TEST CASE DOCUMENTATION AND TESTING RESULTS

LSTC-QA-LS-DYNA-AEROQA-7-3

TEST CASE ID AEROQA-7

Ballistic Impact on Composite Plate

Tested with LS-DYNA® R6.1 Revision 74159

Friday 25th May, 2012

LSTC Livermore Software Technology Corp.

Warranty Disclaimer:

Document Information	
Confidentiality	**external use**
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Contents

1 Introduction

1.1 Purpose of this Document

This document specifies the test case AEROQA-7. 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	Ballistic Impact on Composite Plate
Test Case ID	AEROQA-7
Test Case Status	active
Test Case Classification	Validation
Test Case Source	Boeing UC Berkeley - Mechanical Engineering Department
Tested Keyword	*MAT_COMPOSITE_DMG_MSC, *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_TIEBREAK, *CONTACT_ERODING_SINGLE_SURFACE_ID
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-7 is the validation of a steel projectile impact on a 16 ply composite plate. The reliability and consistency of LS-DYNA® as a finite element solver for this impact simulation involving composite structures is evaluated by performing analyses on different cpu architecture platforms and comparison to experimental results.

3.2 Test Case Description

This QA Test Case contains an impact analysis (see figure 1) with a steel cylinder projectile impacting a 16 ply carbon fiber composite plate. Details on the experimental set up and experimental results can be found in [2].

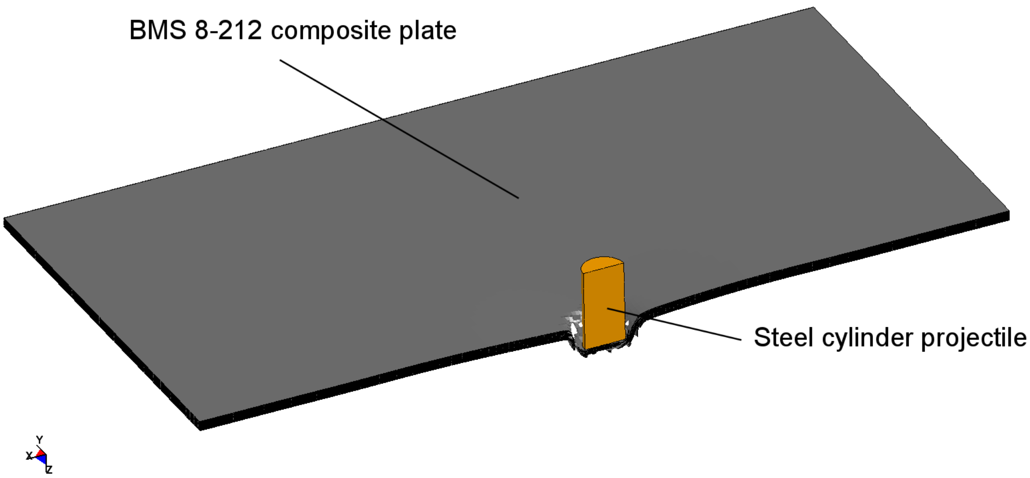

Figure 1: Model sketch: Tool steel cylinder projectile impacting 16 ply BMS 8-212 composite plate

Table 2 contains a short summary of the physical model set up.

Physical Model Information	
projectile geometry	length = 2.0” , diameter = 0.5”
projectile mass	0.082 lb
projectile material	tool steel
projectile initial velocity	4758 in/s
projectile final velocity	4133 in/s
plate geometry	12.0” x 12.0” (clamp frame inside 10” x 10”)
plate material	BMS 8-212
plate material density	0.056 lb per cubic inch
ply orientation	[0/45/90/-45]$_{4s}$

Table 2: Model set-up data

3.3 Model Description

The model geometry is discretized with solid elements for the projectile and for each single ply of the 16 ply composite (see figure 2). Due to symmetry conditions, a half model of the actual geometry is used. Symmetry boundary conditions are applied on the symmetry plane and the outer edges of the composite plate are fully supported. The projectile has an initial z velocity defined on all nodes and is guided along the symmetry plane.
The number of elements and material specifications for the model can be found in table 3 and table 4 reflects the sub test case specification.

