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Small Scale Drop Tower Test for Practice Torpedo Impact Modelling

Paul van der Schaaf

Maritime Platforms Division
Defence Science and Technology Organisation

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ABSTRACT

A small scale drop tower arrangement was used to simulate the dynamics of a practice torpedo impacting a submarine's pressure hull. This experiment provides a set of reference data against which numerical impact models can be tested. To ensure structural similarity, the model hull form used in the experiment is of a T-stiffened cylindrical section. The hull form and the impacting nose shell of the model torpedo have both been designed to deform under drop tower impact loads. To broaden the parameter range of this experiment and thus present a stronger test for numerical impact models, three impact velocities were used with three model hull forms - steel plate with and without stiffeners and aluminium plate without stiffeners. A qualitative comparison of the results for the three model hull forms shows that stiffeners tend to limit the extent of the dent, that aluminium plate has a greater elastic response than that of both stiffened and unstiffened steel plate, and that the nose is flattened for impact against the steel hull form but dimpled for impact against the aluminium hull form. Experimental data presented in this report includes the tensile properties of the nose, hull and stiffener materials, dimensional scans of the deformed noses and hull plates, cross-sections taken through the impact dents, and high speed video and kinematic data of the fall, impact and rebound of the model torpedo nose from the hull form. A supplementary digital data-set is available for the numerical modelling of this experiment.

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Executive Summary

Practice torpedoes may be used as part of the training system for undersea warfare. A practice torpedo behaves in most respects as its warshot counterpart but it is not fitted with an explosive warhead and it is designed not to hit its target. However, if an accidental impact does occur, the concentrated transient load may pose a safety risk to the target vessel.

Critical safety assessments for practice torpedo impact include the response of valves and penetrators, control surfaces, ballast tanks, frame mounted equipment and the pressure hull. This report confines itself to a modelled pressure hull impact.

The simplest method to assess impact safety is to conduct a full scale test. An impractical and expensive option, the results of any one test are only applicable to a limited range of hull and torpedo combinations. An alternative and more general approach is to numerically predict the consequences of an impact.

A small scale drop tower arrangement was used to simulate the dynamics of a practice torpedo impacting a submarine's pressure hull. This experiment provides a set of reference data against which numerical impact models can be tested.

To ensure structural similarity, the model hull form used in the experiment is of a T-stiffened cylindrical section. The hull form and the impacting nose shell of the model torpedo have both been designed to deform under drop tower impact loads. To broaden the parameter range of this experiment, and therefore to present a stronger test of a numerical model, two additional model hull plate variants were used - steel and aluminium plate without stiffeners. The hull forms used with three drop heights for three impact velocities present seven unique impact combinations (not all combinations were conducted).

A qualitative comparison of the results for these three model hull forms shows that stiffeners tend to limit the extent of the dent, that aluminium plate has a greater elastic response than that of both stiffened and unstiffened steel plate, and that the model torpedo nose is flattened for impact against the steel hull form but dimpled for impact against the aluminium hull form. Experimental data presented in this report includes the tensile properties of the nose, hull and stiffener materials, dimensional scans of the deformed model noses and model hull forms, cross-sections taken through the impact dents, and high speed video and kinematic data of the fall, impact and rebound of the model torpedo nose from the model hull form section. A supplementary digital data-set is available for the numerical modelling of this experiment.

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Author

Paul van der Schaaf
Maritime Platforms Division

Paul van der Schaaf was awarded a BSc(Hons) majoring in Physics by the University of Western Australia. Since joining the Defence Science and Technology Organisation he has worked on the shock and bubble dynamics of underwater explosions, the dynamic response of structures, and instrumentation & measurement. He has also worked in the areas of impact dynamics, finite element analysis, shock standards, fault tree analysis and naval platform vulnerability.

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Contents

1. Introduction

A practice torpedo behaves in most respects as its warshot counterpart but it is not fitted with an explosive warhead and it is designed not to hit its target. However, if an accidental impact does occur, the concentrated transient load may pose a safety risk to the target vessel.

Critical safety assessments for practice torpedo impact include the response of valves and penetrators, control surfaces, ballast tanks, frame mounted equipment and the pressure hull. This report confines itself to a modelled pressure hull impact.

The simplest method to assess impact safety is to conduct a full scale test. An impractical and expensive option, the results of any one test are only applicable to a limited range of hull and torpedo combinations. An alternative and more general approach is to numerically predict the consequences of an impact.

This report describes the results of a small scale drop tower simulation of the dynamics of a practice torpedo impacting a submarine's pressure hull, and presents the experimental results as a reference for the testing of numerical practice torpedo impact models generally.

2. Practice Torpedo Impact Drop Tower Model

A small scale drop tower (Fig. 1) was used to simulate the dynamics of a practice torpedo impacting a submarine's pressure hull. The tower was constructed so that experimental impact parameters could be varied, ensuring that there was a sufficient level of deformation in the test pieces, and that the greater range in impact data would present a stronger test of the corresponding numerical impact models.

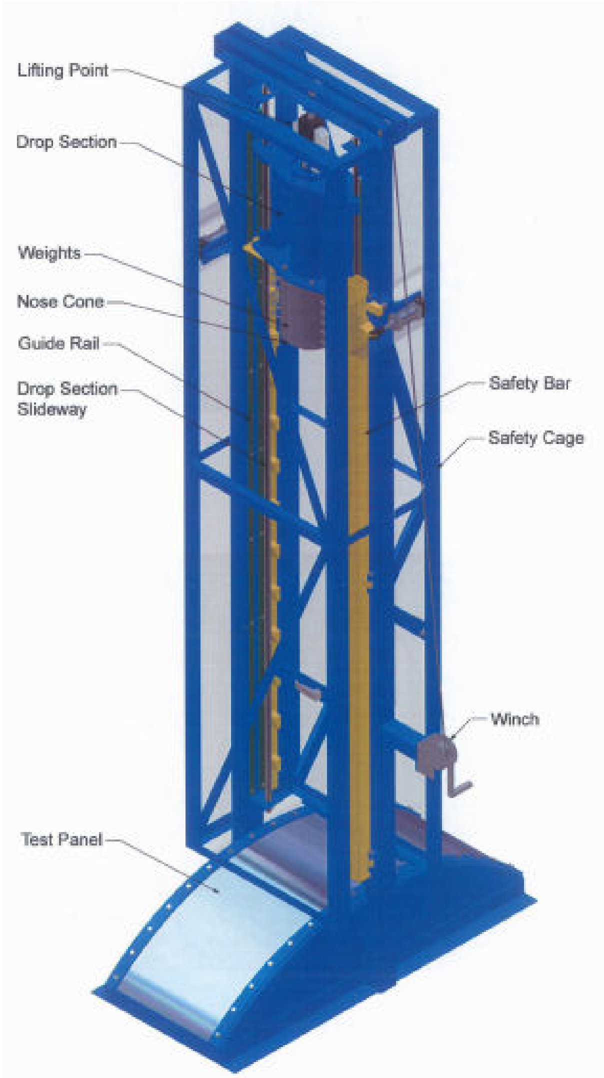


Figure 1. Drop Tower

2.1 Tower

The tower allows for a maximum drop height of 2.3 metres. Guide bars direct the falling drop-carriage onto a model hull section.

2.2 Drop Carriage

The carriage can be fitted with a maximum of six ballast tablets each weighing sixteen kilograms to which a model torpedo nose is attached (Fig. 2). With six ballast tablets attached the carriage achieves its maximum total mass of 140 kilograms. From its maximum drop height the impact speed is 6.7 $m.s^{-1}$ which corresponds to a kinetic energy of 3.1 kJ when the carriage is fitted with all six ballast tablets.

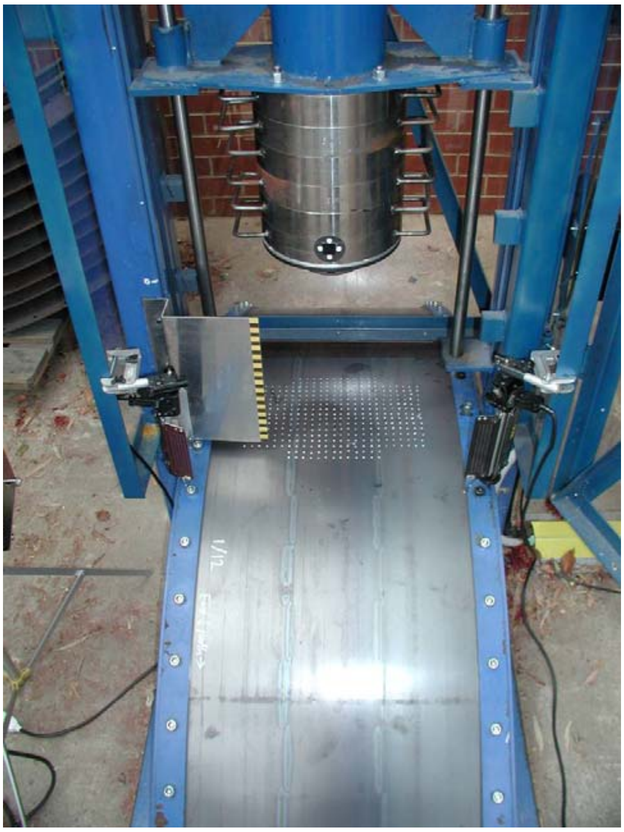


Figure 2. Drop tower showing ballast tablets attached to the drop carriage above the clamped model hull plate prior to a drop. The reference marks on the lowest ballast tablet and the tiger tape attached to the left hand side tower upright are for video motion analysis.

2.3 Model Torpedo Nose

The torpedo noses were spun from 5.5 millimetre thick aluminium alloy sheet into a hemispherical shell with an interior radius of 79 millimetres. The master nose, used for all comparison measurements, is shown in Appendix A. The noses were bolted to the underside of the drop carriage and guided to impact the model hull plate (Fig. 3).

Figure 3. Simulated torpedo nose (r.h.s., post impact)

The manufacturing process has caused a smooth variation in nose thickness of ±12% over the central region (Fig. 4).

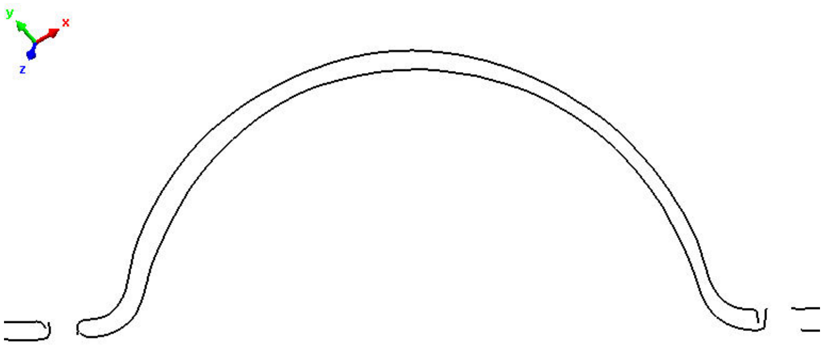


Figure 4. Cross section taken from a 3D scan of a nose showing a degree of thinning caused by the manufacturing process

2.4 Model Hull Plate

Three model hull plate variants were used: steel plate with stiffeners, steel plate without stiffeners and aluminium plate without stiffeners.

The plates are rectangular with dimensions of 1.809 × 0.500 metres, curved along their length on a circular arc of radius 1.265 metres. The steel plate has a thickness of 3 millimetres, the aluminium plate has a thickness of 5 millimetres and the stiffeners divide the plate into thirds along its axis (Figs. 5 & 6).

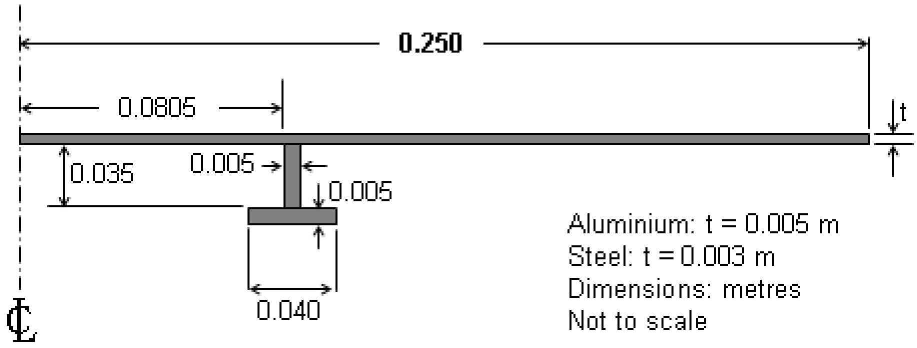


Figure 5. Section of stiffened model hull plate. (Unstiffened plate has equal shared dimensions. Width dimension does not include the plate material held by clamping along the plate's long edges).

