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AN AUTOMATED DATA MANAGEMENT/ANALYSIS SYSTEM FOR SPACE SHUTTLE ORBITER TILES

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SUMMARY

An automated system which combines an engineering data management system with a nonlinear stress analysis program to provide a capability for analyzing a large number of tiles on the Space Shuttle Orbiter is described. Tile geometry data and all data necessary to define the tile loads environment during ascent are stored in the data management system and these data are accessed automatically as needed for the analysis of a particular tile or a set of tiles. The system currently contains approximately 600,000 words of data necessary to analyze the 8,000 tiles on the lower surface of the wing and midfuselage.

User documentation for the automated tile analysis system is given in this report including (1) descriptions of computer programs and data files contained in the system, (2) definitions of all engineering data stored in the data base, (3) characteristics of the tile analytical model, (4) instructions for preparation of user input, and (5) a sample problem to illustrate use of the system. Descriptions of data, computer programs, and analytical models of the tiles are given in sufficient detail to guide extension of the system to include additional zones of tiles and/or additional types of analyses.

INTRODUCTION

The metal primary structure on the external surface of the Space Shuttle Orbiter is protected from the thermal environment by an array of over 30,000 RSI (reusable surface insulation) tiles. Assessment of the integrity of this thermal protection system required that a stress analysis be performed on each tile. A stress analysis program, reference 1, was developed for this purpose. The analysis includes the nonlinear material properties of the strain isolator pads used to attach the tiles to the surface of the Orbiter. Further, this computer program

requires input which includes tile geometry definition, aerodynamic and vibro-acoustic loads, substrate deflections, and materials data. These needed inputs existed in many different forms in various engineering reports. The gathering and preparation of input data for the analysis of a single tile was a time-consuming process (required approximately one man-day per tile) when done manually. Therefore, there was a need to automate this analysis process so that large numbers of tiles could be analyzed in a timely manner.

This report describes a system which was developed to provide automated access of analysis information stored in a data management system and subsequent processing needed to produce results from the nonlinear stress analysis program. This automated analysis process is performed in a single computer run for a single tile or a large number of tiles. The system currently contains approximately 600,000 words of data necessary to analyze the 8,000 tiles on the lower surface of the wing and fuselage as shown in figure 1. The region of tiles which can be analyzed are shown inside the outlined area and are referred to as tile zones W-3, W-4, MF-5, and MF-6. The geometric planform shapes of each tile in this region are shown in the computer-generated plot for the right-hand side of the Orbiter.

The data necessary to analyze these tiles are stored using the Relational Information Management (RIM) system, reference 2, which was developed as part of the NASA-sponsored IPAD project. The RIM system includes an interactive executive with languages to allow a user to make selected online retrievals of any stored data. A FORTRAN interface, which is a set of RIM subroutines, is used by other separate computer programs in the automated system for storage and retrieval of required data. The use of the RIM engineering data management system in the tile analysis process is discussed in reference 3.

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User documentation for the automated tile analysis system is contained in this report. First, a system overview which describes the component computer programs and data files is given. Next, the organization of the various types of engineering data for storage in the data base is discussed. The analytical modeling of the tiles is illustrated by a listing of input instructions to the analysis program for a typical tile. User instructions are given for operation of the RIM interactive executive, the graphic display program, and the automated stress analysis system. A complete set of input and output data for a sample tile is included to illustrate the operation of the automated stress analysis system.

SYSTEM OVERVIEW

The automated data management/analysis system is a collection of computer programs and data files that are used in a coordinated manner for the stress analysis of Orbiter tiles. The major components of this system are shown schematically in figure 2.

The initial effort in the development of the system was to gather, organize, and store the required engineering data in the RIM data base files shown at the bottom of figure 2. The various types of engineering data are indicated along the left side of the figure. The majority of the data was obtained from Rockwell International (RI), Space Systems Group, Downey, California. These data included tile corner point definitions, vibroacoustic loads, substrate deflections, and tile physical data. The corner point definitions were available in punched card format and the vibroacoustic loads and substrate deflections were tabulated in engineering reports. The tile physical data were stored on the TIPS (Tile Information Processing System) data base. Aerodynamic loads data were available from RI but these data were refined and updated by J. Tulinius, NASA-Langley Research Center, and C. Coe, NASA-Ames Research Center, for use in the automated system. Several special purpose data preparation programs were required to transform the engineering data from the

original form to the desired form for storage in RIM. These programs were tailored to handle specific types and forms of data and will not be discussed further in this report. The data are organized into tables for RIM and the purpose of each table will be described in the next section entitled "Engineering Data" with a detailed description of the table entries given in appendix A. Most of these tables were formed by the data preparation programs and loaded into the RIM data files using the RIM FORTRAN interface as shown in figure 2. However, in some instances the tables were formed as data files using an online text editor and loaded using the LOAD submodule of the RIM executive.

The automated data management/analysis system can be used in three different modes as indicated at the top of figure 2. The first mode is to use RIM as a stand-alone system and access any of the desired engineering data using the RIM interactive executive. This capability is usually accessed from an interactive terminal with keyboard input and printed output. It is assumed that a reader of this report is familiar with the detailed user documentation for RIM given in reference 2. Additional user instructions needed for the tile analysis application are contained herein in a subsequent section entitled "Use of RIM Interactive Executive."

In the second mode, graphical displays of selected data are generated on an online terminal and/or offline plotter using a separate program developed for this purpose. The displays present a layout of the tile geometry and a user selected quantity can be annotated on each tile as illustrated by the densified tile indicator shown in figure 1. The RIM interactive executive and graphical display provide the user with the powerful capability of having ready access to the tile engineering data for display in a user selected form. User instructions for the graphic display program are given in a subsequent section of this report.

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The third user mode is to perform automated stress analysis. As shown in figure 2, this mode requires the use of pre- and post-processors to connect the stress analysis program with the RIM data base. A more detailed breakdown of the computer programs and data files used in this process is shown in figure 3. Two sets of user prepared input data, shown on the figure as Input 1 and Input 2, are required to select the tiles and the load conditions to be considered in a particular analysis. The detailed contents and formats of Input 1 and Input 2 are given in a subsequent section entitled "Use of Automated Stress Analysis System." The remainder of the section gives a general description of the stress analysis process shown in figure 3.

The information in Input 1 allows the user to select the tiles to be analyzed and to select the particular Mach number from a prescribed Shuttle Orbiter flight trajectory at which the analysis is to be performed. This information is used by the data access program to extract all data from the RIM data base which is required for a stress analysis. The data are written on two sequential files; one containing tile corner points and material properties and the other one containing all data needed to define the tile loading. The parameters used to define tile loading are also written on file NAML in a namelist format for ease of interpretation by the user. Definitions of the variables contained in this file are given in appendix B.

The information to define the model of the SIP surface and to select the load cases to be analyzed is contained in Input 2. Of principal interest are combinations of individual load components into various design load cases, defined as a function of the location of an aerodynamic shock relative to the tile. Load cases for the contributions of each load source are also available for assessment. The tile corner point file and the tile loads file along with Input 2 are used to generate a tile analytical model needed for stress analysis. This analytical model is in the form of a card image input file to

be read by the stress analysis program. A description of this model is given in the section entitled "Analytical Model of Tile." The stress analysis program computes the maximum stress on each SIP surface for each load case that is specified. This calculated stress information is subsequently processed to determine the load case which produces the largest stress for each tile. These stress values are compared with the allowable stresses and the pertinent stress data are stored in the RIM data files. Various user initiated queries can be made to assess the calculated stress data.

The analysis system is operational on the CDC NOS 1.3 operating system. Sequences of NOS control statements, called procedure files, are used to call programs and data files as needed in the stress analysis process. Because of computing time requirements for the nonlinear stress analysis procedure, interactive use of the system is effective when only a few tiles are to be analyzed. For the analysis of a large number of tiles and/or load cases, operation of the system in a batch mode is desirable.

ENGINEERING DATA

General Organization

All engineering data required for tile analysis are stored using the RIM system. The data are organized in the form of simple tables referred to as relations as illustrated in figure 4. Every relation is given a unique user-assigned name (e.g., NEWAPANL, STS1TRAJ, and NEWLOADS in fig. 4). Each column in a relation is referred to by a name called an attribute and each row of the table is called a tuple. Data can be retrieved a tuple, or multiple tuples, at a time. Generally, data are retrieved by specifying the relation name which contains the data and a Boolean expression to be satisfied by the values of the attributes. For example, to print the contents of the second tuple in relation NEWAPANL shown in figure 4, the following query is used:

SELECT ALL FROM NEWAPANL WHERE PARTNO EQ 190002121

The "WHERE" clause of a query can specify conditions to be satisfied by more than one attribute. The relations defined in this effort have attributes for independent data given first followed by attributes for dependent data. Usually, queries are made by specifying conditions to be satisfied by the independent data although this is not mandatory.

Any attribute in a relation can be designated as a "keyed" attribute. This designation causes an inverted file to be formed for the relation which provides for efficient retrieval of tuples associated with selected values or the key attribute. For the tile application, many of the relations contain tuples of information corresponding to an individual tile which is referenced by a unique part number. Inverted files with a key specified on part number were generated for efficient retrieval of such data.

Many of the relations contain attributes which are set up to refer or point to corresponding attributes in another relation, allowing the data to be related in a hierarchical or network manner. If, using figure 4 as an example, a tile part number (PARTNO) is specified, the aerodynamic panel containing the tile is specified by the identifier AEROPANL in relation NEWAPANL. A point in the flight trajectory is specified by selecting a Mach number MACHNO, in relation STS1TRAJ. The corresponding angle of attack, ALPHA, dynamic pressure, QPSF, and ambient atmospheric pressure, PINF, are then retrieved. Then the aerodynamic panel, Mach number, and angle of attack are used in relation NEWLOADS to determine the pressure differential across a shock, SHOCKJUMP, and an aerobuffet load parameter, ABSHKCPRMS. The data values for MACHNO and ALPHA in relation STS1TRAJ do not have corresponding numerical values in relation NEWLOADS so interpolation is required.

All relations used to store engineering data for the Orbiter tiles are shown in figure 5. Each relation name is underlined and followed by a list of all attributes in the relation. These attributes are shown in transposed form as a column for

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graphical purposes instead of as a row corresponding to tuples as shown in the standard form of figure 4. Some of the attributes appear in more than one relation in figure 5 indicating a correspondence or linking of attributes between relations. A general description of this engineering data is contained in subsequent sub-sections and detailed definitions of the attributes in each relation are given in appendix A.

The engineering data and associated information needed for data access are stored as permanent logical files in the form of RIM data files as indicated in figures 2 and 3. These data are collectively referred to as a data base. The definition of a data base is called a schema. The schema name TILEDB was selected and is used in forming the names of three files TILEDB1, TILEBD2, and TILEDB3 which make up a data base. These files must reside as local files during operation of the automated data management/analysis system. The file TILEDB1 contains the definition of the data base or schema. File TILEDB2 contains all tuples of data in each of the relations. File TILEDB3 contains the information associated with inverted files which were established by specifying key attributes. Data for each of the tile zones W-3, W-4, MF-5, and MF-6 are stored permanently as separate data bases under the names W3DB1, W3DB2, W3DB3 . . . MF6DB1, MF6DB2, and MF6DB3. This use of a separate data base for each tile zone instead of forming a single data base with relations having tile zone as an attribute provided several advantages. These advantages included: (1) shorter data access time because queries were being made on relations with fewer tuples, (2) smaller requirement for local disk space during system execution, (3) updating of data or accommodation of slight differences in data definition could be handled in one zone without affecting the others, and (4) development work could proceed on a new zone without interferring with use of data in completed zones.

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Tile Properties

This section contains a general description of the data used to descr?? tiles, including geometry, physical properties, and SIP material properti.;. All tile data except for SIP material properties was obtained from Rockwell International. The system used to identify a particular tile is illustrated by tile zone MF-5 from a segment of one of the tile layout drawings shown in figure 6. These tiles are located on the bottom surface of the middle fuselage. As mentioned previously, all data for a tile zone are stored on a separate data base. The next breakdown of regions of tiles is by a six-digit drawing number (e.g., 394031 in fig. 6) and an associated three-digit array number (e.g., 004 in fig. 6). Within an array, each tile is given a three-digit dash number (e.g., from -094 to -145 in fig. 6). A unique identifier is established for each tile by combining the drawing number and the dash number into a nine-digit tile part number. These tile part numbers are used as a key attribute in relations containing tile data and are used as input quantities to the automated system to select tiles for analysis.

The geometric description of the tiles is given by the coordinates of points at the tile corners. These corner points are defined on the inner surface of the tile which is attached to the Orbiter skin, called the inner mold line (IML), and on the outer surface of the tile which is exposed to the airstream called the outer mold line (OML). In the subsequent part of the paper the IML will be referred to as inner surface and OML as outer surface. This corner point definition of geometry restricts the tiles which can be analyzed by the automated system to those that can be assumed to have planar (relatively small curvature) IML and OML surfaces. Such tiles are referred to as "acreage" tiles. The acreage tiles can have a general planform, but the majority of tiles considered herein are 6 × 6 inch square tiles as shown in figure 1. The coordinates of the tile corner points were defined relative to various local coordinate systems as indicated in figure 7. Transformation

equations were used to transform all points to a single orbiter coordinate system. These geometry data were stored in relation XYZO as shown at the lower left of figure 5. Each tuple in this relation defines a single tile corner point with attributes giving the part number, drawing number, inner or outer mold line indicator, the local coordinates, number of the transformation equation, and the resulting Orbiter coordinates. Each tile requires as many tuples as it has corner points.

This tile geometry is defined for the right hand side of the Orbiter since the tiles are symmetric to those on the left hand side for the tile zones considered herein. Although tile geometry is symmetric, the material properties associated with the tiles are not necessarily symmetric. The relation TIPSDATA contains tuples of information for all tiles with an indicator denoting the right or left hand side of the Orbiter, the part number of the opposite or symmetric tile, whether or not the tile has been strengthened by densification, and the stress level to which the tile was proof loaded.

The loading history, hence the tile proof level, affects the material properties of the strain isolator pad used to attach the tile to the Orbiter. The material has nonlinear stiffness properties which are needed for the stress analysis. These nonlinear pad stiffnesses were represented as sets of points on stress-displacement curves. Two relations, MATINDEX and MATCURVE, are used to store these material properties. The first relation, MATINDEX, contains the following attributes that are parameters needed to define a particular material curve: the pad type, either filler bar or SIP; the pad thickness; the proof stress level to which the material has been subjected, and a corresponding material number. The points on the stress-displacement curve obtained after the proof test are stored in relation, MATCURVE, for each material number.

The analysis effort herein was focused on assessing the integrity of the undensified tiles. Most undensified tiles are attached using 0.16 inch thick SIP

with a proof load level between 6.0 and 8.0 psi. Material curves for normal or through-the-thickness loading are stored for only two proof stress levels, 6.0 and 8.0 psi, with the 6.0 psi curve used for analysis of tiles proofed at 6.5 psi or less and the 8.0 psi curve used for all other analyses. A single linear curve is adequate to represent the shear stiffness for all SIP's, since the critical stress occurs in the normal direction and not the shear direction.

In addition to the tile geometry and pad material properties, all other tile data are contained in a directory relation, DIRECT, shown at the upper left of figure 5. First, identification information from an engineering drawing is given by drawing number, dash number, and array number as illustrated in figure 6. Next, the number of corner points on the inner and outer mold line are given. The location of a tile relative to major members of the primary structure is an important parameter in determining the loads imposed on the tile by vibratory acceleration and deflections and/or static deformation of the structure to which the tile is attached. The locations of these major members were obtained from finite element structural models which contained the definition of skin panels with edges along ribs and spars in the wing, and frames and stringers in the fuselage. The attribute, SUBSPANL, specifies the skin or substrate panel to which the tile is mounted. Also included are the distances from the tile center of gravity to a rib in the wing or frame in the fuselage CGTORIB and distances between adjacent wing ribs or fuselage frames RIBTORIB. The distance of the tile center of gravity from the leading edge of the Orbiter CGTOLE is a parameter used in the equations for calculating boundary layer thickness and skin friction. The equations used were developed by fitting an exponential function to the curves shown in figures 8 and 9. The resulting equations are shown on inserts to the figures which are taken from engineering reports in their original form. The points used to define the leading edge of the Orbiter were scaled from engineering drawings and are given in table 1.

The next attribute in relation, DIRECT, is NODEORDR which indicates whether the corner points of the tile are in a right-hand or left-hand orientation relative to the Orbiter coordinate system. The tile data are completed by giving the planform coordinates of the tile center of gravity, followed by tile thickness, SIP thickness, and tile density. The tile thickness is obtained by averaging the thicknesses at each set of corner points. As indicated, several of the attributes in relation, DIRECT, required calculations be performed on existing engineering data to put it in a form suitable for use in the automated analysis system. A data preparation program as indicated in figure 2 was used for this purpose.

Tile Loads

The tile loads, which are considered during analysis, come from three sources: (1) static and/or dynamic deflections of the substrate to which the tile is attached; (2) vibratory motion of the tile; and (3) pressures acting on the tile which result from the aerodynamic environment. The static substrate deflections result from the overall structural loading. These substrate deflection data were generated by the Rockwell International subcontractors that were responsible for design of a particular portion of the Orbiter structure, (e.g., Grumman for wing). These data are stored in relation, SUBDEFL, as shown in figure 5. The data are given with respect to the numbered skin panels of the structure as shown in figure 10 for the lower surface of the Orbiter. The corners of these panels given in relation SUBPANL, were used to determine which SUBSPANL contained the center of gravity of a particular tile. The deflections are for a specific flight condition which was taken to be at maximum dynamic pressure during ascent for the calculations herein. The skin panels in the W-3, MF-5, and MF-6 zones have a stringer-stiffened skin construction, and zone W-4 has honeycomb core sandwich construction. The data are stored as amplitudes and wavelengths of skin and stringer deflections.

