ALMA Memo No. 559
Thermal Deformation of Shaped Carbon Fiber-Aluminum Core Sandwiched Structures(III)

Jingquan Cheng
NRAO, Oct. 2006
jcheng@nrao.edu

ROAD MAP
FOR MEMOS 557,558, and 559

Early in 2000, one type of ALMA antenna BUS design was proposed which involved a channel shaped carbon fiber aluminum honeycore sandwiched structure. This type of structure will change its shape as the temperature changes. For verifying this thermal shape change problem, three internal memos were produced in Aug. 2000. These were reproduced here as ALMA Memo Nos. 557, 558 and 559. Memo No. 557 is the first memo which provides theoretical derivation as well as a simple finite element analysis. The memo pointed out that if the channel width is 1m, the surface deformation will be 33 um. The FEA analysis uses a coarse element size. Memo No. 558 is a refined analysis with different constraint conditions. The analysis results are consistent with the first memo. Memo No. 559 is a detailed analysis of the corner problem area. This corner area has high stress concentration, complex strain, and is the main reason for the shape change of the top surface.

In Sept, 2001, a BUS section was tested to verify its thermal performance. After the test data were processed, an internal report was produced. The title of the report is: Antenna BUS Thermal Test Evaluation Report. In this report, test data were used to check the predictions of the early memos. An estimation of the antenna surface deformation was also made from the measurement. If the early BUS design was used, the surface rms error could reach 28 um. The report also provided the explanation of the adjuster's preload change as temperature changes. The internal stress level between the BUS and the panels were also estimated. The highest internal force between panel and BUS may reach 50,000N when temperature change is large.

After these analyses, the sandwiched BUS structure design was modified. In the modified design, the stress of the corner part is absorbed. The top surface has little thermal deformation. These modified ALMA BUS structures were also applied to APEX and the South Pole Sub-millimeter Telescope. As these memos and this report played an important role in ALMA antenna design, these memos are reproduced as they were. The report remains out of public domain. However, astronomers could request the report with conditions.

Thermal Deformation of Shaped Carbon Fiber-Aluminium Core Sandwiched Structures(III)

Jingquan Cheng
National Radio Astronomy Observatory

August, 2000

Abstract

Thermal deformation of an L-shaped structures is discussed in detail. Two different approximations have been made in estimating the angular change of the structure. The first order approximation formulae give upper and lower limits of the angular change, while the second order approximation gives a better estimate. The computer analysis also shows that the deformation is support condition dependent.

1 Introduction

In the previous report, Thermal Deformation of Shaped Carbon Fiber-Aluminium Core Sandwiched Structures, an L-shaped structure has been treated in the same way as the T-shaped structure. This is a first order approximation to the complex deformation problem. In that report, it stated that the angular effect from the h dimension change has been neglected. However, there is no further discussion on this issue. In this report, the deformation problem of the L-shaped structure is discussed in details. Different approximations of this problem will be presented. This discussion together with finite element results will help us in estimating the angular change of this L-shaped sandwiched structure more accurately.

2 First order approximation of the deformation problem for the L-shaped structure

The new Figure 2(a) shows an L-shaped structure and its dimensions. Figure 2(b) is the deformed shape after the temperature increases. For calculating the angluar change θ, the first order approximation is by assuming only one dimension of the structure being changed after the temperature increases. In Figure 2(a), the corner ABCD is a perfect rectangular block. After the temperature increases, the corner could be treated as a new block ABCD in Figure 2(c1). In this block, the right angle A remains unchanged. The height change of BC is neglected. The deformed θ value could be derived as:

$$\theta_1 = \frac{d * \alpha_{Al} * \Delta T}{h}$$

If $d = 0.02m$, $h = 0.072m$, $\theta_1 = 6.66X10^{-5}rad$ for 10 degrees C change. As shown in the previous report, this value agrees with the results of the finite element analysis. However, This approximation has a problem. For the same L-shaped structure, If we examine it from its rotated mirror view, the h side is now replaced by d side. The rectangular block ABCD now looks as ADCB in Figure 2(c2). The resultant angular change would be:

$$\theta_2 = \frac{h * \alpha_{Al} * \Delta T}{d}$$

The value θ_1 and θ_2 are not the same if d and h is not the same. For the previous example, the angles θ_2 will be $(\frac{h}{d})^2 = 12.96$ times as the value of θ_1. $\theta_2 = 8.64X10^{-4}rad$. The θ_2 number is not close to the computer finite element analysis results. The reason of this could be found from Figure 2(b). After the temperature increases, the top surface is lifted up by an amount $\Delta h = h * \alpha_{Al} * \Delta T$. The AB section is no longer aligned with the rest of the top surface. At the same time, when the angle change θ_1 is calculated, the side AD would be pulled towards the right an amount than that of side AB. This can be found from the finite element analysis in the later section. If $h = d$, then $\theta_1 = \theta_2$. By using the first order approximation, we should use either the θ_1 value or θ_2 value, we do not need to add these two numbers together. When $h = d$, the first order approximation gives an upper limit of the deformation. When $h > d$, then the θ_1 value gives a better, and smaller, estimate of the deformation.

3 Second order approximation of the deformation problem for the L-shaped structure

The second order approximation of this problem is shown in Figure 2(d). In this approximation, the right angle A is no longer fixed, the only constraint is that both angles B and D remain at right angles after the temperature changes. This agrees with the small deformation theory of thermal expansion. In the same time, both BC and CD have been expanded by an exact amount. The angular change θ of this second order approximation is:

$$\theta = \frac{\pi}{2} - arctan(\frac{d}{h + \Delta h}) - arctan(\frac{h}{d + \Delta d})$$

where $\Delta d = d * \alpha_{Al} * \Delta T$. For the same example, the calculated θ value is now $1.23X10^{-4} rad$. This is about 1.8 times the θ_1 value. Considering the underestimation of the top surface deformation in the channel structure by using the θ_1 prediction, this second order approximation is close to the real angle change of the structure.

The next approximation should consider the bending of BC and CD edges(ref Figure 2(e)). This could be found from the area expansion result. In Figure 2(d), the area of ABCD is $d * h * (1 + \alpha_{Al} * \Delta T)$. This is smaller than the free expansion number of $d * h * (1 + \alpha_{Al} * \Delta T)^2$. Both edges BC and CD may bend outwards. This could be calculated by the balance of the internal forces. However the sides AB and AD may not remain straight lines when the temperature increases. Therefore this further approximation is not so easy.

4 Computer analysis of the L-shaped structure deformation problem

A simple model has been made for assessing the deformation problem. The model is shown in Figure 3. In the model, plate elements are made of aluminum honeycomb and the yellow beam elements are made of CFRP material. The properties used is similar to the previous report. Following the Figure 2 notations, $d = 0.02m$ and $h = 0.072m$. An analysis has been performed for two different holding conditions. Firstly, we hold grid 2 in all degrees of freedom and hold grid 7 in all degrees except the x direction. The result is shown in Figure 4. The result is made by increasing the temperature by 20 degrees. The θ angle for 10 degrees is $3.3X10^{-4} rads$. In the second case, we hold grid 110 in all degrees of freedom and hold 131 in all except the y direction and increase the temperature 20 degrees, the result is shown in Figure 5. The θ angle for 10 degrees is $4.8X10^{-4} rads$. In the finite element analysis, the AB side in the second holding condition had an obvious tilt effect as we discussed in the previous sections(Figure 5). This effect dose not appear in the first holding condition(Figure 4). From Figure 5, it could be found that the thick side has a larger deformation than the thin one.

