EMA/ME 601 - Homework 3

A new space vehicle, called the General Purpose Spacecraft (GPSC), is being developed by the Jet Propulsion Lab (JPL) to perform a Lunar-surveying mission. The corresponding FEM is illustrated in Fig. 1. The NASTRAN bulk data deck is listed in Table 1 and a listing of the spacecraft's rigid body mass properties, produced by NASTRAN's Grid Point Weight Generator module, is presented in Table 2. Note that the units are weight. A test article has been developed and a modal survey is being planned. The JPL engineers need some help, but they readily know that your very esteemed and famous professor is very busy and important, and could never be bothered with their trivial problems. So, they come to you for help in selecting target modes and sensor locations. A MATLAB file, called "gpsc.mat" has been placed on Dr. Dan's class webpage. It contains a mass and stiffness matrix, "M" and "K", respectively, for a reduced representation of the GPSC, which is not constrained in any way. During the test, the spacecraft will be pinned at the base of the legs pictured below. Vector "DOF1" contains a listing of the dof and their order for "M" and "K". Thirty fixed interface FEM modes, "PHI", have already been supplied and do not have to be recomputed. Vector "DOF2" contains a listing of the dof and their order for "PHI". Vector "w" contains a listing of the corresponding modes in Hertz. I suggest that you reorder all matrices to give a numerically ascending sort. Make listings, plots, etc., to show details of computations and summarize results. Show listings of all MATLAB functions used in this analysis.

1. Generate a MATLAB function to compute *Effective Mass* and use it to rank the fixed interface modes of the spacecraft. Select a set of target modes based upon each of them having at least 5.0% effective mass in any of the six rigid body directions. Determine the total effective mass for your target mode set in each rigid body direction and comment on the sets dynamic completeness.

2. The target modes identified in task 1 will have to be identified during the modal test and then later correlated with the FEM representation. Generate MATLAB functions to rank candidate sensor locations based on *Modal Kinetic Energy* and *Effective Independence*. Pick a single initial candidate set of sensor locations and use your MATLAB functions to select a final set for the test that will accurately identify your target modes using each of the sensor placement techniques. The final sensor sets should contain (n_{target} + 5) locations.

3. Use the *Modal Assurance Criterion* and any other measure that might be appropriate to determine which of the two sensor sets produces the most independent target mode partitions and the greatest target mode response signal strength.

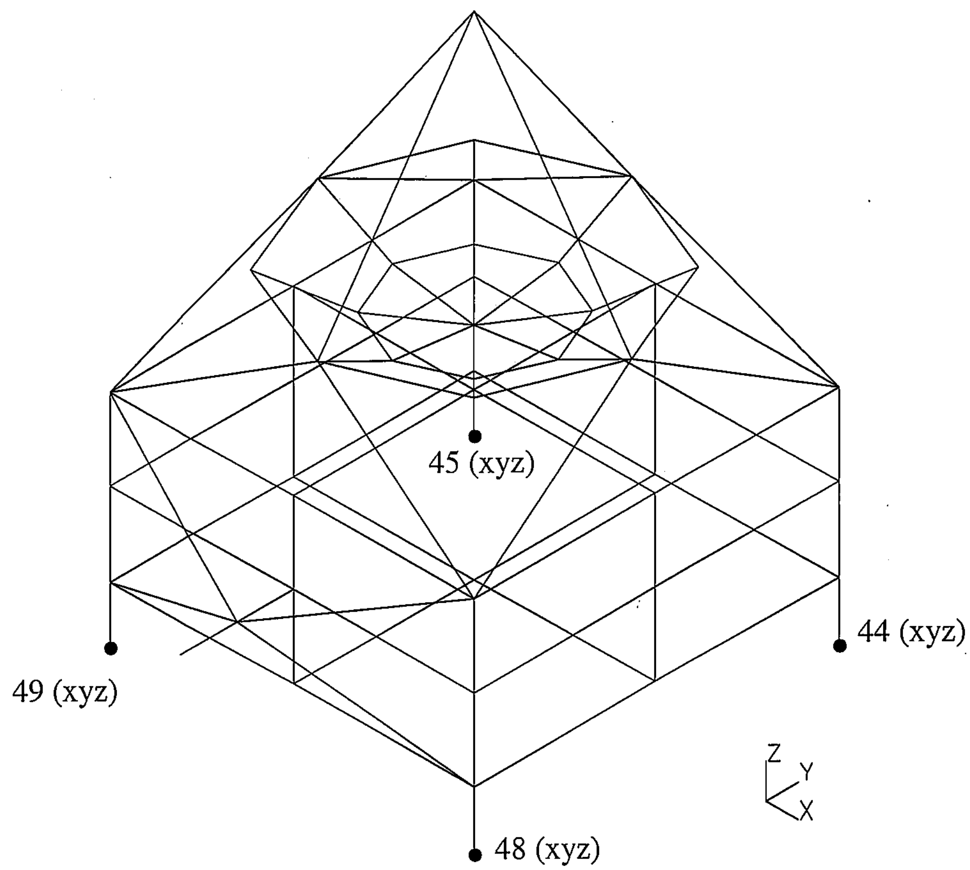


Fig. 1. GPSC finite element model.

1
1 GENERAL PURPOSE SPACECRAFT (GPSC) - FEM OCTOBER 24, 1996 CSA/NASTRAN 2/08/96 PAGE 20
FINITE ELEMENT MODEL (FEM) MATRIX PROCESSING FOR SUPERELEMENT 0 (RESIDUAL)
0 NORMAL MODES ANALYSIS
0 A DISPLACEMENT SET

0	-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	
1=	35-1	35-2	35-3	42-1	42-2	42-3	36-1	36-2	36-3	50-1 =	10
11=	50-2	50-3	43-1	43-2	43-3	46-1	46-2	46-3	47-1	47-2 =	20
21=	47-3	39-1	39-2	39-3	41-1	41-2	41-3	25-1	25-2	25-3 =	30
31=	33-1	33-2	33-3	34-1	34-2	34-3	26-1	26-2	26-3	37-1 =	40
41=	37-2	37-3	28-1	28-2	28-3	31-1	31-2	31-3	38-1	38-2 =	50
51=	38-3	30-1	30-2	30-3	40-1	40-2	40-3	23-1	23-2	23-3 =	60
61=	24-1	24-2	24-3	27-1	27-2	27-3	29-1	29-2	29-3	32-1 =	70
71=	32-2	32-3	19-1	19-2	19-3	20-1	20-2	20-3	21-1	21-2 =	80
81=	21-3	22-1	22-2	22-3	10-1	10-2	10-3	18-1	18-2	18-3 =	90
91=	2-1	2-2	2-3	3-1	3-2	3-3	11-1	11-2	11-3	5-1 =	100
101=	5-2	5-3	13-1	13-2	13-3	14-1	14-2	14-3	6-1	6-2 =	110
111=	6-3	9-1	9-2	9-3	17-1	17-2	17-3	1-1	1-2	1-3 =	120
121=	16-1	16-2	16-3	15-1	15-2	15-3	8-1	8-2	8-3	7-1 =	130
131=	7-2	7-3	4-1	4-2	4-3	12-1	12-2	12-3			