Figure 6. Underside of steel plate showing T-stiffeners

The plate's boundary conditions are clamped along its length and free along its width (Figs. 7 & 8). The width of the plate is measured between the clamps.

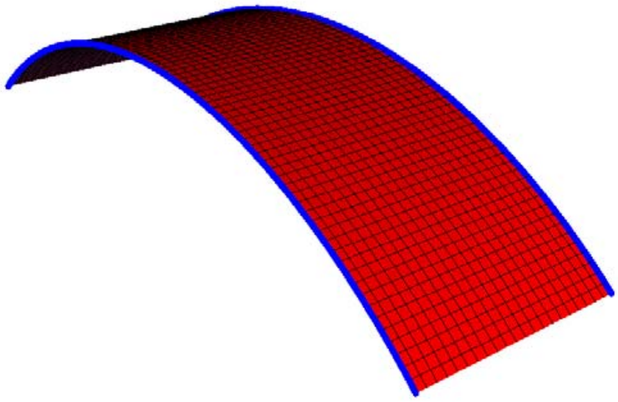


Figure 7. Plate showing boundary conditions as it is fixed in the drop tower. Blue edges clamped, otherwise free.

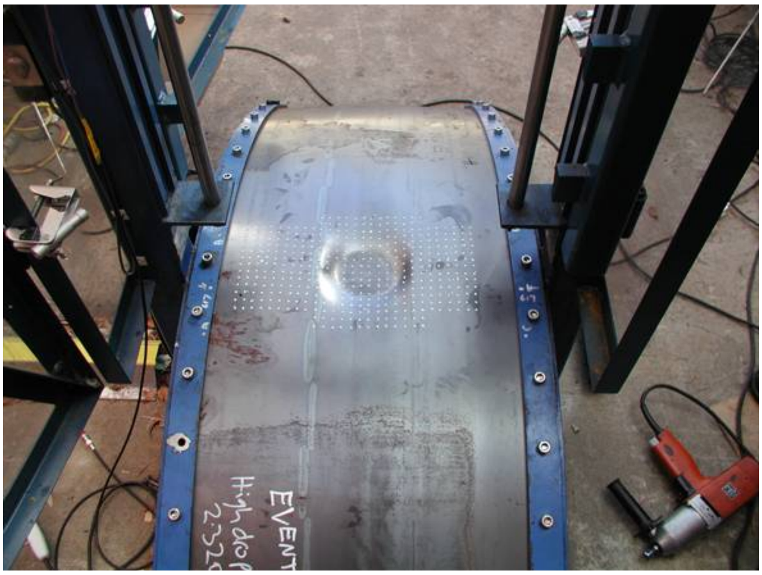


Figure 8. Steel plate with T-stiffeners clamped to the drop tower form, post impact

3. High Speed Video

Each drop event was captured by high speed video at a framing rate of 2000 fps. Imaging of the visual markers attached to the carriage was used to produce displacement-time data for the carriage's fall (Fig. 9), from which velocity-time data were derived, Appendix B. The impact velocity of the carriage was found to be within 3% of the corresponding freefall velocity, this small reduction in impact velocity being attributed to friction between the carriage and the guide bars.

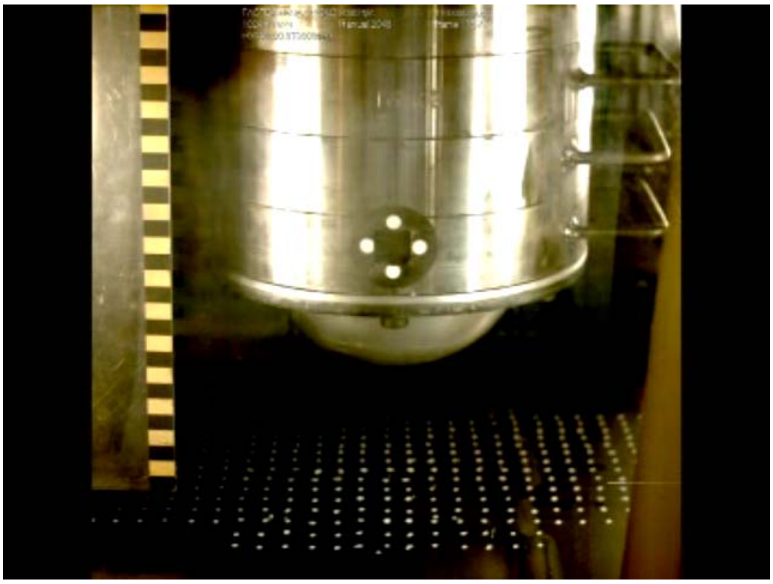


Figure 9. Frame from a high speed video showing the carriage falling towards the plate prior to impact. Tiger tape on the left hand side of the frame and tracking markers attached to the lowest ballast tablet are for video motion analysis.

4. Results

Ten impact tests were conducted. Five against steel plates with stiffeners, two against steel plates without stiffeners and three against unstiffened aluminium plates.

High speed imaging of the impact events was used to produce digitised displacement-time data of the falling drop carriage from which velocity-time data were derived. These data provide the impact and rebound velocities of the carriage, the ratio of which is a measure of the elastic response of the plate. High speed video shows that although the carriage bounces, the dent is formed entirely by the initial impact.

Dimensional scans were taken of the plates and noses. The noses had their entire surface scanned to quantify the degree of thinning caused by the manufacturing process (q.v. §2.3) and to measure thinning due to impact in regions of high strain. The plates only had their top surfaces scanned because the depth of the impact dent compared to its lateral extent suggests that any thinning due to impact is minimal. Dent depth for a nose shell was referenced to the unused master nose, and the dent depth for a plate was referenced to its clamped edges.

Appendix A shows the model's nose geometry. Appendix B contains details of the derivation of the carriage's fall velocity from the displacement data and its subsequent smoothing. Appendix C summarises the experimental results, including the type of hull plate model (aluminium, steel, stiffened or unstiffened), the drop height, carriage mass, impact velocity, rebound velocity, the ratio of the rebound to impact velocities, the impact energy, the shape of the dent in the nose and its dent depth and finally the model hull plate's dent depth. Appendix D presenting a complete set of experimental results, contains Appendix C's data plus graphs of the carriage's displacement and velocity versus time, imaging of the dents in the model nose and hull plate and contour plots of these dented surfaces. Appendix E contains the tensile properties of the model nose, hull and T-stiffener materials tested in accordance with AS1391-2005, Metallic materials – Tensile testing at ambient temperature.

Available on request is a supplementary digital data-set containing Appendices A to E suitable for the numerical modelling of this experiment.

5. Conclusions

The purpose of this experiment was to simulate the dynamics of a practice torpedo impacting a submarine's pressure hull. Data from this experiment can be used as a reference to test numerical impact models. To broaden the parameter range of this experiment, and therefore to present a stronger test of a numerical model, three model hull plate variants were used with three drop heights for three impact velocities presenting seven unique impact combinations (not all combinations were conducted).

A qualitative comparison of the results of this experiment shows that of the three model hull plate variants used: stiffeners tend to limit the extent of the dent, that aluminium plate has a greater elastic response than that of both stiffened and unstiffened steel plate, and that the model torpedo nose was flattened for impact against a steel plate but dimpled for impact against an aluminium plate.

Available on request is a supplementary digital data-set containing model geometry, impact data, material properties and experimental results suitable for the numerical modelling of this experiment.

Appendix A: Master Nose

A nose was scanned and stored in the stereolithographic CAD format, STL (Fig. A1). This file can be used to take measurements from the nose as manufactured and provides nose geometry for finite element modelling.

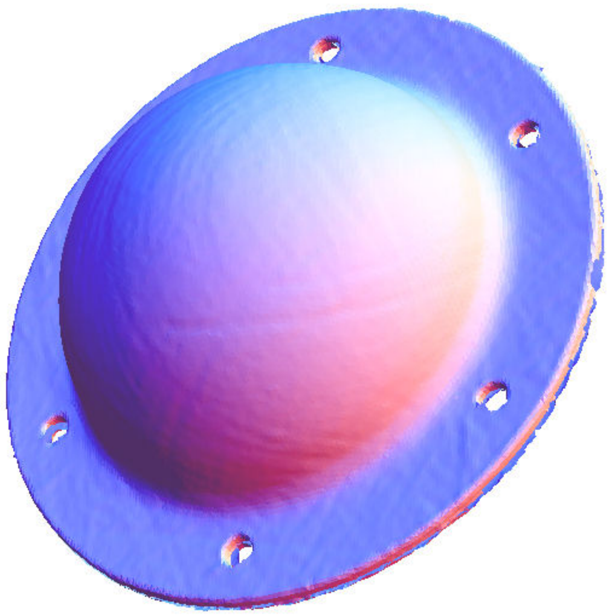


Figure A1. Master nose

Appendix B: Derivation of Velocity Data

Imaging of the carriage fall high speed videos was used to produce digitised displacement-time data. This data was fitted with a third order interpolation function, differentiated and smoothed with either a 41 or 61 sample moving average (depending on noise) to produce a velocity-time data set. The code is written in Mathematica 7.

B.1. Velocity Code

```
Clear["Global`*"]
Directory[]
filePath="filepath here";
eventName="event data file here"
SetDirectory[filePath]
(* Raw data from the text file. *)
dataFromFile=Import[eventName, "Data"];
(* Remove the lateral coordinate, leave the Y coordinate. Convert frames to seconds and mm
to metres. *)
dataWithoutHeader=Drop[dataFromFile,8].{{.0005,0},{0,0},{0,.001}};
data=Drop[dataWithoutHeader,0];
yData=data[[All,2]];
tData=data[[All,1]];
Length[yData]
Length[tData]
xPlot=ListPlot[data, Joined→True, ImageSize→800, PlotStyle→
{Thickness[0.007],Black}, AxesOrigin→{0,0}, Frame→True,
RotateLabel→True, FrameLabel→{{Style["Displacement[m]",
FontFamily→"Arial", Bold, FontSize→32],""},
{Style["Time[s]",
FontFamily→"Arial", Bold, FontSize→32],""}},
FrameTicksStyle→Directive[FontFamily->"Arial", Bold, FontSize→24],
GridLines→Automatic]
Export[filePath<>StringDrop[eventName, -4]<>"XPlot.gif",xPlot]
yIP=Interpolation[data]
vData={#,yIP'[#]}&/@tData;
ListPlot[vData,Joined→True,PlotRange→All,PlotStyle→Thick,
AxesOrigin→{0,0}]
(* This number must be odd. *)
movingAverageWidth=41;
dataVMovAv=MovingAverage[vData[[All,2]], movingAverageWidth];
Length[dataVMovAv]
tVDataFrontDrop=Drop[vData[[All,1]], Floor[movingAverageWidth/2]];
Length[tVDataFrontDrop]
tVDataFrontDropBackDrop=Drop[tVDataFrontDrop, -(movingAverageWidth-
Floor[movingAverageWidth/2]-1)];
vTMovAv=Inner[List, tVDataFrontDropBackDrop, dataVMovAv, List];
```

```
vPlot=ListPlot[vTMovAv, Joined→True, ImageSize→800,
PlotStyle→{Thickness[0.007],Black}, AxesOrigin→{0,0},
Frame→True, RotateLabel→True, PlotRange→All,
FrameLabel→{{Style["Velocity[ms-1]",
FontFamily→"Arial", Bold, FontSize→32],""},
{Style["Time[s]", FontFamily->"Arial", Bold, FontSize→32],""}},
FrameTicksStyle→Directive[FontFamily->"Arial", Bold, FontSize→24],
GridLines→Automatic]
Min[vTMovAv]
Max[vTMovAv]
Export[filePath<>StringDrop[eventName, -4]<>"VPlot.gif",vPlot]
xvPlot=Row[{xPlot, Spacer[100],vPlot}]
Export[filePath<>StringDrop[eventName, -4]<>"XVPlot.gif",xvPlot]
```

Appendix C: Practice Torpedo Impact Drop Tower Model, Data Summary.

