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THE EFFECTS OF SIMPLIFIED IMPACT LIMITER AND LID ARRANGEMENT ON DECELERATIONS DURING CASK DROP TESTING

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ABSTRACT

Reliance solely on full-scale drop testing in partial fulfillment of the requirements to obtain a Certificate of Compliance for a spent fuel transportation package is expensive and no longer common in part due to use of explicit finite element codes. Typically, a combination of finite element modelling, and scale model testing, is part of a benchmarking and validation effort used to support the licensing of the transportation package and to minimize costs and time. Often, certain features of the package are omitted or simplified in a scale model, such as impact limiters, which can be expensive to fabricate, are substituted by a plate, or a single cask lid is used in place of two lids. Such simplifications should be made carefully, however, as there may be distortion in the scaled moment of inertia of the package for a slapdown scenario, which could generate unrealistic g-loads. This paper discusses a sensitivity study of the g-loads experienced by a simplified model with varying lid/impact limiter placement. Recommendations for scale model simplification are provided to compensate for the effects of model distortion when the slapdown configuration is drop tested.

INTRODUCTION

The activity of planning and executing a full-scale drop test of a spent fuel/radioactive waste transportation package is expensive, time consuming, and less common than in years past. More commonly, full-scale drop testing of a package composed of a cask with impact limiters is replaced by a combination of prototype drop testing and computer simulation via explicit finite element codes. Scaled models are typically ½ to as little as ¼ the size of the original. Scale model drop testing is often used to show that impact limiters can remain attached to the cask, generate test results to demonstrate impact limiter performance, and generate cask rigid body decelerations for benchmarking finite element analysis models. This approach typically leads to reduced fabrication costs of the prototype, and the ability to simulate package drops in a consistent and repeatable manner. When it comes to designing a test plan, the designer will have to take into account several variables such as the scale of the model, geometry, materials of construction, instrumentation, number of drops to perform, etc. (further details can be found in reference 1).

When considering the construction of a test specimen, the designer will often wish to make simplifications to eliminate features of the original which do not drive the response of the package. For instance, for a spent fuel cask that has a shield plug and a closure lid, the designer may wish to replace both with just one lid to reduce the manufacturing cost of the prototype since these lids are time consuming to weld and/or bolt. When eliminating lids or impact limiters, the designer must consider maintaining the location of the center of gravity of the package, changes in the overall weight of the package, and try to maintain overall package dimensions. Perhaps a little less obvious is the effect that such simplifications to the package may result in distortion of the (second) moment of inertia of the package, which is the focal point of this paper. The moment of inertia often plays a key role in oblique drops ("slapdown") where a portion of the package, the "nose," falls and strikes the target as defined per 10 CFR 71.73(c)(1), at an angle of incidence, α, followed by the "tail" of the package as shown in Figure 1. In the slapdown scenario, the angular velocity adds to the terminal velocity of the tail end of the package upon landing on an essentially unyielding horizontal surface (reference 2).