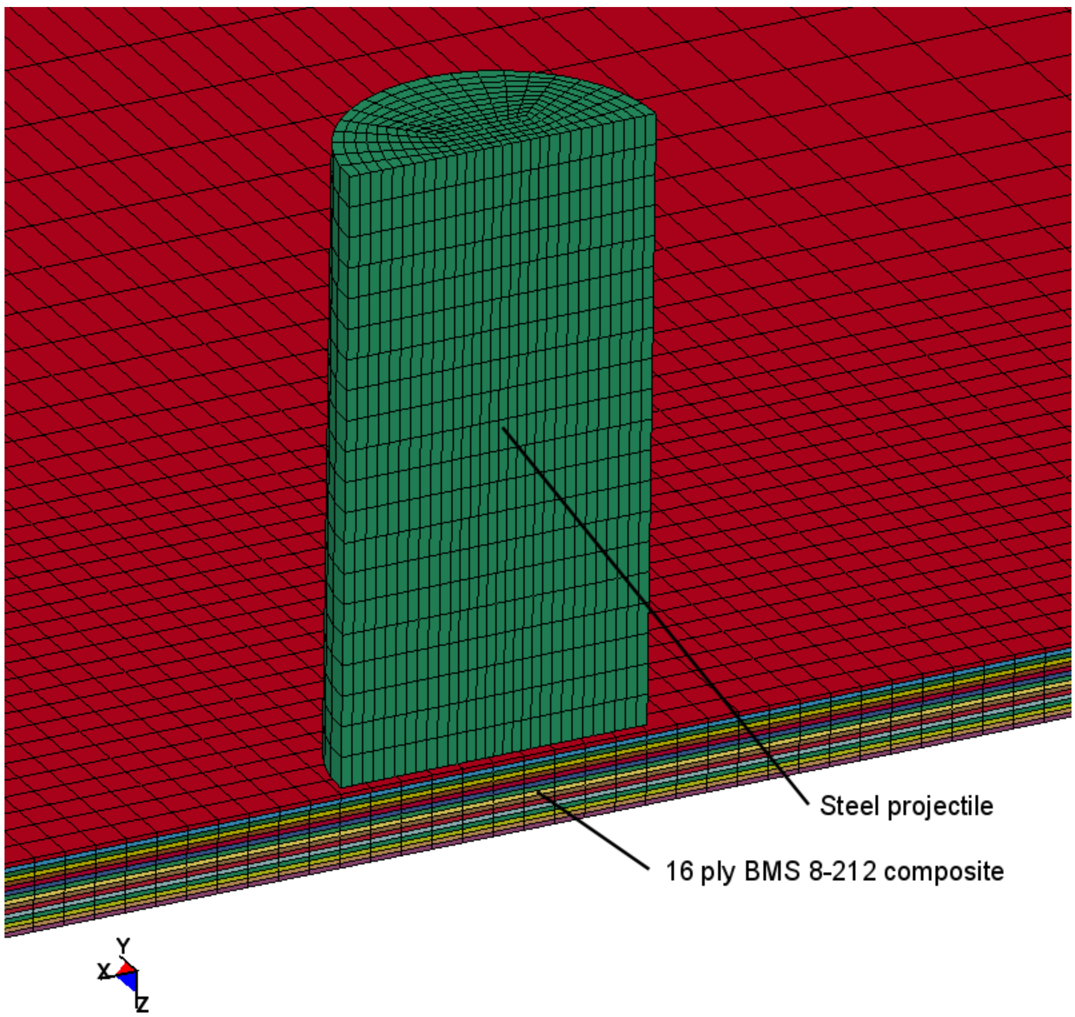

Figure 2: FEA model: Tool steel cylinder projectile impacting 16 ply BMS 8-212 composite plate

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

FEA Model information	
Nodes	122756
Solid elements	61488
Solid materials	17
Parts	17
projectile geometry	length = 1.0” , diameter = 0.5”
projectile mass	0.712E-04 lbfs2/in
projectile material	*MAT_PLASTIC_KINEMATIC
projectile initial velocity	4758 in/s
plate geometry	10.0” x 10.0” x 0.12”
plate material	*MAT_COMPOSITE_DMG_MSC
Units	in (length), s (time), lbf-s^2/in (mass), psi (stress), lbf-in (energy)

Table 3: FEA Model Information

Sub Test Case ID	Input Deck Name
1	aerospace_group_example_07_impact_16_ply_composite.k

Table 4: Specification of sub test cases

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 experimentally determined values or observations.

Test Case Targets				
Target number	output	component type	component id	retrieved from
1	internal energy	global	-	binout/glstat file
2	kinetic energy	global	-	binout/glstat file
3	hourglass energy	global	-	binout/glstat file
4	internal energy	part	100 (projectile)	binout/matsum file
5	kinetic energy	part	100 (projectile)	binout/matsum file
6	z-velocity	part	100 (projectile)	binout/matsum file

Table 5: Test Case targets for QA Test Case ID AEROQA-7

Test case targets one to five are used to evaluate the cross cpu architecture consistency whereas test case target six is used to compare the analysis with the experimental data (see section 4.2).

