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Verification of LS-DYNA Finite Element Impact Analysis by Comparison to Test Data and Classic First Principle Calculations

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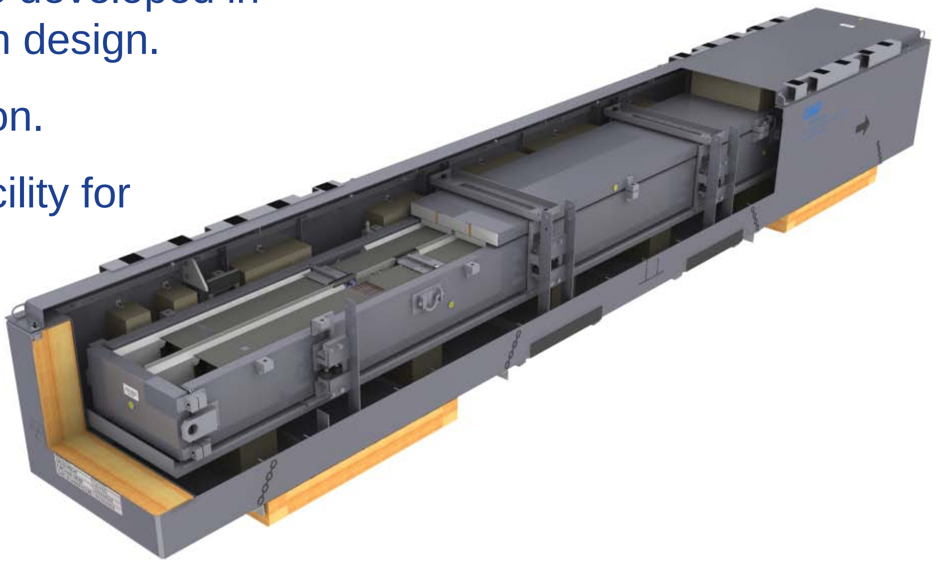
Introduction

Development:

- RAJ-II BWR fresh fuel transport package developed in Japan as replacement for first generation design.
- Drop tested in Japan for METI certification.
- Drop tested in USA at Oak Ridge, TN facility for NRC SAR.
- Drop tested in France by Japanese to validate loose rod container.



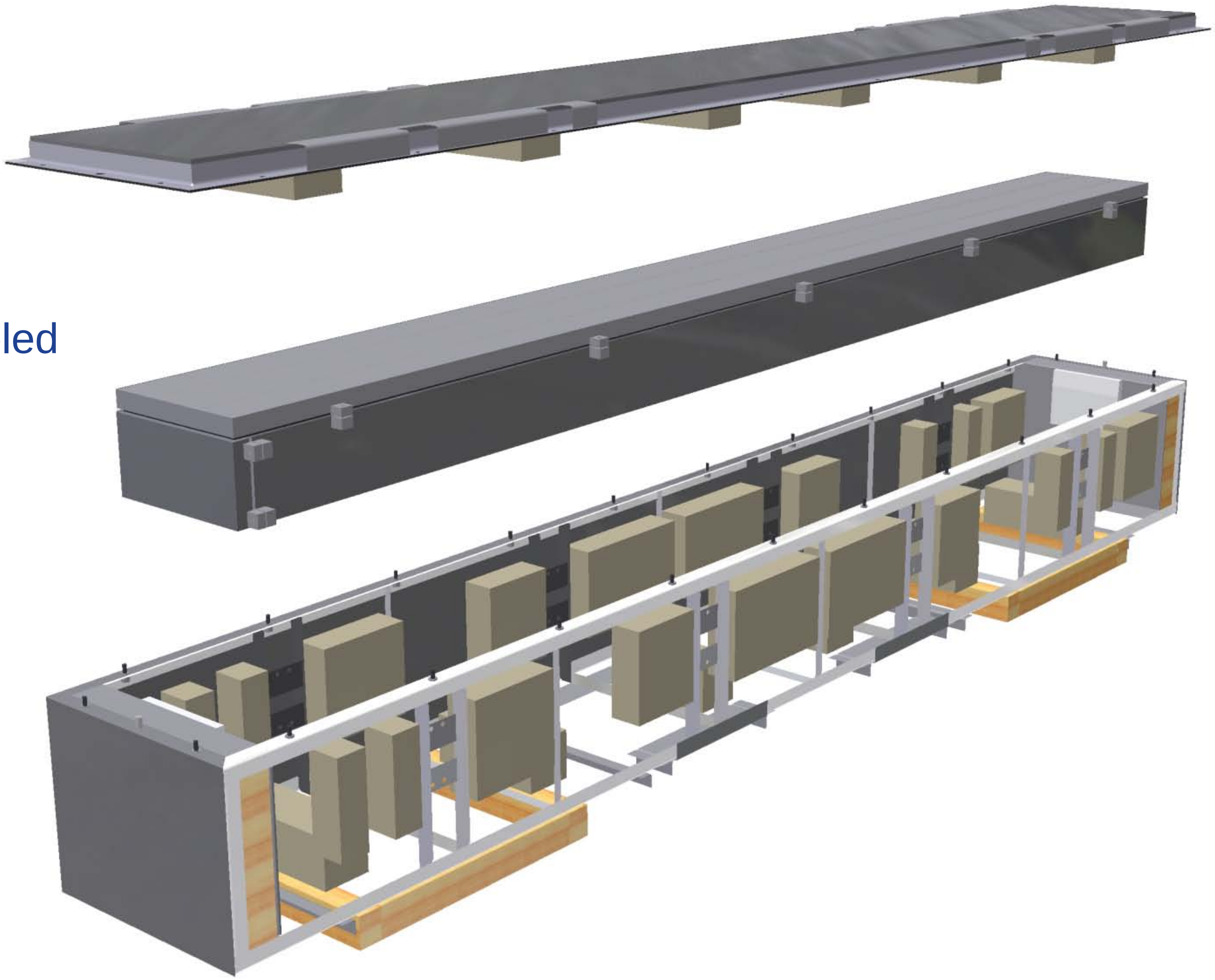
Licensing History:

- Licensed in Japan in the mid 1990’s.
- Licensed in USA in 2005 as replacement for GNF and AREVA first generation packages.
- 2007 – Present, GNF and Westinghouse licensing package in EU. During the licensing review additional information requested concerning the impact performance of the package with respect to IAEA TS-R-1.

LS-DYNA Model

Solid Model:

- Solid model developed in AutoDesk Inventor.
- Model developed from fabrication drawings.
- Crushable materials modeled as solid objects.
- Sheet metal modeled as Surfaces.



GNF
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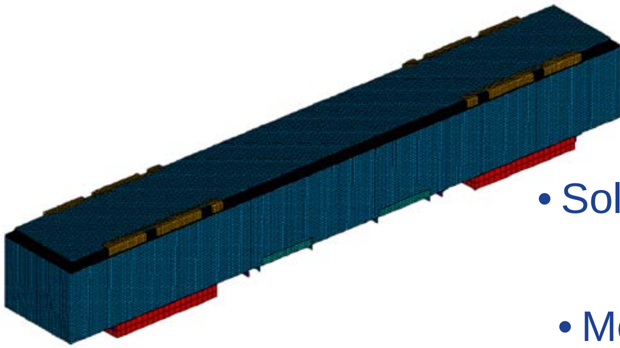
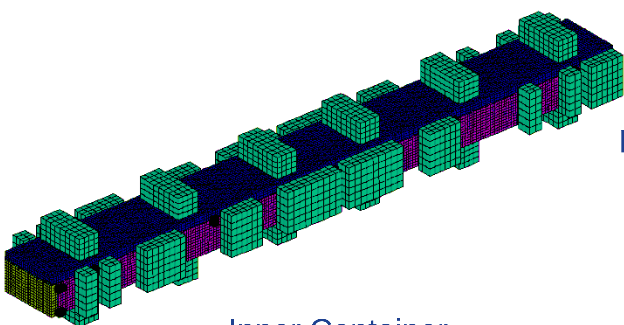
LS-DYNA Model



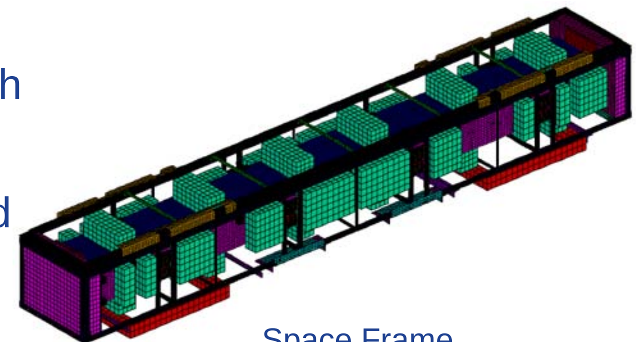
Package Assembly



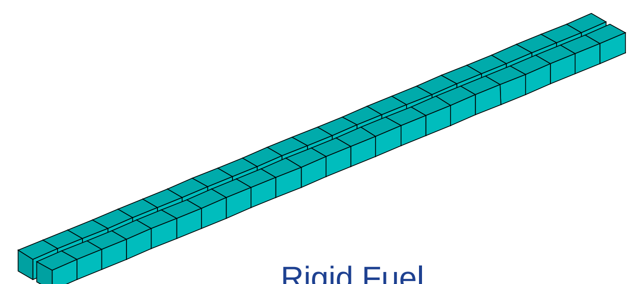
Inner Container with Honeycomb Block

FEA Model:

- Solid model imported into ANSYS Workbench.
- Model meshed with Workbench meshing tools.
- LS-DYNA keyword file created In ANSYS Mechanical.
- Crushable materials modeled with solid elements.
- Sheet metal modeled with shell elements.
- Total of 534853 nodes and 442331 elements



Space Frame



Rigid Fuel Bundle Payload

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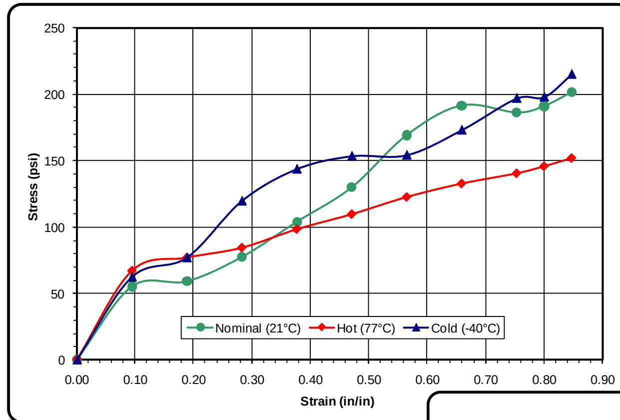
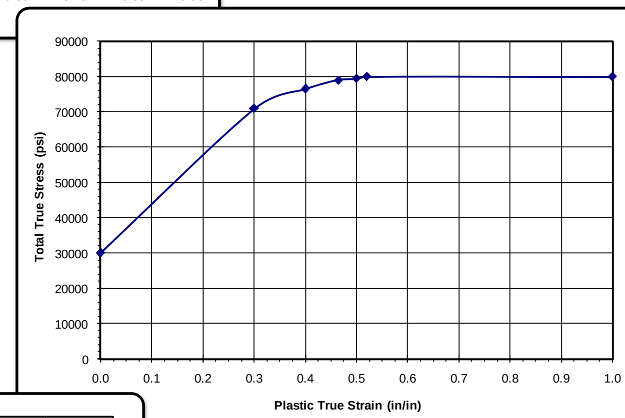
LS-DYNA Model

Material Properties:

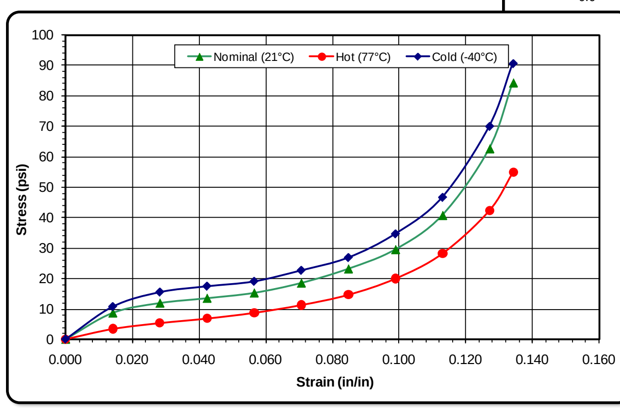
- Honeycomb and Ethafoam properties obtained through laboratory testing.
- Three temperature ranges test including –40°C, 21°C, and 77°C that represents cold, ambient, and hot conditions.
- LS-DYNA material types *MAT_HONEYCOMB and *MAT_CRUSHABLE_FOAM



Honeycomb Engineering Stress-Strain Properties



True Stress Versus True Strain for 304 SS



Ethafoam Engineering Stress-Strain Properties.