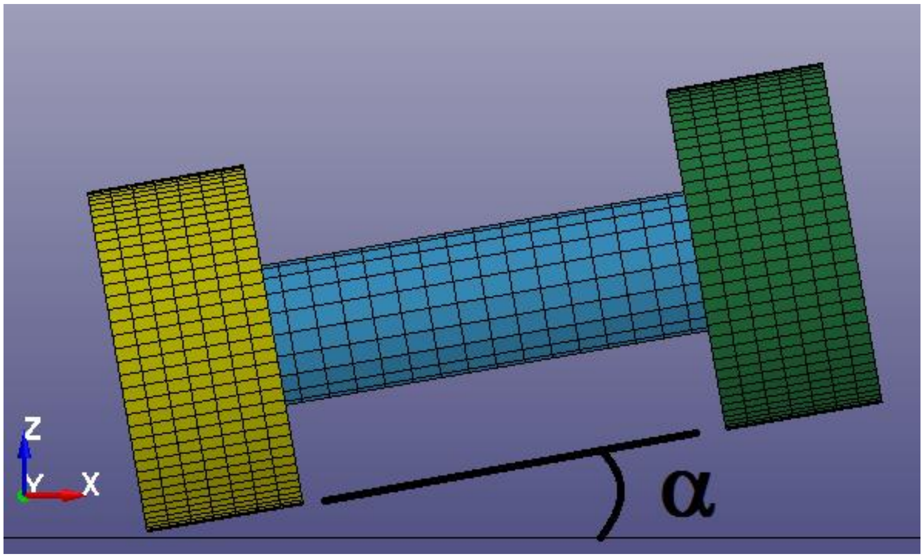
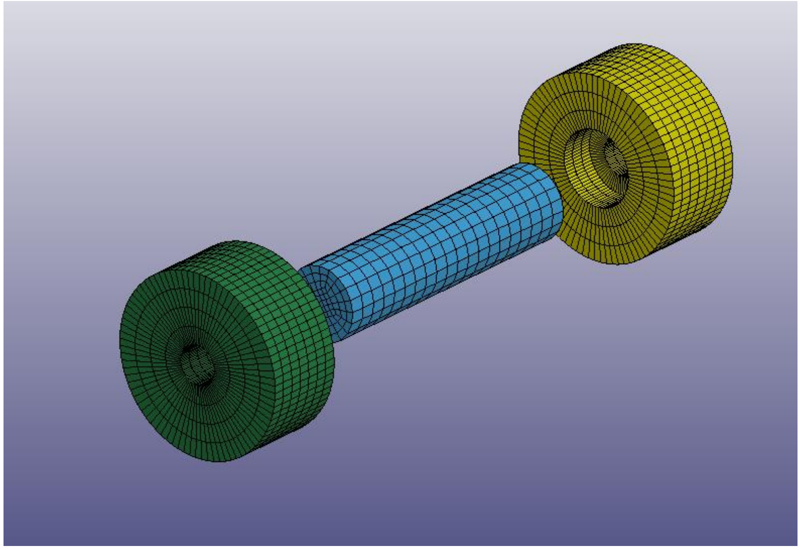


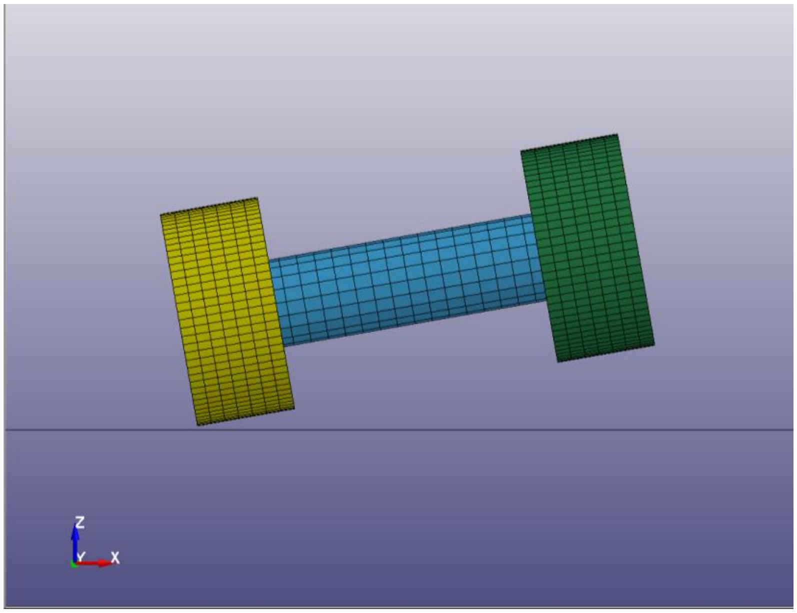
Figure 1. Oblique drop of a package on to a target at angle of incidence α

MODELS USED FOR THE STUDY

To illustrate the effect that the moment of inertia has on the response of a transportation cask during a free drop, two models subjected to the 30 foot (9 m) free drop as described in 10 CFR Part 71.73(c)(1) are simulated using LS-DYNA (R8.1.0). The first model (Model 1, Figure 2a), is an idealized transportation package composed of a cask (blue cylinder) with impact limiters, while the second model (Model 2), is like the first except that it has had one of its impact limiters replaced by a plate (see Figure 2b).

