LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Test Mass Optical Surface Deformation due to Gravity when on a V-block metrology mount

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1 Introduction

The gravitational load (body force) on the Input and End Test Masses (ITM, ETM) needs to be supported when the phase map (surface deformation) is measured during fabrication (or after fabrication as part of the verification process). The stress field created by the gravitational load will cause a deformation of the optic. We are concerned with the deformation of the optical surfaces, which are polished in a horizontal orientation. The results of a finite element analysis of the gravitation load induced deformation of the test mass optic face when mounted in a v-block (one method of mounting for phase map metrology) are presented. This technical note is a companion to T050184-01[1], where the calculated surface deformation due to the gravitational force when hung in a suspension system is presented.

2 Model

The fused silica ITM and ETM dimensions[2,3] are 340 mm diameter by 200 mm thick with 95 mm long flats on each side (nominally 40 kg mass). A three-dimensional finite element model, created with the I-DEAS version-9 software, depicted in Figure 1, represented this geometry. The bevels and the wedge angle of the optics were not included in this model. Based on the experience of the analysis presented in T050184-01, a mapped mesh was used to ensure a purely vertical quasi-rigid-body global motion in response to a vertical gravity vector (i.e. minimize pitch and roll motion).

At the time of this technical note, the ITM and ETM are symmetrically and vertically wedged with an angle on the order of 1 degree. This wedge must be compensated in the metrology mount by tilting the optic axis (cylinder axis) by ~0.5 degree. This nominal pitch angle is not considered in this analysis.

The V-block interface is modeled as two line contacts spaced at ± 60° from the bottom of the optic (as indicated in Figure 1). The displacements in all 6 degrees of freedom are held to zero along these two lines, i.e. no slip. In a actual metrology mount with a slick surface (e.g. Teflon), the tangential stress due to friction may be relieved by slip. This can be modeled with a nonlinear contact analysis, but is not likely to result in a significantly different result.

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[1] D. Coyne, “Test Mass Optical Surface Deformation due to Gravity”, LIGO-T050184-01, 26 Sep 2005.

[2] H. Armandula, G. Billingsley, G. Harry, B. Kells, "Core Optics Components: Conceptual Design Document", LIGO-T000098-02. Also LIGO RODA M050397-00 in review.

[3] G. Billingsley, “RODA: Core Optic sizes, including TMs, BS, FM and RM”, LIGO-M050397-02, 23 Aug 2005.

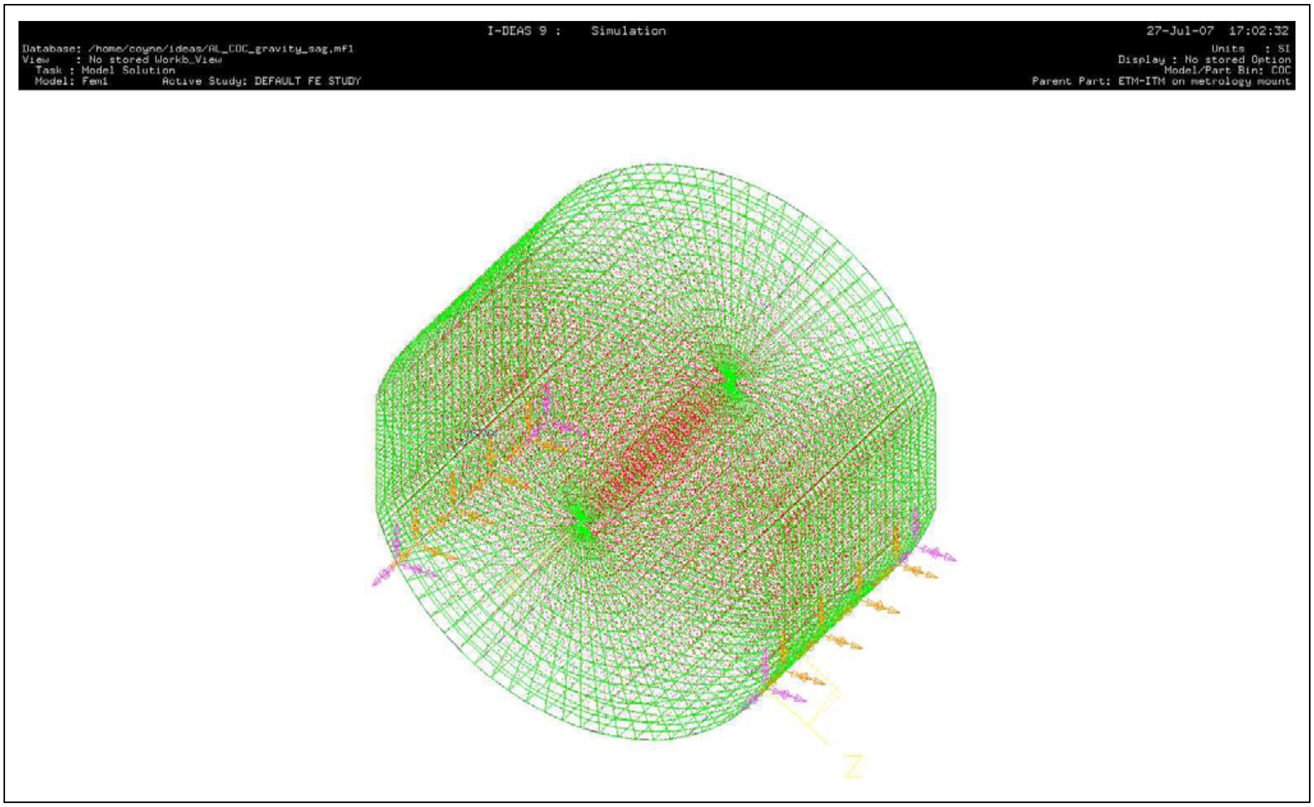

Figure 1: Finite Element Mesh

The mesh consists of 19.0K parabolic, brick elements and 81.7K nodes.