Table C1 contains an impact data summary for each drop event. It tabulates the hull type, impact kinematic parameters, the model nose dent shapes and the model nose and hull plate dent dimensions.

Table C1. Practice torpedo impact drop tower model, impact data summary

Data Set	Model Hull type	Drop Height [m]	Carriage Mass [kg]	Impact Velocity [ms^{-1}]	Rebound Velocity [ms^{-1}]	Rebound / Impact Velocity Ratio[1]	Impact Energy [kJ]	Nose Dent Shape	Nose Dent Depth [m]	Plate Dent Depth [m]
1	Steel stiffened	2	140	-6.26	2.15	0.34	2.74	Flat	NA	0.027
2	Steel stiffened	2	140	-6.21	2.13	0.34	2.70	Flat	0.018	0.025
3	Steel stiffened	1	140	-4.30	1.68	0.39	1.29	Flat	0.012	0.019
4	Steel stiffened	1	140	-4.29	1.69	0.39	1.29	Flat	0.013	0.018
5	Steel stiffened	2.32	140	-6.69	2.22	0.33	3.13	Flat	0.020	0.028
6	Steel unstiffened	2	140	-6.16	2.03	0.33	2.66	Flat	0.016	0.043
7	Steel unstiffened	1	140	-4.30	1.71	0.40	1.30	Flat	0.010	0.029
8	Aluminium unstiffened	1	140	NA[2]	NA	NA	NA	Dimpled	0.024	0.012
9	Aluminium unstiffened	1	140	-4.29	2.54	0.59	1.29	Dimpled	0.024	0.011
10	Aluminium unstiffened	2	140	NA[2]	NA	NA	NA	Dimpled	NA	0.021

1. Absolute value of the ratio.
2. Not available, instrument error.

Appendix D: Practice Torpedo Impact Drop Tower Model, Data.

Data for the impact tests is given in the following ten data sets. Five impact tests were conducted against steel plates with stiffeners, two against steel plates without stiffeners and three against unstiffened aluminium plates.

The time axes on the carriage fall plots measure time from the high speed video's trigger signal. Time zero is not the time of carriage release. The displacement of the carriage is referenced to an arbitrary datum.

D.1. Steel Plate with Stiffeners

D.1.1 Data Set 1

Table B1. Impact Parameters

Hull Type	Drop Height [m]	Drop Carriage Mass [kg]	Impact Velocity [ms^{-1}]	Rebound Velocity [ms^{-1}]	Rebound / Impact Velocity Ratio[1]	Impact Energy	Nose Dent Shape	Nose Dent Depth [m]	Plate Dent Depth [m]	Velocity Data Smoothing Length [samples]
Steel stiffened	2	140	-6.26	2.15	0.34	2.74	Flat	NA	0.027	41

1. Absolute value of the ratio.

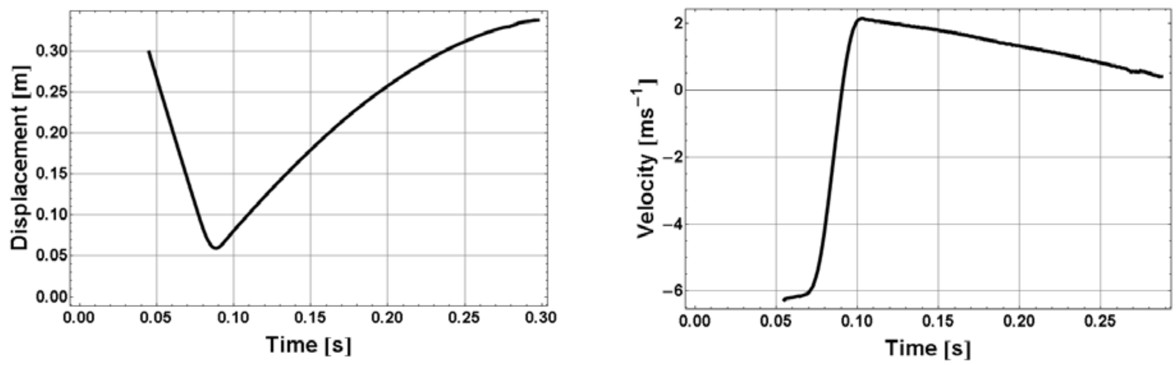


Figure B1. Displacement and velocity of the falling carriage

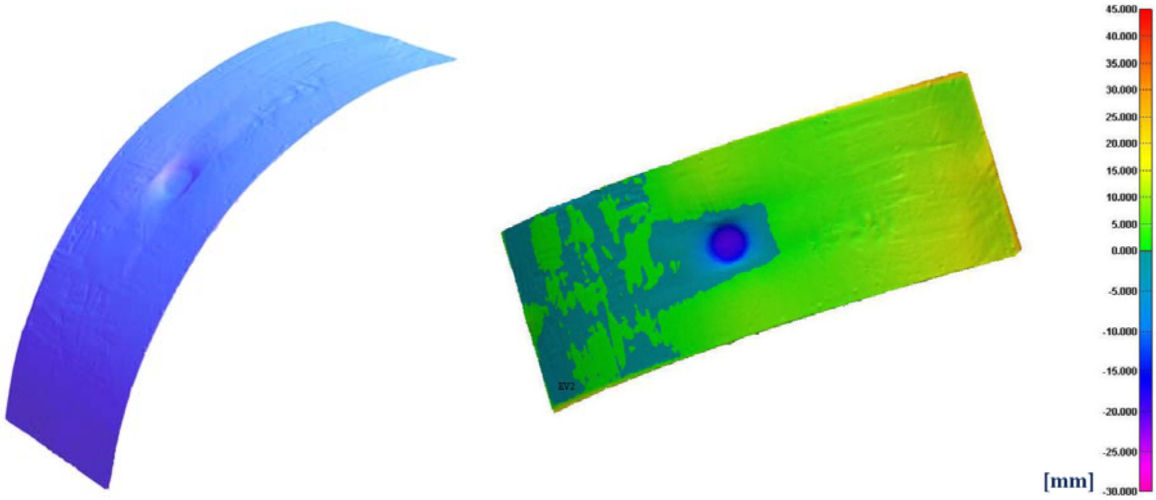


Figure B2. Dented Plate: Surface scan & contour map

Figure B3. Dented Nose

D.1.2 Data Set 2

Table B2. Impact Parameters

Hull Type	Drop Height [m]	Drop Carriage Mass [kg]	Impact Velocity [ms^{-1}]	Rebound Velocity [ms^{-1}]	Rebound / Impact Velocity Ratio[1]	Impact Energy [kJ]	Nose Dent Shape	Nose Dent Depth [m]	Plate Dent Depth [m]	Velocity Data Smoothing Length [samples]
Steel stiffened	2	140	-6.21	2.13	0.34	2.70	Flat	0.018	0.025	41

