Fermilab

Particle Physics Division
Mechanical Department Engineering Note

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Project Internal Reference: 425-2.9.1.4 Ash River Block Pivoter

Project: NOvA

Title: Maximum CG Variance in a Far Detector Block

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Key Words: NOvA, Far Detector, Block Pivoter, CG

Applicable Codes:

Abstract Summary: The following note calculates the maximum variance of the center of gravity in a Far Detector block on the pivoter table.

Introduction and Discussion

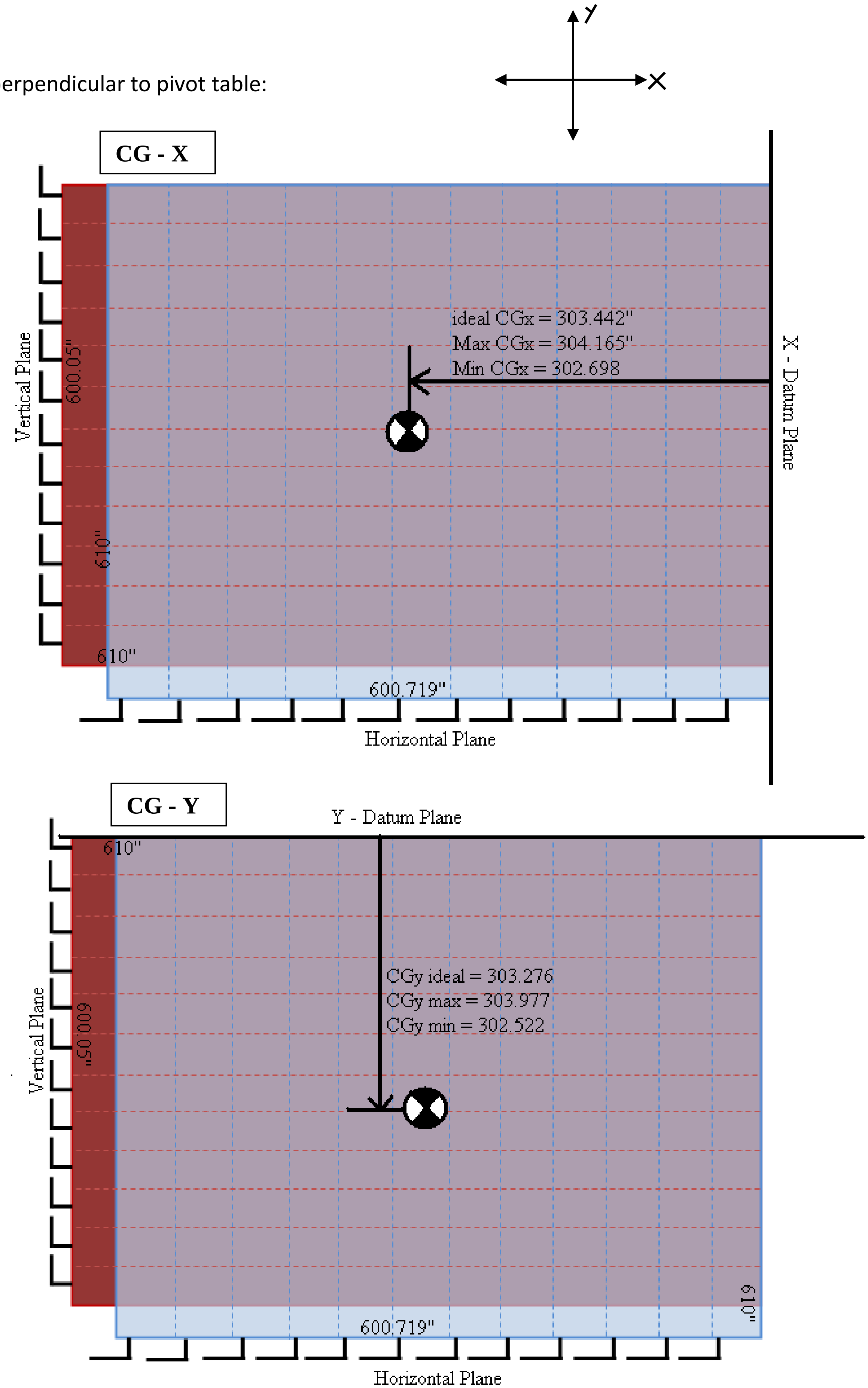
The maximum variance of the center of gravity in a Far Detector block on the pivitor table was calculated in MathCAD separately for the x, y, and z directions based on a minimum and maximum extrusion weight.

