ADAPTATION OF NASTRAN TO AN INTEGRATED SYSTEM OF STRUCTURAL DESIGN ANALYSIS

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ABSTRACT

This paper discusses efforts to integrate NASTRAN into a complete structural analysis system for use by large airframe design projects. The Lockheed-California Company is implementing the use of NASTRAN as a major finite element structural analysis program to determine the static and dynamic behavior of complete airframes as well as structural components. This requires modifications and additions to NASTRAN, to communicate with an existing system, and to provide facilities needed to work within the integrated structural analysis. For this purpose several special DMAP modules were developed and introduced into the CALAC version of the NASTRAN system.

INTRODUCTION

The decision to use NASTRAN as a major analysis tool, implicitly leads, in our opinion, to the need for the user-company to actively pursue to a degree its own development of the program system. Regardless of the quality of the available system, the time will soon arrive when specific company priorities do not coincide with the more general priorities of the NASTRAN Systems Management Office. At this time the company will be forced to respond with either additions and/or modifications to NASTRAN, or development of its own system. In the latter case, its use of NASTRAN would tend to diminish. If used actively, it thus appears unavoidable that a company version will emerge, which deviates, in a variety of aspects, from the officially released NASTRAN level.

The introduction of NASTRAN as the major program to analyze the elastic behavior of the structure required its adaptation and connection into the complete structural system analysis process for determining the response of the aircraft. The purpose of the complete system is the analysis of the environment which has a bearing on the structural integrity of the aircraft. Analyses to be performed include flutter, steady and transient maneuver loads, gust and ground response, and their effects on internal loads, stresses and deflections.

This adaptation requires the integration of NASTRAN with the existing set of computer codes which provide these analyses and which are complementary to the NASTRAN structural analysis program. Modifications and additions to NASTRAN are made in a manner designed not to interfere with existing NASTRAN capabilities and operations nor with potential NASA directed improvements.

While it may be easy to agree on what constitutes a structural analysis system in its totality, agreement on the priorities of specific developments of NASTRAN may not. It is likely to be an entirely different affair for NASA than it is for any one of the industrial users. The readiness of any company to fully accept NASTRAN as a standard system depends on its own in-house programs and the ease with which the former can be modified and adapted without loss in efficiency.

The present paper is therefore an example only of what the Lockheed-California Company has done, and is planning to do in the immediate future, to join NASTRAN as a major (but not the only) finite element analysis program to its structural analysis system.

A discussion of this nature may serve to stimulate ideas and contribute to the formation of system specifications from the practical operation aspects of large aircraft design. It may also revive a concept voiced in last year's meeting, which proposed an industrial user organization working in conjunction with the System Management Office in matters concerning further development of NASTRAN. (See Ref. 1.)

1. AN INTEGRATED STRUCTURAL DESIGN ANALYSIS SYSTEM

To discuss an integrated structural design analysis system we must define its scope and then determine the role of its parts and programs which are to perform its various functions.

1.1 The Total System

The system which will be described here briefly has in similar form been considered throughout the industry. The total analysis system may be said to consist of the complete environment which affects the structural integrity of the aircraft. As such it must incorporate the following major design analysis facets:

1. Structural deformation and stress analysis by finite element methods
2. Weight accounting and mass matrix
3. Aerodynamic forces
4. Static and dynamic loads and design conditions
5. Flutter analysis
6. Detail stress analysis
7. Design strength allowables and margins of safety.

1.2 The CALAC Analysis System

To discuss the activities and the plans of the Lockheed-California Company (CALAC) for development of the NASTRAN system, we should review the structure of the in-house analysis process as it presently exists. This includes NASTRAN as a major finite element analysis tool, which is fully operational and has been used for several important analysis jobs. The concept of the completed system is shown on Table 1.

The Lockheed-California Company's structural analysis operations are based on its extensive system of matrix algebra and functional modules, called FAMAS. The FAMAS system, originally an acronym for Flutter and Matrix Algebra System, has been developed at CALAC and has been expanded in scope far beyond these narrow limits. This system includes the CALAC finite element programs of the force method and several displacement method programs of lesser scope than NASTRAN. These are now gradually being replaced by NASTRAN.