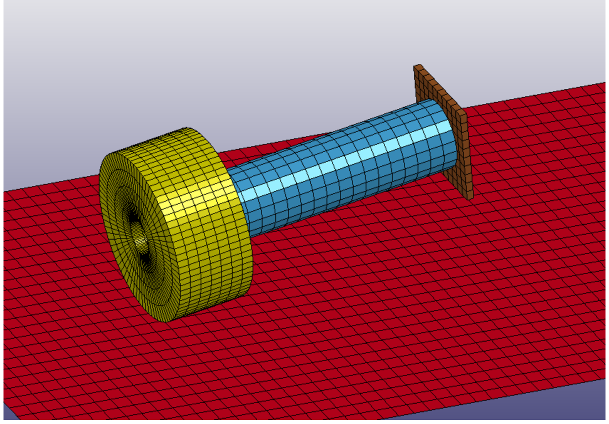


Model 1 (exploded) component view



Model 1 with two impact limiters (10° angle of incidence shown).

Figure 2a. LS-DYNA Representation of Model 1



Model 2 with an impact limiter and plate (angle of incidence is 10^{o}).

Figure 2b. LS-DYNA Representation of Model 2

The casks for Models 1 and 2 are the same and weigh 300,000 lbs. (136,078 kg) while each impact limiter weighs 15,000 lbs. (6,804 kg) as does the plate that is used in place of an impact limiter in Model 2. The center of gravity for both models is located at the same location, which is the geometric center of the cask. Additional dimensions of the packages are described in Table 1. The cask, plate, and impact limiters have been modeled using fully integrated solid elements (ELFORM= -2). The cask and its contents are treated as homogenous and are represented by a solid steel cylinder with an aspect ratio of 4 to 1 and is assumed to be made of ASTM A240 Grade 304 stainless steel. The density of the solid stainless steel cylinder was adjusted so that the overall weight of the cask remains 300,000 lbs. (136,078 kg). In this paper it has been assumed that adequate dunnage will prevent relative movement of the contents within the package. The material model used to represent the solid stainless steel pipe is *MAT_224 (Tabulated Johnson Cook) with parameters provided by ASME at a temperature of 150 ^{o}F (66 ^{o}C). The impact limiters are assumed to be of a homogenous construction and are represented by *MAT_163 (Modified Crushable Foam) with a stress strain curve as shown in Figure 3. The target has been modeled as a rigid surface by constraining all nodes using shell elements. Automatic surface-to-surface contact without friction and SOFT = 2 has been used between components and the target. The simulations were ran with double precision activated.

Excluding the target, the models are composed of up to 5700 elements. The angle of incidence (α) shown in Figure 1 is varied from 0^{o} (side drop scenario) to 20^{o} at 5^{o} increments with additional values between 0^{o} and 5^{o}.

Table 1. Model Dimensions

Feature	Dimension	Unit
Cask length	200 (508)	in (cm)
Cask Diameter	50 (127)	in (cm)
Outer Impact Limiter Diameter	122 (309.9)	in (cm)
Impact limiter Hole Diameter	26.5 (67.3)	in (cm)
Overall Package length (Model 1)	264 (670.6)	in (cm)
Width of Impact limiter	56 (142.2)	in (cm)
Surrogate Plate Width (Model 2)	70.5 (179.1)	in (cm)
Surrogate Plate Density	490 (0.007849)	lb/ft^3 (kg/cm^3)
Surrogate Plate Thickness	10 (25.4)	in (cm)
Impact Limiter Density	41 (0.0006568)	lb/ft^3 (kg/cm^3)