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The vibroacoustic loads are given as the tile normal acceleration, GPEAK, and corresponding dynamic displacement of the substrate, DISPL, for different Mach numbers as shown by the two relations, VIBAC, in figure 5. As indicated, this relation has different independent variable parameters for the wing and for the fuselage. For the wing, the loads are a function of tile size, whether the tile is located on or off a rib, and the tile thickness as illustrated in figure 11. For the fuselage, the loads are related to the location of the tile on the fuselage as given by the substrate panel definition, the distance of the tile from a frame, and the distance of the tile from the Orbiter centerline.

Aerodynamic loads are defined in terms of a set of aerodynamic panels which cover the regions of interest as defined in table 2 and illustrated in figure 12. The aerodynamic panel corresponding to each tile is given in the relation, NEWAPANL, along with the fraction of semispan location, fraction of chord location, and total chord length corresponding to each tile as shown in figure 5. The load parameters for each aerodynamic panel are given in two different forms in relations, NEWLOADS and FORCEMOM. The relation, NEWLOADS, contains parameters which were obtained from wind tunnel tests and which are used to define the pressure distribution acting on the outer surface of a tile. These parameters include the pressure change across a shock for both unseparated and separated flow, aerodynamic pressure gradients in the streamwise and transverse directions, aerobuffet data for both unseparated and separated flow, and finally a reference pressure. A detailed description of how the parameters are used to define a tile surface pressure distribution is given in the section entitled "Analytical Model of Tile." These aerodynamic parameters are functions of Mach number, angle of attack, and are nondimensionalized with respect to dynamic pressure. Relation STS1TRAJ contains tuples of these flight parameters for the STS1 ascent trajectory. When the user inputs tile number and Mach number, all data necessary to define the tile aerodynamic loading is retrieved. In the

initial phases of this study, empirical relations were established to relate the pressures on the inner mold line and side surfaces of the tile to that on the outer mold line. These pressures were needed to calculate total forces and moments acting on the tile. In the later phases of the study, a multitile three-dimensional flow model was developed by a NASA-LaRC group led by G. Ivey. Using this flow model, more precise distributions of pressures on the tile inner and side surfaces could be calculated including effects of initial tile gaps and tile lateral movement under loading. These pressures were integrated to give total forces and moments acting on the tiles. Such calculated forces and moments are given in relation, FORCEMOM, as a function of Mach number, tile thickness, boundary layer thickness, and location of the shock on a tile. Because of the large computational effort to generate such forces and moments, they were calculated at only the previously established critical Mach number for each aerodynamic panel and for minimum and maximum tile thicknesses and boundary layer thicknesses within each panel. Five evenly spaced shock locations across the diagonal of a tile were used in these calculations.

The stresses which were calculated during this study are stored in relations similar to STRS4-24-1 as shown in figure 5. The "4-24-1" indicate that these stresses were calculated or April 24, 1981. The actual tile proof stress, ACTPROOF, is divided by the maximum calculated stress, STRESSMX, to give the stress ratio, SRATIO. The values of the stress ratios were examined to determine the relative safety margins for the tiles.

ANALYTICAL MODEL OF TILE

The analytical model of a tile is described by a set of input commands to the nonlinear stress analysis program, reference 1. In the automated analysis system, these input commands are produced by the analytical model generation program. This program is designed to handle only acreage tiles. An example of a tile model which was generated automatically is shown in appendix C. The description of such a tile

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model contained in the remainder of this section will correspond to the sequence of input commands given in the example.

Geometry and Materials

The tile part number and flight condition for the analytical model are given on the "TITLE" and "CASEID" commands. Coordinates of points at corners of the tile are used to define the tile geometry. The acreage tile planform may have an arbitrary number of corner points, N. A tile with a quadrilateral planform, N = 4, is described in the example. The first group of N nodes define points on the inner mold line with the most forward point designated as node 1 as indicated by its minimum x-coordinate. The second group of N nodes are corresponding points on the outer mold line. The first group of N nodes are then redefined at points at the tile's inner surface using "POINT" commands to account for SIP thickness. The third group of N nodes are defined at a distance of 0.2 inches from the tile inner surface to represent termination of a coating not extending completely to the inside of the tile. These nodes are not used currently since this small effect on total tile mass is neglected. The next groups of N nodes defined using "CORNER" commands are used to define the boundaries of the PAD surfaces. The model shown in appendix C contains an 0.5 inch wide filler bar around the outside perimeter of the tile, two 0.25 inch wide strips of SIP to represent the edge softening effect, and the center SIP surface as illustrated in figure 13. Therefore, three additional groups of N nodes are needed to define these pad boundaries.

All surfaces of the tile are defined by "FACE" commands in the sequence outer, inner and side surfaces. A nonzero density of the tile coating material is specified for all surfaces except the inner surface whose definition is used only for loads calculations inside the model generation program. A set of wedges with triangular planforms are combined to represent a tile with an arbitrary number of

sides. The "CG" command causes the tile center of gravity and weight to be output by the nonlinear stress analysis program.

The first "PAD" command defines the filler bar surface having the material properties given in the subsequent table. The second and third pads are strips of material with their stress-displacement curves adjusted to account for edge softening. The fourth pad represents the center SIP surface.

Applied Loads

All tile loads are represented as sets of concentrated forces and moments which are applied at the tile center of gravity. The coordinates of the tile center of gravity are given on the "NODE" command immediately preceding the "FORCE" and "MOMENT" commands. Forty sets of forces and moments are generated which are described in the "User Input" subsection of the "Use of Automated Stress Analysis System" section and listed in table 3. These load cases include separate contributions from the load sources shown in figure 14 and combinations of the contributions in a manner to represent design load cases. The rationale and methodology used to establish the design load cases are given in reference 4.

Two conditions are examined; (a) when a shock is located ahead of the tile and (b) when a shock is located on the tile as shown in figure 15. For the design load case combinations, condition (a) is represented by load case 1 and condition (b) is represented by load cases 2 through 12 as the shock located at 10 evenly spaced increments along the maximum streamwise dimension of the tile. The shock is oriented perpendicular to the x-axis of the Orbiter.

The profile of the pressure distribution for a shock located on a tile is shown in figure 16. The solid lines are for unseparated flow and the dashed line indicates the reduced pressure level after the shock pressure rise for separated flow. The parameter names used to define this pressure distribution correspond to those given in namelist NAML described in appendix B. In early phases of the tile study,

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pressure distributions on the tile inner surface and sides were assumed to be related to the outer surface pressure distribution by the empirical equations shown in figure 17. The parameters K_1 and K_2 were defined as a function of the shock location on the tile and numerical values were selected to correlate with available test data. These values are contained in the data statements for the PRATIO and SRATIO arrays in the model generation program. An option also exists to use forces and moments from relation FORCEMOM which are calculated using the LaRC Multitile 3-D Flow Model that gives an improved definition of pressures on the tile inner surface and sides. Additional information regarding the tile loads is available in reference 4.

The definition of the tile analytical model is completed by specifying the location and characteristics of deflections of the Orbiter skin under vibroacoustic and steady flight loads. These substrate deflections are defined using "IMPERFECT" commands. Parameters needed for execution of the nonlinear stress analysis procedure are given on the "CONTROL" and "NONSTRESS" commands.

USE OF RIM INTERACTIVE EXECUTIVE

The RIM Interactive Executive is a user interface with commands for (1) definition of the data base schema, (2) data loading, (3) modification of an existing schema or data, and (4) making queries with conditional clauses to access any of the desired data. This capability is usually accessed from an interactive terminal with keyboard input and printed output.

NOS Control Statements

The CDC Network Operating System (NOS) control statements, reference 5, used to execute the RIM Interactive Executive are described in this section. Procedures for logging onto the computer installation have been omitted from the list of statements.

1. GET, TILEDB1 = W3DB1.

2. GET, TILEDB2 = W3DB2.

3. GET, TILEDB3 = W3DB3.

4. GET, RIM.

5. RIM.

Statements 1 through 3 are used to make the data base files available for use. These statements are shown for tiles zone W3. The data bases for other tile zones are retrieved by replacing W3 by W4, MF5, or MF6 in these statements. The RIM Interactive Executive is retrieved and execution initiated using statements 4 and 5.

User Input

User input commands which are available for controlling the operation of RIM are described in reference 2. All tile data bases were created using the name TILEDB which must be subsequently used in the OPEN command. Typical usage of the RIM Interactive Executive for manipulation or querying of the tile data is illustrated in reference 3.

USE OF GRAPHIC DISPLAY PROGRAM

The graphic display program generates a planform view of tile geometry with each tile annotated with any related data. These data can be displayed on an interactive terminal and/or offline plotter. A RIM data base with the name TILEDB must be available as local files and must include the following relations required for plotting:

(a) Relation XYZO containing tile corner points for the area of interest in the form described in appendix A.

(b) Relation PLOTDATA with two attributes, the first being the tile part number PARTNO and the second can be given any name but must contain the data to be plotted for each tile.

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The capabilities of the RIM Interactive Executive are used to form the relation PLOTDATA prior to execution of the graphic display program.

NOS Control Statements

After the user has formed the desired relation PLOTDATA containing data to be plotted, the following statements are used to initiate execution of the graphics display program.

1.   GET, IN = RIMPLOT.

2.   CALL, PRIMGLG.

The source code for the graphics display program is contained in the file RIMPLOT and the procedure file PRIMGLG contains the following statements to compile, load, and initiate program execution.

```
RETURN(LGO)
RFL(101000)
REDUCE(-)
FTN,I=IN,L=XX.
GET(LIBR=RIMLIB)
ATTACH(LIBFTEK/UN=LIBRARY,NA)
ATTACH(LRCGOSF/UN=LIBRARY,NA)
LDSET(LIB=LIBR/LIBFTEK/LRCGOSF,MAP=SBEX/LMAP)
LGO.
```

The statements above will generate displays on an interactive terminal. For generation of plots on an offline plotter, appropriate graphics postprocessor statements must be appended to the PRIMGLG file as illustrated by the following

```
PLOT.CALPOST,33(XO = 1., YO = 1.)
```

```
CONT.//LEROY PEN .2, BLANK PAPER//
```

User Input

Four lines of input data are used to control operation of the graphics display program. These input data are in free-field format and each line is input following a question mark (?) prompt during interactive operation or on successive card images for batch operation.

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Line 1.   The first line contains six real values:

XORG, DX, YORG, DY, XSIZE, YSIZE

where

XORG and YORG are the coordinates of a point in the Orbiter system at which the origin of a local plotting reference frame is located. This origin is located at the lower left-hand of the plot.

DX and DY are the distances in the X and Y Orbiter system represented by 1 inch in the horizontal and vertical plot directions. DY is usually input as a negative value to obtain the desired view of tiles on the lower surface of the right wing.

XSIZE and YSIZE gives the lengths of the horizontal and vertical axes that are included on the plot. These lengths are usually specified such that all tiles will be plotted within the area defined by the axes.

Line 2.   This line contains an integer to indicate the type of data in the second attribute of relation PLOTDATA which is to be annotated on the plot.

where

type = 1 is for TEXT

2 is for INT

3 is for REAL

Line 3.   This line contains an integer which controls the annotation on each tile and depends on the type of data specified in line 2.

If type = 1; Enter the number of letters

If type = 2; Enter -1

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If type = 3; Enter -1 to suppress the decimal point and following digits

or Enter N, the number of digits to be retained after the

decimal point.

Line 4.   This line contains two integers which specify the range of tile part numbers

to be included on the plot.

.   Enter N1 and N2

where N1 is the minimum part number

N2 is the maximum part number

All tiles with part numbers between or equal to N1 and N2 will be plotted.

USE OF AUTOMATED STRESS ANALYSIS SYSTEM

The stress analysis of large numbers of tiles can be performed in a single computer run using the automated stress analysis system. This system is composed of programs and data files necessary for data communication between the nonlinear stress analysis program and RIM. The system automates the entire process beginning with access of tile data from RIM through execution of the nonlinear stress analysis program and subsequent storage of calculated tile stresses. This system is shown schematically in figure 3 and user instructions are given in this section.

NOS Control Statements

NOS control statements are used to invoke the programs and data files shown in figure 3 as needed in the stress analysis process. Because of computing time requirements for the nonlinear stress analysis procedure, interactive use of the system is effective when only a few tiles are to be analyzed. For the analysis of a large number of tiles and/or load cases, operation of the system in a batch mode is desirable. The following control statements are applicable to both interactive and batch operation.

1. GET, TILEDB1 = W3DB1.

2. GET, TILEDB2 = W3DB2.

3. GET, TILEDB3 = W3DB3.

4. GET, IN1 = INPUT1.

5. GET, IN2 = INPUT2.

6. GET, LOADEF = LOADEFW. (or LOADEFM)

7. GET, MODEL = MODELW.   (or MODELM)

8. CALL, EXECANL.

9. NOS statements used to print or save any

   • of the computer files which are generated during

   • the stress analysis process.

Statement	Explanation
1-3.	Used to make the data base files available for use as described in preceding sections.
4.	INPUT1 is the permanent file name for user created input data to the Data Access Program shown with the local file name IN1 and whose contents are described in the next subsection.
5.	INPUT2 is the permanent file name for user created input data to the Analytical Model Generation Program shown with the local file name IN2 and whose contents are described in the next subsection.
6.	LOADEF is the local file name of the Data Access Program LOADEFW for the W3 or W4 tile zones or LOADEFM for the MF5 or MF6 zones.
7.	MODEL is the local file name of the Analytical Model Generation Program MODELW for the W3 or W4 tile zones or MODELM for the MF5 or MF6 zones.

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Statement	Explanation
8.	EXECANL is a file of NOS control statements for sequential execution of the Data Access Program, the Analytical Model Generation Program, and the Stress Analysis Program.

File EXECANL contains the following control statements:

```
    RETURN,LGO.

    RFL(101000)

    REDUCE (-)

    REWIND(IN1, IN2)

    REWIND(LOADS,CORNPT,NAML)

    REWIND(LOADEF)

    FTN(I = LOADEF, L = PR1)

(a) GET, LIBR = RIMLIB.

    LDSET(LIB = LIBR,MAP = SBEX/LMAP)

(b) LGO(IN1,,LOADS,CORNPT,NAML)

    REWIND,LOADS,CORNPT,NAML,MODOUT.

    RETURN,LGO.

    REWIND(MODEL)

    FTN(I = MODEL, L = PR2)

    ATTACH,FTNMLIB/UN = LIBRARY.

    LDSET(LIB = FTNMLIB, MAP = SBEX/LMAP)

(c) LGO(IN2,,LOADS,CORNPT,MODOUT.

    RETURN,LGO.

    REWIND,LOADS,CORNPT,MODOUT.

    GET,COMAND = BCOMTN.

(d) COMAND(MODOUT,OUT,STRESS)

    COMMENT.MODOUT = INPUT,OUT = OUTPUT,STRESS = STRESS FILES

    REWIND,MODOUT,OUT,STRESS.
```

The functions of these control statements are given in reference 5 and the contents of the associated files are described here in. Additional explanations of statements (a), (b), (c), and (d) follow (and refer to fig. 3):

Statement	Explanation
(a)	The RIM FORTRAN Interface is stored as a permanent file named RIMLIB.
(b)	This statement executes the Data Access Program with,

                Input files   IN1

                Output files   LOADS,CORNPT,NAML

| (c) | This statement executes the Analytical Model Generation Program with, |

                Input files   IN2,LOADS,CORNPT

                Output files   MODOUT

| (d) | This statement executes the Stress Analysis Program with |

                Input files   MODOUT

                Output files   OUT, STRESS

The contents of the output files are discussed in a following subsection entitled "Program Output."

User Input

Use of the automated stress analysis system requires two files of user prepared input data, shown in figure 3 as IN1 and IN2. These files are used to select tiles, to specify load conditions, and to specify pad configuration parameters for a particular analysis. These input data are in list directed input form on 80-column card images as described in reference 1. A description of the contents of IN1 follows:

Contents of input file, IN1:

"TILEDB"

"TILEZONE"	PARTNO1	PARTNO2	"FLTCOND"	MACHNO	AEROPANL	"DENSIFIED"
●						
●						
●						
"TILEZONE"	0	0	"FLTCOND"	0.0	0	"0"

Alphanumeric input must be enclosed with quotation marks (") as shown. A floating point value of MACHNO is input and PARTNO1, PARTNO2, and AEROPANL are integers. Definition of input values:

TILEDB   - The name used to identify the three local data base files. This alphanumeric name is used in opening these files and needs only be input at the beginning of file IN1.

Subsequent lines in file IN1 are used to select tiles to be analyzed and to specify the flight conditions. Such lines can be repeated as many times as required and the file is terminated using zeros for the numerical values.

TILEZONE - An alphanumeric name (W3, W4, MF5, or MF6) used to identify the tile zone on analysis output. This name has no other effect on the data access program.

PARTNO1   - The minimum value of tile part number to be selected for analysis. A tile part number is a unique 9-digit integer consisting of a drawing number concatenated with a dash number. A zero value is used to denote the end of the input list.

PARTNO2 - The maximum value of tile part number to be selected for analysis.
Tiles with part numbers greater than or equal to PARTNO1 and less than
or equal to PARTNO2 are selected for analysis subject to further
restrictions by AEROPANL and DENSIFIED. Therefore, a sequence of
tiles can be selected, or only a single tile if PARTNO1 is equal to
PARTNO2.

FLTCOND - An alphanumeric value "ASC" or "DES" used to specify the flight condition
as ascent or descent, respectively. Currently, data are available
for only the ascent condition, so "ASC" must be used.

MACHNO   - The value of Mach number from the flight trajectory at which the stress
analysis is to be performed.

AEROPANL - Only tiles that correspond to the aerodynamic panel input by this value
will be selected for analysis. The location of these aerodynamic
panels is shown in figure 12. In general, different panels have
different critical Mach numbers so this option to restrict tile
selection by aerodynamic panel is needed. If the user does not wish
to restrict tile selection, a zero may be entered for this value.

