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Transient Analysis Mode Participation for Modal Survey Target Mode Selection Using MSC/NASTRAN DMAP

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TRANSIENT ANALYSIS MODE PARTICIPATION

FOR MODAL SURVEY TARGET MODE SELECTION

USING MSC/NASTRAN DMAP

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Abstract

Many methods have been developed to aid analysts in identifying component modes which contribute significantly to component responses. These modes, typically targeted for dynamic model correlation via a modal survey, are known as *target modes*. Most methods used to identify target modes are based on component global dynamic behavior. It is sometimes unclear if these methods identify all modes contributing to responses important to the analyst. These responses are usually those in areas of hardware design concerns. One method used to check the completeness of target mode sets and identify modes contributing significantly to important component responses is *mode participation*. With this method, the participation of component modes in dynamic responses is quantified. Those modes which have high participation are likely modal survey target modes. Mode participation is most beneficial when it is used with responses from analyses simulating actual flight events. For spacecraft, these responses are generated via a structural dynamic coupled loads analysis. Using MSC/NASTRAN DMAP, a method has been developed for calculating mode participation based on transient coupled loads analysis results. The algorithm has been implemented to be compatible with an existing coupled loads methodology and has been used successfully to develop a set of modal survey target modes.

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Nomenclature

Abbreviations

DOF	Degree-of-freedom
DMAP	Direct Matrix Abstraction Program
DRM	Data Recovery Matrix
LeRC	Lewis Research Center
MEM	Modal Effective Mass
MPF	Mode Participation Fraction
NASA	National Aeronautics and Space Administration
WP-02	Work Package Two
WP-04	Work Package Four

Matrices

B	Damping
k,K	Stiffness
m,M	Mass
p,P	Applied loads
R	Recovered responses
T	Transformation
u,U	Physical displacements
$\ddot{u},\ddot{U}$	Physical accelerations
ϕ,Φ	Mode shapes
ξ	Modal displacements
$\dot{\xi}$	Modal velocities
$\ddot{\xi}$	Modal accelerations

Set Notation

a	a-set (analysis DOF)
A	Acceleration responses
D	Displacement responses
e	Elastic modal DOF
h	h-set (system modal DOF)
q	q-set (generalized DOF)
r	Rigid-body modal DOF
t	t-set (total physical interface DOF)
T	Total responses

Introduction

Many methods have been developed to aid analysts in identifying component modes which contribute significantly to component responses. These modes, typically targeted for dynamic model correlation via a modal survey, are known as *target modes*. Most methods used to identify target modes are based on component global dynamic behavior. Such methods include modal effective mass [1] and effective interface mass [2]. Because they are based on general dynamic characteristics of a component, sometimes it is not clear if these methods identify all modes which contribute significantly to responses important to the analyst. Many times, these responses include those which are in areas of hardware design concerns. One method used to check for the completeness of target mode sets and identify modes contributing significantly to important component responses is *mode participation*. With this method, the participation of component modes in dynamic responses is quantified. Those modes which have high participation contribute significantly to responses and are likely modal survey target modes. Mode participation is most beneficial when it is used with responses from analyses simulating actual flight events. For components such as Space Shuttle payloads, these responses are generated via a structural dynamic coupled loads analysis.

Structural dynamic coupled loads analyses for Space Shuttle/payload systems have been performed at NASA LeRC for many years [3]. Such analyses have supported Space Station hardware design efforts including the WP-02/WP-04 Combined Cargo Element shown in Fig. 1. To test-verify the dynamic model representing this Space Shuttle payload, a modal survey was planned. As part of the modal survey pre-test analysis activities, target modes were selected. The initial criteria for target mode selection was based on total modal effective mass. Experience has shown that this method is appropriate when the goal of a modal survey/model correlation activity is to obtain an analytical model which accurately predicts Space Shuttle/payload interface loads during transient analyses. For the Combined Cargo Element, attention was also focussed on areas of the hardware design where margins-of-safety were low. In particular, these areas included interfaces between major hardware components. Given the set of target modes selected using total modal effective mass, analysts questioned whether or not all modes contributing significantly to important component responses had been included. Analysts wanted payload modes contributing significantly to responses in areas of concern to be selected as target modes to better ensure accurate predictions of dynamic loads. To help analysts determine component modes important to responses in areas of concern, mode participation analysis was identified as an appropriate tool. The original set of target modes identified using modal effective mass would be modified to include component modes deemed important based on mode participation analyses.

To perform mode participation analyses for Space Shuttle payloads in support of modal survey activities, a MSC/NASTRAN DMAP sequence was developed. The DMAP is used to quantify component mode participation based on transient coupled loads analysis results. Developed for multi-level MSC/NASTRAN superelement payload models such as that representing the WP-02/WP-04 Combined Cargo Element, a major design feature of the new analytical tool is that it allows for relating superelement responses to the modes of an assembled payload model. This is accomplished through the use of component model response DRMs. The method has been implemented to be compatible with the NASA LeRC coupled loads methodology and has been used successfully to develop a set of modal survey target modes for the WP-02/WP-04 Combined Cargo Element.

The objective of this work was to develop a methodology that would quantify the participation of component model normal modes in coupled loads transient responses. In the following section, the general theory for mode participation calculations using component response DRMs is presented. The implementation of the general theory within a MSC/NASTRAN DMAP sequence is detailed in a subsequent section. Finally, the application of the new mode participation DMAP sequence in selecting a set of Space Station WP-02/WP-04 Combined Cargo Element modal survey target modes is described.

Theory

To identify component modes which contribute significantly to transient analysis component responses, a mode participation methodology has been developed which uses component model DRMs. Component DRMs transform the responses of component model interface and generalized DOF to general component responses (accelerations, forces, stresses, etc.). To better understand the mode participation methodology, it is worthwhile to review calculating component model interface and generalized DOF transient responses and performing transformations made possible by using DRMs.

Let a system for which a structural dynamic coupled loads analysis is to be performed be an assembly of many component models. Neglecting component damping, the equations of motion for the analysis (a-set) DOF of one of the component models are

$$[m_{aa}]\{\ddot{u}_a\} + [k_{aa}]\{u_a\} = \{p_a\} \tag{1}$$

where $[m_{aa}]$, $[k_{aa}]$, and $\{p_a\}$ are the dynamically reduced component a-set DOF mass, stiffness, and applied loads matrices, respectively. The component a-set DOF responses are the displacements $\{u_a\}$ and its derivatives. For a Craig-Bampton [4] reduced component model, the a-set DOF are comprised of the interface (t-set) DOF and generalized (q-set) DOF. The q-set DOF correspond to the component model normal modes of vibration when all t-set DOF are fixed. Given the reduced a-set size matrices of all component models, the a-set size matrices of all models are assembled to form the coupled system a-set DOF equations of motion:

$$[M_{aa}]\{\ddot{U}_a\} + [K_{aa}]\{U_a\} = \{P_a\} \tag{2}$$

In Eq. (2), coupled system damping has yet to be defined, and $[M_{aa}]$, $[K_{aa}]$, and $\{P_a\}$ are the coupled system mass, stiffness, and applied loads matrices, respectively. The coupled system a-set DOF responses are the displacements $\{U_a\}$ and its derivatives.

Typically during a coupled loads analysis, the coupled system equations of motion shown by Eq. (2) are transformed to modal space. The reduction uses the coupled system free-free modes $[\Phi_{ah}]$ generated via a system-level eigenvalue analysis to transform the n_a number of a-set DOF to n_h number of modal (h-set) DOF. Since the number of h-set DOF is usually much less than the number of a-set DOF ($n_h << n_a$), the reduction is made to take advantage of efficiencies gained when solving for the coupled system responses using modal analysis methods. For a modal transient analysis, the responses for the n_h number of coupled system modal DOF are found from solving

$$[M_{hh}]\{\ddot{\xi}_h\} + [B_{hh}]\{\dot{\xi}_h\} + [K_{hh}]\{\xi_h\} = \{P_h\} \tag{3}$$

where $[M_{hh}]$, $[B_{hh}]$, $[K_{hh}]$, and $\{P_h\}$ are the coupled system modal mass, damping, stiffness, and applied loads matrices, respectively, and $\{\xi_h\}$ and its derivatives are the coupled system modal DOF responses. Damping matrix $[B_{hh}]$ is generated external to the coupled system reduction of Eq. (2). Typically, $[B_{hh}]$ is a diagonal matrix with terms proportional to the coupled system eigenvalues. Because the system reduction is made on all component a-set DOF, the coupled system modal DOF responses are functions of all components which are part of the coupled system.

After solving for the coupled system modal DOF responses via Eq. (3), the a-set DOF responses for any component which is part of the system can be solved for. Component a-set DOF accelerations and displacements can be recovered using two basic methods: mode displacement or mode acceleration. For the *mode displacement* method of recovery, the component a-set DOF responses are calculated as

$$\{\ddot{u}_a\} = [\phi_{ah}]\{\ddot{\xi}_h\} \tag{4}$$

and

$$\{u_a\} = [\phi_{ah}]\{\xi_h\} \tag{5}$$

where $[\phi_{ah}]$ is the partition of the coupled system mode shapes $[\Phi_{ah}]$ corresponding to the component a-set DOF. For the *mode acceleration* method, the component a-set DOF responses are

$$\{\ddot{u}_a\} = [\phi_{ah}]\{\ddot{\xi}_h\} \tag{6}$$

and

$$\{u_a\} = [\phi_{ar}]\{\xi_r\} - [\phi_{ae}][\omega_e^{-2}]\{\ddot{\xi}_e\} + [u_a^1]\{P_a\} \tag{7}$$

where "r" and "e" refer to the n_r and n_e number of coupled system rigid-body and elastic modal DOF, respectively. In Eq. (7) [3], $[\phi_{ar}]$ and $[\phi_{ae}]$ are the rigid-body and elastic partitions of $[\phi_{ah}]$, $[\omega_e^{-2}]$ is a diagonal matrix containing the inverse squares of the coupled system elastic circular natural frequencies, $[u_a^1]$ are static displacements of the component a-set DOF due to unit static physical loads applied to the coupled system, and $\{P_a\}$ are the loads applied to the coupled system. Whether the component a-set DOF responses are recovered using a mode displacement or mode acceleration method, they are functions of the coupled system modal DOF responses.

