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NASTRAN GPWG TABLES FOR COMBINED SUBSTRUCTURES

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ABSTRACT

A method for computing the mass and center of gravity for basic and combined substructures stored on the NASTRAN Substructure Operating File (SOF) is described. The three step method recovers SOF data blocks for the relevant substructure, processes these data blocks using a specially developed FORTRAN routine, and generates the NASTRAN gridpoint weight generator (GPWG) table for the substructure in a PHASE2 SOF execution using a Direct Matrix Abstraction Program (DMAP) sequence. Verification data for the process is also provided in this report.

1.0 INTRODUCTION

Once a basic substructure has been put on the Substructure Operating File, the ability to obtain the mass and center of gravity (cg) of the basic substructure or any combined substructure of which it is part is lost in a normal NASTRAN execution. The user is unable to verify the mass and cg of the subsequent combined substructures nor is he able to attest to the quality of the PHASE1 reductions performed on his models. The method described here allows the user to obtain the mass and cg of any substructure that is stored on the SOF and to recover them in the form of the customary GPWG tabular format.

The three step method that is used to obtain the mass and cg of the substructures is described in the next section. Verification of the process is provided after the method description.

2.0 METHODOLOGY

The method used to obtain the GPWG table of a substructure is divided into three steps. The first step is the recovery of the SOF data blocks BGSS, EQSS, and CSTM for the substructure of interest. The second step reformats these data blocks into standard NASTRAN input bulk data. During the third step, the user executes a DMAP sequence

that uses the bulk data from the second step to define the geometry, and the stored mass matrix to calculate the GPWG table. Each of these three steps will be described below.

2.1   Step 1 - Data Block Recovery

Step 1 of the process involves obtaining the SOF data blocks BGSS, EQSS, and CSTM for the substructure of interest from the SOF. The PHASE2 substructure control deck required for this operation is shown in Figure 1. The data is taken from the SOF and written to NASTRAN file FORT17. Sample records for each of the three data blocks are provided in Figure 2.

2.2   Step 2 - Defining Input Bulk Data

Step 2 takes the data blocks recovered from Step 1 and converts them into standard NASTRAN Bulk Data that is used to define the geometry of the model. The SOF data blocks will be described below. The bulk data that is created from the data blocks will also be defined.

2.2.1   BGSS Data Block Description

The BGSS data block contains the location in the basic coordinate system of each internal point in the substructure as well as the output coordinate system of the internal point. If the output coordinate system is -1, the internal point is a scalar point rather than a physical gridpoint of the substructure. The BGSS data are converted to GRID or SCALAR bulk data cards that define the substructure geometry.

2.2.2   EQSS Data Block Description

The EQSS data block contains data that describe the degrees of freedom (DOF) that are associated with each internal point of the substructure. The data is binary coded data that is stored in an integer variable. The on/off sequence of the bit sequence tells NASTRAN the DOF that are retained for that point. For example, the integer value 7 has a bit sequence of 111000 which indicates that DOF 123 were retained and DOF 456 were removed during the PHASE1 execution. The EQSS data are converted to DMI bulk data cards that are used to merge the reduced mass matrix stored on the SOF to a full sized mass matrix in the DMAP sequence.

2.2.3   CSTM Data Block Description

The CSTM data block contains the transformation matrix for each of the output coordinate systems in the substructure. These data are used to make CORD2R bulk data cards so that the correct coordinate transformations are performed inside the GPWG Module.

At the end of Step 2, the user has created a set of NASTRAN bulk data. A sample set of input bulk data is shown in Figure 3.

2.3   Step 3 - Calculate Mass and CG

Step 3 of the process uses a DMAP sequence in conjunction with the bulk data that was created in Step 2 to obtain the GPWG table. The DMAP sequence that is used to calculate the GPWG table is shown in Figure 4. Verification of the method is provided in the next section.

3.0   VERIFICATION

Three test cases were executed to verify the method. The first case uses a simple beam element model that contains no MPC, SPC, or OMIT cards. The second case is a complex combined substructure that comprises 16 basic substructures. The third case uses a Craig-Bampton modally reduced model of the second case. The data provided for these cases demonstrate the validity of the method. Each of the example problems will be discussed below.

Figure 5 shows the simple beam element model that was used for the first test case. The GPWG table from the 'straight' execution (non-substructuring) is shown in Table 1. Table 2 is the GPWG table of the substructure model. The data contained in these tables are identical.