DENSIFIED - Only tiles having the densification status specified by this input
value will be selected for analysis. Available options are:
"Y" - select only densified tiles
"N" - select only undensified tiles
"O" - select both densified and undensified tiles

The second user prepared input file is required by the analytical model
generation program and is denoted as "Input 2" in figure 3. This input file,
called IN2, is used to specify pad configuration parameters and to specify

load cases to be used in the analysis of the tiles selected in IN1. A description of the contents of IN2 follows:

Contents of input file, IN2.

1. Namelist $DATA containing pad configuration parameters.

2. An indicator to specify whether or not a filler bar is to be used in the analyses.

3. A "CONTROL" command to define parameters which control the nonlinear stress analysis and resulting printed output.

4. A sequence of "NONSTRESS" commands to specify sets of load case and imperfection combinations to be used in the analyses.

A description of these four categories of input follows:

1. The representation of the strain isolator pad (SIP) in the analytical model includes an "edge softening" effect which occurs near the edge of the SIP. The method of handling this edge softening is shown schematically in figure 13. The SIP is represented as a center region surrounded by bands of SIP having progressively less stiffness in tension. In compression all regions have the same stiffness. Separate stress-displacement curves for each of the SIP regions are developed using test data for an actual SIP pad which is like a composite of the SIP regions. The center region is given a higher stiffness than the measured composite value and constant multipliers are applied to either the stress or displacement values to obtain the curves for the less stiff bands. The case of multiplying the displacements by constants is illustrated in figure 13 and was determined to be the preferable method to account for edge softening in studies performed using this automated system. Although the method of input is general, the configuration used in studies had two 0.25-inch wide bands with displacement multiplying factors of $K_1 = 1.25$ and $K_2 = 1.50$.

Points on the stress-displacement curve for the center region were
determined such that the sum of forces produced by different stresses
of each individual SIP area would equal the force produced by a stress
from the test curve acting over the total area. The stress-displacement
curve for the center region was adjusted for the edge softening effect
before storage in the data base. As mentioned previously, a curve for a
proof stress of 6.0 psi is used for tiles with an actual proof stress of
6.5 psi or less and an 8.0 psi proof curve is used for all other tiles.

The namelist $DATA used for describing these pad parameters contains the
following values:

NPAD   - An integer specifying the total number of pads defined including the
filler bar, SIP bands, and SIP center region. A filler bar must be
defined although there is a later option to eliminate it from the
analysis. Therefore, NPAD must be equal to or greater than 2.

WIDTH   - An array with the filler bar width being the first value, followed by
widths of the outer to inner SIP bands. Therefore, this array must
contain NPAD-1 values.

FACD   - An array of multiplying factors to be applied to the displacement values
in the tensile portion of the stress-displacement curve starting with
the outer band and progressing to the center region. This array
must contain NPAD-1 values. If scaling of displacements is not done
these values should all be unity.

FACS — An array of multiplying factors to be applied to the stress values in the tensile portion of the stress-displacement curve starting with the outer band and progressing to the center region. This array must contain NPAD-1 values. If scaling of stresses is not done these values should all be unity.

A $ character is used to terminate the namelist.

2. The option to eliminate the filler bar from the analysis is intended for use when linear SIP properties are specified. The material curve for a filler bar which is linear in the compression region is not continuous into the tension region and, hence, will not produce linear results. The indicator is an alphanumeric word in listed directed format as follows:

   "NONLINEAR" - a filler bar is used in the analysis

   "LINEAR"   - the filler bar is eliminated from the analysis.

3. The "CONTROL" command is used by the nonlinear stress analysis program as described in reference 1. The description of this command is repeated herein for completeness. An additional option, using IPRT = 3, for suppressing most of the printed output on TAPE6 is added to eliminate a large print file when many tiles are analyzed in a single run. Also, the maximum stress which is output on TAPE2 is selected from stresses at the SIP corner points and at the grid points specified by NCON. For no imperfections, the maximum stress will occur at a SIP corner, but this location is not necessarily the location of maximum stress when imperfections are included and a large value of NCON should be used.

Command: "CONTROL"

Purpose: The "CONTROL" command is used to define parameters which control the nonlinear stress analysis procedure and the resulting printed output.

Format:

"CONTROL"	IPRT	NDIV	NSTEPS	MESH	TEST	NCON
Default values	0	1	5	10	.01	0

If a "CONTROL" command is not input, the default values shown above will be used.

Description: An iterative solution procedure is used to determine the tile displacements which give equilibrium between the applied loads and reaction of the integrated material stresses in the pads. The accuracy of solution and required computational time are controlled by the values of NSTEPS, MESH, and TEST. The quantity of printed output is controlled by the values of IPRT, NDIV, and NCON.

During the solution procedure, the total applied tile load, which is specified as the combination of load cases on a "NONSTRESS" command, can be applied as a sequence of equal load increments or steps. A converged solution is obtained at each load step. The following values control this solution process:

IPRT - = 0 Print iteration history and resulting stresses at the final load step which is the total applied load.

= 1   Print iteration history at each of NSTEPS
        load steps and print stresses for only the
        final load step.

= 2   Print both iteration history and resulting
        stresses at each load step.

= 3   Print input information only.

NDIV   -   Specifies the number of points along edges
             of pads at which stresses will be calculated
             and printed.

NSTEPS -   Number of load steps to be used in the
             solution process. A larger number of steps
             requires less iterations per step to reach
             convergence. The number of load steps which
             will result in minimum computational time
             is problem dependent. For efficiency,
             NSTEPS should be unity when only linear
             materials are used.

MESH   -   Defines the refinement of a mesh of sub-
             triangles used for numerical integration of
             stresses over a triangular region of a SIP
             or filler bar. Each side of the triangular
             region is divided into "MESH" equal intervals
             in forming the subtriangles. A linear
             distribution of stress is assumed over each
             subtriangle in the mesh. Therefore, greater

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accuracy but longer computation time results from a finer mesh. An example of the sub-triangle pattern for MESH = 4 is shown below.
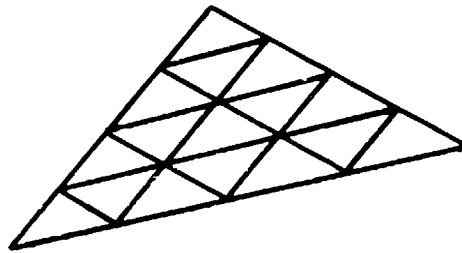
TEST   -   The convergence test parameter for the iterative solution procedure. The iterations are terminated when the difference between each component $(F_x, F_y, F_z, M_x, M_y, M_z)$ of the externally applied loads and pad material reactions is less than the value of TEST.

NCON   -   Number of intervals along both axes of a rectangular grid over each pad at which stresses will be printed. Up to 34 intervals may be specified. If NCON is specified as zero, the stress distributions at the corners of the pad will be calculated exclusively. The boundary of a rectangular grid is calculated from the minimum and

maximum local x and y coordinate values
of the corner points of the pad. If the
pad itself is not rectangular, values on the
grid outside the pad boundary will be printed,
but should not be mistakenly interpreted as
SIP stresses. Only values inside the pad
boundary are SIP stresses.

4. The format of the "NONSTRESS" command, as described in reference 1, is
"NONSTRESS" L1   L2 . . . / IMP1   IMP2 . . . /

Each "NONSTRESS" command causes execution of the nonlinear analysis
program using the load case combination L1 + L2 + . . . and imperfections
IMP1 + IMP2 + . . . This command may be executed multiple times during a
single run for different load conditions and imperfection combinations.
In the automated analysis system, a set of load cases and imperfections
are set up automatically as part of the analytical model generation.
These load cases include separate contributions from a variety of sources
shown in figure 14 and combinations of the contributions in a manner to
represent design load cases. Detailed definitions of the loads and the
methodology used to establish the design load cases are given in
reference 4. Load cases corresponding to different locations of the
aerodynamic shock relative to the tile being analyzed, as shown in
figure 15, are included. When the shock is ahead of the tile, values
for aerobuffet are used for the aerodynamic loading and aerodynamic shock
values are used when the shock is located on the tile. Load cases are
calculated as the shock is positioned at equal increments across the tile
at each 10 percent of the distance between the minimum and maximum
dimension in the global x-direction.

A list of available load cases with corresponding imperfections is given in table 3. Design load cases are given first followed by separate contributions. The load source contributions for vent lag, skin friction, and substrate deformation are the same whether the shock is ahead or on the tile but have been repeated in the list for clarity.

The applied force and moment components for the vibroacoustic deflection and the substrate deformation are all zeros. The vibroacoustic deflection has a long wavelength associated with the first mode of the structural panel and the maximum amplitude is positioned at the center of the tile. The substrate deformation has a short wavelength for stiffened skin structural panels and the maximum amplitude is positioned at the front corner of the center SIP region which is generally the location of maximum stress. Honeycomb core structural panels are used in the W-4 tile zone and the substrate deformations have long wavelengths and are positioned at the tile center. The positioning of these substrate deformations and deflections to give maximum stress was guided by the criterion presented in reference 6.

System Output

Several files of analysis information are produced during execution of the automated stress analysis system. These files are all formatted for display on an interactive terminal or for printed output. The disposition of these files is the user's responsibility and they are not output automatically in any form. Brief descriptions of these files follow with detailed contents of file NAML given in appendix B and an example discussed in the section entitled "Sample Problem."

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Three files are generated by the tile loads program: (1) CORNPT containing tile corner points and pad material curves, (2) LOADS containing a variety of load parameters needed for analysis, and (3) NAML for outputting the LOADS file contents in namelist format. Files CORNPT and LOADS are used directly as input to the analytical model program and are not of interest to the user since their contents are available in other forms intended for interpretation and assessment by a user. File NAML can be printed to give the contents of the LOADS file in namelist format. The description of each value is given in appendix B.

The corner point coordinates and pad material curves are part of the file MODOUT which is produced by the analytical model generation program. This file also contains force and moment components and imperfection descriptions for the load cases discussed in the previous section. File MODOUT consists entirely of input commands to the nonlinear stress analysis program which can be interpreted from the descriptions given in reference 1.

Detailed output from the nonlinear stress analysis program is written on a file named OUT. The quantity of printed data on OUT is controlled by the IPRT parameter on the "CONTROL" command as discussed in the previous section. For use in the automated system this parameter is usually set to give minimum printout (IPRT = 3) unless a full output for the analysis of a single tile is desired for diagnostic purposes. The maximum stress values that are calculated for each tile are of primary interest. Such information is output on a file named STRESS which contains a table of values with each line containing (1) the tile part number, (2) the load case identifier, (3) Mach number, (4) dynamic pressure, (5) angle of attack, and (6) maximum stress. This table can be subsequently processed to add the actual proof stress level for the tile and the ratio, actual proof stress divided by calculated maximum stress. This stress ratio is used for assessment of the integrity of each tile.

CONCLUDING REMARKS

An automated system which combines an engineering data management system with a nonlinear stress analysis program to provide a capability for analyzing a large number of tiles on the Space Shuttle Orbiter is described. Tile geometry data and all data necessary to define the tile loads environment during ascent are stored in the data management system and these data are accessed automatically as needed for the analysis of a particular tile or a set of tiles. The system currently contains approximately 600,000 words of data necessary to analyze the 8,000 tiles on the lower surface of the wing and midfuselage.

User documentation for the automated tile analysis system is given in this report including (1) descriptions of computer programs and data files contained in the system, (2) definitions of all engineering data stored in the data base, (3) characteristics of the tile analytical model, (4) instructions for preparation of user input, and (5) a sample problem to illustrate use of the system. Descriptions of data, computer programs, and analytical models of the tiles are given in sufficient detail to guide extension of the system to include additional zones of tiles and/or additional types of analyses.

RELATION AND ATTRIBUTE DESCRIPTION

This appendix contains detailed descriptions of the relations and attributes used to store the engineering data as shown in figure 5. The descriptions are presented in the same order as in the general, narrative discussion in the section entitled "Engineering Data." The order of presentation is:

XYZO

TIPSDATA

MATINDEX

MATCURVE

DIRECT

SUBPANL

SUBDEFL

VIBAC (WING)

VIBAC (FUSL)

NEWAPANL

NEWLOADS

STS1TRAJ

FORCEMOM

STRS4-24-1

The data types (integer, real, or text) were specified for each attribute in the schema definition of the RIM data files and are indicated herein as INT, REAL, or TEXT at the beginning of each description. All attributes are a single word in length with TEXT referring to a single alphanumeric word with up to 10 characters.

Relation: XYZO

    Con⁺ents: Tile corner points defined in the Orbiter system for the

                             right hand side of the Orbiter.

    Source: NASA requested tape prepared by the master dimensions group

                             at RI which contained tile corner points in local

                             coordinates. A correspondence table giving the coordinate

                             system for each drawing number and the local to Orbiter

                             transformation equations was also obtained from RI.

    Attributes:

      PARTNO   -   (INT) A 9-digit tile part number formed by combining the

                             drawing number and dash number for a tile.

      DRAWNO   -   (INT) A 6-digit tile drawing number.

      IMLOML   ~   (TEXT) A 3-character word indicating the location of the

                             corner point in a particular tuple; IML or OML for inner

                             or outer mold line, respectively.

      XLOCAL
      YLOCAL   -   (REAL) X,Y,Z values in local coordinates in inches
      ZLOCAL

      TRANSF   -   (TEXT) Local to global transformation indicator from

                             correspondence table

      XORBITER
      YORBITER   -   (REAL) X,Y,Z values in Orbiter coordinates, in inches
      ZORBITER

Relation: TIPSDATA

Contents: Selected data from TIPS data base for tiles on both sides of the Orbiter.

Source: NASA requested tape prepa⋅ ' by Tile Information Processing System (TIPS) group at RI.

Attributes:

PARTNO - (INT) A 9-digit tile part number.

LEFTORRT - (TEXT) A 1-character indicator specifying the tile location. R, L, and C for right, left, and center of Orbiter, respectively.

OPPPARTNO - (INT) Corresponding tile part number located symmetrically on the opposite side of the Orbiter.

DENSIFIED - (TEXT) A 1-character indicator Y or N specifying yes the tile is densified or no the tile is not densified.

ACTPROOF - (REAL) The stress level to which the tile was actually proof tested, in psi.

Relation: MATINDEX

Contents: An index giving the attributes of a specified pad material indicator.

Source: Developed for use in automated data management/analysis system.

Attributes:

PADTYPE   —   (TEXT) An indicator of pad type; FB for filler bar or SIP for strain isolator pad.

SIPTHCK   —   (REAL) Pad thickness, either 0.09 or 0.16 inch

PROOF   —   (INT) Stress to which the material was proof tested prior to the test to generate a stress-displacement curve. The integers 6 and 8 indicate proof stresses of 6.0 and 8.0 psi, respectively.

MATNO   —   (INT) A pad material indicator which has a corresponding material curve in relation MATCURVE.

Relation: MATCURVE

Contents: Each tuple is a point on a stress-displacement curve for a specified material pad. The SIP curves are for the center region of a pad that has been adjusted for edge effects.

Source: Test data generated by W. Sawyer at NASA-LaRC and adjusted for edge effects by W. Elber at NASA-LaRC.

Attributes:

MATNO   —   (INT) A pad material indicator.

DISPL   —   (REAL) Value of displacement, in inches.

STRESS   —   (REAL) Value of stress, in psi.

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Relation: DIRECT

    Contents: A directory of assorted data for each tile containing data required in the automated stress analysis procedure.

    Source: These data are calculated by a data preparation computer program written by M. Vallas at LaRC.

    Attributes:

      PARTNO   -   (INT) A 9-digit tile part number.

      DRAWNO   -   (INT) A 6-digit tile drawing number.

      DASHNO   -   (INT) A 3-digit dash or tile number.

      ARRAYNO   -   (INT) Array number used on engineering drawings.

      IMLPTS   -   (INT) Number of tile corner points on the inner and outer
      OMLPTS   mold lines, respectively.

      SUBSPANL   -   (INT) Number designator of the substrate panel on which the tile is mounted. This number refers to a panel defined in relation SUBPANL and points to deflection data given in relation SUBDEFL.

      CGTORIB   -   (REAL) Distance from the tile center of gravity to the closest wing rib or fuselage frame, in inches.

      RIBTORIB   -   (REAL) Distance between wing ribs or fuselage frames for panel on which the tile is located, in inches.

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CGTOLE   -   (REAL) The x-distance from the tile center of gravity to the leading edge of the Orbiter planform, in inches.

NODEORDR   -   (INT) An indicator used by the analytical model generation program to specify whether or not the order of the corner points needs to be reversed before generation of tile geometry. The integer 1 indicates no reordering and a -1 indicates reordering is needed.

CGXI   CGYI   -   (REAL) Average X and Y coordinates of inner mold line tile corner points in the Orbiter coordinate system, in inches.

TILETHCK   -   (REAL) Tile thickness calculated by averaging the corner point thicknesses, in inches.

SIPTHCK   -   (REAL) Thickness of the strain isolator pad obtained from the TIPS data base, in inches.

TILEDENS   -   (REAL) Density of tile material, either 9.0 or 22.0 lbm/ft^3.

Relation: SUBPANL

Contents: Corner points of skin panels in the Orbiter structure on which substrate deformations were defined.

Source: These data were extracted from ASKA finite element structural models by JSC personnel.

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Attributes:

SUBSPANL   –   (INT) Designator for a substrate panel.

X1
Y1
Z1
•
•
•
X4
Y4
Z4

–   (REAL) The X, Y, Z coordinates of the panel corners in the orbiter system, in inches. For triangular panels, X4, Y4, and Z4 are zero.

Relation: SUBDEFL

Contents:

Deformations of the substrate panels.

Source:

These data were compiled by NASA-JSC personnel from subcontractor reports.

Attributes:

SUBSPANL   –   (INT) Designator for a substrate panel.

LOADNO   –   (INT) Unique load case number (should not be confused with load case number for "NONSTRESS" command).

FLTCOND   –   (TEXT) Flight condition indicator such as HI-Q, ENTY, DCNT, or LAND for high-q, entry, descent, and landing.

DEFLSKIN   –   (REAL) Deflection of the skin sheets between stringers of a stiffened panel, in inches.

DEF STRNG   –   (REAL) Deflection of the stringer, in inches.

