A METHODOLOGY TO MODEL PHYSICAL CONTACT BETWEEN STRUCTURAL COMPONENTS IN NASTRAN

N94-13783

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SUMMARY

Two components of a structure which are located side by side, will come in contact by certain force and will transfer the compressive force along the contact area. If the force acts in the opposite direction, the elements will separate and no force will be transferred. If this contact is modelled, the load path will be correctly represented, and the load redistribution results in more realistic stresses in the structure. This is accomplished by using different sets of rigid elements for different loading conditions, or by creating multipoint constraint sets. Comparison of these two procedures is presented for a 4 panel unit (PU) stowage drawer installed in an experiment rack in the Spacelab Life Sciences (SLS-2) payload.

INTRODUCTION

The Spacelab is a reusable laboratory that is carried in the cargo bay of the Space Shuttle. Experiments in several different disciplines such as astronomy, life sciences, and material science are accommodated in this modular laboratory for various Shuttle missions. The experiment hardware is mounted in the experiment racks located in either side of the module, in overhead lockers, or in the center aisle, as shown in Figure 1.

4PU STOWAGE DRAWER
Configuration

The 4 Panel Unit Stowage Drawer is mounted in the experiment rack used in the SLS-2 Mission. The experiment equipment and the accessories are stowed in the drawer. The finite element model of the drawer, with its coordinate system, is shown in Figure 2. The drawer is connected to the slide with 6 screws on each slide, and the slides are connected to the rack posts. The front panel is latched to the front rack posts. Two configurations of the slides are examined.

Case 1: The contact surface is normal to the X-axis, as shown in Figure 4, which is the actual configuration. The slide shown is schematic, and not the actual slide.

Case 2: The contact surface is inclined. This is achieved by raising the slide by 12.7 mm as shown in Figure 5.

The Method of Modelling the Contact

During liftoff and landing flight events, the Shuttle and its payload are exposed to quasi-static and random loads. The +X force brings the right slide and drawer in contact. As a result, this force is transferred to the slide throughout the length of the slide and not just by the screws. When the force acts to the left (-X), the contact along the length is lost and the right slide is connected by screws only. This time the contact takes place between the left slide and the drawer.

Generally, this is modelled using rigid elements. For load case 101, which includes +X force (see Table 1), all the contacts are modelled between the right slide and the drawer, and the analysis is completed. For the load case 103, which includes -X force, contact will be modelled between the left slide and the drawer with a new set of rigid elements, removing the old set of elements, and a second analysis will be performed. This means post-processing will be performed on two output files. The rigid elements simulating contact are shown in Figure 3. These are included in the analyses, as needed.

Alternately, the contact is modelled with a multipoint constraint equation in place of the rigid element. In this method, a different set of MPC equation can be written for a different subcase, resulting in a single analysis for multiple subcases.

CASE 1. CONTACT SURFACE NORMAL TO THE GLOBAL X-AXIS

Modelling of Contact by MPC Equation

A rigid link is used to write the MPC equation, as shown in Figure 6 (ref 1.). Since the physical contact cannot resist moments, no rotations will be allowed at the end of the rigid link. In the current case, the link is horizontal, i.e., $\Delta L = \Delta X = u_1$.

The MPC equation is $u_{1A} - u_{1B} = 0$. The MPC set 1 is written for the subcase 101 to represent right slide contact, and the MPC set 2 is written for the subcase 103 to represent the left slide contact. The MPC equations and the MPC forces are shown in Table 2. The grid points shown are on the slide. Grid points 471 and 472 show forces in opposite directions, indicating tension and lack of contact. In this situation, these equations should be removed and reanalysis must be performed. In the current analysis, this is not pursued.

Modelling with CRIGD2 Elements

The elements modelled and the results for subcase 101 and subcase 103 are shown on Tables 3 and 4, respectively. The dependent degree of freedom is 1. The equation generated corresponds to row 1 of equation 56 (ref. 2) shown below.

$$
\begin{Bmatrix} u_{A_1} \\ u_{A_2} \\ u_{A_3} \\ u_{A_4} \\ u_{A_5} \\ u_{A_6} \end{Bmatrix} =
\begin{bmatrix}
1 & 0 & 0 & 0 & (z_B - z_A) & -(y_B - y_A) \\
0 & 1 & 0 & -(z_B - z_A) & 0 & (x_B - x_A) \\
0 & 0 & 1 & (y_B - y_A) & -(x_B - x_A) & 0 \\
0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 1
\end{bmatrix}
\begin{Bmatrix} u_{B_1} \\ u_{B_2} \\ u_{B_3} \\ u_{B_4} \\ u_{B_5} \\ u_{B_6} \end{Bmatrix}
, \qquad (56)
$$

In the equation, $(Z_B - Z_A)$ corresponds to Z_{AB} on Figure 6 which is zero for this case, and $(Y_B - Y_A)$ is also zero. Hence, the equations generated are the same as the MPC equations and the results from both the analyses will be identical.