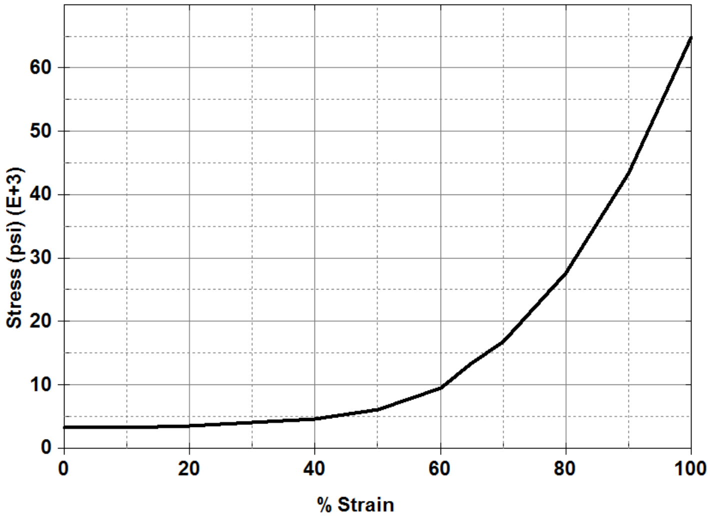


Figure 3. Stress-strain curve used to model the impact limiter material

RESULTS FOR MODEL 1 AND MODEL 2

While the designer can evaluate a cask for various design parameters, inertia loads (aka cask rigid body decelerations) are often a good indicator of the overall demand on the cask. An example of the rigid body deceleration response of Model 1 subjected to a 30 foot (9 meter) drop is shown in Figure 4. In Figure 4, the nose of the package strikes within the first 50 ms of the time history followed by the tail strike, at a 10° angle of incidence. Figure 5 represents the maximum cask g-loads observed during the nose strike as a function of angle of incidence. Responses for angles of incidence less than 2 degrees are not plotted because it is difficult to separate the response of the nose from the tail for Model 1. From Figure 5, it is observed that overall, higher responses are observed for Model 1, the model with two impact limiters, versus Model 2, the model with an impact limiter replaced by a plate. The largest difference in the nose response between both models is found to be at angles of incidence between 3^{o} and 5^{o} degrees, but in general will vary with package design.