WAVESKIN   –   (REAL) Wavelength of the deflected skin sheet, is usually the distance between stringers, in inches.

WAVESTRNG   -   (REAL) Wavelength of the deflected stringer, usually the length of the stiffened panel, in inches.

Relation: VIBAC (WING)

Contents: Vibroacoustic loading data for the W-3 and W-4 tile zones on the wing.

Source: Report prepared by J. West of RI.

Attributes:

TILESIZE   -   (TEXT) Description of tile planform such as 6x6 or 3x6.

ONOFFRIB   -   (TEXT) The word ON indicates the tile is located on a rib and OFF for off of a rib.

FLTCOND   -   (TEXT) Flight condition indicator, only ASC, for ascent data, is available.

TILETHCK   -   (REAL) One of a specified set of tile thicknesses, in inches. Vibroacoustic data for actual tile thicknesses are obtained by interpolation.

MACHNO   -   (REAL) One of a specified set of Mach numbers. Vibroacoustic data for intermediate Mach numbers are obtained by interpolation.

GPEAK   -   (REAL) Peak value of acceleration given in g's. The peak value is three times the RMS value.

DISPL   -   (REAL) The displacement of the center of the substrate panel in its first mode of response, in inches.

Relation: VIBAC (FUSL)

Contents: Vibroacoustic loading data for the MF-5 and MF-6 tile zones on the fuselage.

Source: Report prepared by J. West of RI.

Attributes:

VIBPANL1   -   (INT) Vibroacoustic data for the fuselage is defined over
VIBPANL2   regions which are composed of several substrate deflection panels, having the designator numbers between VIBPANL1 and VIBPANL2 as defined in relation SUBPANL.

FROMFRAME   -   (INT) An integer indicating bounds on the x-distance from a frame for which the vibroacoustic data is applicable

1 = On frame.

2 = Less than 15 inches from frame.

3 = 15 to 20 inches from frame.

4 = 20 to 30 inches from frame.

FROMCL   -   (INT) An integer indicating bounds on the y-distance from the Orbiter centerline for which the vibroacoustic data are applicable.

1 = Less than or equal to 70 inches from centerline.

2 = Greater than 70 inches from centerline.

MACHNO   -   (REAL) One of a specified set of Mach numbers. Vibroacoustic data for intermediate Mach numbers are obtained by interpolation.

GPEAK   -   (REAL) Peak value of vibroacoustic acceleration given in g's. The peak value is three times the RMS value.

DISPL   -   (REAL) The displacement of the center of the substrate panel in its first mode of response, in inches.

SPAN   -   (REAL) Panel span from J. West report which is taken to be distance between major support points at frames, in inches.

Relation: NEWAPANL

Contents: Gives the aerodynamic panel corresponding to each tile. Aerodynamic load parameters are taken to be constant within each panel.

Source: The layout of the aerodynamic panels was selected by J. Tulinius of NASA-LaRC for definition of all aerodynamic load parameters.

Attributes:

PARTNO   -   (INT) A 9-digit tile part number.

ETA   -   (REAL) Fraction of semispan location of the tile. $(0.0 \leq ETA \leq 1.0)$

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XOC — (REAL) Fraction of chord location of the tile.

$(0.0 \leq XOC \leq 1.0)$

CHORD — (REAL) Length of the aerodynamic chord at the y-location

of the tile, in inches.

AEROPANL — (INT) Number designator of the aerodynamic panel

corresponding to the tile. A single aerodynamic panel is

used for all tiles in the MF-5 tile zone and a single

aerodynamic panel is used for all tiles in the MF-6

tile zone. Both panels are designated by the number 1

but each panel refers to different sets of numerical values

for the aerodynamic parameters in their respective data

bases. The wing planform which contains tile zones

W-3 and W-4 is divided into 12 aerodynamic panels as

defined in table 2 and shown in figure 12.

Relation: NEWLOADS

Contents: Aerodynamic loading parameters which were obtained from

wind tunnel test data. These parameters are given as a

function of Mach number and angle of attack and are all

in coefficient form having been nondimensionalized with

respect to dynamic pressure, QPSF, so they are applicable

to any flight trajectory.

Source: The steady aerodynamic parameters such as shock strengths

and aerodynamic gradients were prepared by J. Tulinius

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of NASA-LaRC. The unsteady aerodynamic (aerobuffet)
parameters were prepared by C. Coe of NASA-Ames.

Attributes:

AEROPANL   -   (INT) Aerodynamic panel designator.

MACHNO   -   (REAL) One of a specified set of Mach numbers. Aero-
                 dynamic data for intermediate Mach numbers are obtained
                 by interpolation.

ALPHA   -   (REAL) Angle of attack, in degrees. Data are available
                 for -4.0° and +4.0° and data for intermediate values is
                 interpolated.

SHOCKJUMP   -   (REAL) Coefficient for pressure differential or jump
                 across a shock in unseparated flow, where

                 ΔP_{shock} = SHOCKJUMP*(QPSF/144.0).

SEPARJUMP   -   (REAL) Coefficient for pressure differential or jump
                 across a shock in separated flow, where

                 ΔP_{sep} = SEPARJUMP*(QPSF/144.0).

AEROGRX   -   (REAL) Coefficient for pressure gradient in x-direction,
                 where

                 dP/dx = AEROGRX*(QPSF/144.0)/CHORD

                 where QPSF given in relation STS1TRAJ

                        CHORD given in relation NEWAPANL

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AEROGRY   —   (REAL) Coefficient for pressure gradient in y-direction, where

$$dP/dy = AEROGRY*(QPSF/144.0)/CHORD$$

ABSHKCPRMS —   (REAL) Coefficients for RMS pressure for shock on tile and
ABSEPCPRMS   shock ahead of tile, respectively. These coefficients
are used to calculate aerobuffet loads as follows:

    The aerobuffet loads on an Orbiter tile are assumed to
be in the same ratio, R, as for data from the OS-52
tile test performed by C. Coe at NASA-Ames, i.e.,

Tile aerobuffet load = R*(ABSHKCPRMS or ABSEPCPRMS)

where R = (OS52 buffet load coefficient)/(OS52 RMS

pressure coefficient). Nondimensionalization is such

that for the shock on the tile:

Buffet Force = R*ABSHKCPRMS*TILE AREA*(QPSF/144.0)

Buffet Moment = R*ABSHKCPRMS*TILE AREA*(TILE DIAGONAL/$\sqrt{2}$)*
(QPSF/144.0)

Similar expressions containing ABSEPCPRMS are used for

the shock ahead of the tile. The values of R for the

cases considered are shown in the following table.

	Shock on tile	Shock ahead of tile
Normal force	.180	.45
Pitch moment	.042	.10
Roll moment	.026	.083

REFPRESS   -   (REAL) A pressure coefficient used to establish a reference
                 pressure, PFOOT, on the tile with respect to the
                 ambient pressure, PINF, using the following equation:

PFOOT = REFPRESS*(QPSF/144.0) + PINF/144.0

where

PFOOT is a reference pressure on the tile at the front
or beginning of a shock;

PINF is the ambient pressure which is given as a function
of Mach number for a given flight trajectory as in
relation STS1TRAJ.

Relation: STS1TRAJ

Contents: Parameters for STS-1 cycle 3 ascent flight trajectory.

Source: Extracted from the <u>Space Shuttle Flight Systems Performance</u>
                 <u>Data Book, Volume I - Ascent</u>, Rockwell International,
                 Space Division.

Attributes:

MACHNO   -   (REAL) Mach number.

ALPHA   -   (REAL) Angle of attack, in degrees.

QPSF   -   (REAL) Dynamic pressure, in psf.

PINF   -   (REAL) Ambient pressure, in psf.

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Relation: FORCEMOM

Contents: Steady aerodynamic loads given in terms of total forces and moments at the critical time and associated Mach number in the STS1 flight trajectory for each of the aerodynamic panels.

Source: These forces and moments were calculated using a multitile three-dimensional flow model developed by a NASA-LaRC group led by G. Ivey.

Attributes:

AEROPANL - (INT) Aerodynamic panel designator.

MACHNO - (REAL) The critical Mach number in the STS-1 trajectory for the subject aerodynamic panel. The loading parameters are applicable only for this condition.

TILETHCK - (REAL) Either the minimum or maximum tile thickness within the subject aerodynamic panel. Load parameters for intermediate tile thicknesses are obtained by interpolation.

BLTHCK - (REAL) Either the minimum or maximum boundary layer thickness within the subject aerodynamic panel. Load parameters for intermediate boundary layer thicknesses are obtained by interpolation.

XSL - (REAL) Location of shock given as a fraction of the tile diagonal. Load parameters are available for

XSL = 0.0, 0.25, 0.5, 0.75, 1.0 and intermediate values
are obtained by interpolation.

FORCEZ   -   (REAL) Coefficient for normal force acting on tile where

$$F_{TILE} = FORCEZ*(QPSF/144.0)*TILE\ AREA$$

MOMENTY   -   (REAL) Coefficient for pitching moment acting on tile
                 where

$$M_{TILE} = MOMENTY*(QPSF/144.0)*TILE\ AREA*TILE\ DIAGONAL$$

Relation: STRS4-24-1

Contents: Maximum stresses for each tile which are calculated by the
                nonlinear stress analysis program

Source: Calculations were made on April 24, 1981, using the aero--
                dynamic loads contained in the relation FORCEMOM.

Attributes:

PARTNO   -   (INT) A 9-digit tile part number.

LDCASE   -   (INT) Load case number, corresponding to an entry in
                table 3, which was used in the tile analysis for these
                results.

MACHNO   -   (REAL) Mach number.

STRESSMX   -   (REAL) Maximum calculated stress, in psi.

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ACTPROOF   –   (REAL) The stress level to which the tile was actually proof tested, in psi.

SRATIO   –   (REAL) The stress ratios calculated as

$$SRATIO = ACTPROOF/STRESSMX$$

APPENDIX B

CONTENTS OF FILE NAML

This appendix contains the definition of variables in the file referred to by the name NAML in this report. File NAML is generated by the data access program and contains sets of loads information for all tiles included in an analysis run. The information is in printed format for the namelist $LOADS. Each namelist contains information for single tile.

Variable	Definition
IPARTNO	A 9-digit tile part number formed by combining the drawing number and dash number for a tile.
IDRAWNO	A 6-digit tile drawing number.
IARRAY	A tile array number.
SIPTHK	Pad thickness, either 0.09 or 0.16 inch.
TILTHK	Tile thickness calculated by averaging the corner point thicknesses, in inches.
TILDEN	Density of the tile material, either 9.0 or 22.0 lbm/ft^3.
XMACH	The Mach number at which the analysis is to be performed as specified by the user in INPUT 1 to the data access program.
DYNP	The dynamic pressure corresponding to the Mach number XMACH from the ascent trajectory given in relation STS1TRAJ, in lbf/ft^3.

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Variable	Definition
GPEAK	Peak value of vibroacoustic acceleration given in g's. The peak value is three times the RMS value.
DISPL	Half amplitude of the displacement of the center of the substrate panel in its first mode of response, in inches.
RIBTORIB	Half width of the substrate panel, in inches; is used as the half-wavelength of a cosine wave describing the vibroacoustic deflection.
BLTHK	Aerodynamic boundary layer thickness at the tile center of gravity; calculated using the equation given in figure 8.
SIDEMAX	Length of longest tile side, in inches. This value was used for a Rockwell International shock model and not used currently for loads calculations.
SKFORCE	Skin friction force acting on tile, in lbf; calculated using the equation in figure 9 and further dividing by a correction factor of 2.75.
PVENT	Pressure from lag in tile venting during ascent; taken as a constant 0.15 lbf/in^2.
DEFLSK	Half amplitude of the deflection of skin sheets between ribs of a stiffened panel, in inches; used for substrate deflection load contribution.

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Variable	Definition
DEFLST	Half amplitude of the deflection of the stringer, in inches.
WAVESK	Half-wavelength of a cosine wave describing the skin substrate deflection, in inches.
WAVEST	Half-wavelength of a cosine wave describing the stringer substrate deflection, in inches.
NORDER	An indicator used by the analytical model generation program to specify whether or not the order of the corner points needs to be reversed before generation of tile geometry. The integer 1 indicates no reordering and a -1 indicates reordering is needed.
IML	Number of tile corner points on the inner mold line.
OML	Number of tile corner points on the outer mold line.
CHORD	Length of the aerodynamic chord at the y-location of the tile, in inches.
SJUMP	Pressure differential or jump across a shock for unseparated flow on the tile, in psi.
SEPARJ	Pressure differential or jump across a shock for separated flow on the tile, in psi.
AEROGRX	Pressure gradient in x-direction, in psi/in.

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Variable	Definition
AEROGRY	Pressure gradient in y-direction, in psi/in.
ABLSFP	Aerobuffet lift force acting normal to the tile surface when a shock is ahead of the tile, in lbs.
ABMPSEP	Aerobuffet pitching moment acting about an axis normal to the flow (taken as the y-axis) when a shock is ahead of the tile, in in-lbs.
ABMRSEP	Aerobuffet rolling moment acting about an axis parallel to the flow (taken as the x-axis) when a shock is ahead of the tile, in in-lbs.
ABLSHK ABMPSHK ABMRSHK	Aerobuffet forces and moments when the shock is on the tile corresponding to the three previous definitions for the shock ahead of the tile.
PINFINI	Ambient atmospheric pressure, in psf.
REFPRES	A pressure coefficient used to establish a reference pressure on the tile with respect to the ambient pressure.
PFOOT	The reference pressure on the tile at the foot or beginning of a shock, in psi, where

PFOOT = (REFPRES*DYNP + PINFINI)/144.0

APPENDIX C

EXAMPLE ANALYSIS

This appendix contains listings of files shown in figure 3 that correspond to the analysis of a particular tile. The tile, with part number 191009144, has a 6x6 planform, has its diagonal oriented along the longitudinal axis of the Orbiter, and is located on the lower surface of the main wing box in tile zone W3. The tile is undensified and subject to the loads in aerodynamic panel number 3. Files LOADS, CORNPT, and OUT have been omitted since their contents are usually examined only for error diagnostics.

IN1 - User Input File

Contents of this file are described in the "User Input" subsection of the "Use of Automated Stress Analysis System" section.

```
"TILEDB"
"W3" 191009144 191009144 "ASC" 1.05 3 "V"
"W3" 0 0 "ASC" 0. 0 "0"
```

IN2 - User Input File

Contents of this file are described in the "User Input" subsection of the "Use of Automated Stress Analysis System" section.

```
$DATA NPAD=4,WIDTH(1)=.5,.25,.25,FACS(1)=3*1.0,
FACD(1)=1.5,1.25,1.0,$
"NONLINEAR"
  "CONTROL" 3 1 2 10 .01 10
   "NONSTRESS" 4 / 1 3 /
```

APPENDIX C

NAML - Namelist Output File for Data Access Program

```
$LOADS
IPARTNO = 191009144,
IDRAWNO = 191009,
IARRAY  = 6,
SIPTHK  = .16E+00,
TILTHK  = .15408E+01,
TILDEN  = .9E+01,
XMACH   = .105E+01,
DYNP    = .721874999909J9E+03,
GPEAK   = .461142857142J5E+02,
DISPL   = .11792857142857E-01,
RBTORB  = .97E+01,
BLTHK   = .34893638201296E+01,
SIDEMAX = .60201462905846E+01,
SKFORCE = .75013126534687E+00,
PVENT   = .15E+00,
DEFLBK  = .4E-02,
DEFLBT  = .5E-03,
WAVEBK  = .205E+01,
WAVEBT  = .975E+01,
```

NAML - Continued

```
NORDER   = 1,

IML      = 4,

IOML     = 4,

CHORD    = .66201055825E+03,

SJUMP    = .26749808146138E+01,

SEPARJ   = .19098121134448E+01,

AERDGRX  = .21778771824461E-01,

AERDGRY  = -.22187273378725E-01,

ABLSEP   = .27745209970439E+01,

ABMPSEP  = .36993814142912E+01,

ABMRSEP  = .30704865738617E+01,

ABLSHK   = .29029556864298E+01,

ABMPSHK  = .40641468820571E+01,

ABMRSHK  = .25159004507973E+01,

PINFINI  = .828645E+03,

REFPRES  = -.335903125F+00,

PFOOT    = .40705898030549E+01,

SEND

TILEZN = W3          IFLTCND = A8C          ALPHA=3.8    DENSIFIED = N
```

MODOUT - Analysis Input File

This file is produced by the Model Generatior. program and contains input commands for the nonlinear stress analysis program. These commands are described in reference 1 which should be used to interpret the contents of this file along with the discussion given herein in the section entitled "Analytical Model of Tile."

```
"TITLE"
W3      191009144     6A8C     M ■  1.05     NONLINEAR
"CASEID"    191009144          1.050    721.900     ■3.830
"NODE"      1    1222,63A7      156,9777     273,1459
"NODE"      2    1226,8814      161,2203     273,4998
"NODE"      3    1231,1240      156,9777     272,9564
"NODE"      4    1226,8814      152,7351     272,6031
"NODE"      5    1322,63A7      156,9777     271,4320
"NODE"      6    1226,A814      161,2203     271,7610
"NODE"      7    1231,1240      156,9777     271,2682
"NODE"      8    1226,8814      152,7351     270,9409
"POINT"     1    5    1      1    .160
"POINT"     2    6    ?      2    .160
"POINT"     3    7    3      3    .160
"POINT"     4    8    4      4    .160
"POINT"     1    5    1      9    .200
"POINT"     2    6    ?     10    .200
"POINT"     3    7    3     11    .200
"POINT"     4    8    4     12    .200
"CORNER"    4    1    2     13    .50      .50
"CORNER"    1    2    3     14    .50      .50
"CORNER"    2    3    4     15    .50      .50
"CORNER"    3    4    1     16    .50      .50
"CORNER"    4    1    2     17    .75      .75
"CORNER"    1    2    3     18    .75      .75
"CORNER"    2    3    4     19    .75      .75
"CORNER"    3    4    1     20    .75      .75
"CORNER"    4    1    2     21   1.00     1.00
"CORNER"    1    ?    3     22   1.00     1.00
"CORNER"    2    3    4     23   1.00     1.00
"CORNER"    3    4    1     24   1.00     1.00
"FACE"    5    6    7    8 /       .01100     .06100    25
"FACE"    \    2    3    4 /       .01100    0.00000    26
"FACE"    5    1    2    6 /       .01100     .06100    27
"FACE"    6    2    3    7 /       .01100     .06100    28
"FACE"    7    3    4    8 /       .01100     .06100    29
"FACE"    8    4    1    5 /       .01100     .06100    30
"WEDGE"     1    2    3    5    6    7 /     .00521
"WEDGE"     1    3    4    5    7    8 /     .00521
"CG"     31
```