- Extrusion weight range (based on Rich Talaga's conversation with Dave Pushka):
  - Minimum extrusion weight = 505 lbs
  - Maximum extrusion weight = 515 lbs
- Manifold assembly weight (based on an email from Zeb Krahn to Don Friend): 5 lbs

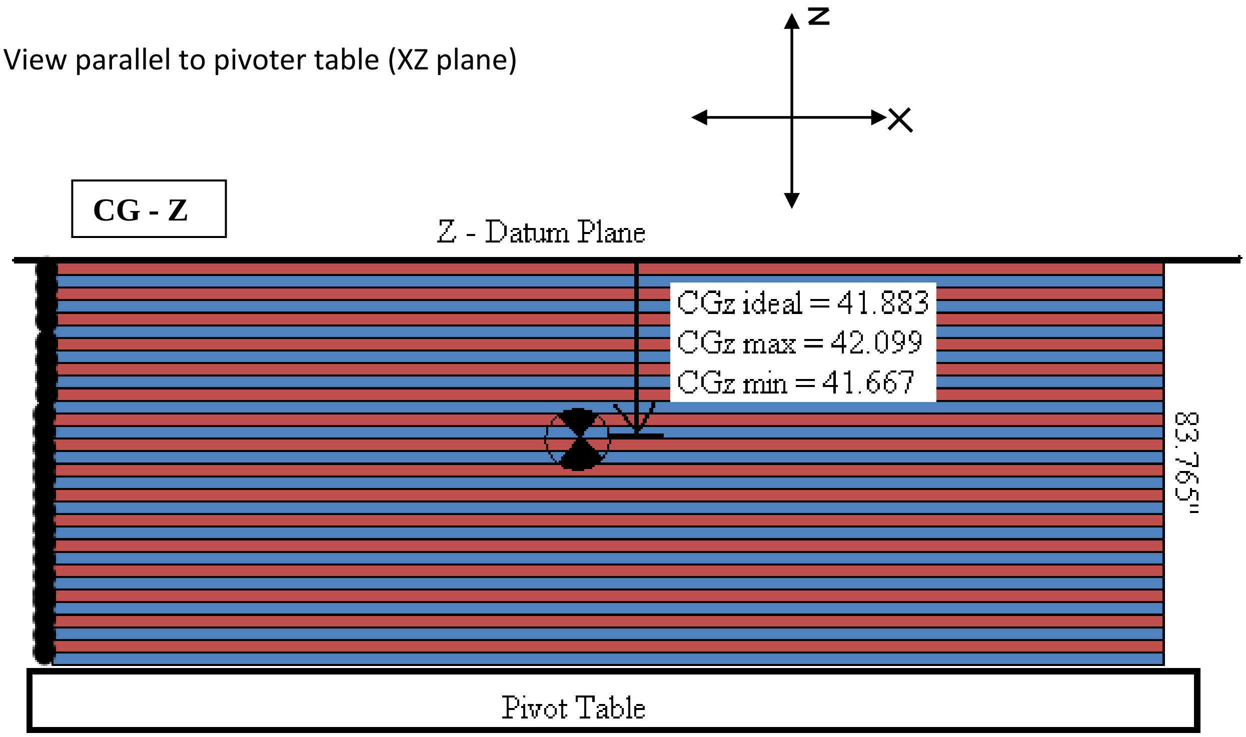
First the ideal CG was computed, meaning the location of the center of gravity if all planes were at the minimum weight. Next the CG was computed for the most extreme situations.

