Summary of the structural issue:

Note: in this discussion, "bottom" means the surface of the impact limiter which contacts the ground, and "top" refers to the impact limiter surface that contacts the cask in an "end drop" event.

AOS' approach to qualifying the package to 30-ft drop conditions is to deform a Finite Element (LIBRA) model of the impact limiter at the "bottom" of the impact limiter (with the "top" fixed) until the strain energy equals the potential energy of the package for a 30-ft drop. Subsequently the reaction forces from these analyses are applied to the cask with equilibrating body forces to determine the effects on the cask.

In Section 2.7.1.1.3 of the SAR, a correlation between impact limiter test deformations and LIBRA is presented. Figure 2-32 is a photograph of a post-end-drop-test AOS-165 sectioned impact limiter which is used to correlate with analysis results. The total height deformation is calculated from the Figure 2-32 photograph as 4.4 in, and compared to an analysis value of 5.5 in. (Note: SAR page 2-88, last two sentences, compare this figure to Figure 2-39, which is a side drop. Assuming a typo, the correct reference is Figure 2-29, but this is for a AOS-100 model. This, however, does not change the issue).

It is apparent from the photograph in Figure 2-32 that the test impact limiter did not deform as assumed in the analysis. Instead of the "bottom" of the impact limiter flattening out (as shown in Figure 2-29), it is obvious that a significant deformation occurred at the "top" of the impact limiter, corresponding to the cask pushing into the impact limiter. This accounts for the deformation at the center of the impact limiter where the foam separated from itself.

Further indication that this occurred is given in p. 2-830 of the SAR (Image 5). The impact limiter deformations at the "bottom" surfaces at the center edges are 2.416 in and 1.745 in, which average 2.081 in (curiously, the reference datum for deformations, the "top" surface, is missing from this image). If this is so, then compared with the Figure 2-32 value for total deformation of 4.4 in, then 4.4 – 2.081 = 2.32 in of deformation must have come from the "top" surface of the impact limiter (pulling down the inner top edges of the impact limiter, as is evident in the top left side of Figure 2-32).

Hence, more than half of the deformation in the impact limiter occurs at the "top" surface, and thus the analysis assumption that the "top" is restrained and the "bottom" moves is incorrect. The displacement distribution, and thus the strain, stress, and derived forces, must be incorrect. Similar behavior accounts for the inner surface gaps shown between pre- and post-test profiles in the Side Drop and Slapdown images in SAR pages 2-831 and 2-832.

In light of this, the methodology employed cannot be considered to be appropriate to evaluate the package for regulatory drop conditions.

Response

The Summary of Structural Issues raises two main questions:

- *It is apparent from the photograph in Figure 2-32 that the test impact limiter did not deform as assumed in the analysis. Instead of the "bottom" of the impact limiter flattening out (as shown in Figure 2-29), it is obvious that a significant deformation occurred at the "top" of the impact limiter, corresponding to the cask pushing into the impact limiter. This accounts for the deformation at the center of the impact limiter where the foam separated from itself.*

And

- *more than half of the deformation in the impact limiter occurs at the "top" surface, and thus the analysis assumption that the "top" is restrained and the "bottom" moves is incorrect.*

The method used to analyze the Impact Limiter for drop loads does not simply apply a fixed deformation pattern, but rather uses a capture procedure whereby the structure connects to the rigid impacting plane as the deformation develops. When the constraint forces between the structure and impacting plane become tensile, the constraints are released. In this manner the contact interface develops according to the deformation resulting from the drop, rather than being arbitrarily assigned.

We believe our procedure to be correct, as it allows the model deformation to determine the amount of ground contact. In addition, we feel that Figure 2-32 does not indicate that our procedure is incorrect. With regard to the Dimensional Data given on Page 2-830, this dimensional data was not used for comparison with the analytical results because it only accounts for the steel shell changes and says nothing about the foam material deformation. The Impact limiter design allows for the steel shell and the foam material to act independently of each other.

Adopting the NRC nomenclature of "bottom" meaning the surface of the impact limiter which contacts the ground, and "top" meaning impact limiter surface that contacts the cask, our explanation of Figure 2-32 is as follows. The impact limiter foam is compressed under the action of cask pressure at the top and ground contact at the bottom. The ground contact initiates at the recess cylinder, and the recess cylinder is driven into the foam, eventually causing the foam section above the cylinder to break off. As noted above, the impact limiter cladding (steel shell) is not attached to the foam. As a result, the cladding disk covering the recess buckled downward, and the broken section of foam falls onto the buckled cladding.

