TEST CASE DOCUMENTATION
AND TESTING RESULTS

TEST CASE ID CESE-VAL-1.1

Shock/boundary Layer Interaction

Tested with LS-DYNA® v980 Revision Beta

Friday 1st June, 2012

LSTC
Livermore Software
Technology Corp.

Document Information	
Confidentiality	**external use**
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Contents

1 Introduction

1.1 Purpose of this Document

This document specifies the test case CESE-VAL-1.1. 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. Results and observations are stated and discussed. Testing results are provided in section 4.1 for the therein mentioned LS-DYNA® version and platforms.

2 Test Case Information

Test Case Summary	
Confidentiality	external use
Test Case Name	Shock/boundary Layer Interaction
Test Case ID	CESE-VAL-1.1
Test Case Status	Under consideration
Test Case Classification	Validation
Metadata	SHOCK WAVES

Table 1: Test Case Summary

3 Test Case Specification

3.1 Test Case Purpose

The purpose of this test case is to test viscous flows and the handling of the interactions occuring between shock waves and boundary layers.

3.2 Test Case Description

This test case consists of an oblique shock wave impacting a solid wall. The flow is considered viscous meaning that a boundary layer will be generated on the solid wall which will result in complex interactions occurring between the oblique shock wave and the boundary layer. Except for very weak shocks, no analytical solutions that accurately describes the behavior of the flow has been provided [1]. Most results and information therefore rely on experimental results making numerical tools very important in order to accurately reproduce and predict these complex interactions.

Figure (1) shows the impact of an incoming oblique shock wave on a boundary layer and the behavior of the flow. In the case of an oblique shock wave impacting a boundary layer, the boundary layer will thicken and possibly separate in the area of the impact point of the incident shock wave. In the case of a boundary layer separation, the reflected shock wave will be generated upstream of the impact point of the incoming shock wave. On the other hand, after the impact point, the boundary layer's thickness should diminish generating expansion waves that may accelerate the flow sufficiently enough in order to make it locally supersonic again and generate a second reflected shock wave. Although not the subject of this test case, a possible turbulent transition of the boundary layer may also occur.

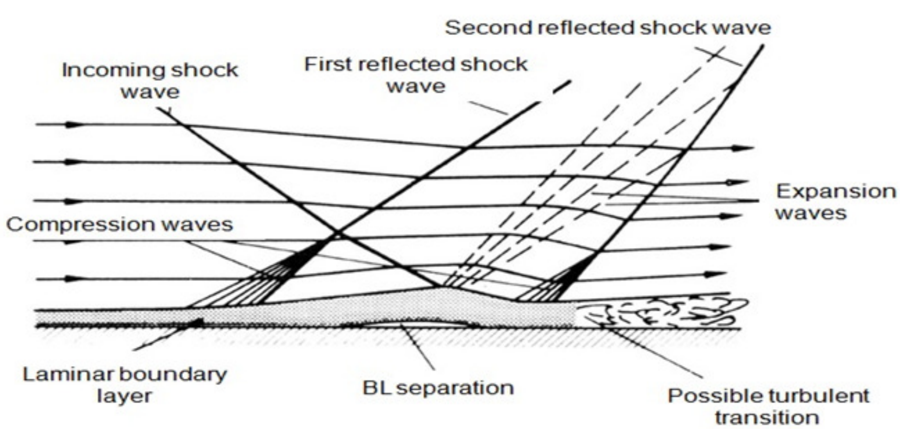


Figure 1: Effects of a shock wave impacting a boundary layer [2]

The test case's objective will be to check the coherent behavior of the interactions between the incident shock wave and the boundary layer. The results for the pressure distribution and skin friction will also be compared to experimental results by [1].

3.3 Model Description

The flow conditions are the same as those described in [1]. The geometry and the parameters are therefore chosen such as the incident shock angle β is equal to 32.6°, the incident Mach number is equal to 2, and the Reynolds number to 2.96×10^5. The characteristic length is the distance from the leading edge (E) of the flat plate to the shock incidence point (F) (See Figure (2)). Figure (3) offers a view of the mesh while Table (2) and (3) give some information on the mesh and the parameters used.