MODOUT - Continued

```
"PAD"      1  "FB"        1    0
     1      4    3    2    1   13   14   15   16   13
 /      1    2    3 /
"MATERIAL"  1  "TABLE"    .160   2A
        -.07876      -9.95000
        -.07640      -8.96000
        -.07490      -8.36000
        -.07299      -7.69000
        -.07106      -7.10000
        -.06870      -6.46000
        -.06677      -5.95000
        -.06386      -5.32000
        -.06120      -4.87000
        -.05847      -4.35000
        -.05537      -3.88000
        -.05242      -3.49000
        -.04909      -3.09000
        -.04535      -2.72000
        -.04106      -2.31000
        -.03732      -2.01000
        -.03284      -1.70000
        -.02850      -1.41000
        -.02423      -1.16000
        -.02053       -.95000
        -.01722       -.79000
        -.01343       -.61000
        -.01112       -.50000
        -.00791       -.37000
        -.00453       -.21000
        -.00177       -.09000
       0.00000       0.00000
         .01600      0.00000
"PAD"      2  "SIP"        2    2
    13     16   15   14   13   17   18   19   20   17
 /      1    2    3 /
"PAD"      3  "SIP"        3    3
    17     20   19   18   17   21   22   23   24   21
 /      1    2    3 /
"PAD"      4  "SIP"        4    4
    21     24   23   22
 /      1    2    3 /
```

MODOUT - Continued

```
"MATERIAL"  2   "TABLE"    .160    36
       -.06000    -5.50000
       -.05600    -4.05000
       -.05200    -3.20000
       -.04800    -2.60000
       -.04400    -2.10000
       -.04000    -1.75000
       -.03600    -1.50000
       -.03200    -1.25000
       -.02800    -1.05000
       -.02400     -.85000
       -.02000     -.70000
       -.01600     -.50000
       -.01200     -.40000
       -.00800     -.30000
       -.00400     -.15000
       0.00000    0.00000
        .00600     .17000
        .01200     .38000
        .01800     .58000
        .02400     .83000
        .03000    1.15000
        .03600    1.53000
        .04200    2.00000
        .04800    2.61000
        .05400    3.55000
        .06000    4.95000
        .06600    6.35000
        .07200    8.20000
        .07800    9.60000
        .08400   11.05000
        .09000   12.10000
        .09600   12.80000
        .10200   12.95000
        .10800   12.85000
        .11400   12.60000
        .12000   11.80000
```

MODOUT - Continued

```
"MATERIAL"  3   "TABLE"   .160    56
         -.06000     -5.50000
         -.05600     -4.05000
         -.05200     -3.20000
         -.04800     -2.60000
         -.04400     -2.10000
         -.04000     -1.75000
         -.03600     -1.50000
         -.03200     -1.25000
         -.02800     -1.05000
         -.02400      -.85000
         -.02000      -.70000
         -.01600      -.50000
         -.01200      -.40000
         -.00800      -.30000
         -.00400      -.15000
        0.00000      0.00000
          .00500       .17000
          .01000       .38000
          .01500       .58000
          .02000       .83000
          .02500      1.15000
          .03000      1.53000
          .03500      2.00000
          .04000      2.61000
          .04500      3.55000
          .05000      4.95000
          .05500      6.35000
          .06000      8.20000
          .06500      9.60000
          .07000     11.05000
          .07500     12.10000
          .08000     12.80000
          .08500     12.95000
          .09000     12.85000
          .09500     12.60000
          .10000     11.80000
```

MODOUT - Continued

```
"MATERIAL"   4   "TABLE"   .160   36
    -.06000      -5.50000
    -.05600      -4.05000
    -.05200      -3.20000
    -.04800      -2.60000
    -.04400      -2.10000
    -.04000      -1.75000
    -.03600      -1.50000
    -.03200      -1.25000
    -.02800      -1.05000
    -.02400       -.85000
    -.02000       -.70000
    -.01600       -.50000
    -.01200       -.40000
    -.00800       -.30000
    -.00400       -.15000
    0.00000       0.00000
     .00400        .17000
     .00800        .38000
     .01200        .58000
     .01600        .83000
     .02000       1.15000
     .02400       1.53000
     .02800       2.00000
     .03200       2.61000
     .03600       3.55000
     .04000       4.95000
     .04400       6.35000
     .04800       8.20000
     .05200       9.60000
     .05600      11.05000
     .06000      12.10000
     .06400      12.80000
     .06800      12.95000
     .07200      12.85000
     .07600      12.60000
     .08000      11.80000
```

MODOUT - Continued

```
"NODE"    32    1226.8755      156.9953      272.0674
"FORCE"       1    32      -.667       1.138       -21.209
"MOMENT"      1    32     -2.857     -13.155         0.000
"FORCE"       2    32       .639        .571       -38.799
"MOMENT"      2    32      -.375     -30.965         0.000
"FORCE"       3    32       .639        .571       -44.505
"MOMENT"      3    32      -.375     -36.104         0.000
"FORCE"       4    32       .639        .571       -50.642
"MOMENT"      4    32      -.375     -36.714         0.000
"FORCE"       5    32       .639        .571       -56.033
"MOMENT"      5    32      -.375     -33.986         0.000
"FORCE"       6    32       .639        .571       -59.82?
"MOMENT"      6    32      -.375     -29.021         0.
"FORCE"       7    32       .639        .571       -61.47?
"MOMENT"      7    32      -.375     -22.841         0.000
"FORCE"       8    32       .639        .571       -60.787
"MOMENT"      8    32      -.375     -16.381         0.000
"FORCE"       9    32       .639        .571       -57.857
"MOMENT"      9    32      -.375     -10.492         0.000
"FORCE"      10    32       .639        .571       -53.119
"MOMENT"     10    32      -.375      -5.043         0.000
"FORCE"      11    32       .639        .571       -47.324
"MOMENT"     11    32      -.375      -3.416         0.000
"FORCE"      12    32       .639        .571       -41.544
"MOMENT"     12    32      -.375      -3.512         0.000
"FORCE"      13    32     -1.306        .567         9.202
"MOMENT"     13    32     -2.487      -2.331        -.184
"FORCE"      14    32      0.000       0.000       -12.208
"MOMENT"     14    32      0.000       0.000         0.000
"FORCE"      15    32      0.000       0.000         0.000
"MOMENT"     15    32      0.000      -3.879         0.000
"FORCE"      16    32      -.121        .571        -5.400
"MOMENT"     16    32      -.375       -.067          .001
"FORCE"      17    32       .759       0.000         0.000
"MOMENT"     17    32      0.000       -.544         -.013
"FORCE"      18    32      0.000       0.000       -21.829
"MOMENT"     18    32      0.000       0.000         0.000
"FORCE"      19    32      0.010       0.000         0.000
"MOMENT"     19    32      0.000      -5.045         0.000
"FORCE"      20    32      0.000       0.000         0.000
"MOMENT"     20    32      0.000       0.000         0.000
"FORCE"      21    32      0.000       0.000         0.000
"MOMENT"     21    32      0.000       0.000         0.000
```

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MODOUT - Continued

"FORCE"	22	32	0.000	0.000	-13.328
"MOMENT"	22	32	0.000	-13.662	0.000
"FORCE"	23	32	0.000	0.000	-19.525
"MOMENT"	23	32	0.000	-19.592	0.000
"FORCE"	24	32	0.000	0.000	-26.126
"MOMENT"	24	32	0.000	-20.991	0.000
"FORCE"	25	32	0.000	0.000	-31.951
"MOMENT"	25	32	0.000	-19.047	0.000
"FORCE"	26	32	0.000	0.000	-36.145
"MOMENT"	26	32	0.000	-14.865	0.000
"FORCE"	27	32	0.000	0.000	-38.171
"MOMENT"	27	32	0.000	-9.464	0.000
"FORCE"	28	32	0.000	0.000	-37.814
"MOMENT"	28	32	0.000	-3.777	0.000
"FORCE"	29	32	0.000	0.000	-35.182
"MOMENT"	29	32	0.000	1.343	0.000
"FORCE"	30	32	0.000	0.000	-3..702
"MOMENT"	30	32	0.000	5.131	0.000
"FORCE"	31	32	0.000	0.000	-25.123
"MOMENT"	31	32	0.000	6.904	0.000
"FORCE"	32	32	0.000	0.000	-19.518
"MOMENT"	32	32	0.000	6.065	0.000
"FORCE"	33	32	0.000	0.000	-11.612
"MOMENT"	33	32	0.000	0.000	0.000
"FORCE"	34	32	0.000	0.000	0.000
"MOMENT"	34	32	0.000	-16.256	0.000
"FORCE"	35	32	-.121	.571	-5.400
"MOMENT"	35	32	-.375	-.067	.001
"FORCE"	36	32	.759	0.000	0.000
"MOMENT"	36	32	0.000	-.544	-.013
"FORCE"	37	32	0.000	0.000	-16.371
"MOMENT"	37	32	0.000	0.000	0.000
"FORCE"	38	32	0.000	0.000	0.000
"MOMENT"	38	32	0.000	-3.784	0.000
"FORCE"	39	32	0.000	0.000	0.000
"MOMENT"	39	32	0.000	0.000	0.000
"FORCE"	40	32	0.000	0.000	0.000
"MOMENT"	40	32	0.000	0.000	0.000

"NODE"	33	1226.8614	156.9777	272.8913		
"NODE"	34	1227.8814	156.9777	272.8913		
"IMPERFECT"	2	4	33	34	.00884	9.70000	9.70000
"IMPERFECT"	3	4	33	34	.00663	9.70000	9.70000
"NODE"	35	1231.1240	156.9777	272.7064		
"IMPERFECT"	1	4	21	35	-.00400	9.75000	2.05000
"CONTROL"	3	1	2	10	.01	10	
"NONSTRESS"	4 /	1	3 /			

APPENDIX C

STRESS - Maximum Stress File

This file contains maximum stress information for each SIP surface that is calculated by the Stress Analysis program. Each 'ine of the file is written as tile part number, the load identifier, Mach number, dynamic pressure, angle of attack, and maximum stress.

```
191009144   4   1.05   721.9   -3.83   3.8044
191009144   4   1.05   721.9   -3.83   5.9959
191009144   4   1.05   721.9   -3.83   9.4065
```

Query of Relation STRS4-24-1

This query print. values of all attributes in the tuple corresponding to tile part number 191009144. The definitions of these attributes are given in appendix A.

```
? OPEN TILEDB
? SELECT ALL FROM STRS4-24-1 WHERE PARTNO EQ 191009144
  PARTNO      LDCASE      MACHNO      STRESSMX    ACTPROOF     SRATIO
---------- ---------- ---------- ---------- ---------- ----------
  191009144           4   1.0500000   9.4065000   8.0000000   0.8505000
```

REFERENCES

1. Giles, Gary L.; and Vallas, Maria: Computer Program for Nonlinear Static Stress Analysis of Shuttle Thermal Protection System - User's Manual. NASA TM 81856, May 1981.

2. Erickson, Wayne J.: User Guide: Relational Information Management (RIM). Report No. D6-IPAD-70023-M, Boeing Commercial Airplane Company, Seattle, Washington, 1981.

3. Giles, Gary L.; and Vallas, Maria: Use of an Engineering Data Management System in the Analysis of Space Shuttle Orbiter Tiles. NASA TM 83215, October 1981.

4. Muraca, Ralph J.: Shuttle Tile Environments and Loads. Presented at the 52nd Shock and Vibration Symposium. New Orleans, Louisiana, October 27-29, 1981.

5. NOS Version 1 Reference Manual. Control Data Corporation Pub. No. 60435400, Rev. H, September 1979.

6. Shore, Charles P.; and Garcia, Ramon: Effects of Substrate Deformation and SIP Thickness on Tile/SIP Interface Stresses for Shuttle Thermal Protection System. NASA TM 81855, July 1980.

TABLE 1.- PLANFORM COORDINATES OF THE ORBITER

LEADING AND TRAILING EDGES

Fuselage L.E.		Wing L.E.	
X	Y	X	Y
236.0	0.0	493.0	100.0
236.5	5.0	944.0	175.0
238.5	10.0	968.0	180.0
241.5	15.0	997.0	190.0
245.5	20.0	1019.0	200.0
251.0	25.0	1036.5	210.0
257.0	30.0	1051.5	220.0
265.0	35.0	1064.0	230.0
274.0	40.0	1075.5	240.0
284.5	45.0	1086.0	250.0
296.0	50.0	1266.0	430.0
309.5	55.0	1279.5	440.0
324.5	60.0	1300.0	450.0
341.0	65.0	1336.5	460.0
358.0	70.0	1382.0	470.0
376.0	75.0		
396.0	80.0		
418.0	85.0		
441.0	90.0		
466.0	95.0		
493.0	100.0		

Fuselage T.E.		Wing T.E.	
Straight line parallel to Y-axis at X = 1618.0		Straight line through	
		X	Y
		1490.0	200.0
		1454.5	400.0

NOTE: Values were scaled from engineering drawings.

TABLE 2.- DEFINITION OF WING AERODYNAMIC PANELS

Wing aerodynamic panel number	Fraction of semispan range	Fraction of chord range
1	Edge of fuselage $<$ ETA $\leq$ .34	0. $<$ XOC $\leq$ .35
2		.35 $<$ XOC $\leq$ .55
3		.55 $<$ XOC $\leq$ .70
4		.70 $<$ XOC $\leq$ Elevon hinge line
5	.34 $<$ ETA $\leq$ .72	0. $<$ XOC $\leq$ .35
6		.35 $<$ XOC $\leq$ .55
7		.55 $<$ XOC $\leq$ .70
8		.70 $<$ XOC $\leq$ Elevon hinge line
9	.72 $<$ ETA $\leq$ 1.0	0. $<$ XOC $\leq$ .35
10		.35 $<$ XOC $\leq$ .55
11		.55 $<$ XOC $\leq$ .70
12		.70 $<$ XOC $\leq$ Elevon hinge line

NOTES: ETA = Y-DISTANCE FROM ORBITER CENTERLINE/WING SEMISPAN

XOC = X-DISTANCE FROM LEADING EDGE/CHORD LENGTH

Planform coordinates of wing are given in table 1.