Table 1. NASTRAN Bulk Data Deck

```
$-----------------------------------------------------------------------
$ G E N E R A L   P U R P O S E   S P A C E C R A F T   M O D E L   ( G P S C)
$-----------------------------------------------------------------------
$ Last modified:  Chris Flanigan  13-May-94
$                 Dan Kammer      17-Oct-96  Transformed to CSA
$-----------------------------------------------------------------------
$
$
$ Concentrated mass data
$ ----------------------
$
$       2       3       4       5       6       7       8       9
$       EID     G       CID     M
CONM2   1001    18      10      200.
CONM2   1002    42      10      425.
CONM2   1003    40      10      250.
$
$ Local coordinate systems
$ ------------------------
$
        CID     RID     A1      A2      A3      B1      B2      B3
$
CORD2R  10      0       0.      0.      0.      0.      0.      1.
        1.      0.      0.
CORD2C  20      10      0.      0.      120.    120.    0.      120.
        0.      0.      0.
$
$ Grid point bulk data
$ --------------------
$
$               ID      CP      X1      X2      X3      CD
$
GRID            1       20  60.000 2.4E-14 0.00000      10
GRID            2       20  60.000  17.500 0.00000      10
GRID            3       20  58.628  12.569  12.758      10
GRID            4       20  58.628  347.43 -12.758      10
GRID            5       20  58.628  12.569 -12.758      10
GRID            6       20  57.223 2.7E-14  18.042      10
GRID            7       20  60.000  342.50 0.00000      10
GRID            8       20  57.223  360.00 -18.042      10
GRID            9       20  58.628  347.43  12.758      10
GRID            10      20  60.000  35.000 0.00000      10
GRID            11      20  54.844  26.341  24.335      10
GRID            12      20  54.844  333.66 -24.335      10
GRID            13      20  54.844  26.341 -24.335      10
GRID            14      20  49.149 3.7E-14  34.415      10
GRID            15      20  60.000  325.00 0.00000      10
GRID            16      20  49.149  360.00 -34.415      10
GRID            17      20  54.844  333.66  24.335      10
GRID            18      20 0.00000 0.00000 0.00000      10
GRID            19      10  39.520  39.520  48.000      10
GRID            20      10 -39.520  39.520  48.000      10
GRID            21      10  39.520 -39.520  48.000      10
GRID            22      10 -39.520 -39.520  48.000      10
GRID            23      10 3.8E-06  39.520  48.000      10
```

```
GRID          24     10  39.520-3.8E-06  48.000      10
GRID          25     10  39.520  39.520  30.000      10
GRID          26     10 -39.520  39.520  30.000      10
GRID          27     10 -39.520 3.8E-06  48.000      10
GRID          28     10  39.520 -39.520  30.000      10
GRID          29     10-3.8E-06 -39.520  48.000      10
GRID          30     10-3.8E-06 -51.520  30.000      10
GRID          31     10 -39.520 -39.520  30.000      10
GRID          32     10 0.00000 0.00000  48.000      10
GRID          33     10 3.8E-06  39.520  30.000      10
GRID          34     10  39.520-3.8E-06  30.000      10
GRID          35     10  39.520  39.520  12.000      10
GRID          36     10 -39.520  39.520  12.000      10
GRID          37     10 -39.520 3.8E-06  30.000      10
GRID          38     10-3.8E-06 -39.520  30.000      10
GRID          39     10  39.520 -39.520  12.000      10
GRID          40     10-3.8E-06 -63.520  30.000      10
GRID          41     10 -39.520 -39.520  12.000      10
GRID          42     10 3.8E-06  39.520  12.000      10
GRID          43     10  39.520-3.8E-06  12.000      10
GRID          44     10  39.520  39.520 0.00000      10
GRID          45     10 -39.520  39.520 0.00000      10
GRID          46     10 -39.520 3.8E-06  12.000      10
GRID          47     10-3.8E-06 -39.520  12.000      10
GRID          48     10  39.520 -39.520 0.00000      10
GRID          49     10 -39.520 -39.520 0.00000      10
GRID          50     10 0.00000 0.00000  12.000      10
$
$  Centerline grid at the interface plane
$  --------------------------------------
$
$             ID      CP      X1      X2      X3      CD
GRID          99      10      0.      0.      0.       0
$
$            EID         REFGRID    REFC     WT1      C1      G1      G2
RBE3          99              99  123456     1.0     123      44      45
              48      49
$
$
$  Shell elements
$  --------------
$
$            EID     PID      G1      G2      G3
CTRIA3         1      13       3       6       1
CTRIA3         2      13       2       3       1
CTRIA3         3      13       5       2       1
CTRIA3         4      13       8       5       1
CTRIA3         5      13       4       8       1
CTRIA3         6      13       7       4       1
CTRIA3         7      13       9       7       1
CTRIA3         8      13       6       9       1
$
$            EID     PID      G1      G2      G3      G4
CQUAD4         9      13       6       3      11      14
CQUAD4        10      13       3       2      10      11
CQUAD4        11      13       2       5      13      10
CQUAD4        12      13       5       8      16      13
```

```
CQUAD4      13      13       8       4      12      16
CQUAD4      14      13       4       7      15      12
CQUAD4      15      13       7       9      17      15
CQUAD4      16      13       9       6      14      17
$
$
$  Bar elements
$  ------------
$
$          EID     PID      GA      GB      X1      X2      X3
CBAR        17       5      41      49   1.000   0.000   0.000
CBAR        18       5      36      45   1.000   0.000   0.000
CBAR        19       5      39      48   1.000   0.000   0.000
CBAR        20       5      35      44   1.000   0.000   0.000
CBAR        21       2      46      41   0.000   0.000   1.000
CBAR        22       2      36      46   0.000   0.000   1.000
CBAR        23       2      41      47   0.000   0.000   1.000
CQUAD4      24      10      50      47      41      46
CQUAD4      25      10      50      46      36      42
CBAR        26       2      42      36   0.000   0.000   1.000
CBAR        27       2      47      39   0.000   0.000   1.000
CQUAD4      28      10      50      43      39      47
CQUAD4      29      10      50      42      35      43
CBAR        30       2      35      42   0.000   0.000   1.000
CBAR        31       2      39      43   0.000   0.000   1.000
CBAR        32       2      43      35   0.000   0.000   1.000
CBAR        33       5      31      41   1.000   0.000   0.000
CQUAD4      34      11      37      46      41      31
CQUAD4      35      11      37      26      36      46
CBAR        36       5      26      36   1.000   0.000   0.000
CBAR        37       4      41      30   0.000   0.000   1.000
CQUAD4      38      11      38      31      41      47
CQUAD4      39      11      33      42      36      26
CBAR        40       4      30      39   0.000   0.000   1.000
CQUAD4      41      11      38      47      39      28
CQUAD4      42      11      33      25      35      42
CBAR        43       5      28      39   1.000   0.000   0.000
CQUAD4      44      11      34      28      39      43
CQUAD4      45      11      34      43      35      25
CBAR        46       5      25      35   1.000   0.000   0.000
CBAR        47       2      30      40   0.000   0.000   1.000
CBAR        48       2      38      30   0.000   0.000   1.000
CBAR        49       5      22      31   1.000   0.000   0.000
CQUAD4      50      11      37      31      22      27
CQUAD4      51      11      37      27      20      26
CBAR        52       5      20      26   1.000   0.000   0.000
CBAR        53       4      22      30   0.000   0.000   1.000
CQUAD4      54      11      38      29      22      31
CQUAD4      55      11      33      26      20      23
CBAR        56       4      21      30   0.000   0.000   1.000
CQUAD4      57      11      38      28      21      29
CQUAD4      58      11      33      23      19      25
CBAR        59       5      21      28   1.000   0.000   0.000
CQUAD4      60      11      34      24      21      28
CQUAD4      61      11      34      25      19      24
CBAR        62       5      19      25   1.000   0.000   0.000
CBAR        63       3      27      22   0.000   0.000   1.000
```

```
CBAR        64      3      20      27   0.000    0.000    1.000
CBAR        65      3      22      29   0.000    0.000    1.000
CQUAD4      66     12      32      27      22       29
CQUAD4      67     12      32      23      20       27
CBAR        68      3      23      20   0.000    0.000    1.000
CBAR        69      3      29      21   0.000    0.000    1.000
CQUAD4      70     12      32      29      21       24
CQUAD4      71     12      32      24      19       23
CBAR        72      3      19      23   0.000    0.000    1.000
CBAR        73      3      21      24   0.000    0.000    1.000
CBAR        74      3      24      19   0.000    0.000    1.000
CBAR        75      4      22      15   0.000    0.000    1.000
CBAR        76      4      15      21   0.000    0.000    1.000
CBAR        77      4      21      14   0.000    0.000    1.000
CBAR        78      4      14      19   0.000    0.000    1.000
CBAR        79      4      19      10   0.000    0.000    1.000
CBAR        80      4      10      20   0.000    0.000    1.000
CBAR        81      4      20      16   0.000    0.000    1.000
CBAR        82      4      16      22   0.000    0.000    1.000
CBAR        83      4      15      18   0.000    0.000    1.000
CBAR        84      4      14      18   0.000    0.000    1.000
CBAR        85      4      10      18   0.000    0.000    1.000
CBAR        86      4      16      18   0.000    0.000    1.000
CBAR        87      2      47      50   0.000    0.000    1.000
CBAR        88      2      43      50   0.000    0.000    1.000
CBAR        89      2      42      50   0.000    0.000    1.000
CBAR        90      2      46      50   0.000    0.000    1.000
$
$  CONSTRAIN BASE OF LEGS
$  ----------------------
$
$       SID     C       G1      G2      G3      G4
SPC1    10      123456  44      45      48      49
$
$
$  GENERAL PURPOSE SPACECRAFT  -  pretest model
$  --------------------------
$
$  MATERIAL AND PHYSICAL PROPERTY DATA
$  -----------------------------------
$
$           PID     MID       A      I1      I2       J
PBAR          2       1      4.    1.33    1.33   2.667
PBAR          3       1      1.   .0833   .0833   .1667
PBAR          4       1   .7654  .04662  .04662  .09324
PBAR          5       1      9.    6.75    6.75    12.5
$
$
$           PID     MID       T    MID2  12I/T3    MID3    TS/T     NSM
PSHELL       10       1      1.       1               1              .5
PSHELL       11       1     .25       1               1
PSHELL       12       1     .25       1               1
PSHELL       13       1      .5       1               1
$
$           MID       E       G      NU     RHO
MAT1          1  1.E+07              .3      .1
$
```

