# TEST CASE DOCUMENTATION AND TESTING RESULTS (TESTED WITH LS-DYNA® R5.1.1 REVISION 67000)

# TEST CASE ID AEROQA-4

## Blade Containment - Blade Fragment impacts Zylon Fabric

Prepared by LS-DYNA® Aerospace Working Group

| Document Information | |
|---|---|
| Confidentiality | **external use** |
| Document Identifier | LSTC-QA-LS-DYNA-AEROQA-4-1 |
| Number of pages | 19 |
| Date created | Wednesday 6th July, 2011 10:24 |
| Distribution | LS-DYNA® Aerospace Working Group / internal LSTC QA |

## Disclaimer:

# Contents

# 1 Introduction

## 1.1 Purpose of this Document

This document specifies the test case AEROQA-4. It provides general test case information like name and ID as well as information to the confidentiality, status, and classification of the test case.
A detailed description of the test case is given, the purpose of the test case is defined, and the tested features are named. The test case specifications also state the target measures for testing and the expected results, as well as their pass and fail criteria.
Testing results are provided in section 5 for the therein mentioned LS-DYNA® version and platforms.

# 2 Test Case Information

| Test Case Summary | |
|---|---|
| Confidentiality | external use |
| Test Case Name | Blade Containment - Blade Fragment impacts Zylon Fabric |
| Test Case ID | AEROQA-4 |
| Test Case Status | active |
| Test Case Classification | Validation |
| Test Case Source | NASA Glenn Research Center<br>Arizona State University<br>Honeywell Engines, Systems and Services<br>SRI International |
| Tested Keyword | *MAT_USER_DEFINED_MATERIAL_MODELS,<br>*CONTACT_AUTOMATIC_SINGLE_SURFACE,<br>*CONTACT_AUTOMATIC_SURFACE_TO_SURFACE |
| Member of Test Suite | AEROQA SUITE |
| Metadata | AEROQA |

Table 1: Test Case Summary

# 3 Test Case Specification

## 3.1 Test Case Purpose

The purpose of QA Test Case ID AEROQA-4 is the validation of an impact experiment on layered dry fabric rings performed at NASA Glenn Research Center [2] . The reliability and consistency of LS-DYNA® as a finite element solver for this impact simulation involving textile structures is evaluated by performing analyses with different modelling approaches for the textile (see table 4).

## 3.2 Test Case Description

This QA Test Case contains an impact analysis (see figure 1) using a 304L stainless steel projectile impacting 24 layers of dry fabric rings made from Zylon AS®.

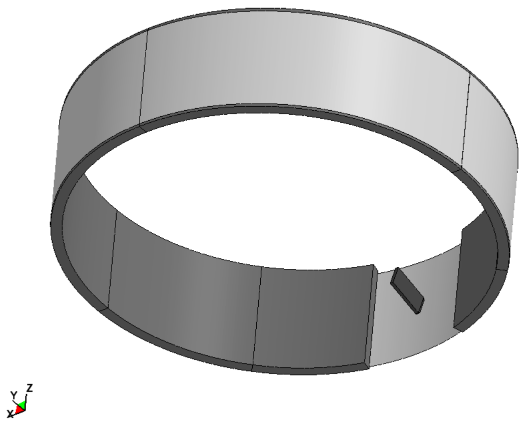


Figure 1: Model sketch: 304L stainless steel projectile impacting 24 layers of Zylon AS®

Table 2 contains a short summary of the physical model set up. Details on the experimental set up can be found in [2].

| Physical Model Information | |
|---|---|
| ring geometry | outer diameter = 40.0”<br>inner diameter = 38.0”<br>hight = 10.0” |
| ring opening | 10.0” |
| fabric geometry | 24 layers, hight = 10.0” |
| fabric material | Zylon AS® PBO |
| Fabric areal density | 0.01575 g/cm$^2$ |
| projectile geometry | length = 4.0” , high = 2.0”, thickness = 0.188” |
| projectile mass | 0.7 lb |
| projectile material | 304L stainless steel |
| projectile initial velocity | 10800.00 in/ms (incline 15 degree) |
| projectile final velocity | 0.00 in/ms |

Table 2: Model set-up data

## 3.3 Model Description

The model geometry is discretized with solid elements for the projectile and shell elements for the layers of dry fabric rings (see figure 2). The number of elements and material specifications for the model can be found in table 3.