4.2 Pass/Fail Criteria

These are the Pass/Fail criteria used for the cross cpu architecture consistency and the Validation of the Test Case ID AEROQA-7.

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

- For a specific test case target, the maximum distance between an x-y pair of a slope of one cpu architecture/software version combination to at least one x-y pair of all other tested cpu architecture/software version combinations is 15% of the maximum slope value.
- The test case target 6 (z-velocity part 100 - projectile) is in the range [4752.95 in/s : 3513.05 in/s] (+/-15% of experimental achieved velocity of 4133 in/s).

Otherwise the the cross cpu architecture consistency and validation fails.

5 Test Case Results

5.1 Software and Hardware Specifications

In order to ensure cross-platform 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	Operating system	CPU type	MPI-Protocol	Number of cpu's [1]
sandwich	SUSE LES 11.1	Intel® Xeon® E7- 8837 @ 2.67GHz	hpmpi	4
ham	CentOS 5.4	AMD® Opteron ® 8435 @ 800MHz	hpmpi	4
sgi64d	SUSE LES 9.4	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	R6.1	74159	SMP	SP	ls971.74159.R6.1
LS-DYNA®	971	R6.1	74159	SMP	DP	ld971.74159.R6.1
LS-DYNA®	971	R6.1	74159	MPP	SP	mpp971.74159.R6.1
LS-DYNA®	971	R6.1	74159	MPP	DP	mpd971.74159.R6.1

[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-7 completed with all combinations of software and hardware defined in section 5.1 (1 * 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 and validation summary is:

- **PASS** - Pass criteria in section 4.2 is attained.
- **FAILED** - Pass criteria in section 4.2 is not attained.
- **ERROR** - sub test case terminates due to error.
- **N/A** - sub test case was not calculated.

Sub Test Case ID	PASS/FAILED
1	**FAILED**

Table 8: Validation results summary for QA Test Case ID AEROQA-7

5.3 Result Details

The following subsections contain detailed results for the QA Test Case ID AEROQA-7 for LS-DYNA® R6.1 Revision 74159.

For each sub test case defined in section 3.3 there is a graph displaying the time history of the result target defined in section 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:
'aerospace_group_example_07_impact_16_ply_composite.k: matsum_kinetic_energy_100' 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 100 derived from the 'matsum' output file.

Legend:
'matsum_kinetic_energy_100_sandwich_ls971.74159.R6.1_4' states that the graph shows the kinetic energy of part 100 derived from the 'matsum' output file for an input deck which was calculated on the 'sandwich' platform with a LS-DYNA® R6.1 Revision 74159 binary (SMP, single precision) on four processors.