TABLE 3.- LOAD CASE DESCRIPTIONS

Load case	Description	Corresponding imperfection	
Design load case combinations			
1	Shock ahead of tile	1	2
2	Shock on tile at X/C = 0.0	1	3
3	0.1		
4	0.2		
5	0.3		
6	0.4		
7	0.5		
8	0.6		
9	0.7		
10	0.8		
11	0.9		
12	1.0	1	3
Separate load source contributions for shock ahead of tile			
13	Aerogradient in x-direction	0	
14	Aerobuffet force		
15	Aerobuffet moment		
16	Vent lag		
17	Skin friction		
18	Vertical component of vibroacoustic g-load		
19	Lateral component of vibroacoustic g-load	0	
20	Vibroacoustic deflection	2	
21	Substrate deformation	1	
Separate load source contributions for shock on tile			
22	Shock on tile at X/C = 0.0	0	
23	0.1		
24	0.2		
25	0.3		
26	0.4		
27	0.5		
28	0.6		
29	0.7		
30	0.8		
31	0.9		
32	1.0		
33	Aerobuffet force		
34	Aerobuffet moment		
35	Vent lag		
36	Skin friction		
37	Vertical component of vibroacoustic g-load		
38	Lateral component of vibroacoustic g-load	0	
39	Vibroacoustic deflection	3	
40	Substrate deformation	1	
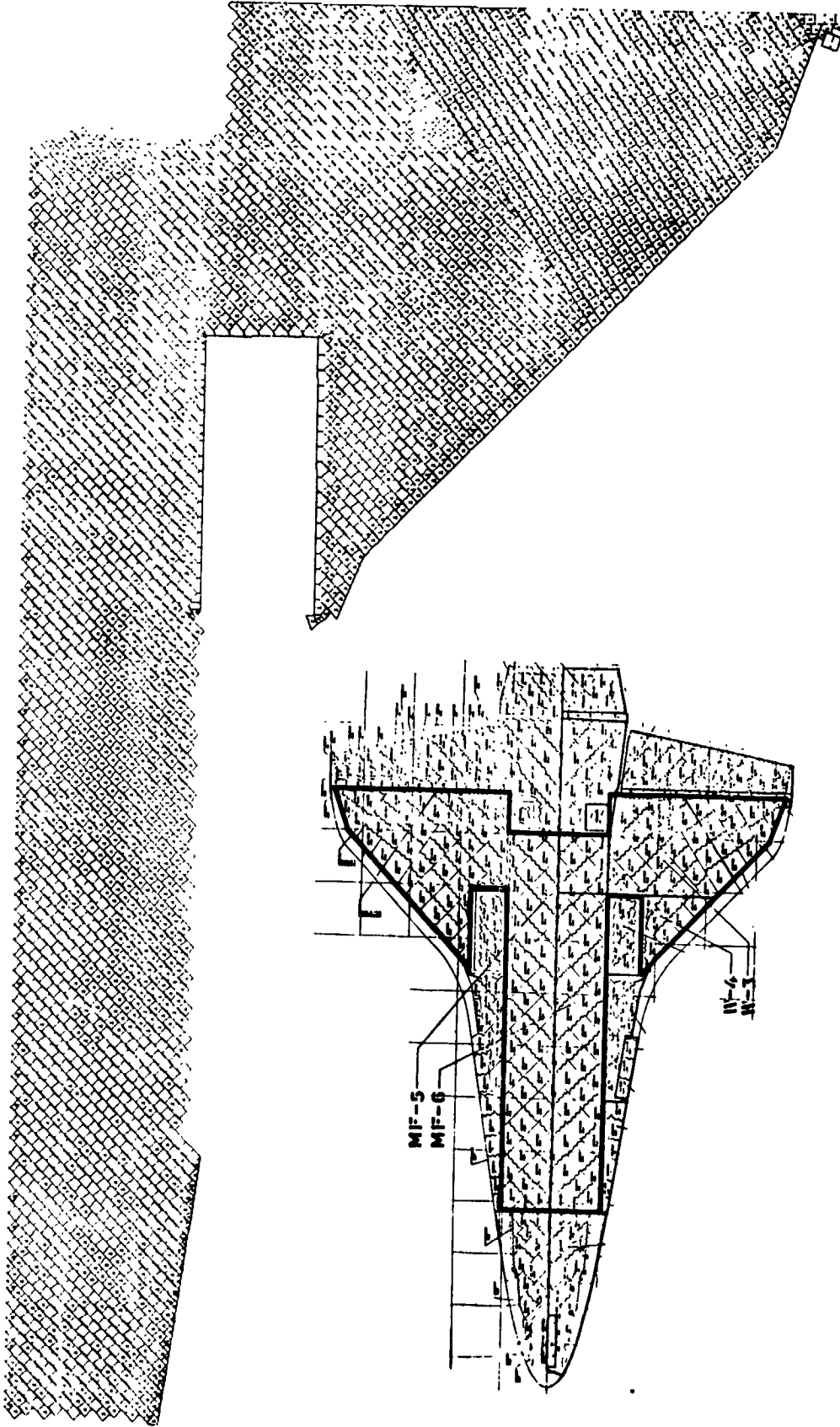
Figure 1.- Regions of Orbiter tiles included in automated data management system.
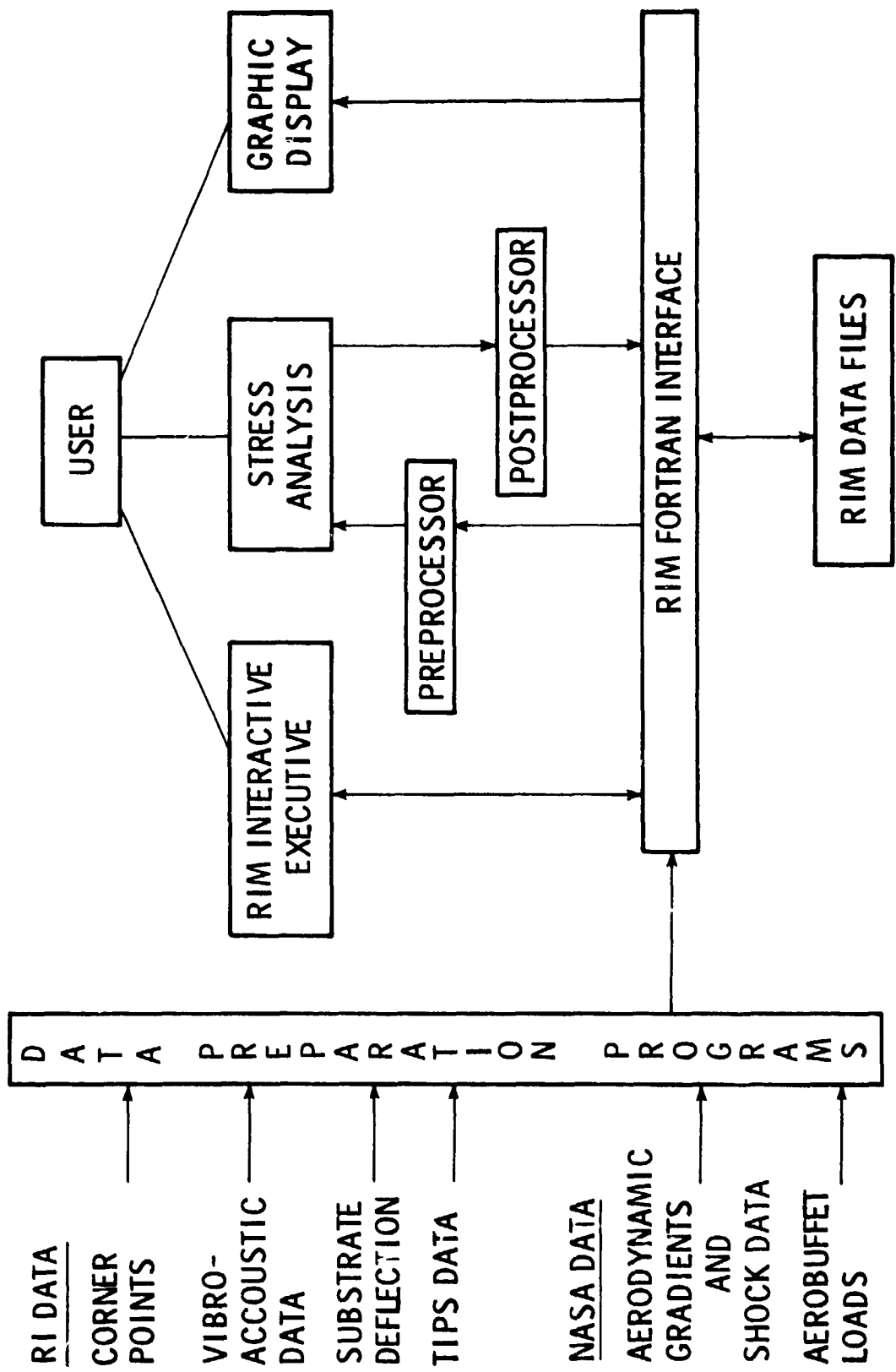
Figure 2.— Automated data management/analysis system for Orbiter tiles.
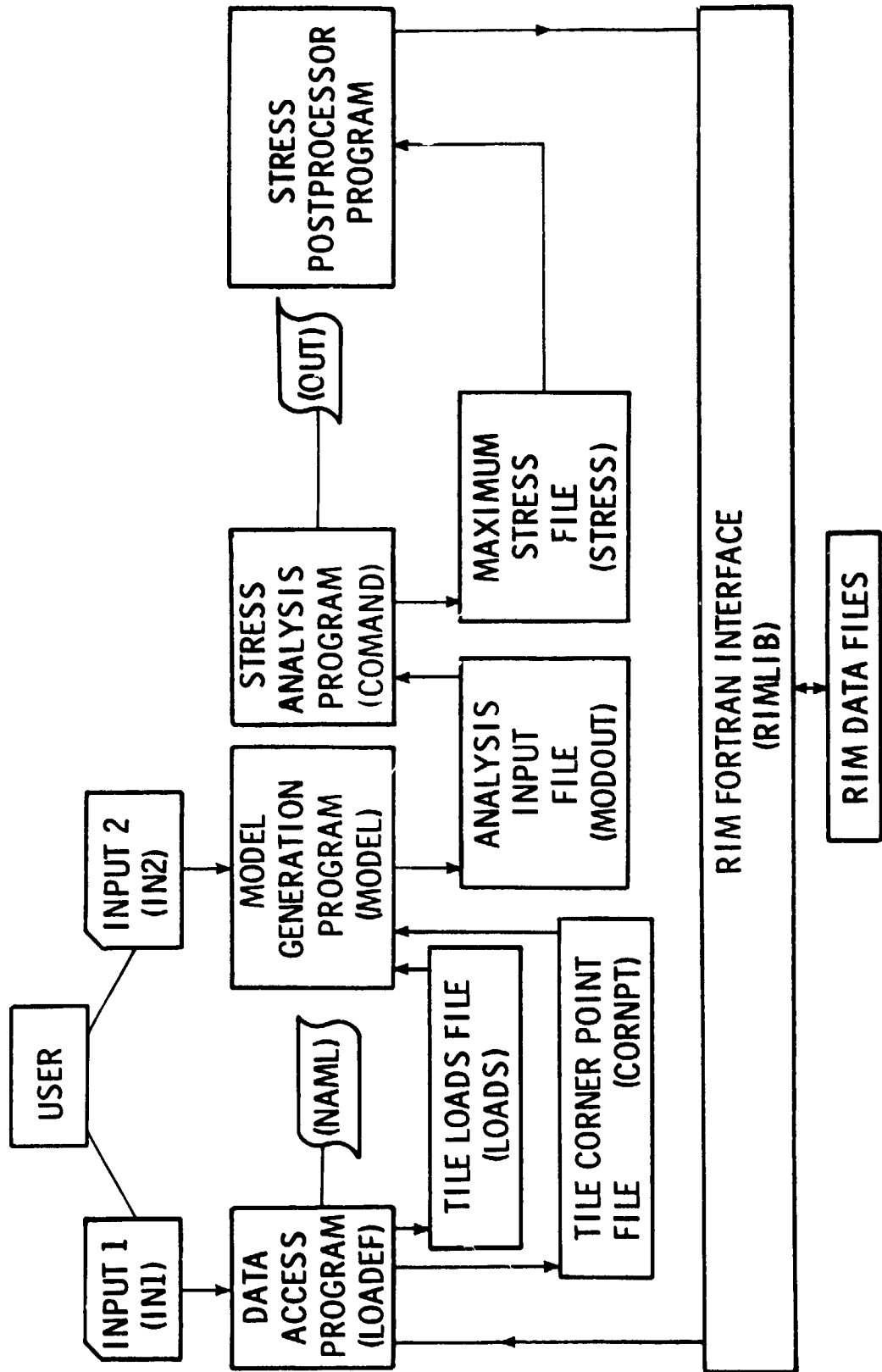
Figure 3.- Automated system for tile stress analysis.

RELATION NEWAPANL

PARTNO	ETA	XOC	CHORD	AEROPANL
191013071	0.3339951	0.6935504	662.01055	3
190002121	0.2211589	0.7106694	990.32901	4
191013152	0.2933740	0.7709775	780.20517	4
191014066	0.6409095	0.2424357	334.80461	5
191012155	0.4378044	0.4900482	459.88206	6

RELATION STSITRAJ

MACHNO	ALPHA	QPSF	PINF
0.9300000	-3.6300000	622.00000	1019.4700
0.9600000	-3.7000000	627.00000	979.47000
1.0000000	-3.8600000	632.00000	910.97000
1.0400000	-3.8600000	635.00000	844.65000
1.1200000	-3.7100000	636.00000	719.02000

RELATION NEWLOADS

AEROPANL	MACHNO	ALPHA	SHOCKJUMP	ABSHKCPRMS
4	0.9500000	-4.0000000	0.5940000	0.1100000
4	1.0500000	-4.0000000	0.5360000	0.0630000
4	1.1000000	-4.0000000	0.5260000	0.0730000
4	0.9500000	4.0000000	0.5770000	0.1100000
4	1.0500000	4.0000000	0.4250000	0.0630000
4	1.1000000	4.0000000	0.4880000	0.0730000

Figure 4.- Sample relations showing typical data values.

DIRECT
PARTNO
DRAWNO
DASHNO
ARRAYNO
IMLPTS
OMLPTS
SUBSPANL
CGTORIB
RIBTORIB
CGTOLE
NODEORDR
CGXI
CGYI
TILETHCK
SIPTHCK
TILEDENS

XYZO
PARTNO
DRAWNO
IMLOML
XLOCAL
YLOCAL
ZLOCAL
TRANSF
XORBITER
YORBITER
ZORBITER

SUBDEFL
SUBSPANL
LOADNO
FLTCOND
DEFLSKIN
DEFLSTRNG
WAVESKIN
WAVESTRNG

VIBAC (WING)
TILESIZE
ONOFFRIB
FLTCOND
TILETHCK
MACHNO
GPEAK
DISPL

VIBAC (FUSL)
VIBPANL1
VIBPANL2
FROMFRAME
FROMCL
MACHNO
GPEAK
DISPL
SPAN

STSITRAJ
MACHNO
ALPHA
QPSF
PINF

NEWLOADS
AEROPANL
MACHNO
ALPHA
SHOCKJUMP
SEPARJUMP
AEROGRX
AEROGRY
ABSHKCPRMS
ABSEPCPRMS
REFPRESS

SUBPANL
SUBSPANL
X1
Y1
Z1
-
-
-
X4
Y4
Z4

NEWAPANL
PARTNO
ETA
XOC
CHORD
AEROPANL

FORCEMOM
AEROPANL
MACHNO
TILETHCK
BLTHCK
XSL
FORCEZ
MOMENTY

STRS4 - 24 - 1
PARTNO
LDCASE
MACHNO
STRESSMX
ACTPROOF
SRATIO

TIPSDATA
PARTNO
LEFTORRT
OPPPARTNO
DENSIFIED
ACTPROOF

MATINDEX
PADTYPE
SIPTHCK
PROOF
MATNO

MATCURVE
MATNO
DISPL
STRESS

Figure 5.- Organization of all engineering data used for tile analysis.
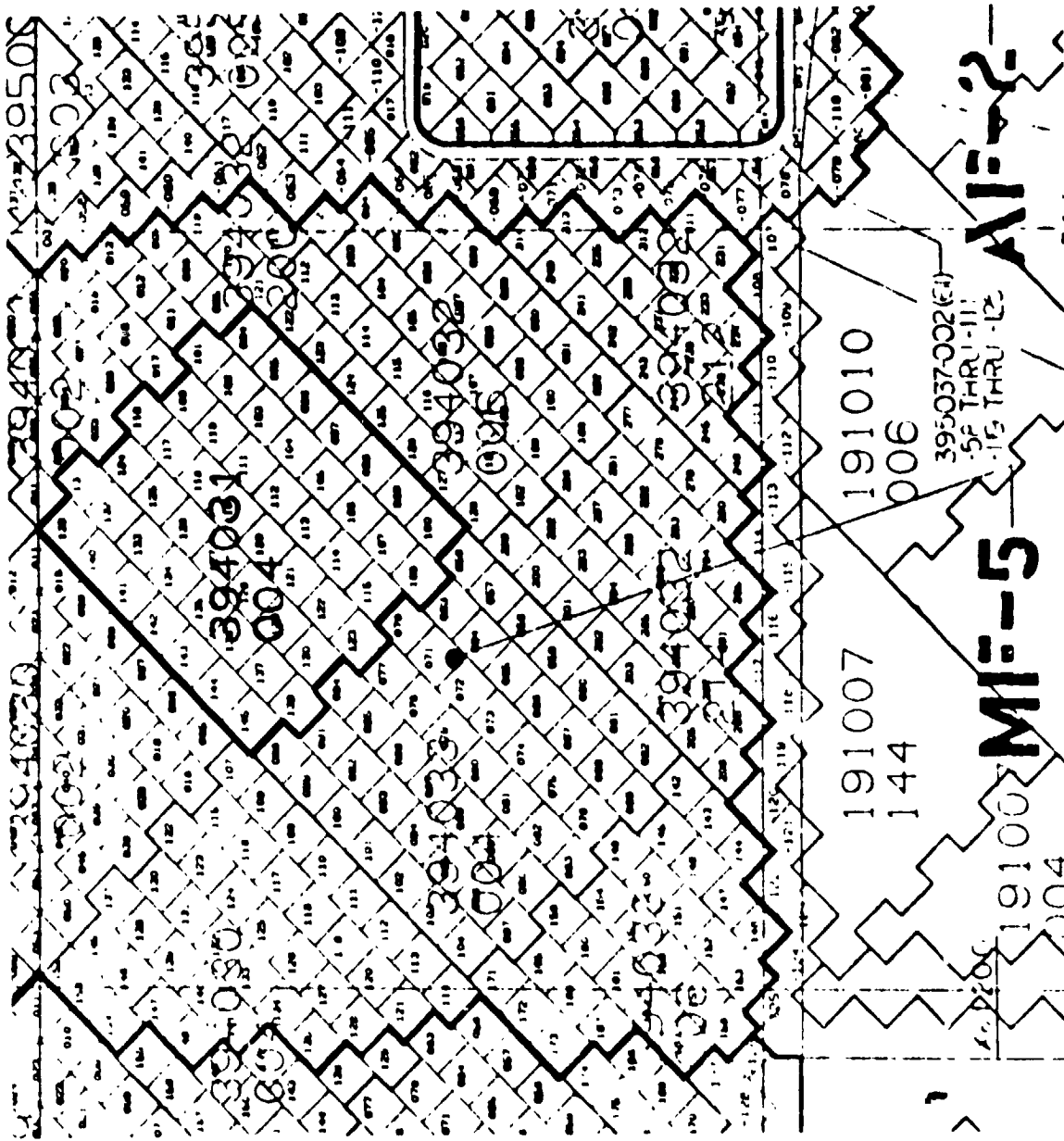
Figure 6.- Segment of a tile layout drawing.
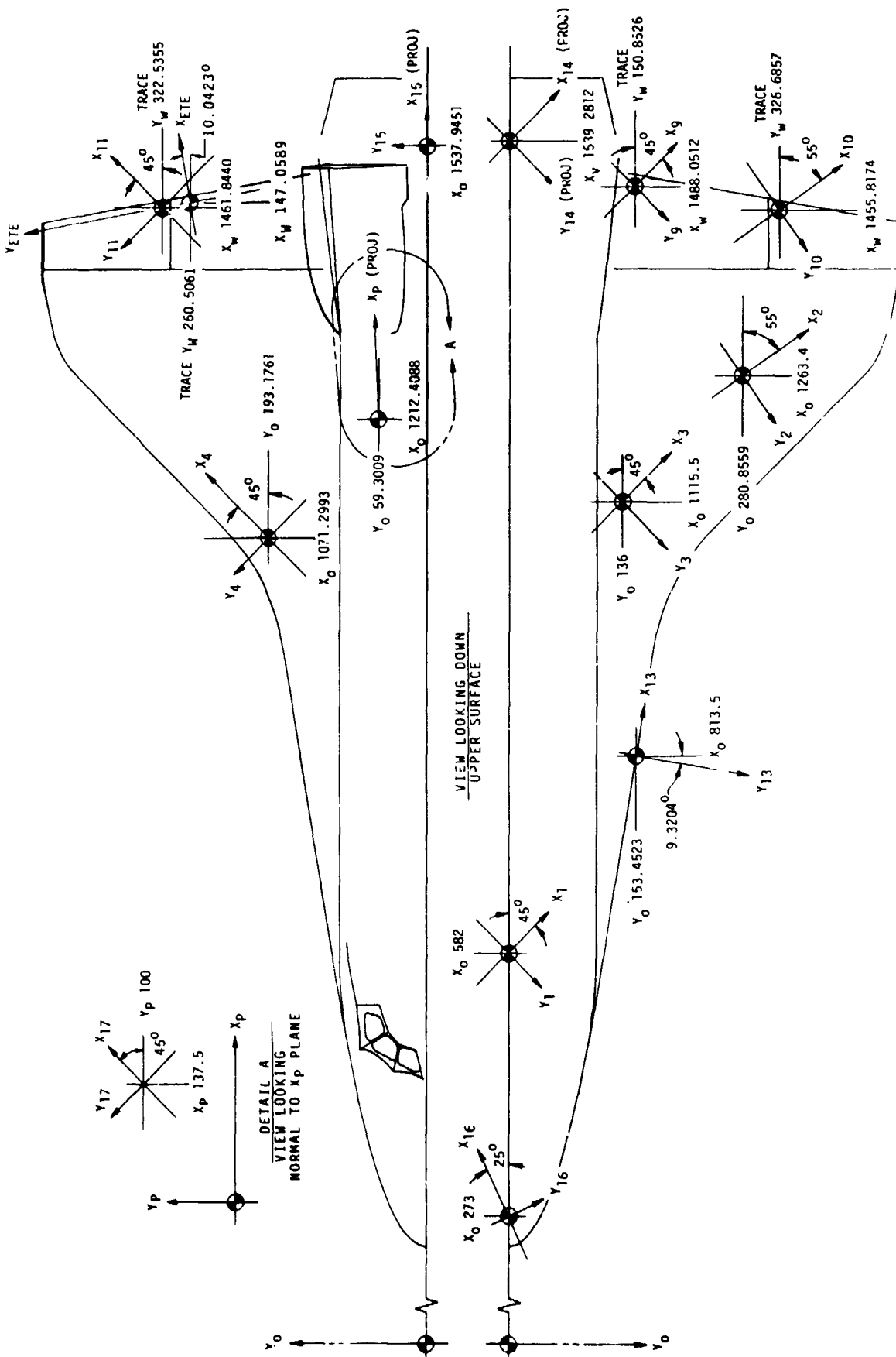
Figure 7.- Local coordinate systems used for definition of tile geometry.