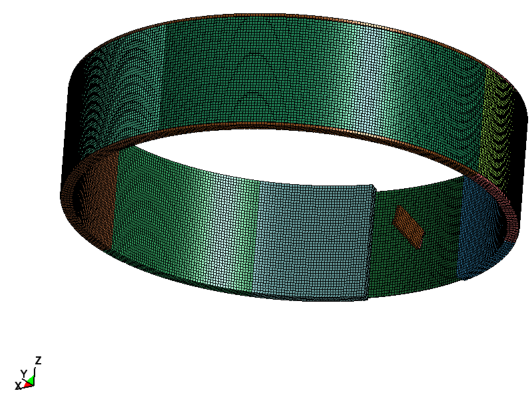


Figure 2: FEA model: 304L stainless steel projectile impacting 24 layers of Zylon AS®

| **FEA Model information** | | | | | | |
|---|---|---|---|---|---|---|
| Sub Test Case ID [1] | 1 | 2 | 3 | 4 | 5 | 6 |
| Nodes | 120695 | 120695 | 120695 | 141359 | 162023 | 182687 |
| Solid elements | 77888 | 77888 | 77888 | 77888 | 77888 | 77888 |
| Solid materials | 8 | 8 | 8 | 8 | 8 | 8 |
| Shell elements | 20130 | 20130 | 20130 | 40320 | 60480 | 80640 |
| Shell materials | 5 | 5 | 5 | 5 | 5 | 5 |
| Parts | 13 | 13 | 13 | 13 | 13 | 13 |
| Number of shell layers | 1 | 1 | 1 | 2 | 3 | 4 |
| Integration points per layers | 24 | 24 | 24 | 12 | 8 | 6 |
| fabric material | *MAT_USER_DEFINED_MATERIAL_MODELS [2] | | | | | |
| ring geometry | outer diameter = 40.0” Thickness = 1.0” hight = 10.5” | | | | | |
| fabric geometry | hight = 10.0” | | | | | |
| projectile geometry | length = 4.0” , high = 2.0”, thickness = 0.3125” | | | | | |
| projectile velocity | $v_y = -10.47836$ in/ms $v_x = -2.8076701$ in/ms | | | | | |

[1] Sub Test Case ID refers to the ID's in table 4

[2] For details on this user material see [3]

Table 3: FEA Model Information

Six variations (called sub test cases) of the model are set up with different discetization approaches for the 24 fabric layers in the physical model, and different treatment of the segment-based contact (SBOPT parameter), and optional solid element thickness (SLDTHK parameter). A summary of these six sub test cases can be found in table 4.

| Sub Test Case ID | SBOPT [1] | SLDTHK [2] | Shell Layers [3] | IP [4] | Input Deck Name |
|---|---|---|---|---|---|
| 1 | 0 | 0.000 | 1 | 24 | zylon1x24.k |
| 2 | 4 | 0.016 | 1 | 24 | zylon1x24_sliding_option.k |
| 3 | 0 | 0.016 | 1 | 24 | zylon1x24_solid_thickness_ls971only.k |
| 4 | 0 | 0.000 | 2 | 12 | zylon2x12.k |
| 5 | 0 | 0.000 | 3 | 8 | zylon3x8.k |
| 6 | 0 | 0.000 | 4 | 6 | zylon4x6.k |

[1] Parameter SBOPT in optional Card A in *CONTACT keyword (see [1] for Details)
[2] Parameter SLDTHK in optional Card B in *CONTACT keyword (see [1] for Details)
[3] Number of shell layers for discretization of the 24 Layers in the physical model

[4] Number of integration points per shell layer, IP times number of shell layers equals 24 layers in the physical model

Table 4: Specification of sub test cases

The material definitions and their parameters can be found in the input decks.

# 4 Test Specifications

## 4.1 Test Case Targets

Table 5 displays the test case targets. The test case targets specify values or a series of values taken from the finite element analysis solution of the test case and they are used in a comparison of analysis results and experimental data. They are chosen in a way that they can be directly or indirectly compared to the experimental determined values or observations.

| Test Case Targets | | | | |
|---|---|---|---|---|
| Target number | output | component type | component name | retrieved from |
| 1. | kinetic energy | part | 1136 | binout/matsum file |
| 2. | kinetic energy | part | 1236 | binout/matsum file |

Table 5: Test Case targets for QA Test Case ID AEROQA-4

The target values are chosen to identify the kinetic energy loss of the projectile during the impact event. Target number 1 is the kinetic energy of the body of the projectile (see figure 3 for definition of the body and the cap of the projectile). Target number 2 is the kinetic energy of the cap of the projectile, the part which comes initially in contact with the fabric. The targets are used to evaluate the perforation of the fabric (see section 4.2).

