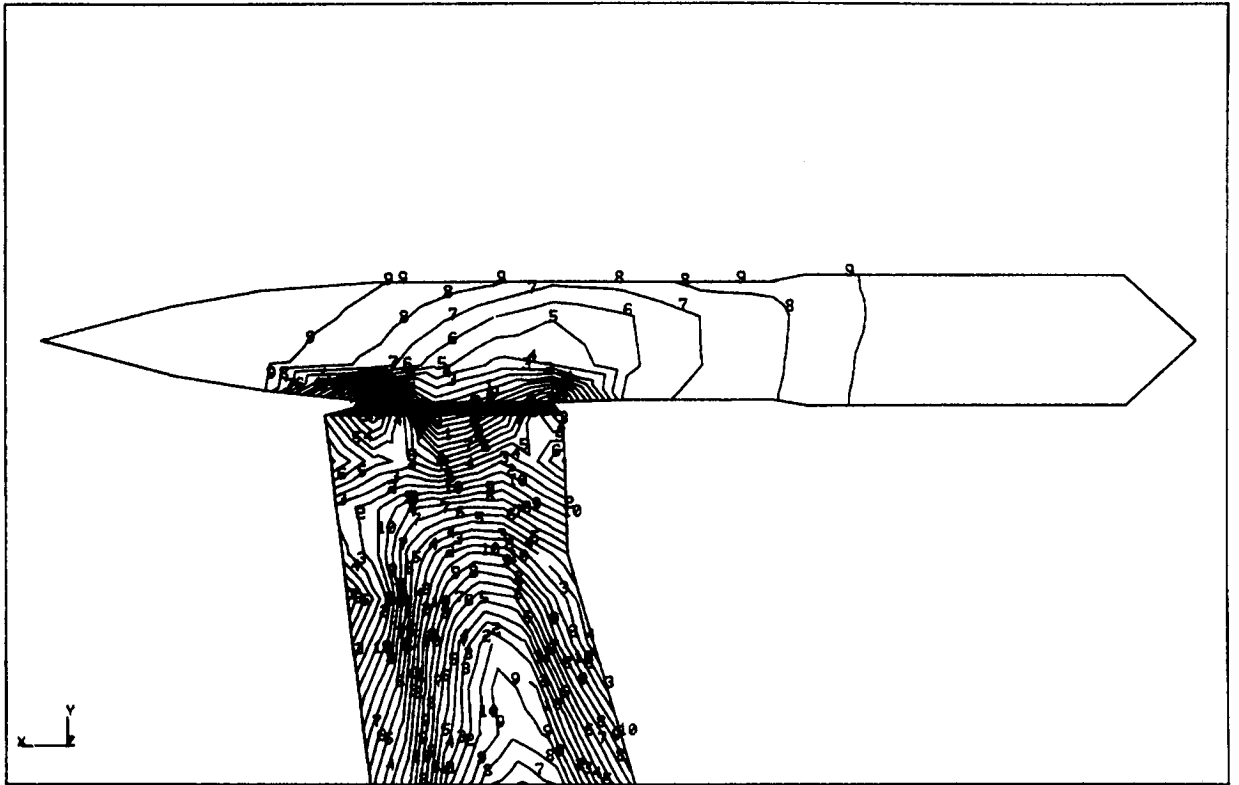


FIGURE 9 - STRESS CONTOURS FOR SPECIAL MISSION WING CONFIGURATION

OUTPUT\_DISPLAY  
COMPOSITE OUTBOARD LANDING GEAR DOOR  
DISPLACEMENTS

23-DEC-83 16:08:57  
LOAD CASE: 0

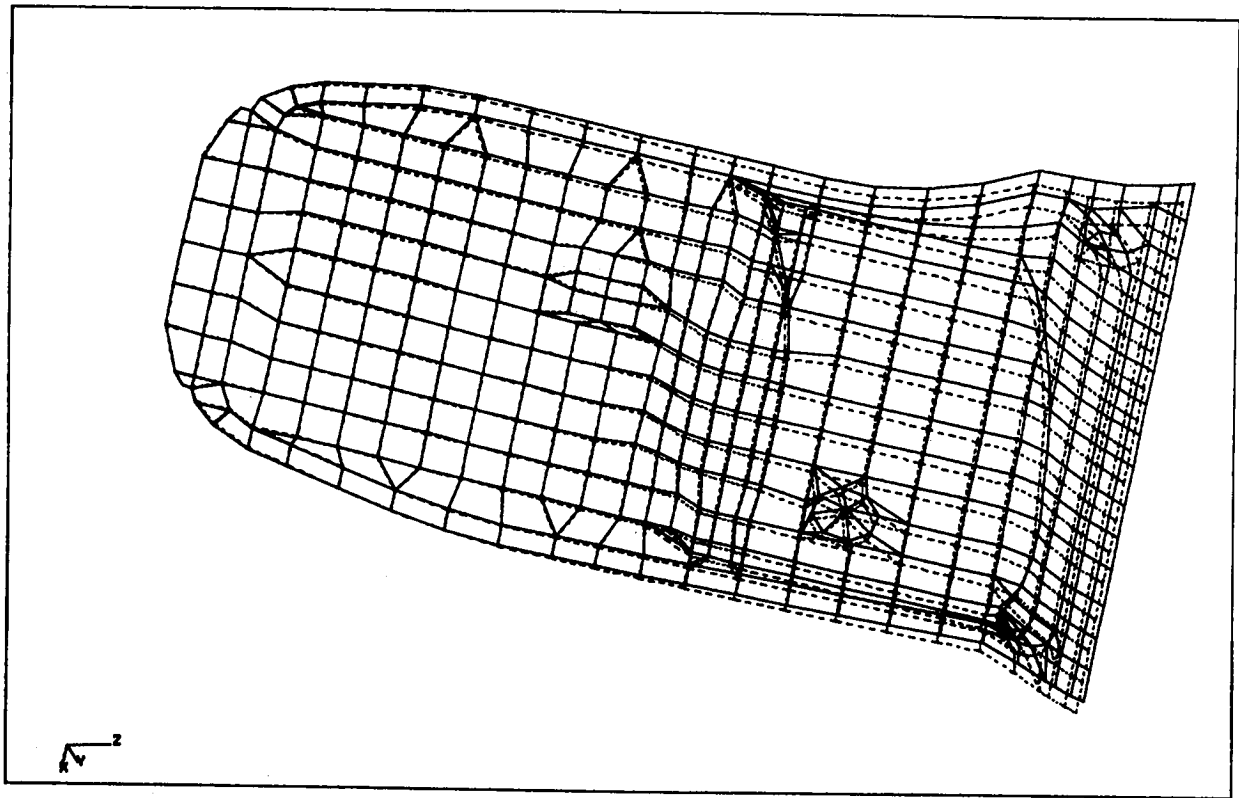