The FAMAS system has completely compatible matrix input/output within all its programs, contains a very extensive matrix algebra and manipulation system, and a large family of functional modules for aerodynamic loads, structural response and flutter analysis, which are of prime importance in the present context. The system was extensively used during the SST design study, L-1011 and S-3A programs. It is operated by a simple program calling system, and has also a compiler for programming strings of matrix equations much like FORTRAN algebraic expressions. The general capabilities of this system are summarized on Table 2. In some algebraical and functional modules the NASTRAN and FAMAS systems contain duplicate capabilities. In general, however, they supplement each other extensively.

A variety of theories are used in FAMAS to calculate aerodynamic force influence coefficient matrices, including important procedures to update theoretical values with experimental flight and wind tunnel data. A paper given by John Lewolt of CALAC at the August 1972 meeting of the AIAA, Reference 2, discusses this capability in considerable detail.

The FAMAS input/output compatibility permits any matrix, specifically stiffness-, flexibility-, aero- and mass- matrices,resulting directly from a previously executed program module, or from data storage, to be used, as in NASTRAN, as input to subsequent vibration, load and flutter analysis. Any design load matrix thus generated can be fed into an airplane finite element structural analysis program for determining internal loads, stresses and deflections. Any matrix, for example, stress matrices, can be scanned row by row, that is, element by element, for the most critical columns (design conditions), or can further be processed. In addition, FAMAS stress matrices can be fed into special programs for comparison with data banks of design allowables to calculate margins-of-safety.

The complete analysis sequence can therefore be performed by computer operations without unnecessary human transcription or other handling of data block communication between programs. As many analyses steps as desired and practical can be performed in a single job submittal to the computer. Interruptions of the automatic computing flow are dictated principally by the need to check intermediate results and introduce human judgement. When the capabilities of the FAMAS system are joined by the finite element analysis capabilities of NASTRAN through an automatic data communication, a powerful integrated analysis system will be the result. Table 3 shows a summary of the capabilities of the combined system, which communicates through tape and disc storage without human data handling.

1.3 NASTRAN's Part in the System

The part which NASTRAN is playing in the combined system includes, of course, all its finite element analysis capabilities in static, dynamic, and structural stability,excepting special problems where separate programs may be preferable. There are however, some problem areas within NASTRAN itself which we feel must eventually be resolved to make its use as a tool for finite element analysis of aircraft structures better adapted to project needs. These concern, in our view, the following major areas:

- Extended analysis checking capabilities for force equilibrium and improvement of checking and location of matrix singularities.

- Improved stress analysis capability primarily through the addition of finite elements with better stress definition within the standard degrees of freedoms.

- Substructure coupling is of great importance for large airframe analysis; methods to streamline the present capability of NASTRAN in this field are being pursued at CALAC.

2. NASTRAN MODIFICATIONS AND ADDITIONS

Several new DMAP modules were added into NASTRAN, those which serve the specific purpose of connecting NASTRAN with FAMAS, and those which were needed to amplify its operational capability and flexibility within the CALAC analysis system. The Job Control Language (JCL) in the IBM-360 system permits a single, uninterrupted job run from either NASTRAN into FAMAS, or vice versa. This provides adequate operational flexibility, since interruptions for the purpose of intermediate data checking are required anyway.

2.1 The Process of Adaptation of NASTRAN

The new facilities designed to complement the integrated system were added as DMAP modules into the NASTRAN system. The following general principles were applied in adding the required features.

- The modification of existing NASTRAN modules and their operation under the original NASTRAN calling code name was avoided. Instead a new DMAP module under a new calling code was formed, consisting, if necessary, of original subroutines as well as new subroutines. This prevents the disruption of basic NASTRAN capabilities in the rigid formats even if NASA makes changes in the basic modules at a later date.

- Similarly, variations or additions to existing tables were given new identities, with a format identical or similar to the existing one if feasible.

- To avoid (for the time being) the need to define many new bulk data cards, and the ensuing complications, pitfalls and delays, it was decided to input special data types by means of the direct input tables DTI. These can fairly well be accommodated to a card format similar to bulk data type cards. This method also avoids accidental collision with new bulk cards introduced by NASA. However, since bulk data cards are preferable, an agreement of NSMO, reserving some special code letter for user card types might be advantageous.

