# ANALYZING DEPLOYMENT OF SPACECRAFT APPENDAGES USING MSC/NASTRAN

by

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## ABSTRACT

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MSC/NASTRAN's direct linear transient dynamic solution procedure (Rigid Format Solution 27) can be utilized as a powerful, low cost tool for dynamic analysis. In particular, it provides the capability to analyze the effect of rigid body translations and rotations (enforced deployment displacements) on spacecraft appendage structural dynamic response. The fact that "NOLIN" pseudo-nonlinear elements can be utilized to model gaps (and impact transients resulting from gap closure) and Coulomb dampers without the necessity to regenerate the stiffness matrix, increases the applicability of the procedure while reducing computational cost by at least an order of magnitude. A simple example is presented to demonstrate the requisite input data, the solution process and the resulting output. Display of the deployment motion and the residual structural dynamic motion after impacting stops is possible using PATRAN-G version 2.4 and a simple FORTRAN program (provided) for data post-processing.

## DISCUSSION:

The structural dynamic analysis of the effect of rigid body motions enforced during deployment of a spacecraft appendage can be determined using MSC/NASTRAN's linear transient solution procedure (rigid format 27). Although the procedure does not allow for large displacement nonlinearities, Solution 27 utilizes a time-step integration process which does permit the calculation of rigid body motions due to enforced displacements. These rigid body motions can accumulate to be "large" compared with geometric dimensions, as long as the stiffness matrix of the structure remains constant throughout the deployment process. Thus, the restriction imposed by small displacement theory constrains structural dynamic response to comparatively small values. Also, the choice of an appropriate coordinate system (for example, a cylindrical system for a rotationally deployed appendage) is important for the display of solution results.

The effect of gap elements and Coulomb dampers, which introduce nonlinearities into the analysis process, can also be accounted for in Solution 27 through the use of pseudo nonlinear elements called "NOLINi" elements in MSC/NASTRAN. The use of these elements is discussed in MSC's HANDBOOK FOR DYNAMIC ANALYSIS (Reference 1). As stated therein, in order to enhance the stability of the Newmark-Beta solution algorithm, the NOLIN elements can be combined with either CELASi or CDAMP elements to achieve the desired force versus deflection or velocity curves. The NOLINi elements introduce compensatory loadings which are added to the actual applied forces, based on the previous iteration solution. Thus, the ordinary linear dynamic solution can be utilized for the class of nonlinear problems where the NOLINi elements can express the nonlinear functions. The NOLINi elements are flexible in application, however. For example, it is possible to achieve modified viscous dampers which have threshold limits (i.e., dampers which respond linearly with velocity only after a given absolute velocity is achieved). These are shown in the example.

The solution process is outlined in the following paragraphs for the simple spacecraft appendage shown in Figure 1, which represents a cylindrical structure weighing 132 lbs. fastened to a flexible L-shaped arm. Deployment is achieved by means of a force which displaces the arm along a helical screw, causing it to simultaneously translate and rotate against the resistance of both Coulomb and modified viscous damping. The deployment motion is limited by stops with given flexibility on both the rotational and translational degrees of freedom. In order to simulate the effect of the helical drive, a fictitious moment is applied to the model simultaneously with the driving force.

## I. THE FINITE ELEMENT MODEL

Bar elements are used to simulate the L-shaped arm and the cylindrical structure, as shown in Figure 1. The mass of the cylinder is lumped at a node representing the center of gravity of the structure, while the bar properties are chosen to reflect the frequency of its fundamental cantilever mode (25 Hz). This simple representation is deemed appropriate to analyze for the effect of the deployment motion and subsequent impact transient shock on the system's structural dynamic response. A cylindrical coordinate system is chosen since the deployment consists of a helical motion (combined translation and rotation) of the arm, as shown in the Figure. The gap elements, which simulate the effect of stops limiting the deployment motion, and the Coulomb and modified viscous dampers included in the model are also shown in the Figure. Figure 2 illustrates the method for achieving the desired gap and damping forces using the composite NOLIN and CELAS or CDAMP elements. It is to be noted that, in the example, the frictional (Coulomb) damping has been imposed only on the translational motion; true frictional resistance would also act on the rotational motion. This can easily be provided through the use of another damper on that degree of freedom, sized according to the pitch of the helix to achieve the correct damping versus angular velocity.

## II. ASSUMPTIONS AND DATA CALCULATIONS

The actual analysis will usually require an iterative process to achieve the correct values of the input force and moment driving functions so that the stops are impacted both torsionally and longitudinally with the correct timing. Initial values for these parameters can be derived using the mass and mass moment of inertia of the system once an assumption regarding the shape of the driving function versus time diagram has been made. Figure 3 also provides the calculations for the relevant driving moment and damping parameters, based on the assumed driving force. For the simple example problem, we make the assumption of a constant driving force (after an initial ramp, as shown in Figure 3) acting along the axis of the shaft; thus, constant linear and torsional accelerations will result from the helical motion. Also, a maximum viscous damping force of 1 lb. is assumed, while a threshold of 0.01 in./sec. is assumed for illustration purposes. A Coulomb damping force of 1 lb. is assumed, and the longitudinal stop stiffness is estimated at 1000 lbs./in., and the torsional stop stiffness at 1,000,000 in.lbs./radian. Using these values Figure 4 shows the resulting NOLIN, CELAS and CDAMP force parameters.