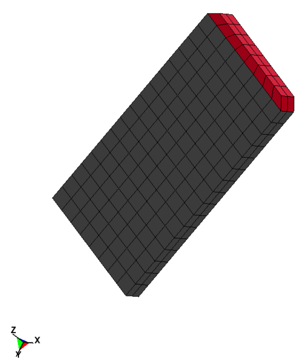

Figure 3: Part identification of the projectile: Grey coded is part 1136 (body), red coded is part 1236 (cap)

## 4.2 Pass/Fail Criteria

These are the Pass/Fail criteria used for the Validation of the Test Case ID AEROQA-4.

A test case passes if all of the following criteria are reached:

- The test case target 1 (kinetic energy part 1136) is less than 20% of the initial kinetic energy.
- The test case target 2 (kinetic energy part 1236) is less than 20% of the initial kinetic energy.

Otherwise the Validation fails.

# 5 Test Case Results

## 5.1 Software and Hardware Specifications

In order to ensure cross cpu architecture consistency, the herein mentioned sub test cases are run on platforms specified in table 6 and the results are calculated with software versions defined in table 7.

| Platform Name | CPU type | MPI-Protocol | Number of cpu's [1] |
|---|---|---|---|
| sandwich | Intel® Xeon® E7- 8837 @ 2.67GHz | hpmpi | 4 |
| ham | AMD® Opteron ® Processor 8435 @ 800MHz | hpmpi | 4 |
| sgi64d | Intel® Itanium® 2 @ 1.6GHz | hpmpi | 4 |

[1] Number of cpu's used for calculation of the test case

Table 6: Used Platforms and CPU Type's

| Product | Version | Release | Revision | Parallel type [1] | Precision [2] | executable |
|---|---|---|---|---|---|---|
| LS-DYNA® | 971 | R5.1.1 | 67000 | SMP | SP | ls971.67000.R5.1.1 |
| LS-DYNA® | 971 | R5.1.1 | 67000 | SMP | DP | ld971.67000.R5.1.1 |
| LS-DYNA® | 971 | R5.1.1 | 67000 | MMP | SP | mpp971.67000.R5.1.1 |
| LS-DYNA® | 971 | R5.1.1 | 67000 | MMP | DP | mpd971.67000.R5.1.1 |

[1] MPP = Massively Parallel Processing, SMP = Symmetric Multiprocessing

[2] SP = single precision, DP = double precision

Table 7: Tested LS-DYNA® version

## 5.2 Results Summary

Table 8 contains the results of the QA Test Case ID AEROQA-4 completed with all combinations of software and hardware defined in section 5.1 (6 * 3 * 4 total calculation runs).
Details on the test results can be found in the section 5.3.

The table 8 cross cpu architecture consistency summary is:

- **PASS** - Pass criteria in section 4.2 is attained.
- **FAILED** - Pass criteria in section 4.2 is not attained.

| Sub Test Case ID | PASS/FAILED |
|---|---|
| 1 | **PASS** |
| 2 | **PASS** |
| 3 | **PASS** |
| 4 | **FAILED** |
| 5 | **PASS** |
| 6 | **PASS** |

Table 8: Validation results summary for QA Test Case ID AEROQA-4

## 5.3 Result Details

The following subsections contain detailed results for the QA Test Case ID AEROQA-4 for LS-DYNA® R5.1.1 Revision 67000.

For each sub test case defined in section 3.3 there is a graph displaying the time history of the result target defined in 4.1 for the platform and software version combinations defined in section 5.1.

The title of the graph states the name of the input deck, the result file name, and the output separated by underscores. The legend contains the result file name, output, platform, and executable. The last number of the legend specifies the number of cpu's used to calculate the example. A leading minus sign refers to the compatibility option for SMP calculations (see [1] for details on this option).

**Example for title and legend:**

*Title:*
'zylon1x24.k: matsum_kinetic_energy_1136 R^2=0' states that the input deck for sub test case 1 was used to calculate these results. The component displayed is the kinetic energy of part 1136 derived from the 'matsum' output file.