Discussions of the Two Methods

As expected, the results from both of these methods are the same.

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CASE 2. CONTACT SURFACE INCLINED TO THE GLOBAL X-AXIS

Only subcase 101, which involves +X and +Z loads, will be used in the following analyses. Due to these forces, contact will be made in the X and Z directions as shown in Figure 5.

Modelling with MPC Equations

MPC equations are written to satisfy the geometry of the rigid links shown in Figure 6. As stated before, no rotation will be allowed.

Hence $\Delta L = \dfrac{X_{AB}}{L} u_1 + \dfrac{Z_{AB}}{L} u_3$ (1)

from the geometry of the inclined link in Figure 5,

X_{AB} = 18.606 mm, Z_{AB} = 12.7 mm , L= 22.527 mm

Substituting in equation (1)

ΔL = .8259 u_1 + .5638 u_3

ΔL_A = .8259 u_{1A} + .5638 u_{3A}

ΔL_B = .8259 u_{1B} + .5638 u_{3B}

to satisfy the condition $\Delta L_A - \Delta L_B$ = 0, the MPC equation is

.8259 $(u_{1A} - u_{1B})$ + .5638 $(u_{3A} - u_{3B})$ = 0   (2)

Table 5 shows all the MPC equations input for all the contacts, followed by the forces of multipoint constraint, in the grid points on the slides.

Modelling with CRIGD2 Elements

CRIGD2 are modelled with components 1 and 3 as dependent degrees of freedom to simulate the contact in X and Z directions. The constraint equations generated correspond to rows 1 and 3, in the equation 56. The term $(Z_B - Z_A)$ in row 1 and $(X_B - X_A)$ in row 3 are non-zero. These terms correspond to component 5, and it is expected that constraint moment R2 will be generated. The list of elements and the results are tabulated in Table 6.

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Modelling with CRIGDR Elements

CRIGDR elements are modelled with component 1 as the dependent degree of freedom. The remaining 5 translational components are considered as reference degrees of freedom (ref. 2). Equation 48 (ref. 2) is used in the element formulation shown below.

$$(u_{A1} - u_{B1})\, l_1 + (u_{A2} - u_{B2})\, l_2 + (u_{A3} - u_{B3})\, l_3 = 0 \qquad (48)$$

In this equation, direction cosine $l_2 = 0,\ l_1 = \dfrac{XAB}{L},\ l_3 = \dfrac{ZAB}{L}$

which essentially is MPC equation (2), and the results from this analysis will be same as from the MPC equation.

A list of the elements and the results are tabulated in Table 7.

Comparison of the Three Analyses

It is shown that the formulation of MPC equations and the CRIGDR are identical, and the results tabulated in Tables 5 and 7 are identical as expected. The CRIGD2 results are different than the other two because this involves rotations. In this instance, R2 moments are generated as expected and the Z components are off by about ±20 percent.

CONCLUSIONS

The best way to model contact is by writing MPC equations since a single analysis, is possible for multiple subcases. CRIGDR is the second choice.

REFERENCES

1. Harry G. Schaeffer: MSC/NASTRAN Primer, Static and Normal Modes Analysis, Schaeffer Analysis Inc, Mont Vernon, 1979, pp.143-145
2. The NASTRAN Theoretical Manual: NASA SP-221(06), National Aeronautics And Space Administration, Washington D.C., 1981

TABLE 1 TOTAL APPLIED FORCE ON THE STRUCTURE (NEWTONS)