FIGURE 10 - COMPOSITE GEAR DOOR STATIC DEFORMED SHAPE

OUTPUT\_DISPLAY  
COMPOSITE OUTBOARD LANDING GEAR DOOR (LOFT CONTOUR  
MAX PRIN STRESS BOTTOM SURFACE

23-DEC-83 15:37:21  
LOAD CASE: 0

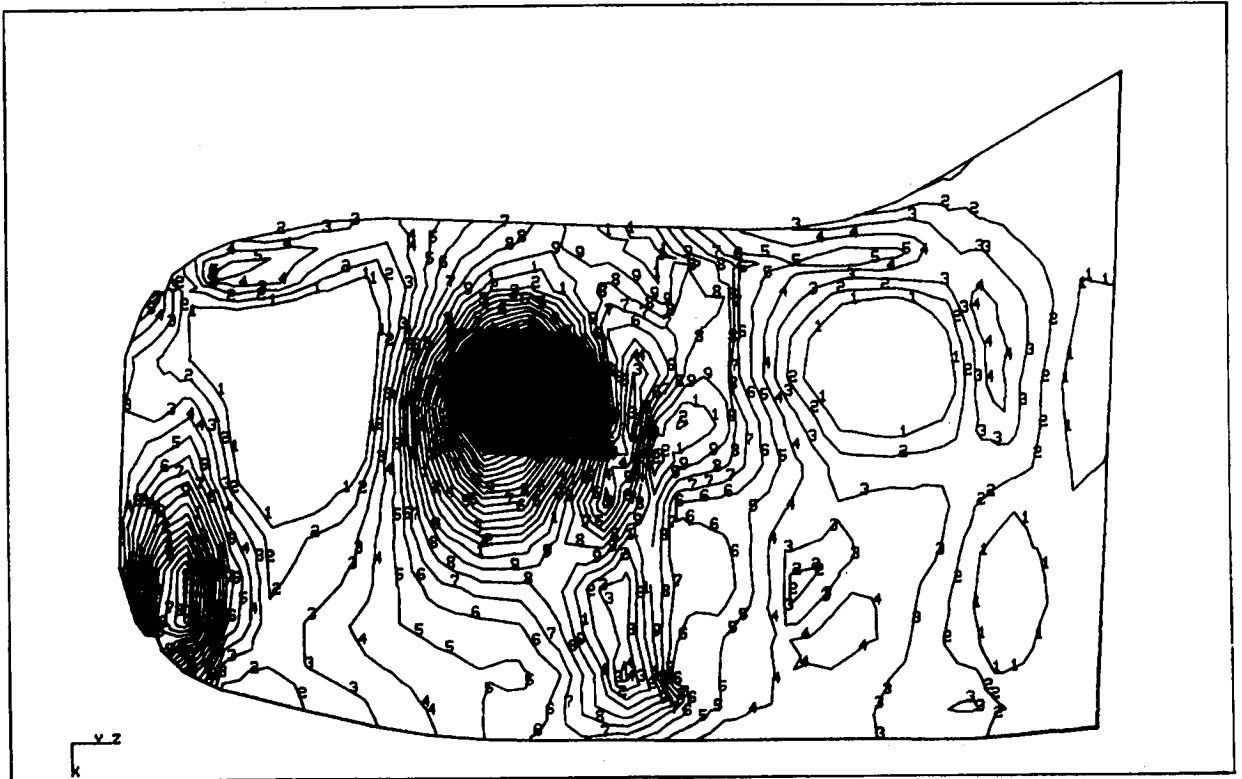