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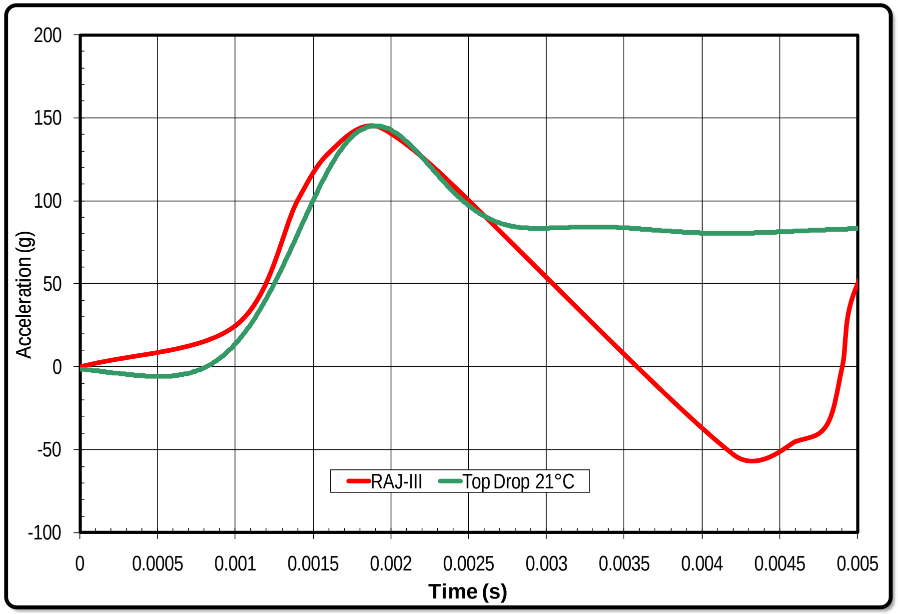
LS-DYNA Model

Benchmark with Test Results:

- LS-DYNA honeycomb material property defines an instantaneous modulus of elasticity that accounts for the column buckling of the honeycomb cell.
- The instantaneous modulus of elasticity was adjusted until the initial peak acceleration matched the French top drop test results.
- The French drop test represents the best recorded data for any of the RAJ-II test programs.



Benchmark of LS-DYNA with Drop Test Results

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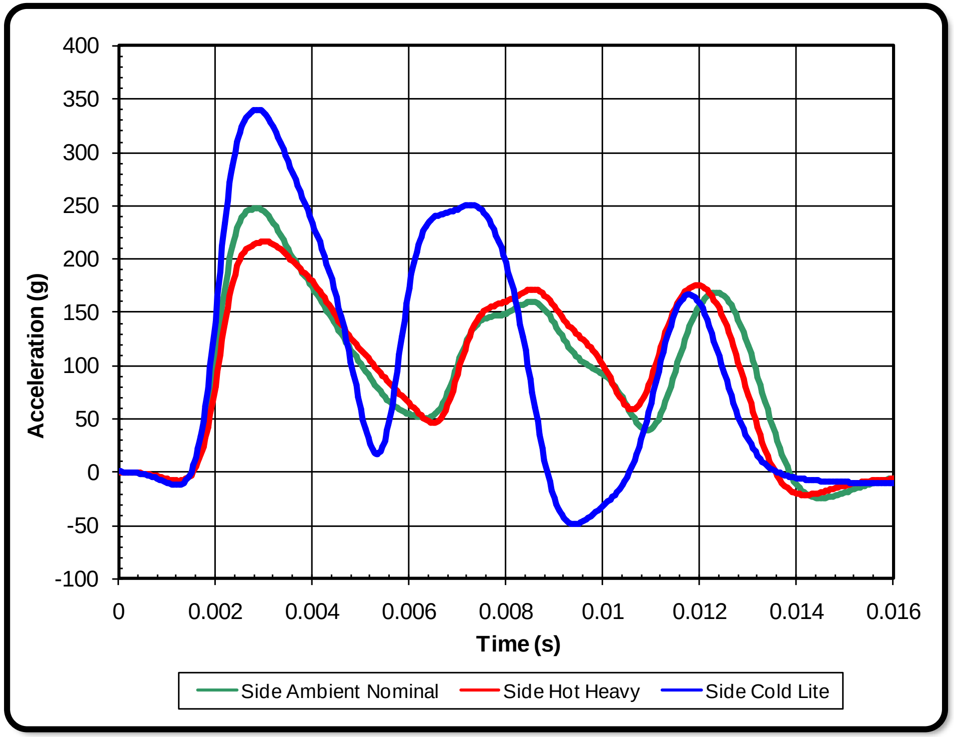
Analysis Results

Side Drop:

- Maximum accelerations occur when lightest fuel bundles is coupled with coldest temperature (-40°C). Accelerations increase 5%.
- Heaviest fuel bundle coupled with hot conditions results in 9% decrease in accelerations.
- The peak acceleration is 340g at 500 Hz.