DIRECTION	X	Y	Z
SUBCASE 101	1001.2	175.3	276.4
SUBCASE 103	-897.0	175.3	276.4

TABLE 2 PARTIAL INPUT AND RESULTS - CASE 1
SUBCASES 101,103 - USE OF MPC EQUATIONS

$ MPC EQUATIONS TO SIMULATE CONTACT IN X-DIR
$ FOR SUBCASE 101 CASE 1

MPC	1	454	1	1.0	1070	1	-1.0
MPC	1	471	1	1.0	1104	1	-1.0
MPC	1	472	1	1.0	1138	1	-1.0
MPC	1	473	1	1.0	1172	1	-1.0
MPC	1	474	1	1.0	1206	1	-1.0
MPC	1	475	1	1.0	1240	1	-1.0
MPC	1	476	1	1.0	1291	1	-1.0
MPC	1	477	1	1.0	1342	1	-1.0
MPC	1	478	1	1.0	1376	1	-1.0

$ MPC EQUATIONS TO SIMULATE CONTACT IN -X-DIR
$ FOR SUBCASE 103 CASE 1

MPC	2	5454	1	1.0	6070	1	-1.0
MPC	2	5471	1	1.0	6104	1	-1.0
MPC	2	5472	1	1.0	6138	1	-1.0
MPC	2	5473	1	1.0	6172	1	-1.0
MPC	2	5474	1	1.0	6206	1	-1.0
MPC	2	5475	1	1.0	6240	1	-1.0
MPC	2	5476	1	1.0	6291	1	-1.0
MPC	2	5477	1	1.0	6342	1	-1.0
MPC	2	5478	1	1.0	6376	1	-1.0

F O R C E S   O F   M U L T I - P O I N T   C O N S T R A I N T

SUBCASE 101   CASE 1

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
471	G	2.000663E+00	0.0	0.0	0.0	0.0	0.0
472	G	9.827873E-01	0.0	0.0	0.0	0.0	0.0
473	G	-2.369567E-01	0.0	0.0	0.0	0.0	0.0
474	G	-8.407188E-01	0.0	0.0	0.0	0.0	0.0
475	G	-4.436086E+00	0.0	0.0	0.0	0.0	0.0
476	G	-5.899112E+00	0.0	0.0	0.0	0.0	0.0
477	G	-2.644422E+00	0.0	0.0	0.0	0.0	0.0
478	G	-4.057768E+00	0.0	0.0	0.0	0.0	0.0

SUBCASE 103   CASE 1

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
5471	G	-1.609514E+00	0.0	0.0	0.0	0.0	0.0
5472	G	-7.575473E-01	0.0	0.0	0.0	0.0	0.0
5473	G	3.009112E-01	0.0	0.0	0.0	0.0	0.0
5474	G	8.103580E-01	0.0	0.0	0.0	0.0	0.0
5475	G	3.798277E+00	0.0	0.0	0.0	0.0	0.0
5476	G	4.936887E+00	0.0	0.0	0.0	0.0	0.0
5477	G	2.151909E+00	0.0	0.0	0.0	0.0	0.0
5478	G	3.283999E+00	0.0	0.0	0.0	0.0	0.0

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        TABLE 3 PARTIAL INPUT AND RESULTS - CASE 1
           SUBCASE 101 - USE OF CRIGD2 ELEMENTS
$ RIGID ELEMENTS MODELED TO SIMULATE CONTACT IN X-DIR
$ FOR LOADCASE 101   CASE 1
CRIGD2         480     454    1070        1
CRIGD2         481     471    1104        1
CRIGD2         482     472    1138        1
CRIGD2         483     473    1172        1
CRIGD2         484     474    1206        1
CRIGD2         485     475    1240        1
CRIGD2         486     476    1291        1
CRIGD2         487     477    1342        1
CRIGD2         488     478    1376        1


SUBCASE 101                    CASE1
F O R C E S    O F   M U L T I - P O I N T   C O N S T R A I N T

POINT ID.    TYPE          T1          T2     T3     R1     R2     R3
      471     G        2.000663E+00   0.0    0.0    0.0    0.0    0.0
      472     G        9.827873E-01   0.0    0.0    0.0    0.0    0.0
      473     G       -7.369567E-01   0.0    0.0    0.0    0.0    0.0
      474     G       -8.407188E-01   0.0    0.0    0.0    0.0    0.0
      475     G       -4.436086E+00   0.0    0.0    0.0    0.0    0.0
      476     G       -5.899112E+00   0.0    0.0    0.0    0.0    0.0
      477     G       -2.644422E+00   0.0    0.0    0.0    0.0    0.0
      478     G       -4.057767E+00   0.0    0.0    0.0    0.0    0.0