*Legend:*
'matsum_kinetic_energy_1136_sandwich_ls971.67000.R5.1.1_4' states that the graph shows the kinetic energy of part 1136 derived from the 'matsum' output file for an input deck which was calculated on the 'sandwich' platform with a LS-DYNA® R5.1.1 Revision 67000 binary (SMP, single precision) on four processors.

### 5.3.1 Sub Test Case ID 1 - Test Target 1

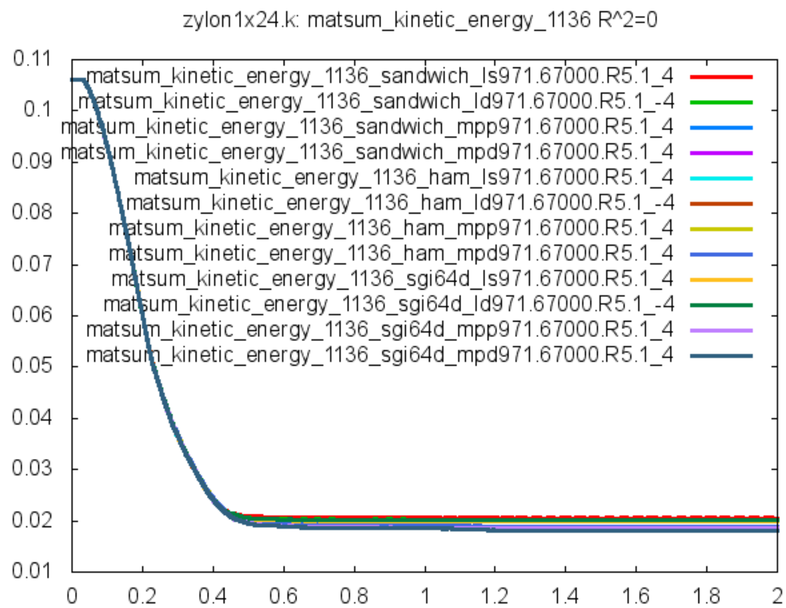


Figure 4: Cross platform results, kinetic energy part 1136, sub test case ID 1

### 5.3.2 Sub Test Case ID 1 - Test Target 2

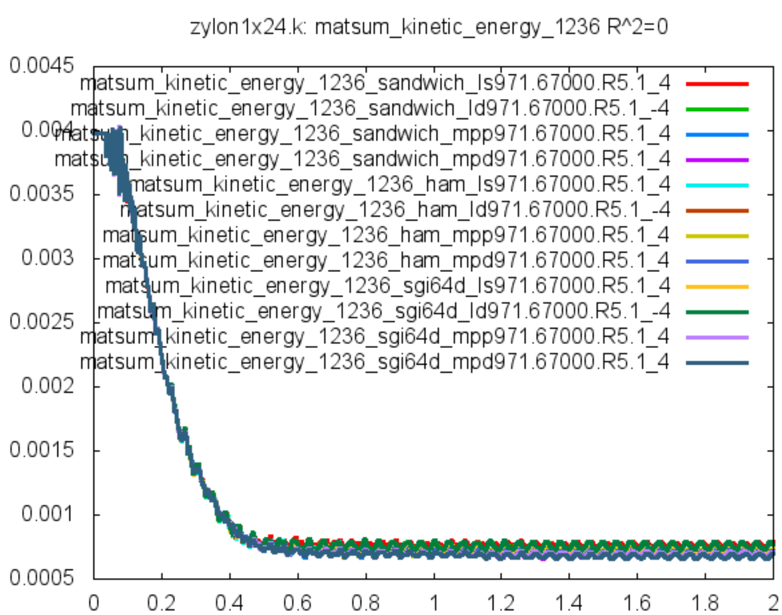


Figure 5: Cross platform results, kinetic energy part 1236, sub test case ID 1

