ACCURATE ENFORCED MOTION ANALYSIS USING MSC/NASTRAN SUPERELEMENTS

Christopher C. Flanigan
SDRC Engineering Services Division, Inc.
San Diego, California

ABSTRACT

The standard approach for performing an enforced motion analysis in MSC/NASTRAN uses very large masses and forces to obtain the desired motion at selected locations. This approach can lead to inaccurate results if the large masses are too large or too small.

An alternate approach for enforced motion analysis is presented in this paper. The alternate method uses the Craig-Bampton superelement capability in MSC/NASTRAN to form the required matrices for a direct solution of the equations of enforced motion. The need for large masses is eliminated, resulting in improved accuracy. In addition, the enforced motion analysis is performed directly, eliminating the need for Lagrange multipliers.

A rigid format alter for performing the new enforced motion analysis method is included in the paper. An example problem is presented to demonstrate the new method and to illustrate some of the pitfalls of enforced motion analysis.

1994 MSC/NASTRAN World Users Conference
Orlando, Florida
June 20-24, 1994

ACCURATE ENFORCED MOTION ANALYSIS USING MSC/NASTRAN SUPERELEMENTS

Christopher C. Flanigan
SDRC Engineering Services Division, Inc.
San Diego, California

Nomenclature

Acronyms

DOF	Degrees of freedom
DMAP	Direct matrix abstraction program
DRM	Data recovery matrix
MSC	MacNeal-Schwendler Corporation
NASTRAN	NASA Structural Analysis Program

Matrices

B	Damping
I	Identity
K	Stiffness
M	Mass
P	Applied loads
P'	Pseudo loads
U	Displacement
$\dot{U}$	Velocity
$\ddot{U}$	Acceleration

Subscripts

f	f-set (free DOF : g - m - s)
g	g-set (all DOF)
m	m-set (DOF constrained by MPC)
q	q-set (component mode DOF)
s	s-set (DOF restrained by SPC)
t	t-set (physical boundary DOF)

Introduction

Enforced motion transient analysis is a very important capability for the design of dynamic components. In enforced motion transient analysis (also known as "base shake"), motion histories are prescribed at selected locations in a component. The responses at other locations caused by the prescribed motion are calculated by a special transient analysis. Typical applications for enforced motion transient analysis include spacecraft coupled to a launch vehicle and road vehicles traveling over rough terrain. The base shake method is often used to perform trade studies for modified components using the interface motion histories from a previous system coupled transient analysis.

MSC/NASTRAN has the ability to perform enforced motion analysis using the "seismic mass" approach [1]. In this method, extremely large masses or inertias are placed at the enforced motion locations. Extremely large forces are applied to the large masses to cause the desired motion histories. The seismic mass approach has traditionally been prone to numerical error. If the seismic masses are not sufficiently large, dynamic feedback from the component causes the motion of the seismic masses to deviate from the prescribed histories. If the seismic masses are too large, numerical ill-conditioning can occur in the mass matrix and eigensolution.

This paper presents an alternate formulation for enforced motion transient analysis. The alternate method is based on a simple explicit algorithm that eliminates the need for seismic masses, thereby improving the accuracy of the enforced motion solution. The alternate method is implemented using superelement methods in MSC/NASTRAN to easily generate the required matrices. The alternate method is illustrated using an example problem. Finally, some of the limitation of enforced motion analysis are presented.

Theory

The derivation of the alternate method for enforced motion begins with the component equations of motion:

$$K_{ff}\,X_f + B_{ff}\,\dot{X}_f + M_{ff}\,\ddot{X}_f = P_f \tag{1}$$

Using MSC/NASTRAN superelement methodology [2], the equations of motion can be reduced from the f-set to the a-set:

$$\begin{bmatrix} K_{tt} & 0 \\ 0 & K_{qq} \end{bmatrix} \begin{Bmatrix} U_t \\ U_q \end{Bmatrix} + \begin{bmatrix} B_{tt} & B_{tq} \\ B_{qt} & B_{qq} \end{bmatrix} \begin{Bmatrix} \dot{U}_t \\ \dot{U}_q \end{Bmatrix} +$$

$$\begin{bmatrix} M_{tt} & M_{tq} \\ M_{qt} & M_{qq} \end{bmatrix} \begin{Bmatrix} \ddot{U}_t \\ \ddot{U}_q \end{Bmatrix} = \begin{Bmatrix} P_t \\ P_q \end{Bmatrix} \tag{2}$$

The form of (2) assumes that standard MSC/NASTRAN superelement capabilities are used. Since MSC/NASTRAN uses an enhanced version of the Craig-Bampton modal synthesis method [3], the off-diagonal partitions of the stiffness matrix are null. The form of (2) would be different if any other modal synthesis method were used such as the MacNeal-Rubin residual flexibility method [4,5].