TABLE 2. NASTRAN Grid Point Generator

1 GENERAL PURPOSE SPACECRAFT (GPSC) - FEM OCTOBER 24, 1996 CSA/NASTRAN 2/08/96 PAGE 14
FINITE ELEMENT MODEL (FEM) MATRIX PROCESSING FOR SUPERELEMENT 0 (RESIDUAL)
0 NORMAL MODES ANALYSIS

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

0 REFERENCE POINT = 0

MO - RIGID BODY MASS MATRIX IN BASIC COORDINATE SYSTEM

5.712471E+03	.000000E+00	.000000E+00	.000000E+00	1.218244E+05	2.064367E+02
.000000E+00	5.712471E+03	.000000E+00	-1.218244E+05	.000000E+00	6.225555E-04
.000000E+00	.000000E+00	5.712471E+03	-2.064367E+02	-6.225555E-04	.000000E+00
.000000E+00	-1.218244E+05	-2.064367E+02	1.140252E+07	-1.265985E-01	1.039334E-02
1.218244E+05	.000000E+00	-6.225555E-04	-1.265985E-01	9.685567E+06	3.085192E+05
2.064367E+02	6.225555E-04	.000000E+00	1.039334E-02	3.085192E+05	9.654570E+06

S - TRANSFORMATION MATRIX FOR SCALAR MASS PARTITION

1.000000E+00	.000000E+00	.000000E+00
.000000E+00	1.000000E+00	.000000E+00
.000000E+00	.000000E+00	1.000000E+00

DIRECTION MASS AXIS SYSTEM (S)	MASS	X-C.G.	Y-C.G.	Z-C.G.
X	5.712471E+03	.000000E+00	-3.613790E-02	2.132604E+01
Y	5.712471E+03	1.089818E-07	.000000E+00	2.132604E+01
Z	5.712471E+03	1.089818E-07	-3.613790E-02	.000000E+00

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

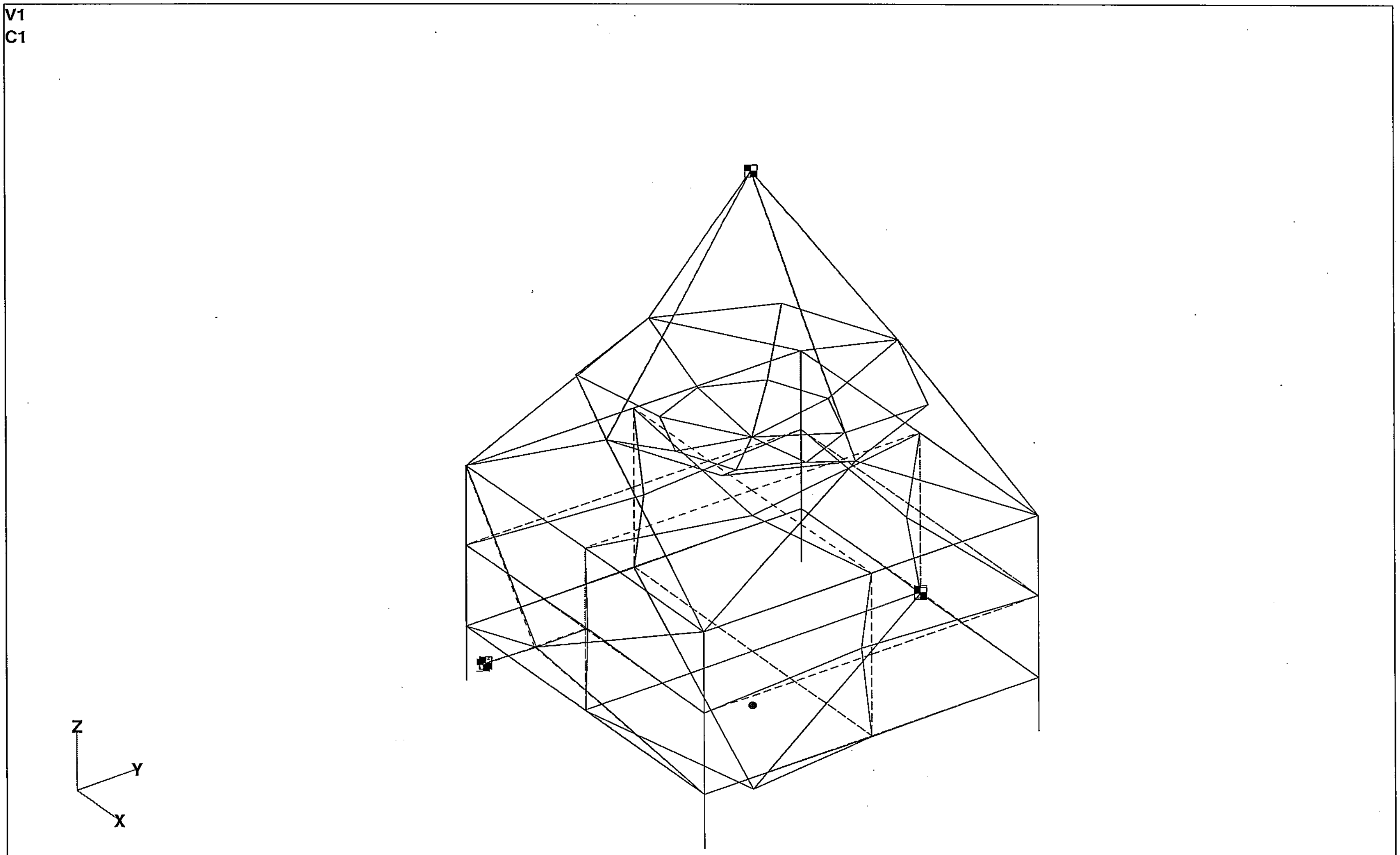
8.804481E+06	1.266210E-01	-2.366998E-02
1.266210E-01	7.087536E+06	-3.041167E+05
-2.366998E-02	-3.041167E+05	9.654562E+06