       TABLE 4 PARTIAL INPUT AND RESULTS -CASE 1
          SUBCASE 103 - USE OF CRIGD2 ELEMENTS
$ RIGID ELEMENTS MODELED TO SIMULATE CONTACT IN -X-DIR
$ FOR SUBCASECASE 103  CASE 1
CRIGD2        5480    5454    6070        1
CRIGD2        5481    5471    6104        1
CRIGD2        5482    5472    6138        1
CRIGD2        5483    5473    6172        1
CRIGD2        5484    5474    6206        1
CRIGD2        5485    5475    6240        1
CRIGD2        5486    5476    6291        1
CRIGD2        5487    5477    6342        1
CRIGD2        5488    5478    6376        1


F O R C E S    O F   M U L T I - P O I N T   C O N S T R A I N T
POINT ID.    TYPE          T1          T2     T3     R1     R2     R3
     5471     G       -1.609514E+00   0.0    0.0    0.0    0.0    0.0
     5472     G       -7.575473E-01   0.0    0.0    0.0    0.0    0.0
     5473     G        3.009112E-01   0.0    0.0    0.0    0.0    0.0
     5474     G        8.103580E-01   0.0    0.0    0.0    0.0    0.0
     5475     G        3.798277E+00   0.0    0.0    0.0    0.0    0.0
     5476     G        4.936887E+00   0.0    0.0    0.0    0.0    0.0
     5477     G        2.151909E+00   0.0    0.0    0.0    0.0    0.0
     5478     G        3.283999E+00   0.0    0.0    0.0    0.0    0.0
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TABLE 5 PARTIAL INPUT AND RESULTS -CASE 2
SUBCASE 101 - USE OF MPC EQUATIONS

```
$ MPC EQUATIONS TO SIMULATE CONTACT IN X AND Z DIR
$ FOR SUBCASE 101 CASE 2 (INCLINED SURFACE)
MPC          1    454     1  0.8259    1070     1 -0.8259        +MPC1
+MPC1             454     3  0.5638    1070     3 -0.5638
MPC          1    471     1  0.8259    1104     1 -0.8259        +MPC2
+MPC2             471     3  0.5638    1104     3 -0.5638
MPC          1    472     1  0.8259    1138     1 -0.8259        +MPC3
+MPC3             472     3  0.5638    1138     3 -0.5638
MPC          1    473     1  0.8259    1172     1 -0.8259        +MPC4
+MPC4             473     3  0.5638    1172     3 -0.5638
MPC          1    474     1  0.8259    1206     1 -0.8259        +MPC5
+MPC5             474     3  0.5638    1206     3 -0.5638
MPC          1    475     1  0.8259    1240     1 -0.8259        +MPC6
+MPC6             475     3  0.5638    1240     3 -0.5638
MPC          1    476     1  0.8259    1291     1 -0.8259        +MPC7
+MPC7             476     3  0.5638    1291     3 -0.5638
MPC          1    477     1  0.8259    1342     1 -0.8259        +MPC8
+MPC8             477     3  0.5638    1342     3 -0.5638
MPC          1    478     1  0.8259    1376     1 -0.8259        +MPC9
+MPC9             478     3  0.5638    1376     3 -0.5638
```

SUBCASE 101   CASE 2 (INCLINED SURFACE)
F O R C E S   O F   M U L T I - P O I N T   C O N S T R A I N T

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
471	G	2.349882E+00	0.0	1.604145E+00	0.0	0.0	0.0
472	G	1.092854E+00	0.0	7.460357E-01	0.0	0.0	0.0
473	G	1.307303E+00	0.0	8.924297E-01	0.0	0.0	0.0
474	G	-1.051737E+00	0.0	-7.179675E-01	0.0	0.0	0.0
475	G	-4.542925E+00	0.0	-3.101224E+00	0.0	0.0	0.0
476	G	-6.415951E+00	0.0	-4.379844E+00	0.0	0.0	0.0
477	G	-2.202427E+00	0.0	-1.503485E+00	0.0	0.0	0.0
478	G	-3.147465E+00	0.0	-2.148615E+00	0.0	0.0	0.0

TABLE 6 PARTIAL INPUT AND RESULTS - CASE 2
      SUBCASE 101 - USE OF CRIGD2 ELEMENTS
$ RIGID ELEMENTS MODELED TO CONTACT IN X AND Z-DIR
$ DUE SUBCASE 101 CASE 2