The second case used a combined substructure (pseudo-structure in NASTRAN parlance) made up of 16 basic substructures. The mass and cg of the combined substructure calculated using PHASE1 GPWG data taken from each of the basic substructures is provided in Table 3. The GPWG table of the combined pseudostructure is provided in Table 4. Any discrepancies between these data can be attributed to changes introduced by the SPC, MPC, and Guyan reductions performed during the PHASE1 executions of the individual basic substructures.

The final test case used a Craig-Bampton modally reduced model of the second test case. The GPWG table for this execution is provided in Table 5. A comparison of the data in this table with that in Table 4 shows good agreement between the two models, the only large discrepancy being in the x direction. The discrepancy in the x direction can be attributed to the addition of extra x mass to the Craig-Bampton model. Discrepancies in the y and z directions can be attributed to the Craig-Bampton modal reduction.

The three test cases discussed above show good agreement with expected results. Hence, the method is considered verified.

4.0   CONCLUSION

A method for obtaining PHASE2 Grid Point Weight Generator tables of substructures stored on the Substructure Operating File has been described. Data from several test executions were provided. These data verify the method.

ACRONYMS AND ABBREVIATIONS

cg   Center of gravity

DMAP   Direct Matrix Abstraction Program

DOF   Degree(s) of freedom

GPWG   Gridpoint Weight Generator

SOF   Substructure Operating File

NASTRAN   NASA Structural Analysis program

```
SUBSTRUCTURE PHASE2
PASSWORD = password
SOF(1) = FTxx
SOFOUT(EXTERNAL) FORT17, DISK
  POSITION = REWIND
     NAMES = model id
     ITEMS = BGSS
SOFOUT(EXTERNAL) FORT17, DISK
  POSITION = NOREWIND
     NAMES = model id
     ITEMS = EQSS
SOFOUT(EXTERNAL) FORT17, DISK
  POSITION = NOREWIND
     NAMES = model id
     ITEMS = CSTM
```

FIGURE 1.   NASTRAN PHASE2 DECK FOR RECOVERY
                 OF SOF DATA BLOCKS

```
DIT     0                                    2    2    1    2
FULL                10                             2    1    3
MDI     0     0           6    6    0         1    0    0
              5     3     3                        1    0    2    0

        BGSS
FULL          6     20                            3    1    3
   10 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
   10 2.000000E+01 0.000000E+00 0.000000E+00 0.000000E+00
   10 1.500000E+01 1.000000E+01 1.000000E+01 0.000000E+00
FULL          2                                   2    1    2

DIT     0                                    10    6    0    1    0    3    0
FULL
MDI
        EQSS
FULL    0     3           6    5FULL               1    0    2
FULL    1     10    63    15    2              1    2    63    3    3    63    25
FULL                                                                   19   63
FULL    1     10    7     10    2         1    13    3    63    4    4    63
        EQSS
        1     63          2                        1    2                     5    4
                                                                              5    63

DIT     0                                    10    6    0    1    0    3    0
FULL
MDI
        CSTM
FULL    0     3           2     2         1    0    2
FULL          8     4              1           1    1
FULL   10     9     10    1.000000E+00 0.000000E+00                            1
        CSTM
   1 0.000000E+00 1.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 1.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 1.000000E+00
FULL          9     0                              1    2
FULL          0     0                              1    3
&EOF
&EOF
```

FIGURE 2. DATA BLOCKS BGSS, EQSS, AND CSTM FOR TEST CASE 1

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SORTED BULK DATA ECHO

| CARD COUNT	1	2	3	4	5	6	7	8	9	10
1-	DMI	CP	0	2	1	1	1	30	1	
2-	DMI	CP	1.0	1	1.0	1.0	1.0	1.0	1.0	+DMI 1
3-	+DMI	11.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	+DMI 2
4-	+DMI	21.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	+DMI 3
5-	+DMI	31.0	1.0		1.0	1.0	1.0	1.0	1.0	+DMI 4
6-	+DMI	41.0								
7-	GRID	*1								*GRD 1
8-	*GRD	1	0.00000	0		.00000		.00000		
9-	GRID	*2								*GRD 2
10-	*GRD	2	0.00000	0		10.00000		.00000		
11-	GRID	*3								*GRD 3
12-	*GRD	3	0.00000	0		20.00000		.00000		
13-	GRID	*4								*GRD 4
14-	*GRD	4	0.00000	0		5.00000		10.00000		
15-	GRID	*5								*GRD 5
16-	*GRD	5	0.00000	0		15.00000		10.00000		
	ENDDATA									