1. Absolute value of the ratio

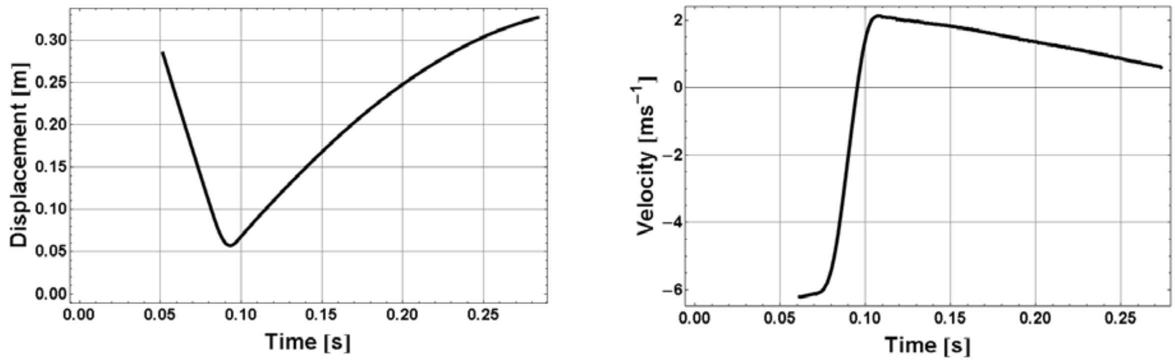


Figure B4. Displacement and velocity of the falling carriage

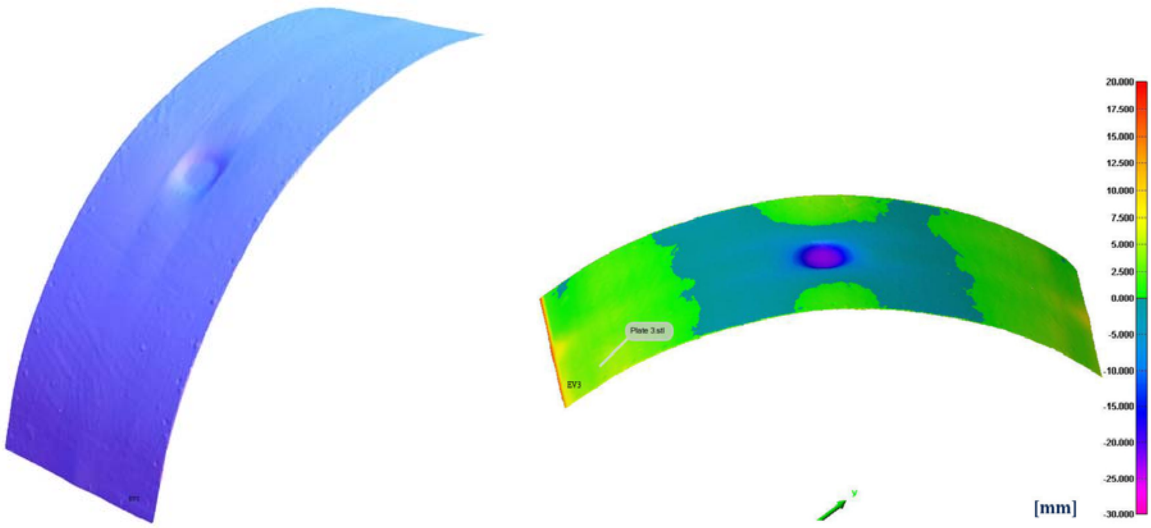


Figure B5. Dented Plate: Surface scan & contour map

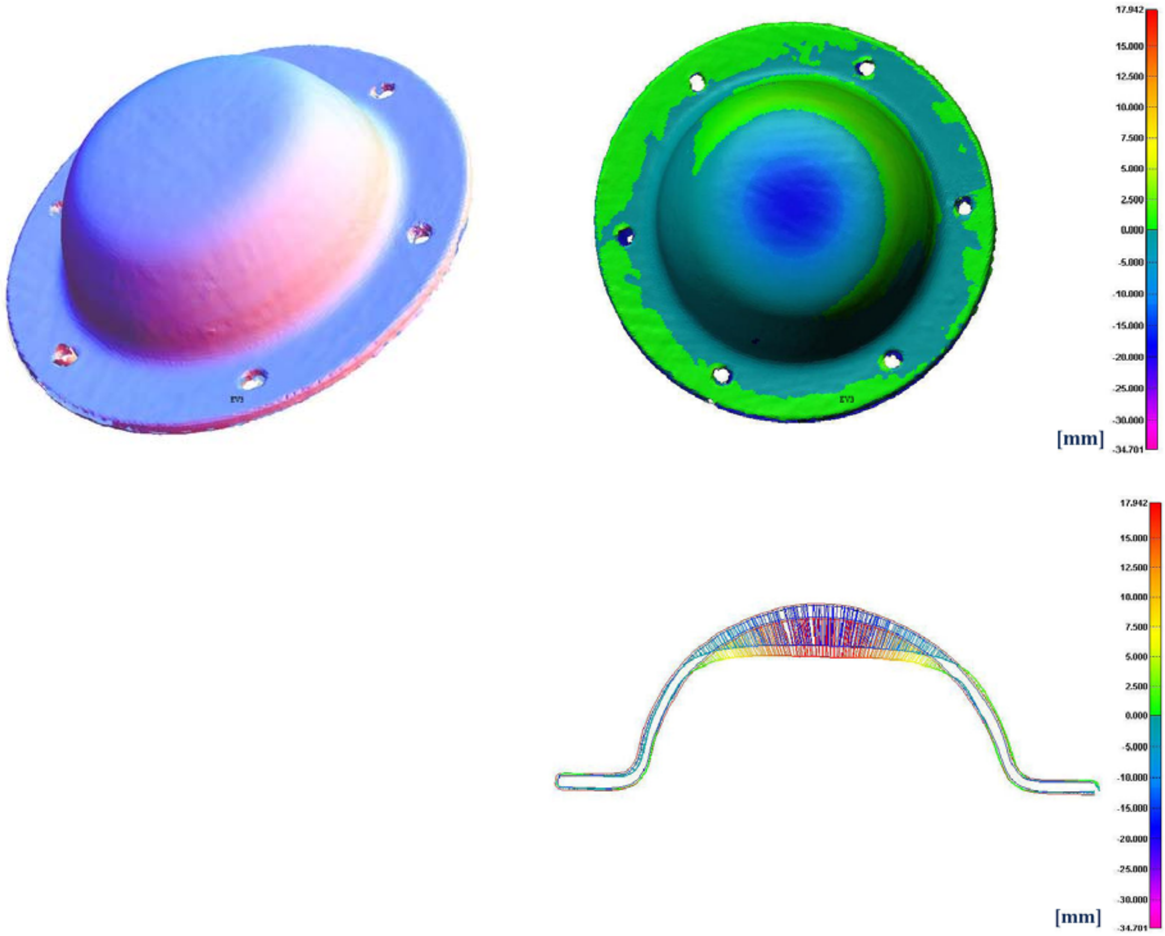


Figure B6. Nose: Full surface scan, contour map and cross-section

D.1.3 Data Set 3

Table B3. Impact Parameters

Hull Type	Drop Height [m]	Drop Carriage Mass [kg]	Impact Velocity [ms^{-1}]	Rebound Velocity [ms^{-1}]	Rebound / Impact Velocity Ratio[1]	Impac t Energ y [kJ]	Nose Dent Shape	Nose Dent Depth [m]	Plate Dent Depth [m]	Velocity Data Smoothing Length [samples]
Steel stiffened	1	140	-4.30	1.68	0.39	1.29	Flat	0.012	0.019	41

1. Absolute vaule of the ratio.

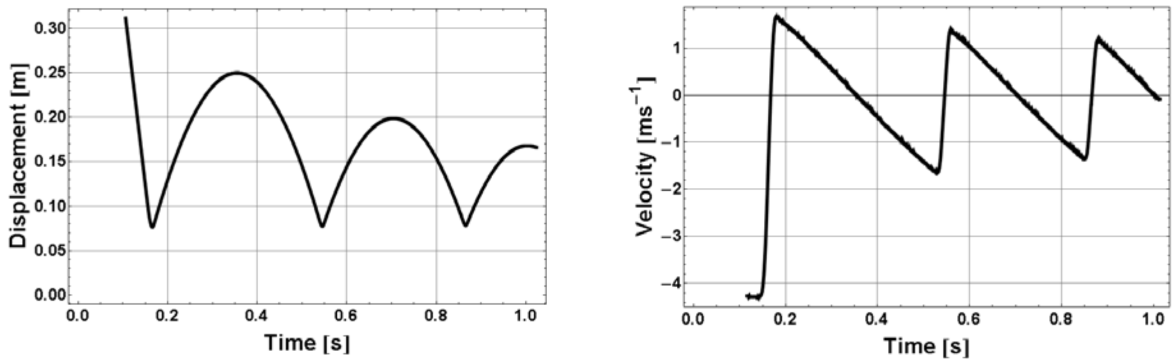


Figure B7. Displacement and velocity of the falling carriage

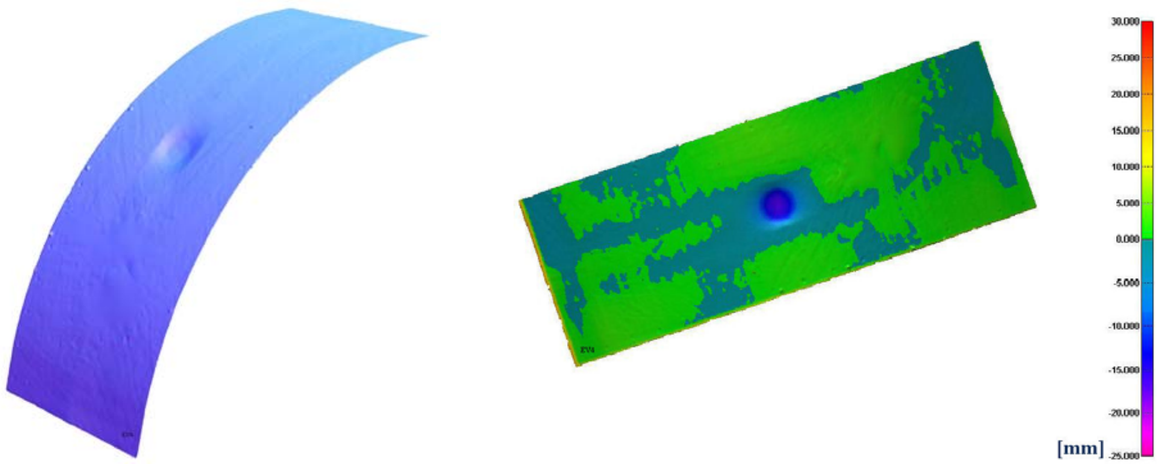


Figure B8. Dented Plate: Surface scan & contour map

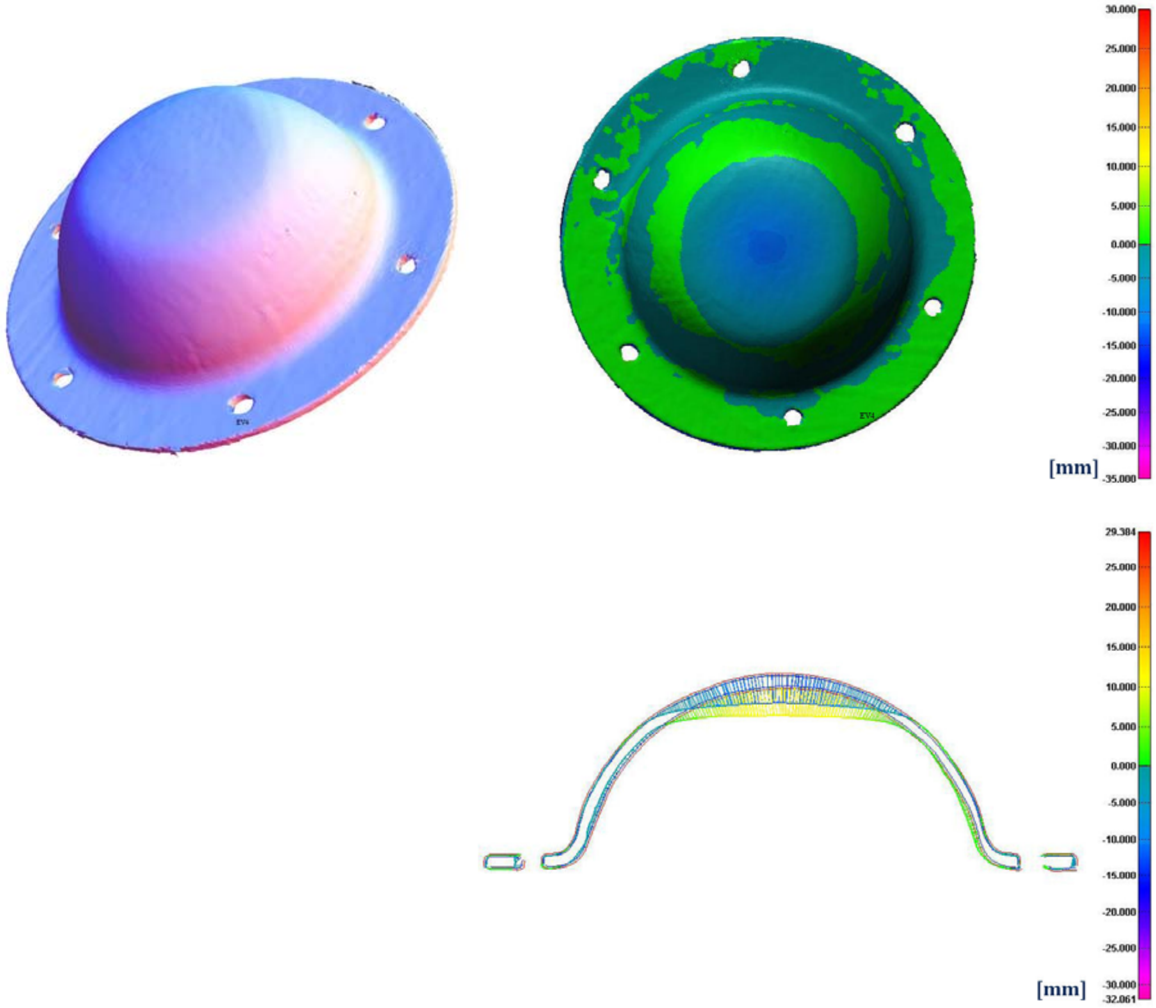


Figure B9. Nose: Full surface scan, contour map and cross-section

D.1.4 Data Set 4

Table B4. Impact Parameters

Hull Type	Drop Height [m]	Drop Carriage Mass [kg]	Impact Velocity $[ms^{-1}]$	Rebound Velocity $[ms^{-1}]$	Rebound / Impact Velocity Ratio[1]	Impact Energy [kJ]	Nose Dent Shape	Nose Dent Depth [m]	Plate Dent Depth [m]	Velocity Data Smoothing Length [samples]
Steel stiffened	1	140	-4.29	1.69	0.39	1.29	Flat	0.013	0.018	41