As explained previously, the component a-set DOF can be partitioned into n_t number of total physical interface (t-set) DOF and n_q number of generalized (q-set) DOF. Partitioning the component a-set DOF accelerations and displacements,

$$\{\ddot{u}_a\} = \begin{Bmatrix} \{\ddot{u}_t\} \\ \{\ddot{u}_q\} \end{Bmatrix}; \qquad \{u_a\} = \begin{Bmatrix} \{u_t\} \\ \{u_q\} \end{Bmatrix} \tag{8a,b}$$

Given the partition of the component a-set DOF and considering the partition of the coupled system modal DOF, the mode displacement solution for the component a-set DOF accelerations and displacements shown by Eq. (4) and Eq. (5), respectively, can be rewritten as

$$\begin{Bmatrix} \{\ddot{u}_t\} \\ \{\ddot{u}_q\} \end{Bmatrix} = \begin{bmatrix} [\phi_{tr}] & [\phi_{te}] \\ [\phi_{qr}] & [\phi_{qe}] \end{bmatrix} \begin{Bmatrix} \{\ddot{\xi}_r\} \\ \{\ddot{\xi}_e\} \end{Bmatrix} \tag{9}$$

and

$$\begin{Bmatrix} \{u_t\} \\ \{u_q\} \end{Bmatrix} = \begin{bmatrix} [\phi_{tr}] & [\phi_{te}] \\ [\phi_{qr}] & [\phi_{qe}] \end{bmatrix} \begin{Bmatrix} \{\xi_r\} \\ \{\xi_e\} \end{Bmatrix} \tag{10}$$

Similarly, the mode acceleration solution for the component a-set DOF accelerations and displacements shown by Eq. (6) can be rewritten as Eq. (9), and the displacements shown by Eq. (7) can be rewritten as

$$\begin{Bmatrix} \{u_t\} \\ \{u_q\} \end{Bmatrix} = \begin{bmatrix} [\phi_{tr}] & -[\phi_{te}][\omega_e^{-2}] & [u_t^1] \\ [\phi_{qr}] & -[\phi_{qe}][\omega_e^{-2}] & [u_q^1] \end{bmatrix} \begin{Bmatrix} \{\xi_r\} \\ \{\ddot{\xi}_e\} \\ \{P_a\} \end{Bmatrix} \tag{11}$$

The above discussion focusses on the solution of component model a-set DOF accelerations and displacements using either a mode displacement or mode acceleration method. Given these responses, the efficient recovery of general component responses using DRMs is next considered. A DRM can transform the component a-set DOF responses to general component responses as

$$\begin{Bmatrix} \{R_A\} \\ \{R_D\} \end{Bmatrix} = \begin{bmatrix} [T_{Aa}] & [0_{At}] \\ [T_{Da}] & [T_{Dt}] \end{bmatrix} \begin{Bmatrix} \{\ddot{u}_a\} \\ \{u_t\} \end{Bmatrix} \tag{12}$$

where $\{R_A\}$ and $\{R_D\}$ are the n_A number of recovered accelerations and n_D number of recovered displacement-dependent responses (displacements, forces, etc.), respectively. Note that Eq. (12) shows a DRM for a component mode acceleration transformation to generate internal responses. Matrix $[T_{Aa}]$ is the partition of the DRM transforming component a-set DOF accelerations into internal accelerations. Matrices $[T_{Da}]$ and $[T_{Dt}]$ combine to transform the component a-set DOF accelerations and t-set DOF displacements into internal displacement-dependent responses. Partitioning the component a-set DOF terms of Eq. (12) into t-set DOF and q-set DOF terms, Eq. (12) can be rewritten as

$$\begin{Bmatrix} \{R_A\} \\ \{R_D\} \end{Bmatrix} = \begin{Bmatrix} \{R_A^t\} + \{R_A^q\} \\ \{R_D^t\} + \{R_D^q\} \end{Bmatrix} = \begin{bmatrix} [T_{At}] & [T_{Aq}] & [0_{At}] \\ [T'_{Dt}] & [T_{Dq}] & [T_{Dt}] \end{bmatrix} \begin{Bmatrix} \{\ddot{u}_t\} \\ \{\ddot{u}_q\} \\ \{u_t\} \end{Bmatrix} \tag{13}$$

where

$$\begin{Bmatrix} \{R_A^t\} \\ \{R_A^q\} \\ \{R_D^t\} \\ \{R_D^q\} \end{Bmatrix} = \begin{bmatrix} [T_{At}] & [0_{Aq}] & [0_{At}] \\ [0_{At}] & [T_{Aq}] & [0_{At}] \\ [T'_{Dt}] & [0_{Dq}] & [T_{Dt}] \\ [0_{Dt}] & [T_{Dq}] & [0_{Dt}] \end{bmatrix} \begin{Bmatrix} \{\ddot{u}_t\} \\ \{\ddot{u}_q\} \\ \{u_t\} \end{Bmatrix} \tag{14}$$

The above discussion centers on calculating component a-set DOF responses and then calculating general component responses using DRMs. Mode participation analysis is used to identify which component modes contribute significantly to component responses. The component modes are those used to reduce the component model and correspond to the component q-set DOF. For this application, mode participation analysis identifies important modes by calculating *mode participation fractions* (MPFs). Mode participation fractions are defined as follows: Given a component response at an instant in time, a particular component mode MPF is defined as the response due to the corresponding component q-set DOF divided by the sum of all component q-set DOF responses. In this way, component modes which contribute most to a response are identified by q-set DOF with high MPFs.

To develop an equation with which MPFs can be calculated, first consider the component q-set DOF partitions of Eq. (14):

$$\begin{Bmatrix} \{R_A^q\} \\ \{R_D^q\} \end{Bmatrix} = \begin{bmatrix} [T_{Aq}] \\ [T_{Dq}] \end{bmatrix} \{\ddot{u}_q\} \tag{15}$$

Equation (15) can be written in a simpler form as

$$\{R_T\} = [T_{Tq}]\{\ddot{u}_q\} \tag{16}$$

where $\{R_T\}$ contains the sums of all component q-set DOF contributions to the n_T number of total recovered responses ($n_T=n_A+n_D$), and $[T_{Tq}]$ is the partition of the DRM transforming the q-set DOF accelerations to the q-set DOF contributions. For any jth response within $\{R_T\}$, the sum of all q-set DOF contributions to that response is

$$R_j = [T_{jq}]\{\ddot{u}_q\} \tag{17}$$

where $[T_{jq}]$ is the jth row of $[T_{Tq}]$. The multiplication shown by Eq. (17) can also be written as the summation

$$R_j = \sum_{i=1}^{n_q} R_j^i = \sum_{i=1}^{n_q} T_{jq}^i \, \ddot{u}_q^i \tag{18}$$

The n_q number of terms shown in Eq. (18) are the individual q-set DOF responses which contribute to the jth response. Given these individual contributions, the MPF for the ith q-set DOF is calculated as

$$MPF_j^i = \frac{R_j^i}{R_j} = \frac{T_{jq}^i \, \ddot{u}_q^i}{R_j} \tag{19}$$

As can be seen from the above derivation, calculating MPFs for a particular component response is relatively straight forward. The MPFs are used to identify which component modes contribute most to responses of interest. It is important to note that identifying modal survey target modes based upon mode participation calculations requires engineering judgement. Judgement is required when selecting which responses to investigate and interpreting analytical results. An illustration of this is given via an example in a following section.

Implementation using MSC/NASTRAN DMAP

A mode participation methodology has been implemented as a MSC/NASTRAN DMAP sequence compatible with the NASA LeRC coupled loads methodology. A DMAP listing is provided in the Appendix. The DMAP sequence is operated as a data recovery restart using modal transient analysis results. The input data to the DMAP sequence are illustrated in Fig. 2. System modal DOF transient responses, system mode shapes, component model data and transformation matrices, and component response DRMs are required. The loads applied to the coupled system are also needed if system modal DOF mode acceleration recovery is desired. Although the DMAP sequence has been designed to be used with the NASA LeRC coupled loads methodology, the same input data could be obtained from standard MSC/NASTRAN solution sequences.

The mode participation DMAP sequence was written under the assumption that the component response DRM used for the calculations is of a form shown in Eq. (12). The DRM is for the recovery of internal responses using component model mode acceleration techniques. This DRM format is one used often within the NASA LeRC coupled loads methodology. However, minimum modifications could be made to the mode participation DMAP to accommodate different DRM types. A flow-chart illustrating the basic mode participation DMAP operations is shown in Fig. 3. Given system modal DOF transient responses found via Eq. (3) and component model data and transformation matrices, the component a-set DOF accelerations and t-set DOF displacements are calculated using either mode displacement (Eq. (9) and Eq. (10)) or mode acceleration (Eq. (9) and Eq. (11)) data recovery. The method of recovery is an option to the analyst. The component response DRM is then read in INPUTT4 format. The DRM is created using custom DMAP sequences [3]. For a multi-level MSC/NASTRAN superelement model, the DRM is used to relate component responses within any superelement to the a-set DOF responses of the assembled model. In this way, any general component response of a multi-level superelement model can be related, via the DRM, to the q-set DOF responses, hence the component modes, of the entire assembled model.

To perform mode participation analysis for one or all component response(s) defined within the DRM is an option to the analyst. Given that mode participation calculations can be performed for any output time instant of a transient analysis, the time instant for mode participation analysis is also an option. The analyst can allow calculations to be automatically performed for the time instant of absolute maximum response, or the analyst can input the time instant of interest using a parameter. Once the component response(s) and analysis time instant have been defined, the corresponding row(s) of the DRM and column of the component boundary responses are extracted. Intermediate calculations include individual component q-set DOF response contributions and the sum of all component q-set DOF response contributions shown by Eq. (18). Lastly, MPFs for the particular response(s) are generated using Eq. (19). These data are written to the MSC/NASTRAN .F06 file for post-processing.