FIGURE 3. SAMPLE INPUT BULK DATA

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```
BEGIN      $
PARAM      //*ADD*/DRY/1/0   $
SOFI       /M1,,,,,/DRY/*model id*/*MMTX*/   $
MERGE,     ,,,M1,CP,/MGG////   $
GP1        GEOM1,GEOM2,/GPL,EQEXIN,GPDT,CSTM,BGPDT,SIL/S,N,LUSET/
           NOGPDT/ALWAYS=-1   $
GPWG       BGPDT,CSTM,EQEXIN,MGG/OGPWG/V,Y,GRDPNT=0/C,Y,WTMASS   $
OFP        OGPWG,,,,,//S,N,CARDNO   $
END        $
```

FIGURE 4.   NASTRAN DMAP SEQUENCE
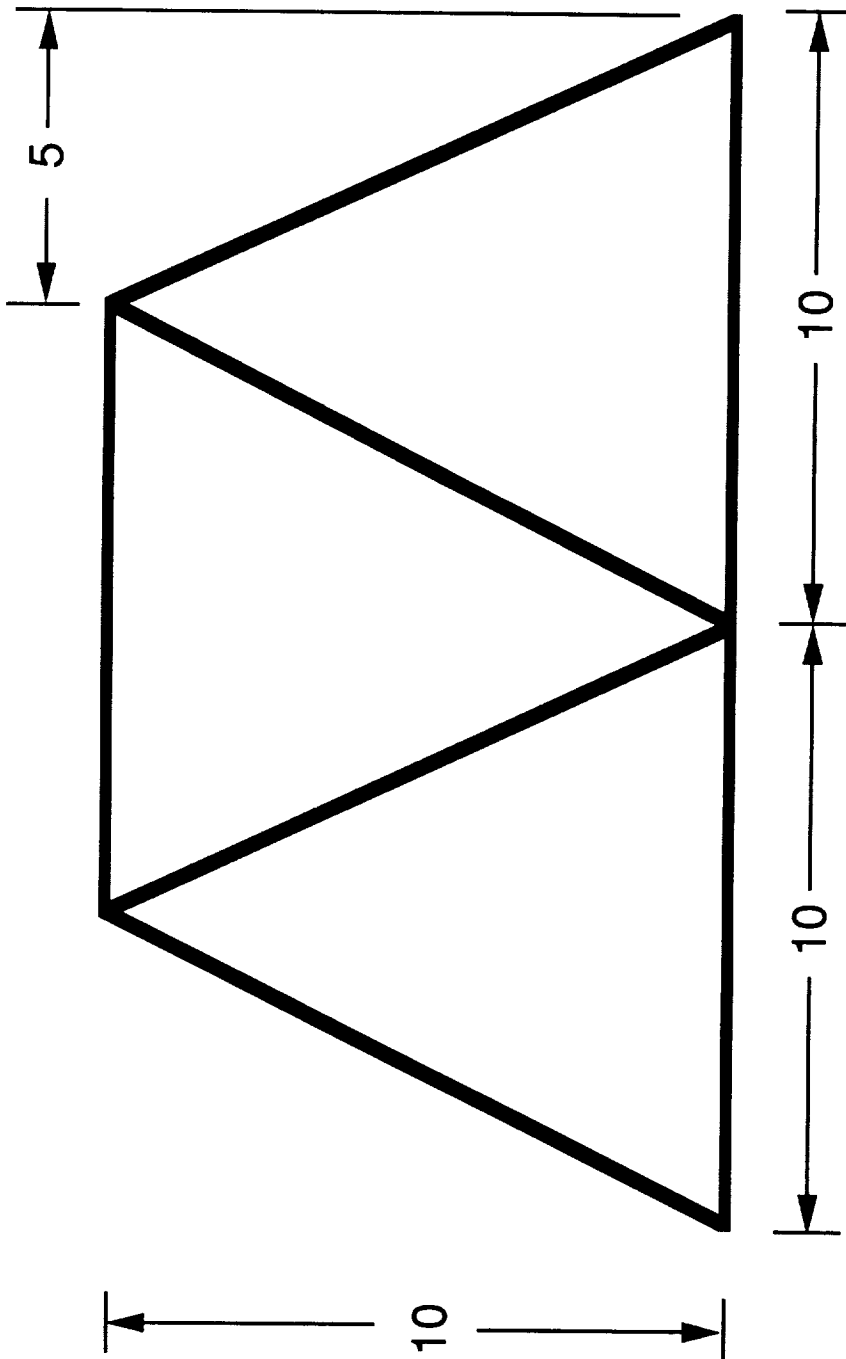
FIGURE 5. SIMPLE BEAM MODEL FOR TEST CASE 1

A = 1.0
ρ = 0.00259

TABLE 1. GPWG TABLE FOR TEST CASE 1 - STRAIGHT EXECUTION

O U T P U T   F R O M   G R I D   P O I N T   W E I G H T   G E N E R A T O R

REFERENCE POINT = 0

MO - RIGID BODY MASS MATRIX IN BASIC COORDINATE SYSTEM