Side Drop Accelerations
(Cold, Ambient and Hot Conditions)

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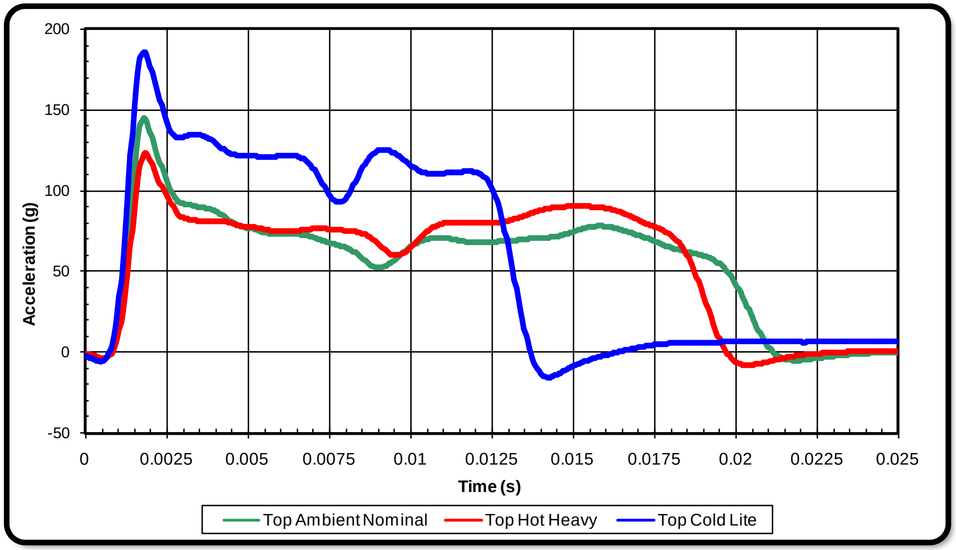
Analysis Results

Top Drop:

- Like the side drop maximum accelerations occur when lightest fuel bundles is coupled with coldest temperature (-40°C).
- The peak acceleration is 186g at 500 Hz.



Top Drop Accelerations
(Cold, Ambient and Hot Conditions)

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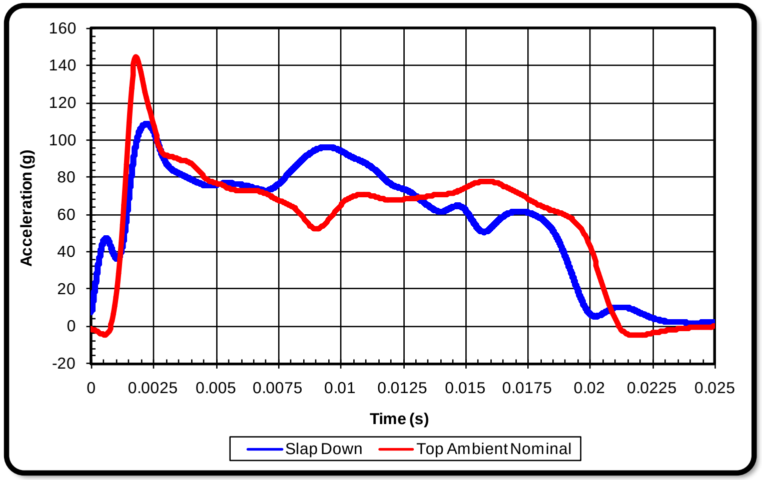
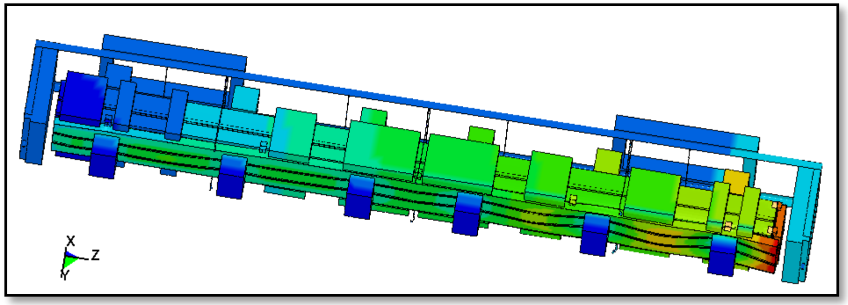
Analysis Results

Slap-down/Whiplash:

- The analysis results show that the RAJ-II is more efficient during the slap-down event than the flat top drop.
- During slap-down, honeycomb surface area is initially only available at the point impact and gradually increases as the impact progresses.
- Due to the geometry of the packaging, the initial peak acceleration is much higher during the flat top or side events.