- Situation for maximum CG variance (*see illustrations on next page for clarification*):
  - X direction:
    - Vertical modules: All at minimum weight
    - Horizontal modules: A full half in a plane (6) are at maximum weight, and the other full half are at minimum weight
  - Y direction:
    - Vertical modules: A full half in a plane (6) are at maximum weight, and the other full half are at minimum weight
    - Horizontal modules: All at minimum weight
  - Z direction
    - The top 8 horizontal and vertical planes are at maximum weight, and the bottom 8 horizontal and vertical planes are at minimum weight

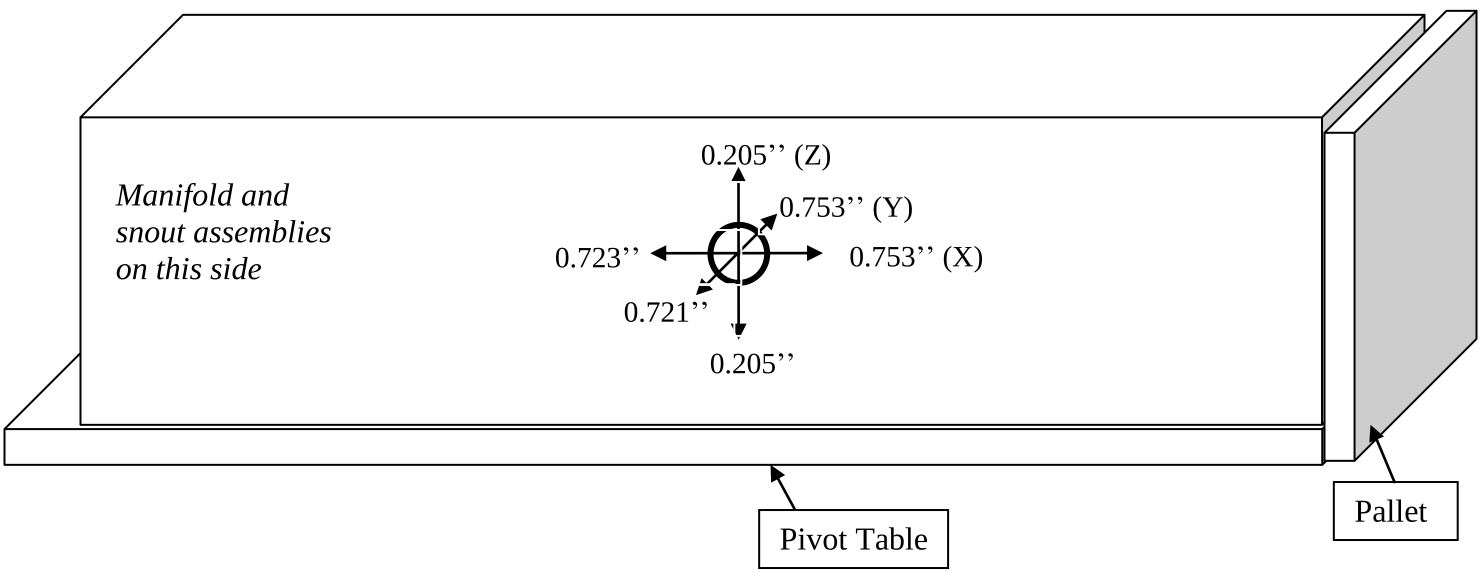
View perpendicular to pivot table:



View parallel to pivoter table (XZ plane)



Summary Table	Range (from datum's specified in pictures above)	Variance	
CG – X	302.689'' – 304.165''	+0.753'', – 0.723''	1.476'' total X variance
CG – Y	302.522'' – 303.997''	+0.721, – 0.753''	1.474'' total Y variance
CG – Z	41.667'' – 42.099''	+ or – 0.205''	0.205'' total Z variance



Beginning of MathCAD Script

Important Dimensions

$VPlane_y := 600.05in$ $VPlane_x := 610in$ $VPlane_z := 2.602$ $Block_z := 83.765in$