5.3.1 Sub Test Case ID 1 - Test Target 1

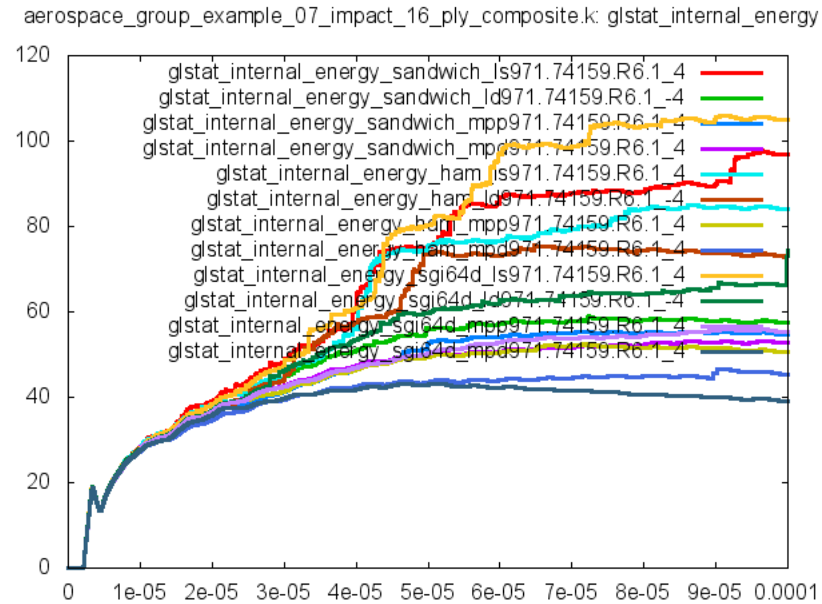

Figure 3: Cross platform results, global internal energy, sub test case ID 1

5.3.2 Sub Test Case ID 1 - Test Target 2

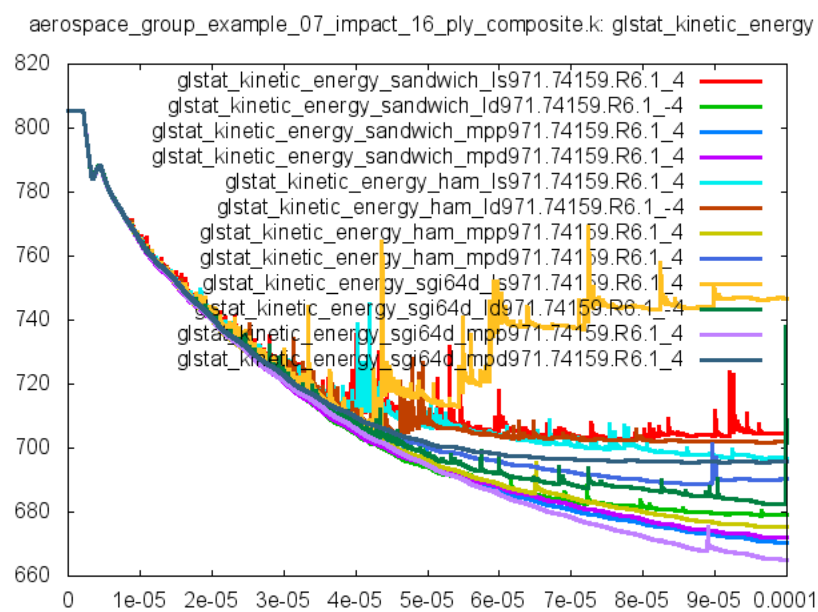

Figure 4: Cross platform results, global kinetic energy, sub test case ID 1

5.3.3 Sub Test Case ID 1 - Test Target 3

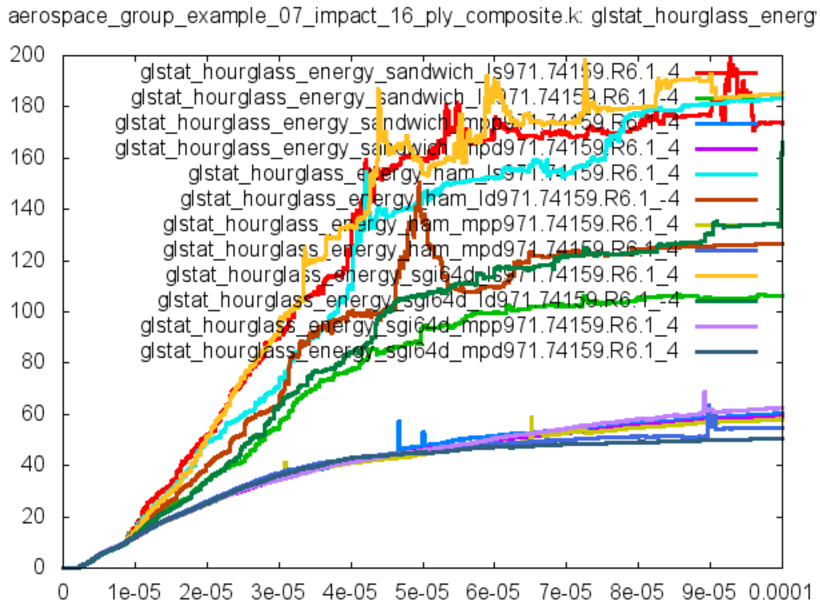

Figure 5: Cross platform results, global hourglass energy, sub test case ID 1

5.3.4 Sub Test Case ID 1 - Test Target 4

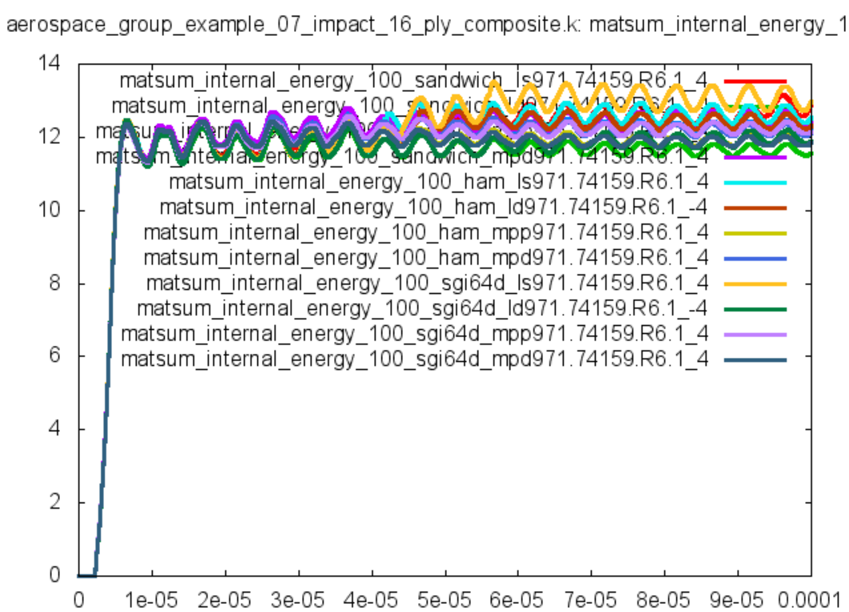

Figure 6: Cross platform results, internal energy part 100, sub test case ID 1