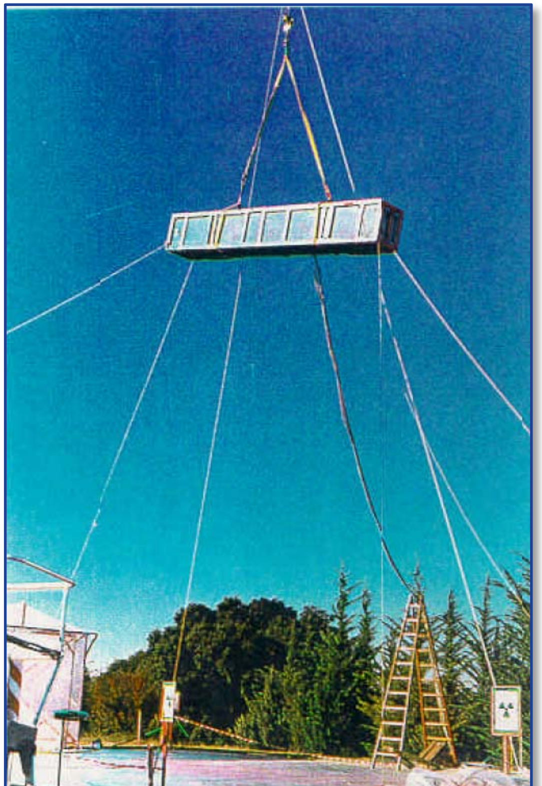
Top Drop versus Slap-down Accelerations



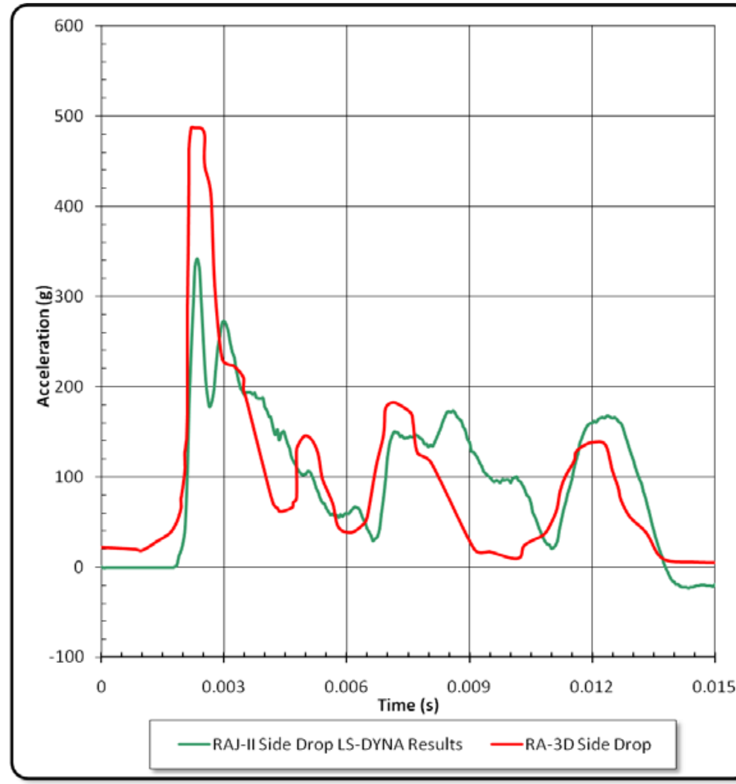
Benchmarking

Comparison with Historic Test Results:

- To benchmark the LS-DYNA analysis results, comparison to historic drop test is used.



- The RA-3D package is a first generation design similar to the RAJ-II
- RA-3D drop tests included natural uranium bundles of common designs to perform the regulatory testing.



Comparison of LS-DYNA and RA-3D Test

- Good agreement between the RAJ-II LS-DYNA analysis results and RA-3D test results including the impact duration. The peak acceleration of the RA-3D is higher than that of the RAJ-II because of increased honeycomb surface area during the initial impact.

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Benchmarking

Impact Predictions with Classic First Principle Calculations:

- To further benchmark these results, a hand calculation predicts the peak acceleration.