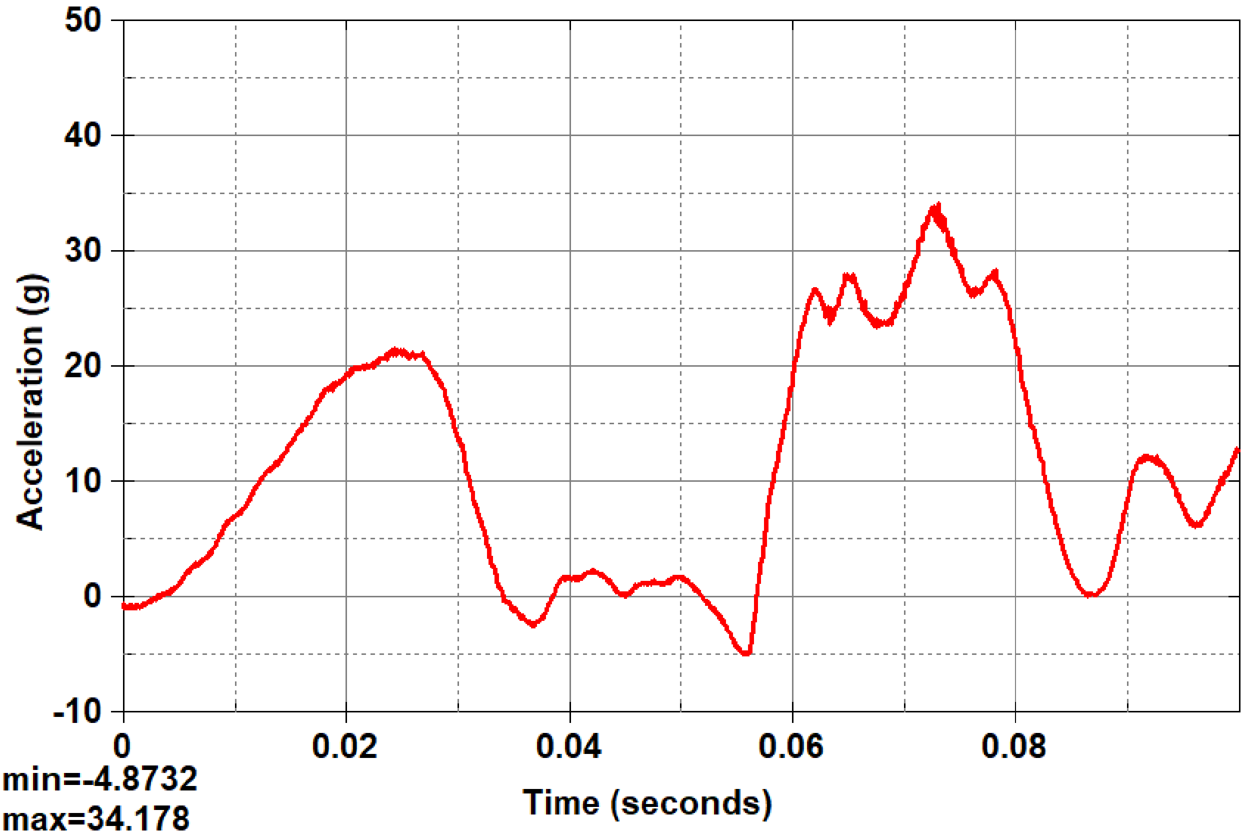


Figure 4. Rigid body deceleration in the z-direction of Model 1 (angle of incidence of 10^{o} shown)

Examining the results for Model 1 alone, it is observed that the tail strike as compared to the nose, generates a higher response due to rotation caused by slapdown. Also, the magnitude of the response in a “true” design is most likely to be higher than the idealized cases depicted here, since impact limiters to the author’s knowledge, are never homogenous and isotropic in construction, have additional support structures such as ribs, fins and exterior steel “skins” which tend to stiffen the limiter to some degree. Often times when wood and/or foam is employed as impact limiter material, more than one type is used, and often has varying density and grain orientation.