5.3.5 Sub Test Case ID 1 - Test Target 5

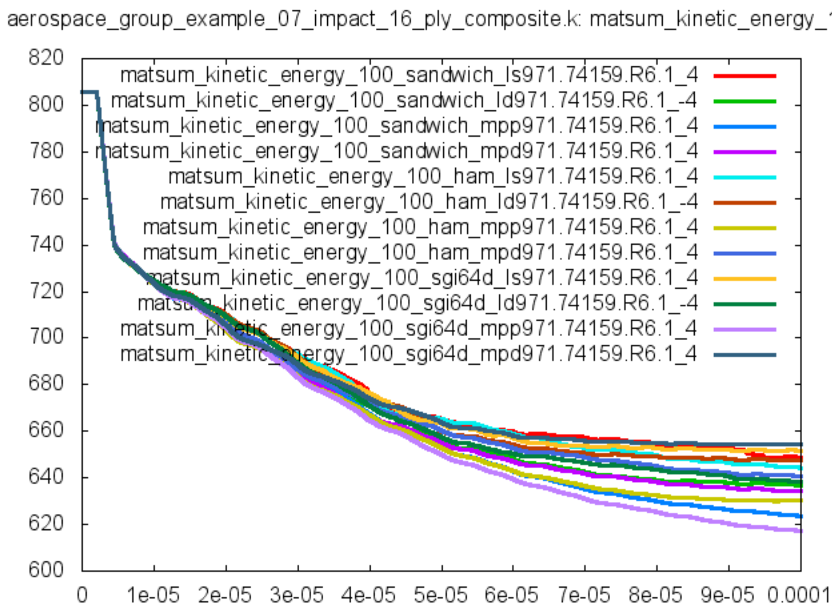

Figure 7: Cross platform results, kinetic energy part 100, sub test case ID 1

5.3.6 Sub Test Case ID 1 - Test Target 6

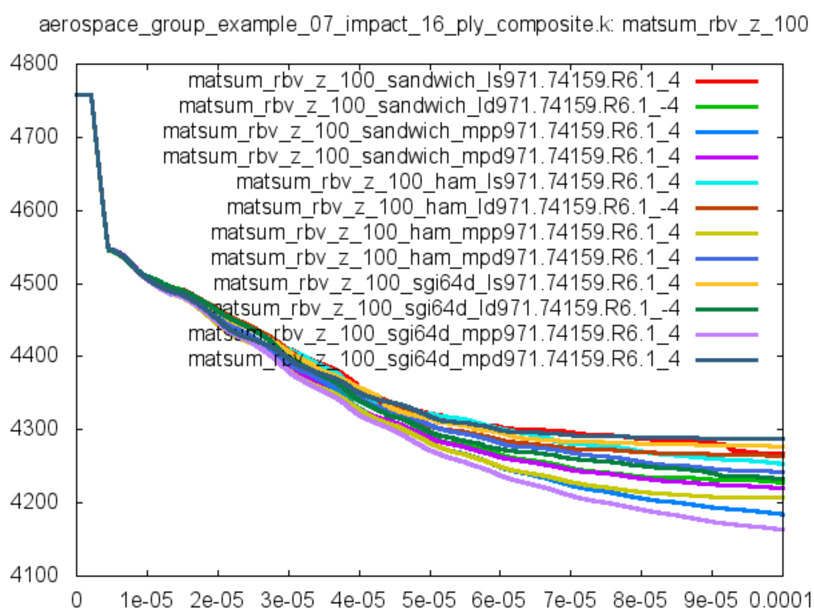

Figure 8: Cross platform results, z-velocity part 100, sub test case ID 1

References

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

[2] D. POWELL, T. ZOHDI, AND G. JOHNSON, *Impact and Delamination Failure Characterization of BMS 8-212 Air Traffic Organization*, Final Report DOT/FAA/AR-08/48, U.S. Department of Transportation, Federal Aviation Administration, Office of Aviation Research, Washington, D.C. 20591, October 2008.