DYNAMICS OF PACKAGE CUSHIONING

by

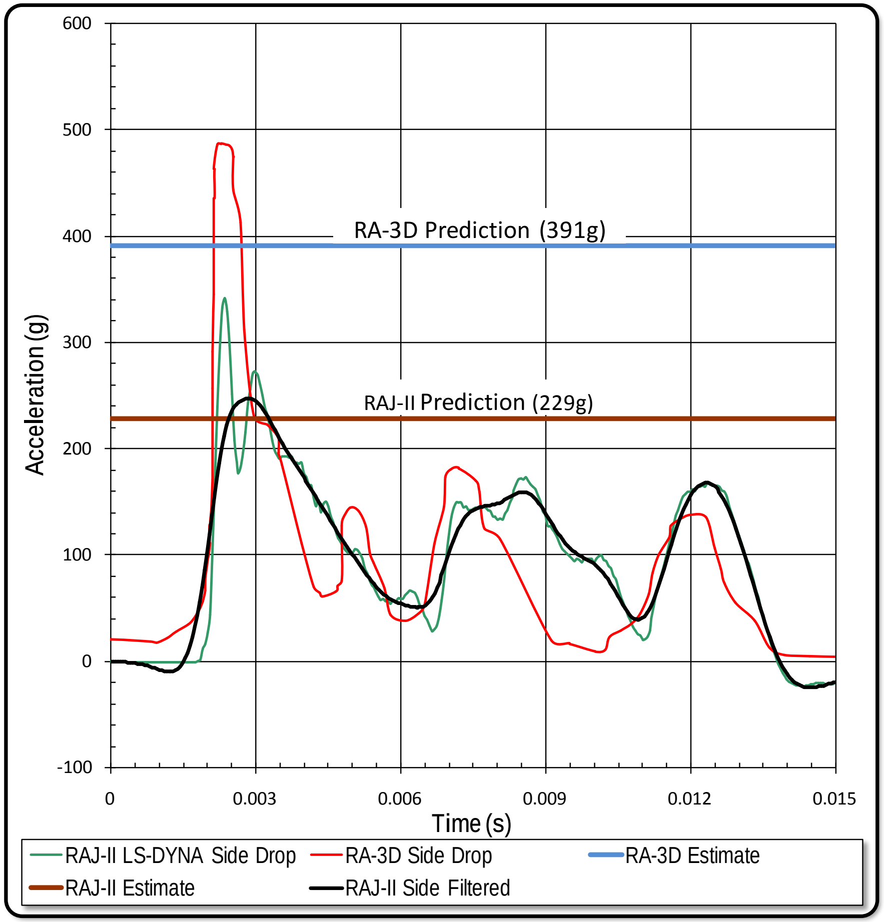
R. D. Mindlin
Bell Telephone Laboratories

July 1945

BELL TELEPHONE SYSTEM
TECHNICAL PUBLICATIONS
MONOGRAPH B-1369

- Benchmarking possible because of the simple geometry of the RAJ-II and RA-3D honeycomb design.

- Methodology developed by Mindlin established the basis for predicting acceleration of packaged items.



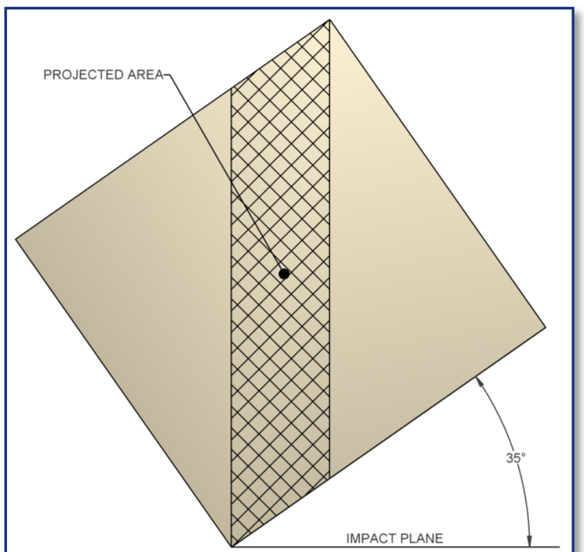
LS-DYNA, RA-3D Test, and Hand Calculations

- Using this methodology able to provide reasonable estimate.