- Since the special NASTRAN modules added will not be used frequently in the many standard applications, they have not at this time been introduced in any rigid formats, but are, when needed, inserted instead of, or in addition to, regular DMAP sequences by ALTER sets.

2.2 New CALAC-NASTRAN Modules

To accomplish the connection between the NASTRAN and FAMAS systems, and provide the additional operational flexibility necessary, a series of special CALAC-NASTRAN DMAP modules have been added or are in preparation for the following functions.

1. User designated data blocks for input or output onto tapes (INPUTT, ØUTPUT)
2. NASTRAN-FAMAS interface matrix transcription (FAMASIØ)
3. Element force and stress output table are written into NASTRAN matrix format (ELMAT).
4. Generation of a case control tables for large numbers of load cases internal to NASTRAN, based on the content of the displacement matrix (LDCØNTRL).
5. Rewriting of NASTRAN matrix print output format, and punched card input in the FAMAS format (MATPRN).
6. Development of a gridpoint load matrix and mass matrix balanced for a given external load location (LØADGEN).
7. Formation of a diagonal matrix (DIAGMAT).
8. Generating multipoint constraint conditions (MPCGEN) (planning stage).

The principal function and techniques of these new modules are described in more detail below.

2.2.1 INPUTT and ØUTPUT Modules

The user designated tape input and output, already discussed in last year's colloquium, were written for CALAC by MacNeal-Schwendler Corp. These modules are briefly discussed again. The two modules permit user designated data blocks to be written on, or input from tape at any suitable DMAP sequence location, into a NASTRAN run from other than, or in addition to, the checkpoint restart tape. With this capability previously calculated data can be read into a single run from as many different tapes as the computer equipment permits. This is a prime requirement for substructure coupling, but has many other useful operational possibilities.

2.2.2 NASTRAN-FAMAS Interface

The item of prime importance to the integration of NASTRAN with the CALAC system is the interface module. A DMAP module, FAMASIØ, accompanied by appropriate Job Control Language, permits rewriting any set of NASTRAN matrices into the FAMAS format onto a FAMAS system tape, and subsequently continuing with any matrix operation sequence in the latter system. Similarly, it is possible to start with an operational sequence in FAMAS, transit into NASTRAN, using FAMASIØ to copy the matrices into the NASTRAN format for continuation and conclusion of the run in NASTRAN with any type of rigid format or DMAP operation. The importance of this step is visible from Table 4.

In this fashion all the design load analysis capabilities of the FAMAS system are joined with the finite element analysis capabilities of NASTRAN. Similarly, NASTRAN stiffness or structural flexibility matrices, vibration mode vectors, etc., can be used in direct link with the flutter analysis system in FAMAS, as well as the aero-elastic loads calculations.

2.2.3 Element Force and Stress Matrices

The conversion of the NASTRAN element force and stress tables into matrix format has several applications. At present this has been completed for ROD, BAR, and SHEAR elements. The stress matrix contains a column vector for each subcase. The rows correspond to element stresses, row numbers are related to element numbers according to a key given by parameters of the module. In the simplest form the row number is identical to the element number. The most important aspect within the CALAC structural analysis system is the transcription of complete stress or force tables into matrix form for subsequent transfer, with FAMASIØ, into the FAMAS system, where they are used in an existing scanning program. This program scans each row of a matrix (the stress at one point) for, say, the six largest positive values and the six largest negative values. This provides a quick picture of critical design conditions in a given region of the structure.

The formation of NASTRAN element force and stress matrices also permits, through FAMAS, the use of a variety of margin-of-safety- programs in conjunction with data banks of stress allowables.

2.2.4 Case Control Module

To appreciate the significance of this module it is first necessary to explain the arrangement of design load matrices as generated in FAMAS and transcribed into NASTRAN. The total number of columns in the matrix is usually over a thousand, with each column number permanently assigned to a specific load condition. The thousand-order matrix is fairly sparse, only the few hundred columns corresponding to load conditions critical in the region analyzed being occupied. Inches or feet of meaningless output for null conditions can be avoided in NASTRAN with an extensive case control, shown below. One subcase is called out for each column of the displacement matrix UGV.