For the simple example, the requisite helical motion could have been achieved very simply by the use of a multiple point constraint equation, requiring that the rotational degree of freedom (theta) of point 3, for example, be equal to the translational motion of the same point in the Z direction degree of freedom (along the axis of the shaft), divided by a constant related to the pitch of the helix. However, a more general type of coupled motion, such as one wherein the rotation might be delayed or stop during the translation, could not be achieved so easily. Instead, the capability for specifying force versus time behavior via the "TABLED1" input card (in the present case, using the "MOMENT" forcing function) permits this more complicated motion to be achieved via the trial and error process. In that case, there would be different TABLED1 cards for the force and moment, called out by different TLOADi cards, as specified on the DLOAD card. However, the user is cautioned to study Appendix B-1 of MSC/NASTRAN's HANDBOOK FOR DYNAMIC ANALYSIS regarding the effect of abrupt changes in time steps or forcing functions to insure that spurious loadings have not been introduced into the solution (i.e., study the OLOAD print-out carefully). The large mass method has been used to enforce the time-history motion.

## III. INPUT DATA DECK

Figure 5 provides the executive, case control and bulk data decks required for performing the analysis and achieving the preliminary results. Using this information, the actuating force as well as the fictitious moment can be adjusted and reruns made until the stops are contacted with the appropriate timing.

## IV. RESULTS OF THE ANALYSIS

Figure 6 shows the resulting XYOUT data plots of displacement versus time for node points 2 and 3, which contact the stops, and node point 10 at the center of gravity of the cylinder. Then, either a restart or a new run is made using SORT1 output to obtain printout of displacements for the times at which impact with the stops occur and when maximum structural dynamic response is achieved. Figure 7 illustrates the input executive and case control data decks for the new run (showing the DMAP Alter required for earlier versions of Solution 27 in order to obtain the SORT1 output). Additional data of interest, such as element internal stresses or forces, SPC forces, or nodal accelerations can be selected to be output as desired at the selected times.

## V. POST-PROCESSING OF RESULTS

It is possible to edit the output data file containing the SORT1 formatted results, which presumably has been rewound and copied to a file prior to printing, using any standard editor. This editing process can be used to extract data for display or animation of the deployment motion, animation of the residual structural dynamic response after impacting the stops, or for display of peak internal forces, displacements or stresses using a graphical post-processor. PATRAN-G version 2.4 offers the capability for display of displacement results in a local coordinate system. Thus, display of the combined translational and rotational deployment motion is possible. Figure 8 provides the source code for a simple FORTRAN program (Cyber version), written expressly for the example problem. This program reads the edited MSC/NASTRAN Solution 27 output file of displacements at impact (entitled "TAPE13"), the output file of peak displacements (TAPE14"), and another edited portion of the output file containing "GRID" cards ("TAPE16"). These files are shown in Figure 9. It then produces a PATRAN-G readable ASCII file for the impact displacements ("TAPE18"). Once this displacement file is read in as results information into PATRAN-G, the local cylindrical coordinate frame in which the displacement degrees of freedom are expressed can be selected with the command "SET,RESCORD,LOCAL". The deployment motion can then be displayed, or even animated if the graphics device permits.

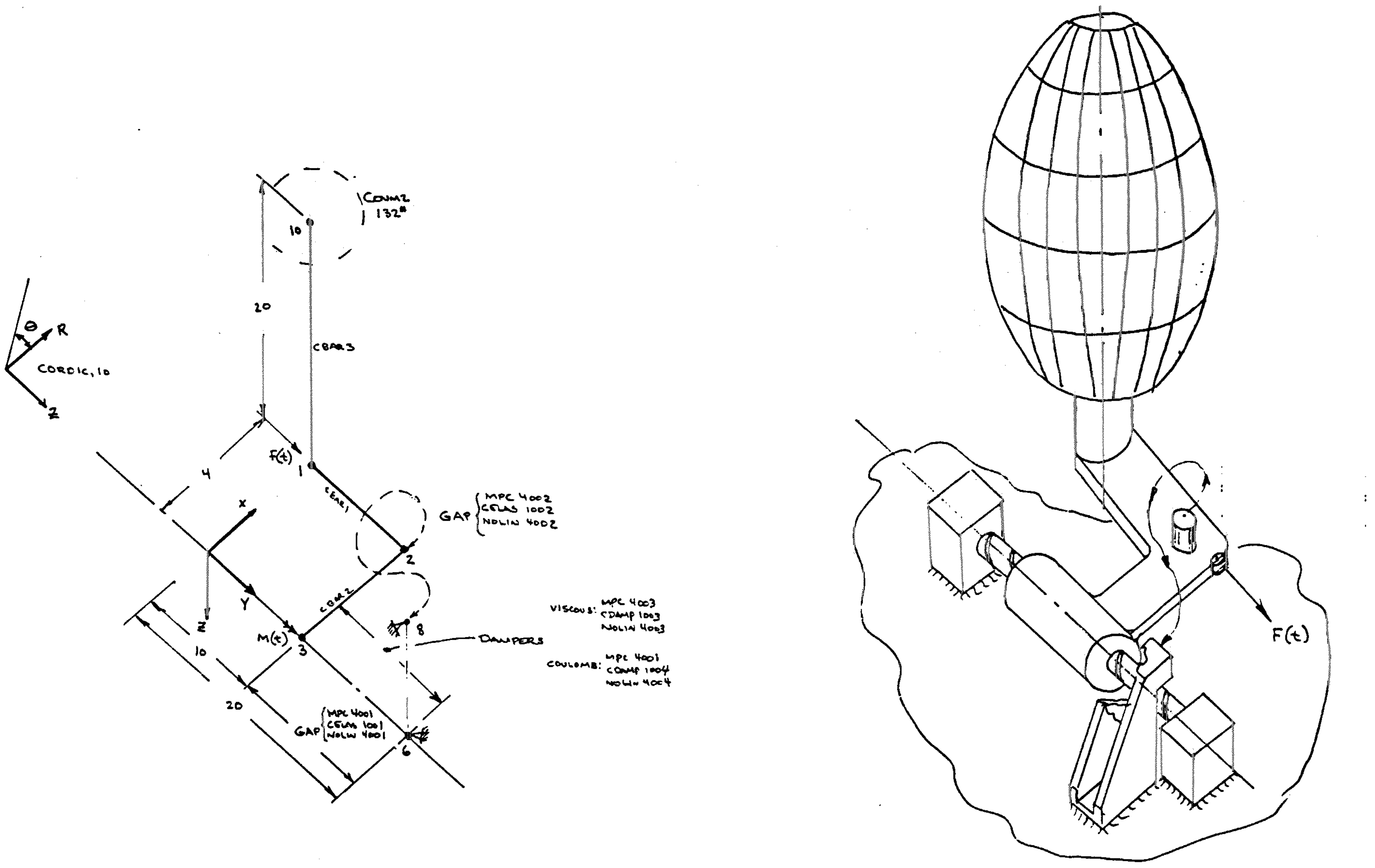
Similarly, the peak structural dynamic response resulting from impact with the stops can be displayed. In this case, however, the model geometry must be updated so that the configuration for the neutral position becomes the geometry existing at the moment of impact with the stop(s). The updating can be somewhat complicated if the original geometry was generated, for example, in the basic rectangular coordinate system, while displacements are measured in a local cylindrical system. However, the simple FORTRAN program also transforms the original geometry (given earlier as TAPE16) from the basic coordinate system to the local cylindrical system, reads the edited output file provided earlier for the displacements at time of impact (TAPE14), and produces a new model nodal geometry file ("TAPE17"). This "GRID" file can be inserted into the bulk data deck using an editor in place of the original "GRID" data, and the deck translated into a neutral file using, for example, PDA's PATRAN translator "NASPAT". The FORTRAN program also calculates the difference between the peak displacements and the nominal displacements at impact and creates a PATRAN displacement results file which can then be used to display the dynamic response ("TAPE18"). Figure 10 shows these files.