The photograph in Figure 2-32 provides a reasonable measure of the total foam deformation. The dimension A does not change appreciably under impact, and is used as a reference dimension to relate dimensions on the photograph to cask dimensions. The dimension B is the compressed height, and is used to evaluate the total deformation. However, our explanation in the SAR of how we calculated the displacement from Figure 2-32 is inconsistent with the dimensions A and B on Figure 2-32. To be consistent with our explanation on SAR Page 2-88, the dimensions A and B on the figure corresponded to the variables "a & b" in the analysis.

Further verification of the adequacy of the approach taken is presented in Appendix 2.12.6 "Impact (Free-Drop) Test Report, page 2-798. The pressure sensitive film shows small to zero stress at the inner plate of the "top" boundary indicating little deformation on the region. In addition, the time-lapse high speed photography presented on page 2-797 shows the flattening of the "bottom" surface due to the impact event.

The un-deformed and deformed 165 analytical models for a head-on drop are shown in Figures 1 and 2. We believe the model and analytical method to be both appropriate and adequate for Impact Limiter analyses as verified by the drop test results. In addition, we believe the analytical results show good agreement with the observed behavior and deformations, and the drop tests thereby provide verification of our analytical methods.

As per the Note: "*SAR page 2-88, last two sentences, compare this figure to Figure 2-39, which is a side drop. Assuming a typo, the correct reference is Figure 2-29, but this is for a AOS-100 model. This, however, does not change the issue*": This is a typographical error the figure which should be referenced is Figure 2-37. "Head-on Drop Force and Energy-AOS-165A Prototype".