3 Calculated Stress & Deformation Field

The stress contours (Figures 2, 3 and 4) show that only the region immediately adjacent to the bond area has significant stress, as expected.

The finite element analysis indicates a peak transverse (normal to the optic face) deformation of 1.7 nm p-v for the full aperture, 0.4 nm p-v for a 200 mm diameter aperture and 0.3 nm p-v for a 150 mm diameter aperture (as shown best in Figure 12).

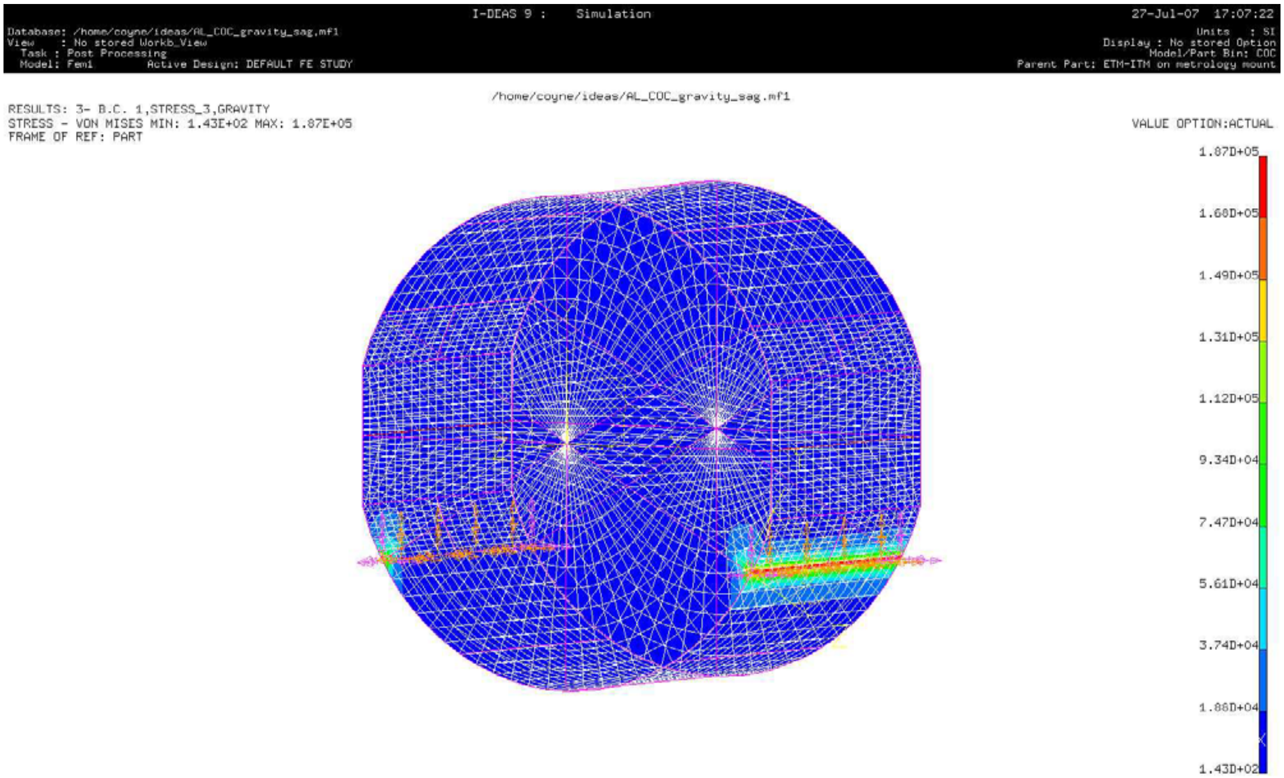

Figure 2: Stress Contours (Von Mises stress, linear scale)