I(Q) - PRINCIPAL INERTIAS

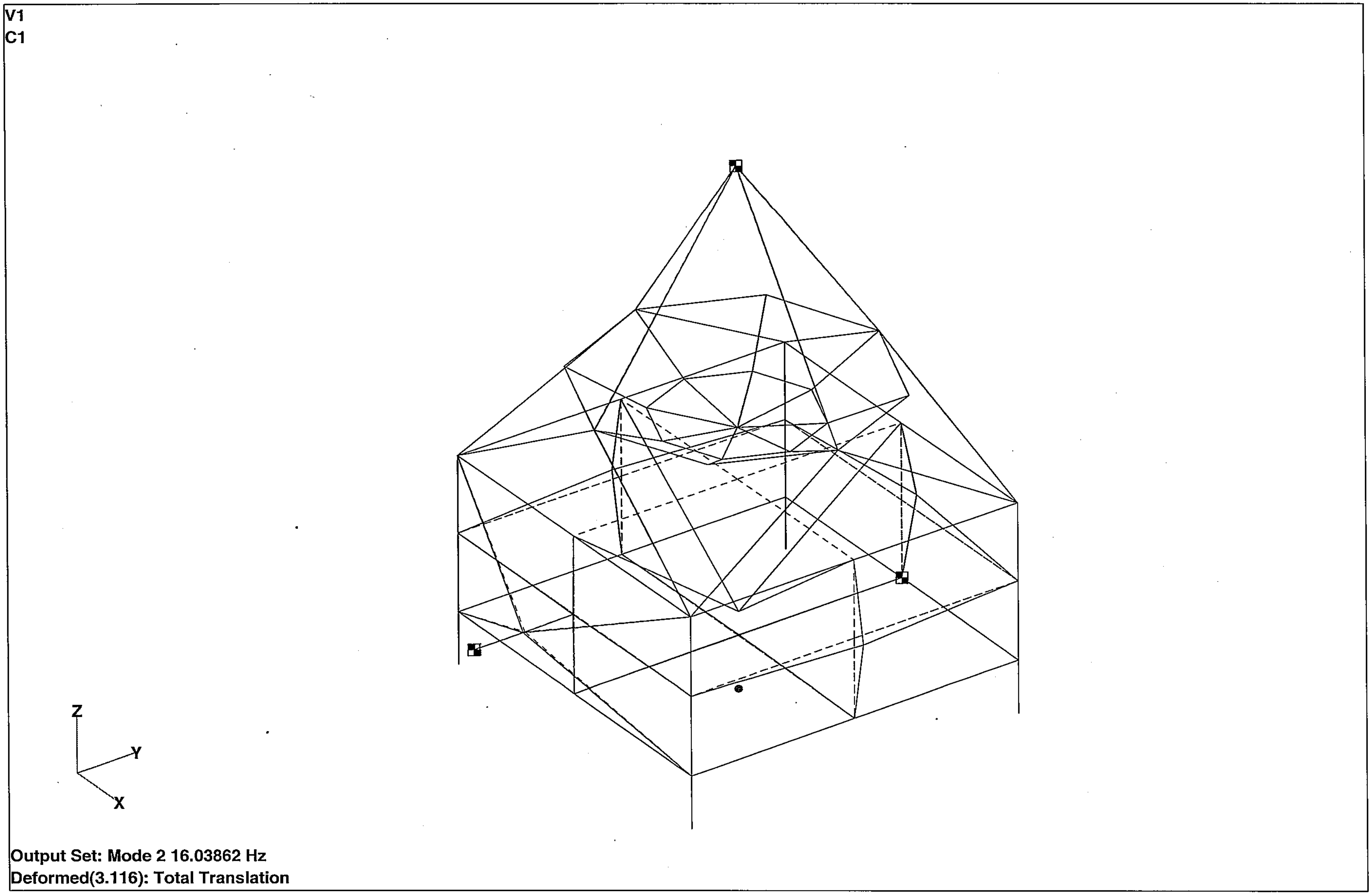
8.804481E+06		
	7.051999E+06	
		9.690099E+06

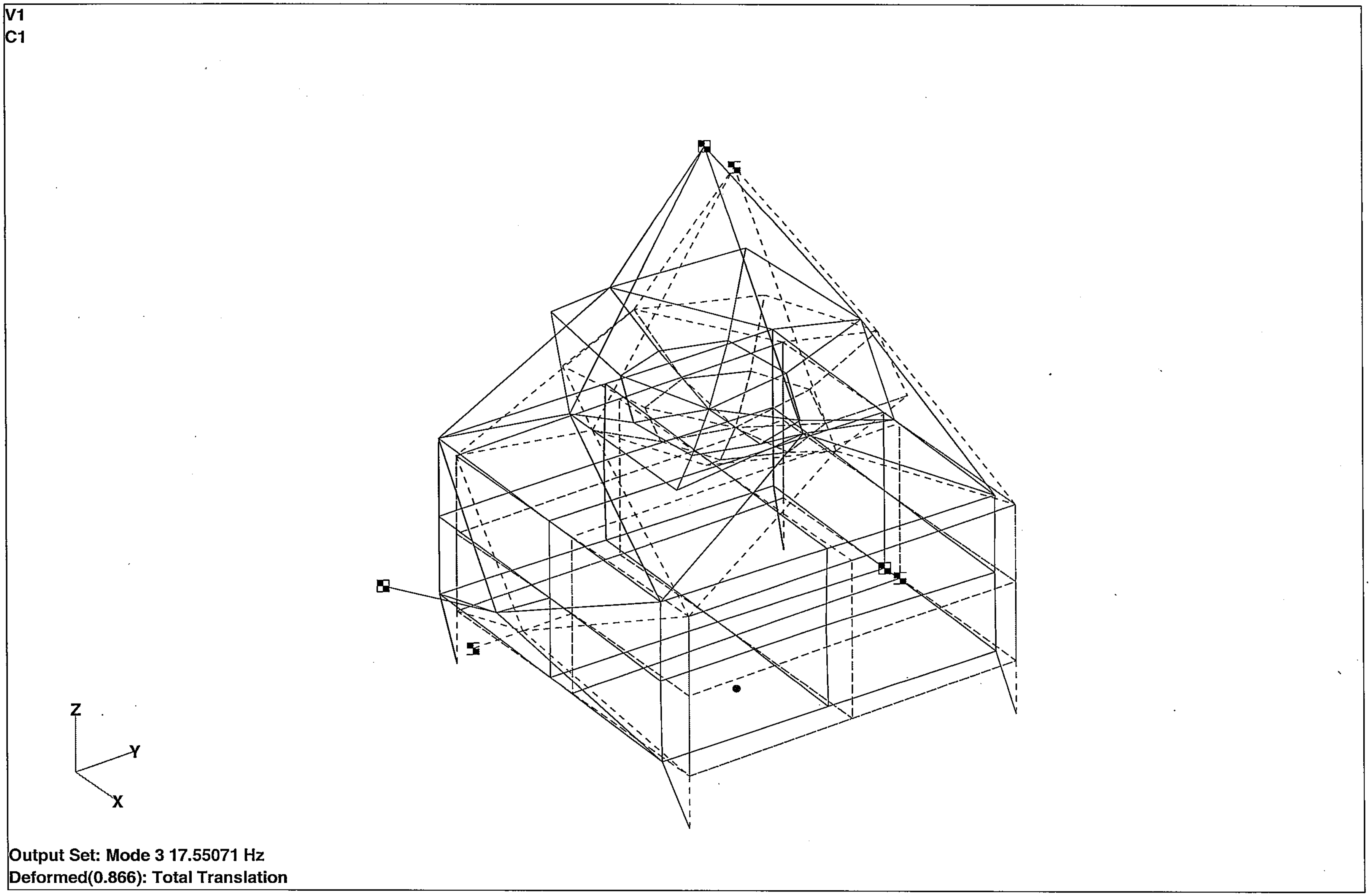
Q - TRANSFORMATION MATRIX
I(Q) = QT*IBAR(S)*Q