## CONCLUSION:

MSC/NASTRAN's Solution 27 provides a viable means of performing pseudo nonlinear dynamic response calculations for a variety of problems, including the effect of rigid body motions occurring during deployment of appendages on the structural dynamic response. The Newmark-Beta algorithm employed in the solution is a proven, unconditionally stable method for performing the time-step integration process on linear problems. The application for nonlinear problems of the type discussed is a simple extension of the method. It is recommended, however, that the effect of changes in the magnitude of the time step be studied to insure that the solution is accurate. The use of a simple post-processing program enables graphic display of the results for better visualization.

# REFERENCES

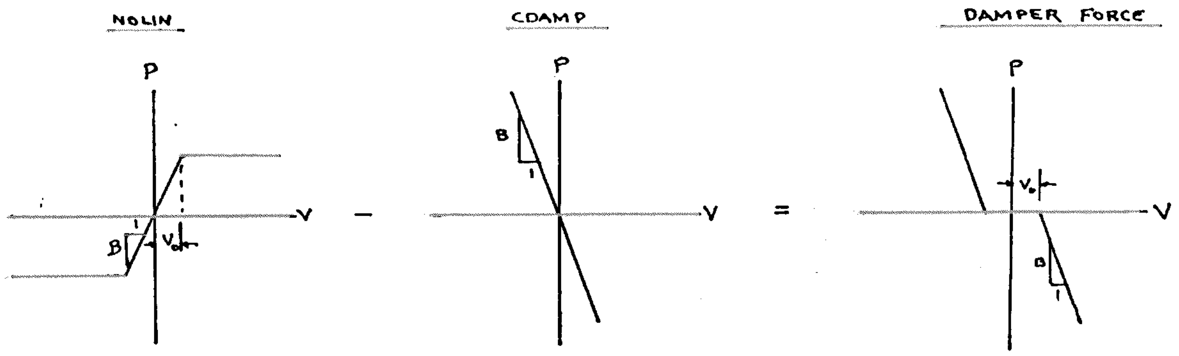
1. M. A. Gockel, ed., "HANDBOOK FOR DYNAMIC ANALYSIS", MacNeal-Schwendler Corp.