The equations for enforced motion analysis can be significantly simplified using the following assumptions and limitations:

- Component modal damping only ($B_{tt} = B_{tq} = 0$)
- No internally applied forces ($P_q = 0$)

Using these assumptions, (2) can be rewritten as:

$$\begin{bmatrix} K_{tt} & 0 \\ 0 & K_{qq} \end{bmatrix} \begin{Bmatrix} U_t \\ U_q \end{Bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & B_{qq} \end{bmatrix} \begin{Bmatrix} \dot{U}_t \\ \dot{U}_q \end{Bmatrix} + \begin{bmatrix} M_{tt} & M_{tq} \\ M_{qt} & M_{qq} \end{bmatrix} \begin{Bmatrix} \ddot{U}_t \\ \ddot{U}_q \end{Bmatrix} = \begin{Bmatrix} P_t \\ 0 \end{Bmatrix} \tag{3}$$

The lower partition of (3) can be written as:

$$K_{qq}\,U_q + B_{qq}\,\dot{U}_q + M_{qt}\,\ddot{U}_t + M_{qq}\,\ddot{U}_q = 0 \tag{4}$$

or

$$K_{qq}\,U_q + B_{qq}\,\dot{U}_q + M_{qq}\,\ddot{U}_q = -M_{qt}\,\ddot{U}_t \tag{5}$$

The accelerations of the t-set DOF are prescribed using the values from the original coupled loads analysis. This relationship for the t-set accelerations can be added to (5) to form the equations of enforced motion for the a-set DOF:

$$\begin{bmatrix} 0 & 0 \\ 0 & K_{qq} \end{bmatrix} \begin{Bmatrix} U_t \\ U_q \end{Bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & B_{qq} \end{bmatrix} \begin{Bmatrix} \dot{U}_t \\ \dot{U}_q \end{Bmatrix} + \begin{bmatrix} I_{tt} & 0 \\ 0 & M_{qq} \end{bmatrix} \begin{Bmatrix} \ddot{U}_t \\ \ddot{U}_q \end{Bmatrix} = \begin{Bmatrix} P'_t \\ P'_q \end{Bmatrix} \tag{6}$$

where

$$\begin{Bmatrix} P'_t \\ P'_q \end{Bmatrix} = \begin{Bmatrix} \ddot{U}_t \\ -M_{qt}\,\ddot{U}_t \end{Bmatrix} \tag{7}$$

(6) is in the standard form for a modal transient analysis. The solution of (6) will be very efficient and extremely accurate if modal (uncoupled) damping is used. Non-diagonal damping will couple the equations of motion, thereby requiring a longer a slightly less accurate solution using the Newmark-Beta method.

Internal responses such as element forces and stresses can be recovered using standard MSC/NASTRAN data recovery capabilities. Alternatively, better efficiency and accuracy can be obtained using data recovery matrix methods [6].

Implementation

The alternate method for enforced motion analysis is implemented in MSC/NASTRAN using a rigid format alter. The rigid format alter for SOL 72 is included in Appendix A To use the alternate method, the user must comply with the following requirements:

- The enforced motion component must be defined as a single superelement or as a multiple superelements assembled into a single "collector" superelement..
- The enforced motion DOF must be exterior to the component.
- Fixed-interface component modes must be calculated (do not use free or mixed-interface modes).
- The residual structure must include only the exterior DOF of the upstream component. No additional grids or elements may be added to the residual structure.
- The enforced motion DOF must be listed on SUPORT entries in the residual structure.
- The acceleration histories for the t-set DOF must be defined as "applied loads" using TABLED1 cards and related input.
- Component modal damping may be defined using a TABDMP1 table.
- Standard Case Control and Bulk Data input must be defined for performing a modal transient analysis.

The rigid format alter forms the required matrices for the enforced acceleration transient analysis (6,7). A modal transient analysis is performed using the prescribed accelerations and the user-specified modal damping. If needed, nonzero initial conditions could be added by two methods:

- Special rigid format alters [7,8]
- Changing the approach code from 'MODES' to 'DIRECT' for the TRD1 transient response DMAP module and manually defining initial conditions using IC and TIC entries.

The use of the rigid format alter and the required user operations are illustrated in the following section.

Example Problem

The example problem was a typical aerospace application including a spacecraft coupled to a rocket motor as shown in Figure 1. The system was excited by thrust transients applied to the rocket nozzle. A baseline coupled loads analysis was performed using standard methods to obtain the accelerations at the spacecraft interface. The interface accelerations were converted to TABLED1 statements to perform the enforced motion analysis.

The input file for the enforced motion analysis of the spacecraft is shown in Figure 2. The spacecraft was defined as a single superelement with the interface DOF exterior to the superelement. Fixed-interface component modes were calculated to 75 Hz. 1% modal damping for the component modes was defined using a TABDMP1 table. The acceleration histories were defined using DLOAD, TLOAD1, DAREA, and TABLED1 statements.

The results from the enforced motion analysis were compared to those of the baseline coupled loads analysis. In addition, a "seismic mass" analysis was performed using the standard capabilities in MSC/NASTRAN. The acceleration histories of the enforced motion DOF exactly matched the histories prescribed from the coupled loads analysis as shown in Figure 3 and Table 1. The interior accelerations were reasonably accurate as shown in Table 2. However, there were substantial variations in the element loads as shown in Table 3. For most of the element forces, similar results were obtained from the seismic mass and enforced acceleration methods. The reasons for the differences between the standard analysis and the enforced motion analyses are discussed in the following section.