```
***
*  1.93528321E-01  0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00 -8.38141606E-01 *
*  0.00000000E+00  1.93528321E-01  0.00000000E+00  0.00000000E+00  0.00000000E+00 -1.93528321E+00 *
*  0.00000000E+00  0.00000000E+00  1.93528321E-01  8.38141606E-01 -1.93528321E+00  0.00000000E+00 *
*  0.00000000E+00  0.00000000E+00  8.38141606E-01  8.38141606E+00 -8.38141606E+00  0.00000000E+00 *
*  0.00000000E+00  0.00000000E+00 -1.93528321E+00 -8.38141606E+00  2.69338942E+01  0.00000000E+00 *
* -8.38141606E-01 -1.93528321E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00  3.53153102E+01 *
***
```

S - TRANSFORMATION MATRIX FOR SCALAR MASS PARTITION

```
***
* 1.00000000E+00  0.00000000E+00  0.00000000E+00 *
* 0.00000000E+00  1.00000000E+00  0.00000000E+00 *
* 0.00000000E+00  0.00000000E+00  1.00000000E+00 *
***
```

DIRECTION MASS AXIS SYSTEM (S)	MASS	X-C.G.	Y-C.G.	Z-C.G.
X	1.93528321E-01	0.000000000E+00	4.330847293E+00	0.000000000E+00
Y	1.93528321E-01	1.000000000E+01	0.000000000E+00	0.000000000E+00
Z	1.93528321E-01	1.000000000E+01	4.330847293E+00	0.000000000E+00

I(S) - INERTIAS RELATIVE TO C.G.

```
***
* 4.751552755E+00  1.421085472E-14  0.000000000E+00 *
* 1.421085472E-14  7.581062046E+00  0.000000000E+00 *
* 0.000000000E+00  0.000000000E+00  1.233261480E+01 *
***
```

I(Q) - PRINCIPAL INERTIAS

```
***
* 4.751552755E+00 *
* 7.581062046E+00 *
* 1.233261480E+01 *
***
```

Q - TRANSFORMATION MATRIX - I(Q) = QT*I(S)*Q

```
***
* 1.000000000E+00  0.000000000E+00  0.000000000E+00 *
* 0.000000000E+00  1.000000000E+00  0.000000000E+00 *
* 0.000000000E+00  0.000000000E+00  1.000000000E+00 *
***
```

TABLE 2. GPWG TABLE FOR TEST CASE 1 - SUBSTRUCTURE EXECUTION

O U T P U T   F R O M   G R I D   P O I N T   W E I G H T   G E N E R A T O R

REFERENCE POINT =   0

M0 - RIGID BODY MASS MATRIX IN BASIC COORDINATE SYSTEM

```
***
* 1.93528321E-01   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00  -8.38141606E-01 *
* 0.0000000E+00    1.93528321E-01  0.0000000E+00   0.0000000E+00   0.0000000E+00   1.93528321E+00 *
* 0.0000000E+00    0.0000000E+00   1.93528321E-01  8.38141606E-01 -1.93528321E+00  0.0000000E+00 *
* 0.0000000E+00    0.0000000E+00   8.38141606E-01  8.38141606E+00 -8.38141606E-01  0.0000000E+00 *
* 0.0000000E+00    0.0000000E+00  -1.93528321E+00 -8.38141606E-01  2.69338942E+01  0.0000000E+00 *
* -8.38141606E-01  1.93528321E+00  0.0000000E+00   0.0000000E+00   0.0000000E+00   3.53153102E+01 *
***
```

S - TRANSFORMATION MATRIX FOR SCALAR MASS PARTITION