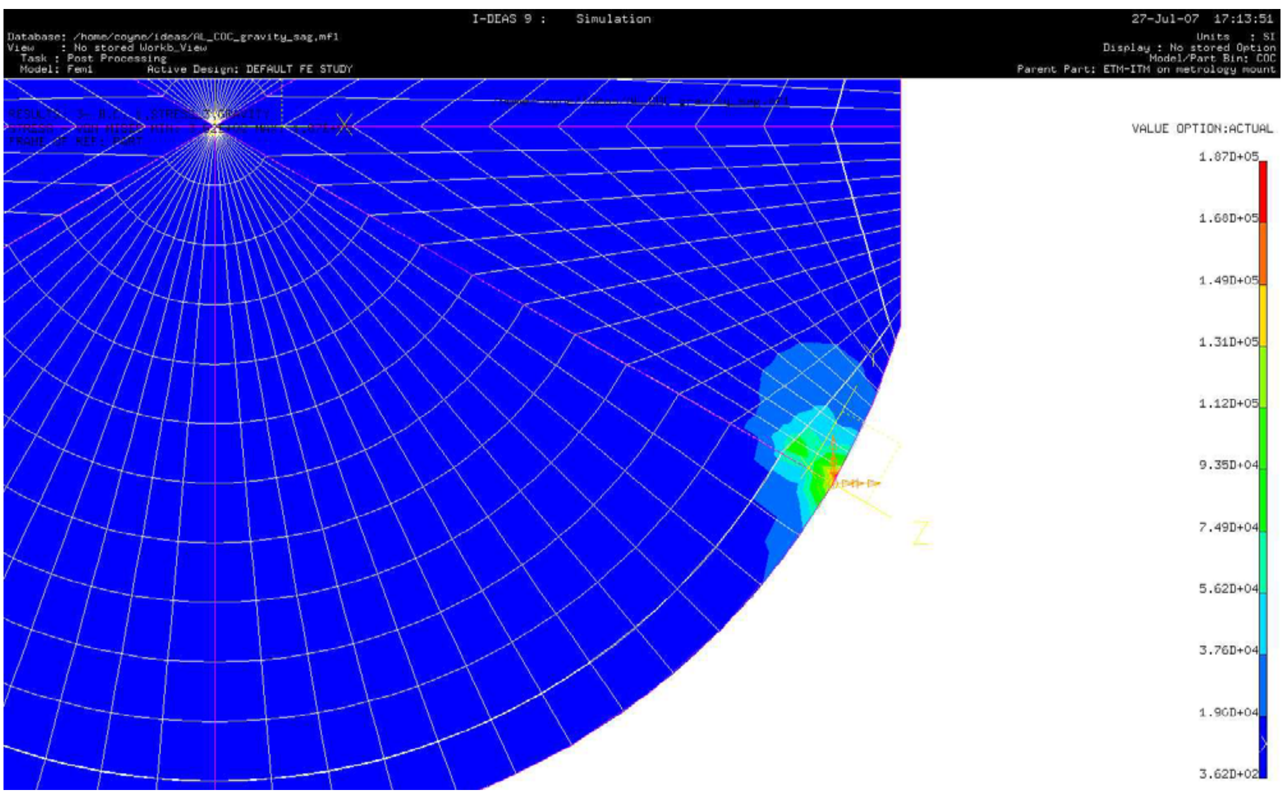

Figure 3: Close-up and cut-away of the stress contours (Von Mises stress, linear scale)

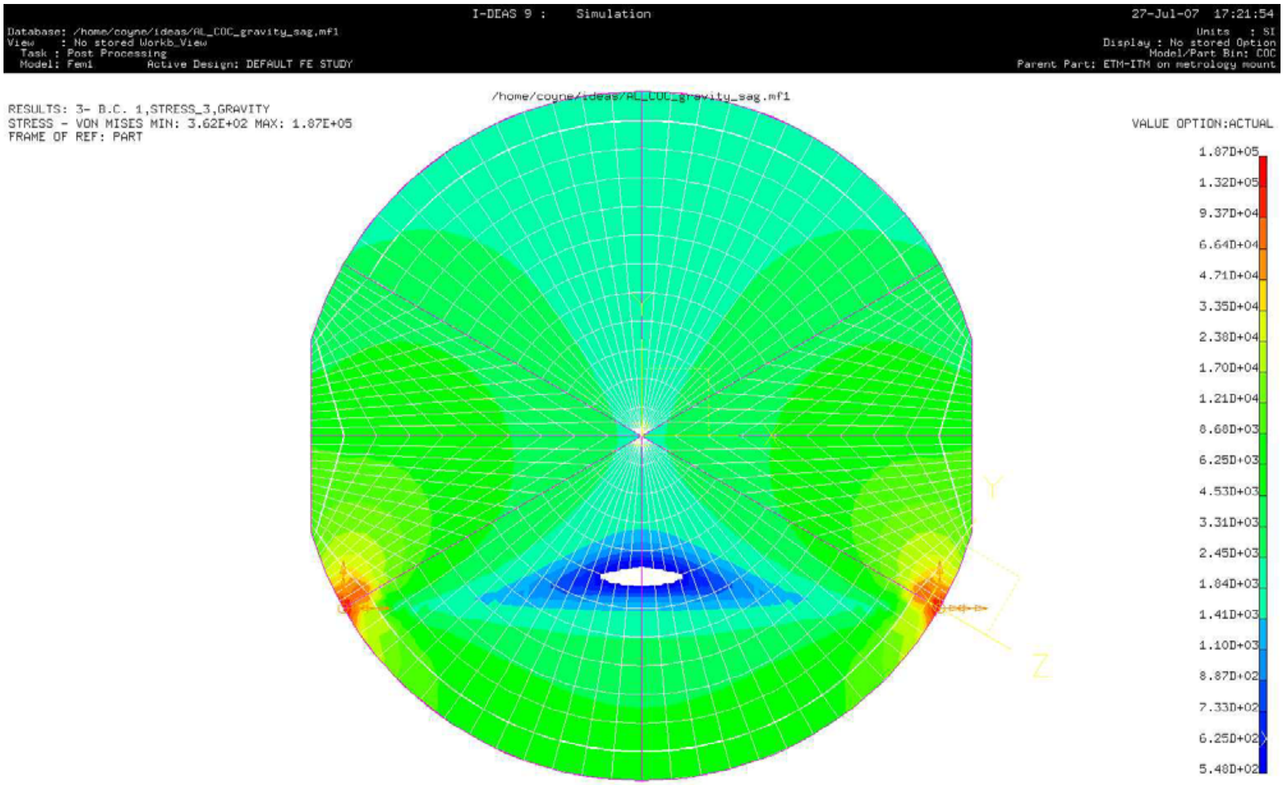

Figure 4: Stress contours for central vertical plane of optic (Von Mises stress, log scale)