$HPlane_y := 610in$ $HPlane_x := 600.719in$ $HPlane_z := 2.602$

Extrusion weight range

$W_{extMIN} := 505lbf$ $W_{extMAX} := 515lbf$

Module weight range

Number of extrusions per module, $N_{ext} := 2$ $N_{mod} := 12$

$W_{modMIN} := W_{extMIN} \cdot N_{ext} = 1010\,lbf$ *Minimum module weight*

$W_{modMAX} := W_{extMAX} \cdot N_{ext} = 1030\,lbf$ *Maximum module weight*

CG - X

-Setting datum to horizontal plane edge (Using extrusion lengths only)

-Try with the 6 left-most horz modules at min weight and 6 right most horz modules at max weight, and vice versa

-Assume all 12 vert modules at min weight (all 16 planes)

$N_{planes} := 16$

$W_{12ManAsy} := 5lbf \cdot N_{mod} = 60\,lbf$ *Weight of 12 manifold assemblies, adding 4.678" to the total height*

$CGx_{mans} := VPlane_x + 4.678 \cdot 0.33in = 611.544\,in$ *Estimated CGx (due to triangular geometry) for manifold assemblies*

$M_{xMans} := W_{12ManAsy} \cdot CGx_{mans} = 36692.624 \cdot in \cdot lbf$ *Moment from manifolds*

$W_{Vplane} := W_{modMIN} \cdot N_{mod} = 12120\,lbf$ *Min weight of a vertical plane*

$W_{Hplane} := W_{modMIN} \cdot N_{mod} = 12120\,lbf$ *Weight of ideal Horz plane*

$CGx_{Vplane} := VPlane_x \cdot 0.5 = 305\,in$ *CGx distance to vertical plane*

$CGx_{Hplane} := HPlane_x \cdot 0.5 = 300.36\,in$ *CGx ideal Horz plane*

$M_{Vplane} := W_{Vplane} \cdot CGx_{Vplane} = 3696600 \cdot lbf \cdot in$ *Moment from Vert plane*

$M_{Hplane} := W_{Hplane} \cdot CGx_{Hplane} = 3640357.14 \cdot lbf \cdot in$ *Moment from ideal Horz plane*

$$CGx_{ideal} := \frac{\left(M_{Vplane} + M_{Hplane} + M_{xMans}\right)}{W_{Hplane} + W_{Vplane} + W_{12ManAsy}} = 303.442\,in$$ *CGx ideal*

$W_{HplaneMIN} := W_{modMIN} \cdot \frac{N_{mod}}{2} = 6060\,lbf$ *Weight of the lighter side Horz plane*

$W_{HplaneMAX} := W_{modMAX} \cdot \frac{N_{mod}}{2} = 6180\,lbf$ *Weight of the heavier side Horz plane*

$CGx_{HminPlanes} := HPlane_x \cdot 0.25 = 150.18\,in$ *Horz. plane CGx distance to datum of light side*

$CGx_{HmaxPlanes} := HPlane_x \cdot 0.75 = 450.539\,in$ *Horz. plane CGx distance to datum of heavy side*

$M_{HplaneMIN} := W_{HplaneMIN} \cdot CGx_{HminPlanes} = 910089.285 \cdot lbf \cdot in$ *Moment from light Horz plane side on right*

$M_{HplaneMAX} := W_{HplaneMAX} \cdot CGx_{HmaxPlanes} = 2784332.565 \cdot lbf \cdot in$ *Moment from heavy Horz plane side on left*

$$CGx_{actual} := \frac{\left(M_{Vplane} + M_{HplaneMIN} + M_{HplaneMAX} + M_{xMans}\right)}{W_{Vplane} + W_{HplaneMIN} + W_{HplaneMAX} + W_{12ManAsy}} = 304.165\,in$$

$CGx_{diff} := CGx_{actual} - CGx_{ideal} = 0.723\,in$ *<u>CGx varience with heavy horz modules on left</u>*

$CGx_{HminPlanes1} := HPlane_x \cdot 0.75 = 450.539\,in$ *Horz. plane CGx distance to datum of light side*