```
***
* 1.00000000E+00   0.00000000E+00   0.00000000E+00 *
* 0.00000000E+00   1.00000000E+00   0.00000000E+00 *
* 0.00000000E+00   0.00000000E+00   1.00000000E+00 *
***
```

DIRECTION MASS AXIS SYSTEM (S)	MASS	X-C.G.	Y-C.G.	Z-C.G.
X	1.93528321E-01	0.0000000E+00	4.330847293E+00	0.000000000E+00
Y	1.93528321E-01	1.00000000E+01	0.000000000E+00	0.000000000E+00
Z	1.93528321E-01	1.00000000E+01	4.330847293E+00	0.000000000E+00

I(S) - INERTIAS RELATIVE TO C.G.

```
***
* 4.7515552755E+00  1.421085472E-14   0.0000000E+00 *
* 1.421085472E-14   7.581062046E+00   0.0000000E+00 *
* 0.00000000000E+00  0.0000000E+00    1.233261480E+01 *
***
```

I(Q) - PRINCIPAL INERTIAS

```
***
* 4.7515552755E+00                                    *
*                  7.581062046E+00                    *
*                                   1.233261480E+01   *
***
```

Q - TRANSFORMATION MATRIX - I(Q) = QT*I(S)*Q

```
***
* 1.00000000E+00   0.0000000E+00   0.0000000E+00 *
* 0.00000000E+00   1.0000000E+00   0.0000000E+00 *
* 0.00000000E+00  .0.0000000E+00   1.0000000E+00 *
***
```

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TABLE 3. MASS AND SUMMARY FOR TEST CASE 2

Structure	Mass	X-C.G.	Y-C.G.	Z-C.G.
APAL	5.389	1141.125	-1.134	359.726
APLAT	6.728	1158.744	-1.805	410.715
ASTRUT	0.369	1160.547	-0.129	372.939
ATCS	0.886	959.030	-71.278	390.090
CPAC	1.276	1182.138	17.198	354.407
EU	0.562	1207.724	22.010	336.323
FPAL	5.805	1015.142	6.069	361.969
FPLAT	7.137	1047.601	13.446	406.102
FSTRUT	0.351	1042.066	0.142	372.978
IGLOO	3.808	947.519	0.263	358.548
ISOASSY	1.500	1180.181	-57.152	418.016
SPHERE1	0.147	984.000	-58.922	425.189
SPHERE2	0.147	984.000	58.922	425.189
SUSIM	0.751	1209.700	-71.200	391.600
TU	0.964	1208.029	-20.736	337.345
TOTAL	35.820	1085.615	-2.069	382.287

TABLE 4. GPWG TABLE FOR TEST CASE 2

O U T P U T   F R O M   G R I D   P O I N T   W E I G H T   G E N E R A T O R

REFERENCE POINT =   0

MO - RIGID BODY MASS MATRIX IN BASIC COORDINATE SYSTEM

```
***
*  3.58097988E+01 -1.80881318E-07  2.63223649E-07  6.27762442E-05  1.36892055E+04  7.30915994E+01 *
* -1.80881323E-07  3.58097995E+01 -3.14055231E-07 -1.36892058E+04  2.22413846E-04  3.88794590E+04 *
*  2.63223679E-07 -3.14055197E-07  3.56843584E+01 -7.42786562E+01 -3.87534840E+04 -3.20814805E-04 *
*  6.27762447E-05 -1.36892058E+04 -7.42786562E+01  5.34050882E+06  9.04648197E+04 -1.48764079E+07 *
*  1.36892055E+04  2.22413830E+04 -3.87534840E+04  9.04648197E+04  4.76251078E+07  3.07591410E+04 *
*  7.30915994E+01  3.88794590E+04 -3.20814868E-04 -1.48764079E+07  3.07591410E+04  4.25489537E+07 *
***
```

S - TRANSFORMATION MATRIX FOR SCALAR MASS PARTITION

```
***
*  1.00000000E+00  0.00000000E+00  0.00000000E+00 *
*  0.00000000E+00  1.00000000E+00  0.00000000E+00 *
*  0.00000000E+00  0.00000000E+00  1.00000000E+00 *
***
```

DIRECTION

MASS AXIS SYSTEM (S)	MASS	X-C.G.	Y-C.G.	Z-C.G.
X	3.58097878E+01	1.753046550E-06	-2.041106120E+00	3.822754085E+02
Y	3.58097949E+01	1.085721215E+03	6.210977143E-06	3.822754093E+02
Z	3.56843536E+01	1.086007588E+03	-2.081546639E+00	-8.990348149E-06

I(S) - INERTIAS RELATIVE TO C.G.