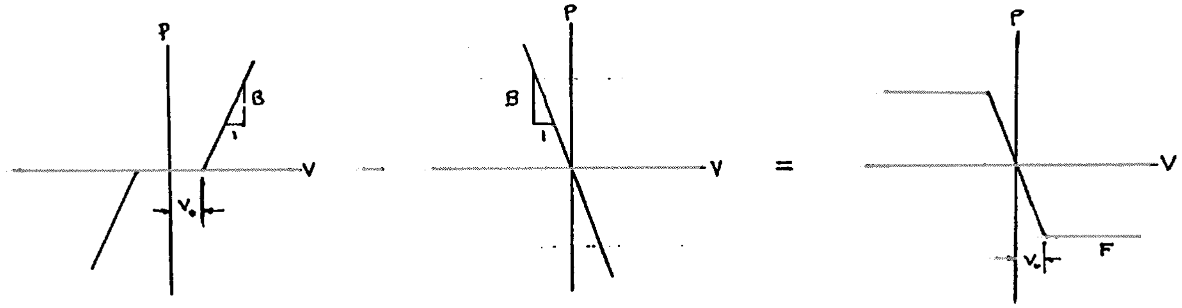
FINITE ELEMENT MODEL

SIMPLE SPACECRAFT APPENDAGE

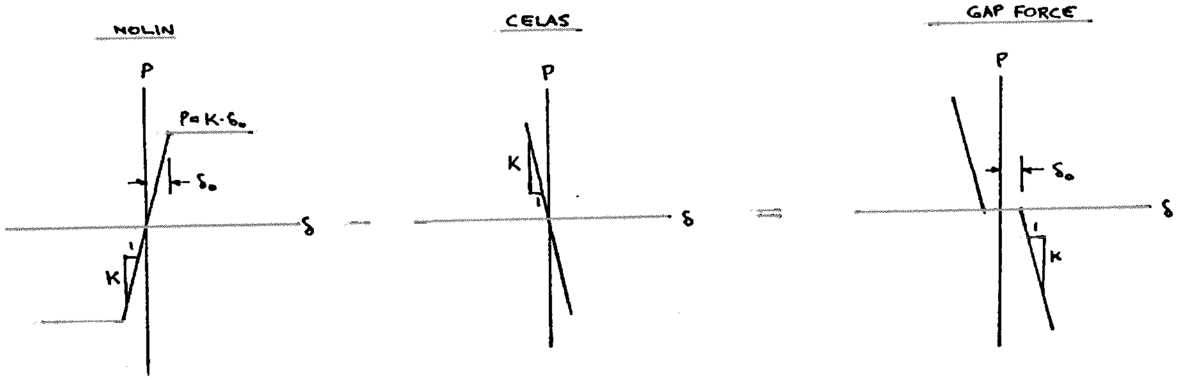
FIGURE 1



MODIFIED VISCOUS DAMPER



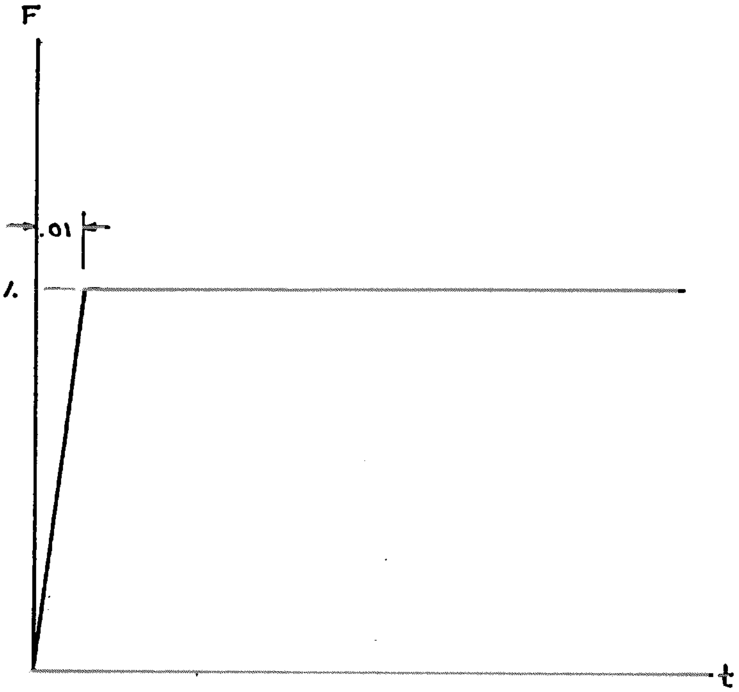
COULOMB DAMPER



GAP ELEMENT

PSEUDO NONLINEAR ELEMENTS

FIGURE 2



DRIVING FORCE DIAGRAM

TOTAL DISPLACEMENT = 10 INCHES = $X$ IN $t$ = 3 secs
$\dot{X} = X / t = 3.33$ in.sec.
FOR VISCOUS DAMPING FORCE = 1 LB.
$F = B \dot{X} = 1.0$ lb.
$B = F / \dot{X} = 0.3$ lb/in/sec
ASSUMING CONSTANT ACCELERATION:
$X = \ddot{X} t^2 / 2 = 10$
$\ddot{X} = 20 / t^2 = 20 / 3^2 = 20 / 9$
$F_{net} = M \ddot{X} = (132 \times 20)/(386.4 \times 9) = 0.76$lbs

TOTAL REQ'D FORCE = COULOMB + VISCOUS DAMPING FORCES + $F_{net}$
$F_{gross} = 1.0 + 1.0 + 0.76 = 2.76$ lbs.

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ANGULAR DISPLACEMENT = 90 DEGREES IN $t$ = 3 secs

$\theta = (PI / 2) / 10.0 = PI / 20$

DISTANCE OF MASS FROM AXIS OF ROTATION = $R$ = 20.4 inches
$M = (PI / 20)\ F_{net}\ R^2 = 50$ in.lbs.

CALCULATION OF DRIVING FORCE PARAMETERS

FIGURE 3

```
DEFINITION OF SPOINTS:
      SPOINT 4001  =  3(Z)  -  6(Z)
      SPOINT 4002  =  2(0)  -  8(0)
      SPOINT 4003  =  2(Z)  -  6(Z)

SCALAR SPRINGS:
  CELAS2 1001 =  1000 lb./in. ON DISPLACEMENT OF SPOINT 4001
  CELAS2 1002 =  1,000,000 in.lb./rad. ON ROTATION "    4002

SCALAR DAMPERS:
  CDAMP1 1  = VISCOUS DAMPER:   B  =  0.34 lb./in./sec. ON
                                 VELOCITY OF SPOINT 4003
  CDAMP1 2  = COULOMB DAMPER:   B  =  100.0 lb./in./sec. ON
                                 VELOCITY OF SPOINT 4001
```