Application to Modal Survey Target Mode Selection

A mode participation analysis methodology for general component responses was developed in support of Space Station WP-02/WP-04 Combined Cargo Element modal survey pre-test analysis activities. The Combined Cargo Element was designed to be lifted into space by the Space Shuttle. A design for the payload is shown in Fig. 1. In the figure, the payload is appropriately aligned with the Space Shuttle X_o, Y_o, and Z_o axes. The payload was approximately forty-five feet long (X_o direction), fifteen feet wide (Y_o direction), and fifteen feet high (Z_o direction). It was designed to mount within the Space Shuttle cargo bay at six attach points (eight DOF). The payload was to attach in two DOF in the X_o direction, two DOF in the Y_o direction, and four DOF in the Z_o direction. The finite element model representing the payload for transient dynamic analyses is shown in Fig. 4. The model had a weight of 35,400 lb and consisted of approximately 79,000 MSC/NASTRAN g-set DOF. For dynamic analyses, the model was substructured into a multi-level superelement model. The payload model superelement tree is shown in Fig. 5. Fixed at the eight Space Shuttle interface DOF, the first fifty-six payload frequencies and their translational modal effective masses were as listed in Table 1.

The criteria originally used to identify Combined Cargo Element modal survey target modes was based solely on total translational modal effective mass. The goals for total modal effective mass were equal to 90% in the X_o direction, 90% in the Y_o direction, and 75% in the Z_o direction. The lower value for the Z_o direction was due to the redundancy in Z_o attach DOF to the Space Shuttle. Choosing translational modal effective mass percentages for each payload fixed-interface mode listed in Table 1 greater than 2.0%, the original set of modal survey target modes was as listed in Table 2. Twelve payload modes were chosen. Only the modal effective masses greater than 2.0% for each mode are shown in Table 2.

Modal effective mass was appropriate for identifying target modes important for accurately predicting Space Shuttle/payload interface loads. However, analysts also wanted the target mode set to include modes that contributed significantly to dynamic transient responses in areas of low payload hardware design margins-of-safety. Mode participation analyses were performed for key payload responses to investigate whether or not additional target modes could be identified. A typical area of concern was as highlighted in Fig. 4. Regions such as this corresponded to major hardware interfaces and were represented in the loads analysis model by the interfaces between superelements 1 and 4 and superelements 2 and 4 (refer to Fig. (5)). Since the regions of interest were very similar in terms of design and dynamic response, the remaining discussion focusses on the interface between superelements 1 and 4. For mode participation analysis, a DRM was generated for recovering the interface loads between superelements 1 and 4 in the area of concern. For interface load recovery, the DRM was post-multiplied by the a-set DOF responses of the assembled payload model. The q-set DOF responses corresponded to the payload fixed-interface modes, some of which are listed in Table 1. As an example of the mode participation analyses, one of the interface loads investigated was aligned along the Space Shuttle Y_o axis. Significant payload q-set DOF contributions to that load are shown in Fig. 6. Referring to Fig. 6, payload modes 28, 29, and 30 contributed significantly to the response. This observation was also noted for mode participation analyses made for other interface loads. Hence, these three payload modes were added to the set of modal survey target modes as shown in Table 2. Note that the modal effective masses for modes 28, 29, and 30 are not significant with respect to the 2.0% criteria. However, mode participation analyses showed that these modes contributed significantly to dynamic responses in areas of concern for hardware design margins-of-safety.

In most engineering applications, a significant number of component modes may be identified via mode participation analyses as being significant contributors to component responses. This set of modes will probably be much larger than a set of target modes selected via modal effective mass or other techniques. Many times, constraints placed on analysts and modal survey test personnel require that the total set of target modes be prioritized. Hence, it is important that engineering judgement play an important role in selecting additional target modes based on mode participation analyses.

Summary

A mode participation analysis methodology has been developed and implemented using MSC/NASTRAN DMAP. The methodology, designed for transient dynamic coupled loads analyses, quantifies which fixed-interface component modes participate most in component responses. Knowing which component modes significantly participate in internal component dynamic responses can aide the analyst during modal survey pre-test analysis activities in selecting candidate target modes. The methodology takes advantage of efficiencies gained using MSC/NASTRAN superelement capabilities and component data recovery matrices. The methodology is designed to be compatible with the NASA LeRC coupled loads analysis methodology.

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Table 1. WP-02/WP-04 Combined Cargo Element Fixed-interface Normal Modes Summary Natural Frequencies and Modal Effective Mass

Mode	Freq. (Hz)	X_o MEM (%)	Y_o MEM (%)	Z_o MEM (%)	Mode	Freq. (Hz)	X_o MEM (%)	Y_o MEM (%)	Z_o MEM (%)
1	6.66	0.1	87.5	0.1	29	19.09	0.0	0.0	0.5
2	8.30	49.8	0.3	21.4	30	19.16	0.0	0.0	1.4
3	9.40	46.4	0.0	26.7	31	19.41	0.0	0.0	0.0
4	10.60	0.2	6.0	0.1	32	19.46	0.0	0.0	0.1
5	12.66	0.2	1.4	0.3	33	19.51	0.0	0.0	0.0
6	13.08	0.0	0.0	2.1	34	19.81	0.0	0.0	0.0
7	13.46	0.1	0.6	0.2	35	19.86	0.0	0.1	0.1
8	13.93	0.0	0.0	0.5	36	19.98	0.0	0.5	0.3
9	14.08	0.0	0.2	0.0	37	20.06	0.0	0.0	0.0
10	14.17	0.0	0.0	0.2	38	20.50	0.0	0.0	0.0
11	14.18	0.1	0.0	0.2	39	20.82	0.1	0.0	0.0
12	14.26	0.0	0.0	4.7	40	20.85	0.0	0.0	0.0
13	14.33	0.6	0.1	8.6	41	20.86	0.1	0.0	0.0
14	14.51	0.0	0.0	3.7	42	20.92	0.0	0.0	0.4
15	15.00	0.0	0.0	2.1	43	21.17	0.0	0.0	0.5
16	15.17	0.0	0.1	0.0	44	21.29	0.0	0.1	0.3
17	15.56	0.1	0.1	1.3	45	21.41	0.0	0.0	0.6
18	16.26	0.0	0.0	0.5	46	21.45	0.0	0.0	0.0
19	16.60	0.0	0.0	2.2	47	21.55	0.0	0.2	0.0
20	16.75	0.0	0.0	0.0	48	21.60	0.0	0.0	0.3
21	17.11	0.1	0.1	0.3	49	21.63	0.2	0.0	0.1
22	17.26	0.0	0.0	0.3	50	21.69	0.0	0.0	0.8
23	17.38	0.1	0.0	0.3	51	21.89	0.0	0.0	0.1
24	17.77	0.1	0.0	3.4	52	21.96	0.0	0.0	0.0
25	17.95	0.0	0.1	0.1	53	22.17	0.0	0.1	0.5
26	18.27	0.0	0.0	0.1	54	22.18	0.3	0.0	0.0
27	18.51	0.0	0.0	0.3	55	22.33	0.0	0.0	0.1
28	18.68	0.0	0.0	0.5	56	23.09	0.0	0.2	5.5

Table 2. WP-02/WP-04 Combined Cargo Element Modal Survey Target Modes Pre-test Analysis Sets Before and After Considering Mode Participation

Only Considering MEM					After Considering Mode Participation				
Mode	Freq. (Hz)	X_o MEM (%)	Y_o MEM (%)	Z_o MEM (%)	Mode	Freq. (Hz)	X_o MEM (%)	Y_o MEM (%)	Z_o MEM (%)
1	6.66		87.5		1	6.66		87.5	
2	8.30	49.8		21.4	2	8.30	49.8		21.4
3	9.40	46.4		26.7	3	9.40	46.4		26.7
4	10.60		6.0		4	10.60		6.0	
6	13.08			2.1	6	13.08			2.1
12	14.26			4.7	12	14.26			4.7
13	14.33			8.6	13	14.33			8.6
14	14.51			3.7	14	14.51			3.7
15	15.00			2.1	15	15.00			2.1
19	16.60			2.2	19	16.60			2.2
24	17.77			3.4	24	17.77			3.4
					28	***18.68***	***0.0***	***0.0***	***0.5***
					29	***19.09***	***0.0***	***0.0***	***0.5***
					30	***19.16***	***0.0***	***0.0***	***1.4***
56	23.09			5.5	56	23.09			5.5
Total		97.2	94.1	80.5	Total		97.2	94.1	82.9

Note: MEM percentages not shown are less than 2.0%; however, total MEM percentages include these values.

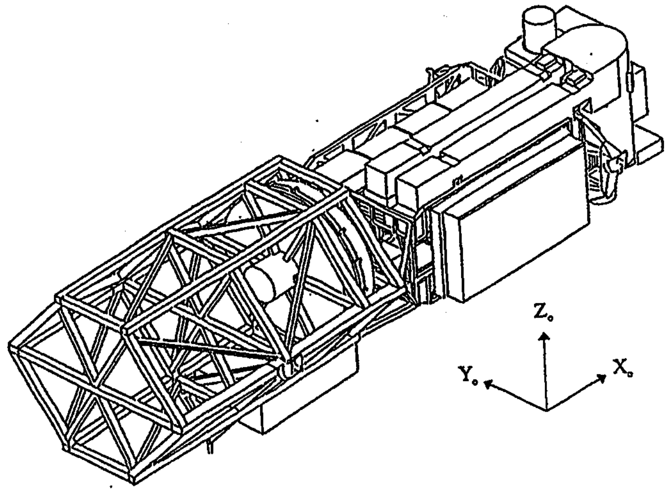

Figure 1.—The Space Station WP-02/WP-04 Combined Cargo Element Space Shuttle payload.

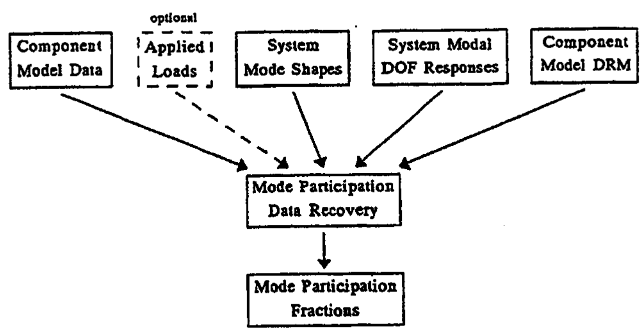

Figure 2.—Mode participation analyses are performed as modal transient analysis data recovery restarts.

