TEST CASE DOCUMENTATION AND TESTING RESULTS

LSTC-QA-LS-DYNA-AWG-ERIF-4-6

TEST CASE ID AWG-ERIF-4

Steel Projectile Impacts Kevlar® Fabric

Tested with LS-DYNA® R8.0.0 Revision 96167

Tuesday 10th March, 2015

LSTC
Livermore Software
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Document Information	
Confidentiality	external use
Document Identifier	LSTC-QA-LS-DYNA-AWG-ERIF-4-6
Author(s)	Prepared by LS-DYNA® Aerospace Working Group
Number of pages	13
Date created	Tuesday 10th March, 2015
Distribution	LS-DYNA® Aerospace Working Group / internal LSTC QA

Contents

1 Introduction

1.1 Purpose of this Document

This document specifies the test case AWG-ERIF-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	Steel Projectile Impacts Kevlar® Fabric
Test Case ID	AWG-ERIF-4
Test Case Status	active
Test Case Classification	Validation
Test Case Source	Arizona State University (ASU) NASA Glenn Research Center
Tested Keyword	*MAT_DRY_FABRIC (ASU material model Version 1.3)
Member of Test Suite	AWG ERIF SUITE
Metadata	AWG ERIF

Table 1: Test Case Summary

3 Test Case Specification

3.1 Test Case Purpose

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

3.2 Test Case Description

This Test Case contains an impact analysis (see figure 1) using a 304L stainless steel projectile impacting 8 layers (Model LG612) [1] and 32 layers (Model LG969) [2] of dry fabric rings made from Kevlar® 49 P-Aramid.

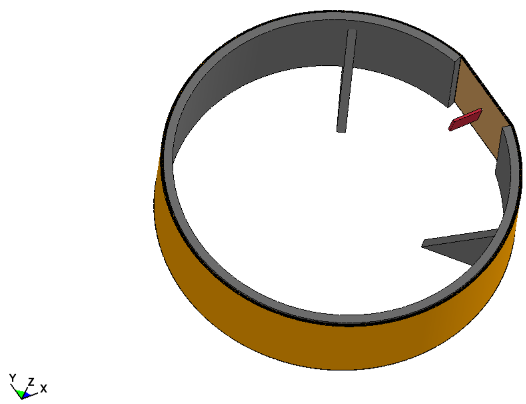

Figure 1: Model sketch: 304L stainless steel projectile impacting Kevlar® 49

Table 2 contains a short summary of the physical model set up. Details on the experimental set up can be found in [4] and [1].

Physical Model Information		
Model	LG612	LG969
fabric geometry	8 layers, height = 10.0”	32 layers, height = 10.0”
ring geometry	outer diameter = 40.0” inner diameter = 38.0” height = 10.5”	
ring opening	10.0”	
fabric material	Kevlar® 49 P-Aramid	
fabric areal density	0.02275 g/cm^2	
projectile geometry	length = 4.0” , height = 2.0”, thickness = 0.3124”	
projectile mass	324 g	
projectile material	304L stainless steel	
projectile initial velocity	10.779 in/ms	9.252 in/ms
projectile final velocity	9.864 in/ms	0.00 in/ms

Table 2: Model set-up data

[1] Model number refers to the File No, in [4]
[2] Model number refers to the File No, in [1]

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.

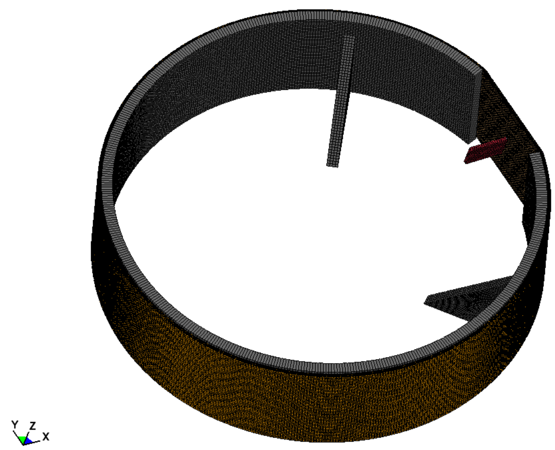

Figure 2: FEA model: 304L stainless steel projectile impacting Kevlar® 49

Two experimental set-ups are used. The two experimental set ups are named after their File No. in [4] and [1]. LG612 is an experiment where the projectile was not contained by the fabric layers. LG969 is an experiment where the projectile was contained.
Two modelling approaches for the experimental set-ups are used. The CMS (Concentric Modelling System) approach models the fabric in concentric wraps around the steel ring, whereas in the SMS (Spiral Modelling System) approach the fabric is wrapped continuously around the steel ring. The SMS approach mimics the actual test conditions.
A summary of these four sub test cases can be found in table 4.