Limitations

While this paper presents an alternate method for more accurate enforced motion analysis, there are basic accuracy limitations of the enforced motion approach. These limitations are especially significant for coupled system solutions such as the example problem shown in Figure 1.

As shown in Tables 2 and 3, the interior results from the enforced motion analysis did not match those from the baseline coupled analysis even though there were no changes to the spacecraft model. For some of the element loads, the differences were extremely large. There were three major causes for the response differences. First, the modal damping of 1% applied to the system modes is not numerically equivalent to 1% damping applied to the component modes. The differences between system and component mode damping can be even more significant when the damping is higher.

The second cause of differences between coupled and enforced motion results is the modal content of the two problems. For the example problem, component modes were calculated to 75 Hz, and system modes were retained to 50 Hz. When calculating system modes, there is always truncation of the component mode information whenever the system mode frequency limit is below the component mode frequencies. However, all component modes are retained for the enforced motion analysis. Therefore, component mode truncation effects may cause the coupled and enforced motion results to be different even though there are no differences in the component models.

The third cause of differences between coupled and enforced motion results is the data recovery equations. For the standard analysis, data recovery was performed using the mode displacement method and the system modes. However, for the enforced motion analyses, the data recovery equations are similar to component data recovery matrices [6]. As noted in [6], there can be substantial differences in results calculated using mode displacement and component DRM methods.

Because of the three sources of differences between coupled and enforced motion results, it is recommended that enforced motion analysis be used with care. Special attention should be placed on accurate data recovery methods if internal loads are required.

A new class of analysis methods has recently been developed to try to address the differences between component and system results. These new methods, called Reanalysis [9,10], attempt to obtain the accuracy of the coupled system analysis using techniques similar to an enhanced base shake analysis. Initial results using these methods appear promising. Eventually, when greater experience is developed, Reanalysis methods may replace base shake methods for component analysis.

Conclusions

An alternate approach for performing enforced motion transient analysis was developed. The alternate method uses an explicit formulation that eliminates the need for large seismic masses at the enforced motion DOF. The alternate method was implemented using a rigid format alter in MSC/NASTRAN. The accuracy of the alternate method is better than the standard seismic mass algorithm in MSC/NASTRAN. However, enforced motion analysis should always be used with caution because of the accuracy differences between component and system transient analysis.

References

1. MSC/NASTRAN Application Manual, Volume 1, Section 2.7, "Automated Enforced Motion in Dynamic Analysis - Base Excitation," The MacNeal-Schwendler Corporation, Los Angeles, California.
2. MSC/NASTRAN Handbook for Superelement Analysis, The MacNeal-Schwendler Corporation, Los Angeles, California.
3. Craig, R.R., and Bampton, M.C.C., "Coupling of Substructures for Dynamic Analysis," AIAA Journal, Vol. 6, No. 7, July 1968.
4. MacNeal, R.H., "A Hybrid Method of Component Mode Synthesis," Computers & Structures, 1971, pp. 581-601.
5. Rubin, S., "Improved Component Mode Representation for Structural Dynamic Analysis," AIAA Journal, Vol. 13, No. 8, August 1975, pp. 995-1006.
6. Flanigan, C.C., "Efficient and Accurate Procedures for Calculating Data Recovery Matrices," 1989 MSC/NASTRAN World Users Conference, Los Angeles, California, March 13-17, 1989.
7. Flanigan, C.C., "Methods for Calculating and Using Modal Initial Conditions in MSC/NASTRAN," 1980 MSC/NASTRAN World Users Conference, Los Angeles, California, March, 1980.
8. Abdallah, Ayman A., A.R. Barnet, O.M. Ibrahim, R.T. Manella, "Solving Modal Equations of Motion with Initial Conditions Using MSC/NASTRAN, Part 1: Implementing Exact Mode Superposition," 1993 MSC/NASTRAN World Users Conference, Washington, D.C., May 24-28, 1993.
9. Blelloch, P., and Flanigan, C., "A Time Domain Approach for Spacecraft Reanalysis," 33rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Dallas, TX, April 13-15, 1992.
10. Trubert, M., and Peretti, L., "A Cost-Effective Component Modes Analysis for Shuttle Payloads Using a Combination of Frequency Domain and Time Domain Approaches, Paper 85-0733, AIAA/ASME/ASCE/AHS 26th SDM Conference, Orlando, Florida, April 15-17, 1985.