1. Absolute value of the ratio.

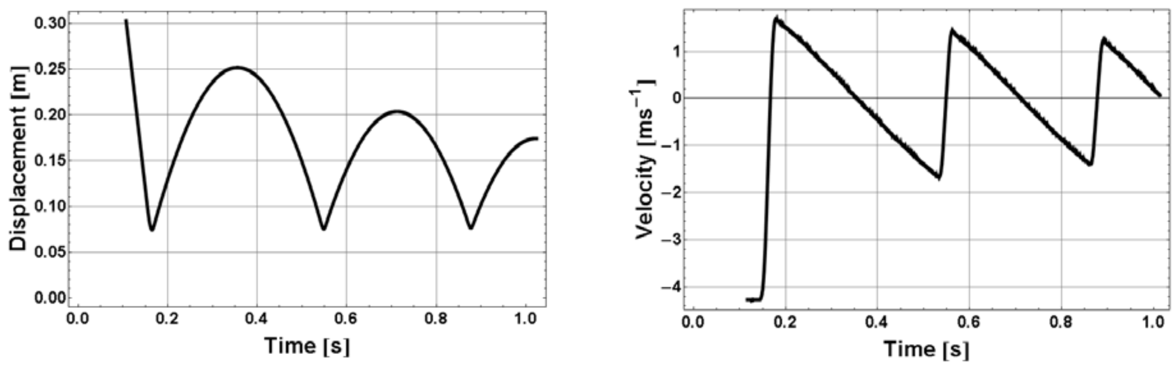


Figure B10. Displacement and velocity of the falling carriage

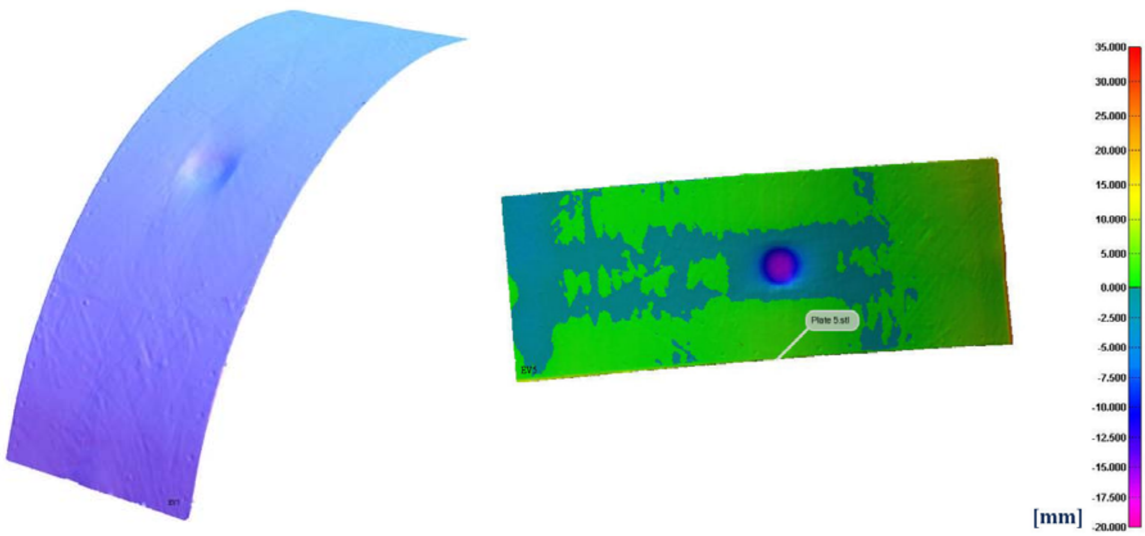


Figure B11. Dented Plate: Surface scan & contour map

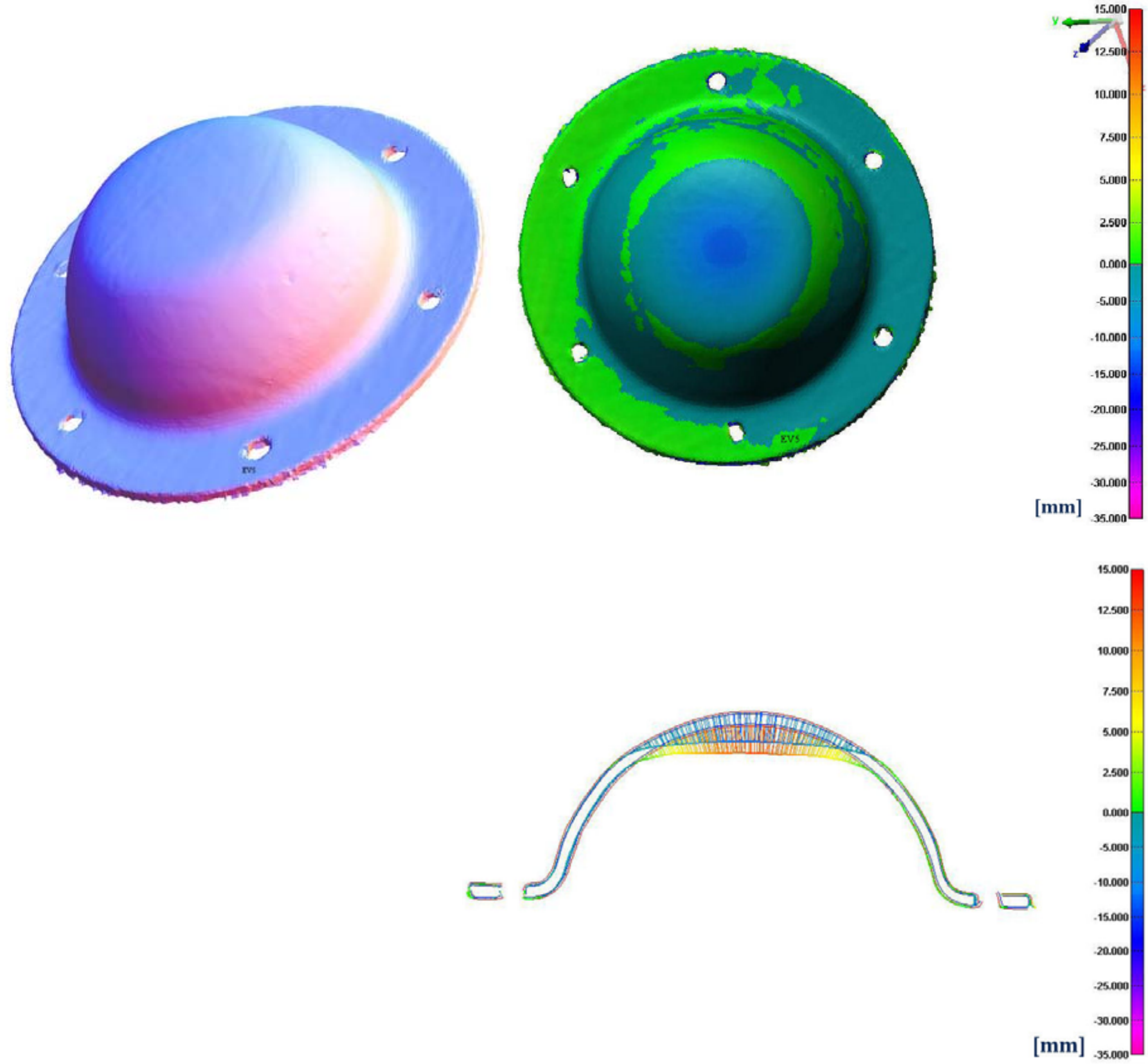


Figure B12. Nose: Full surface scan, contour map and cross-section

D.1.5 Data Set 5

Table B5. Impact Parameters

Hull Type	Drop Height [m]	Drop Carriage Mass [kg]	Impact Velocity [ms^{-1}]	Rebound Velocity [ms^{-1}]	Rebound / Impact Velocity Ratio[1]	Impact Energy [kJ]	Nose Dent Shape	Nose Dent Depth [m]	Plate Dent Depth [m]	Velocity Data Smoothing Length [samples]
Steel stiffened	2.32	140	-6.69	2.22	0.33	3.13	Flat	0.020	0.028	61

1. Absolute value of the ratio.

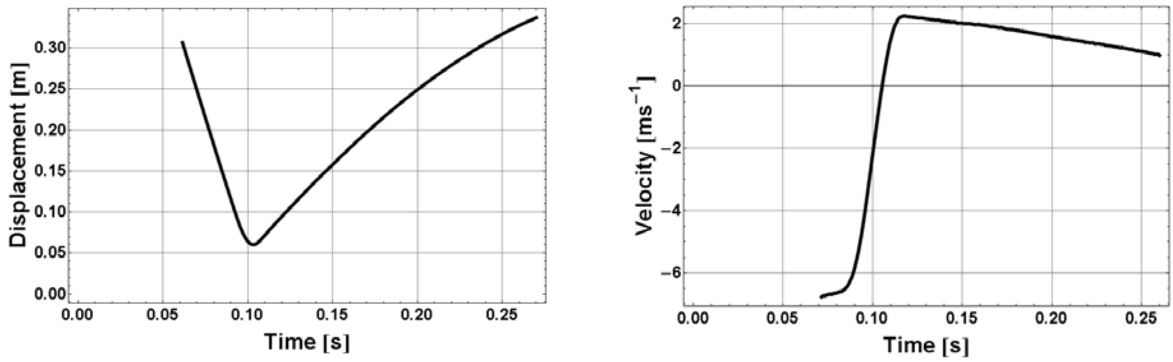


Figure B13. Displacement and velocity of the falling carriage

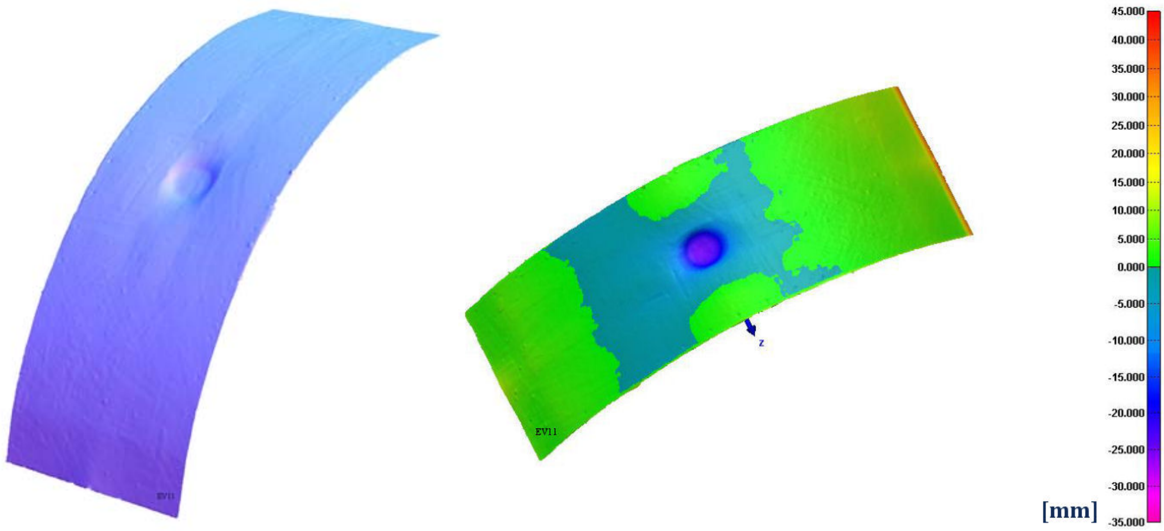


Figure B14. Dented Plate: Surface scan & contour map

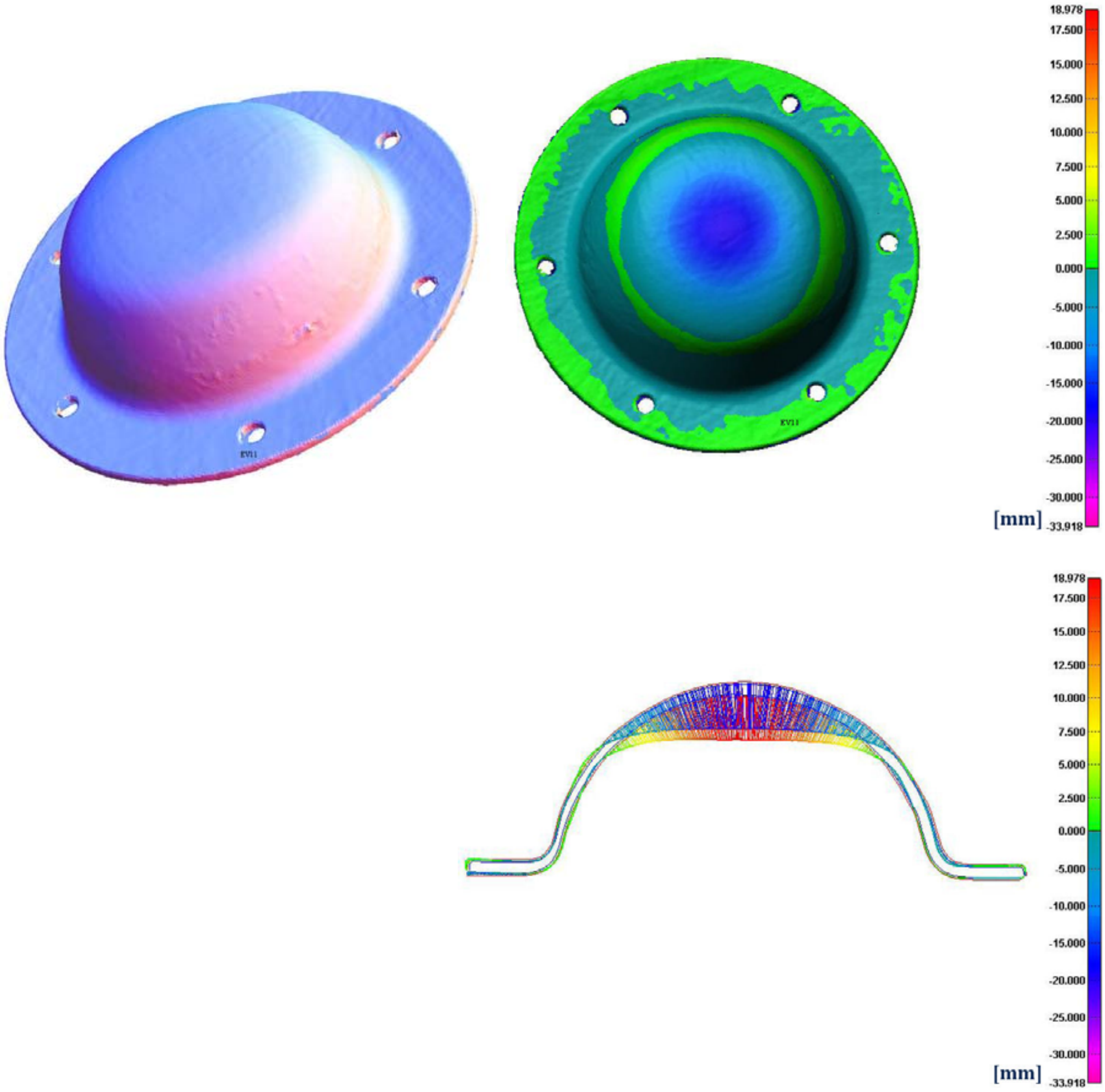


Figure B15. Nose: Full surface scan, contour map and cross-section

D.2. Steel Plate without Stiffeners

D.2.1 Data Set 6

Note that the plate scan contour map shows a large displacement deviation at one end of the plate. This occurs because scans was taken with the plate free of the drop tower.