CRIGD2	480	454	1070	13
CRIGD2	481	471	1104	13
CRIGD2	482	472	1138	13
CRIGD2	483	473	1172	13
CRIGD2	484	474	1206	13
CRIGD2	485	475	1240	13
CRIGD2	486	476	1291	13
CRIGD2	487	477	1342	13
CRIGD2	488	478	1376	13

SUBCASE 101   CASE 2 (INCLINED SURFACE)
F O R C E S   O F   M U L T I - P O I N T   C O N S T R A I N T

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
471	G	2.494523E+00	0.0	2.121828E+00	0.0	3.069774E-01	0.0
472	G	1.101543E+00	0.0	9.281644E-01	0.0	1.291067E-01	0.0
473	G	1.320337E+00	0.0	5.013174E-01	0.0	-2.929534E-01	0.0
474	G	-1.060023E+00	0.0	-5.814678E-01	0.0	1.040862E-01	0.0
475	G	-4.534455E+00	0.0	-2.838911E+00	0.0	1.877255E-01	0.0
476	G	-6.437643E+00	0.0	-3.742413E+00	0.0	4.775038E-01	0.0
477	G	-2.220512E+00	0.0	-1.282993E+00	0.0	1.704635E-01	0.0
478	G	-3.182428E+00	0.0	-1.670981E+00	0.0	3.672205E-01	0.0

     TABLE 7 PARTIAL INPUT AND RESULTS CASE 2
      SUBCASE 101 -USE OF CRIGDR ELEMENTS
$ RIGID ELEMENTS TO SIMULATE CONTACT IN X AND Z -DIR
$ FOR SUBCASE 101 CASE 2 (INCLINED SURFACE)

CRIGDR	480	454	1070	1
CRIGDR	481	471	1104	1
CRIGDR	482	472	1138	1
CRIGDR	483	473	1172	1
CRIGDR	484	474	1206	1
CRIGDR	485	475	1240	1
CRIGDR	486	476	1291	1
CRIGDR	487	477	1342	1
CRIGDR	488	478	1376	1