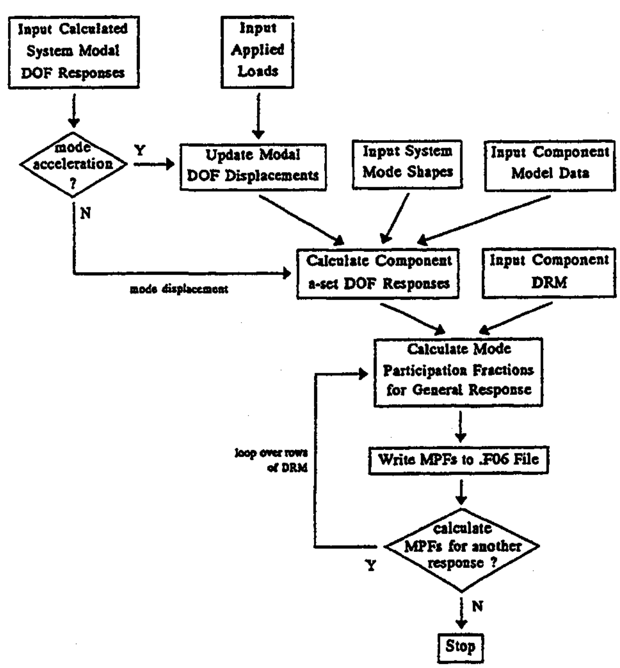

Figure 3.—Operational flow for mode participation DMAP sequence.

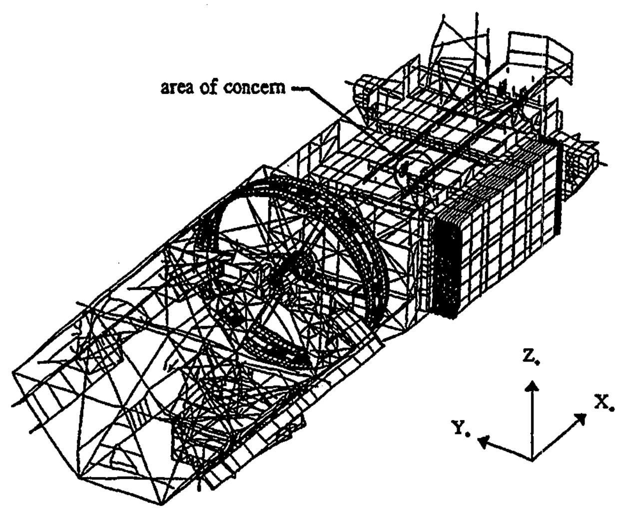

Figure 4. —Finite element representation of the WP-02/WP-04 Combined Cargo Element for dynamic loads analyses.

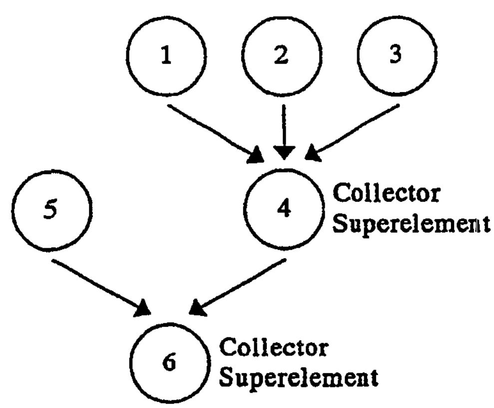

Figure 5.—Multi-level superelement tree for the WP-02/WP-04 Combined Cargo Element dynamic loads analysis model.

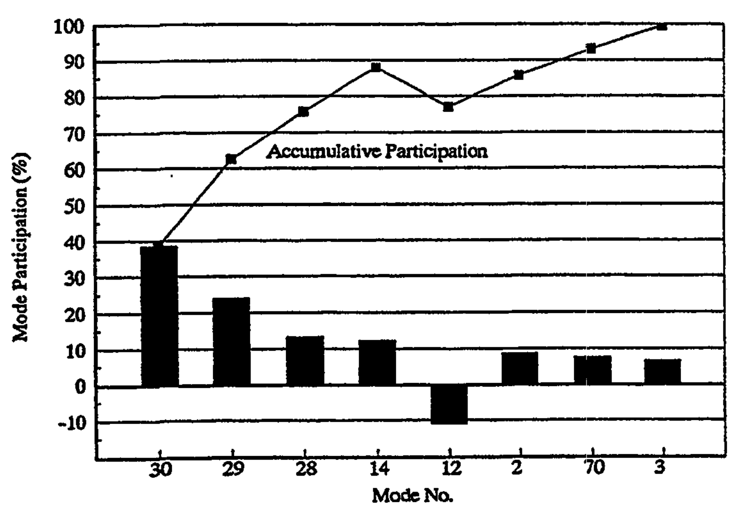

Figure 6.—WP-02/WP-04 Combined Cargo Element modes 28, 29, and 30 were identified as candidate modal survey target modes based on mode participation analysis.