Table B6. Impact Parameters

Hull Type	Drop Height [m]	Drop Carriage Mass [kg]	Impact Velocity [ms^{-1}]	Rebound Velocity [ms^{-1}]	Rebound / Impact Velocity Ratio[1]	Impact Energy [kJ]	Nose Dent Shape	Nose Dent Depth [m]	Plate Dent Depth [m]	Velocity Data Smoothing Length [samples]
Steel unstiffened	2	140	-6.16	2.03	0.33	2.66	Flat	0.016	0.043	41

1, Absolute value of the ratio.

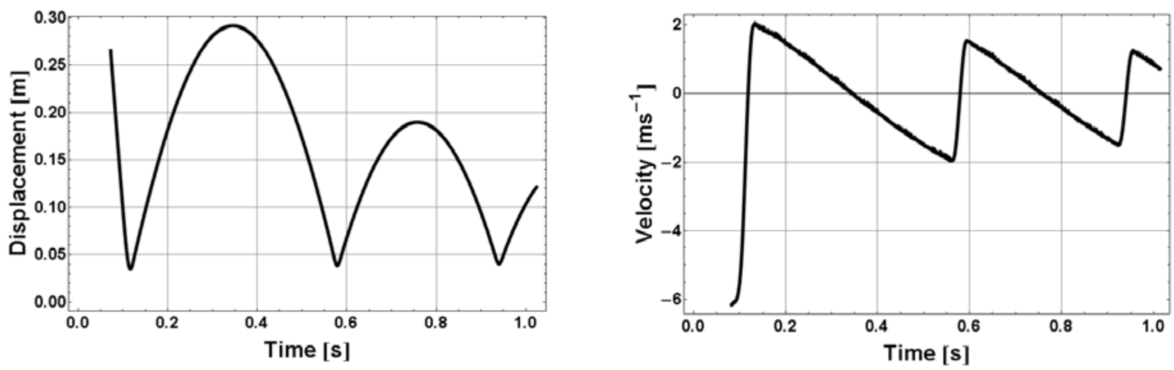


Figure B16. Displacement and velocity of the falling carriage

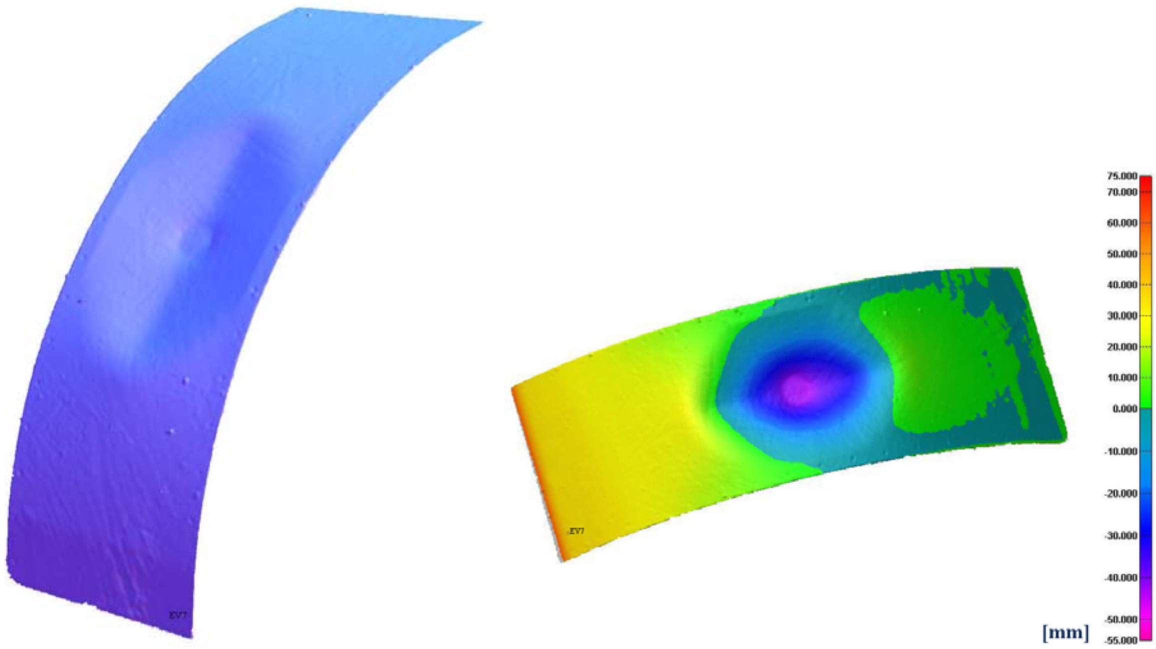


Figure B17. Dented Plate: Surface scan & contour map

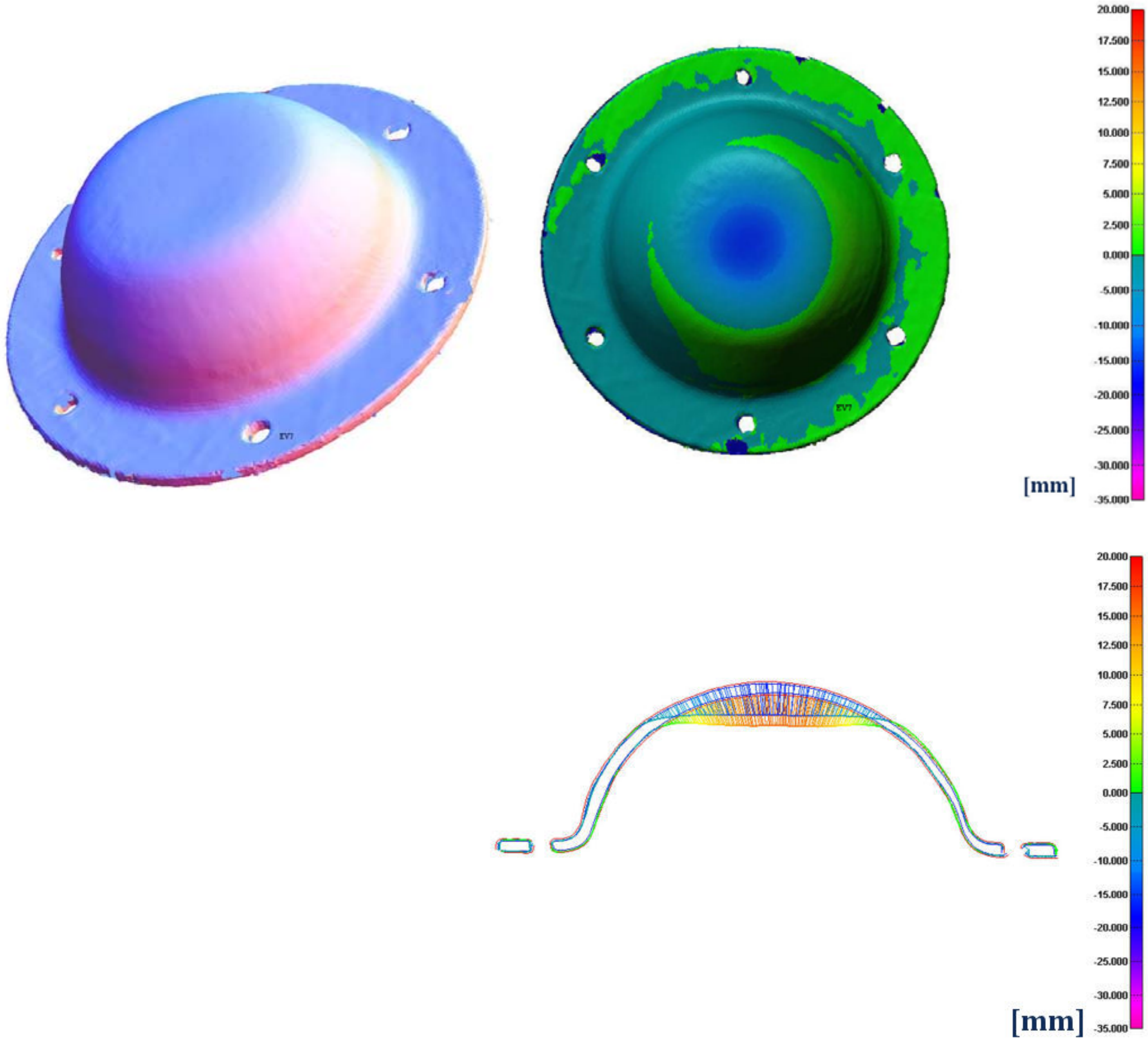


Figure B18. Nose: Full surface scan, contour map and cross-section

D.2.2 Data Set 7

Table B7. Impact Parameters

Hull Type	Drop Height [m]	Drop Carriage Mass [kg]	Impact Velocity [ms^{-1}]	Rebound Velocity [ms^{-1}]	Rebound / Impact Velocity Ratio[1]	Impact Energy [kJ]	Nose Dent Shape	Nose Dent Depth [m]	Plate Dent Depth [m]	Velocity Data Smoothing Length [samples]
Steel unstiffened	1	140	-4.30	1.71	0.40	1.30	Flat	0.010	0.029	41

