TEST CASE DOCUMENTATION AND TESTING RESULTS

LSTC-QA-LS-DYNA-AEROQA-2-2-12

TEST CASE ID AEROQA-2-2

Fan Blade-Off Containment Test, Generic Soft Wall Containment

Tested with LS-DYNA® R11.0 Revision 130010

Tuesday 6th November, 2018

LSTC Livermore Software Technology Corp.

Warranty Disclaimer:

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1 Introduction

1.1 Purpose of this Document

This document specifies the test case AEROQA-2-2. 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	Aerospace Working Group Internal Use
Test Case Name	Fan Blade-Off Containment Test, Generic Soft Wall Containment
Test Case ID	AEROQA-2-2
Test Case Status	active
Test Case Classification	Qualitative Study
Test Case Source	Honeywell Engines, Systems and Services Arizona State University (ASU)
Tested Keyword	*MAT_DRY_FABRIC, *MAT_TABULATED_JOHNSON_COOK
Testing Method	example
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-2-2 is the qualitative study of a fan blade-out event for containment. Details of the containment model for the fan can be found in [3], and details of the fabric material model can be found in [2].
The reliability and consistency of LS-DYNA® as a finite element solver is evaluated by performing an analyses on the containment model for this fan blade-out event (see table 4).

3.2 Test Case Description

This QA Test Case contains a fan blade-out containment test (see figure 1). The model contains two fan blades (the released blade and the following blade), all the blade platforms, the fan containment case, and the Kevlar fabric containment layer. The red coded fan blade in figure 1 is the released blade.

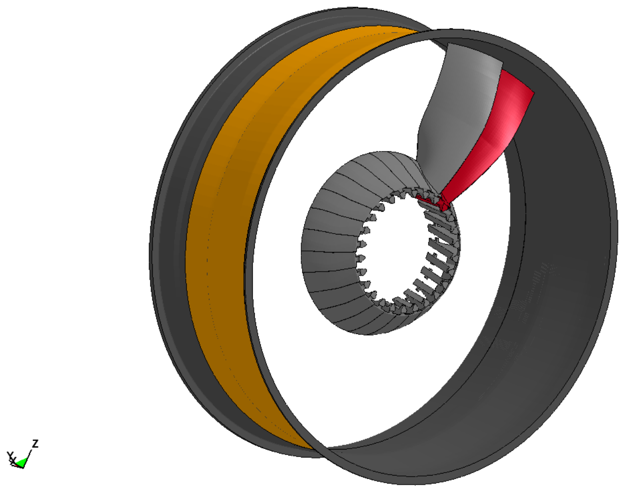

Figure 1: Model sketch: Fan Blade-Out Containment Test, Generic Soft Wall Containment

Table 2 contains a short summary of the physical model set up. Details on the sub model of the engine can be found in [3]. The materials are not further specified and can be chosen in the finite element model as appropriate.

Physical Model Information	
Fan case diameter	approx. 42.72”
fabric material	Kevlar®
number of fabric layers	88
Initial rotational velocity	880.00 (x-axis)

Table 2: Model set-up data

3.3 Model Description

The model geometry is discretized with solid elements for the fan containment case, fan blades and blade platforms. The fabric is discretized with one layer of shell elements (see figure 2). The number of elements and material specifications for the model can be found in table 3. The material for the fan blades and the fan containment case are not related to a specific material and can be chosen as appropriate.

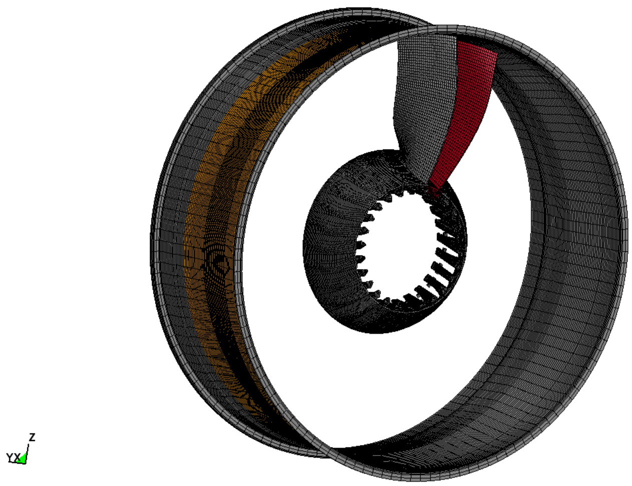

Figure 2: FEA model: Fan Blade-Out Containment Test, Generic Soft Wall Containment