SUBCASE 101   CASE 2 (INCLINED PLANE)
F O R C E S   O F   M U L T I - P O I N T   C O N S T R A I N T

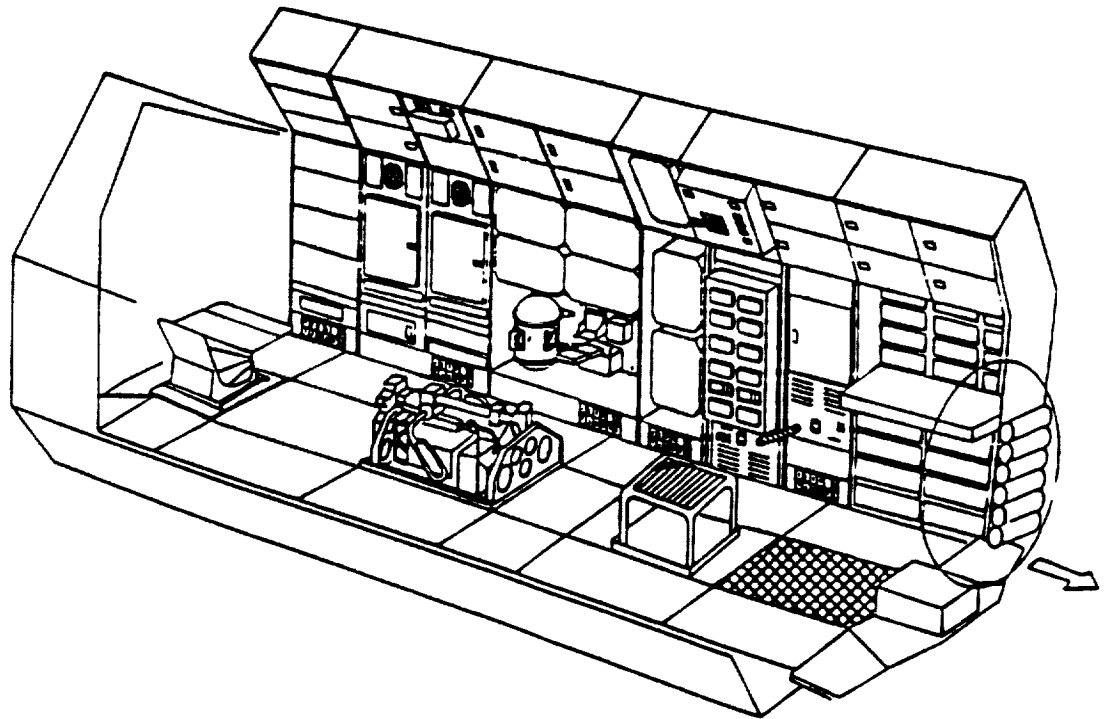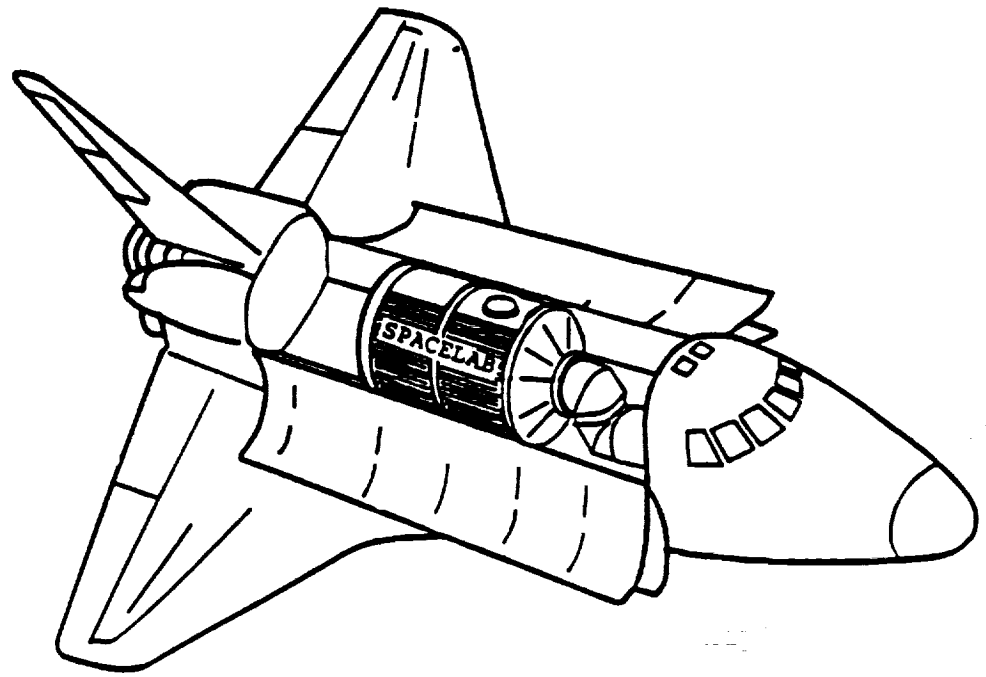| POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
471	G	2.378163E+00	0.0	1.623320E+00	0.0	0.0	0.0
472	G	1.119243E+00	0.0	7.639883E-01	0.0	0.0	0.0
473	G	1.316421E+00	0.0	8.985810E-01	0.0	0.0	0.0
474	G	-1.053347E+00	0.0	-7.190084E-01	0.0	0.0	0.0
475	G	-4.543006E+00	0.0	-3.101028E+00	0.0	0.0	0.0
476	G	-6.414644E+00	0.0	-4.378596E+00	0.0	0.0	0.0
477	G	-2.183337E+00	0.0	-1.490333E+00	0.0	0.0	0.0
478	G	-3.126624E+00	0.0	-2.134214E+00	0.0	0.0	0.0