1. Absolute value of the ratio.

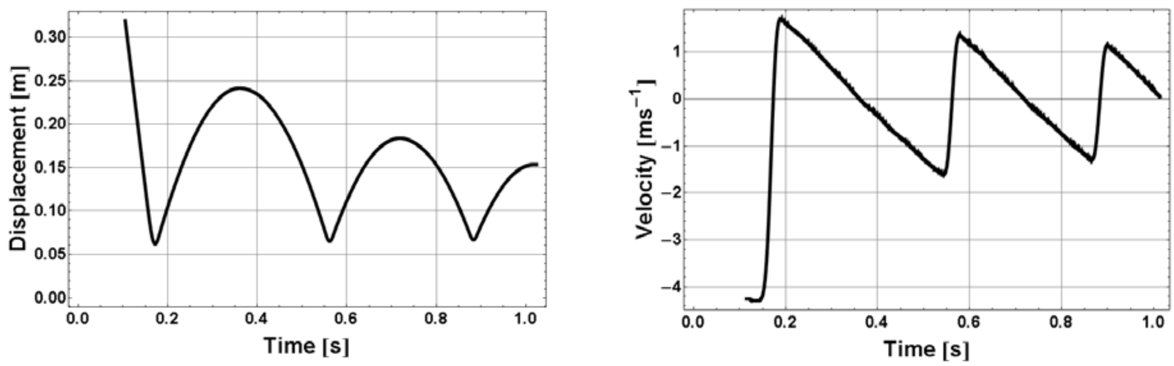


Figure B19. Displacement and velocity of the falling carriage

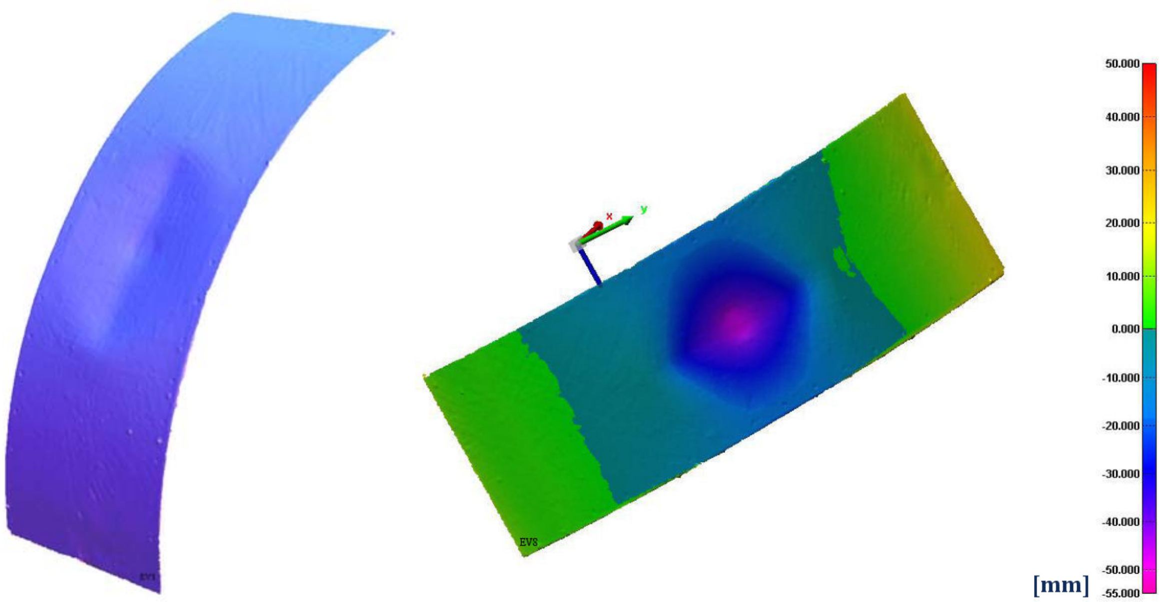


Figure B20. Dented Plate: Surface scan & contour map

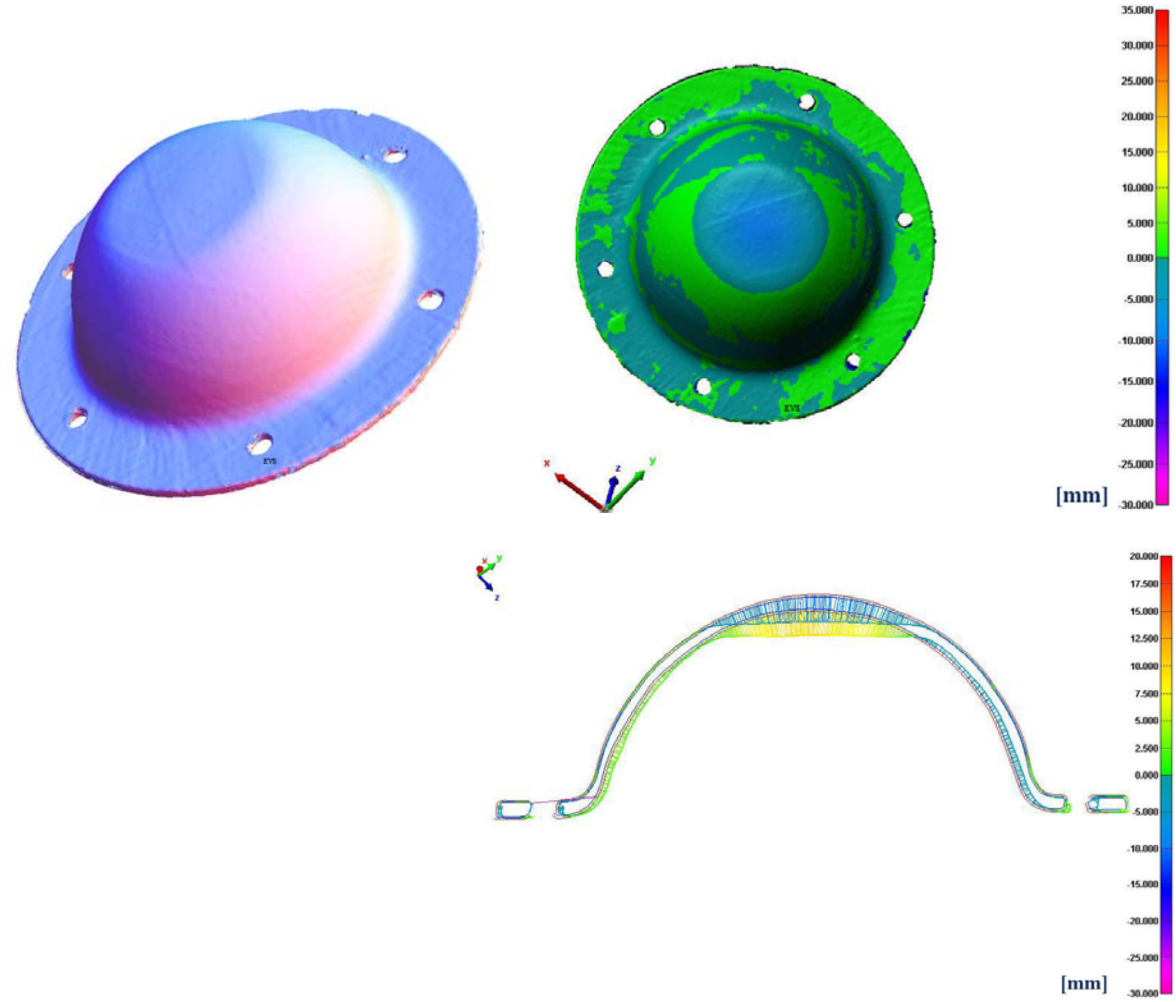


Figure B21. Nose: Full surface scan, contour map and cross-section

D.3. Aluminium Plate without Stiffeners

D.3.1 Data Set 8

Table B8. Impact Parameters

Hull Type	Drop Height [m]	Drop Carriage Mass [kg]	Impact Velocity [ms^{-1}]	Rebound Velocity [ms^{-1}]	Rebound / Impact Velocity Ratio	Impact Energy [kJ]	Nose Dent Shape	Nose Dent Depth [m]	Plate Dent Depth [m]	Velocity Data Smoothing Length [samples]
Aluminium unstiffened	1	140	NA*	NA	NA	NA	Dimpled	0.024	0.012	NA

* Instrument error

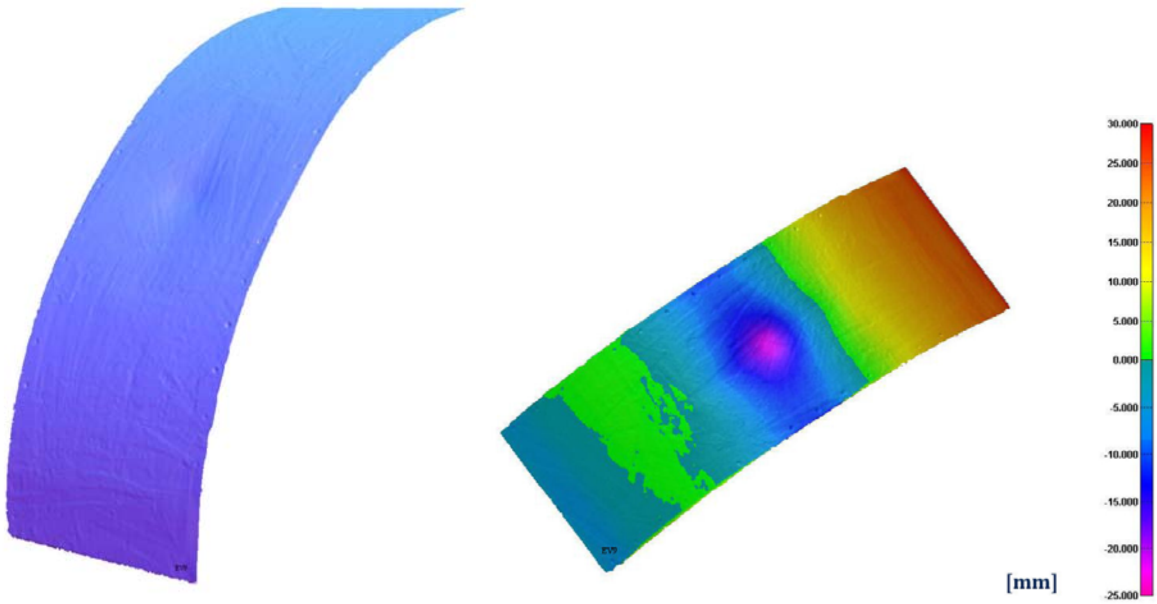


Figure B22. Dented Plate: Surface scan & contour map

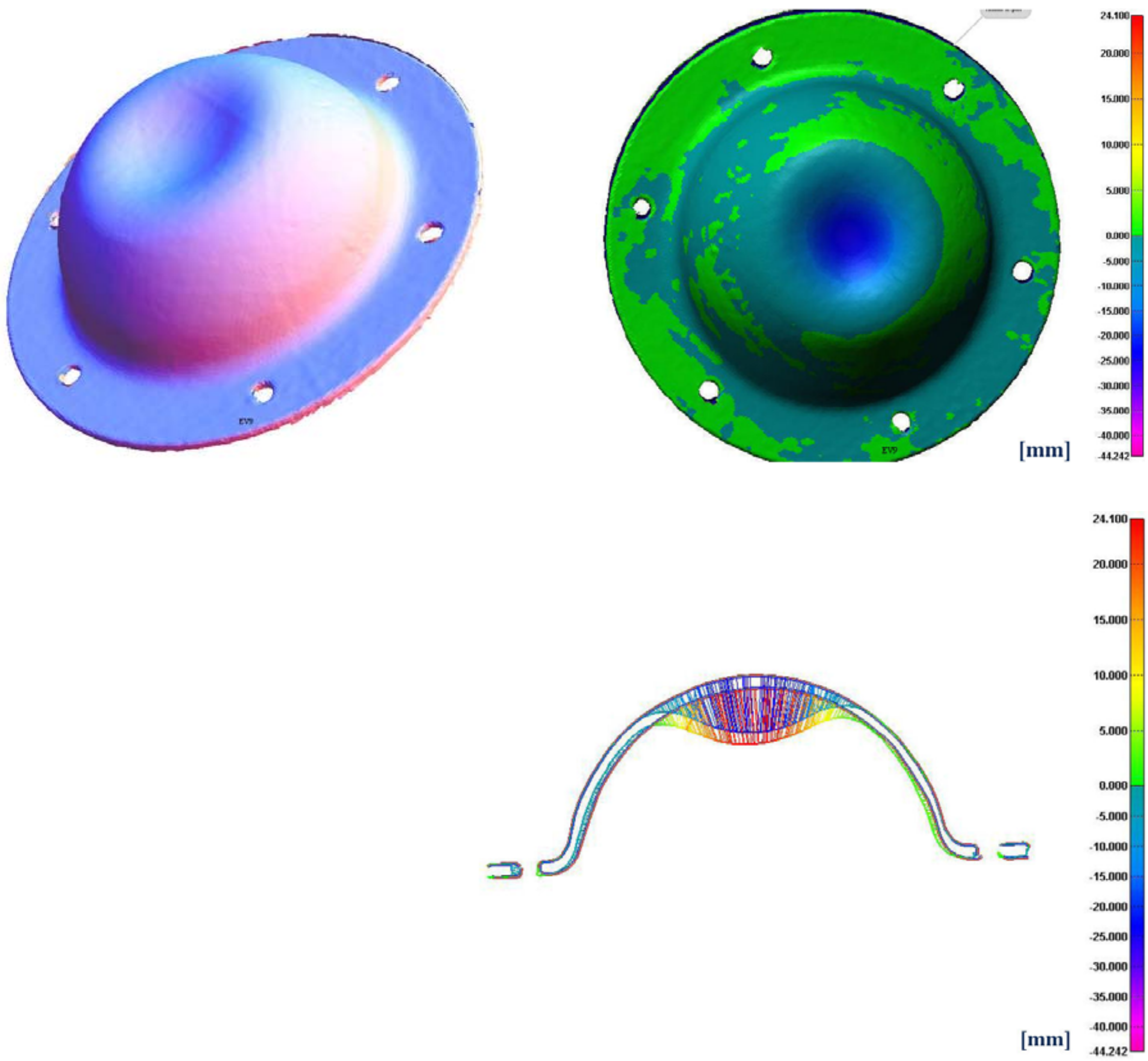


Figure B23. Nose: Full surface scan, contour map and cross-section

D.3.2 Data Set 9

Table B9. Impact Parameters

Hull Type	Drop Height [m]	Drop Carriage Mass [kg]	Impact Velocity [ms^{-1}]	Rebound Velocity [ms^{-1}]	Rebound / Impact Velocity Ratio	Impact Energy [kJ]	Nose Dent Shape	Nose Dent Depth [m]	Plate Dent Depth [m]	Velocity Data Smoothing Length [samples]
Aluminium unstiffened	1	140	-4.29	2.54	0.59	1.29	Dimpled	0.024	0.011	41