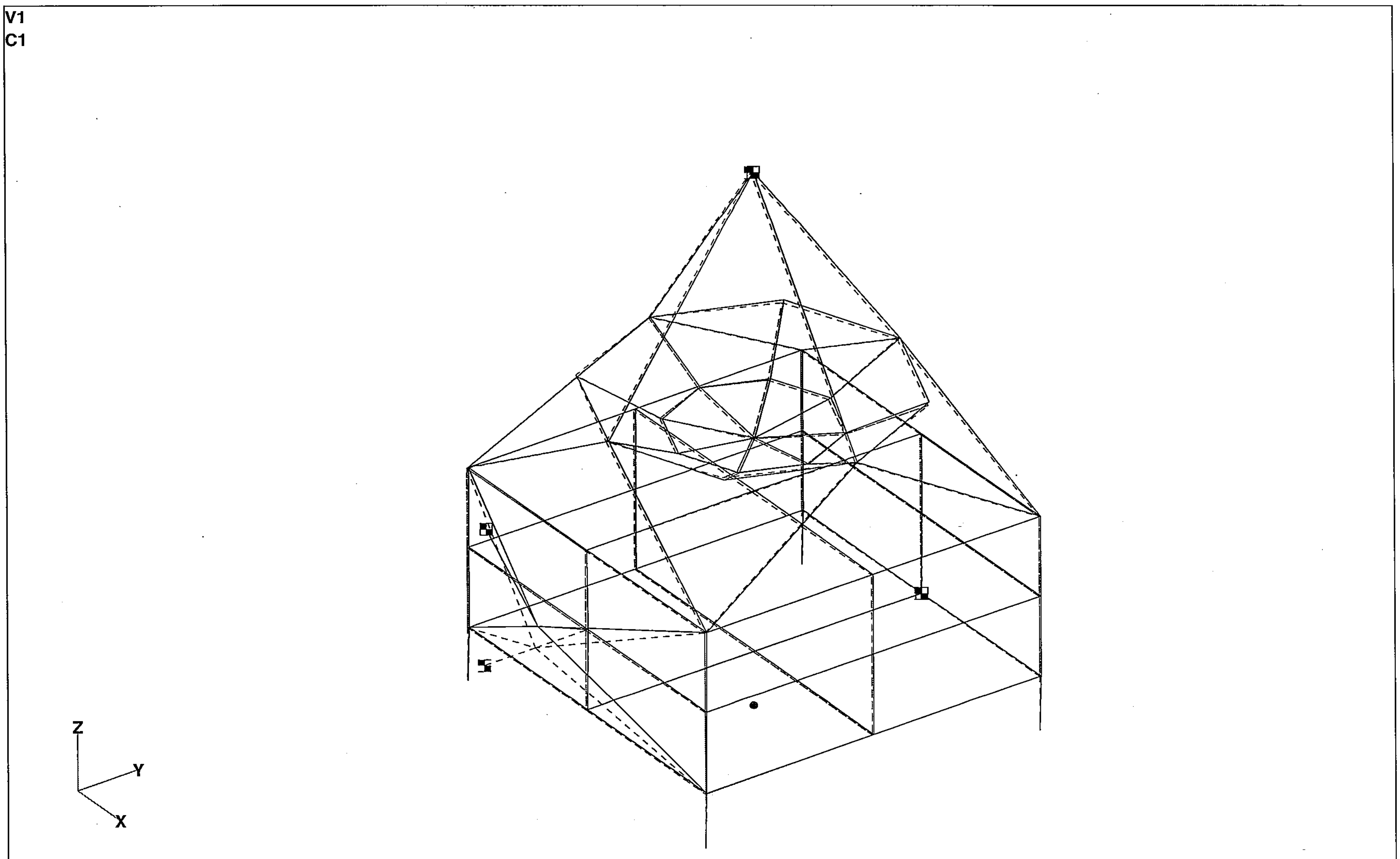
1.000000E+00	.000000E+00	.000000E+00
.000000E+00	9.932418E-01	1.160630E-01
.000000E+00	-1.160630E-01	9.932418E-01