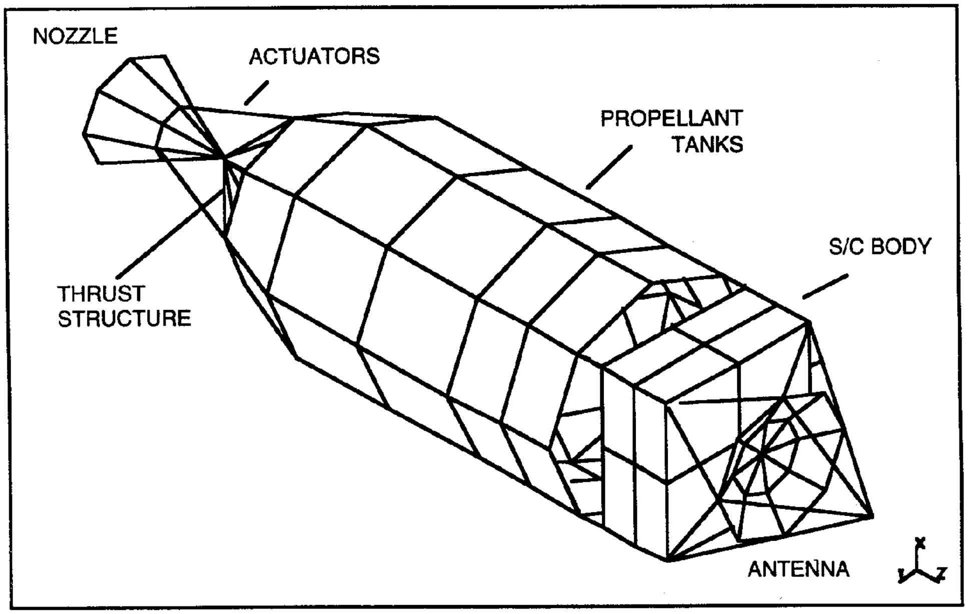

Figure 1. The example problem included a spacecraft coupled to a rocket motor.

```
ASSIGN MASTER='gpsc_enfa.MASTER'
ASSIGN DBALL ='gpsc_enfa.DBALL'
ASSIGN USRSOU='gpsc_enfa.USRSOU'
ASSIGN USROBJ='gpsc_enfa.USROBJ'
DBSETDEL USRSOU,USROBJ
$
ID       GPSC,ENFA
SOL      72       $ Modal transient analysis
TIME     30       $ 30 CPU minutes
DIAG     8        $ Print matrix trailers
$
COMPILE SOL72,SOUIN=MSCSOU,NOLIST,NOREF
INCLUDE 'rf72d339.v67'
$
CEND
TITLE    =GENERAL PURPOSE SPACECRAFT
SUBTITLE =ENFORCED ACCELERATION TRANSIENT ANALYSIS
$
ECHO = NONE                 $ Do not print bulk data deck
SEALL = ALL                 $ Required for SOL 72
$
SUBCASE 10
  SUPER 10                  $ GPSC superelement
  METHOD = 75               $ Component modes to 75 Hz
$
SUBCASE 1000
  LABEL = RESIDUAL STRUCTURE
  METHOD = 75               $ Component modes to 75 Hz
  TSTEP = 1                 $ Numerical integration data
  DLOAD = 1                 $ Dynamic loads
  SDAMP = 1                 $ Modal damping
$
OUTPUT(XYPLOT)
SEPLOT 0
INCLUDE 'gpsy_acce.xyp'
$
SEPLOT 10
INCLUDE 'gpsc_acce.xyp'
INCLUDE 'gpsc_elfor.xyp'
$
BEGIN BULK
$
$  PARAMETER CARDS
$  ---------------
$
PARAM   AUTOSPC YES
PARAM   GRDPNT  0
PARAM   USETPRT 0
PARAM   WTMASS  .00259
$
$  Deactivate DDRMM and MODACC
$
PARAM   DDRMM   -1
PARAM   MODACC  -1
```

(page 1 of 3)

Figure 2. The above input deck was used to perform the enforced acceleration transient analysis.

```
$
$  EIGENVALUE SOLUTION DATA
$  ------------------------
$
EIGRL   75              75.
$
$  GPSC BULK DATA
$  --------------
$
INCLUDE 'gpsc.blk'
INCLUDE 'gpsc.prp'
INCLUDE 'gpsc.sup'
$
$  ENFORCED ACCELERATION DATA
$  --------------------------
$
$  Define the enforced acceleration DOF (T-set of upstream SE)
$
SUPORT  44      123456
SUPORT  45      123456
SUPORT  48      123456
SUPORT  49      123456
$
$  Enforced accelerations (24 enforced accel DOF)
$
DLOAD   1       1.      1.      441     1.      442     1.      443
        1.      444     1.      445     1.      446     1.      451
        1.      452     1.      453     1.      454     1.      455
        1.      456     1.      481     1.      482     1.      483
        1.      484     1.      485     1.      486     1.      491
        1.      492     1.      493     1.      494     1.      495
        1.      496
$
$       SID     DAREA   DELAY   TYPE    TABLED1
TLOAD1  441     441                     441
TLOAD1  442     442                     442
TLOAD1  443     443                     443
TLOAD1  444     444                     444
TLOAD1  445     445                     445
TLOAD1  446     446                     446
$
TLOAD1  451     451                     451
TLOAD1  452     452                     452
TLOAD1  453     453                     453
TLOAD1  454     454                     454
TLOAD1  455     455                     455
TLOAD1  456     456                     456
$
TLOAD1  481     481                     481
TLOAD1  482     482                     482
TLOAD1  483     483                     483
TLOAD1  484     484                     484
TLOAD1  485     485                     485
TLOAD1  486     486                     486
```