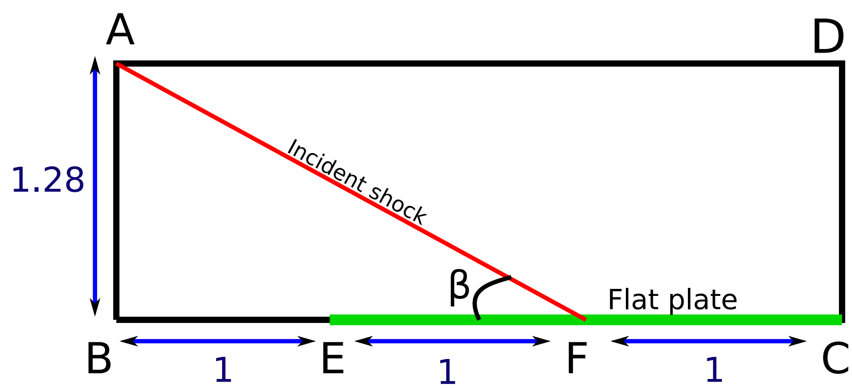


Figure 2: Test Case Geometry

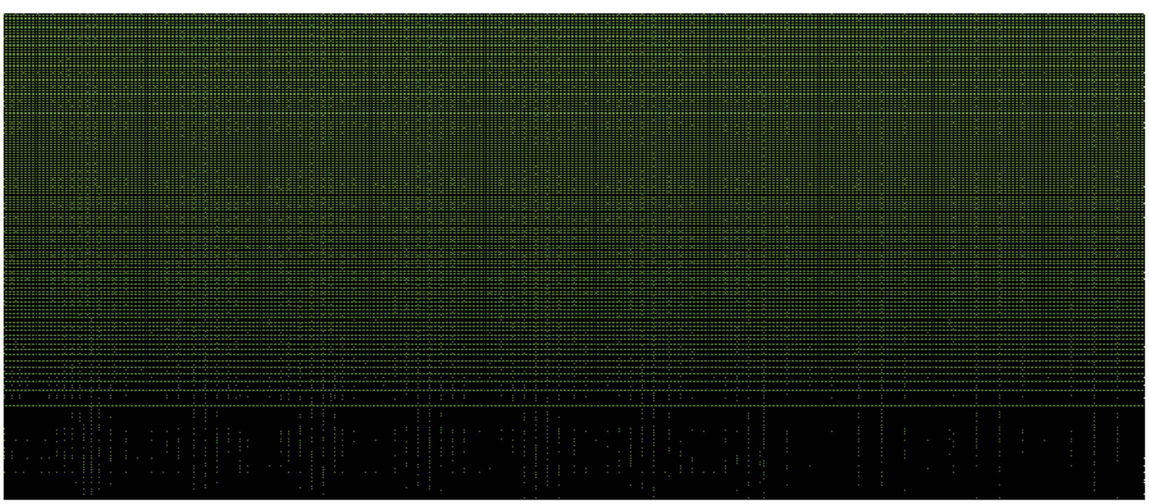


Figure 3: Test Case Mesh

Model information	
Elements in AB direction	300
Bias in AB direction	15
Elements in AD direction	300
Total number of elements	90 000

Table 2: Test Case Mesh information

Model physical parameters		
Specific heat at constant volume	0.446429	
Specific heat at constant pressure	0.625	
Sutherland C1 coefficient	6.566e-6	
Sutherland C2 coefficient	0.9436	
	AB	AD
Velocity in the x-direction	1.0	0.966435
Velocity in the y-direction	0.0	-0.052482
Pressure	0.1785714	0.212134
Density	1	1.13074

Table 3: Test Case Parameters

4 Test Case Results

4.1 Test Case observations

The final pressure of the flow after all incident and reflected shocks is equal to 1.44 times the pressure of the incoming flow which is in good agreement with the expected result of $\frac{P_{final}}{P_{incoming}} = 1.4$ given by [1]. Figure (4) shows pressure isocontours. For better visualization, Figure (5) zooms on the separation zone where the boundary layer separation and the two reflected shock waves can be correctly identified. The length of the separation region is equal to 0.19 ± 0.01 which is in good agreement with [1] that stipulates that the separation length should be inversely proportional to the eighth root of the Reynolds number. Finally, Figure(6) shows the good agreement between the experimental results and the numerical results regarding the pressure distribution and the skin friction along the wall.

