Development of Honeycomb Impact Limiters

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INTRODUCTION

General Atomics (GA), has a contract with DOE's Office of Civilian Radioactive Waste Management (OCRWM) to develop two legal weight truck casks to transport spent fuel. The GA-4 and GA-9 Casks transport four pressurized-water-reactor (PWR) and nine boiling-water-reactor (BWR) spent fuel assemblies, respectively.

The preliminary designs for the GA-4 and GA-9 Casks include honeycomb impact limiters on the top and bottom of the cask bodies to protect them during any normal transport or hypothetical accident drop onto an unyielding surface. To evaluate the response of the cask during a drop, we need load versus deflection curves for the impact limiters at different impact angles. GA has developed an analytical method which in conjunction with engineering test results will be used to determine the impact limiter load versus deflection curves.

STRUCTURAL DESIGN

Honeycomb is well known for its efficient and predictable energy absorbing capabilities. Standard honeycomb is frequently used to provide impact protection in cases where the loading is in one direction. Because the standard honeycomb structure is unidirectional and its energy absorbing efficiency is reduced when crushed at angles off from the principal axis, this type of honeycomb is not commonly used for complete three dimensional impact limiters. Unidirectional honeycomb is used successfully on circumferential impact limiters and multi-directional honeycombs are used for complete impact limiters. GA found that a more weight efficient impact limiter can be designed with unidirectional honeycomb even though the impact limiter size increases.

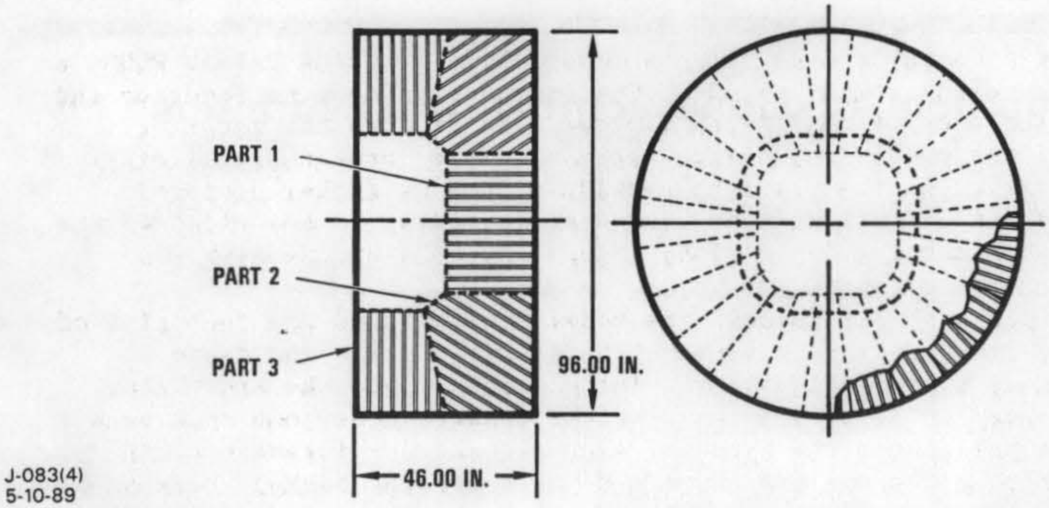

Figure 1. Preliminary Design of Honeycomb Impact Limiters for the GA-4 and GA-9 Casks

Figure 1 shows the preliminary design of the impact limiters used on both of the GA-4 and GA-9 Casks. The design uses standard aluminum honeycomb. Because the standard honeycomb structure is unidirectional, and the impact limiter absorbs energy in three dimensions, the impact limiter is made up of three basic parts shown in Figure 1:

Part 1 Covers the end section at the bottom or top of the cask. The cell orientation of the honeycomb is parallel to the length of the cask.

Part 2 Corner section around the cask. The part consists of twenty-four 15° segments. The honeycomb cell orientation of each segment lines up radially with the center of the cask at an angle of 30° from the length of the cask.

Part 3 Circumferential section around the sides of the cask. The part consists of twenty-four 15° segments. The cells of each segment lined up radially with the center of the cask and are perpendicular to the length of the cask.

All impact limiter surfaces are covered with an aluminum exterior surface which facilitates decontamination.