$\delta = 0.2468 (\Delta x)^{0.8295}$
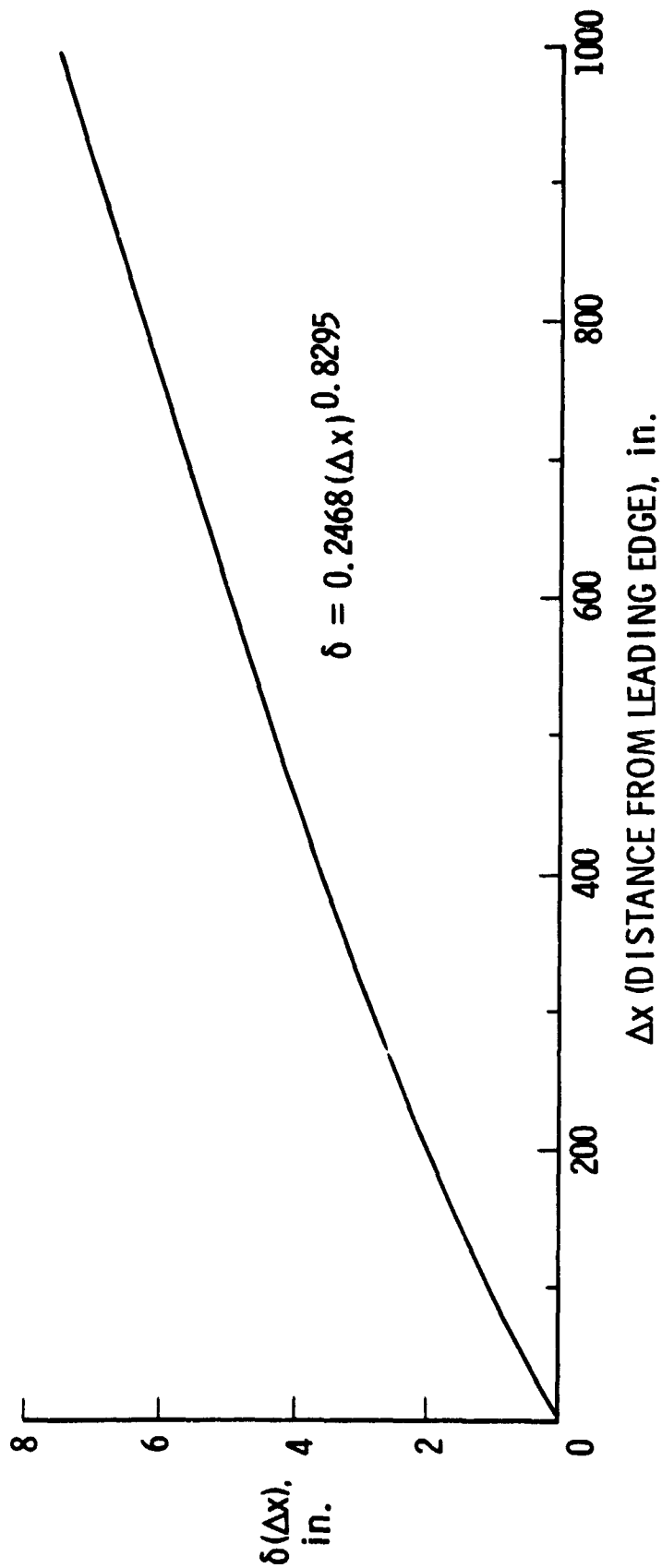
Figure 8.- Boundary layer thicknesses distribution on Orbiter wing.

80

NOTE:

FOR DESCENT, RATIO DATA BY
‥SCENT-TO-ASCENT q, i.e., 375/818

$C_f \times q = 0.2397(\Delta x)^{-0.2176}$
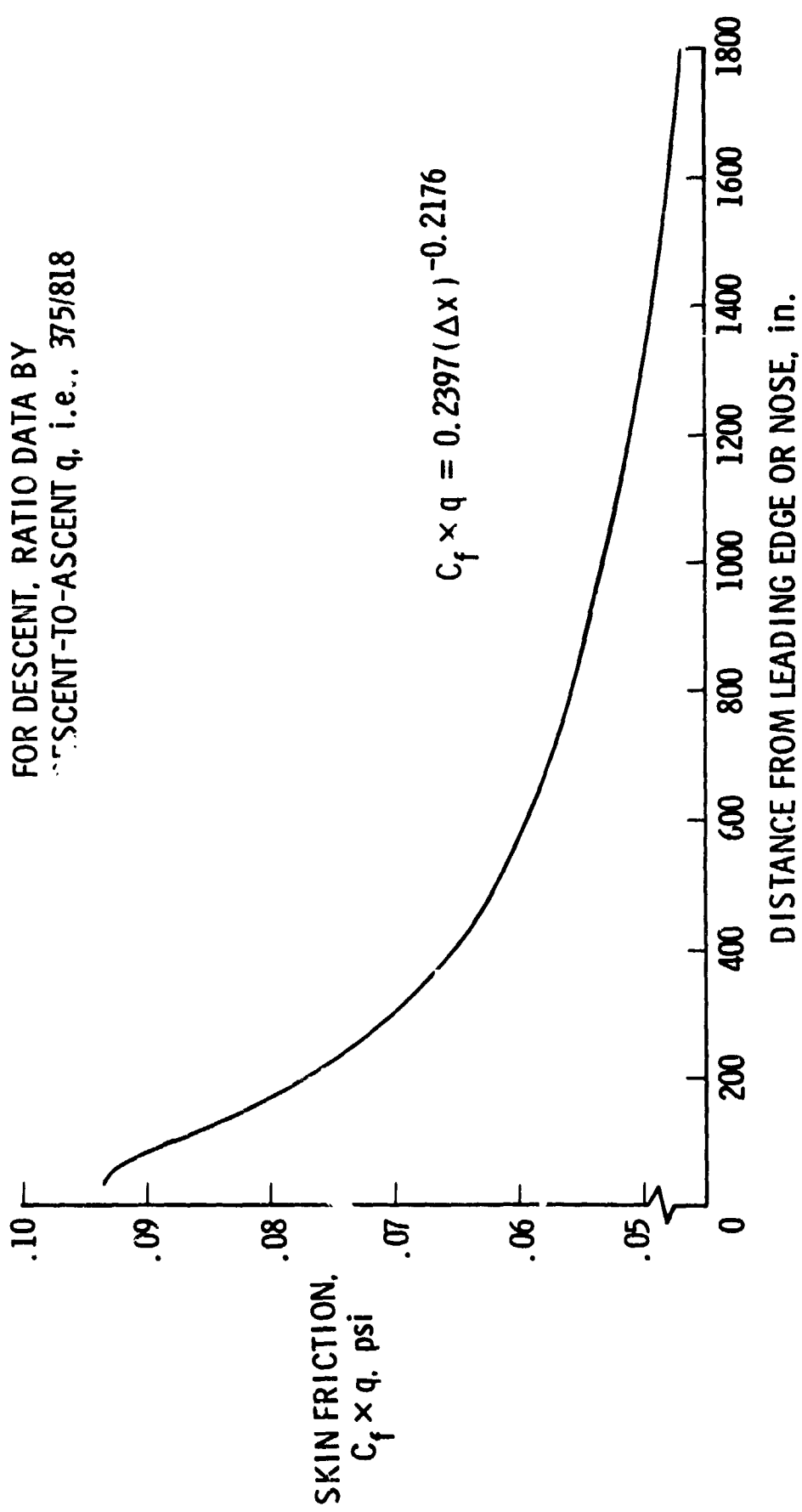
Figure 9.— Skin friction for Orbiter wing, fuselage, and vertical tail.
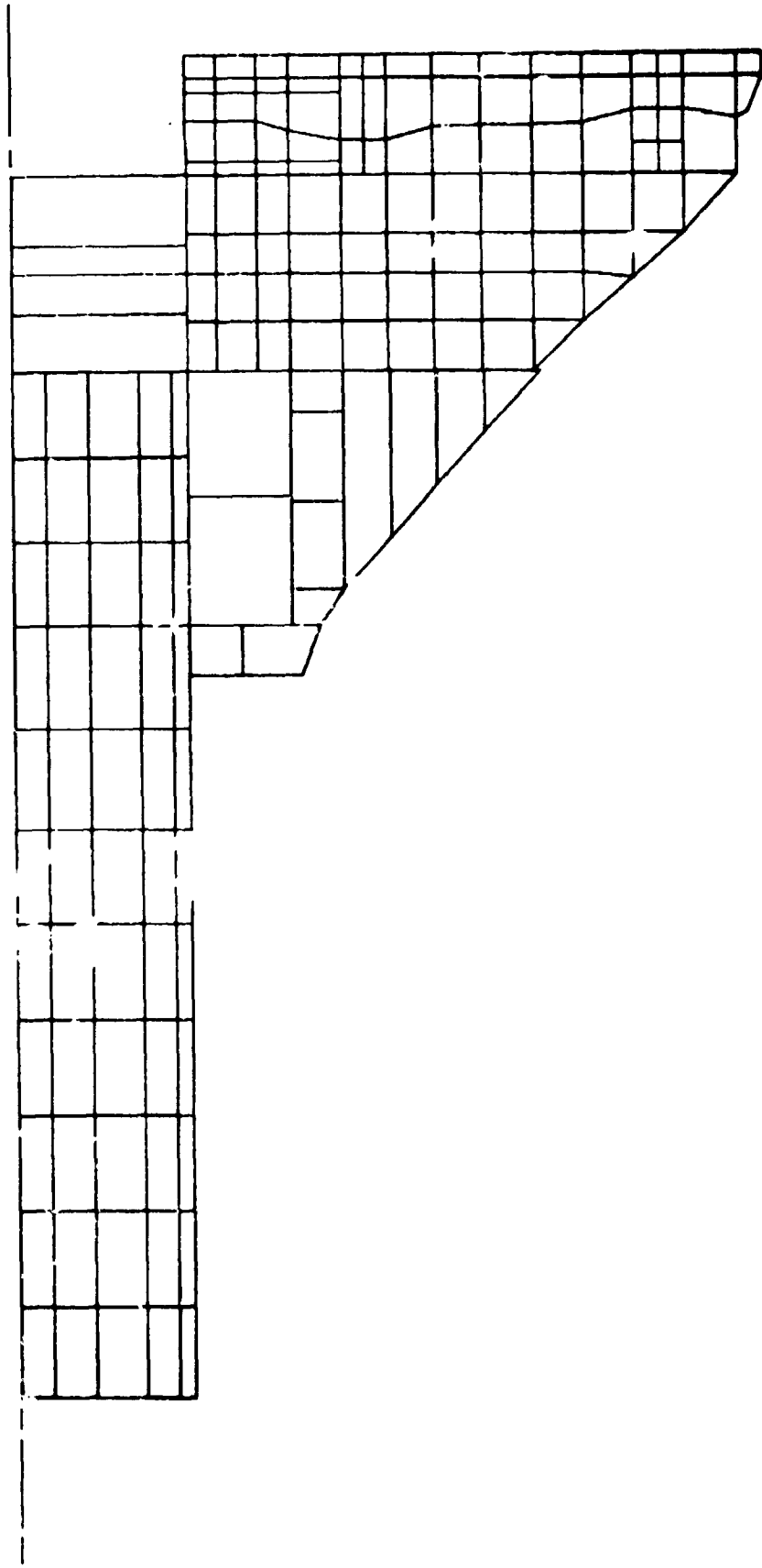
Figure 10.- Structural panels on lower surface of Orbiter.

PREPARED BY: T. WEST
CHECKED BY:
DATE: 2/18/80
REF.

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DWG. NO.

V-3 Dynamic Load Failures - $\xi = 1.3$

LOCATION	TIME	TILE F_n (Hz)	G PEAK	DISPL. (in)	SPAN (in)	S/P STRESS (psi)
6x6 x 1.0" TILE AT RIB	LIFT-OFF	183.1	66.4	N/A	N/A	0.60536
	MACH 0.9		62.7			0.57113
	MACH 1.25		78.9			0.71901
	MACH 1.40		78.9			0.71901
6x6 x 1.0" TILE <1.5" FROM RIB	LIFT-OFF	183.1	81.4	1.36×10^{-2}	21.0	0.74141
	MACH 0.9		79.5	2.33×10^{-2}		0.72245
	MACH 1.25		99.8	3.00×10^{-2}		0.90949
	MACH 1.40		99.8	3.00×10^{-2}		0.90949
6x6 x 1.25" TILE AT RIB	LIFT-OFF	165.6	62.7	N/A	N/A	0.69898
	MACH 0.9		62.2			0.69330
	MACH 1.25		78.3			0.87282
	MACH 1.40		78.3			0.87282
6x6 x 1.25" TILE <1.5" FROM RIB	LIFT-OFF	165.6	76.8	1.25×10^{-2}	21.0	0.85307
	MACH 0.9		78.7	2.49×10^{-2}		0.87697
	MACH 1.25		99.1	3.01×10^{-2}		1.10404
	MACH 1.40		99.1	3.01×10^{-2}		1.10404
6x6 x 1.50" TILE AT RIB	LIFT-OFF	152.2	59.7	N/A	N/A	0.78695
	MACH 0.9		61.5			0.80804
	MACH 1.25		77.2			1.01727
	MACH 1.40		77.2			1.01727

Figure 11.- Typical vibroacoustic data.
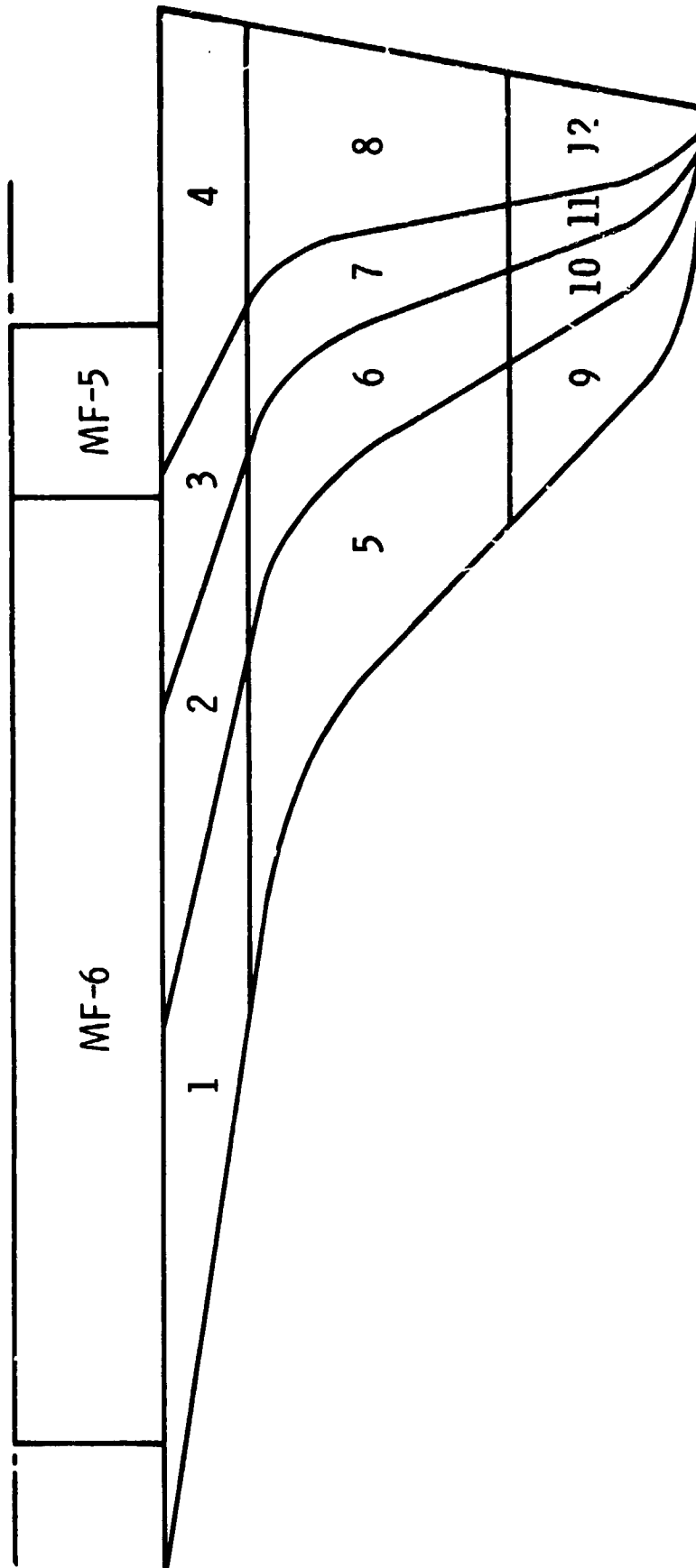
Figure 12.- Definition of aerodynamic panels.