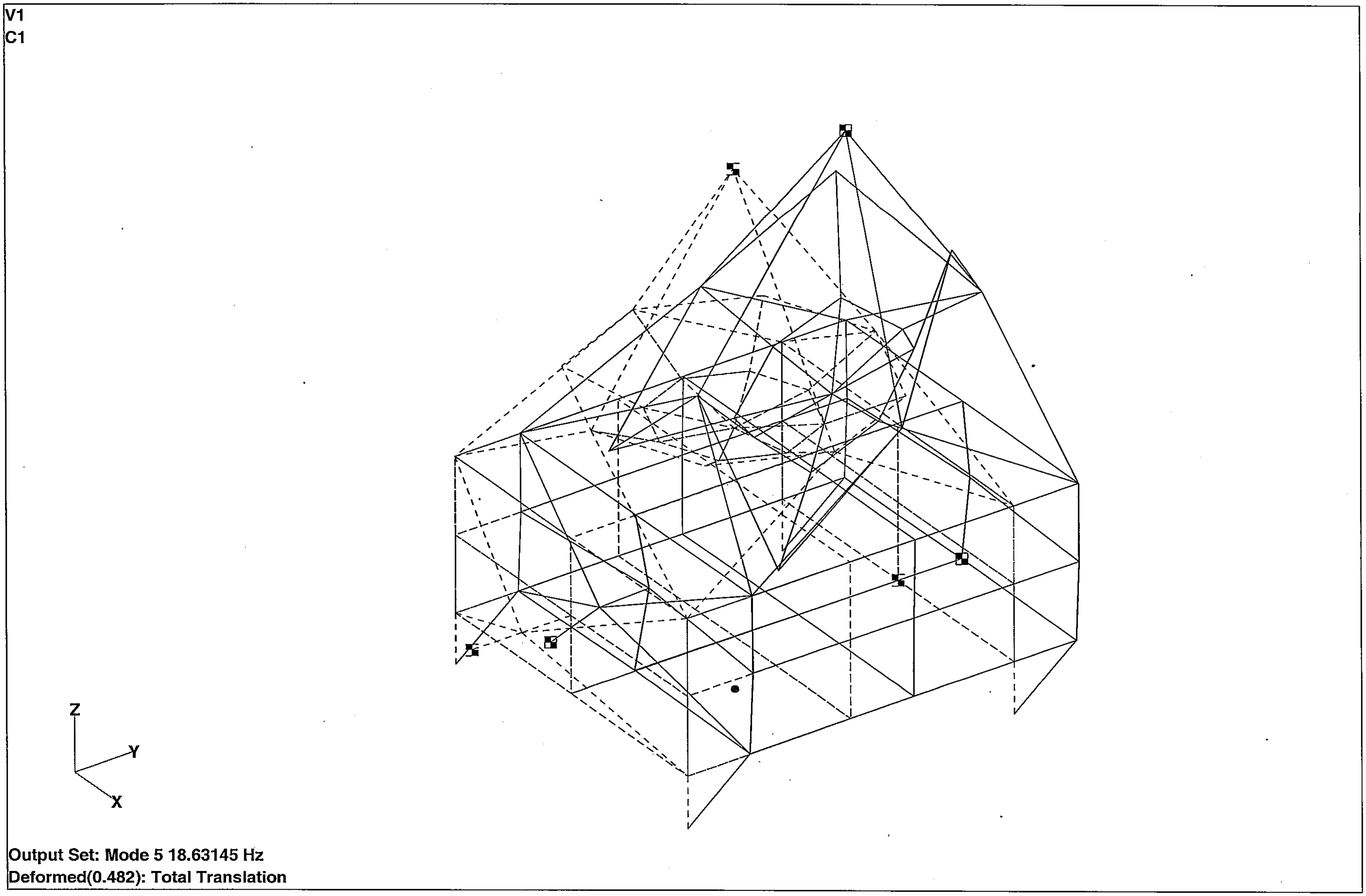
Output Set: Mode 1 13.58455 Hz
Deformed(0.631): Total Translation