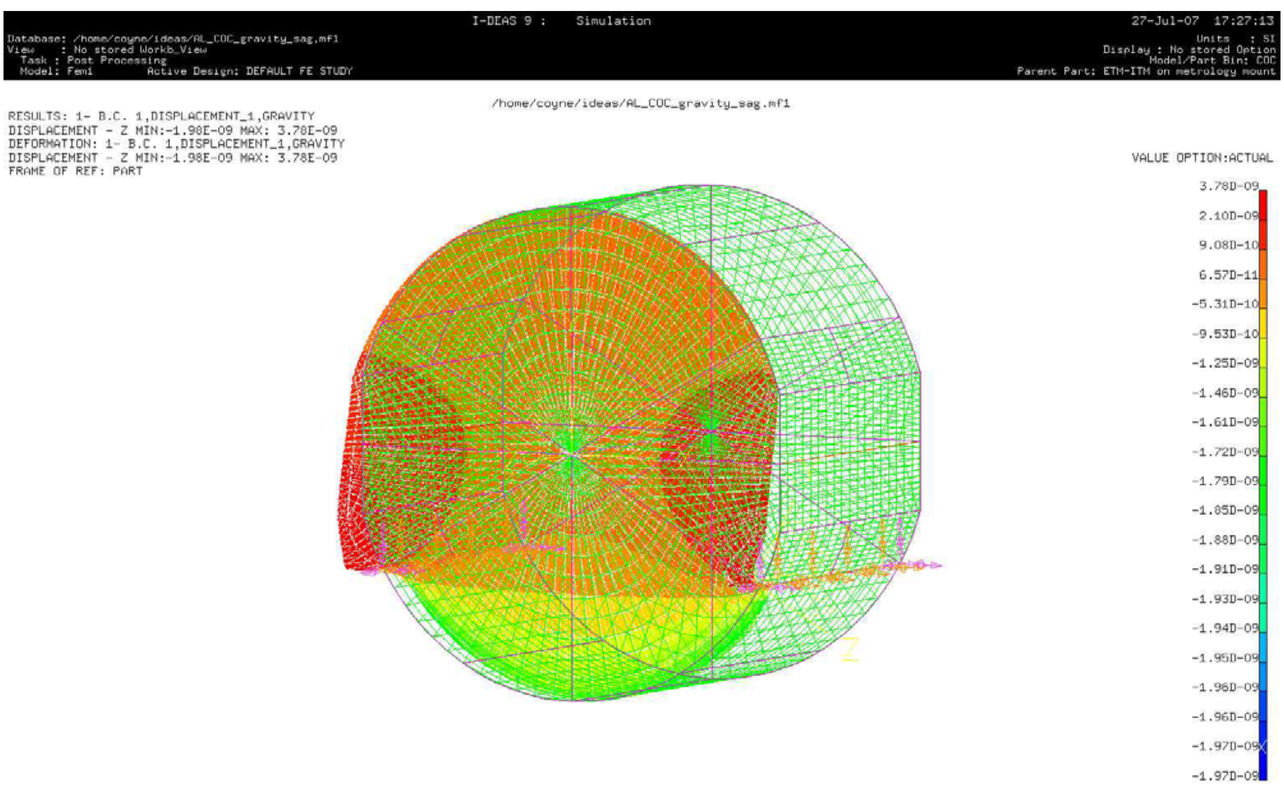

Figure 5: Front Surface Normal Displacement

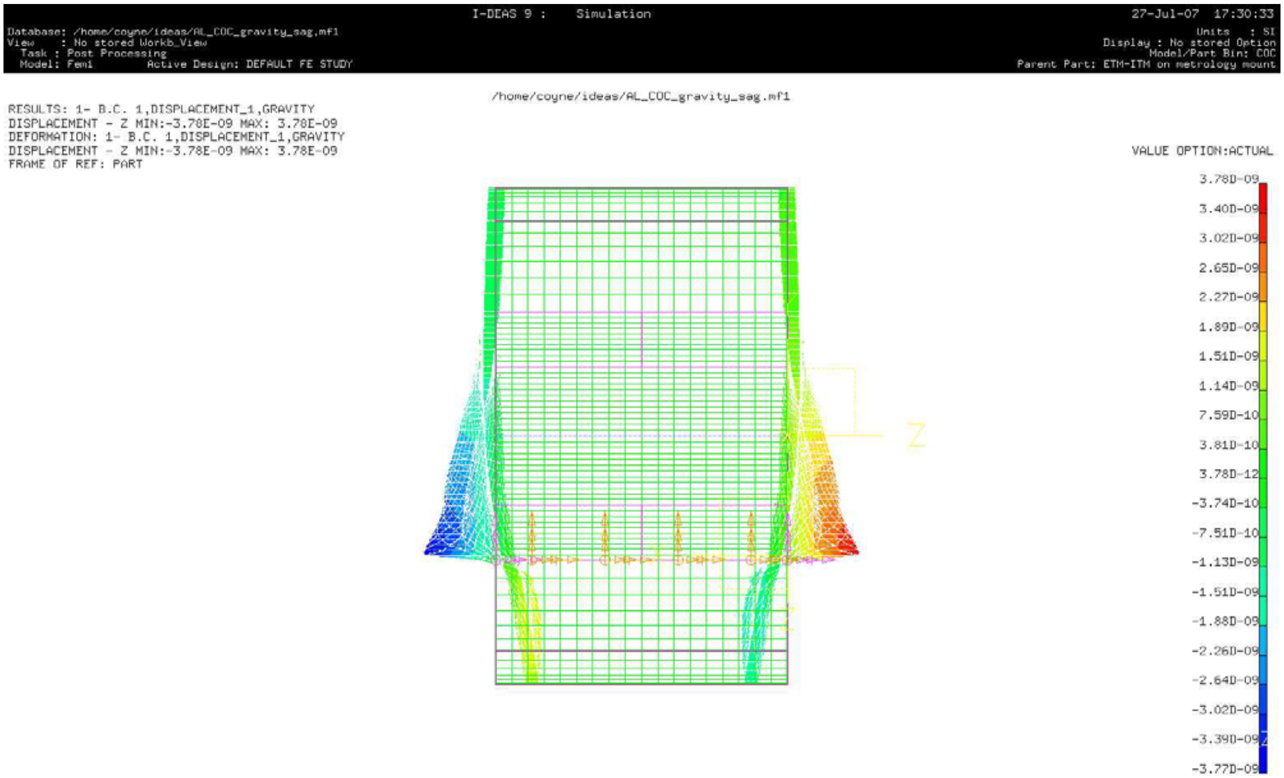

Figure 6: Front & Rear Surface Normal Deformation