FIGURE 11 - COMPOSITE GEAR DOOR STRESS CONTOURS

OUTPUT\_DISPLAY  
COMPOSITE OUTBOARD LANDING GEAR DOOR  
DISPLACEMENTS

9-JAN-84 09:57:34  
MODE: 0 FREQ: 0.00E+00

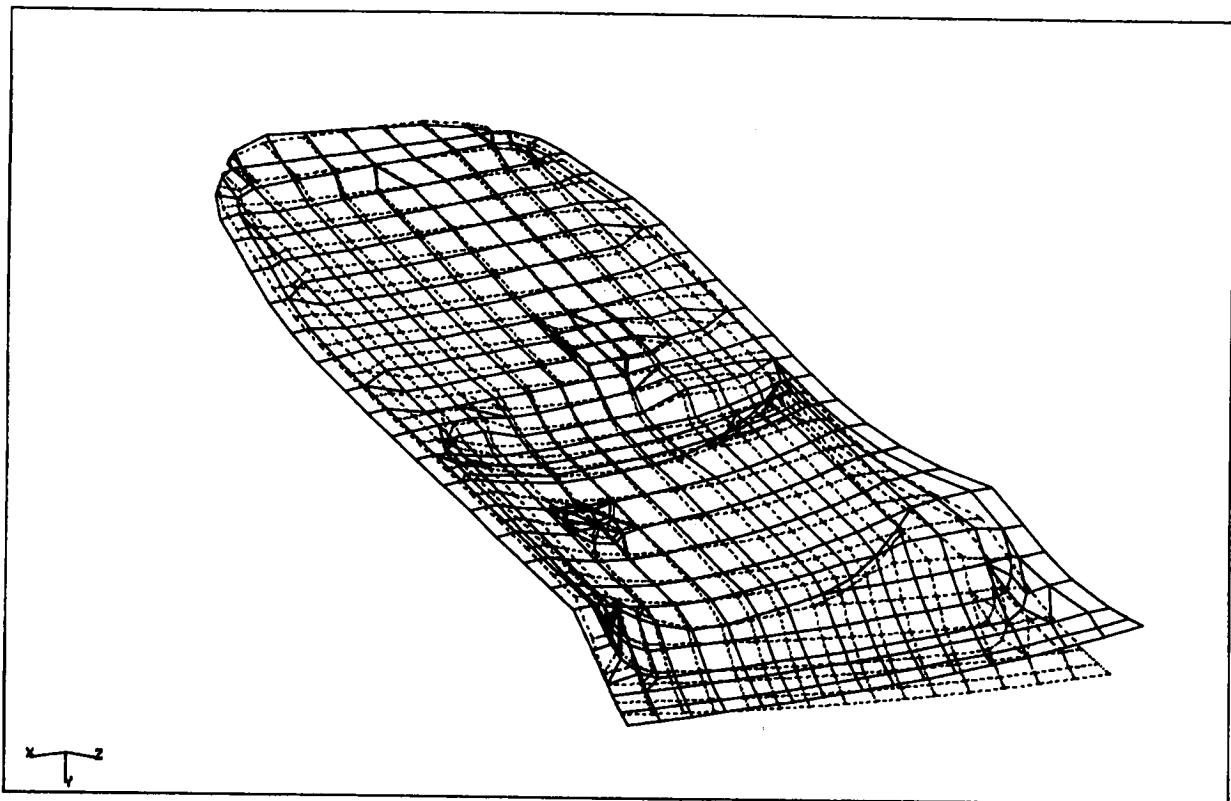


FIGURE 12 - COMPOSITE GEAR DOOR MODE SHAPE