5 Conclusion

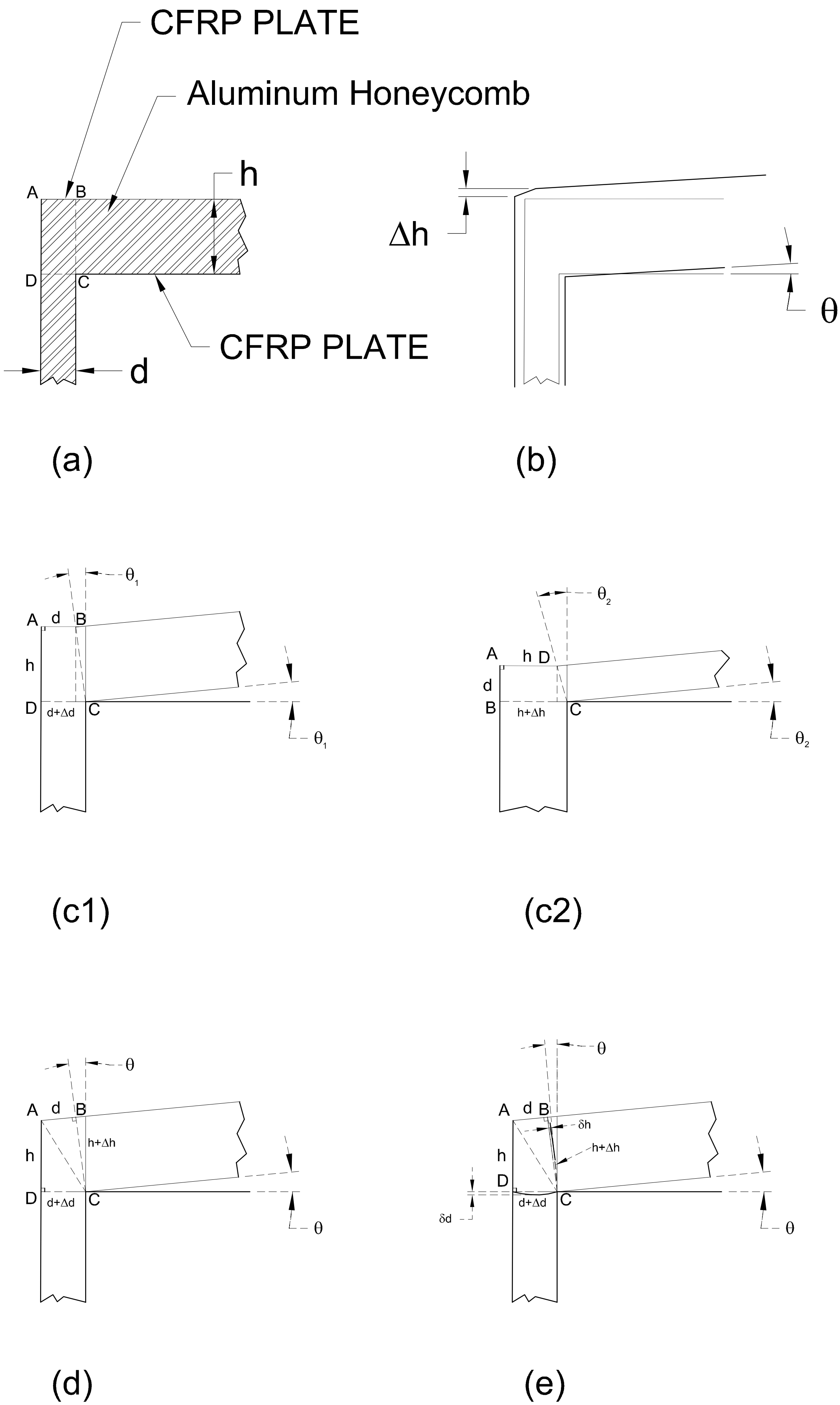
The L-shaped sandwich structure has a thermal deformation problem. This report gives two different approximations. The first approximation defines a range of the deformed angular change. The second approximation gives a better estimation. However, the real situation of the L-shaped structure is complex. The computer results show that different holding conditions have different effects on the actual angular changes of the structure.

Jeff Kingsley has recommended a number of constraint conditions in Thermal Deformation of Shaped Carbon Fiber-Aluminium Core Sandwiched Structures(II) and Victor Gasho helped in figures.

Note: this part of the report does not have a Figure 1.

6 Reference

Cheng, Jingquan, Thermal Deformation of Shaped Carbon Fiber-Aluminium Core Sandwiched Structures, NRAO, 2000.



CFRP PLATE
Aluminum Honeycomb
A
B
h
D
C
CFRP PLATE
d
Δh
θ
(a)
(b)
θ1
A
d
B
h
D
d+Δd
C
θ1
θ2
A
h
D
d
B
h+Δh
C
θ2
(c1)
(c2)
θ
A
d
B
h+Δh
h
D
d+Δd
C
θ
θ
A
d
B
δh
h+Δh
h
D
δd
d+Δd
C
θ
(d)
(e)