NON-LINEAR ELEMENT PARAMETERS

**FIGURE 4**

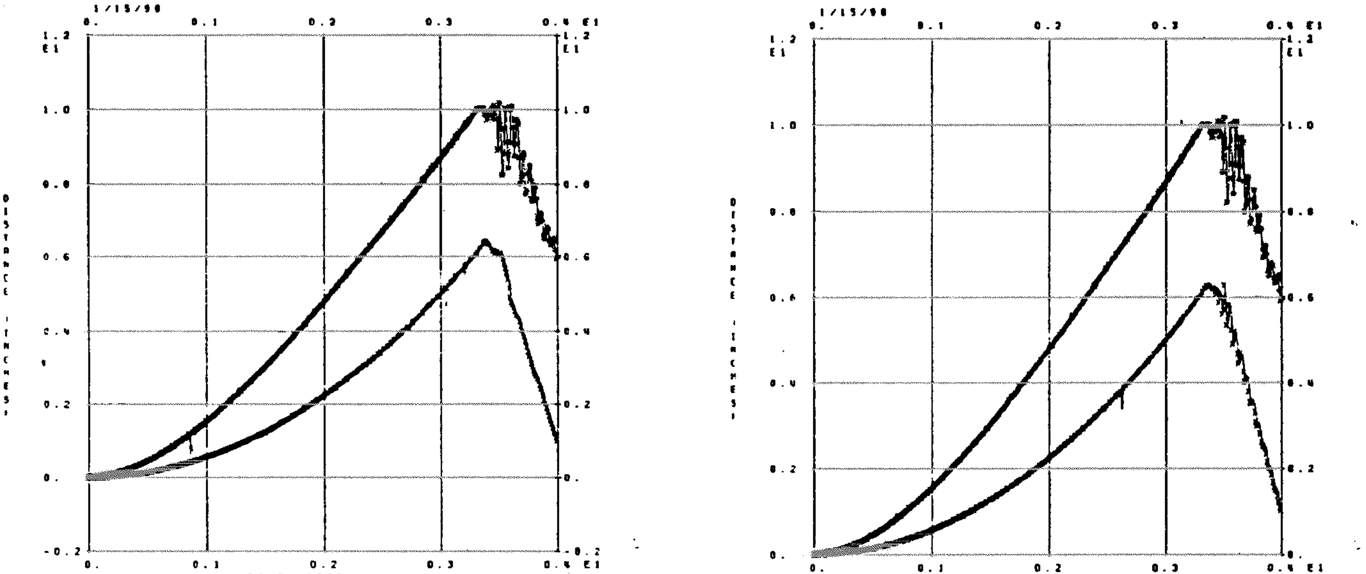
```
ID DEPLOY,DYNAMIC
SOL 27
DIAG 8,9,13,50
TIME 20
CEND
TITLE=  TRANSIENT DYNAMIC ANALYSIS OF DEPLOYMENT OF DAMPED SYSTEM
SUBTITLE=  COULOMB DAMPING = 1 LB.
LABEL=  FW PALMIERI
SET 1=1,2,3,10,4001,4002,4003,4004
SET 2=1,2,3,10
DISP(PLOT)=1
VELO(PLOT)=2
ACCE(PLOT)=2
SET 3=4001,THRU,4004
NLLOAD=3
SET 4=1003,1004
ELFORCE=4
SET 5=2,3
OLOAD=5
SPC=100
ECHO=SORT
MPC=200
NONLINEAR=300
SUBCASE 1
  LABEL=   DEPLOYMENT OF SIMPLE SYSTEM
 DLOAD=31
 TSTEP=21
 LOADSET=1000
OUTPUT(XYPLOT)
  CSCALE=1.8
  XAXIS=YES
  YAXIS=YES
  XGRID LINES=YES
  YGRID LINES=YES
  CURVELINESYMB=1
  XTITLE=                TIME (SECS)
  YTITLE=            DISTANCE (INCHES)
  TCURVE=      MOTION OF NODE 1 (END OF ARM UNDER SENSOR)
  XYPRINT,XYPLOT DISPLACEMENT RESPONSE /1(4),1(5)/1(8)
  TCURVE=      MOTION OF NODE 2 ( END OF ARM)
  XYPRINT,XYPLOT DISPLACEMENT RESPONSE /2(4),2(5)/2(8)
  TCURVE=      MOTION OF NODE 3 (SLIDER)
  XYPRINT,XYPLOT DISPLACEMENT RESPONSE /3(5),3(8)
  TCURVE=      MOTION OF NODE 10 (MASS)
  XYPRINT,XYPLOT DISPLACEMENT RESPONSE /10(4),10(5)/10(8)
  TCURVE=      FORCE IN VISCOUS DAMPER 1003 AND  1004
  XYPRINT,XYPLOT ELFORCE RESPONSE /1003(2)/1004(2)
```

```
BEGIN BULK
DLOAD,31,1.,1.,1
LSEQ,1000,33,1
CONM2,999,10,0,132.
TSTEP,21,4000,1.-3,10
TLOAD1,1,33,,,110
GRID,1,0,4.
GRID,2,0,4.,10.
GRID,3,0,0.,10.
GRID,4,0,,,-1.
GRID,5,0,0.,0.,0.
GRID,6,0,0.,20.,0.
GRID,8,0,0.,10.,-4.
*,10,=,4.,0.,-20.
GRDSET,,,,,,10
CORD1C,10,5,3,1
$.......................................................
$
$     FOLLOWING ARE CONSTRAINTS ON SYSTEM
$
SPC1,100,1245,3
SPC1,100,123456,4,THRU,8
$
$.........................................................
FORCE,1,1,0,2.7,0.,1.,0.
MOMENT,1,3,0,49.0,0.,1.,0.
TABLED1,110
,0.,0.,.01,1.,120.,1.,ENDT
$
$                    INPUT FOR GAP ELEMENTS
$
SPOINT,4001,THRU,4004
MPC,200,3,3,1.,4001,,-1.
,,6,3,-1.
MPC,200,2,2,1.,4002,,-1.
,,8,2,-1.
MPC,200,2,3,1.,4003,,-1.
,,6,3,-1.
CELAS2,1001,1.E3,4001
CELAS2,1002,1.E6,4002
CDAMP1,1003,1,4003
CDAMP1,1004,2,4001
PDAMP,1,.34
PDAMP,2,100.
NOLIN1,300,4001,,1.,4001,,1001
NOLIN1,300,4002,,1.,4002,,1002
NOLIN1,300,4003,,1.,4003,10,1003
NOLIN1,300,4001,,1.,4001,10,1004
TABLED1,1001
,0.,0.,10.0,1.E4,11.,1.E4,ENDT
TABLED1,1002
,0.,0.,6.283,6.283E6,11.,6.283E6,ENDT
TABLED1,1003
,-1.,-.0014,-.01,-.0014,0.,0.,SKIP
,.01,.0014,1.,.0014,ENDT
TABLED1,1004
,-1.01,-100.,-.01,0.,.01,0.,SKIP
,1.01,100.,ENDT
$
$.......................................................
PARAM,AUTOSPC,YES
PARAM,GRDPNT,0
PARAM,WTMASS,.002588
$.........................................................

$.........................................................
$
$
MAT1,10,1.+7,,.3,.001
CBAR,1,1,1,2,0.,1.,0.
=,*1,=,*1,*1,==
=,*1,2,1,10,1.,0.,0.
PBAR,1,10,1.,.022,.333,.333
PBAR,2,10,1.,2.2,3.33,3.33
ENDDATA
```