Appendix

DMAP Sequence for

Mode Participation Analysis

```
SUBDMAP MODEPART $
$  CALCULATE MODE PARTICIPATION                                    (MODEPART)
$=========================================================================
$  MODE PARTICIPATION FRACTIONS
$  MSC/NASTRAN VERSION 67
$
$  THIS DMAP CALCULATES MODE PARTICPATION FRACTIONS (MPF) FOR THE
$  GENERALIZED (Q-SET) D.O.F. CONTRIBUTIONS OF A COMPONENT RESPONSE.
$  THE MPF FOR A PARTICULAR Q-SET D.O.F. IS DEFINED AS THE PARTICULAR
$  Q-SET D.O.F. CONTRIBUTION DIVIDED BY THE TOTAL Q-SET CONTRIBUTION TO
$  THE TOTAL RESPONSE.  THE RESPONSES ARE RECOVERED VIA DATA RECOVERY
$  MATRICES (DRM) FORMED BY THE RUNS DRM1 AND DRM2.  THE Q-SET D.O.F.
$  BELONG TO THE COMPONENT DEFINED AS THE "BASE" SUPERELEMENT IN THE
$  DRM RUNS.
$
$
$  REQUIREMENTS TO USE THIS DMAP SEQUENCE -
$-------------------------------------------------------------------------
$  FILE MANAGEMENT SECTION -
$
$    THE FOLLOWING DATA BASE FILES MUST BE AVAILABLE -
$    - RUN DATA BASE
$    - SYSTEM MODES DATA BASE
$    - COMPONENT DATA BASE (IF SEPARATE FROM SYSTEM DATA BASE)
$    - QTRAN DATA BASE
$    - FORCING FUNCTION DATA BASE
$    - FFMAX DATA BASE
$    - UNTLD DATA BASE
$
$    THE FOLLOWING FORTRAN FILES MUST BE AVAILABLE -
$    - DRM FILE (CREATED VIA DRM1, DRM2, AND DRMEXT)
$      NOTE: THE FILE MAY NOT BE NEEDED IF A RESTART IS REQUESTED
$-------------------------------------------------------------------------
$  EXECUTIVE CONTROL DECK -
$    THIS DMAP SEQUENCE (DO NOT USE A RIGID FORMAT)
$    DIAG 8, 14, AND 20 RECOMMENDED
$-------------------------------------------------------------------------
$  CASE CONTROL DECK -
$    NO REQUIREMENTS - STANDARD TITLING (TITLE, SUBTITLE, LABEL)
$-------------------------------------------------------------------------
$  BULK DATA DECK -
$
$
$    REQUIRED PARAMATER CARDS -
$
$    PARAM,CSEID      - DEFINE THE SUPERELEMENT ID FOR THE DRM.  THIS ID
$                       SHOULD BE THE "BASE SUPERELEMENT" ID FROM THE DRM
$                       RUNS (DRM1 AND DRM2)
$                       (NO DEFAULT - REQUIRED)
$
$    PARAM,DLOAD      - DEFINE THE LOAD CASE ID
$                       (NO DEFAULT - REQUIRED)
$
$    PARAM,FFSEID     - DEFINE THE FORCED SUPERELEMENT ID
$                       (NO DEFAULT - REQUIRED)
$
$
$    IMPORTANT PARAMATER CARDS - ONE OF THE FOLLOWING MUST BE RESET
$
$    PARAM,DRMACCE    - "-1" INDICATES DRM IS FOR ACCELERATIONS ONLY
$                       (DEFAULT = 0 - DRM NOT ONLY ACCE)
$
$    PARAM,DRMALL     - "-1" INDICATES DRM IS FOR ACCE AND DISP
$                       (DEFAULT = 0 - DRM NOT FOR ACCE AND DISP)
$
$    PARAM,DRMDISP    - "-1" INDICATES DRM IS FOR DISPLACEMENTS ONLY
```

```
$                       (DEFAULT = 0 - DRM NOT ONLY DISP)
$
$
$    OPTIONAL PARAMATER CARDS -
$
$    PARAM,DRMID      - DRM ID USED WHEN STORING DRM ON DATA BASE
$                       (DEFAULT = 0)
$
$    PARAM,DYNFCTR    - FACTOR APPLIED TO THE ELASTIC PORTION OF THE
$                       DYNAMIC RESPONSE
$                       (DEFAULT = 1.0)
$
$    PARAM,FACTOR     - "-1" INDICATES MODAL RESPONSES AND APPLIED LOADS
$                       ARE NOT BEING FACTORED (FASTER RUN)
$                       (DEFAULT = 0 - FACTOR EVEN THOUGH MAY BE 1.0)
$
$    PARAM,FUNITID    - FORTRAN UNIT ID OF DRM FILE
$                       (DEFAULT = 14)
$
$    PARAM,NOMODACC   - "-1" INDICATES USE MODE DISPLACEMENT FOR SOLVING
$                       BOUNDARY SOLUTION
$                       (DEFAULT = 0 - USE MODE ACCELERATION)
$
$    PARAM,NORBDISP   - "-1" INDICATES RIGID-BODY MODAL DISPLACEMENTS ARE
$                       SET TO ZERO
$                       (DEFAULT = 0 - KEEP MODAL RB DISPLACEMENTS)
$
$    PARAM,RESPONSE   - DEFINE THE RESPONSE NO. OF THE DRM FOR CALCULATING
$                       MODE PARTICIPATION FRACTIONS.
$                       (DEFAULT = -1 - MPF'S FOR ALL RESPONSES IN DRM)
$
$    PARAM,RESTART    - "-1" INDICATES RESTART RUN WHERE BOUNDARY SOLUTION
$                       AND DRM ARE FETCHED FROM THE DATA BASE.  FRACTIONS
$                       ARE CALCULATED FOR A NEW RESPONSE AND/OR NEW TIME
$                       (DEFAULT = 0 - PERFORM ENTIRE RUN)
$
$    PARAM,SOLTIME    - DEFINE THE COLUMN NO. OF THE BOUNDARY SOLUTION
$                       CORRESPONDING TO TIME OF INTEREST.
$                       (DEFAULT = -1 - AUTOMATIC SEARCH COL OF ABS MAX)
$
$    PARAM,STATFCTR   - FACTOR APPLIED TO THE STATIC PORTION OF THE
$                       RESPONSE
$                       (DEFAULT = 1.0)
$
$    PARAM,TSETRESP   - IF +1, PORTIONS OF TOTAL RESPONSE DUE TO T-SET DOF
$                       ACCELERATIONS AND DISPLACEMENTS PRINTED
$                       (DEFAULT = -1 - DO NOT PRINT T-SET RESPONSES)
$-------------------------------------------------------------------------
$  EXAMPLE NASTRAN DECK -
$
$    ID      MODE,PARTICIPATION
$    ASSIGN MASTER = 'MODEPART.MASTER'
$    ASSIGN DBALL  = 'MODEPART.DBALL'
$    ASSIGN USRSOU = 'MODEPART.USRSOU'
$    ASSIGN USROBJ = 'MODEPART.USROBJ'
$    INIT DBALL,LOGICAL=(DBALL(100000))
$    $
$    ASSIGN FF=TRLG.MASTER $
$    DBLOCATE LOGI=FF $
$    $
$    ASSIGN FFX=FFMAX.MASTER $
$    DBLOCATE LOGI=FFX $
$    $
$    ASSIGN QTR=QTRAN.MASTER $
$    DBLOCATE LOGI=QTR $
$    $
```

```
$    ASSIGN UNIT=UNTLD.MASTER $
$    DBLOCATE LOGI=UNIT $
$    $
$    ASSIGN SYS=SYSMODES.MASTER $
$    DBLOCATE LOGI=SYS $
$    $
$    ASSIGN INPUTT4=DRM.OPT4, UNIT=11, FORM=FORMATTED $
$    $
$    ACQUIRE NDDLOLD
$    $
$    TIME    60 $
$    DIAG    8,14,20 $
$    SOL     MODEPART $
$    COMPILE MODEPART,NOLIST,NOREF
$    INCLUDE MODEPART.V67
$    CEND
$    TITLE    = MODE PARTICIPATION FRACTIONS
$    SUBTITLE = ALL DRM RESPONSES (TIME OF ABSOLUTE MAX)
$    LABEL    = LOAD CASE 2165
$    $
$    BEGIN BULK
$    $
$    $  PARAMATERS
$    $
$    PARAM,CSEID,100            $  DEFINE DRM SUPERELEMENT ID
$    PARAM,DLOAD,2165           $  DEFINE DLOAD ID
$    PARAM,DRMALL,-1            $  DRM CONTAINS ACCE AND DISP
$    PARAM,DRMID,101            $  DEFINE THE DRM ID (FOR DBSTORE)
$    PARAM,DYNFCTR,1.50         $  DEFINE DYNAMIC FACTOR
$    PARAM,FFSEID,99            $  DEFINE FORCED SUPERELEMENT ID
$    PARAM,STATFCTR=1.0         $  DEFINE STATIC FACTOR
$    $
$    ENDDATA
$
$-----------------------------------------------------------------------
$  HISTORY DOCUMENTATION -
$
$  VERSION 1.0   A. BARNETT & O. IBRAHIM  11-MAY-92
$                - ORIGINAL VERSION
$                - CALCULATE PARTICIPATION FRACTIONS FOR ANY RESPONSE
$                  USING DATA RECOVERY MATRICES
$  VERSION 1.1   NADINE MACK              05-JUN-92
$                - CONVERTED TO VERSION 67
$  VERSION 1.2   A. BARNETT & O. IBRAHIM  18-JUN-92
$                - CORRECT LOGIC WHEN TOTAL DRM IS FORMED FROM SEPARATE
$                  PIECES READ AS INPUTT4.  IT IS ASSUMED THAT ALL T-
$                  AND Q-SET D.O.F. ARE REPRESENTED IN FINAL MATRIX.
$  VERSION 1.3   A. BARNETT & O. IBRAHIM  14-MAY-93
$                - ADD LOGIC FOR AUTOMATIC SEARCH FOR TIME OF ABS MAX
$                  RESPONSE AND CORRESPONDING MPF CALCULATION
$                - ADD LOGIC FOR AUTOMATIC LOOPING OVER ALL RESPONSES
$                  WITHIN DRM
$  VERSION 1.4   A. BARNETT & O. IBRAHIM  17-MAY-93
$                - ADD OPTIONAL PARAM FOR PRINTING T-SET RESPONSES
$=======================================================================
$234567890123456789012345678901234567890123456789012345678901234567890
$        1         2         3         4         5         6         7
$
$  SET DEFAULT VALUES
$  ------------------
$
TYPE      PARM,,I,Y,CONTINU=-1 $                   CONTINUE RESPONSES
TYPE      PARM,,I,Y,CSEID=-1 $                     DRM SUPERELEMENT ID
TYPE      PARM,,I,Y,DLOAD=0 $                      DLOAD ID
TYPE      PARM,,I,Y,DRMACCE=0 $                    DRM FOR ACCE
TYPE      PARM,,I,Y,DRMALL=0 $                     DRM FOR ACCE AND DISP
TYPE      PARM,,I,Y,DRMDISP=0 $                    DRM FOR DISP
TYPE      PARM,,I,Y,DRMID=0 $                      DRM ID
TYPE      PARM,,RS,Y,DYNFCTR=1.0 $                 DYNAMIC FACTOR
TYPE      PARM,,I,Y,EXTTIME=1 $                    TIME TO EXTRACT
TYPE      PARM,,I,Y,FACTOR=0 $                     PERFORM FACTORING
TYPE      PARM,,I,Y,FFSEID=-1 $                    FORCED SUPERELEMENT ID
TYPE      PARM,,I,Y,FUNITID=14 $                   FORTRAN UNIT ID