FEA Model information	
Nodes	150778
Solid elements	77900
Thick shell elements	10625
Shell elements	5250
Parts	6
Number of shell layers	1
Fabric layers per shell	88
Fabric material	*MAT_DRY_FABRIC [1]
Containment material	*MAT_TABULATED_JOHNSON_COOK
Initial rotational velocity	$\omega_x = 880.00$
Unit system	in (length), s (time), lbf-s^2/in (mass), lbf (force), psi (stress), lbf-in (energy)

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

Table 3: FEA Model Information

A summary of the test case can be found in table 4.

Sub Test Case ID	Input Deck Name
1	fbo.k

Table 4: Specification of sub test cases

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

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 on different cpu architectures. They are chosen in a way that they are representative of the numerical model.

Test Case Targets				
Target number	Output	Component Type	Component Id	retrieved from
1	kinetic energy	global	-	binout/glstat file
2	internal energy	global	-	binout/glstat file
3	hourglass energy	global	-	binout/glstat file
4	sliding interface energy	global	-	binout/glstat file

Table 5: Test Case targets for QA Test Case ID AEROQA-2-2

The targets are used to evaluate the numerical stability of the sub test case (see section 4.2).

4.2 Pass/Fail Criteria

These are the Pass/Fail criteria used for the evaluation of the Test Case ID AEROQA-2-2.

The sub test case passes if the test case target data falls within the corridor bounds. Otherwise the test fails.

The test case corridors are upper and lower bounds for the test case targets. The corridors were updated from LS-DYNA® R9.0 Revision 108899 to R11.0 Revision 130010 because the *MAT_224 AL2024 data was updated to V2.0. They were defined based on the test target data by the following process:

- For a specific test case target, interpolate the data from different platform and executable (R11.0 Revision 130010) combinations, so that the time domain is the same.
- Calculate the upper and lower bounds by:

$$bound_{up}(i) = max(i) + 0.2 \times [max(i) - min(i)] + 0.05 \times peak$$
$$bound_{low}(i) = min(i) - 0.2 \times [max(i) - min(i)] - 0.05 \times peak$$

  where $max(i)$, $min(i)$ are the maximum and minimum values at the i_{th} time step across all platforms and executable (R11.0 Revision 130010) combinations the test case was calculated with, $peak$ is the maximum absolute y value across the whole time domain, $bound_{up}(i)$ and $bound_{low}(i)$ are the upper and lower bounds for the i_{th} time step.

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]
sand1	SUSE LES 11.0	Intel® Xeon® E5-2680 @ 2.70GHz	Platform MPI 08.02.00.00	8
dinar3b	SUSE LES 11	AMD® Opteron ® 6276 @ 2300MHz	Platform MPI 8.2.0.0	8

[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	R11.0	130010	SMP	DP	ld971.130010.R11.0
LS-DYNA®	971	R11.0	130010	MPP	DP	mpd971.130010.R11.0

[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 QA Test Case ID AEROQA-2-2 completed with all combinations of software and hardware defined in section 5.1 (1 * 2 * 2 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**

Table 8: Test results summary for QA Test Case ID AEROQA-2-2

5.3 Result Details

The following subsections contain detailed results for the Test Case ID AEROQA-2-2 for LS-DYNA® R11.0 Revision 130010.

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 test case ID and the name of input deck. The legend contains the result file name, output, platform, executable and number of cpu's separated by comma. A minus sign before the number of cpu's refers to the compatibility option for SMP calculations (see [1] for details on this option).

Example for title and legend:

Title:

'AWG_ERIF_TEST_CASE_2_2: fbo.k' states the test case ID 2_2 and name of the input deck for sub test case 1.