ANALYTICAL PROCEDURE

In order to obtain the load versus deflection curve for impact limiters with standard unidirectional honeycomb, GA developed a method that obtains the foot print of the crush and the backed area of honeycomb for any orientation and depth. A crush strength is then assigned to each part of the impact limiter depending on the backing conditions, cell orientations and crush angle. The steps required are described in the following sections.

The Model

GA created a computer model of the impact limiter using PATRAN PLUS, a geometry modeling computer code. The model contained the interior and exterior outlines of the impact limiter. We divided the interior outline of the model into pieces separating the three impact limiter parts described in the previous section. Then we futher divided Part 2 and Part 3 outline into segments, according to the width of the 15° honeycomb sections on a plane across the edge of the cask.

We used a plane to cut through the model and obtained the footprint of the impact limiter as it crushes at any desired angle and depth. Later we made a projection of the inner outline onto the crush footprint in order to determine the areas of crushed honeycomb that were backed. We calculated the areas of each segment at different crush depths. Figure 2 shows the model and the different backed areas on the impact limiter when crushed 28 inches at a 45° angle. Only half of the impact limiter is shown since the design is symmetric.

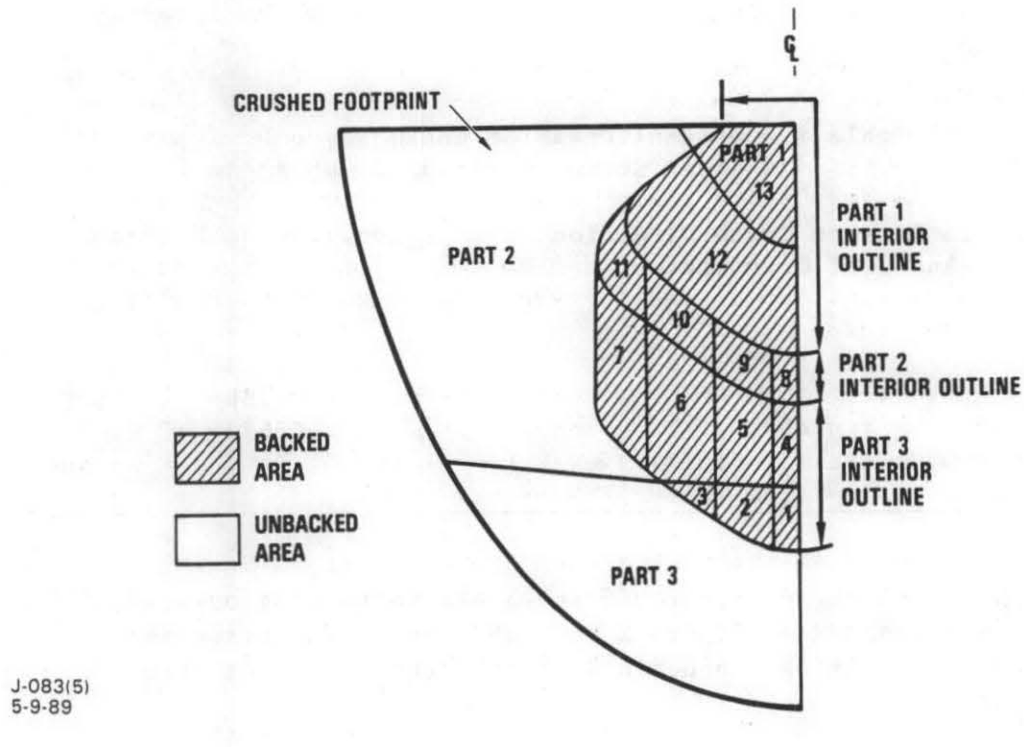

Figure 2. Model Showing Crush Footprint and Backed Areas for a Crush Angle of 45° and a Crush Depth of 28 Inches

Force Determination

In order to calculate the force required to crush any one segment on the model we assigned a crushing force that varies from the nominal honeycomb crush strength depending on the following parameters:

Orientation of the honeycomb cell axis with respect to the crushing direction.

Backing conditions:

Cask backing: The cask backs the crushed honeycomb.

Honeycomb backing: Honeycomb oriented at a different angle backs the crushed honeycomb.

Unbacked: The crushed honeycomb is not backed in any way. We assumed this honeycomb does not provide any energy absorption during deformation.

The paper "Development of Circumferential Honeycomb Impact Limiters for a Defense High Level Waste Shipping Cask" develops a method to establish the crush strength of honeycomb when the direction of crush varies from the direction of the honeycomb cell. This method determines the crush strength as a fraction of the nominal crush strength. Table 1 shows the effectiveness factors associated with different crushing angles.