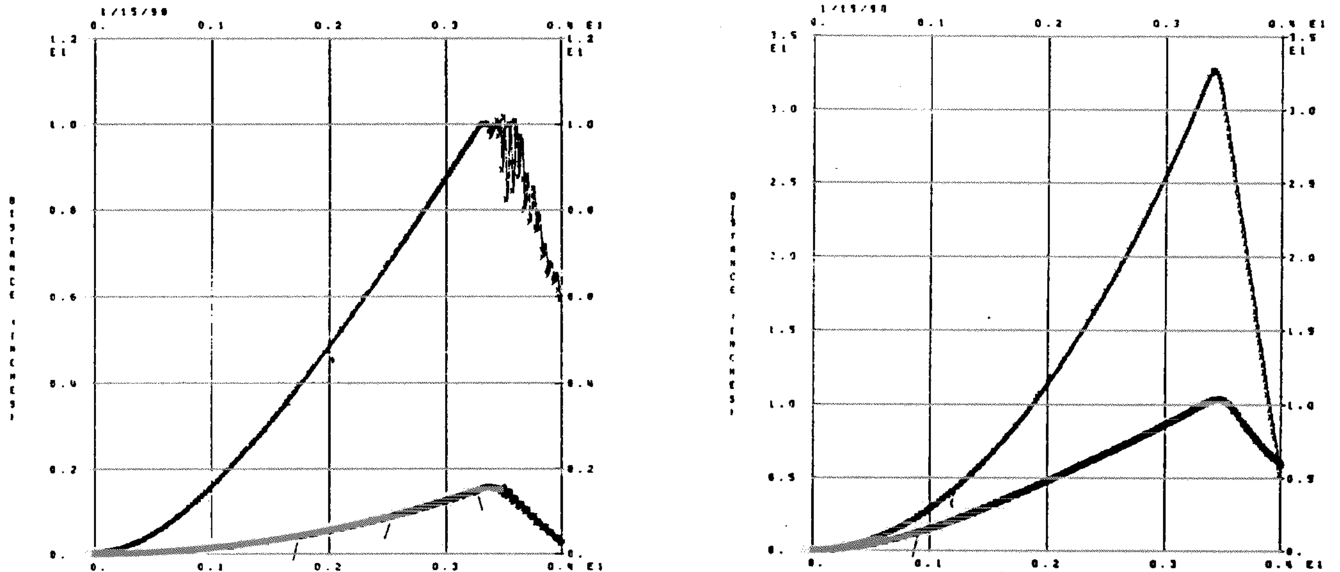
INITIAL RUN INPUT DATA DECK

FIGURE 5



MOTION OF NODE 1 (END OF ARM UNDER SENSOR)
TRANSIENT DYNAMIC ANALYSIS OF DEPLOYMENT OF DAMPED SYSTEM
COULOMB DAMPING = 1 LB.
DEPLOYMENT OF SIMPLE SYSTEM

MOTION OF NODE 2 ( END OF ARM)
TRANSIENT DYNAMIC ANALYSIS OF DEPLOYMENT OF DAMPED SYSTEM
COULOMB DAMPING = 1 LB.
DEPLOYMENT OF SIMPLE SYSTEM



MOTION OF NODE 3 (SLIDER)
TRANSIENT DYNAMIC ANALYSIS OF DEPLOYMENT OF DAMPED SYSTEM
COULOMB DAMPING = 1 LB.
DEPLOYMENT OF SIMPLE SYSTEM

MOTION OF NODE 10 (MASS)
TRANSIENT DYNAMIC ANALYSIS OF DEPLOYMENT OF DAMPED SYSTEM
COULOMB DAMPING = 1 LB.
DEPLOYMENT OF SIMPLE SYSTEM

XYOUT RESULTS PLOTS

FIGURE 6

```
ID DEPLOY,DYNAMIC
SOL 27
DIAG 8,9,13,50
TIME 20
     ALTER 449  $
     JUMP LSORT1  $
     ALTER  477,478 $
     ALTER  481,481  $
CEND
TITLE=  TRANSIENT DYNAMIC ANALYSIS OF DEPLOYMENT OF DAMPED SYSTEM
SUBTITLE=    SLOW DEPLOYED SYSTEM,COULOMB=1 LB,VISCOUS=1 LB.
LABEL=  FW PALMIERI
SET 1=1,2,3,10,4001,4002,4003,4004
SET 2=1,2,3,10
DISP(SORT1)=1
VELO(SORT1)=2
ACCE(SORT1)=2
SET 3=4001,THRU,4004
NLLOAD=3
ELFORCE(SORT1)=ALL
SET 4=2,3
OLOAD=4
SPC=100
SET 5=3.07,3.075,3.08,3.085,3.09,3.095,3.10,3.105,3.11,3.115,3.12,
      3.125,3.13,3.135,3.14,3.145,3.15,3.155,3.16
OTIME=5
ECHO=SORT
MPC=200
NONLINEAR=300
SUBCASE 1
  LABEL=   DEPLOYMENT OF SIMPLE SYSTEM
 DLOAD=31
 TSTEP=21
 LOADSET=1000
BEGIN BULK
```