### 5.3.3 Sub Test Case ID 2 - Test Target 1

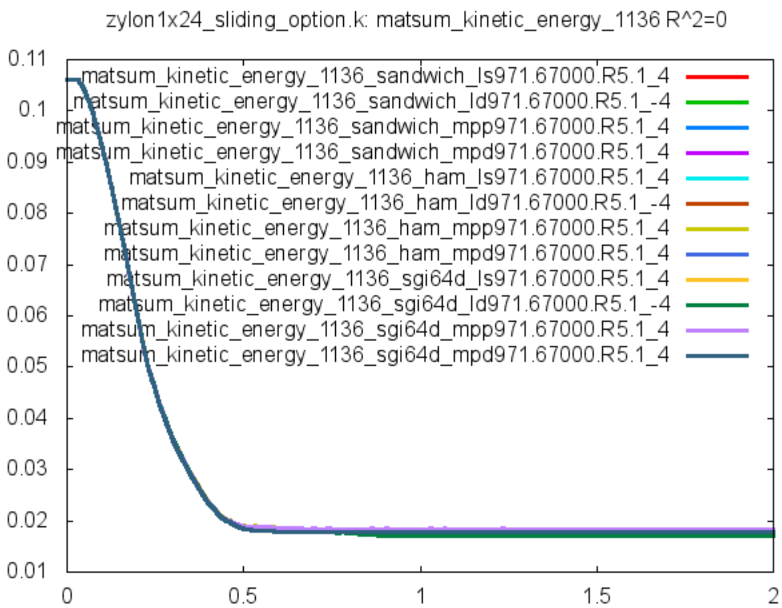


Figure 6: Cross platform results, kinetic energy part 1136, sub test case ID 2

### 5.3.4 Sub Test Case ID 2 - Test Target 2

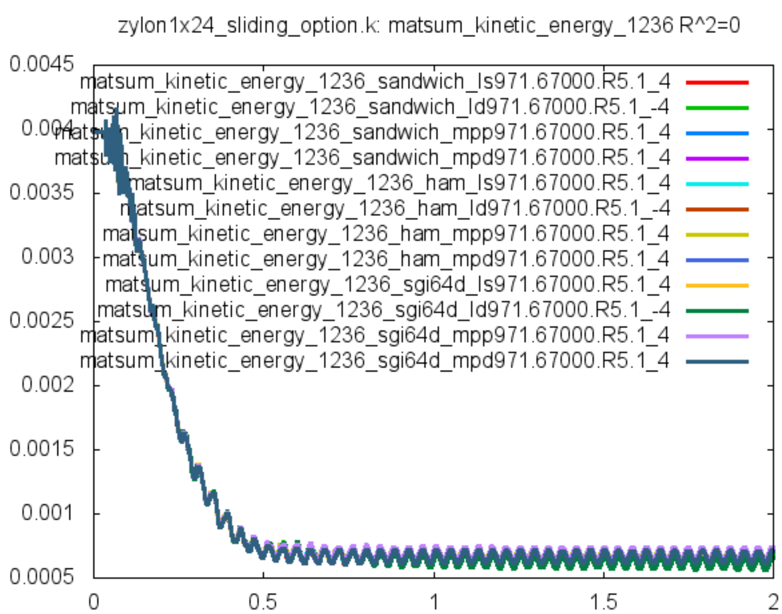


Figure 7: Cross platform results, kinetic energy part 1236, sub test case ID 2

#### 5.3.5 Sub Test Case ID 3 - Test Target 1

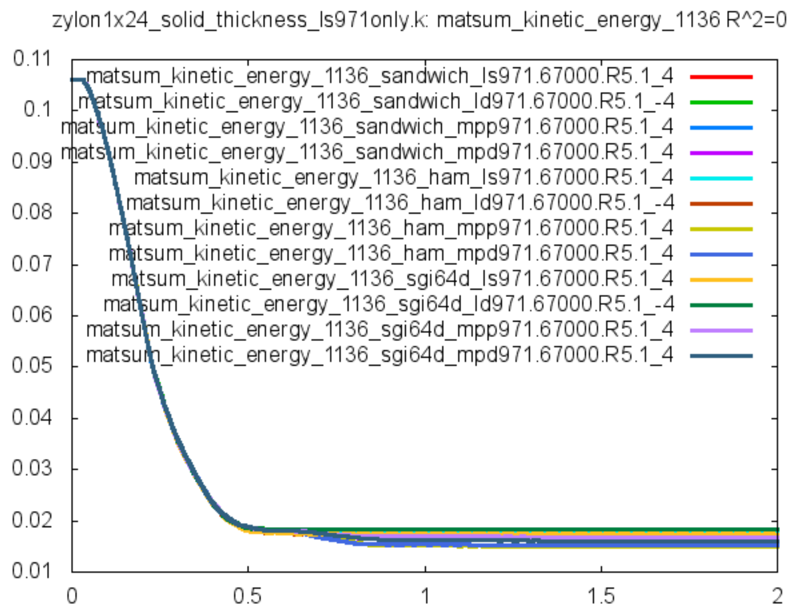


Figure 8: Cross platform results, kinetic energy part 1136, sub test case ID 3

#### 5.3.6 Sub Test Case ID 3 - Test Target 2

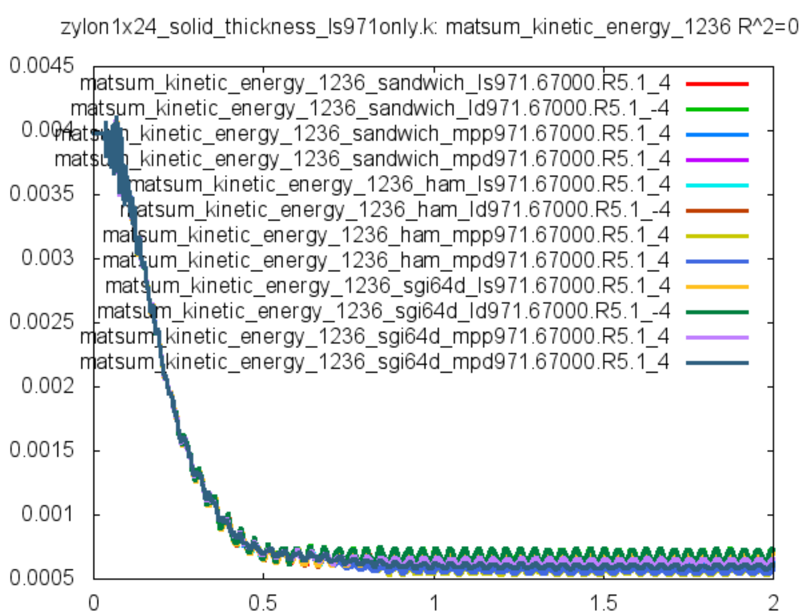