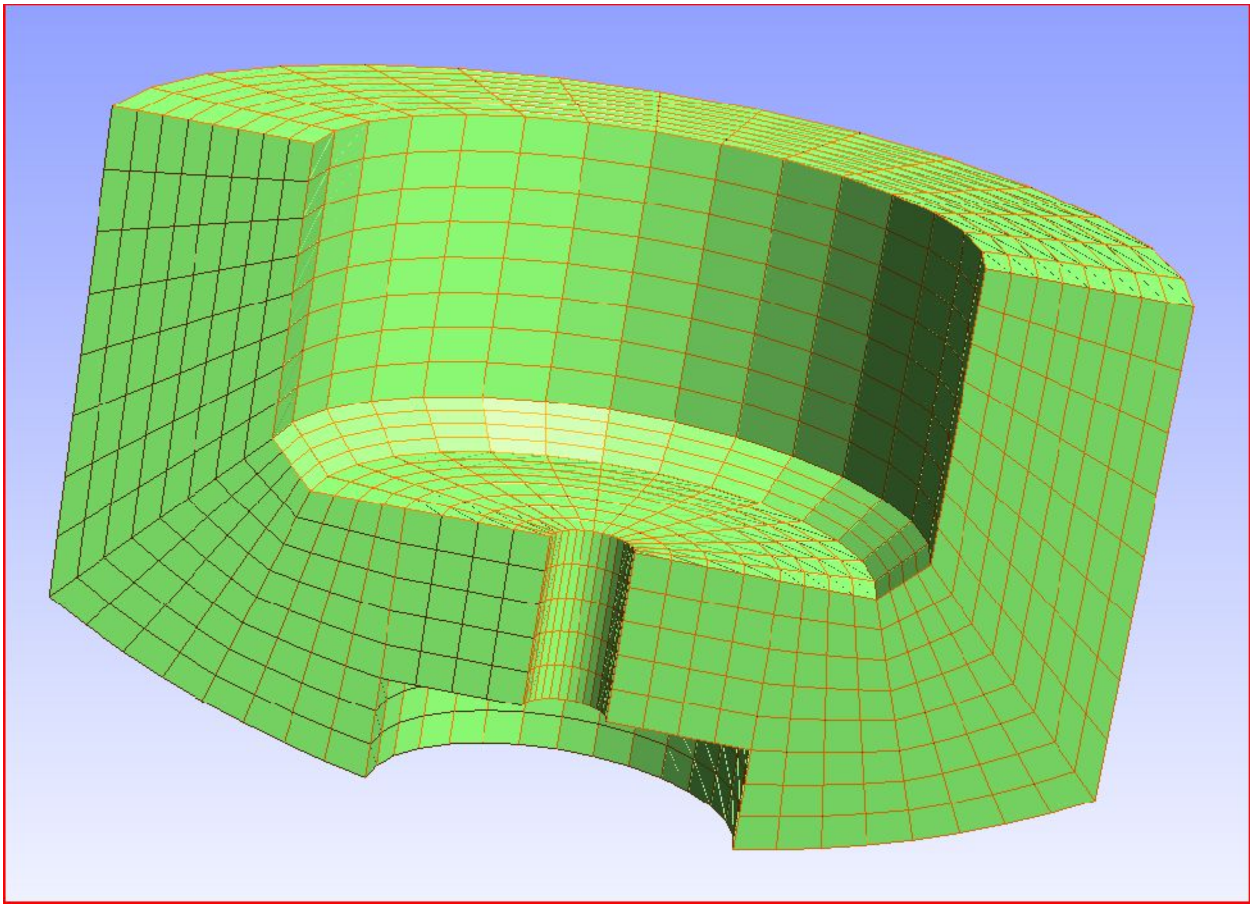

Figure 1. Un-deformed Model of Impact Limiter

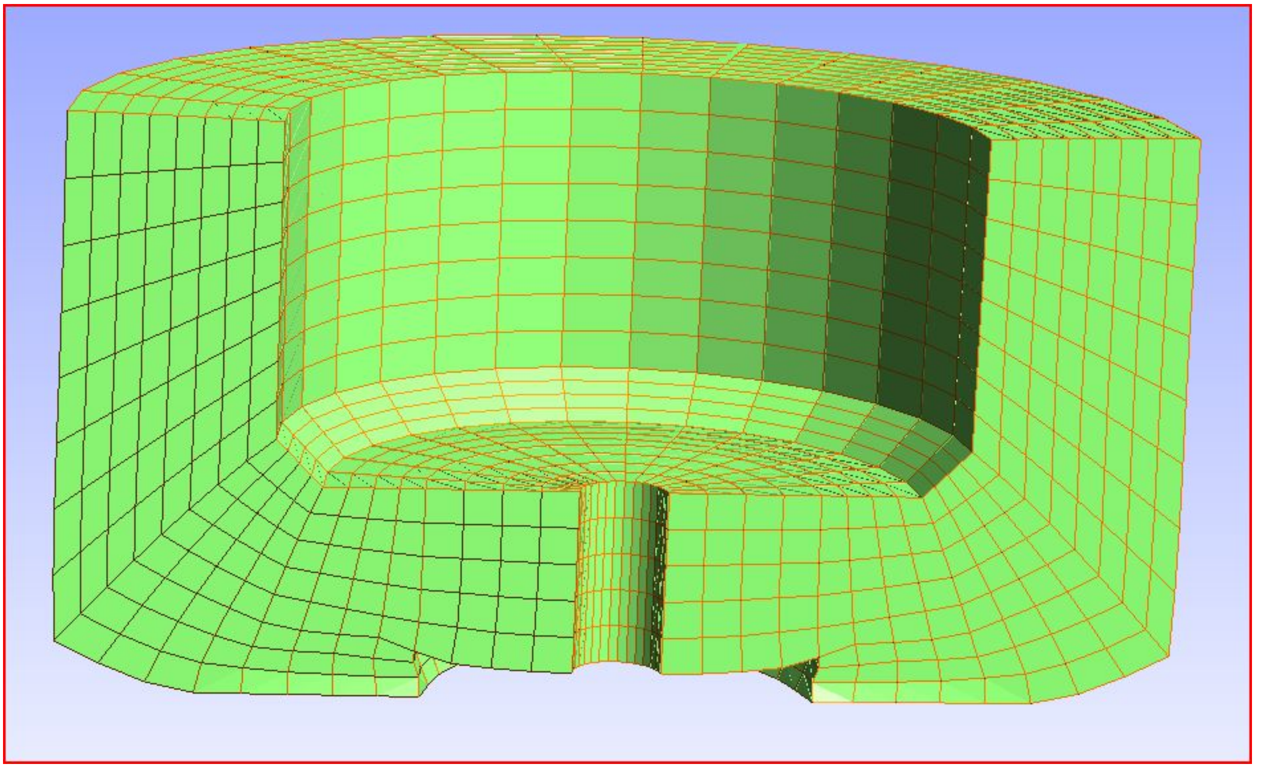

Figure 2. Deformed Model 165 Impact Limiter for Head-on Drop