Figure 2

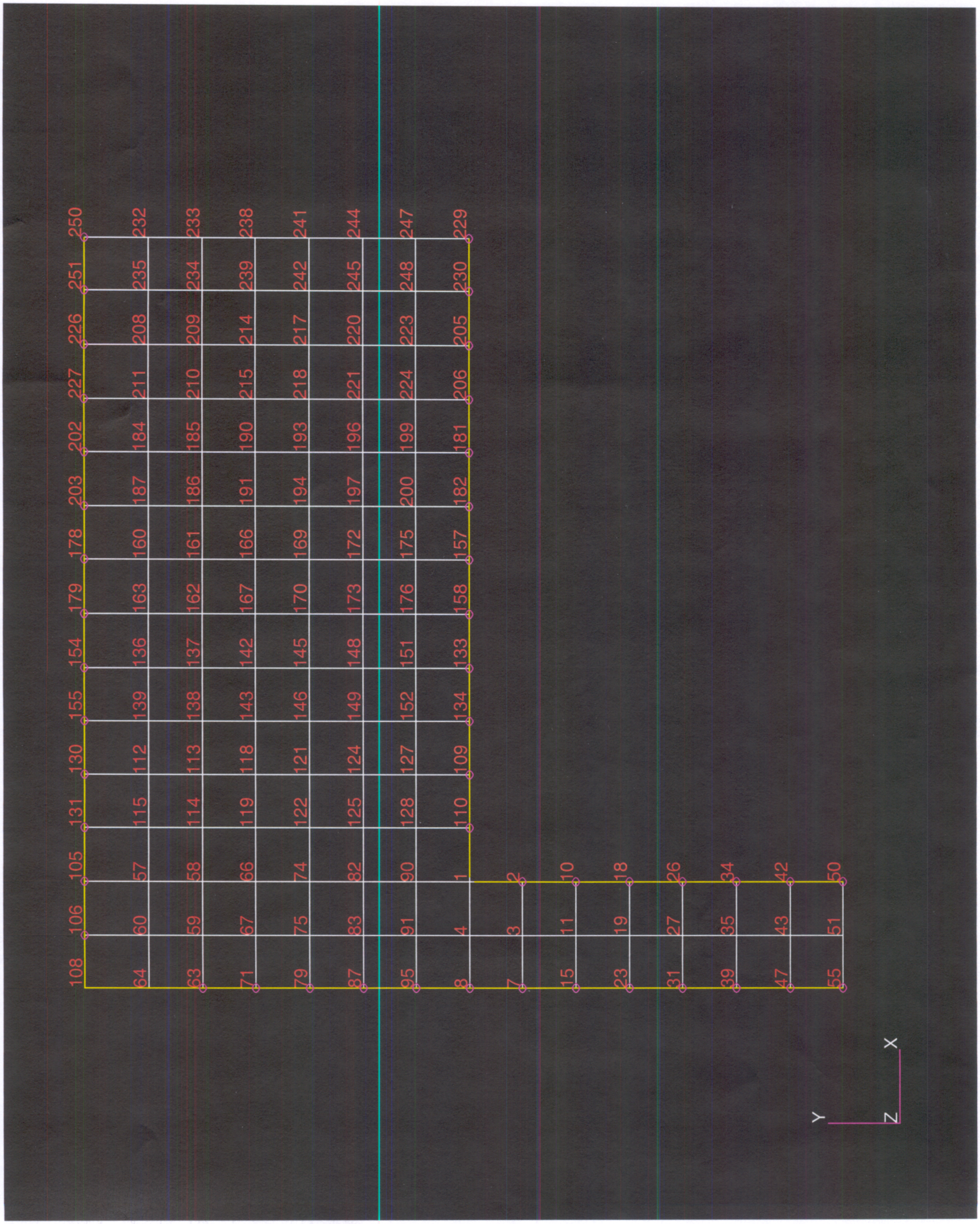
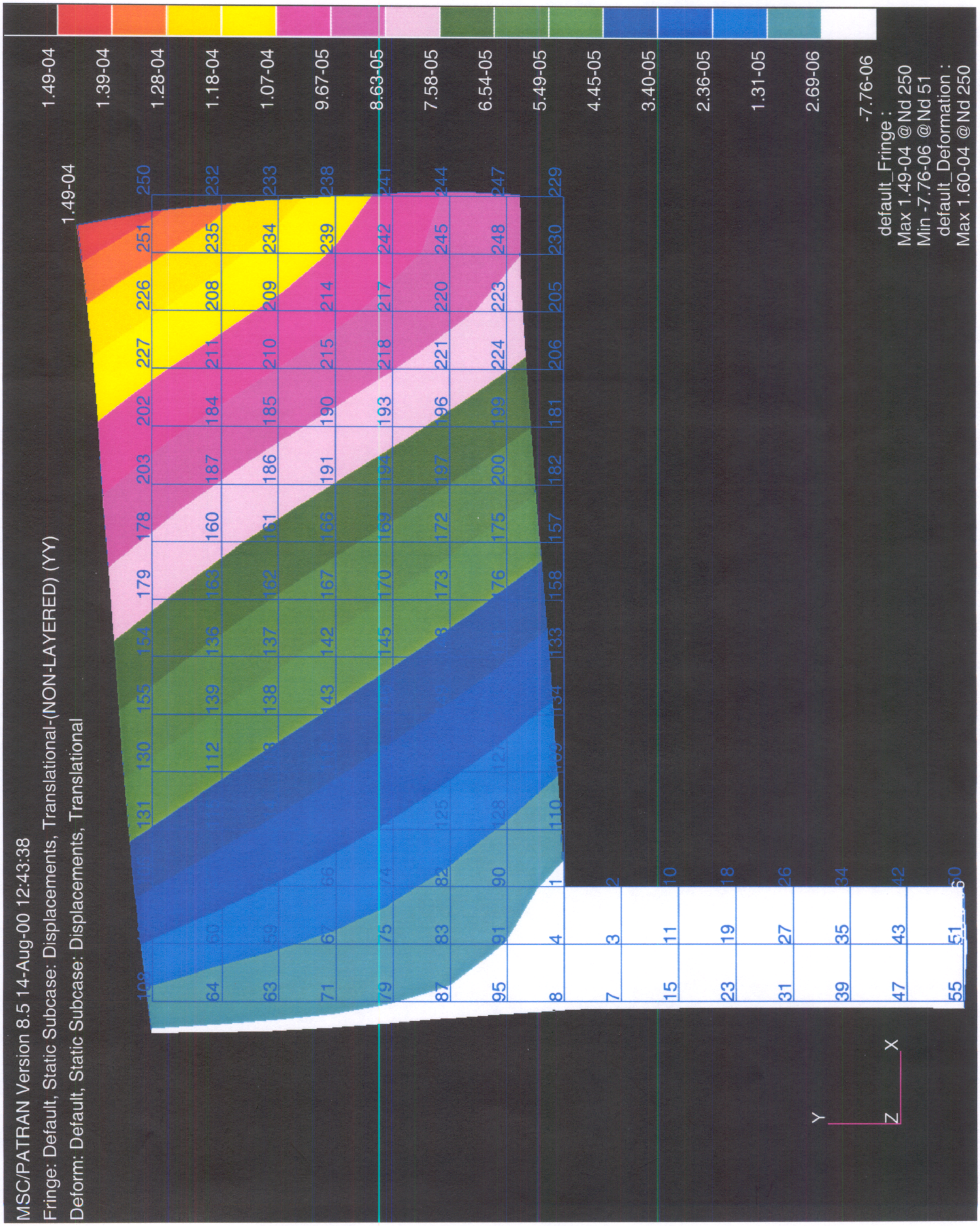