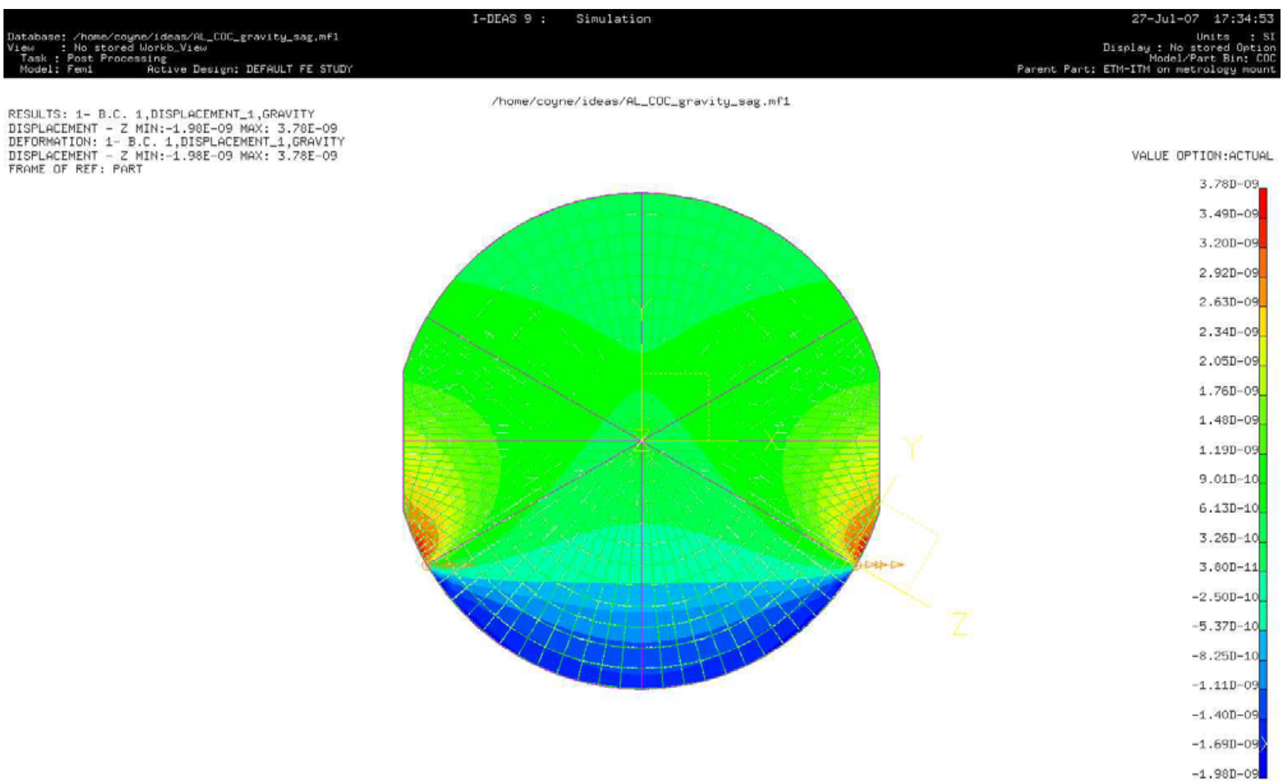

Figure 7: Front Surface Normal Deformation: Full Aperture

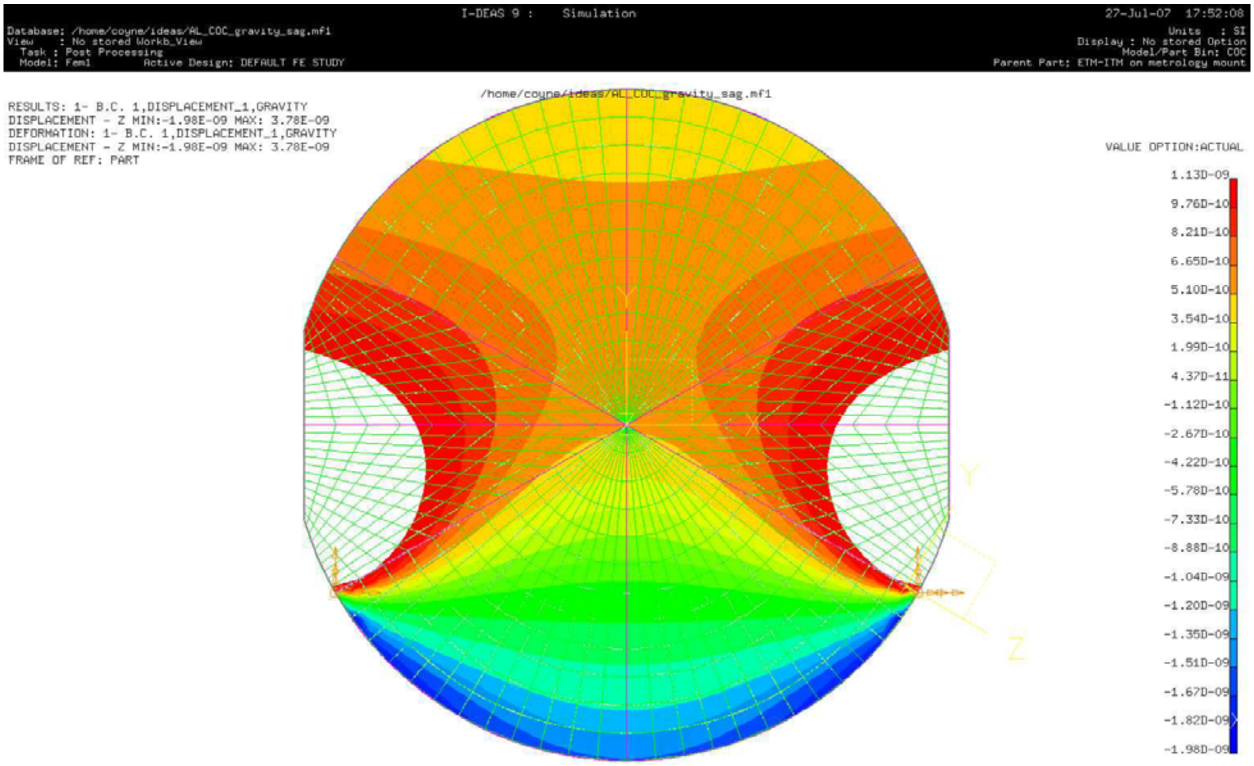

Figure 8: Front Surface Normal Deformation: 200 mm diameter Aperture (by setting upper limit on contour scale)

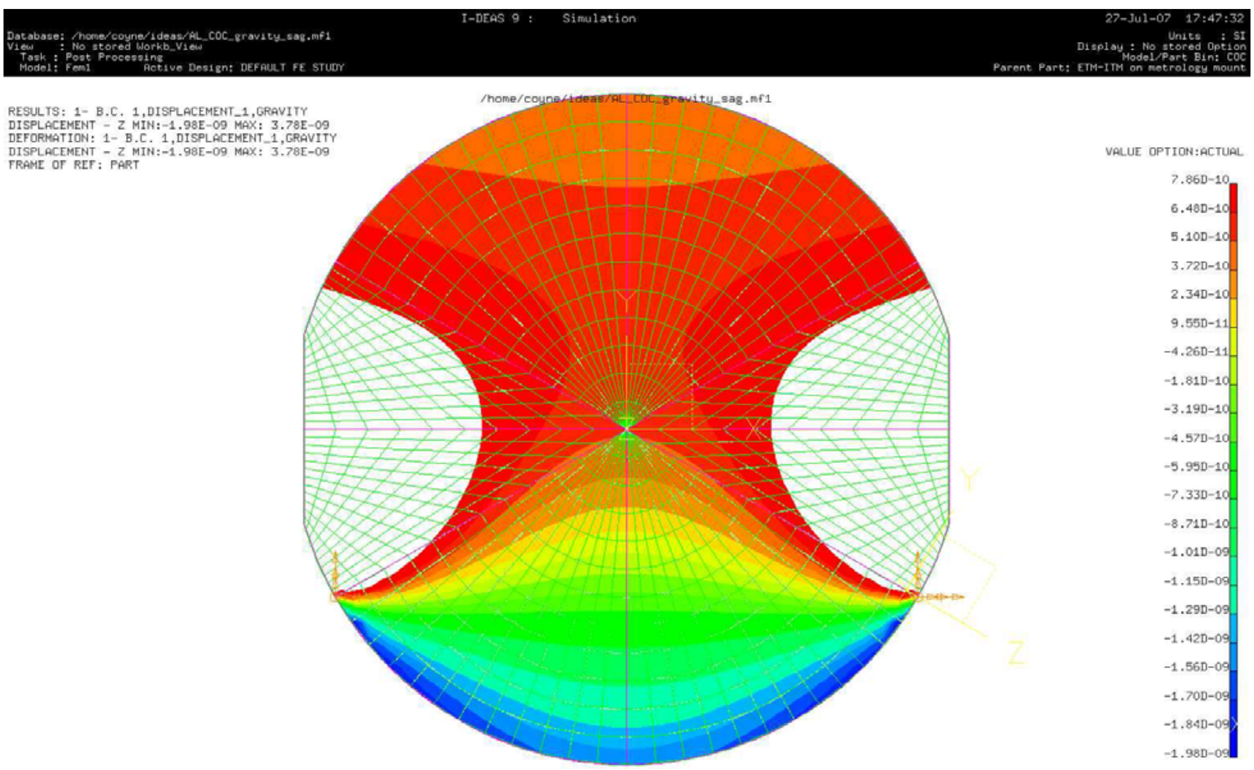

Figure 9: Front Surface Normal Deformation: 200 mm diameter Aperture (by setting upper limit on contour scale)