**SORT1 CASE CONTROL DECK**

**FIGURE 7**

```
??       PROGRAM REFOR1(TAPE5,TAPE6,INPUT=TAPE5,OUTPUT=TAPE6,TAPE13,TAPE14,
     +   TAPE15,TAPE16,TAPE17,TAPE18,TAPE19)
C
C
C    A PROGRAM TO READ TWO NASTRAN SOLUTION 27 DISPLACEMENT FILES
C     AND WRITE A NASTRAN GRID BULK DATA DECK MODIFIED TO REFLECT
C     THE POSITION AT TIME OF IMPACTING THE STOPS AND A PATRAN
C     READABLE DISPLACEMENT FILE FOR THE DISPLACEMENTS FROM THIS
C     POSITION, AS WELL AS A PATRAN READABLE DISPLACEMENT FILE FOR
C     THE DISPLACEMENTS AT TIME OF STOP IMPACT
C
C        TAPE6 =GEOMETRY CHECK FILE (X,Y,Z,R(INCHES);X,Z(INCHES);
C                          NODEID,R,TH,Z(INCHES,RADIANS))
C (DISP)-TAPE13=DISPLACEMENT AT TIME OF IMPACTING STOPS  (INCHES)
C (DISQ)-TAPE14=DISPLACEMENT AT TIME OF PEAK RESPONSE  (INCHES)
C        TAPE15=CHECK FILE FOR  DISPLACEMENTS AT IMPACT (IN.,RAD.)
C        TAPE16=GEOMETRY FILE CONTAINING GRID CARDS FROM BULK ECHO (IN.)
C        TAPE17=NEW BULK DATA GRID CARDS FOR GEOMETRY AT IMPACT (IN.,DEC.)
C (DISR)-TAPE18=PATRAN READABLE RESULTS FILE OF PEAK DISPLS AFTER IMPACT
C (DISS)-TAPE19=PATRAN READABLE RESULTS FILE OF DISPLACEMENTS AT IMPACT
C
C
      DIMENSION DISP(6),TITLE(80),DISQ(6),DISR(6),DISS(6)

      CHARACTER*80 TITLE
C
      WRITE(15,2)
    2 FORMAT('  TRANSIENT DYNAMIC ANALYSIS OF DEPLOYMENT',/,
     +'    4    4   8.923507E+01     2     6',/,'  ',/,
     +'. FW PALMIERI')
      WRITE(18,2)
      WRITE(19,2)
    5 DO 10 I=1,7
      READ(13,400,ERR=438) TITLE
      READ(14,400,ERR=440) TITLE
   10 CONTINUE
      DO 11 I=1,6
      READ(16,400,ERR=442) TITLE
   11 CONTINUE
      DO 30 I=1,4
      READ(13,35,END=500,ERR=550)  NODEID,(DISP(J),J=1,6)
      READ(14,35,END=510,ERR=560)  NODEID,(DISQ(J),J=1,6)
      DO 12 J=1,6
      DISR(J)=DISQ(J)-DISP(J)
   12 CONTINUE
      READ(16,450,END=520,ERR=460) NODID,X,Y,Z
      IF(NODID.LT.NODEID) GOTO 12
      IF(NODID.GT.NODEID) STOP 'UNEQUAL NODE IDS'
      R=(X**2+Z**2)**0.5
      IF(R.EQ.0.0) THEN
              R1=1.0
              GOTO 13
                    ENDIF
       R1=R
   13 CONTINUE

      DISP(2)=DISP(2)/R1
      DISR(2)=DISR(2)*57.296/R1
      DISS(2)=DISP(2)*57.296
      DISS(1)=DISP(1)
      DO 14 K=3,6
      DISS(K)=DISP(K)
   14 CONTINUE
      WRITE(15,40)  NODEID,(DISP(J),J=1,6)
      WRITE(18,40)  NODEID,(DISR(J),J=1,6)
      WRITE(19,40)  NODEID,(DISS(J),J=1,6)
      WRITE(6,41) X,Y,Z,R
      IF(X.EQ.0.0) THEN
         IF(Z.GT.0.0) THEN

              TH=-1.5708
           ELSEIF(Z.LT.0.0) THEN
              TH=1.5708
           ELSEIF(Z.EQ.0.0) THEN
             TH=0.0
                ENDIF
               GOTO 20
              ENDIF
      WRITE(6,*) X,Z
      IF(X.NE.0.0) THEN
         IF(Z.EQ.0.0) THEN
           TH=0.0
           GOTO 20
                ENDIF
           ENDIF
        TH=ATAN(-1.*Z/X)
   20 CONTINUE
      Z=Y
      WRITE(6,42) NODEID,R,TH,Z
      RP=R+DISP(1)
      THP=(TH+DISP(2))*57.296
      ZP=Z+DISP(3)
      WRITE(17,452) NODEID,RP,THP,ZP
   30 CONTINUE
      CALL EXIT
       GOTO 5
   35 FORMAT(I14,10X,6E15.6)
   40 FORMAT(I8,6E13.7)
   41 FORMAT(4E13.7)
   42 FORMAT(I8,3E13.7)
  400 FORMAT(80A1)
  438 WRITE(6,439)
  439 FORMAT('  ERROR READING FILE 13 TITLE')
      CALL EXIT
  440 WRITE(6,441)
  441 FORMAT('  ERROR READING FILE 14 TITLE')
       CALL EXIT
  442 WRITE(6,443)
  443 FORMAT('  ERROR READING FILE 16 TITLE')
      CALL EXIT
  450 FORMAT(38X,I8,8X,3F8.0)
  452 FORMAT('GRID',4X,I8,'10',6X,3F8.4)
  460 WRITE(6,461)
  461 FORMAT(' ERROR READING GRID VALUES FROM FILE 16')
      CALL EXIT
  452 FORMAT('GRID',4X,I8,'10',6X,3F8.4)
  460 WRITE(6,461)
  461 FORMAT(' ERROR READING GRID VALUES FROM FILE 16')
      CALL EXIT
  500 WRITE(6,501)
  501 FORMAT(3X,' END OF FILE 13')
      CALL EXIT
  510 WRITE(6,511)
  511 FORMAT(3X,' END OF FILE 14')
      CALL EXIT
  520 WRITE(6,521)
  521 FORMAT(3X,' END OF FILE 16')
      CALL EXIT
  550 WRITE(6,551)
  551 FORMAT(3X,'ERROR READING FILE 13 DISPLACEMENTS')
      CALL EXIT
  560 WRITE(6,561)
  561 FORMAT(3X,'ERROR READING FILE 14 DISPLACEMENTS')
      CALL EXIT
      END
```