250 251 226 227 202 203 178 179 154 155 130 131 105 106 108
232 235 208 211 184 187 160 163 136 139 112 115 57 60 64
233 234 209 210 185 186 161 162 137 138 113 114 58 59 63
238 239 214 215 190 191 166 167 142 143 118 119 66 67 71
241 242 217 218 193 194 169 170 145 146 121 122 74 75 79
244 245 220 221 196 197 172 173 148 149 124 125 82 83 87
247 248 223 224 199 200 175 176 151 152 127 128 90 91 95
229 230 205 206 181 182 157 158 133 134 109 110 1 4 8
2 3 7
10 11 15
18 19 23
26 27 31
34 35 39
42 43 47
50 51 55
X
Y
Z

FIGURE 3



MSC/PATRAN Version 8.5 14-Aug-00 12:43:38
Fringe: Default, Static Subcase: Displacements, Translational-(NON-LAYERED) (YY)
Deform: Default, Static Subcase: Displacements, Translational
1.49-04
1.39-04
1.28-04
1.18-04
1.07-04
9.67-05
8.63-05
7.58-05
6.54-05
5.49-05
4.45-05
3.40-05
2.36-05
1.31-05
2.69-06
-7.76-06
default_Fringe :
Max 1.49-04 @Nd 250
Min -7.76-06 @Nd 51
default_Deformation :
Max 1.60-04 @Nd 250
Y
Z
X