TYPE      PARM,,I,Y,NOMODACC=0 $                   USE MODE ACCELERATION
TYPE      PARM,,I,Y,NORBDISP=0 $                   KEEP RB MODAL DISP
TYPE      PARM,,I,Y,RESPONSE=-1 $                  RESPONSE NO. FROM DRM
TYPE      PARM,,I,Y,RESTART=0 $                    RESTART RUN
TYPE      PARM,,I,Y,SOLTIME=-1 $                   SOLUTION TIME
TYPE      PARM,,I,Y,STARTCNT=0 $                   COL TO START EXT SEARCH
TYPE      PARM,,I,Y,STARTRES=0 $                   COL TO START RESPONSES
TYPE      PARM,,RS,Y,STATFCTR=1.0 $                STATIC FACTOR
TYPE      PARM,,I,Y,TSETRESP=-1 $                  PRINT T-SET RESPONSES
TYPE      PARM,,I,N,CARDNO=0,PFILE=0 $             CARD AND PLOT COUNTERS
$
$  PATH QUALIFIERS
$  ---------------
$
TYPE      PARM,NDDL,I,Y,PEID $
TYPE      PARM,NDDL,I,N,SEID $
$
$  ALLOW OVERWRITES
$  ----------------
$
FILE      DRMQX=OVRWRT $
FILE      DRMTAX=OVRWRT $
FILE      DRMTDX=OVRWRT $
FILE      DRMTX=OVRWRT $
FILE      DRMX=OVRWRT $
FILE      NOQUNIT=OVRWRT $
FILE      NOQUNITT=OVRWRT $
FILE      QSETMPF=OVRWRT $
FILE      QSETMPFT=OVRWRT $
FILE      QSETRESP=OVRWRT $
FILE      QSETRSPX=OVRWRT $
FILE      QSETTERM=OVRWRT $
FILE      QSTTERMT=OVRWRT $
FILE      SOLN=OVRWRT $
FILE      TOTRESP=OVRWRT $
FILE      TOTSOLX=OVRWRT $
FILE      TSETRESP=OVRWRT $
FILE      TSETRSPA=OVRWRT $
FILE      TSETRSPD=OVRWRT $
FILE      UQDDX=OVRWRT $
FILE      UQDDXT=OVRWRT $
FILE      UTDDX=OVRWRT $
FILE      UTX=OVRWRT $
FILE      VSOLNMX=OVRWRT $
$
$  ASSIGN DATA BLOCK DEFINITIONS
$  -----------------------------
$
TYPE      DB,EQEXINS     $     PATH=MP          LOCATION=DBUP
TYPE      DB,GPLS        $     PATH=MP          LOCATION=DBUP
TYPE      DB,SILS        $     PATH=MP          LOCATION=DBUP
TYPE      DB,USET        $     PATH=MP          LOCATION=DBDN
$
$         DMAP DATA BLOCK AND PARAMETER ALLOCATION TO DATA BASE
$                 THE PATHS ARE DEFINED AS FOLLOWS:
$                    PATH MP    UZR,MODEL,PEID $
$
TYPE,PARM,NDDL,CHAR8,N,IFPX $ LOCATIONS
TYPE,PARM,NDDL,I,Y,MODEL,NL99,SEIDP,SOLID,SOLP,UZR $ QUALIFIERS
```

```
$
TYPE DB CASECC,PCDB,XYCDB,POSTCDB,FORCE,BULK,EPT,MPT,EDT,DIT,
        DYNAMICS,GEOM1,GEOM2,GEOM3,GEOM4,MATPOOL,AXIC,PVT,DMI,
        DTI,DTINDX,EDOM $
TYPE PARM,,CHAR8,Y,IFP='DEFAULT'
$
IFP1    /CASECC,PCDB,XYCDB,POSTCDB,FORCE/S,N,NOGOIFP1 $
XSORT   FORCE,/IBULK/S,N,NOGOXSRT $ FOR NODATA ETC. OPTION
IFP     IBULK/
        GEOM1Q,IEPT,IMPT,IEDT,IDIT,IDYNAMIC,IGEOM2,IGEOM3,IGEOM4,,
        FP6SCR,IMATPOOL,AXIC,PVT,DMI,DMINDX,DTI,DTINDX,,
        EDOM,DEQATN,DEQINDX/
        S,N,NOGOIFP $
IF (NOGOIFP1 OR NOGOXSRT OR NOGOIFP) THEN $
  MESSAGE //'ERROR IN USER INPUT - RUN TERMINATED'/ $
  EXIT $
ENDIF $
$
IF (IFP <>'DEFAULT') IFPX=IFP $
$
SETVAL //NP/S,Y,MODEL/NP/S,Y,NL99/NP/S,Y,SEIDP $ QUALIFIERS
SETVAL //NP/S,Y,SOLID/NP/S,Y,SOLP/NP/S,Y,UZR $ QUALIFIERS
$
PARAMR   //'COMPLEX'//STATFCTR/0.0/S,N,STATFCTC $ COMPLEX FOR ADD MOD
PARAMR   //'COMPLEX'//DYNFCTR/0.0/S,N,DYNFCTC $  COMPLEX FOR ADD MODULE
$
$  DATABASE IS VALID FROM THIS POINT ON
$  ---------------------------------
$
PUTSYS(1,125) $  HONOR RESTART/NOKEEP OPTION FROM NOW ON.
$
COND     NODBPRT,DBDICT $  PRINT DATA BASE DICTIONARY
  DBDIR     //V,Y,DBDRPRJ=0/V,Y,DBDRVER=0/V,Y,DBDROPT=63 $
  PARAM     //'NOP'/S,Y,DBDICT=-1 $  SET DEFAULT
LABEL    NODBPRT $
$
$  CHECK THAT THE SUPERELEMENT ID IS SPECIFIED
$  ----------------------------------------
$
PARAM    //'LE'/V,N,BADSEID/CSEID/0 $           -1 IF CSEID .LE. 0
IF (BADSEID=-1) THEN $
  MESSAGE  //'FATAL ERROR - CSEID HAS NOT BEEN SET'/ $
ENDIF $
$
$  CHECK THAT THE DLOAD SET ID IS SPECIFIED
$  -------------------------------------
$
PARAM    //'LE'/S,N,BADDLOAD/DLOAD/0 $          -1 IF DLOAD .LE. 0
IF (BADDLOAD=-1) THEN $
  MESSAGE  //'FATAL ERROR - DLOAD HAS NOT BEEN SET'/ $
ENDIF $
$
$  CHECK THAT THE FORCED SUPERELEMENT IS SPECIFIED
$  --------------------------------------------
$
PARAM    //'LE'/S,N,BADFFID/FFSEID/0 $          -1 IF FFSEID .LE. 0
IF (BADFFID=-1) THEN $
  MESSAGE  //'FATAL ERROR - FFSEID HAS NOT BEEN SET'/ $
ENDIF $
$
$  TERMINATE THE RUN IF ANY ERRORS ENCOUNTERED
$  ----------------------------------------
$
COND     ERROR,BADDLOAD $                       ERROR IF BAD DLOAD
COND     ERROR,BADFFID $                        ERROR IF BAD FFSEID
COND     ERROR,BADSEID $                        ERROR IF BAD SEID
```

```
$
$  FETCH SUPERELEMENT COMPONENT DATA
$  -------------------------------
$
SEID = CSEID $
PEID = CSEID $
$
DBVIEW   CSILS = SILS (WHERE SEID=CSEID) $
DBVIEW   CGPLS = GPLS (WHERE SEID=CSEID) $
DBVIEW   CUSET = USET (WHERE SEID=CSEID) $
DBVIEW   CEQEXINS = EQEXINS (WHERE SEID=CSEID) $
PARAML   CUSET//'USET'//////'A'/S,N,NOASET/
                           'T'/S,N,NOTSET/
                           'Q'/S,N,NOQSET $      NO. OF DOF
$
$  IF THIS IS A RESTART, GO TO MPF CALCULATION
$  ----------------------------------------
$
COND     CALCMPF,RESTART $
$
$  EXTRACT THE RIGID-BODY AND ELASTIC MODAL ACCELERATIONS
$  ---------------------------------------------------
$
CALL     DBFETCH /UHVF,,,,/DLOAD/0/0/0/0 $       FETCH MODAL RESPONSES
PARAML   UHVF//'PRESENCE'////S,N,NOUHVF $        -1 IF NO UHVF
IF (NOUHVF=-1) THEN $
  MESSAGE  //'FATAL ERROR - UHVF DATA BLOCK REQUIRED BUT NOT FOUND'/ $
ENDIF $
COND     ERROR,NOUHVF $                          ERROR IF NO UHVF
PARAML   UHVF//'TRAILER'/1/S,N,NOCOLU $          NO. OF COL IN UHVF
PARAML   UHVF//'TRAILER'/2/S,N,NOMODES $         NO. OF MODES IN UHVF
MATGEN   ,/VUXA/4/1/NOCOLU//1/3/3/ $             ONES FOR ACCELERATIONS
MATGEN   ,/VHRBEL/6/NOMODES/6/NOMODES $          H = RB / EL
PARTN    UHVF,VUXA,VHRBEL/,,QDDRB1,QDDEL1/1 $    ACCE OF RB AND EL
$
$  APPLY FACTORS TO THE RIGID-BODY AND ELASTIC MODAL ACCELERATIONS
$  ------------------------------------------------------------
$
$
$    PARAM,STATFCTR APPLIED TO RIGID-BODY MODE CONTRIBUTIONS
$    PARAM,DYNFCTR APPLIED TO ELASTIC MODE CONTRIBUTIONS
$
EQUIV    QDDRB1,QDDRB/FACTOR $                   EQUIV IF NO FACTORING
EQUIV    QDDEL1,QDDEL/FACTOR $                   EQUIV IF NO FACTORING
COND     DNFACTR1,FACTOR $                       SKIP IF NO FACTORING
ADD      QDDRB1,/QDDRB/STATFCTC $                MULT BY STATIC FACTOR
ADD      QDDEL1,/QDDEL/DYNFCTC $                 MULT BY DYNAMIC FACTOR
LABEL    DNFACTR1 $                              END OF FACTORING
$
$  FORM COMPONENT T-SET / Q-SET PARTITIONING VECTOR
$  ---------------------------------------------
$
VEC      CUSET/CVATQ/'A'/'COMP'/'Q' $            ONES FOR Q-SET DOF
MATPRN   CVATQ// $                               PRINT
MATGPR   CGPLS,CUSET,CSILS,CVATQ//'H'/'A' $      PRINT
$
$  PARTITION THE COMPONENT SYSTEM MODES
$  --------------------------------
$
$
$    THEY ARE FIRST PARTITIONED INTO RIGID-BODY AND ELASTIC SETS; THEN
$    ACCORDING TO T-SET AND Q-SET DOF MEMBERSHIP
$
CALL     DBFETCH /HULVS,,,,/0/CSEID/1/0/0 $      A-SET MODE SHAPES
PARAML   HULVS//'PRESENCE'////S,N,BADHULVS $     -1 IF NO ULVS
IF (BADHULVS=-1) THEN $
  MESSAGE  //'FATAL ERROR - ULVS FOR MODES REQUIRED BUT NOT FOUND'/ $
ENDIF $
```

```
COND     ERROR,BADHULVS $                                ERROR IF NO ULVS
PARTN    HULVS,VHRBEL,/HULVSRB,,HULVSEL,/1 $             COL PARTITION
PARTN    HULVSRB,,CVATQ/PHITR,PHIQR,,/1 $                ROW PARTITION
PARTN    HULVSEL,,CVATQ/PHITE,PHIQE,,/1 $                ROW PARTITION
$
$  CALCULATE COMPONENT T-SET, Q-SET, AND A-SET ACCELERATIONS
$  ------------------------------------------------------------
$
MPYAD    PHITR,QDDRB,/UTDDRB $                           UTDDRB = PHITR * QDDRB
MPYAD    PHITE,QDDEL,/UTDDEL $                           UTDDEL = PHITE * QDDEL
ADD      UTDDRB,UTDDEL/UTDD $                            UTDD = UTDDRB + UTDDEL
MPYAD    PHIQR,QDDRB,/UQDDRB $                           UQDDRB = PHIQR * QDDRB
MPYAD    PHIQE,QDDEL,/UQDDEL $                           UQDDEL = PHIQE * QDDEL
ADD      UQDDRB,UQDDEL/UQDD $                            UQDD = UQDDRB + UQDDEL
MERGE    UTDD,UQDD,,,,CVATQ/UADD/1 $                     ROW MERGE
$
$  CALCULATE COMPONENT T-SET DISPLACEMENTS VIA MODE ACCELERATION
$  ------------------------------------------------------------
$
MATGEN   ,/VUXD/4/1/NOCOLU//1/3/1/ $                     ONES FOR DISPLACEMENTS
PARTN    UHVF,VUXD,VHRBEL/,,QRB1,QEL1/1 $                DISP OF RB AND EL
COND     MDDISP,NOMODACC $                               SKIP IF MODE DISP
$