FORTRAN SOURCE CODE

FIGURE 8

```
                              TAPE 13

------------------------------------------------------------------------------

1     TRANSIENT DYNAMIC ANALYSIS OF DEPLOYMENT OF DAMPED SYSTEM            JANUARY  17, 1990  MSC/NASTRAN 11/23/83   PAGE    20
         SLOW DEPLOYED SYSTEM,COULOMB=1 LB,VISCOUS=1 LB.
0       DEPLOYMENT OF SIMPLE SYSTEM                                                                             SUBCASE 1
      TIME =  3.080000E+00
                                                D I S P L A C E M E N T   V E C T O R

      POINT ID.    TYPE          T1             T2             T3             R1             R2             R3
             1       G       3.267631E-04   6.286049E+00   1.003157E+01   2.357798E-04  -3.836635E-05   1.571024E+00
             2       G       4.584312E-07   6.285920E+00   1.003157E+01  -2.124779E-05  -2.115870E-05   1.571197E+00
             3       G       0.0            0.0            1.003152E+01   0.0            0.0            1.571844E+00
      .     10       G       2.000886E-03   3.204266E+01   1.003636E+01   9.685646E-06  -2.440590E-04   1.571014E+00

------------------------------------------------------------------------------


                              TAPE 14

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1     TRANSIENT DYNAMIC ANALYSIS OF DEPLOYMENT OF DAMPED SYSTEM            JANUARY  17, 1990  MSC/NASTRAN 11/23/83   PAGE    32
         SLOW DEPLOYED SYSTEM,COULOMB=1 LB,VISCOUS=1 LB.
0       DEPLOYMENT OF SIMPLE SYSTEM                                                                             SUBCASE 1
      TIME =  3.100000E+00
                                                D I S P L A C E M E N T   V E C T O R

      POINT ID.    TYPE          T1             T2             T3             R1             R2             R3
             1       G      -2.178407E-02   6.330298E+00   9.937810E+00   1.003368E-02   2.666963E-03   1.588584E+00
             2       G      -3.935999E-05   6.245936E+00   9.937815E+00   1.646524E-03   1.189488E-03   1.573243E+00
             3       G       0.0            0.0            9.940199E+00   0.0            0.0            1.555827E+00
            10       G      -3.004311E-02   3.242923E+01   1.013785E+01   4.573624E-03  -9.269223E-03   1.589477E+00

------------------------------------------------------------------------------


                              TAPE 16

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1     TRANSIENT DYNAMIC ANALYSIS OF DEPLOYMENT OF SIMPLE SYSTEM            JANUARY   3, 1990  MSC/NASTRAN 11/23/83   PAGE     3
         ANALYSIS FOR CASE WITH SYSTEM WITH FLEXIBLE MASS/ARM
0       FW PALMIERI
0                                                    S O R T E D   B U L K   D A T A   E C H O
                 CARD
                 COUNT        .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10  .
                   12-        GRID   1       0       4.
                   13-        GRID   2       0       4.      10.
                   14-        GRID   3       0       0.      10.
                   15-        GRID   4       0                       -1.
                   16-        GRID   5       0       0.      0.      0.
                   17-        GRID   6       0       0.      20.     0.
                   18-        GRID   8       0       0.      10.     -4.
                   19-        GRID   10      0       4.      0.      -20.
```

INPUT FILES

FIGURE 9

```
                                  TAPE 17
--------------------------------------------------------------------------------

GRID            110         4.0003 90.0414 10.0316
GRID            210         4.0000 90.0395 20.0316
GRID            310          .0000   .0000 20.0315
GRID           1010        20.3981168.7036 10.0364

--------------------------------------------------------------------------------


                                  TAPE 18
--------------------------------------------------------------------------------

  TRANSIENT DYNAMIC ANALYSIS OF DEPLOYMENT
    4   10   1.085940E+00     10      6

  FW PALMIERI
       1-.2211083E-01 .6338227E+00-.9376000E-01 .9797900E-02 .2705329E-02 .1756000E-01
       2-.3981842E-04-.5727308E+00-.9375500E-01 .1667772E-02 .1210647E-02 .2046000E-02
       3 .0000000E+00 .0000000E+00-.9132100E-01 .0000000E+00 .0000000E+00-.1601700E-01
      10-.3204400E-01 .1085940E+01 .1014900E+00 .4563938E-02-.9025164E-02 .1846300E-01

--------------------------------------------------------------------------------


                                  TAPE 19
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  TRANSIENT DYNAMIC ANALYSIS OF DEPLOYMENT
    4   10   9.004137E+01     1      6

  FW PALMIERI
       1 .3267631E-03 .9004137E+02 .1003157E+02 .2357798E-03-.3836635E-04 .1571024E+01
       2 .4584312E-06 .9003952E+02 .1003157E+02-.2124779E-04-.2115870E-04 .1571197E+01
       3 .0000000E+00 .0000000E+00 .1003152E+02 .0000000E+00 .0000000E+00 .1571844E+01
      10 .2000886E-02 .9001320E+02 .1003636E+02 .9685646E-05-.2440590E-03 .1571014E+01

--------------------------------------------------------------------------------
```

**OUTPUT FILES**

**FIGURE 10**