TWO OUTER BANDS OF SIP ASSUMED TO BE SOFTER,
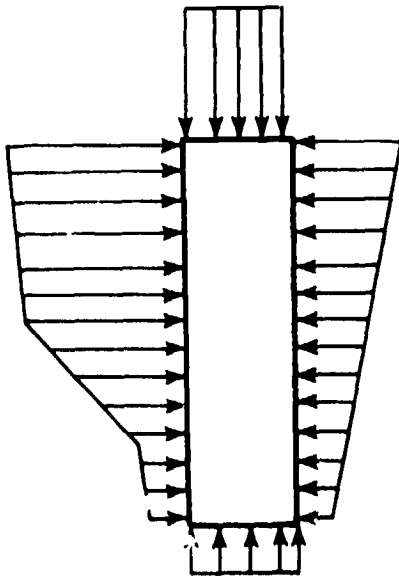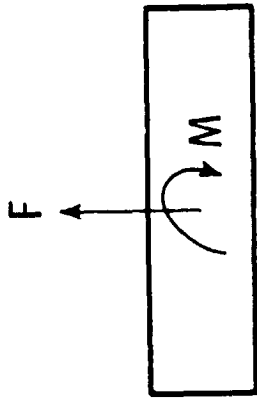CENTER REGION STIFFER THAN MEASURED STIFFⁱ IESS
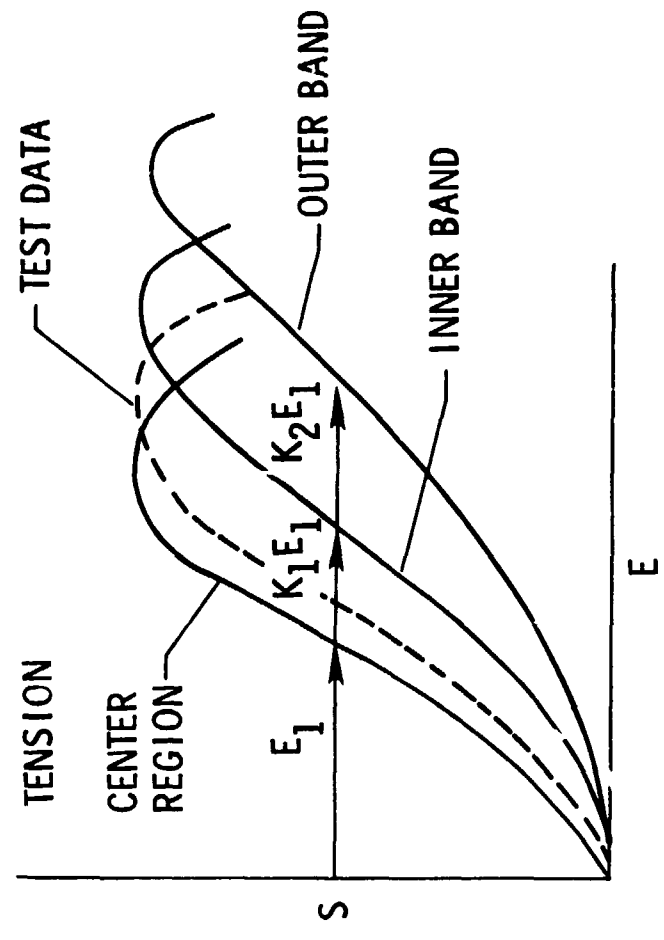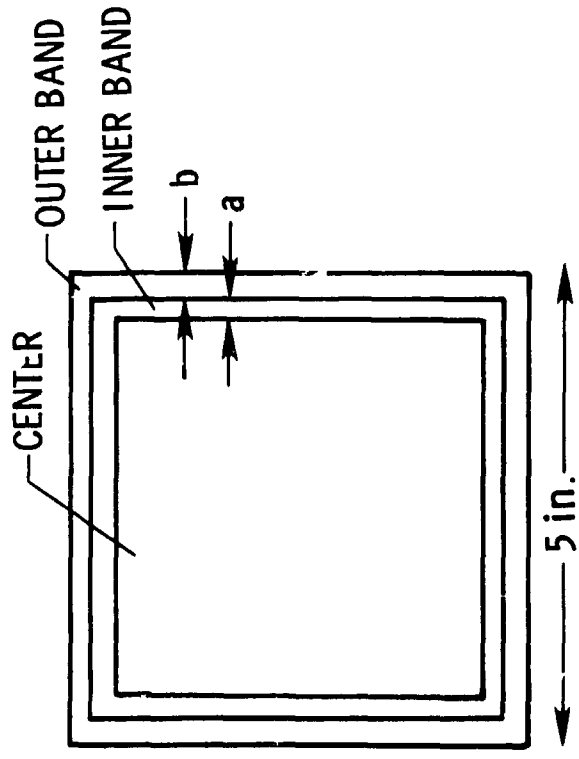
Figure 13.- Representation of SIP edge softening.

VENT LAG

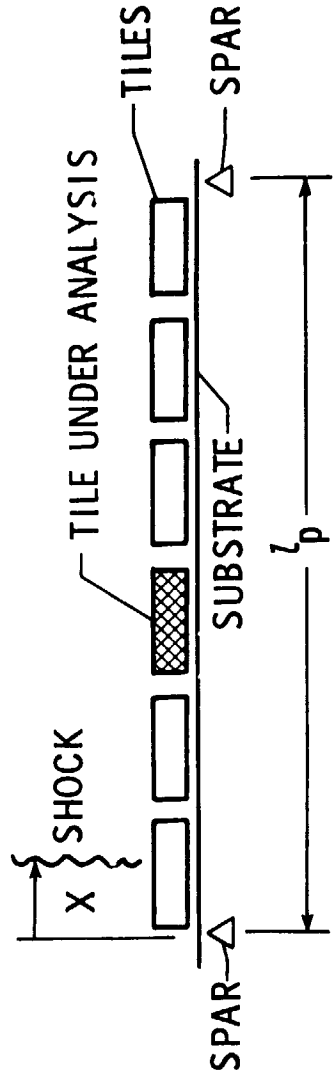SUBSTRATE DEFLECTION

AEROBUFFET
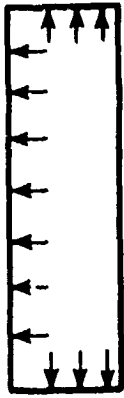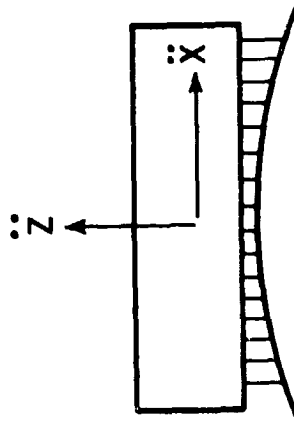
VIBROACOUSTIC LOADS
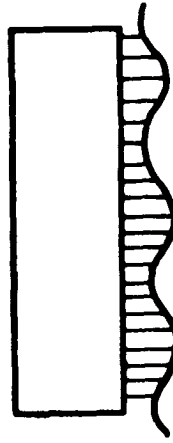
STEADY AERODYNAMICS

SKIN FRICTION

Figure 14.- Sources of tile loading.
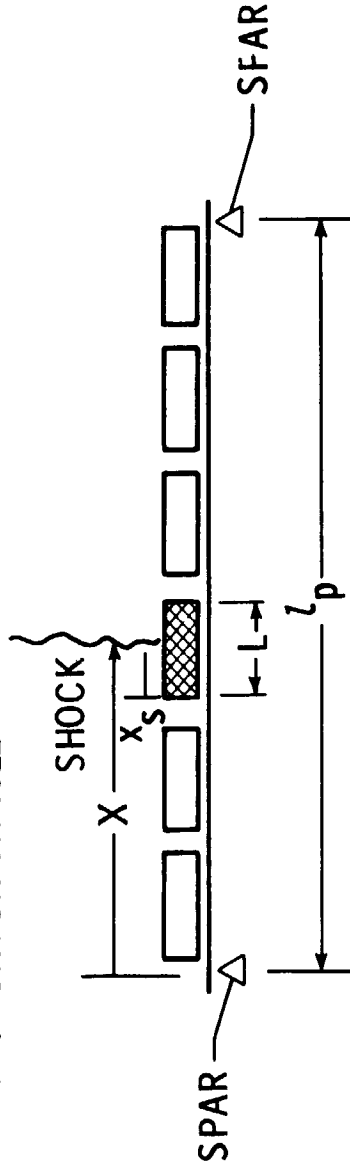
CASE a. - SHOCK AHEAD OF TILE

CASE b. - SHOCK ON TILE

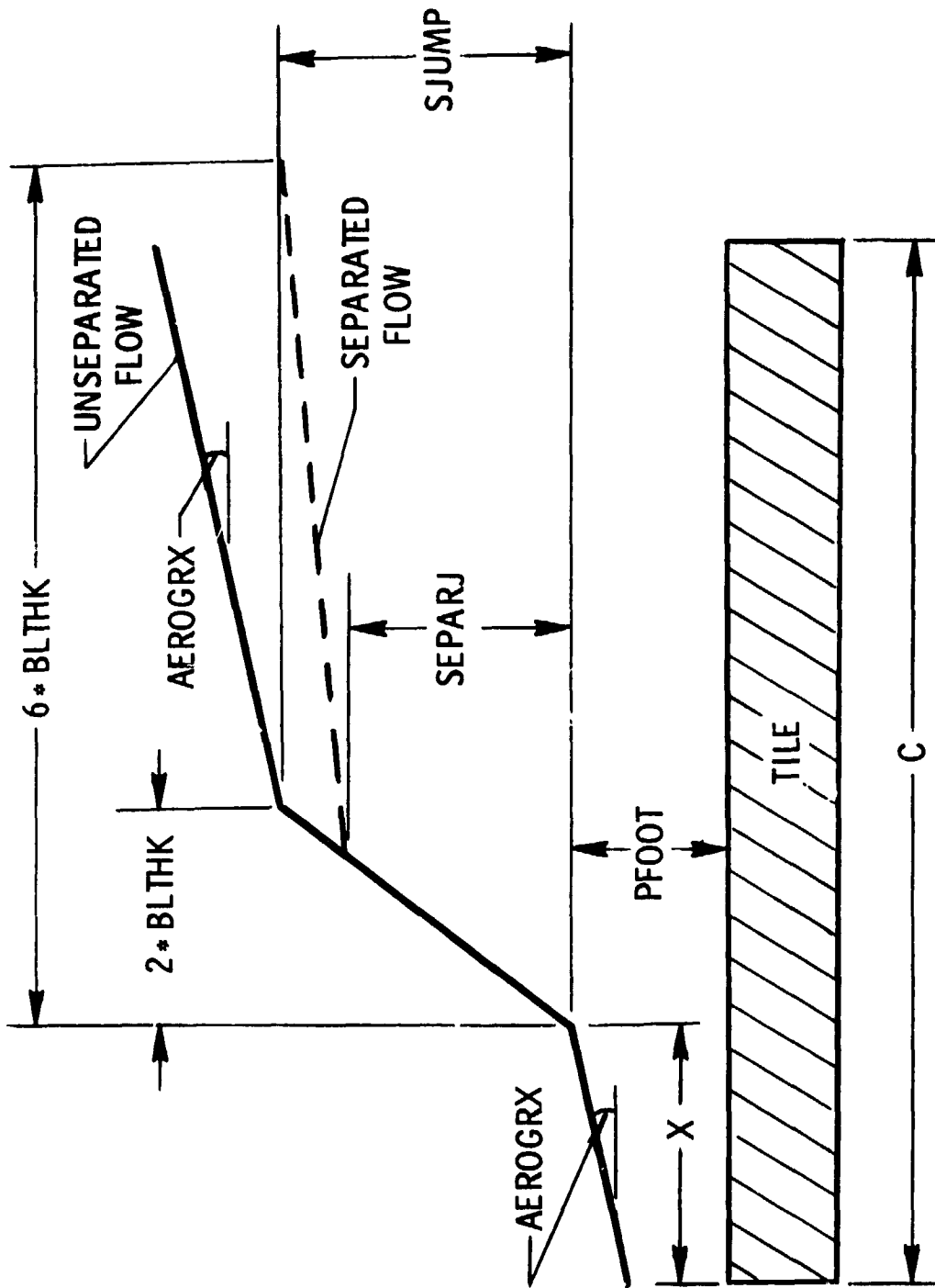Figure 15.- Location of aerodynamic shock relative to tile being analyzed.

Figure 16.- Profile of an aerodynamic shock pressure distribution on the outer surface of a tile.

SHOCK PROFILE
FROM FIGURE 16

CONSTANT PRESSURES
DOWN TILE SIDES AT
OUTER SURFACE VALUES

LINEAR PRESSURE
DISTRIBUTION ON
INNER SURFACE
DEFINED BY:

$$P_{ic} = P_{oc}/(1 - K_1)$$
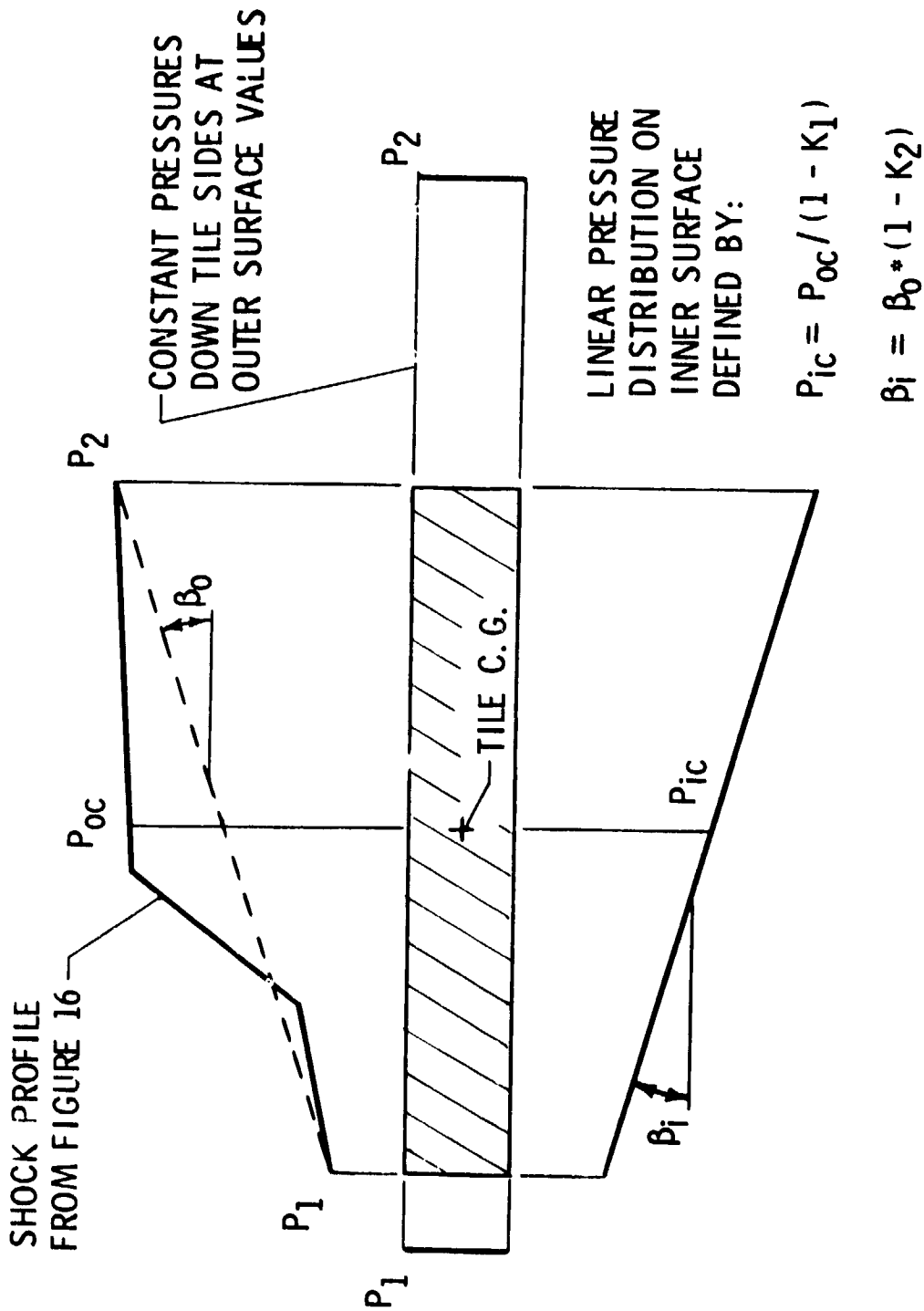
$$\beta_i = \beta_0 * (1 - K_2)$$

TILE C.G.

Figure 17.- Empirical relations for pressures on sides and inner surface to pressures on outer surface of tile.