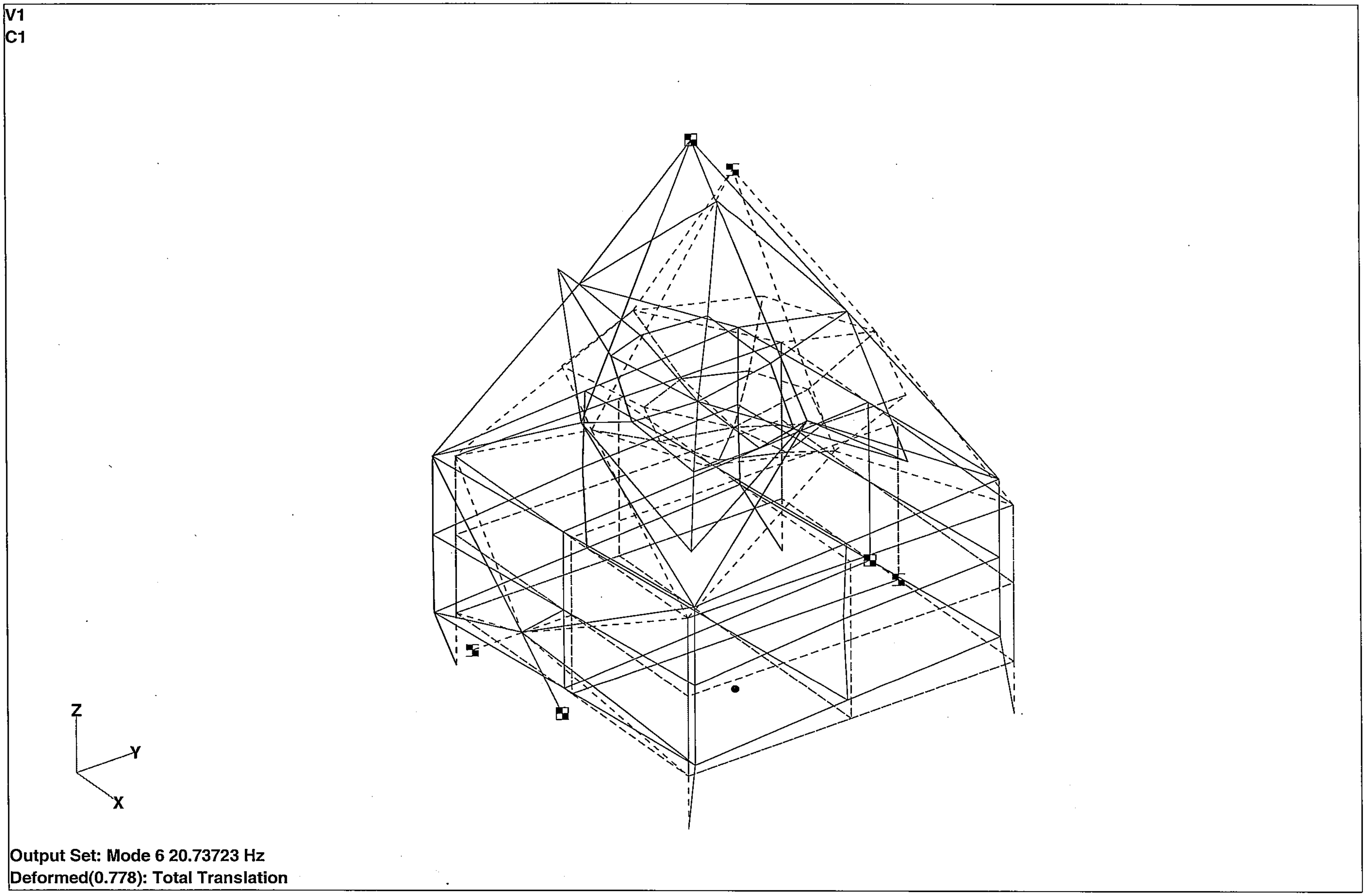

V1
C1
Z
Y
X
Output Set: Mode 2 16.03862 Hz
Deformed(3.116): Total Translation


V1
C1
Z
Y
X
Output Set: Mode 3 17.55071 Hz
Deformed(0.866): Total Translation

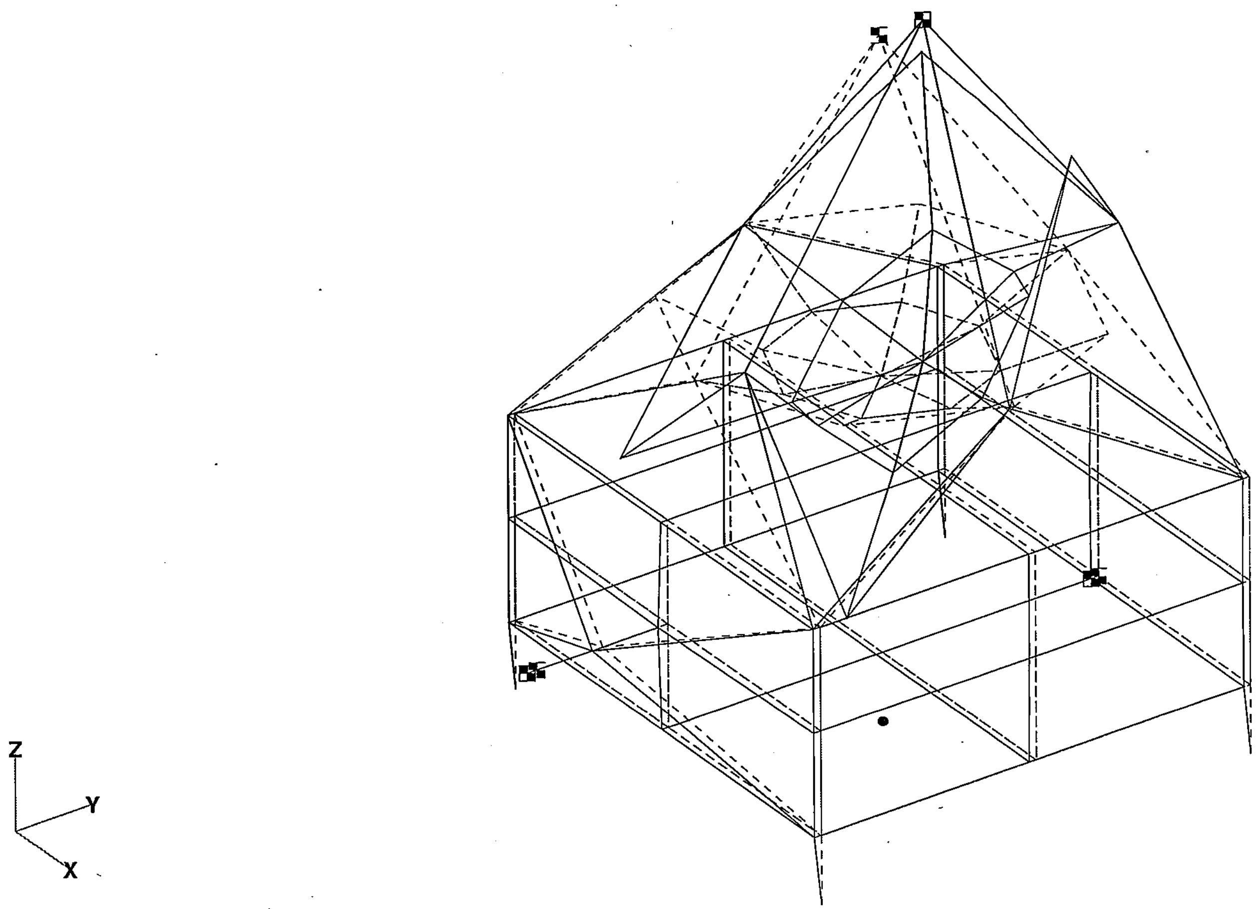


Output Set: Mode 4 17.65018 Hz
Deformed(1.234): Total Translation


V1
C1
Z
Y
X
Output Set: Mode 5 18.63145 Hz
Deformed(0.482): Total Translation

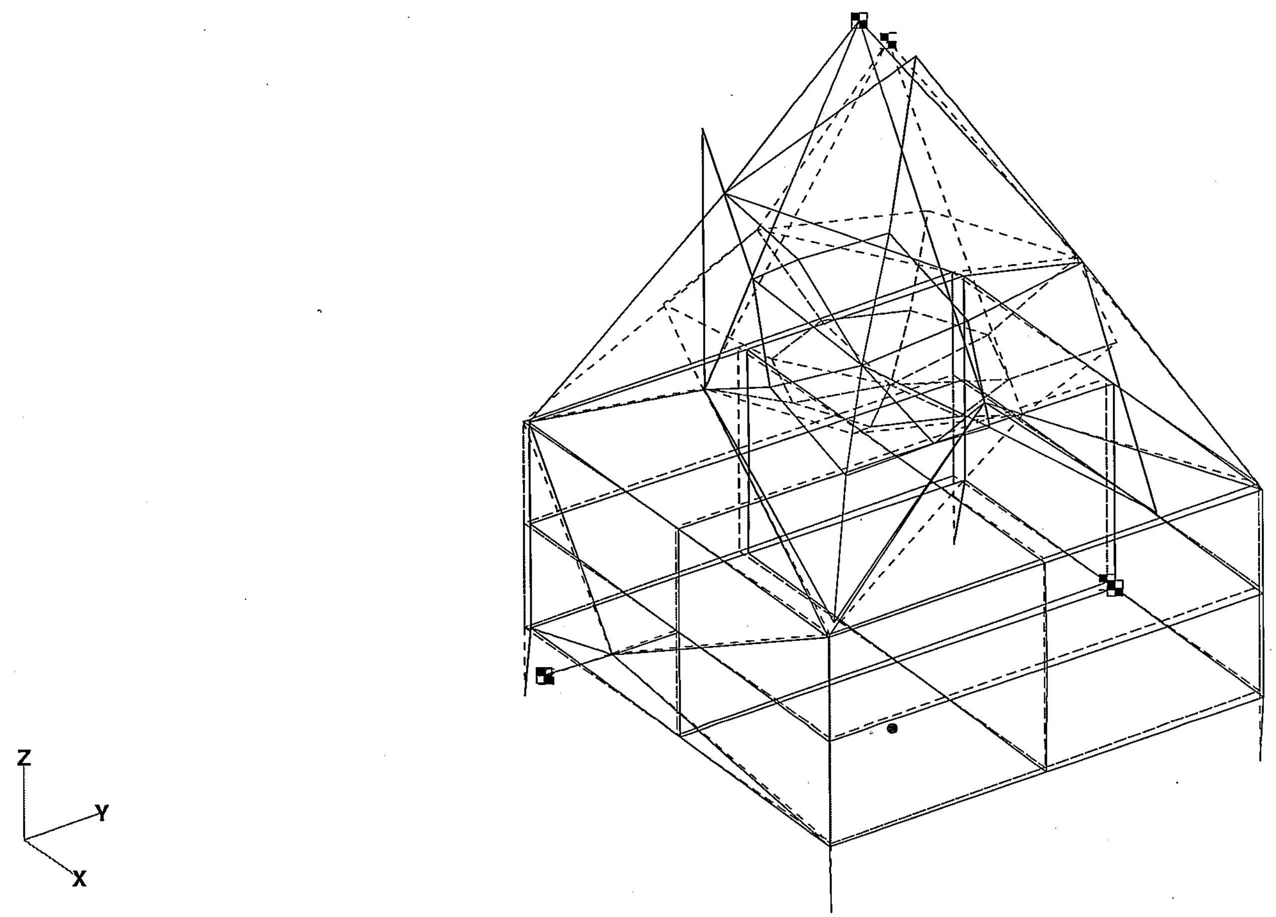

V1
C1
Z
Y
X