Legend:

'glstat_internal_energy,ham,ls971.130010.R11.0,4' states that the graph shows the internal energy derived from the 'glstat' output file for an input deck which was calculated on the 'ham' platform with a LS-DYNA® R11.0 Revision 130010 binary (SMP, single precision) on four processors.

5.3.1 Sub Test Case ID 1 - Test Target 1

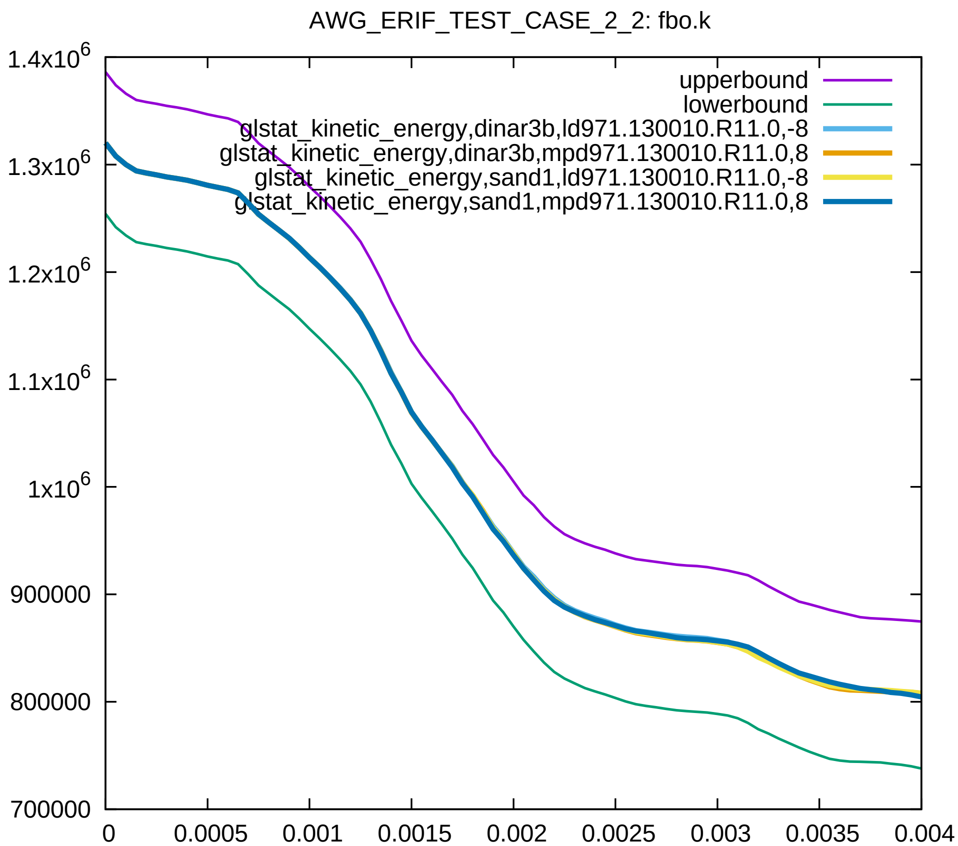

Figure 3: Cross platform results, global kinetic energy, sub test case ID 1

5.3.2 Sub Test Case ID 1 - Test Target 2