FIGURE 4

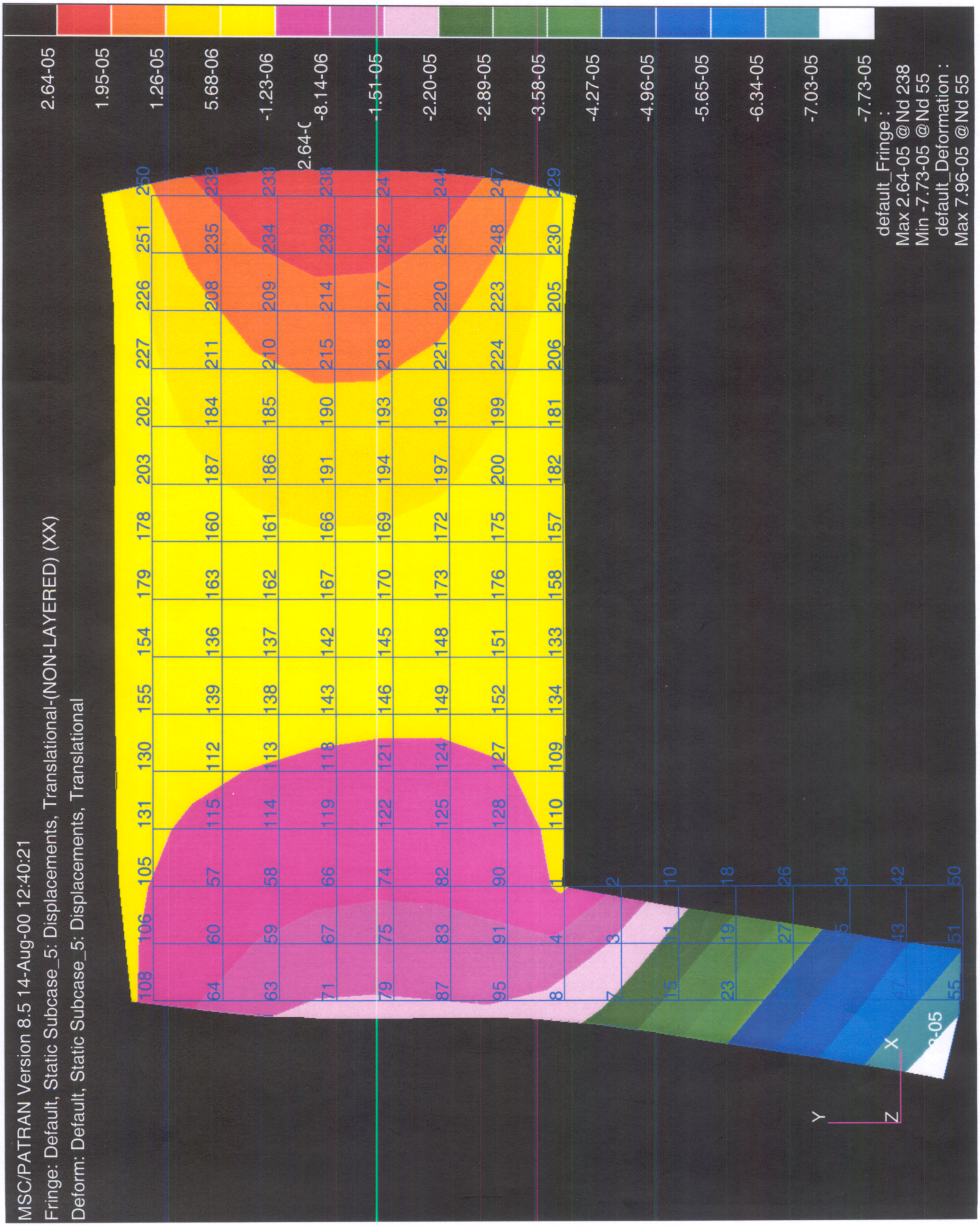

MSC/PATRAN Version 8.5 14-Aug-00 12:40:21
Fringe: Default, Static Subcase_5: Displacements, Translational-(NON-LAYERED) (XX)
Deform: Default, Static Subcase_5: Displacements, Translational
2.64-05
1.95-05
1.26-05
5.68-06
-1.23-06
-8.14-06
-1.51-05
-2.20-05
-2.89-05
-3.58-05
-4.27-05
-4.96-05
-5.65-05
-6.34-05
-7.03-05
-7.73-05
default_Fringe :
Max 2.64-05 @Nd 238
Min -7.73-05 @Nd 55
default_Deformation :
Max 7.96-05 @Nd 55
Y
Z
X

FIGURE 5