FIG. 1.   TYPICAL SPACELAB CONFIGURATION

SDRC I-DEAS 4.0: Pre/Post Processing
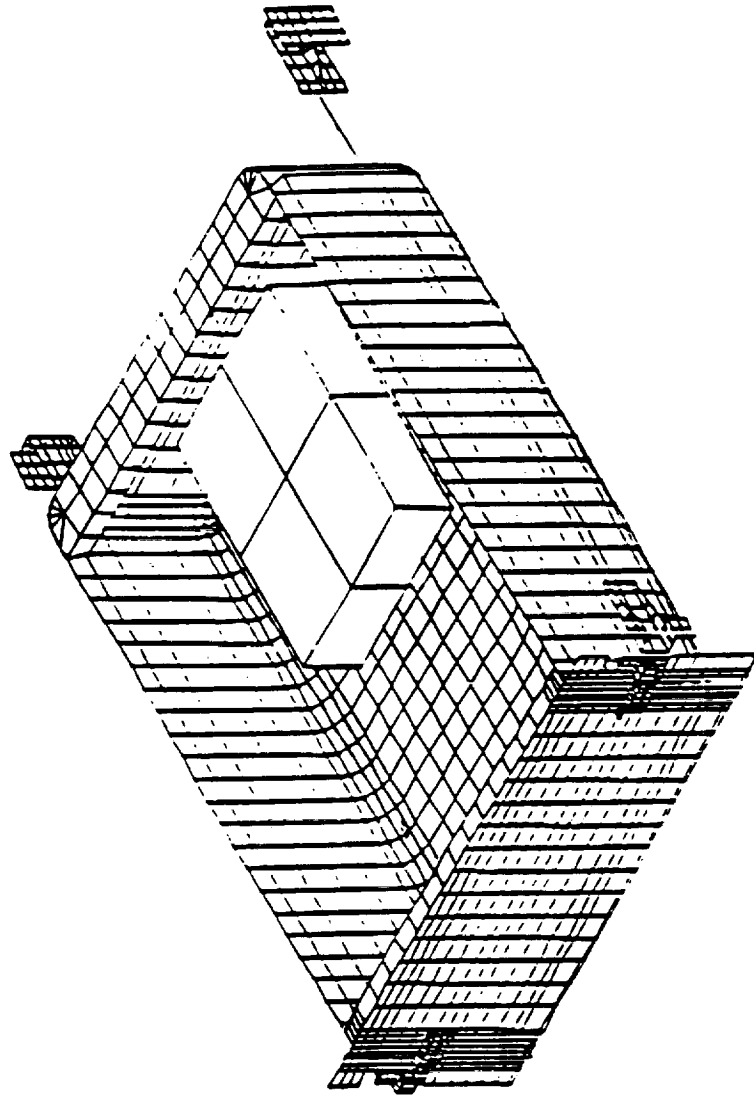
4PU STOWAGE DRAW R ASSEMBLY
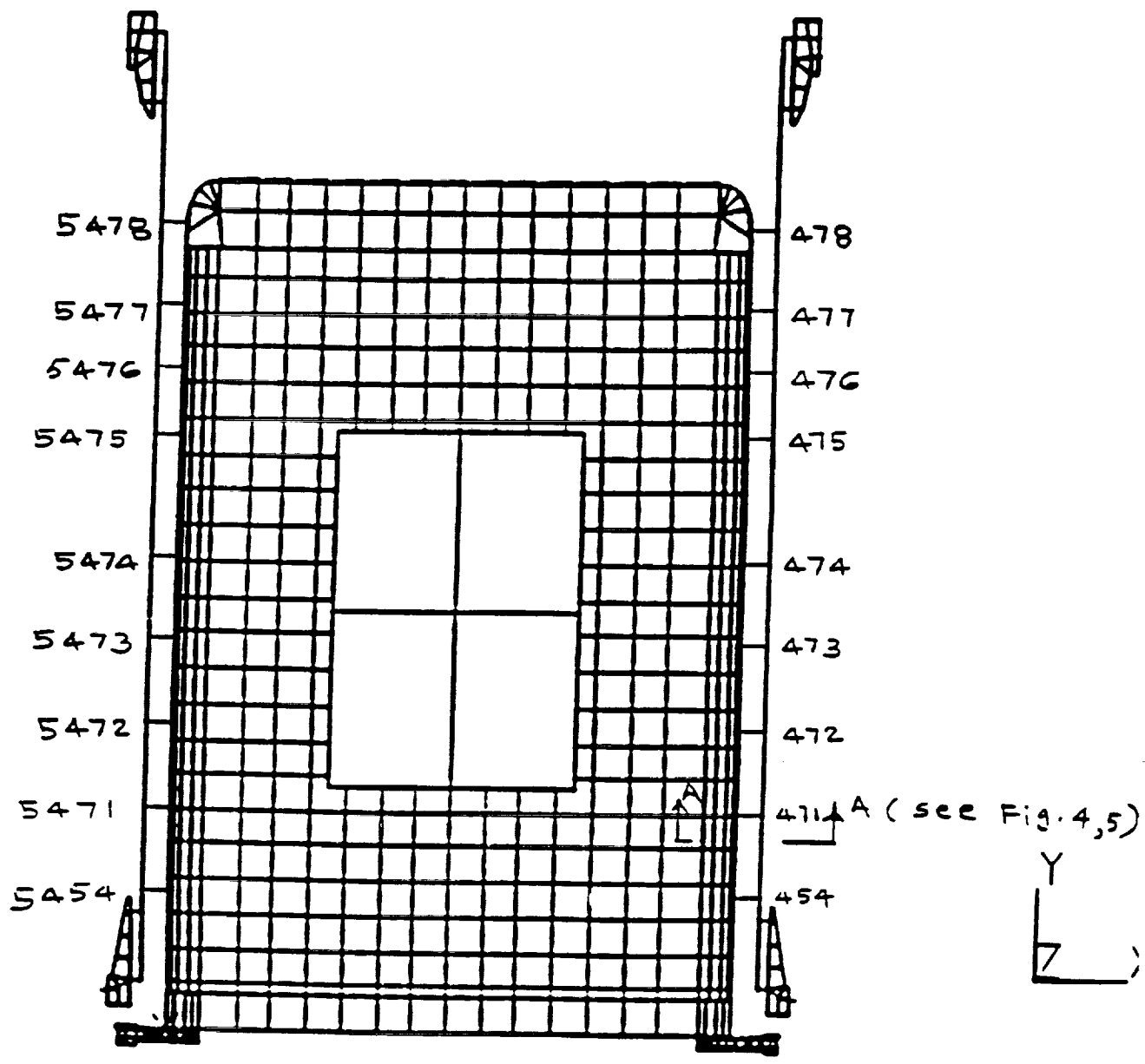
FIG. 2 FINITE ELEMENT MODEL