<u>Case Control</u>

MPC
SPC

Subcase 1 Subcase 2 Subcase 3	Null Cases
Subcase 4 OLOAD SPCFORCES ELSTRESS ELFORCE	Non-null Case
Subcase 5 Subcase 6	Null Cases

etc., for as many subcases as columns in UGV.

Writing the control cards for these thousands of subcases would be tedious work spiked with potential errors, and requiring previous knowledge of the location of occupied columns in the load matrix transcribed from FAMAS. The module LDCØNTRL is designed to eliminate the human element from writing this case control language. The solution vector matrix UGV for the load matrix, read in from FAMAS in lieu of the NASTRAN solution generator module SSG1, can be obtained by a single fictitious LOAD call in CASE CONTROL.

This new module LDCØNTRL is ALTERed into the rigid format of NASTRAN just prior to the solution data recovery module SDR2. It scans the column headers of the displacement matrix UGV for null and non-null columns, and writes the extensive case control table in the format of NASTRAN CASECC, but now designated LDCASE. Using this control table in SDR2 in lieu of CASECC results in output tables for non-null conditions only, avoiding all output of zero conditions. The subcase numbers identifying the NASTRAN output table are identical to the column numbers of the non-null vectors in the original displacement vectors UGV.

The stress matrix module picks up the subcase numbers from the stress output tables to form stress columns identified, therefore, by the same numbers as the displacement vectors.

2.2.5 Matrix Print Output and Card Input

The standard NASTRAN matrix input (DMI) and print output (MATPNT) were found to be somewhat inconvenient, the print identification of rows and columns not providing a clear picture. Intermediate and end result checking require an easily readable matrix print format. Non-rigid format operations require an easy tabular form for input. A new matrix card input was provided using the various CALAC matrix input forms. The NASTRAN matrix print MATPNT output was replaced by the standard CALAC-FAMAS format. This output identifies the column and row numbers of all non-zero terms, and does not print zero terms. This eliminates the need to count lines when searching for specific elements and is much easier to read. A comparison of the two matrix output formats is shown on Tables 5 and 6.

2.2.6 Load and Mass Matrix Generation

A DMAP module LØADGEN has been designed to generate gridpoint load column vectors which load a given limited set of gridpoints, and which are in balance with a given general load vector at a given, non-gridpoint, location. To explain the rationale and the function of this module we review the transition from the loads or mass network to the structural network. The two networks are hardly ever congruent, and therefore a transformation is required. Also the use of the NASTRAN mass matrix generation facilities is impractical for large aircraft parts. To relate the mass with model element properties, where the structural weight is less than 25% of the total aircraft weight, and to keep the mass data for the structural-dynamic analysis consistent with the weight accounting of the vehicle is an almost insurmountable task of manual calculation and bookkeeping.

It was found necessary to form directly a gridpoint mass matrix which is consistent with weight accounting data. Coordinates of all gridpoints are available in NASTRAN, total mass and centroid locations of suitably small aircraft regions are given by the weight accounting system. The same type of data are available for design loads,which are assumed uniform over given regions with an established load centroid; the loads network usually is established by criteria for aerodynamic loads calculations and does not correspond to the structure.

The procedure adopted in the present program to determine gridpoint loads uses the following principle: A (mass) weighting is judiciouly assigned to each NASTRAN gridpoint of a selected point set. The centroid and the inertias of the weighted point set are determined, the given load vector is transformed from its location to the CG of the point set. This imparts an acceleration to the point set, which in turn determines inertia forces in the gridpoints from which the load column is formed. While this approach is very general and flexible, its successful use depends on the rationale used to input the gridpoint weighting factors, and requires careful evaluation of the resulting load vector. It can best be used in connection with an interactive or graphic input-output system. Additional work in this area is yet required to determine suitable algorithms to mechanize the determination of a rational gridpoint weighting based on the aircraft geometry and weight accounting.

The completed result of this procedure is a load matrix [Lp] in all the unconstrained D.O.F. for p unit load or unit mass regions. A linear combination of these columns results in a proper design condition for the structural model.

$$\{PG\}_{c,1} = [Lp]_{c,p} * \{Pd\}_{p,1}$$

[Lp] is the transformation matrix between structural network and aero-loads network.

{Pd} is a design load case in the loads network.