Output Set: Mode 6 20.73723 Hz
Deformed(0.778): Total Translation

V1
C1



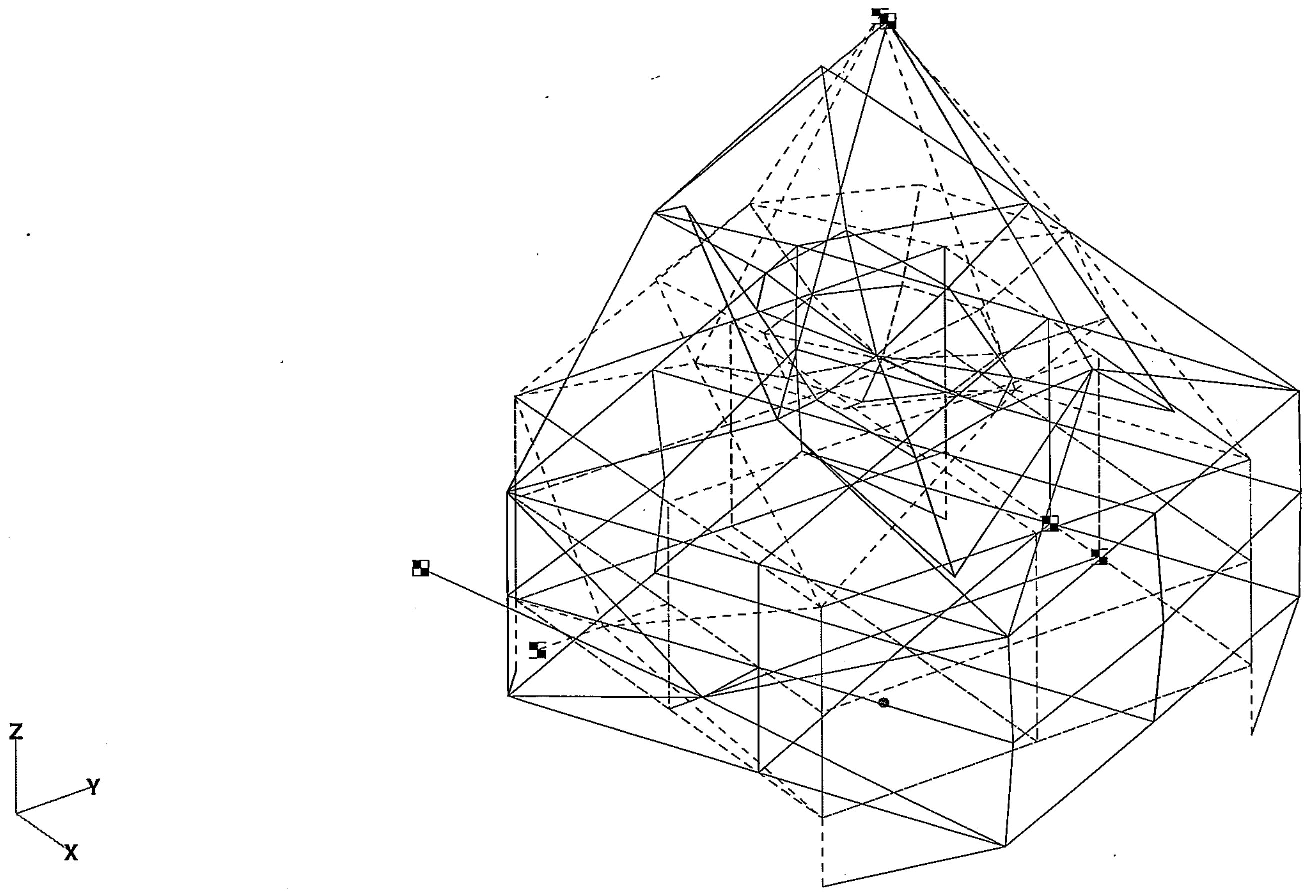
Output Set: Mode 7 24.9424 Hz
Deformed(2.258): Total Translation

V1
C1

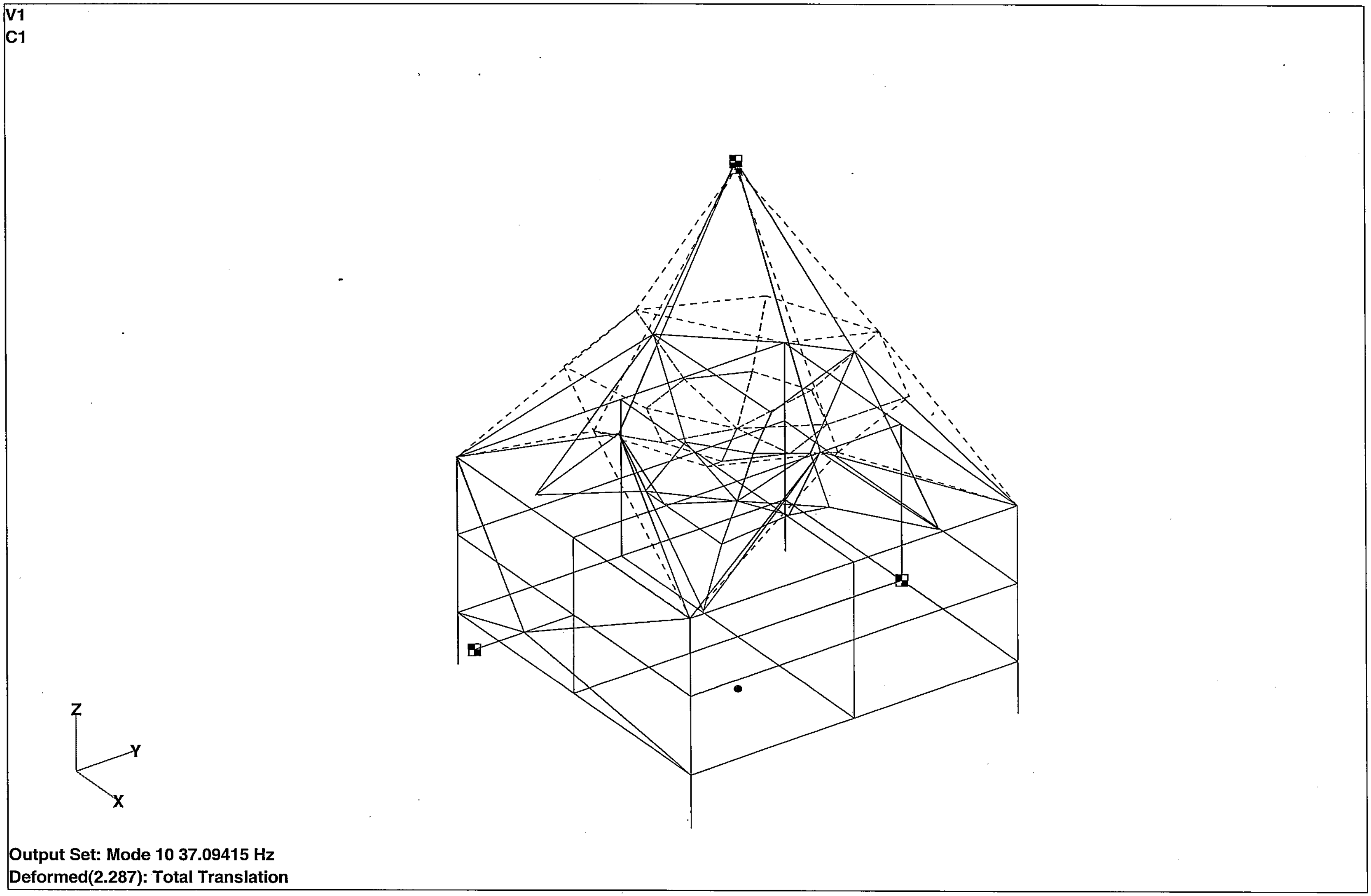


Output Set: Mode 8 25.03358 Hz
Deformed(2.212): Total Translation

V1
C1



Output Set: Mode 9 29.94975 Hz
Deformed(0.419): Total Translation


V1
C1
Z
Y
X
Output Set: Mode 10 37.09415 Hz
Deformed(2.287): Total Translation