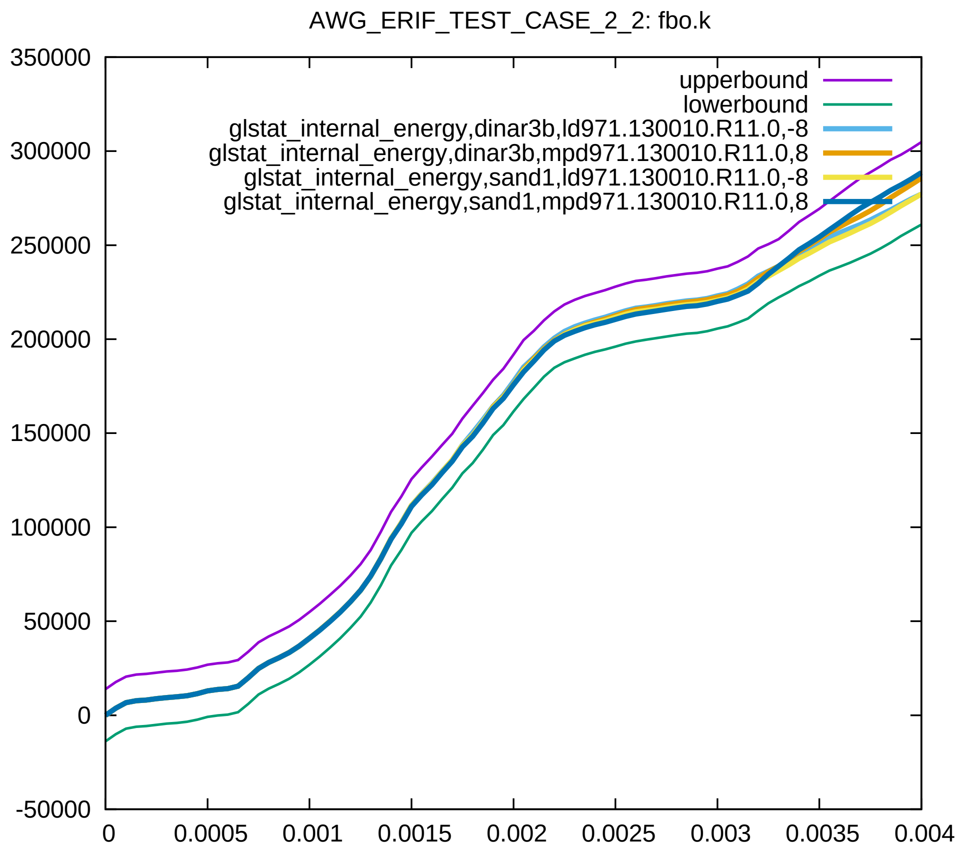

Figure 4: Cross platform results, global internal energy, sub test case ID 1

5.3.3 Sub Test Case ID 1 - Test Target 3

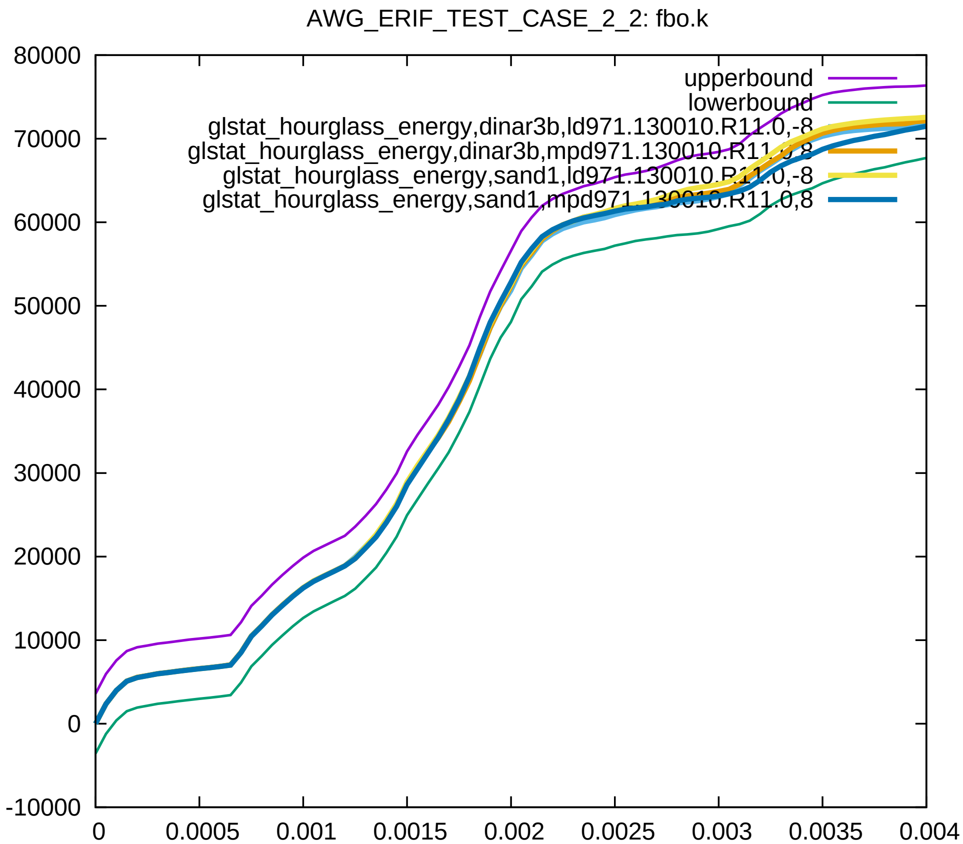

Figure 5: Cross platform results, global hourglass energy, sub test case ID 1

5.3.4 Sub Test Case ID 1 - Test Target 4

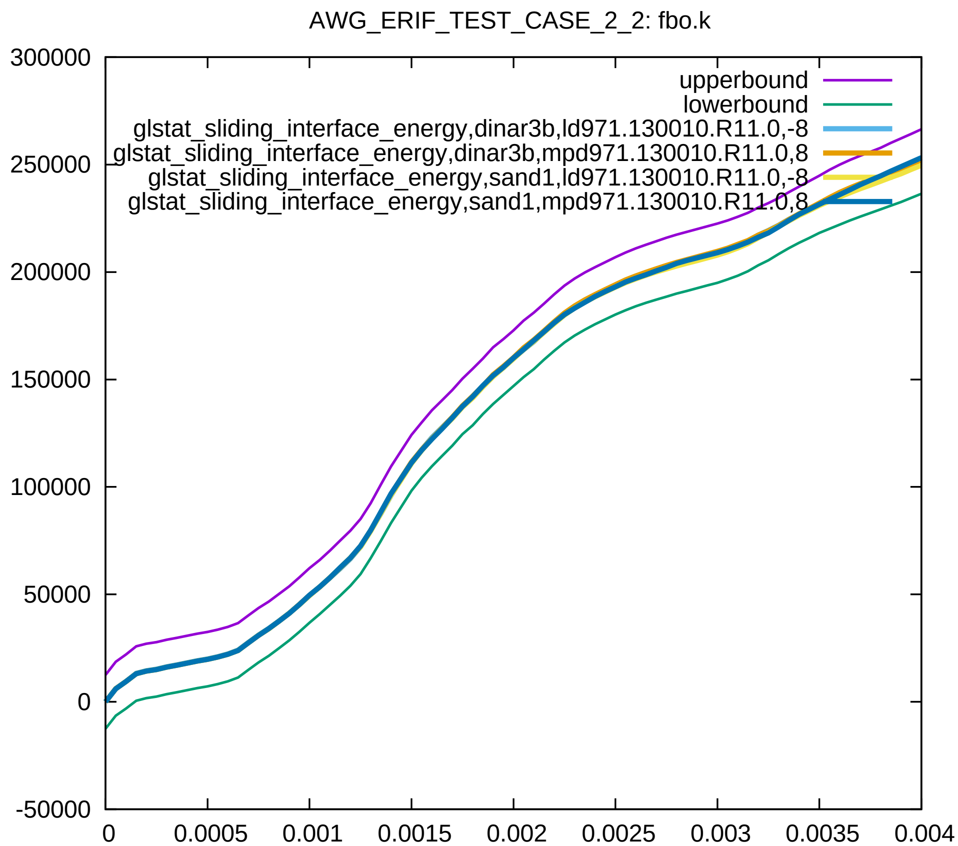

Figure 6: Cross platform results, global sliding interface energy, sub test case ID 1

References

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

[2] 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.

[3] I. V. Vintilescu, *Explicit Finite Element Modeling of Multilayer Composite Fabric for Gas Turbine Engine Containment Systems, Phase II Part 4: Model Simulation for Ballistic Tests, Engine Fan Blade-Out, and Generic Engine*, Final Report DOT/FAA/AR-08/37,P4, U.S. Department of Transportation, Federal Aviation Administration, Office of Aviation Research, Washington, D.C. 20591, February 2009.