A multiplication with regional masses {Ms} results in a column of gridpoint masses

$$\{MG\} = [Lp] * \{Ms\}$$

Conversion of {MG} into a diagonal matrix results in a diagonal mass matrix [MGG] for the structural model. The module and the corresponding DMAP instructions can be ALTERed into a rigid format to replace either or both of SMA2 and SSG1 functional modules which generate the mass and the gridpoint load matrices respectively.

2.2.7 Diagonal Matrix

A minor but operationally useful facility was the design of DMAP module DIAGMAT which rewrites any column of a NASTRAN matrix on the diagonal of a square matrix of same order. Alternatively it generates a diagonal matrix of given size and given scalar value.

2.2.8 Multipoint Constraint Equation Generator

A module for this purpose is in the study stage. Final plans at CALAC will depend heavily on what the detail plans of the NSMO are. There are several requirements which should in our opinion be considered in the generation of multipoint constraint equations. These are based on our experience with the MPC system and are summarized as follows:

- o The MPC equations facility are an extremely versatile feature with a wide range of applications. Means should be investigated to reduce the computer time expenditure for large systems.
- o It should be made possible to input the MPC equations in any of the defined coordinate systems, performing the necessary transformations into the global system internally to the program.
- o MPC equations can be generated internally based on one or more (connected) elements which are made rigid to create a full rigid body. There is however a necessary special feature, which might be called a semi-rigid body, which has significant advantages. Such a situation results when only part of the independent element variables of the elements used are declared rigid. Thus, for instance, if BAR elements are used to build the semi-rigid body, only bending in one plane of an element may be rigid.
- o Another capability to form MPC equations may be provided, which is the result of a force equilibrium condition between the loads in the independent D.O.F. and the force in the dependent freedom.

The theory of the necessary relations has been established and the detail program requirements are now being worked out. The decision to go ahead with programming will depend on NASA's plans in this area.

CONCLUSIONS

The previous discussions give some examples of the type of development which we at CALAC feel a user-company has to undertake if it intends to adopt NASTRAN as a major part of its structural analysis system. The use of NASTRAN at the Lockheed-California Company is steadily increasing, but so is the need for in-house development of NASTRAN.

It is evident that NASA is continuing to pursue the development of capability improvements of a general nature. However, we feel strongly that an active user-company will find it necessary to become intimately familiar with the NASTRAN system in order to enable it to successfully develop the capabilities within NASTRAN needed to fulfill its particular requirements.

REFERENCES

1. NASTRAN User's Experiences, September 1971, NASA TM X-2378.
2. W. A. Stauffer, J. G. Lewolt, and F. M. Hoblit, "Application of Advanced Methods to the Determination of Design Loads of the Lockheed L-1011 TriStar," AIAA 4th Aircraft Design, Operations and Flight Test Meeting. 7 August 1972. AIAA 72-775.