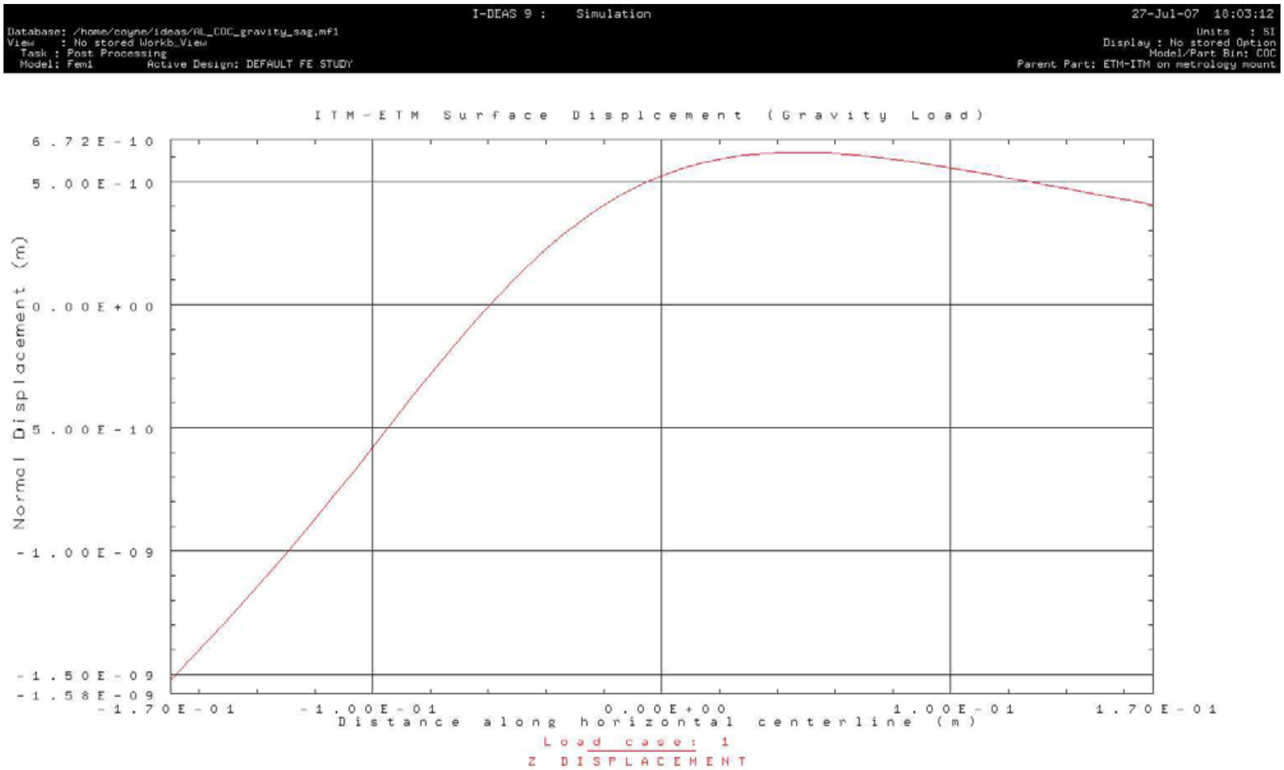

Figure 10: Front Surface Normal Deformation: along vertical centerline (vs vertical coordinate)