(page 2 of 3)

Figure 2. The above input deck was used to perform the enforced acceleration transient analysis.

```
$
TLOAD1  491     491                             491
TLOAD1  492     492                             492
TLOAD1  493     493                             493
TLOAD1  494     494                             494
TLOAD1  495     495                             495
TLOAD1  496     496                             496
$
$       SID     GRID    DOF     S
DAREA   441     44      1       1.
DAREA   442     44      2       1.
DAREA   443     44      3       1.
DAREA   444     44      4       1.
DAREA   445     44      5       1.
DAREA   446     44      6       1.
$
DAREA   451     45      1       1.
DAREA   452     45      2       1.
DAREA   453     45      3       1.
DAREA   454     45      4       1.
DAREA   455     45      5       1.
DAREA   456     45      6       1.
$
DAREA   481     48      1       1.
DAREA   482     48      2       1.
DAREA   483     48      3       1.
DAREA   484     48      4       1.
DAREA   485     48      5       1.
DAREA   486     48      6       1.
$
DAREA   491     49      1       1.
DAREA   492     49      2       1.
DAREA   493     49      3       1.
DAREA   494     49      4       1.
DAREA   495     49      5       1.
DAREA   496     49      6       1.
$
INCLUDE 'enfacce.tbl'
$
$  TSTEP DATA
$  ----------
$
TSTEP   1       500     .001    1
$
$  MODAL DAMPING DATA
$  ------------------
$
TABDMP1 1       CRIT
        0.      .01     100.    .01     ENDT
$
ENDDATA
```

(page 3 of 3)

Figure 2. The above input deck was used to perform the enforced acceleration transient analysis.

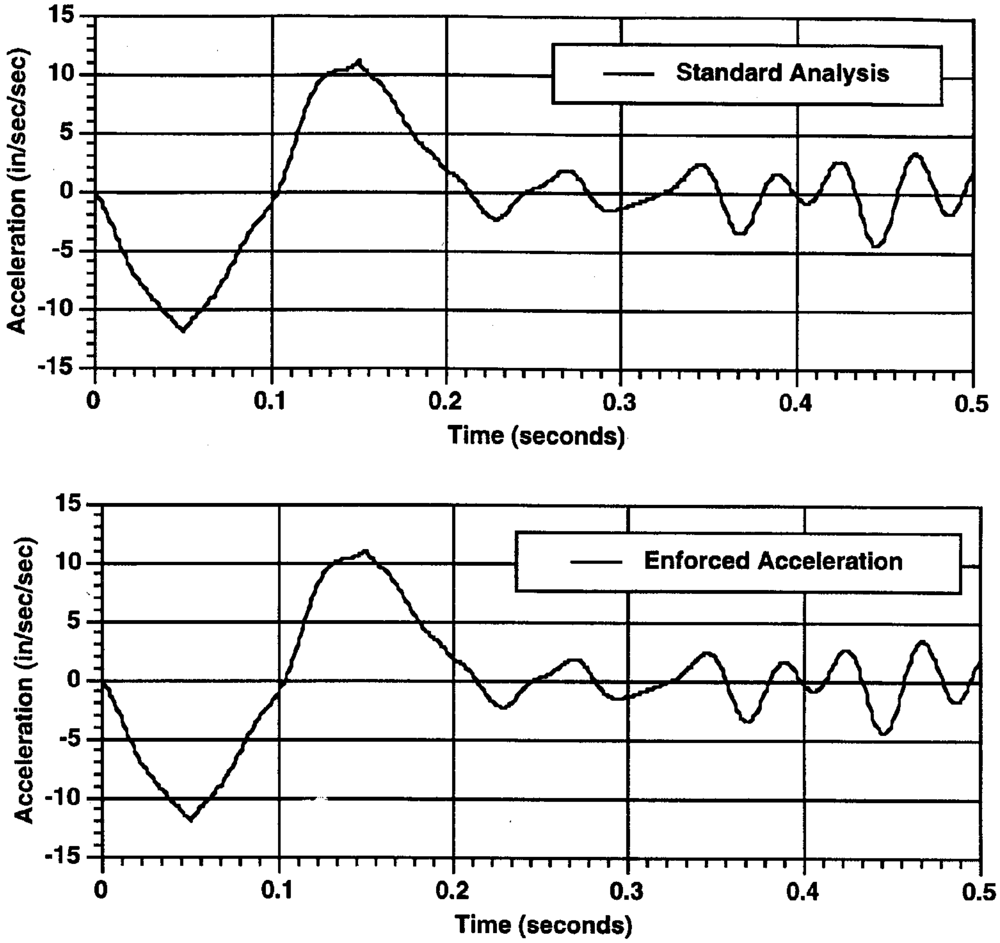

Figure 3. The enforced accelerations at the boundary DOF were identical to those from the standard coupled analysis.

Table 1. Boundary accelerations.