TABLE 1

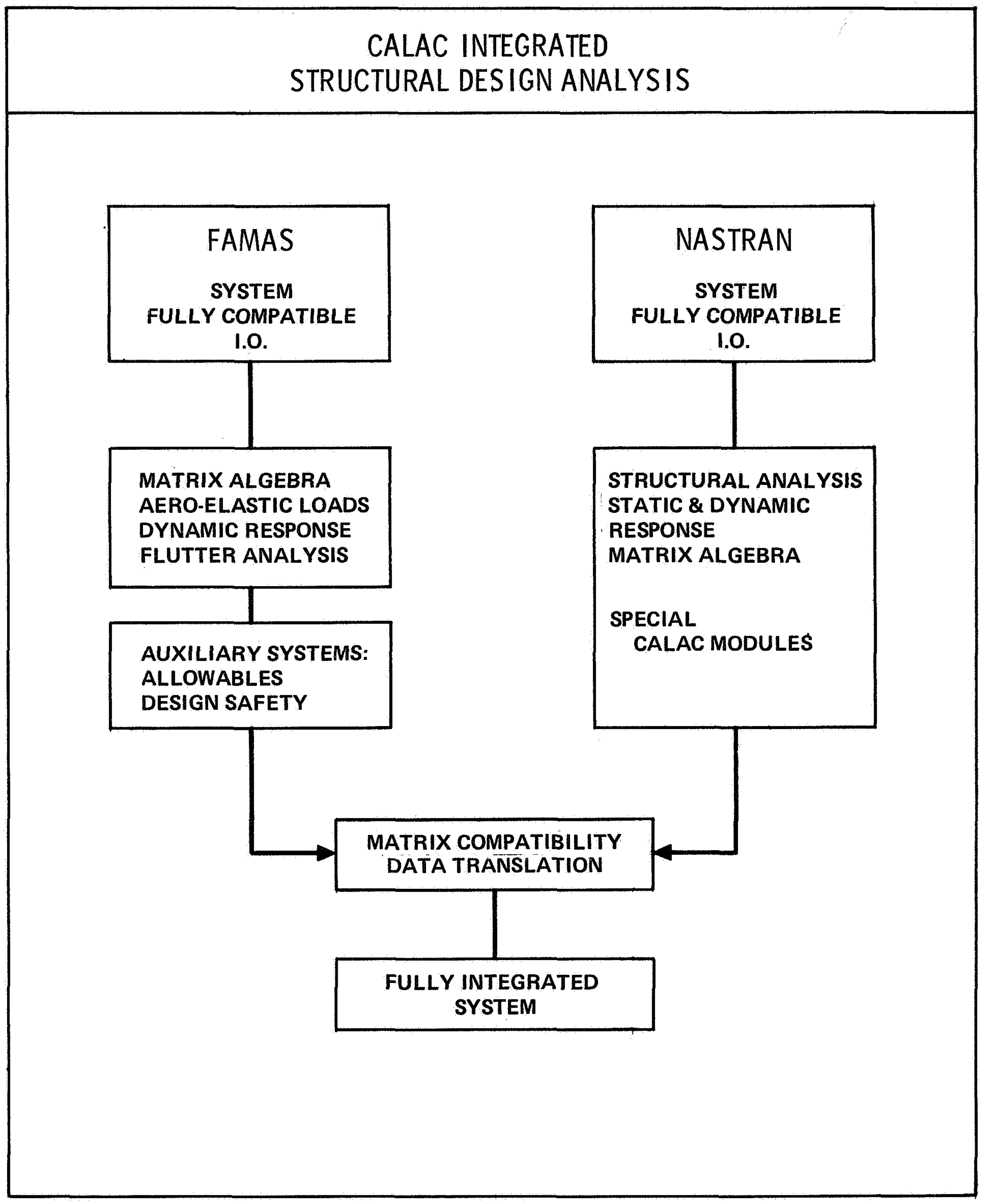
CALAC INTEGRATED
STRUCTURAL DESIGN ANALYSIS
FAMAS
SYSTEM
FULLY COMPATIBLE
I.O.
NASTRAN
SYSTEM
FULLY COMPATIBLE
I.O.
MATRIX ALGEBRA
AERO-ELASTIC LOADS
DYNAMIC RESPONSE
FLUTTER ANALYSIS
STRUCTURAL ANALYSIS
STATIC & DYNAMIC
RESPONSE
MATRIX ALGEBRA
SPECIAL
CALAC MODULES
AUXILIARY SYSTEMS:
ALLOWABLES
DESIGN SAFETY
MATRIX COMPATIBILITY
DATA TRANSLATION
FULLY INTEGRATED
SYSTEM

TABLE 2

CALAC – FAMAS SYSTEM

* EXTENSIVE MATRIX ALGEBRA & MANIPULATION APPROXIMATELY 50 MODULES

* SEVERAL FAMILIES OF FUNCTIONAL MODULES FOR AERO-ELASTIC ANALYSIS (See Ref. 2)

- AERODYNAMIC LOAD-DEFLECTION INFLUENCE MATRICES
  - Lifting line theories.
  - Mach Box (Supersonic)
  - Kernel Function
  - Doublet Lattice
  - Vortex Lattice
  - Piston theory
  - Reduction of wind-tunnel data and subsequent correction of theoretical matrices.
- STABILITY DERIVATIVES
- MASS-MATRICES
- MODAL ANALYSIS, VIBRATIONS
- FLUTTER ANALYSIS
- AIRCRAFT LOAD ANALYSES
  - Steady } maneuvers
  - Transient } maneuvers
  - Dynamic Gust Response Incl. Power Spectral Density Methods
  - Ground Handling & Landing Impact Response