$  EXTRACT THE NON-ZERO ROWS FROM THE APPLIED LOADS MATRIX
$  ------------------------------------------------------------
$
CALL     DBFETCH /PDFX,,,,/DLOAD/FFSEID/0/0/0 $          APPLIED LOADS
PARAML   PDFX//'PRESENCE'////S,N,BADPDF $                -1 IF NO PDF
IF (BADPDF=-1) THEN $
   MESSAGE  //'FATAL ERROR - PDF DATA BLOCK REQUIRED BUT NOT FOUND'/ $
ENDIF $
COND     ERROR,BADPDF $                                  ERROR IF NO PDF
CALL     DBFETCH /PGMAXALL,,,,/0/FFSEID/0/0/0 $          MAX. DYNAMIC LOADS
PARAML   PGMAXALL//'PRESENCE'////S,N,BADPGMAX $          -1 IF NO PGMAXALL
IF (BADPGMAX=-1) THEN $
   MESSAGE  //'FATAL ERROR - PGMAXALL REQUIRED BUT NOT FOUND'/ $
ENDIF $
COND     ERROR,BADPGMAX $                                ERROR IF NO PGMAXALL
PARTN    PDFX,,PGMAXALL/,PDFNZ1,,/1 $                    KEEP NON-ZERO ROWS
$
$  APPLY FACTOR TO THE STATIC PORTION OF THE RESPONSES
$  ------------------------------------------------------------
$
$
$    PARAM,STATFCTR APPLIED TO UNIT LOAD CONTRIBUTIONS
$
EQUIV    PDFNZ1,PDFNZ/FACTOR $                           EQUIV IF NO FACTORING
COND     DNFACTR2,FACTOR $                               SKIP IF NO FACTORING
ADD      PDFNZ1,/PDFNZ/STATFCTC $                        MULT BY STATIC FACTOR
LABEL    DNFACTR2 $                                      END OF FACTORING
$
$  FORM THE INVERSE OF THE EIGENVALUE (OMEGA-SQ) MATRIX
$  ------------------------------------------------------------
$
CALL     DBFETCH /KHH,MHH,,,/DLOAD/0/0/0/0 $             SYSTEM DATA
ADD      MHH,KHH/OMSQINV1///2 $                          MATRIX "DIVIDE"
PARTN    OMSQINV1,VHRBEL,/,,,OMSQINV/ $                  ELIM. RB MODES
$
$  PARTITION THE UNIT LOAD STATIC DEFLECTIONS TO T-SET DOF
$  ------------------------------------------------------------
$
CALL     DBFETCH /SULVS,,,,/0/CSEID/0/0/0 $              A-SET DEFLECTIONS
PARAML   SULVS//'PRESENCE'////S,N,BADSULVS $             -1 IF NO ULVS
IF (BADSULVS=-1) THEN $
  MESSAGE  //'FATAL ERROR - SULVS DATA BLOCK REQUIRED BUT NOT FOUND'/ $
ENDIF $
COND     ERROR,BADSULVS $                                ERROR IF NO ULVS
PARTN    SULVS,,CVATQ/SULVST,,,/1 $                      ROW PARTITION
$
$  CALCULATE T-SET DISPLACEMENTS DUE TO ELASTIC RESPONSE
$  ------------------------------------------------------------
$
SMPYAD   PHITE,OMSQINV,QDDEL,,,/UTEL/3/-1 $              -1*PHITE*OMSQINV*QDDEL
MPYAD    SULVST,PDFNZ,/UTPDF $                           UTPDF = SULVST * PDFNZ
ADD      UTEL,UTPDF/UT1 $                                UT1 = UTEL + UTPDF
JUMP     DNUT1 $                                         GOTO TO RB DISP
$
$  CALCULATE COMPONENT T-SET DISPLACEMENTS VIA MODE DISPLACEMENT
$  ------------------------------------------------------------
$
LABEL    MDDISP $
$
$  APPLY FACTOR TO THE ELASTIC DYNAMIC PORTION OF THE RESPONSES
$  ------------------------------------------------------------
$
$
$    PARAM,DYNFCTR APPLIED TO ELASTIC MODE CONTRIBUTIONS
$
EQUIV    QEL1,QEL/FACTOR $                               EQUIV IF NO FACTORING
COND     DNFACTR3,FACTOR $                               SKIP IF NO FACTORING
ADD      QEL1,/QEL/DYNFCTC $                             MULT BY DYNAMIC FACTOR
LABEL    DNFACTR3 $                                      END OF FACTORING
$
$  CALCULATE T-SET DISPLACEMENTS DUE TO ELASTIC RESPONSE
$  ------------------------------------------------------------
$
MPYAD    PHITE,QEL,/UT1 $                                UT1 = PHITE * QEL
$
$  INCLUDE RIGID-BODY CONTRIBUTION TO T-SET DISPLACEMENTS (IF REQUIRED)
$  ------------------------------------------------------------
$
LABEL    DNUT1 $
EQUIV    UT1,UT/NORBDISP $                               EQUIV IF NO RB DISP
COND     DNSOLVE,NORBDISP $                              SKIP IF NO RB DISP
$
$  APPLY FACTOR TO THE RIGID-BODY DYNAMIC PORTION OF THE RESPONSES
$  ------------------------------------------------------------
$
$
$    PARAM,STATFCTR APPLIED TO RIGID-BODY MODE CONTRIBUTIONS
$
EQUIV    QRB1,QRB/FACTOR $                               EQUIV IF NO FACTORING
COND     DNFACTR4,FACTOR $                               SKIP IF NO FACTORING
ADD      QRB1,/QRB/DYNFCTC $                             MULT BY DYNAMIC FACTOR
LABEL    DNFACTR4 $                                      END OF FACTORING
$
$  CALCULATE T-SET DISPLACEMENTS DUE TO RIGID-BODY RESPONSE
$  ------------------------------------------------------------
$
MPYAD    PHITR,QRB,/UT2 $                                UT2 = PHITR * QRB
ADD      UT1,UT2/UT $                                    UT = UT1 + UT2
$
$  STORE ACCELERATIONS AND DISPLACEMENTS ON DATA BASE
$  ------------------------------------------------------------
$
LABEL    DNSOLVE $
CALL     DBSTORE UADD,UTDD,UQDD,,//DLOAD/CSEID/'DBALL'/0 $ STORE ACCELS
CALL     DBSTORE UT,,,,//DLOAD/CSEID/'DBALL'/0 $ STORE DISPLACEMENTS
$
$  MERGE THE COMPONENT BOUNDARY RESPONSES
$  ------------------------------------------------------------
$
PARAM    //'ADD'/S,N,NOAT/NOASET/NOTSET $                NOAT = NOASET + NOTSET
MATGEN   ,/VAT/6/NOAT/NOASET/NOTSET $                    ZEROES FOR A-SET
MERGE    UADD,UT,,,,VAT/UADDUT/1 $                       ROW MERGE
```

```
$
$  FETCH THE DRM
$  -------------
$
$    FOR ACCELERATIONS, THE DRM EQUATION IS
$
$      ACCE = (ACCELRM * UADD)
$
$    FOR DISPLACEMENTS (DISP. DEPENDENT RESPONSES), THE DRM EQUATION IS
$
$      DISP = (DISPLRM2 * UADD) + (DISPLRM1 * UT)
$
$    FOR ACCELERATIONS AND DISPLACEMENTS, THE DRM MATRIX EQUATION IS
$
$      ACCE      ACCELRM  :     0            UADD
$      ----  =  -------------------   *     ----
$      DISP      DISPLRM2 : DISPLRM1          UT
$
$    A MAXIMUM OF FIVE DRM'S WILL BE READ.  THEY ARE
$      1. CONTROL MATRIX (ALWAYS READ)
$      2. ACCELRM
$      3. DISPLRM1
$      4. DISPLRM2
$      5. CONTROL MATRIX (ALWAYS READ)
$
$    THE FORMAT OF THE DRM INPUTT4 STATEMENT LINE DEPENDS UPON WHAT IS
$    BEING DATA RECOVERED.
$
COND     ACCEONLY,DRMACCE $                              GOTO ONLY ACCE DRM
COND     DISPONLY,DRMDISP $                              GOTO ONLY DISP DRM
COND     ACCEDISP,DRMALL $                               GOTO ALL DRM
MESSAGE  //'FATAL ERROR - DRM TYPE HAS NOT BEEN SPECIFIED VIA PARAM'/ $
JUMP     ERROR $                                         ERROR IF NOTHING RESET
$
LABEL    ACCEONLY $
INPUTT4  /DUM1,ACCELRM,DUM2,,/3/FUNITID//0 $             BCD READ ONLY ACCELRM
PARAML   ACCELRM//'TRAILER'/1/S,N,NOCOLAC $              NO. OF COL OF ACCELRM
PARAM    //'EQ'/S,N,NOCOLEQA/NOCOLAC/NOASET $            -1 IF NOCOLAC = NOASET
EQUIV    ACCELRM,ACCELRMX/NOCOLEQA $                     ACCELRMX = ACCELRM
COND     DNEXPNDA,NOCOLEQA $                             SKIP IF NO EXPAND
MATGEN   ,/VDRMNULL/6/NOASET/NOCOLAC/NOASET $            ZEROS FOR ACCELRM
MERGE    ACCELRM,,,,VDRMNULL,/ACCELRMX/1 $               COL MERGE W/ NULLS
LABEL    DNEXPNDA $
MERGE    ACCELRMX,,,,VAT,/DRM/1 $                        COL MERGE W/ NULLS
MERGE    UADD,,,,,VAT/TOTSOL/1 $                         ROW MERGE W/ NULLS
JUMP     DNDRM $
$
LABEL    DISPONLY $
INPUTT4  /DUM1,DISPLRM1,DISPLRM2,DUM2,/4/FUNITID//0 $ BCD  ONLY DISP'S
PARAML   DISPLRM2//'TRAILER'/1/S,N,NOCOLD2 $             NO. OF COL OF DISPLRM2
PARAM    //'EQ'/S,N,NOCOLEQA/NOCOLD2/NOASET $            -1 IF NOCOLD2 = NOASET
EQUIV    DISPLRM2,DISPLRMX/NOCOLEQA $                    DISPLRMX = DISPLRM2
COND     DNEXPNDD,NOCOLEQA $                             SKIP IF NO EXPAND
MATGEN   ,/VDRMNULL/6/NOASET/NOCOLD2/NOASET $            ZEROS FOR DISPLRM2
MERGE    DISPLRM2,,,,VDRMNULL,/DISPLRMX/1 $              COL MERGE W/ NULLS
LABEL    DNEXPNDD $
MERGE    DISPLRMX,,DISPLRM1,,VAT,/DRM/1 $                DRM = DISP2 : DISP1
EQUIV    UADDUT,TOTSOL/ALWAYS $                          TOTSOL = UADDUT
JUMP     DNDRM $
$
LABEL    ACCEDISP $
INPUTT4  /DUM1,ACCELRM,DISPLRM1,DISPLRM2,DUM2/5/FUNITID//0 $ BCD  ALL
PARAML   ACCELRM//'TRAILER'/2/S,N,NOACCE $               NO. ROWS ACCELRM
PARAML   DISPLRM1//'TRAILER'/2/S,N,NODISP $              NO. ROWS DISPLRM1
PARAM    //'ADD'/S,N,NOAD/NOACCE/NODISP $                NOAD = NOACCE + NODISP
MATGEN   ,/VAD/6/NOAD/NOACCE/NODISP $                    ZEROES FOR ACCE
```

```
PARAML   ACCELRM//'TRAILER'/1/S,N,NOCOLAC $              NO. OF COL OF ACCELRM
PARAM    //'EQ'/S,N,NOCOLEQA/NOCOLAC/NOASET $            -1 IF NOCOLAC = NOASET
EQUIV    ACCELRM,ACCELRMX/NOCOLEQA $                     ACCELRMX = ACCELRM