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

FEA Model information				
Sub Test Case ID [1]	1	2	3	4
Model ID	LG612	LG969	LG612	LG969
Modelling approach	CMS	CMS	SMS	SMS
Nodes	146176	217578	93079	218090
Solid elements	81652	28442	28648	28652
Solid materials	3	3	3	3
Shell elements	40520	162240	40320	162280
Shell materials	4	16	4	16
Parts	7	19	7	19
Number of shell layers	2	8	2	8
Fabric layers per shell	4	4	4	4
Fabric material	*MAT_DRY_FABRIC (ASU material model Version 1.3) [2]			
Ring geometry	outer diameter = 40.0” thickness = 1.0” height = 10.5”			
Fabric geometry	height = 10.0”			
Projectile geometry	length = 4.0” , height = 2.0”, thickness = 0.3124”			
Projectile velocity	$v_x = 10.779$ in/ms	$v_x = 9.252$ in/ms	$v_x = 10.779$ in/ms	$v_x = 9.252$ in/ms
Unit system	in (length), ms (time), Mlbf-ms^2/in (mass), Mlbf (force), Mpsi (stress), Mlbf-in (energy)			

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

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

Table 3: FEA Model Information

Sub Test Case ID	File No. [1]	Modelling Approach [2]	Input Deck Name
1	LG612	CMS	CMS_LG612.in
2	LG969	CMS	CMS_LG969.in
3	LG612	SMS	SMS_LG612.in
4	LG969	SMS	SMS_LG969.in

[1] Correspond to the File No. in [4] and in [1]

[2] CMS (Concentric Modeling System) and SMS (Spiral Modeling System)

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	kinetic energy	part	11	binout/matsum file

Table 5: Test Case targets for Test Case ID AWG-ERIF-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). The target is used to evaluate the perforation of the fabric (see section 4.2).

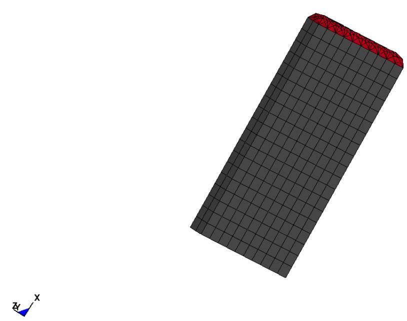

Figure 3: Part identification of the projectile: Grey coded is part 11 (body), red coded is part 12 (cap)

4.2 Pass/Fail Criteria

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

A sub test case passes if the following criteria is reached for the related Sub Test Case ID's:

- The test case target 1 (kinetic energy part 11) is greater than 70% of the initial kinetic energy for Sub Test Case ID 1 and 3 (projectile uncontained).
- The test case target 1 (kinetic energy part 11) is less than 5% of the initial kinetic energy for Sub Test Case ID 2 and 4 (projectile contained).

Otherwise the 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	Platform MPI 8.2.0.0	4
ham	CentOS 5.4	AMD® Opteron ® 8435 @ 800MHz	Platform MPI 8.1.0.0	4
sgi64d	SUSE LES 9.4 [2]	Intel® Itanium® 2 @ 1.6GHz	SGI MPT 1.13	4

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

[2] SGI PROPACK 4

Table 6: Used Platforms and CPU Type's

Product	Version	Release	Revision	Parallel type [1]	Precision [2]	executable
LS-DYNA®	971	R8.0.0	96167	SMP	SP	ls971.96167.R8.0.0
LS-DYNA®	971	R8.0.0	96167	SMP	DP	ld971.96167.R8.0.0
LS-DYNA®	971	R8.0.0	96167	MPP	SP	mpp971.96167.R8.0.0
LS-DYNA®	971	R8.0.0	96167	MPP	DP	mpd971.96167.R8.0.0

[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 Test Case ID AWG-ERIF-4 completed with all combinations of software and hardware defined in section 5.1 (4 * 2 * 3 total calculation runs).
Details on the test results can be found in the section 5.3.

The table 8 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	**PASS**
2	**PASS**
3	**PASS**
4	**PASS**

Table 8: Validation results summary for Test Case ID AWG-ERIF-4

5.3 Result Details

The following subsections contain detailed results for the Test Case ID AWG-ERIF-4 for LS-DYNA® R8.0.0 Revision 96167.