TABLE 3 INTEGRATED STRUCTURAL DESIGN ANALYSIS SYSTEM

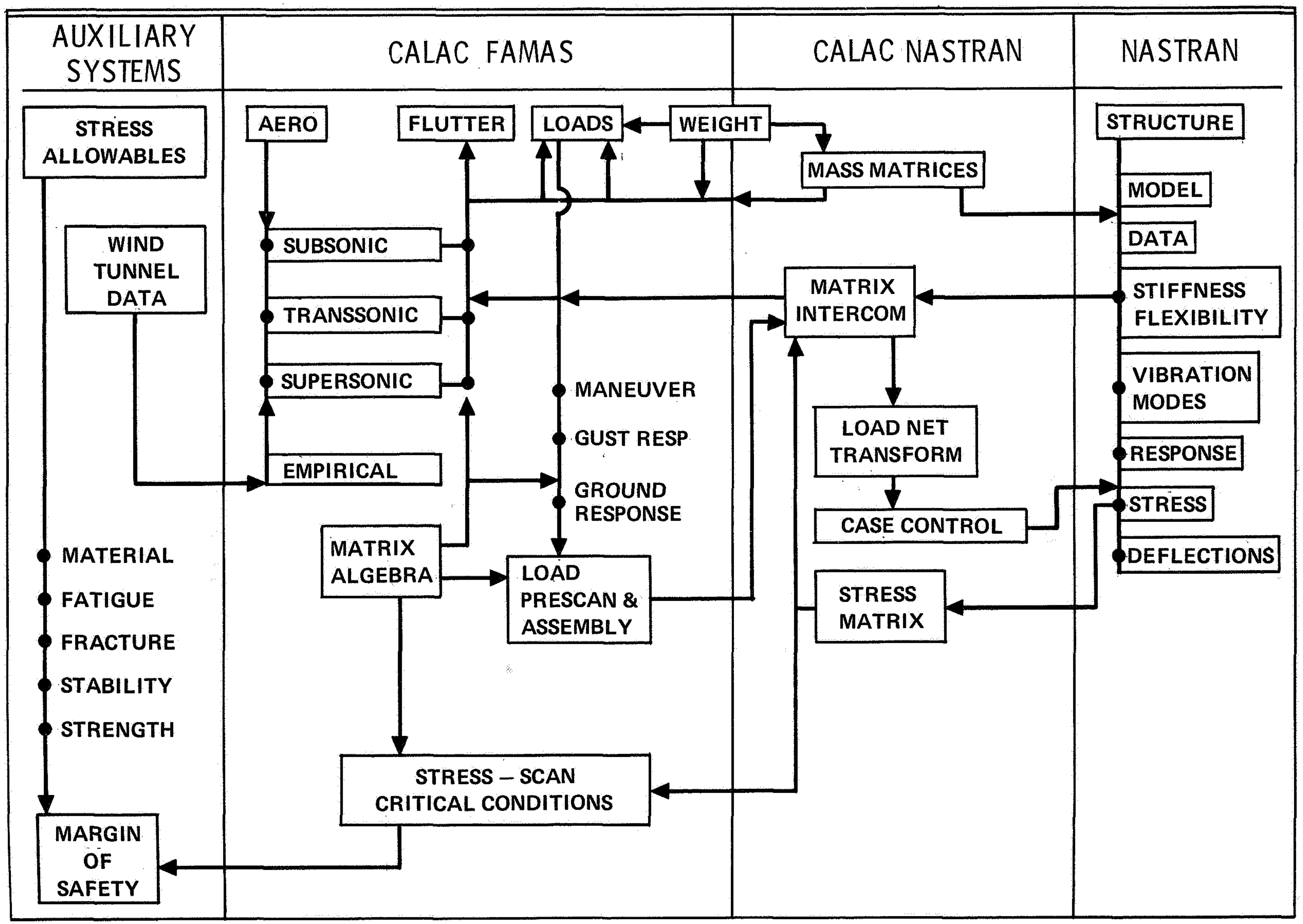

TABLE 4

EXAMPLE OF A COMBINED NASTRAN – FAMAS OPERATION

RUN 1

NASTRAN CONTROL →

- NASTRAN STRUCTURAL DATA
- CONSTRAINED STIFFNESS OR FLEXIBILITY MATRIX
- NASTRAN CHECKPOINT
- MATRIX OUTPUT IN FAMAS FORMAT (FAMASIØ)