Grid	DOF	Standard Analysis	Enforced Accel.	Enf. Accel. Difference	Seismic Mass	Seis. Mass Difference
44	1	-0.031	-0.031	0.0%	-0.031	0.0%
44	2	0.032	0.032	0.0%	0.032	0.0%
44	3	0.666	0.666	0.0%	0.666	0.0%
44	4	-0.002	-0.002	0.0%	-0.002	0.0%
44	5	0.003	0.003	0.0%	0.003	0.0%
44	6	0.000	0.000	0.0%	0.000	0.0%
45	1	-0.040	-0.040	0.0%	-0.040	0.0%
45	2	-0.039	-0.039	0.0%	-0.039	0.0%
45	3	0.662	0.662	0.0%	0.662	0.0%
45	4	0.004	0.004	0.0%	0.004	0.0%
45	5	-0.005	-0.005	0.0%	-0.005	0.0%
45	6	0.001	0.001	0.0%	0.001	0.0%
48	1	-0.038	-0.038	0.0%	-0.038	0.0%
48	2	-0.038	-0.038	0.0%	-0.038	0.0%
48	3	0.662	0.662	0.0%	0.662	0.0%
48	4	-0.003	-0.003	0.0%	-0.003	0.0%
48	5	0.004	0.004	0.0%	0.004	0.0%
48	6	0.000	0.000	0.0%	0.000	0.0%
49	1	-0.030	-0.030	0.0%	-0.030	0.0%
49	2	0.034	0.034	0.0%	0.034	0.0%
49	3	0.712	0.712	0.0%	0.712	0.0%
49	4	0.003	0.003	0.0%	0.003	0.0%
49	5	0.002	0.002	0.0%	0.002	0.0%
49	6	0.000	0.000	0.0%	0.000	0.0%

Table 2. Interior accelerations.

Grid	DOF	Standard Analysis	Enforced Accel.	Enf. Accel. Difference	Seismic Mass	Seis. Mass Difference
1	1	0.103	0.100	-2.7%	0.100	-2.7%
1	2	0.105	0.101	-3.5%	0.101	-3.5%
1	3	0.698	0.677	-3.0%	0.677	-3.0%
18	1	0.135	0.138	2.6%	0.138	2.6%
18	2	0.133	0.133	-0.7%	0.133	-0.7%
18	3	0.665	0.662	-0.4%	0.662	-0.4%
19	1	0.068	0.068	-0.9%	0.068	-0.9%
19	2	0.061	0.063	2.5%	0.063	2.5%
19	3	0.665	0.665	0.0%	0.665	0.0%
30	1	0.056	0.055	-2.4%	0.055	-2.4%
30	2	0.067	0.065	-3.0%	0.065	-3.0%
30	3	0.700	0.697	-0.4%	0.697	-0.4%
40	1	0.080	0.080	0.3%	0.080	0.3%
40	2	0.067	0.065	-2.9%	0.065	-2.9%
40	3	0.790	0.771	-2.4%	0.771	-2.4%

Table 3. Interior element forces.

Element	Item Code	Standard Analysis	Enforced Accel.	Enf. Accel. Difference	Seismic Mass	Seis. Mass Difference
17	2	-700.9	-636.2	-9.2%	-636.4	-9.2%
17	3	800.4	778.4	-2.7%	754.0	-5.8%
17	4	60.3	-84.0	-239.2%	-96.3	-259.7%
17	5	-83.6	176.1	-310.6%	225.9	-370.2%
17	6	-63.3	-50.0	-21.0%	-48.8	-22.9%
17	7	73.6	66.0	-10.3%	60.5	-17.8%
17	8	-435.7	-408.6	-6.2%	-408.7	-6.2%
17	9	-11.7	-11.7	0.6%	-11.8	0.8%
18	2	-1375.2	-1320.3	-4.0%	-1320.0	-4.0%
18	3	-1368.4	-1354.4	-1.0%	-1355.9	-0.9%
18	4	307.4	-274.2	-189.2%	-272.1	-188.5%
18	5	-305.7	280.7	-191.8%	282.6	-192.4%
18	6	-140.2	-126.9	-9.5%	-126.9	-9.5%
18	7	-138.4	-136.3	-1.6%	-136.5	-1.3%
18	8	-230.8	-204.6	-11.3%	-204.6	-11.3%
18	9	-33.8	-34.1	1.1%	-34.1	1.1%
37	8	-300.3	-261.9	-12.8%	-262.0	-12.8%
40	8	-300.2	-262.7	-12.5%	-262.9	-12.4%
47	2	-2646.8	-2343.5	-11.5%	-2343.7	-11.5%
47	3	243.1	243.3	0.1%	243.6	0.2%
47	6	-220.6	-195.3	-11.5%	-195.3	-11.5%
47	7	20.3	20.3	0.1%	20.3	0.2%
47	8	18.5	19.4	4.9%	19.4	4.9%
48	2	392.8	361.3	-8.0%	361.3	-8.0%
48	3	-15.7	-15.7	-0.1%	-15.7	0.0%
48	4	-2585.1	-2289.1	-11.5%	-2289.2	-11.4%
48	5	232.2	232.5	0.1%	232.8	0.2%
48	6	240.7	214.5	-10.9%	214.5	-10.9%
48	7	-20.7	-20.7	0.1%	-20.7	0.2%
48	8	23.6	21.0	-11.1%	21.0	-11.2%
53	8	296.5	264.6	-10.8%	264.6	-10.8%
56	8	296.8	264.9	-10.7%	265.0	-10.7%
75	8	-47.0	-49.5	5.4%	-49.5	5.4%
76	8	-25.5	-30.8	21.0%	-30.8	21.0%
77	8	-28.2	-20.7	-26.8%	-20.8	-26.3%
78	8	-47.5	-32.5	-31.6%	-32.5	-31.6%
79	8	-71.0	-35.9	-49.4%	-36.0	-49.4%
80	8	-60.0	-25.8	-57.1%	-25.7	-57.2%