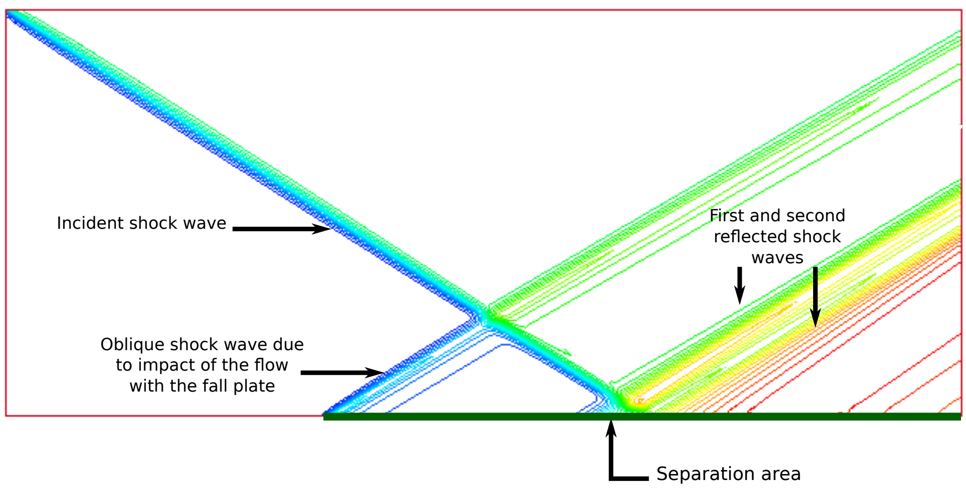


Figure 4: Test Case Pressure isocontours

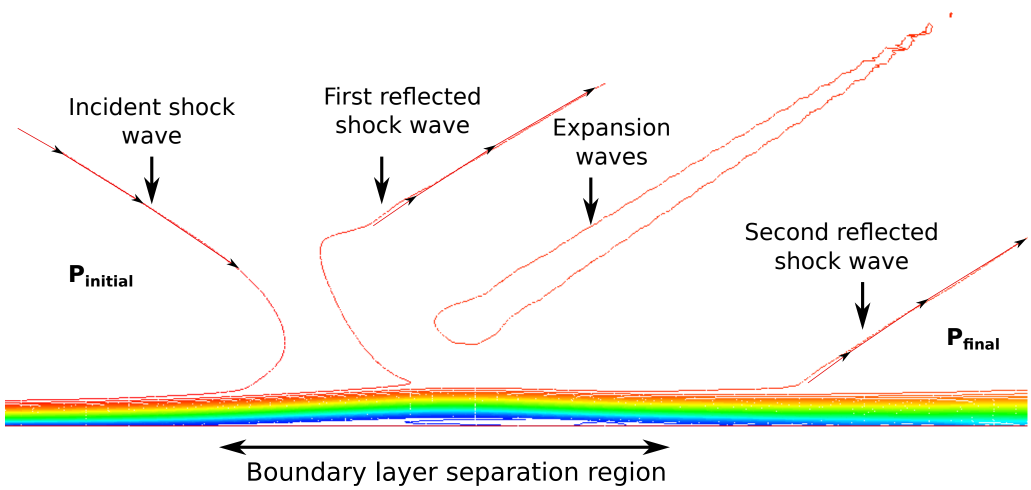
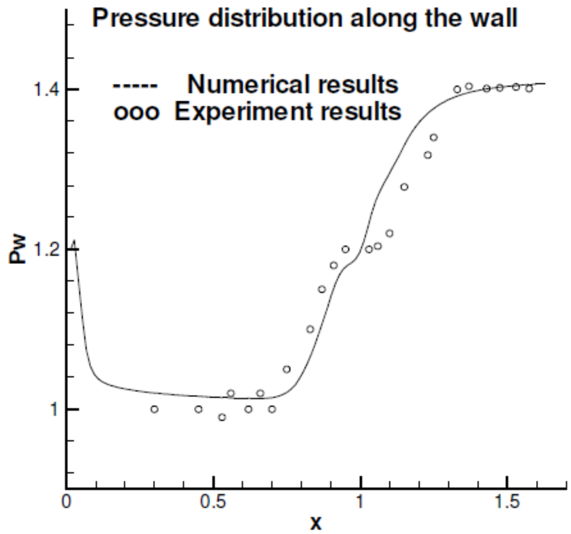


Figure 5: Test Case Velocity isocontours, zoom on the separation zone



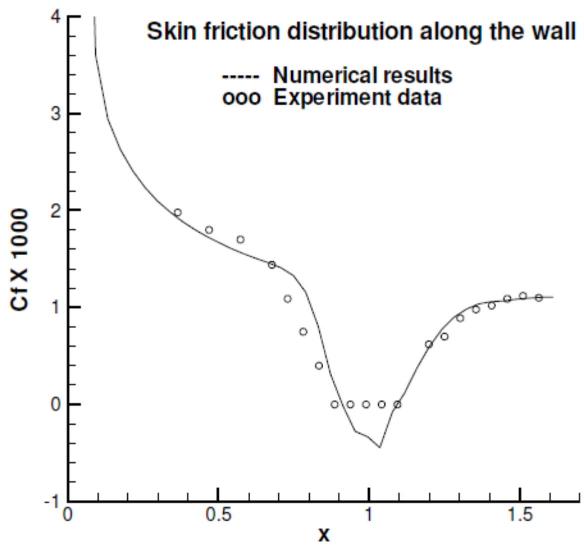


Figure 6: Comparison between numerical results and experimental results given by [1]

References

[1] G. I. T. L. Hakkinen, R.J. and S. Abarbanel, *The interaction of an oblique shock wave with a laminar boundary layer*, NASA Memo 2-18-59W, (1959).

[2] G. L. Xavier Carbonneau, Laurent Joly, *Physics and dynamics around compressible flows*, ISAE, 2009.