NASTRAN – FAMAS INTERFACE

END RUN 1

RUN 2

FAMAS CONTROL →

- FAMAS DATA
- MASS MATRICES
- AERO MATRICES
- READ "NASTRAN" STIFFNESS MATRIX
- MANEUVER
- GUST RESPONSE
- GROUND RESPONSE

} PROGRAMS

- DESIGN CONDITION MATRICES

FAMAS – NASTRAN INTERFACE

NASTRAN CONTROL →

- CHECKPOINT RESTART FROM RUN 1
- READ FAMAS LOAD MATRICES (FAMASIØ)
- CONCLUSION OF NASTRAN STATIC ANALYSIS. OUTPUT

END RUN 2

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                                                                      FEBRUARY 10, 1972   NASTRAN  8/11/71
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TABLE 5 ORIGINAL NASTRAN MATRIX PRINT FORMAT MATPRN

```
 MATRIX B        (GINO NAME 1C2 ) IS A REAL        10 CCLUMN X    25 ROW RECTANG  MATRIX.

 COLUMN    1 I =    3 J=    5
  1.00000E CC  C.0          1.COCCCE CO

 COLUMN    2 I =    2 J=    3
  2.00000E CC  2.00CCCE 00

 COLUMN    3 I =    3 J=   22
  3.00000E CO  0.0          C.C          0.0          0.0          0.0          0.0          0.0          0.0          0.0
  0.0          0.0          C.C          0.0          0.0          0.0          0.0          1.00000E OC  2.00000E 00  3.00000E 00

 COLUMN    4 I =    1 J=    3
 -1.00000E 00  4.0CCCCE 00  4.COCCCF 00

 COLUMN    5 I =    3 J=    3
  5.00000E 00

 COLUMN    6 I =    2 J=    5
  1.00C00E 01  6.00CCCE 00 -2.CCCOCE CO  3.00000E 00

 COLUMN    7 I =    1 J=    3
  1.C0000E 00  2.00CCCE CO  7.CCCCCE 00

 COLUMN    8 I =    3 J=   14
  8.00000E CC  C.0          C.C          0.0          0.0          1.00000E 00  0.0          0.0          0.0          0.0
  1.00000E CO  2.0000CE 00

 COLUMN    9 I =    2 J=    3
 -3.00000E 00  9.0CCCCE CO

 COLUMN   10 I =    3 J=    3
  1.00000E 01

 THE NUMBER OF NON-ZERO WORDS IN THE LONGEST RECCRD = 3160
```

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                                                                      FEBRUARY 10, 1972   NASTRAN  8/11/71
```

TABLE 6 REVISED MATRIX PRINT FORMAT IN CALAC NASTRAN SYSTEM

```
 MATRIX B        (CINO NAME 1C2 ) IS A REAL        10 CCLUMN X    25 ROW RECTANG  MATRIX.

  COL  ROW                ROW                RCW                ROW                ROW                ROW
   1    3   1.CCCCCE CC     5  1.COCCOE CC
   2    2   2.COOCCE CC     3  2.CCCCOF CC
   3    3   3.COOOCE CC    2C  1.CCOCOE CO    21  2.00000E 00    22  3.00000E 00
   4    1  -1.CCOOCE CC     2  4.CCCCCE 00     3  4.00000E 00
   5    3   5.CCCCCE CC
   6    2   1.COOCCE C1     3  6.C0000E 00     4 -2.00000E 00     5  3.00000E 00
   7    1   1.COOCCE OC     2  2.CCOCCE OC     3  7.00000E 00
   8    3   8.COOOCE CC     8  1.COOOCE 00    13  1.00000E 00    14  2.00000E 00
   9    2  -3.CCOCCE CC     3  9.CCCCCE CO
  10    3   1.COCCCE C1

 THE NUMBER OF NCN-ZERO WORDS IN THE LONGEST RECCRD = 3160
```