Table 1. Effectiveness of the Honeycomb Crush Strength Versus Crush Angle

Angle Between Crush Direction And Cell Orientation	Effectiveness Factor
0°	1
15°	0.913
30°	0.756
45°	0.633

Table 2 shows how the combined effectiveness factors associated with the crush areas shown in Figure 2 were obtained. The force is obtained by multiplying the nominal crush strength by the effectiveness factor.

The analysis of the impact limiter must include the effects of temperature, strain rate and manufacturing tolerances on the honeycomb properties. The manufacturer of the honeycomb certifies the crush strength of the honeycomb to be within $^{+}$12.5% of the nominal value over the temperature range of -20°F to 200°F. This range includes all variances due to manufacturing and material tolerances. When subjected to a 44-ft/sec strain rate, the crushing strength of the honeycomb may increase above the static value. We have conservatively increased the crush strength 20% above the static crush value. These effects will be confirmed during engineering tests discussed in latter sections.

Table 2. Effectiveness Factors for Backed Areas of Impact Limiter Crushed at an Angle of 45° and a Depth of 28 Inches

AREA	PART BEING CRUSHED	BACKING		RADIAL DIRECTION		ANGLE OF PART		COMBINED EFFECTIVENESS FACTOR
		PART NO.	EFFECTIVENESS FACTOR	OF BACKING (DEGREES)	EFFECTIVENESS FACTOR	TO CRUSH DIRECTION (DEGREES)	EFFECTIVENESS FACTOR	
1	3	3	1	0	1	45	0.633	0.633
2	3	3	1	15	0.913	45	0.633	0.578
3	3	3	1	30	0.756	45	0.633	0.478
4	2	3	0	0	1	15	0.913	0
5	2	3	0	25	0.913	15	0.913	0
6	2	3	0	30	0.756	15	0.913	0
7	2	3	0	45	0.633	15	0.913	0
8	2	2	1	0	1	15	0.913	0.913
9	2	2	1	15	0.913	15	0.913	0.834
10	2	2	1	30	0.756	15	0.913	0.690
11	2	2	1	45	0.633	15	0.913	0.578
12	2	1	0.755	0	1	15	0.913	0.690
13	1	1	1	0	1	45	0.633	0.633

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Force Versus Deflection Curves

For each drop orientation desired, the force developed by the crushing footprint was determined for several crushing depths. A force versus deflection curve was then obtained for the impact limiter for crushing orientations ranging from an end drop to a side drop, at 15° increments.

The force versus deflection curves can be adjusted to include temperature and strain rate effects, and variations on crush strength due to manufacturing tolerances, thus creating a range of possible load versus deflection curves. Figure 3 shows the envelope of force versus deflection curves for the GA-4 and GA-9 Casks impact limiter crushing at a 45° angle.

TESTING

GA developed an engineering test program to confirm and support the assumptions made during design. The tests also help optimize the impact limiter design and provide actual load versus deflection curves at different impact directions.

The test program has two phases. GA will use the data developed during the first phase of testing to optimize the impact limiter design. The second phase will test the optimized impact limiters to develop actual load versus deflection curves at different angles of crush.