Verification

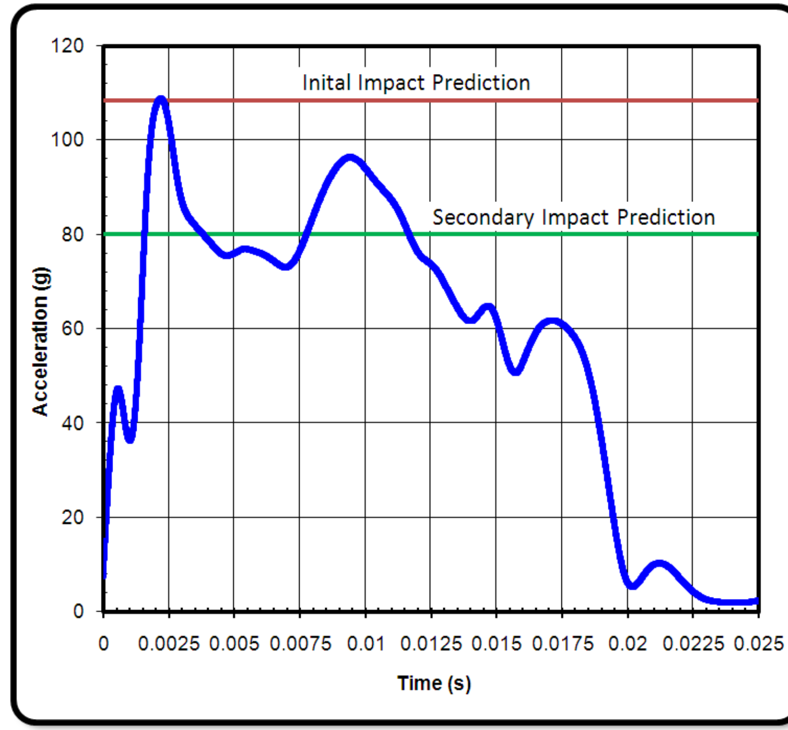
Independent Verification using Classic First Principle Calculations:

- To further benchmark these results, a hand calculation predicts the peak acceleration.



- Using the Mindlin method, independent verification was performed to predict the initial and secondary impact during slap-down.

- The load was considered to be carried by only the cross section of the honeycomb block supported by the bottom of the container parallel to the acceleration.



LS-DYNA Slap-Down Results Compared to Hand Calculations

- The estimate of the peak acceleration during the initial impact is within 2g of the acceleration predicted by LS-DYNA. The hand calculation estimates a lower acceleration for the secondary peak as compared to LS-DYNA. However, the hand calculation values closely corresponds to the values predicted by the computer model.

Conclusions

- This evaluation shows that testing, finite element analysis, and first principle calculations are all good methods for evaluating the performance of a package.
- With all methods, the key to good results is having well defined geometry and materials.
- When all three methods are utilized, it is possible to benchmark analytical models that can be used to further improve packaging design.

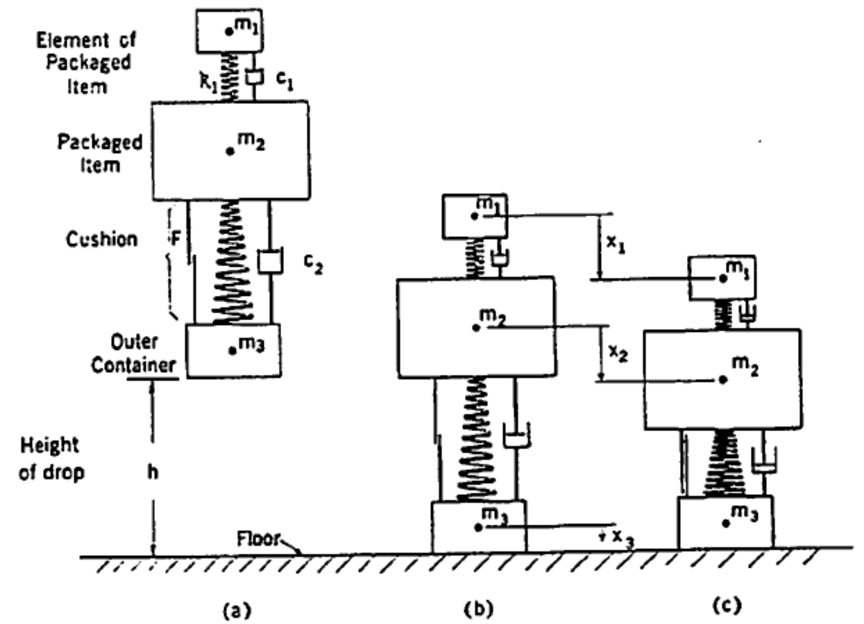


Fig. 0.2.2—Idealized mechanical system representing a package in a drop test.

PART I

MAXIMUM ACCELERATION AND DISPLACEMENT