APPENDIX A

Rigid Format Alter for
SOL 72

```
$  ENFORCED ACCELERATION TRANSIENT ANALYSIS
$-----------------------------------------------------------------------
$  Rigid Format 72 - Modal Transient Analysis with Superelements
$  MSC/NASTRAN Version 67
$
$
$  This alter performs an enforced acceleration transient analysis.
$  See the referenced technical paper for more information.
$
$
$  Reference:  "Accurate Enforced Motion Analysis using
$              MSC/NASTRAN Superelements," 1994 MSC/NASTRAN
$              World User's Conference, Orlando, Florida,
$              June 20-24, 1994.
$
$
$  Requirements to use this alter -
$-----------------------------------------------------------------------
$
$  EXECUTIVE DECK:
$
$    SOL 72
$    COMPILE SOL72,SOUIN=MSCSOU,NOLIST,NOREF
$    Include this alter immediately before the "CEND" card.
$
$-----------------------------------------------------------------------
$
$  CASE CONTROL DECK:
$
$    Standard requests for a modal transient analysis (METHOD,
$    DLOAD, TSTEP, and SDAMP).
$
$    The METHOD requests for the upstream superelement and the
$    residual structure should specify the same frequency range.
$
$-----------------------------------------------------------------------
$
$  BULK DATA DECK:
$
$    The physical exterior (T-set) DOF of the component must be
$    entered on SUPORT statements.
$
$    The accelerations at the component T-set DOF must be defined
$    as "applied loads".
$
$    The DDRMM and mode acceleration options must be deactivated.
$
$-----------------------------------------------------------------------
$
$  EXAMPLE NASTRAN DECK:
$
$    ID      ENF,ACCE
$    SOL     72
$    TIME    30
$    DIAG    8
$    COMPILE SOL72,SOUIN=MSCSOU,NOLIST,NOREF
$    INCLUDE RF72D339
$    CEND
$    TITLE    = GENERAL PURPOSE SPACECRAFT
$    SUBTITLE = ENFORCED ACCELERATION TRANSIENT ANALYSIS
$    $
$    SEALL    = ALL             $ All superelement operations
$    $
$    SUBCASE 10
$      SUPER 10
$      LABEL = GENERAL PURPOSE SPACECRAFT
$      METHOD = 75              $ Component modes to 75 Hz
$    SUBCASE 10000
$      LABEL = RESIDUAL STRUCTURE
$      METHOD = 75              $ Component modes to 75 Hz
$      DLOAD  = 1               $ Dynamic loads (enf. accel.)
$      TSTEP  = 1               $ Integration steps
```

```
$      SDAMP  = 1                $ Damping for component modes
$    $
$    BEGIN BULK
$    .
$    .  Bulk data for structural model
$    .
$    $
$    $  Deactivate DDRMM and MODACC
$    $
$    PARAM,DDRMM,-1
$    PARAM,MODACC,-1
$    $
$    $  Enforced motion DOF
$    $
$    SUPORT,44,123456
$    SUPORT,45,123456
$    SUPORT,48,123456
$    SUPORT,49,123456
$    $
$    $  Define enforced accelerations
$    $
$    DLOAD,1,1.,1.,1,1.,2,1.,3
$    ,1.,4,1.,5,1.,6
$    $
$    TLOAD,1,1,,,1
$    DAREA,1,100,1,1.
$    TABLED1,1
$    ,0.,0.,.002,.106,.004,.327,.006,.763
$    .
$    .  Remaining enforced acceleration data
$    .
$    $
$    $  1% damping on component modes
$    $
$    TABDMP1,1,CRIT
$    ,0.,.01,100.,.01,ENDT
$    $
$    $  Integration steps
$    $
$    TSTEP,1,1000,.001,1
$    $
$    ENDDATA
$
$-----------------------------------------------------------------------
$
$  HISTORY DOCUMENTATION:
$
$    07-Feb-94   Chris Flanigan
$      -Original version
$
$=======================================================================
$2345678901234567890123456789012345678901234567890123456789012345678901 2
$        1         2         3         4         5         6         7
$
$  Form "classic" Craig-Bampton component matrices
$
ALTER    834 $ V67                              After LABEL LNORC
LAMX     ,,CMLAMA/CMLAMAT/-1 $                  Build matrix from LAMA
MATMOD   CMLAMAT,,,,,/MQQDIAG1,/1/4 $           Extract Gen. M (diag)
MATMOD   CMLAMAT,,,,,/KQQDIAG1,/1/5 $           Extract Gen. K (diag)
MATGEN   ,/QNULL/7/NOQSET/1 $                   Q-set null column