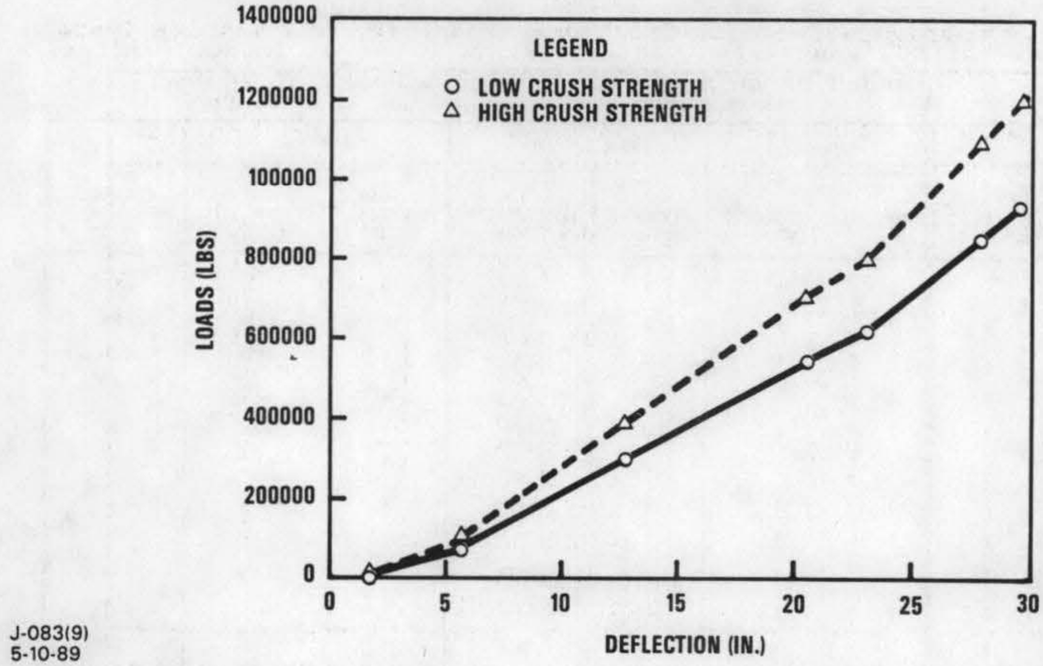

Figure 3. Envelope of Force-Deflection Curves for the GA-4 and GA-9 Casks Impacting at 45° Angle

First Phase

The first phase of the engineering tests is divided into two types of tests:

- Honeycomb Behavior Tests. The initial tests will provide the basis for understanding the behavior of honeycomb crushing at different angles and the effects of backing, scaling, temperature and impact velocity. Table 3 shows the tests planned to investigate crush angle, backing and scaling. In addition, small sample tests will be performed to investigate the variation of crush strength as a function of temperature and strain rate.

- Impact Limiter Behavior Tests. Recognizing that the interaction of the different honeycomb components in an impact limiter provides confinement and modifies the behavior of the honeycomb, the impact limiter will be tested to develop data on the behavior of the honeycomb in an impact limiter configuration. The test configuration will replicate the preliminary impact limiter design. Two crush angles will be tested on one 1/4-scale impact limiter test article.

Second Phase

The second phase of the engineering tests will obtain force versus deflection curves for six 1/4-scale impact limiters. Since the design of the impact limiter is not axisymmetrical, tests will be made with the impact on the corner and flat areas of the cask. Table 4 shows the angles that will be tested.

Table 3. Configurations for Crush Angle, Backing and Scaling Tests

TEST NO.	CRUSH ANGLE	SAMPLE SIZE (IN.)	NO. OF SAMPLES PER TEST
1	0°	4 x 7 x 5	
2	7.5°	4 x 7 x 5	2
3	15°	4 x 7 x 5	4[1]
4	22.5°	4 x 7 x 5	4[1]
5	30°	4 x 7 x 5	4[1]
6	37.5°	4 x 7 x 5	4[1]
7	45°	4 x 7 x 5	4[1]
8	45°	1/2 SCALE SECTION MODEL	2
9	45°	1/4 SCALE SECTION MODEL	2
10	0°	1/4 SCALE SECTION MODEL	2

[1] TWO SAMPLES WILL BE TESTED APPLYING LOAD IN THE RIBBON DIRECTION (L) AND TWO SAMPLES WILL BE TESTED APPLYING LOAD IN THE DIRECTION TRANSVERSE TO THE RIBBON (W).

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Table 4. Quarter-Scale Engineering Tests Planned to Demonstrate Impact Limiter Behavior

1)	90°	ACROSS DIAGONALS ↓
	15°	
2)	30°	
	75°	
3)	45°	
	60°	
4)	0°	
5)	15°	ACROSS FLATS ↓
	90°	
6)	45°	
	60°	

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INTEGRATION OF TEST AND ANALYSIS

After the tests are completed, a comparison of test and analytical results will be performed. The analytical approach will be adjusted, as appropriate, to better represent the behavior shown during the tests. This may include changing other variables, such as the effectiveness factors, the area calculations and the backing assumptions.

After test and analytical approach results are reconciled, the force versus deflection curves for orientations not tested will be produced by analysis.

ACKNOWLEDGMENTS

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REFERENCES

PATRAN PLUS, Computer Code, Version 2.2, Issued by PDA Engineering (1987).

Zimmer, A., Koploy, M., et al., "Development of Circumferential Honeycomb Impact Limiters For a Defense High Level Waste Shipping Cask", Vol I, p. 113, Waste Management '88.