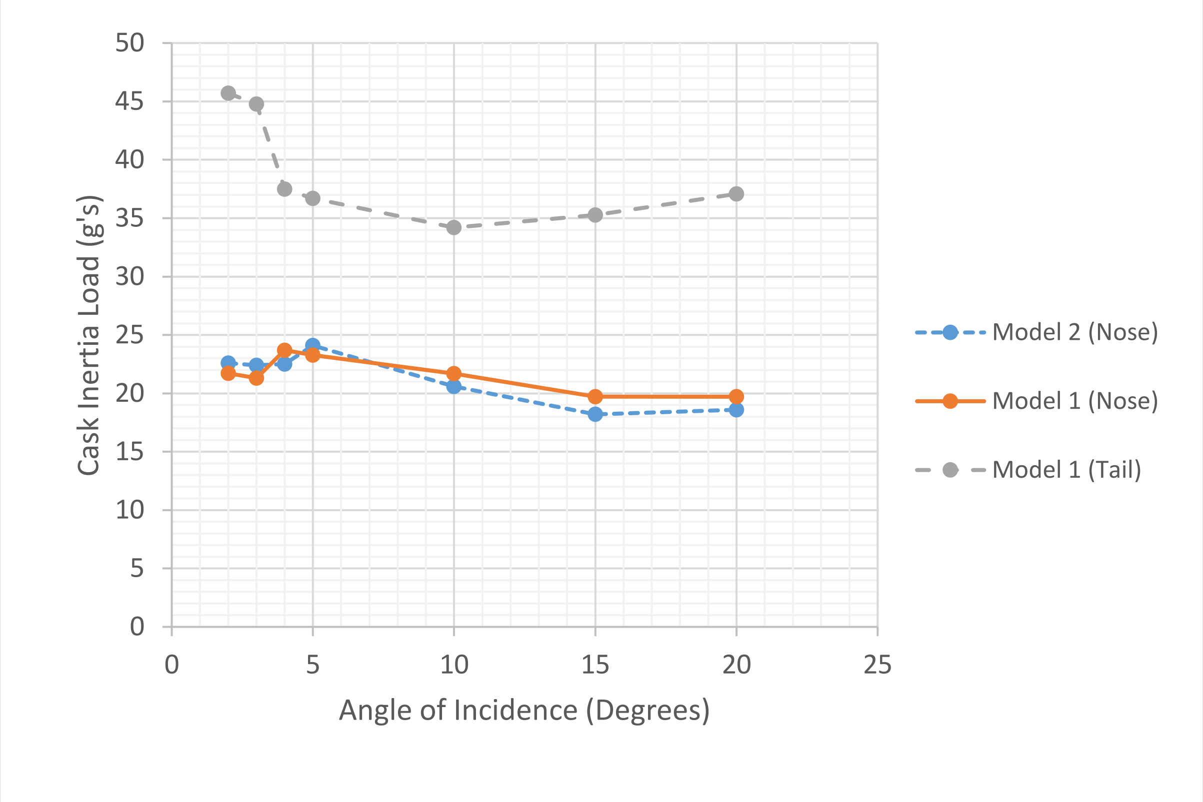


Figure 5. Model 1 (only impact limiters) vs Model 2 (impact limiter and plate) illustrating the moment of inertia's effect on the cask response

ACCOUNTING FOR THE MOMENT OF INERTIA

The analyst has several options that could be employed to adjust the moment of inertia for a given design. In general, the moment of inertia (I) (also known as the second moment of inertia) of a body with mass *m* about its centroid is defined as follows:

$$\int_m r^2 dm = I$$

For a solid cylinder in a slap-down scenario, the moment of inertia about its centroid as shown in Figure 1 is:

$$I = \frac{1}{4} M (R^2 + \frac{L^2}{3})$$

Where:

M = mass of the cylinder

L = length of the cask

R = radius of the cylinder

For a square plate, the moment of inertia about its centroid in a slap down scenario as shown in Figure 2 is:

$$I = \frac{1}{12} M(a^2 + b^2)$$

Where:

M = mass of the plate

a = length of the plate

b = thickness of the plate

The moment of inertia for the models examined in this work can be calculated about any axis by the above formulas in conjunction with the parallel axis theorem. The moment of inertia of the plate used in Model 2 is only a third of the impact limiter with respect to its own center of gravity. Observing the formulas presented, an analyst can manipulate mass and/or geometry of the model, but, must be mindful of other unintended changes when these variables are changed. For instance, in Model 2, increasing the mass of the plate can easily be used to increase the moment of inertia, but would change the centroid of the package if dimensions of the package are left as is. In order to maintain the center of gravity of Model 2 in this case, it would be tempting to then increase the density of the impact limiter in tandem with the plate, but such a material may not exist.

FUTURE CONSIDERATIONS

This work focused on one of many parameters that a designer has to consider when developing a test plan and constructing a prototype to be used in a drop testing campaign. In this work, friction forces that occur between the package and the target have not been considered. These forces typically generate an additional moment on the cask that can be investigated in a parametric study. Further investigations could involve changes to content weight, location, and unrestricted content movement.

REFERENCES

1) Mok, G.C., Carlson, R.W., Lu, S.C., and Fischer, L.E. *Guidelines for Conducting Impact Tests on Shipping Packages for Radioactive Material*. UCRL-ID-121673 Livermore National Laboratories, Livermore, CA September 1995.

2) Code of Federal Regulations, Title 10, Part 71, *Packaging and Transportation of Radioactive Material*.