ADD      QNULL,MQQDIAG1/MQQDIAG $               Add or truncate rows
ADD      QNULL,KQQDIAG1/KQQDIAG $               Add or truncate rows
MATMOD   MQQDIAG,,,,,/MQQ,/28 $                 Form into full matrix
MATMOD   KQQDIAG,,,,,/KQQ,/28 $                 Form into full matrix
VEC      USET/VAQT/'A'/'Q'/'T' $                A = Q / T
MATGEN   ,/OQNULL/7/NOOSET/NOQSET $             O x Q null matrix
ADD      OQNULL,PHIOZ/PHIOQ $                   Add or trunc columns
MERGE    PHIOQ,,,,VAQT,/GOAQ/1 $                Column merge
MPYAD    MOO,GOAT,MOA/MOA1 $                    Static mass coupling
MPYAD    GOAQ,MOA1,/MQT/1 $                     Mass coupling matrix
TRNSP    MQT/MTQ $                              Transpose
```

```
MERGE    MQQ,,,,VAQT,/MLAA2 $                       Symmetric merge
ADD5     MQT,MTQ,MLAA2,,/MLAA1 $                    Add partitions
MODTRL   MLAA1////6 $                               Label as symmetric
MERGE    KQQ,,,,VAQT,/KLAA $                        Symmetric merge
JUMP     MAKEGOA $                                  Go on to make GOA
ALTER    853 $ V67                                  Before forming GOA
LABEL    MAKEGOA $                                  Make GOA
$
$
$  Prior to calculating system modes, remove the R-set partitions
$  of the system stiffness and mass matrices.  This will cause the
$  "system modes" to be identical to the fixed-interface component
$  modes of the upstream superelement.
$
ALTER    1021,1052 $ V67                            Remove auto-OMIT
PARTN    MKAA,VALCOMP,/KXX,,,/ $                    Symmetric partition
PARTN    MMAA,VALCOMP,/MXX,,,/ $                    Symmetric partition
ALTER    1057,1057 $ V67                            Replace READ
READ     KXX,MXX,,,EED,,CASES,/LAMA,PHIX,MI,OEIGS/
         V,N,READAPP='MODES'/S,N,NEIGV $            Modes
ALTER    1061,1061 $ V67                            Replace REIGL
REIGL    KXX,MXX,DYNAMICS,CASES,,,,/LAMA,PHIX,MI,
         EIGVMAT,OUTVEC/V,N,READAPP/S,N,NEIGV $     Modes
ALTER    1066,1071 $ V67                            Remove auto-expand
MERGE    PHIX,,,,,VALCOMP/PHIA/1 $                  Row merge
$
$
$  Build A-set matrices for the enforced acceleration solution
$
$       KHH |  0             MHH |  0            BHH |  0
$  K = -----+-----      M = -----+-----     B = -----+-----
$        0  |  0              0  | IRR            0  |  0
$
ALTER    1131,1131 $ V67                            Replace TRD1
MATGEN   ,/IRR/1/NORSET $                           R-set identity matrix
MATGEN   ,/NULLLL/7/NOLSET/NOLSET $                 Null L-set sq. matrix
ADD      NULLLL,KHH/KHH1 $                          KHH merged to L-set
ADD      NULLLL,MHH/MHH1 $                          MHH merged to L-set
ADD      NULLLL,BHH/BHH1 $                          BHH merged to L-set
MERGE    KHH1,,,,VALCOMP,/KAAENFA/ $                KAA for enforced accel
MERGE    MHH1,,,IRR,VALCOMP,/MAAENFA/ $             MAA for enforced accel
MERGE    BHH1,,,,VALCOMP,/BAAENFA/ $                BAA for enforced accel
$
$
$  Build A-set forces for the enforced acceleration solution
$
$           ..
$     -Mqt Ut    -Mlr Pr
$  P = -------- = -------
$        ..          Pr
$        Ut
$
PARTN    PDT,,VALCOMP/,PRT,,/1 $                    Row partition
MPYAD    MLR,PRT,/PLT//-1 $                         - MLR * PRT
MERGE    PLT,PRT,,,,VALCOMP/PAENFA/1 $              Row merge
$
$  Perform the transient solution
$
TRD1     CASES,TRL,NLFT,DIT,KAAENFA,BAAENFA,MAAENFA,PAENFA/
         UHVF,PNLH/'MODAL'/NOUE/V,Y,NONCUP=-1/0 $ Modal transient
$
$  Remove solution set output
$
ALTER    1133,1149 $ V67                            Remove MODOUT, HSORT1
$
$  Rename the transient response output
$
ALTER    1155,1155 $ V67                            Replace MPYAD
ADD      UHVF1,/UDV $                               Rename
$
$==End of RF72D339=====================================================
```