Figure 9: Cross platform results, kinetic energy part 1236, sub test case ID 3

#### 5.3.7 Sub Test Case ID 4 - Test Target 1

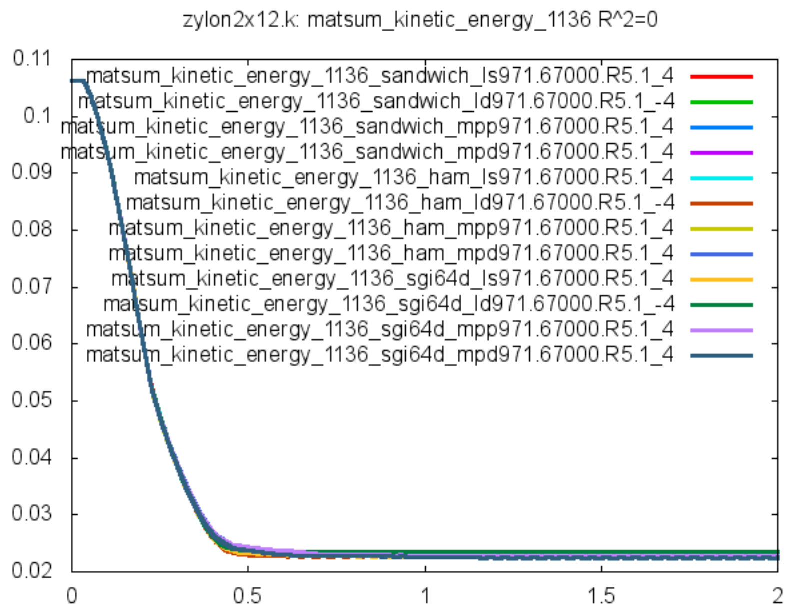


Figure 10: Cross platform results, kinetic energy part 1136, sub test case ID 4

#### 5.3.8 Sub Test Case ID 4 - Test Target 2

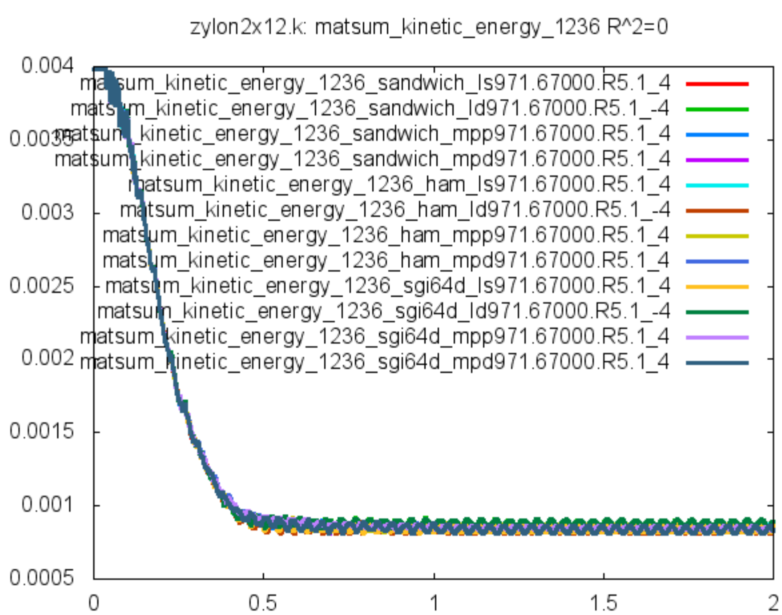


Figure 11: Cross platform results, kinetic energy part 1236, sub test case ID 4

### 5.3.9 Sub Test Case ID 5 - Test Target 1

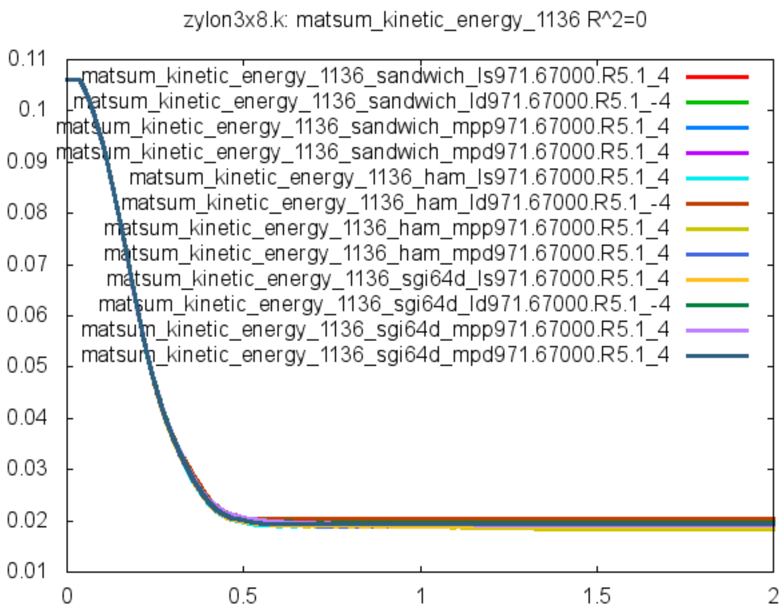


Figure 12: Cross platform results, kinetic energy part 1136, sub test case ID 5

### 5.3.10 Sub Test Case ID 5 - Test Target 2

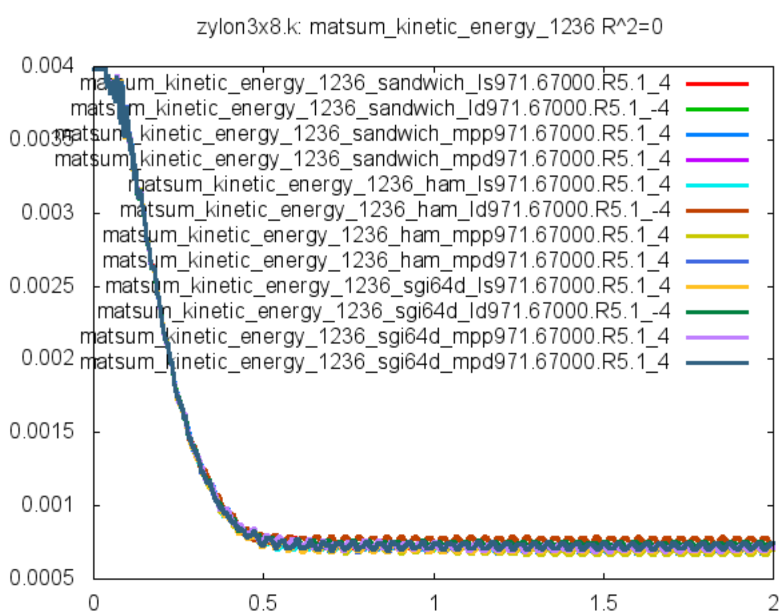