$CGx_{HmaxPlanes1} := HPlane_x \cdot 0.25 = 150.18\,in$ *Horz. plane CGx distance to datum of heavy side*

$M_{HplaneMIN1} := W_{HplaneMIN} \cdot CGx_{HminPlanes1} = 2730267.855 \cdot lbf \cdot in$ *Moment from light Horz plane side on left*

$M_{HplaneMAX1} := W_{HplaneMAX} \cdot CGx_{HmaxPlanes1} = 928110.855 \cdot lbf \cdot in$ *Moment from heavy Horz plane side on right*

$$CGx_{actual1} := \frac{\left(M_{Vplane} + M_{HplaneMIN1} + M_{HplaneMAX1} + M_{xMans}\right)}{W_{Vplane} + W_{HplaneMIN} + W_{HplaneMAX} + W_{12ManAsy}} = 302.689\,in$$

$CGx_{diff1} := CGx_{actual1} - CGx_{ideal} = -0.753\,in$ *<u>CGx varience with heavy horz modules on right</u>*

<u>Maximum CGx varience: 0.723" to the left or 0.753" to the right</u>

CG - Y

-Setting datum to vertical plane edge (Using extrusion lengths only)

-Try with the 6 top vert modules at min weight and 6 bottom most vertical modules at max weight, and vice versa

-Assume all 12 horz modules at min weight (all 16 planes)

$CGy_{mans} := HPlane_x + 4.678 \cdot 0.33in = 602.263\,in$ *Estimated CGx (due to triangular geometry) for manifold assemblies*

$M_{yMans} := W_{12ManAsy} \cdot CGx_{mans} = 36692.624 \cdot in \cdot lbf$ *Moment from manifolds*

$W_{Vplaney} := W_{modMIN} \cdot N_{mod} = 12120\,lbf$ *Min weight of Horz plane*

$W_{Hplaney} := W_{modMIN} \cdot N_{mod} = 12120\,lbf$ *Min weight of ideal vertical plane*

$CGy_{Vplane} := VPlane_y \cdot 0.5 = 300.025\,in$ *CGy distance to vertical plane*

$CGy_{Hplane} := HPlane_y \cdot 0.5 = 305\,in$ *CGy ideal Horz plane*

$M_{Vplaney} := W_{Vplaney} \cdot CGy_{Vplane} = 3636303 \cdot lbf \cdot in$ *Moment from Vert plane*

$M_{Hplaney} := W_{Hplaney} \cdot CGy_{Hplane} = 3696600 \cdot lbf \cdot in$ *Moment from ideal Horz plane*

$$CGy_{ideal} := \frac{\left(M_{Vplaney} + M_{Hplaney} + M_{yMans}\right)}{W_{Hplaney} + W_{Vplaney} + W_{12ManAsy}} = 303.276\,in$$ *CGy ideal*

$W_{VplaneMIN} := W_{modMIN} \cdot \frac{N_{mod}}{2} = 6060\,lbf$ *Weight of the lighter side vert plane*

$W_{VplaneMAX} := W_{modMAX} \cdot \frac{N_{mod}}{2} = 6180\,lbf$ *Weight of the heavier side vert plane*

$CGy_{VminPlanes} := VPlane_y \cdot 0.25 = 150.012\,in$ *vert plane CGy distance to datum of light side*

$CGy_{VmaxPlanes} := VPlane_y \cdot 0.75 = 450.037\,in$ *vert plane CGy distance to datum of heavy side*

$M_{VplaneMIN} := W_{VplaneMIN} \cdot CGy_{VminPlanes} = 909075.75 \cdot lbf \cdot in$ *Moment from light vert plane side on right*

$M_{VplaneMAX} := W_{VplaneMAX} \cdot CGy_{VmaxPlanes} = 2781231.75 \cdot lbf \cdot in$ *Moment from heavy vert plane side on left*

$$CGy_{actual} := \frac{\left(M_{Hplaney} + M_{VplaneMIN} + M_{VplaneMAX} + M_{yMans}\right)}{W_{Hplaney} + W_{VplaneMIN} + W_{VplaneMAX} + W_{12ManAsy}} = 303.997\,in$$