EQUIV    DISPLRM2,DISPLRMX/NOCOLEQA $                    DISPLRMX = DISPLRM2
COND     DNEXPND,NOCOLEQA $                              SKIP IF NO EXPAND
MATGEN   ,/VDRMNULL/6/NOASET/NOCOLAC/NOASET $            ONES FOR NULLS
MERGE    ACCELRM,,,,VDRMNULL,/ACCELRMX/1 $               COL MERGE W/ NULLS
MERGE    DISPLRM2,,,,VDRMNULL,/DISPLRMX/1 $              COL MERGE W/ NULLS
LABEL    DNEXPND $
MERGE    ACCELRMX,DISPLRMX,,DISPLRM1,VAT,VAD/DRM/1 $  NON-SYM MERGE
EQUIV    UADDUT,TOTSOL/ALWAYS $                          TOTSOL = UADDUT
$
LABEL    DNDRM $
CALL     DBSTORE DRM,TOTSOL,,,//DLOAD/DRMID/'DBALL'/0 $ STORE IN DBASE
JUMP     SKPFTCH $                                       SKIP FETCH IF COLD RUN
$
$  BEGIN CALCULATING MODE PARTICIPATION FRACTIONS
$  ---------------------------------------------
$
LABEL    CALCMPF $
CALL     DBFETCH /DRM,TOTSOL,,,/DLOAD/DRMID/0/0/0 $ FETCH DRM & SOLN
CALL     DBFETCH /UQDD,UTDD,UT,,/DLOAD/CSEID/0/0/0 $ FETCH UQDD,UTDD,UT
$
$  EXTRACT THE REQUIRED ROW FROM DRM
$  --------------------------------
$
LABEL    SKPFTCH $                                       HERE IF COLD RUN
IF (RESPONSE > 0) THEN $                                 SET FLAG FOR CONTINUE
         CONTINU = 0 $
ENDIF $
TRNSP    DRM/DRMT $                                      TRANSPOSE DRM
MATGEN   ,/VQDDX/6/NOAT/NOTSET/NOQSET/NOTSET $           ONES FOR Q-SET
COND     NOTSET1,TSETRESP $                              JUMP IF NO T-SET RESP
MATGEN   ,/VTDDX/6/NOAT/0/NOTSET/NOASET $                ONES FOR T-SET
MATGEN   ,/VTX/6/NOAT/NOASET/NOTSET $                    ONES FOR T-SET
LABEL    NOTSET1 $
PARAML   DRMT//'TRAILER'/1/S,N,NORESP $                  NO OF RESPONSES
PARAM    //'ADD'/S,N,CNTRESP/STARTRES/1 $                BEGIN COUNTER
LABEL    TOPLOOP1 $                                      TOP OF RESPONSE LOOP
COND     AUTORESP,RESPONSE $                             GOTO ALL RESP SELECT
JUMP     GETRESP $                                       SKIP ALL RESP SELECT
LABEL    AUTORESP $
RESPONSE = CNTRESP $                                     SET RESPONSE NUMBER
LABEL    GETRESP $
MATMOD   DRMT,,,,,/DRMTX,/1/RESPONSE $                   EXTRACT COL FROM DRMT
TRNSP    DRMTX/DRMX $                                    ROW FROM DRM
PARTN    DRMX,VQDDX,/,,DRMQX,/1 $                        COL PARTITION
COND     NOTSET2,TSETRESP $                              SKIP IF NO T-SET RESP
PARTN    DRMX,VTDDX,/,,DRMTAX,/1 $                       COL PARTITION
PARTN    DRMX,VTX,/,,DRMTDX,/1 $                         COL PARTITION
LABEL    NOTSET2 $
$
$  SET THE TIME INSTANT FOR MPF CALCULATION
$  ---------------------------------------
$
IF (SOLTIME > 0) THEN $
         EXTTIME = SOLTIME $                             DEFINE TIME TO EXTRACT
         JUMP GETSOLN $                                  SKIP AUTO TIME SELECT
ENDIF $
MPYAD    DRMX,TOTSOL,/SOLN $                             CALCULATE SOLUTION
MATMOD   SOLN,,,,,/VSOLNMX,/6 $                          ABSOLUTE MAX EXTREMA
PARAML   VSOLNMX//'DMI'/1/1/S,N,SOLNMX $                 CONVERT VECTOR TO REAL
PARAM    //'ADD'/S,N,CNTTIME/STARTCNT/1 $                BEGIN COUNTER
LABEL    TOPLOOP2 $                                      TOP OF LOOP
PARAML   SOLN//'DMI'/CNTTIME/1/S,N,CMPARX $              EXTRACT VALUE CNTTIME
PARAMR   //'ABS'/S,N,COMPARE/CMPARX $                    ABSOLUTE VALUE
```

```
IF (COMPARE = SOLNMX) THEN $
        EXTTIME = CNTTIME $                          SET SOLUTION TIME
        JUMP GETSOLN $                               JUMP TO GET REQ'D SOLN
ENDIF $
CNTTIME  = CNTTIME + 1 $                             NEXT TIME STEP
REPT     TOPLOOP2,10000 $
$
$  EXTRACT THE REQUIRED COL FROM SOLUTIONS
$  ---------------------------------------
$
LABEL    GETSOLN $
MATMOD   TOTSOL,,,,,/TOTSOLX,/1/EXTTIME $            EXTRACT COL FROM SOL
MATMOD   UQDD,,,,,/UQDDX,/1/EXTTIME $                EXTRACT COL FROM UQDD
COND     NOTSET3,TSETRESP $                          SKIP IF NO T-SET RESP
MATMOD   UTDD,,,,,/UTDDX,/1/EXTTIME $                EXTRACT COL FROM UTDD
MATMOD   UT,,,,,/UTX,/1/EXTTIME $                    EXTRACT COL FROM UT
LABEL    NOTSET3 $
$
$  CALCULATE THE TOTAL RESPONSE AND THE Q-SET RESPONSE
$  ---------------------------------------------------
$
MPYAD    DRMX,TOTSOLX,/TOTRESP $                     TOTAL = DRMX * TOTSOLX
MPYAD    DRMQX,UQDDX,/QSETRESP $                     QSETR = DRMQX * UQDDX
$
$  CALCULATE Q-SET MODE PARTICIPATION FRACTIONS
$  --------------------------------------------
$
TRNSP    UQDDX/UQDDXT $                              TRANSPOSE UQDDX
ADD      DRMQX,UQDDXT/QSTTERMT///1 $                 TERMWISE MULTIPLY
MATGEN   ,/NOQUNIT/6/NOQSET/0/NOQSET $               UNIT VECTOR
TRNSP    NOQUNIT/NOQUNITT $                          TRANSPOSE NOQUNIT
MPYAD    QSETRESP,NOQUNITT,/QSETRSPX $               FULL QSETRESP
ADD      QSTTERMT,QSETRSPX/QSETMPFT///2 $            TERMWISE DIVIDE
$
$  CALCULATE THE T-SET RESPONSE (IF REQUIRED)
$  ------------------------------------------
$
COND     NOTSET4,TSETRESP $                          SKIP IF NO T-SET RESP
MPYAD    DRMTAX,UTDDX,/TSETRSPA $                    T-SET ACCE RESP
MPYAD    DRMTDX,UTX,/TSETRSPD $                      T-SET DISP RESP
ADD      TSETRSPA,TSETRSPD/TSETRESP $                T-SET TOTAL RESP
LABEL    NOTSET4 $
$
$  OUTPUT RESULTS
$  --------------
$
TRNSP    QSTTERMT/QSETTERM $                         TRANSPOSE FOR OUTPUT
TRNSP    QSETMPFT/QSETMPF $                          TRANSPOSE FOR OUTPUT
MATPRT   TOTRESP// $                                 PRINT TOTAL RESPONSE
COND     NOTSET5,TSETRESP $                          SKIP IF NO T-SET RESP
MATPRT   TSETRSPA// $                                PRINT T-SET ACCE RESP
MATPRT   TSETRSPD// $                                PRINT T-SET DISP RESP
MATPRT   TSETRESP// $                                PRINT T-SET TOTAL RESP
LABEL    NOTSET5 $
MATPRT   QSETRESP// $                                PRINT Q-SET RESPONSE
MATPRT   QSETTERM// $                                PRINT Q-SET TERMS
MATPRT   QSETMPF// $                                 PRINT Q-SET MPF'S
$
$  NEXT RESPONSE (IF REQUIRED)
$  ---------------------------
$
COND     NEXTRESP,CONTINU $
JUMP     FINIS $                                     TO END IF NOT ALL RESP
LABEL    NEXTRESP $
IF (CNTRESP = NORESP) THEN $
         JUMP FINIS $                                TO END IF DONE
```

```
ENDIF $
CNTRESP  = CNTRESP + 1 $                             INCREMENT RESP NO
RESPONSE = -1 $                                      RESET RESPONSE
REPT     TOPLOOP1,10000 $                            TO TOP OF LOOP
$
$  COME HERE IF ERROR
$  ------------------
$
LABEL    ERROR $
PRTPARM  ////1 $                                     PRINT PARAMETER TABLE
$
$  END OF DMAP
$  -----------
$
LABEL    FINIS $
DBDIR    ////$                                       DATA BASE DICTIONARY
END $
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13. ABSTRACT ***(Maximum 200 words)***

Many methods have been developed to aid analysts in identifying component modes which contribute significantly to component responses. These modes, typically targeted for dynamic model correlation via a modal survey, are known as *target modes*. Most methods used to identify target modes are based on component global dynamic behavior. It is sometimes unclear if these methods identify all modes contributing to responses important to the analyst. These responses are usually those in areas of hardware design concerns. One method used to check the completeness of target mode sets and identify modes contributing significantly to important component responses is *mode participation*. With this method, the participation of component modes in dynamic responses is quantified. Those modes which have high participation are likely modal survey target modes. Mode participation is most beneficial when it is used with responses from analyses simulating actual fight events. For spacecraft, these responses are generated via a structural dynamic coupled loads analysis. Using MSC/NASTRAN DMAP, a method has been developed for calculating mode participation based on transient coupled loads analysis results. The algorithm has been implemented to be compatible with an existing coupled loads methodology and has been used successfully to develop a set of modal survey target modes.

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