Figure 13: Cross platform results, kinetic energy part 1236, sub test case ID 5

#### 5.3.11 Sub Test Case ID 6 - Test Target 1

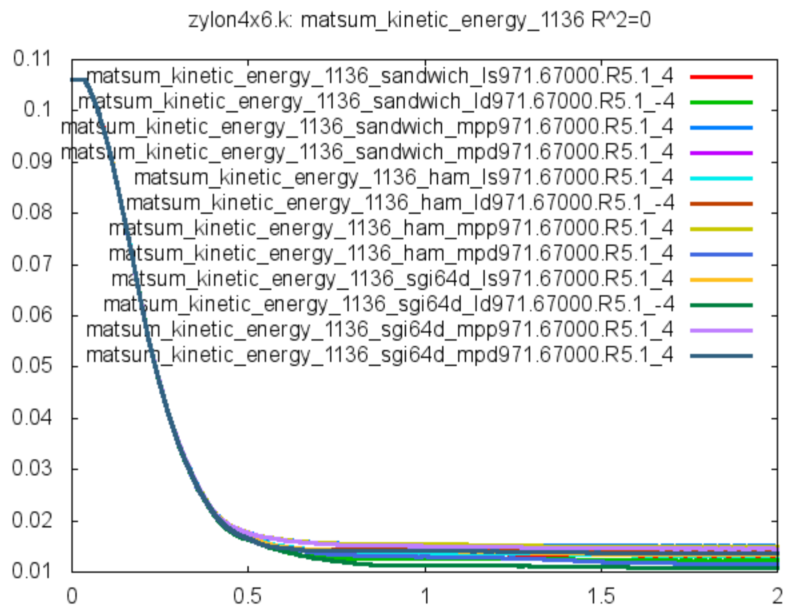


Figure 14: Cross platform results, kinetic energy part 1136, sub test case ID 6

#### 5.3.12 Sub Test Case ID 6 - Test Target 2

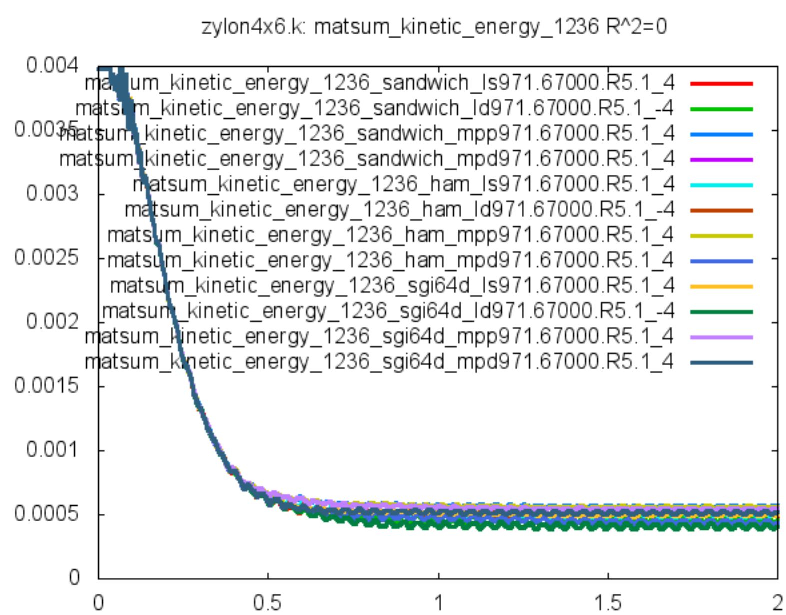


Figure 15: Cross platform results, kinetic energy part 1236, sub test case ID 6

# References

[1] LSTC, *LS-DYNA KEYWORD USER MANUAL*, 7374 Las Positas Road, Livermore, CA, 94551, USA, version 971 ed., May 2007.

[2] J. M. Pereira and D. M. Revilock, *Explicit Finite Element Modeling of Multilayer Composite Fabric for Gas Turbine Engine Containment, Part 2: Ballistic Impact Testing*, Final Report DOT/FAA/AR-04/40,P2, U.S. Department of Transportation, Federal Aviation Administration, Office of Aviation Research, Washington, D.C. 20591, November 2004.

[3] J. Simmons, D. Erlich, and D. Shockey, *Explicit Finite Element Modeling of Multilayer Composite Fabric for Gas Turbine Engine Containment, Part 3: Model Development and Simulation of Experiments*, Final Report DOT/FAA/AR-04/40,P3, U.S. Department of Transportation, Federal Aviation Administration, Office of Aviation Research, Washington, D.C. 20591, November 2004.