$CGy_{diff} := CGy_{actual} - CGy_{ideal} = 0.721\,in$ <u>*CGy varience with heavy vert modules on left*</u>

$CGy_{VminPlanes1} := VPlane_y \cdot 0.75 = 450.037\ in$ *Horz. plane CGx distance to datum of light side*

$CGy_{VmaxPlanes1} := VPlane_y \cdot 0.25 = 150.012\ in$ *Horz. plane CGx distance to datum of heavy side*

$M_{VplaneMIN1} := W_{VplaneMIN} \cdot CGy_{VminPlanes1} = 2727227.25 \cdot lbf \cdot in$ *Moment from light Horz plane side on left*

$M_{VplaneMAX1} := W_{VplaneMAX} \cdot CGy_{VmaxPlanes1} = 927077.25 \cdot lbf \cdot in$ *Moment from heavy Horz plane side on right*

$$CGy_{actual1} := \frac{\left(M_{Hplaney} + M_{VplaneMIN1} + M_{VplaneMAX1} + M_{yMans}\right)}{W_{Hplaney} + W_{VplaneMIN} + W_{VplaneMAX} + W_{12ManAsy}} = 302.522\ in$$

$CGy_{diff1} := CGy_{actual1} - CGy_{ideal} = -0.753\ in$ *CGx varience with heavy horz modules on right*

Maximum CGy varience: 0.721" to the top or 0.753" to the bottom

CG - Z

-Setting datum to top plane edge

-Block is symmetric about the z axis, set top 6 horz and vert planes to max, and bottom 6 horz and vert planes to min

W

$W_{HtopMAX} := W_{modMAX} \cdot 8 = 8240\ lbf$ *Weight of the 6 heavy top horz modules*

$W_{VtopMAX} := W_{modMAX} \cdot 8 = 8240\ lbf$ *Weight of the 6 heavy top vert modules*

$W_{MAXtop} := W_{HtopMAX} + W_{VtopMAX} = 16480\ lbf$ *Total weight of top modules*

$CG_{ztop} := Block_z \cdot 0.25 = 20.941\,in$ *CGz distance to heavy top half*

$W_{Hbottom} := W_{modMIN} \cdot 8 = 8080\,lbf$ *Weight of the 6 light bottom horz modules*

$W_{Vbottom} := W_{modMIN} \cdot 8 = 8080\,lbf$ *Weight of the 6 light bottom vert modules*

$W_{Totalbottom} := W_{Vbottom} + W_{Hbottom} = 16160\,lbf$ *Total weight of bottom modules*

$CG_{zbottom} := Block_z \cdot 0.75 = 62.824\,in$ *CGz distance to light bottom half*

$W_{topideal} := W_{Totalbottom} = 16160\,lbf$ *Weight of ideal top half*

$M_{topideal} := W_{topideal} \cdot CG_{ztop} = 338410.6 \cdot in \cdot lbf$ *Moment from ideal top half*

$M_{bottom} := W_{Totalbottom} \cdot CG_{zbottom} = 1015231.8 \cdot in \cdot lbf$ *Moment from bottom half*

$CGz_{ideal} := \frac{\left(M_{topideal} + M_{bottom}\right)}{W_{topideal} + W_{Totalbottom}} = 41.883\,in$ *CGz ideal (centerline)*

$M_{topMAX} := W_{MAXtop} \cdot CG_{ztop} = 345111.8 \cdot lbf \cdot in$ *Moment from heavy top*

$CGz_{actual} := \frac{\left(M_{topMAX} + M_{bottom}\right)}{W_{MAXtop} + W_{Totalbottom}} = 41.677\,in$ *CGz actual with heavy top*

$CG_{zvarience} := CGz_{ideal} - CGz_{actual} = 0.205\,in$

<u>Maximum varience of the CGz is 0.205 inches toward the top or bottom</u>