```
***
*  1.073074696E+05 -9.797635452E+03  1.374675257E+04 *
* -9.797635452E+03  3.054835813E+05 -2.818020008E+03 *
*  1.374675257E+04 -2.818020008E+03  3.365510838E+05 *
***
```

I(Q) - PRINCIPAL INERTIAS

```
***
*  1.060227511E+05                                   *
*                   3.377348479E+05                  *
*                                    3.055845357E+05 *
***
```

Q - TRANSFORMATION MATRIX - I(Q) = QT*I(S)*Q

```
***
* -9.971039046E-01 -6.370888760E-02  4.153289213E-02 *
* -4.814661098E-02  1.060602325E-01 -9.931934006E-01 *
*  5.887025853E-02 -9.923166857E-01 -1.088204390E-01 *
***
```

TABLE 5. GPWG TABLE FOR TEST CASE 3

O U T P U T   F R O M   G R I D   P O I N T   W E I G H T   G E N E R A T O R

REFERENCE POINT =   0

MO - RIGID BODY MASS MATRIX IN BASIC COORDINATE SYSTEM

```
***                                                                                           ***
*  3.61827734E+01   3.37269825E-07   7.36971850E-06  -1.24223283E-04   1.38187648E+04   7.30920865E+01  *
*  3.37269768E-07   3.58098030E+01  -3.31714290E-07  -1.36892061E+04   6.17809186E-04   3.88794605E+04  *
* -3.31714091E-07   7.36971860E-06   3.56843560E+01  -7.42786658E+01  -3.87534782E+04  -3.08294358E-04  *
* -1.24223268E-04  -1.36892061E+04  -7.42786658E+01   5.34050862E+06   9.04646580E+04  -1.48764072E+07  *
*  1.38187648E+04   6.17808982E+04  -3.87534782E+04   9.04646580E+04   4.76711615E+07   3.07595132E+04  *
*  7.30920865E+01   3.88794605E+04  -3.08294577E-04  -1.48764072E+07   3.07595132E+04   4.25502349E+07  *
***                                                                                           ***
```

S - TRANSFORMATION MATRIX FOR SCALAR MASS PARTITION

```
***                                                    ***
*  1.00000000E+00   0.00000000E+00   0.00000000E+00  *
*  0.00000000E+00   1.00000000E+00   0.00000000E+00  *
*  0.00000000E+00   0.00000000E+00   1.00000000E+00  *
***                                                    ***
```

DIRECTION MASS AXIS SYSTEM (S)	MASS	X-C.G.	Y-C.G.	Z-C.G.
X	3.618277342E+01	-3.433216173E-06	-2.020079712E+00	3.819155764E+02
Y	3.580980296E+01	1.085721151E+03	1.725251566E-05	3.822753812E+02
Z	3.568435601E+01	1.086007499E+03	-2.081547044E+00	-8.639482173E-06

I(S) - INERTIAS RELATIVE TO C.G.

```
***                                                       ***
*  1.073075349E+05  -9.797469966E+03   1.374666989E+04  *
* -9.797469966E+03   3.069920234E+05  -2.844506799E+03  *
*  1.374666989E+04  -2.844506799E+03   3.378346633E+05  *
***                                                       ***
```

I(Q) - PRINCIPAL INERTIAS

```
***                                                       ***
*  1.060308852E+05                                      *
*                    3.390214067E+05                    *
*                                     3.070819296E+05   *
***                                                       ***
```

Q - TRANSFORMATION MATRIX - I(Q) = QT*I(S)*Q

```
***                                                       ***
* -9.971403308E-01  -6.340796537E-02   4.111679123E-02  *
* -4.778493476E-02   1.075110325E-01  -9.930548715E-01  *
*  5.854708022E-02  -9.921798264E-01  -1.102335320E-01  *
***                                                       ***
```