FIG 3. PLAN VIEW SHOWING RIGID ELEMENTS
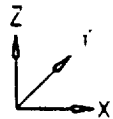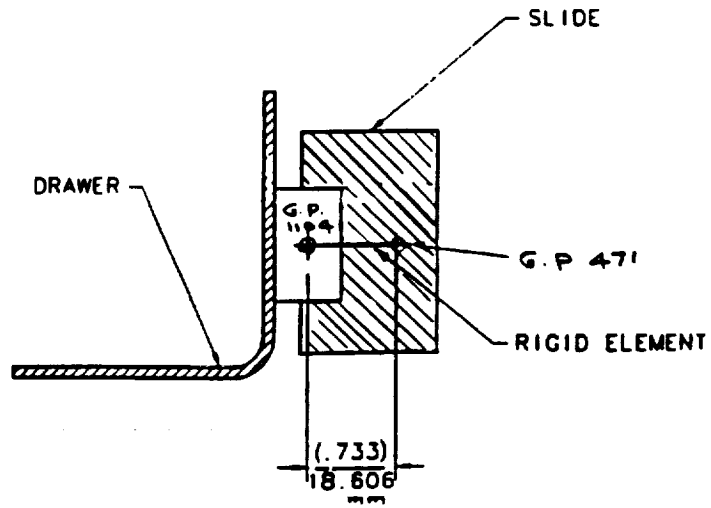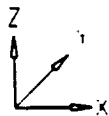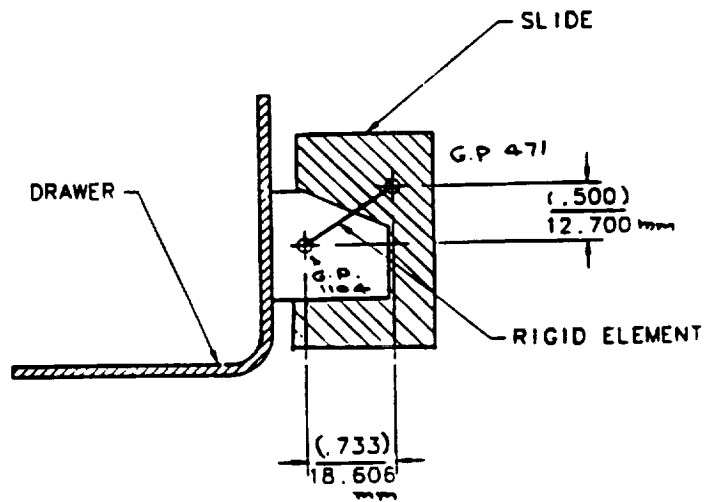CONNECTING DRAWER TO SLIDE
(The numbers shown are grid points on the slide)

FIG. 4 SECTION A-A FOR CASE 1

FIG. 5 SECTION A-A FOR CASE 2

FIG. 6 PLANAR RIGID LINK

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