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 [2] for details on this option).

Example for title and legend:

Title:
'CMS_LG612.k: matsum_kinetic_energy_11' 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 11 derived from the 'matsum' output file.

Legend:
'matsum_kinetic_energy_11_sandwich_ld971.96167.R8.0.0_4' states that the graph shows the kinetic energy of part 11 derived from the 'matsum' output file for an input deck which was calculated on the 'sandwich' platform with a LS-DYNA® R8.0.0 Revision 96167 binary (SMP, double precision) on four processors.

5.3.1 Sub Test Case ID 1 - Test Target 1

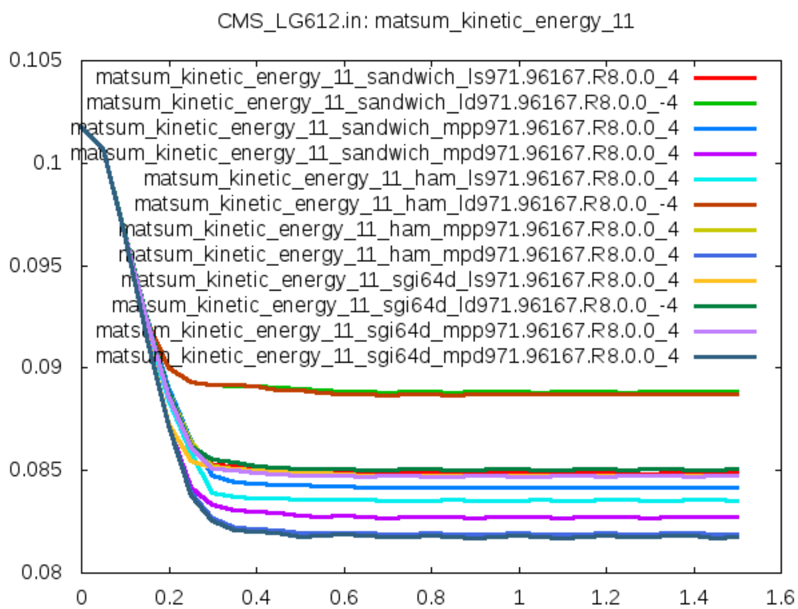

Figure 4: Cross platform results, kinetic energy part 11, sub test case ID 1

5.3.2 Sub Test Case ID 2 - Test Target 1

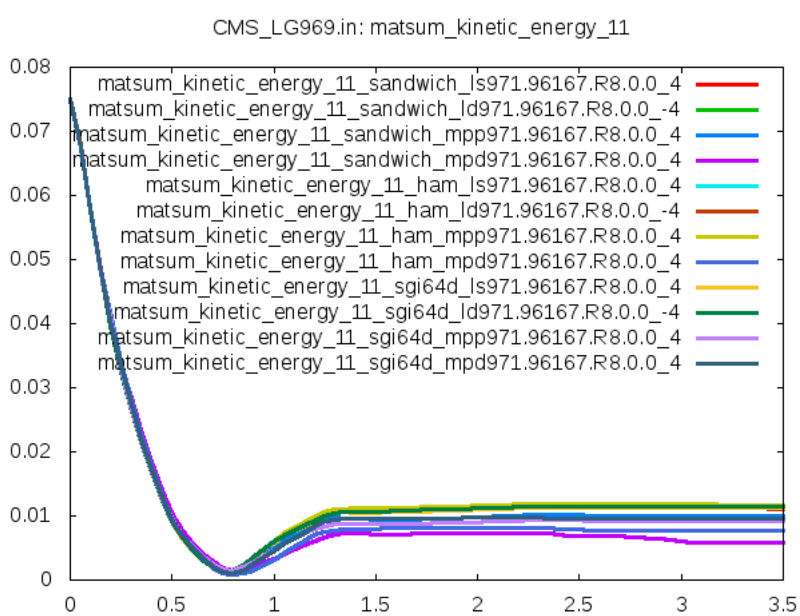

Figure 5: Cross platform results, kinetic energy part 11, sub test case ID 2

5.3.3 Sub Test Case ID 3 - Test Target 1

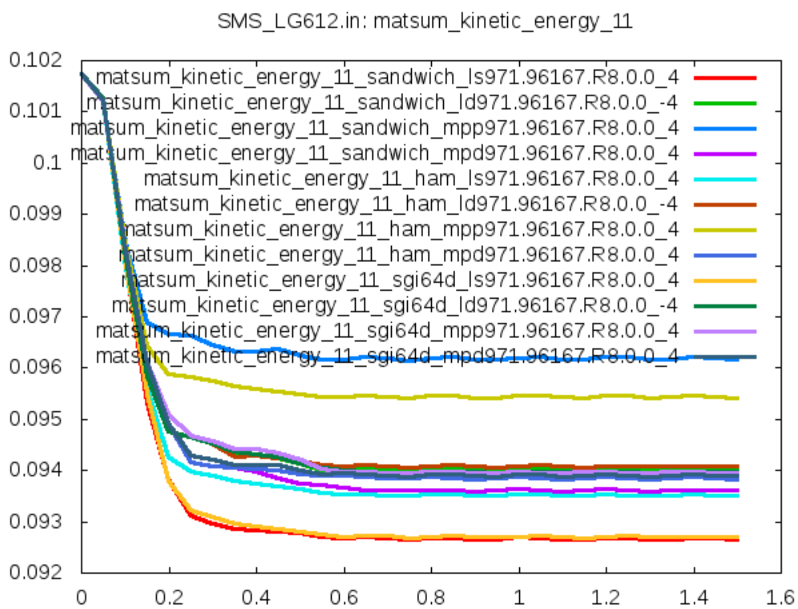

Figure 6: Cross platform results, kinetic energy part 11, sub test case ID 3

5.3.4 Sub Test Case ID 4 - Test Target 1

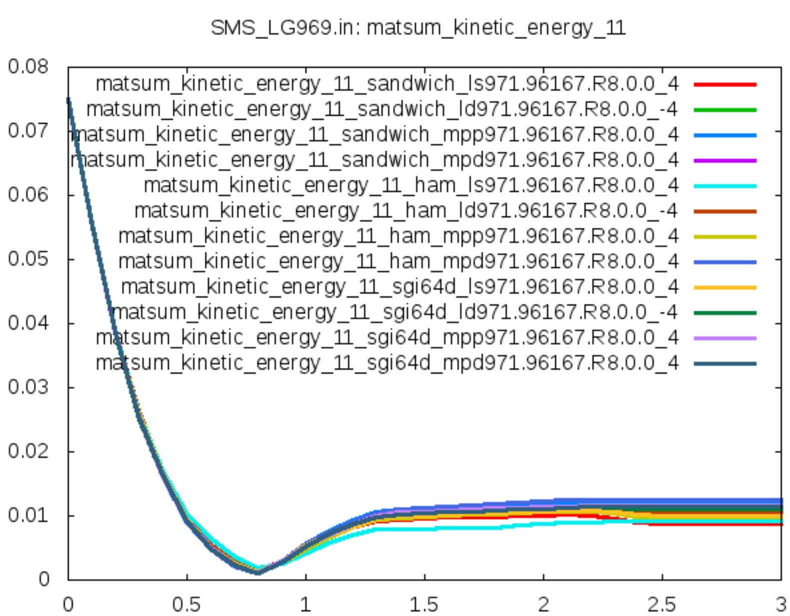

Figure 7: Cross platform results, kinetic energy part 11, sub test case ID 4

References

[1] *Explicit Finite Element Modeling of Multilayer Composite Fabric for Gas Turbine Engine Containment Systems, Phase III*, tech. rep., U.S. Department of Transportation, Federal Aviation Administration, Office of Aviation Research, Washington, D.C. 20591, in preparation.

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

[3] S. D. Rajan, B. Mobasher, Z. Stahlecker, S. Bansal, D. Zhu, M. Morea, and K. Dhandapani, *Explicit Finite Element Modeling of Multilayer Composite Fabric for Gas Turbine Engine Containment Systems, Phase III Part 1: Arizona State University Material Model and Numerical Simulations*, Final Report DOT/FAA/AR-10/23,P1, U.S. Department of Transportation, Federal Aviation Administration, Office of Aviation Research, Washington, D.C. 20591, January 2011.

[4] D. M. Revilock and J. M. Pereira, *Explicit Finite Element Modeling of Multilayer Composite Fabric for Gas Turbine Engine Containment Systems, Phase II Part 2: Ballistic Impact Testing*, Final Report DOT/FAA/AR-08/37,P2, U.S. Department of Transportation, Federal Aviation Administration, Office of Aviation Research, Washington, D.C. 20591, February 2009.