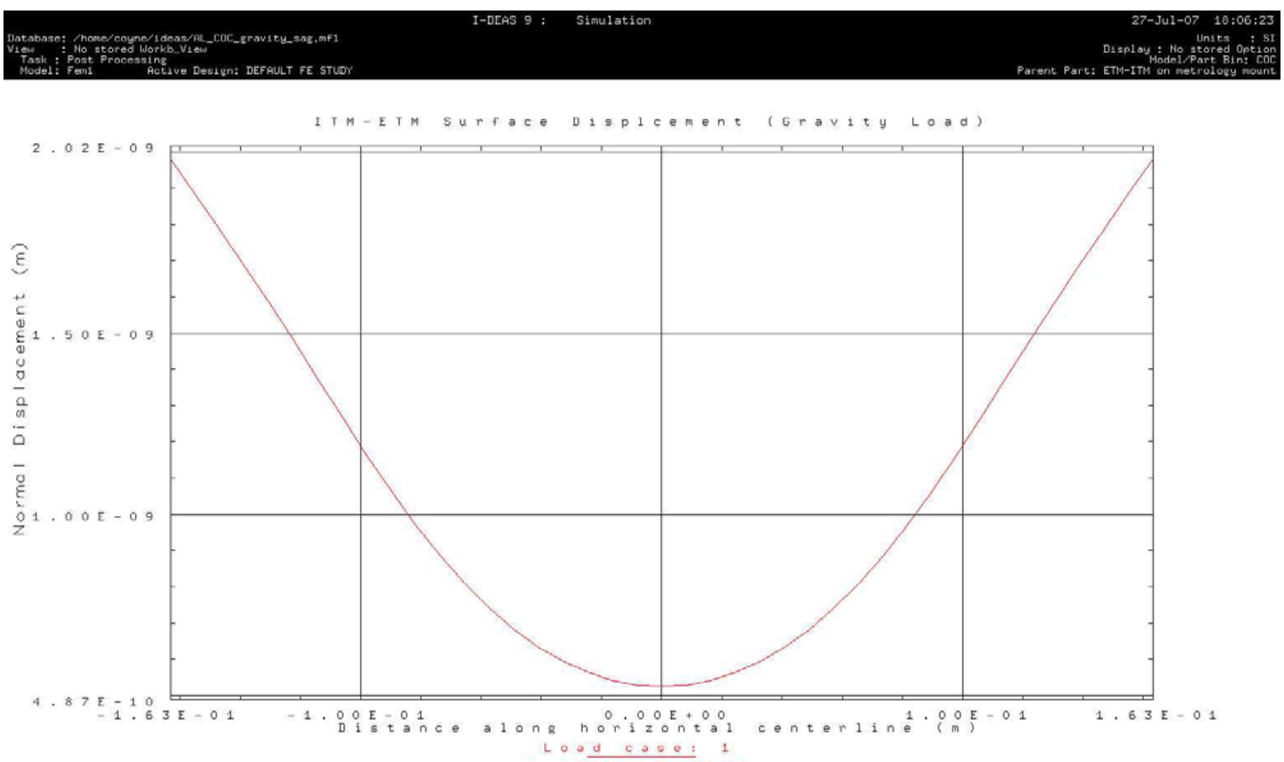

Figure 11: Front Surface Normal Deformation: along horizontal centerline

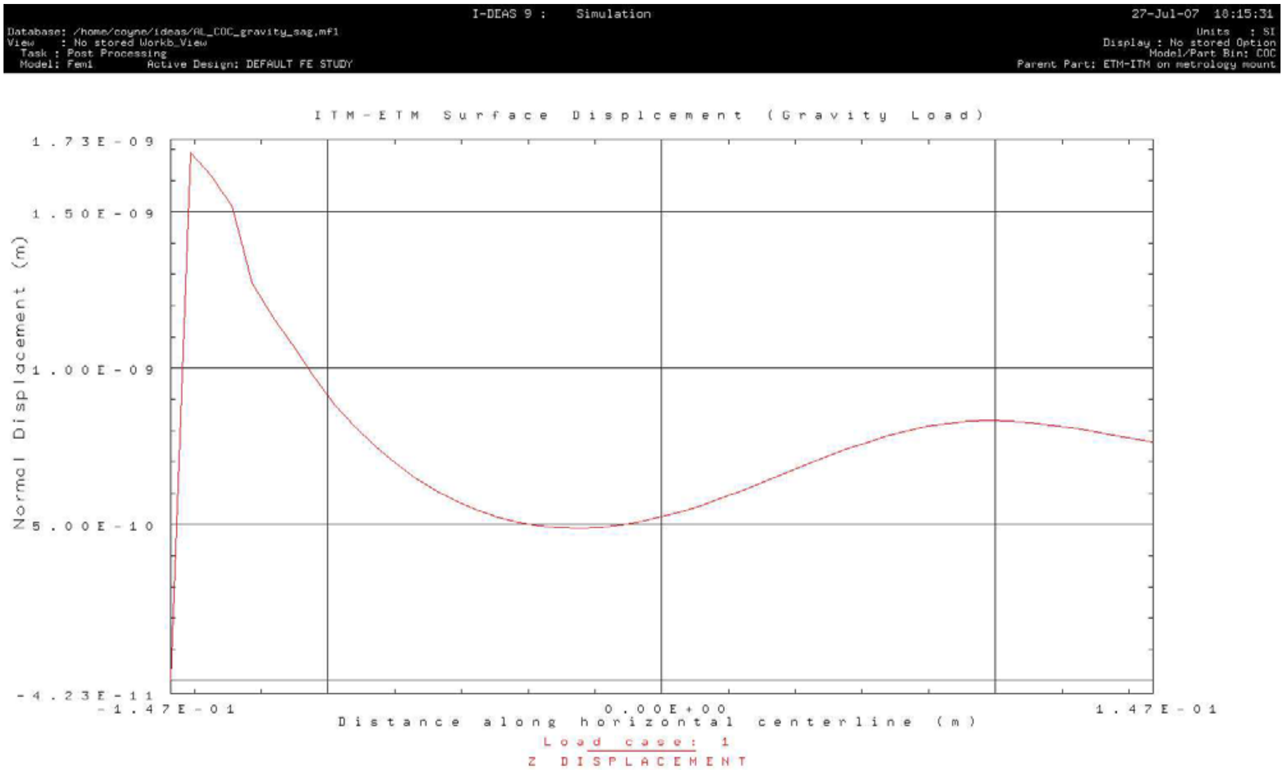

Figure 12: Front Surface Normal Deformation: along 2-8 o'clock line (vs horizontal coordinate)