1. Absolute value of ratio.

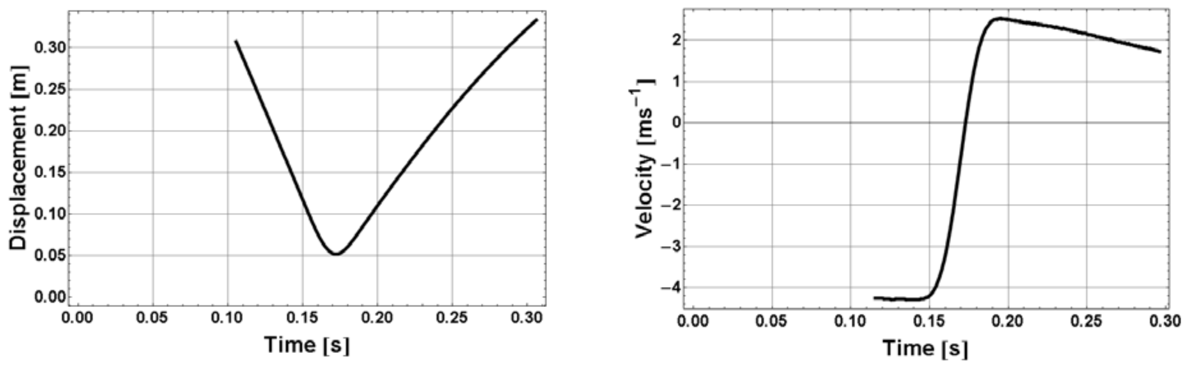


Figure B24. Carriage fall

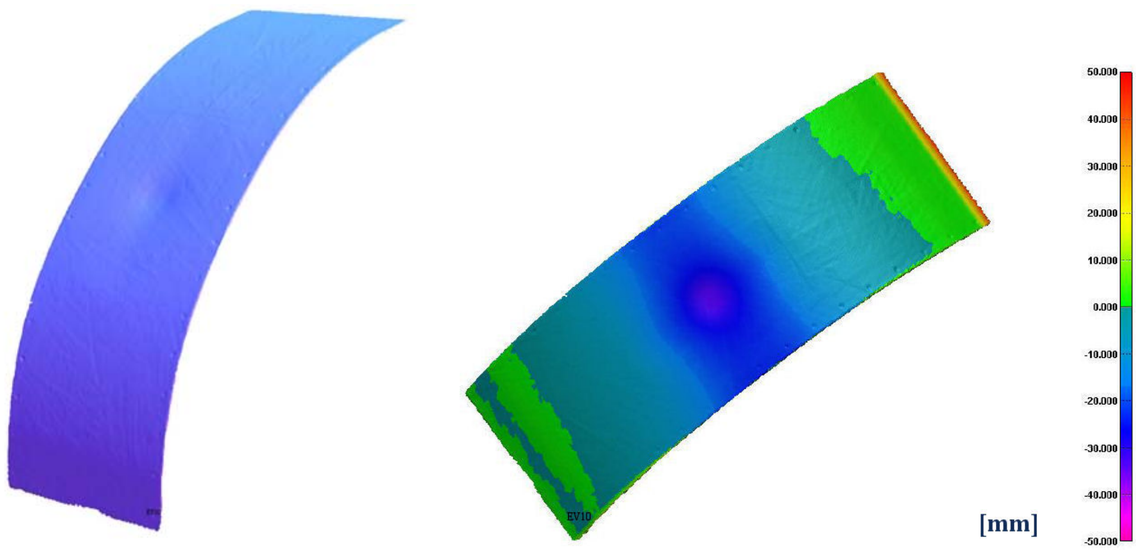


Figure B25. Dented Plate: Surface scan & contour map

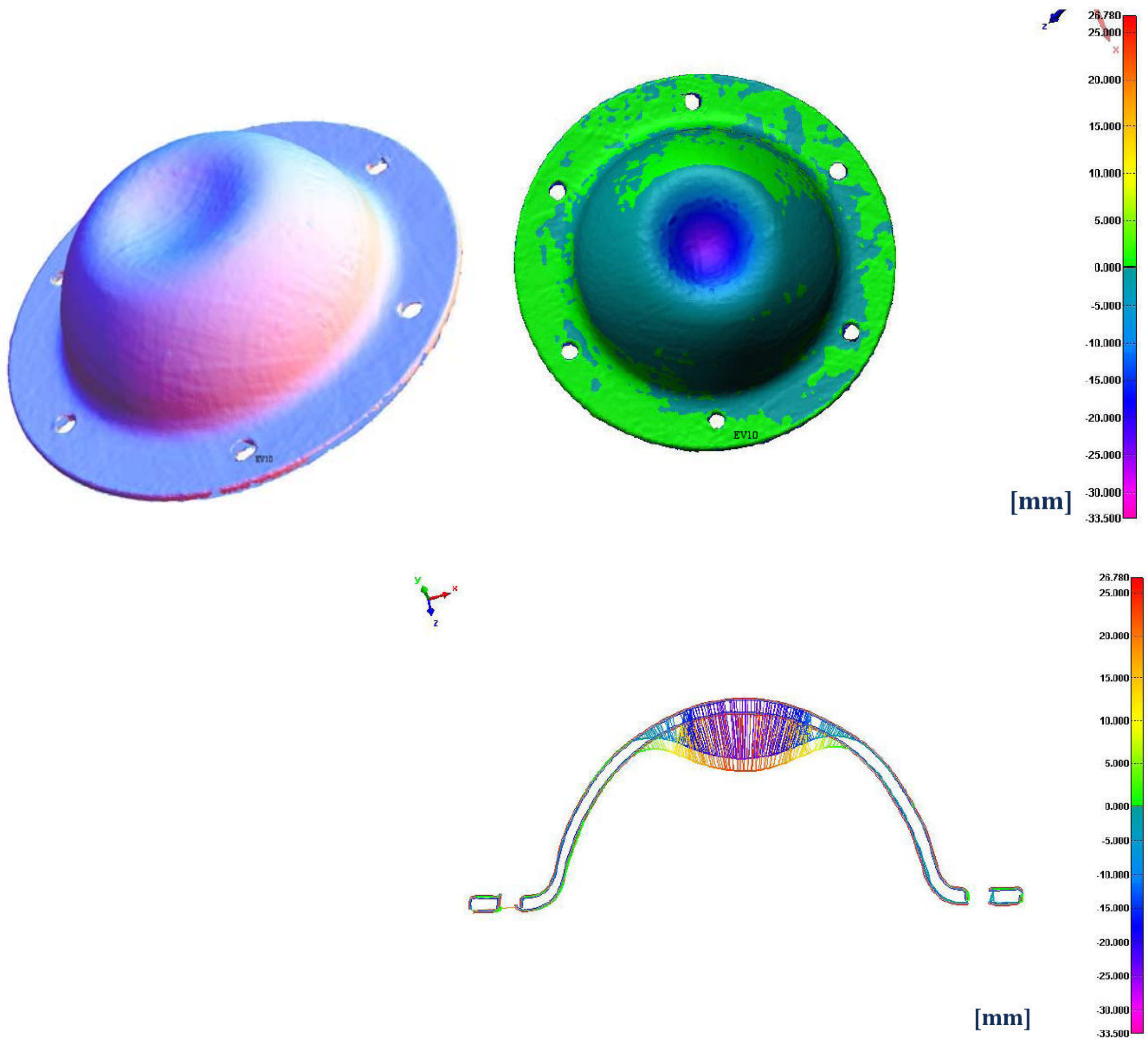


Figure B26. Nose: 3D Full surface scan, contour map and cross-section

D.3.3 Data Set 10

Table B10. Impact Parameters

Hull Type	Drop Height [m]	Drop Carriage Mass [kg]	Impact Velocity [ms^{-1}]	Rebound Velocity [ms^{-1}]	Rebound / Impact Velocity Ratio	Impact Energy [kJ]	Nose Dent Shape	Nose Dent Depth [m]	Plate Dent Depth [m]	Velocity Data Smoothing Length [samples]
Aluminium unstiffened	2	140	NA*	NA	NA	NA	Dimpled	NA	0.021	NA

* Instrument error

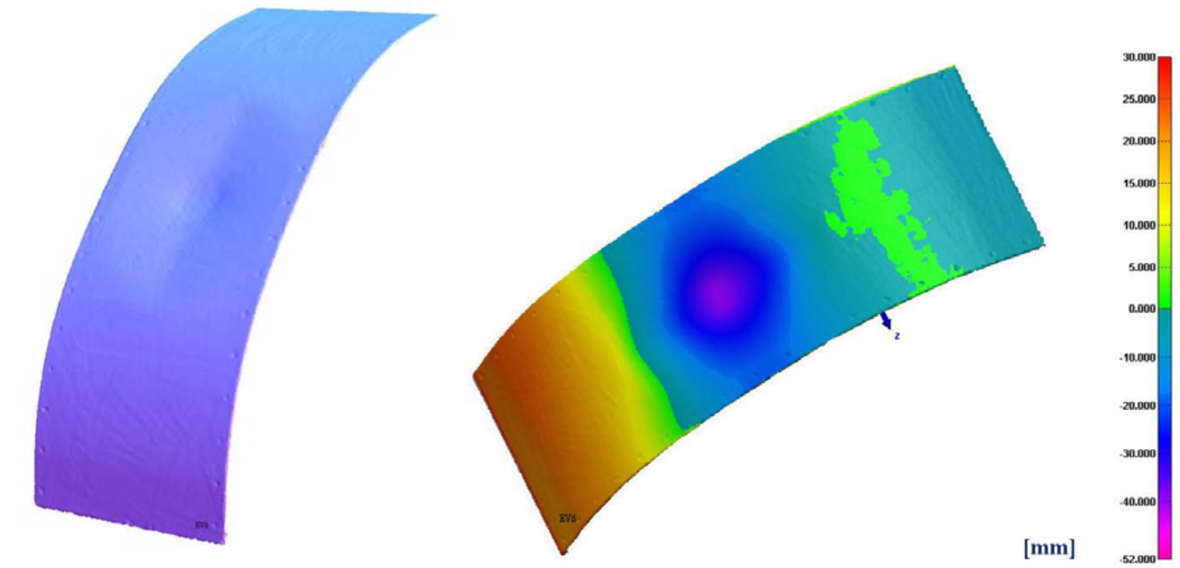


Figure B27. Dented Plate: Surface scan & contour map

Figure B28. Nose

Appendix E: Material Properties

E.1. Model Torpedo Nose

Table E1. Tensile test results for the model nose aluminium. Four coupons were cut from nose shells, two from dented nose shells (Dented 1 & 2), and two from a sectioned unused nose shell (Half 1 & 2).

Melbourne Testing Services

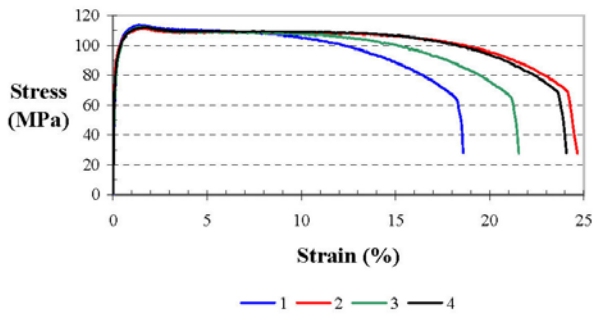
Unit 1/15 Pickering Road
Mulgrave Vic 3170
Telephone: 9560 2759
Mobile: 0419 116 733

Tensile Test Report

Report No:	MT-06/157-F	**CLIENT:**	DSTO
Report Date:	5-Jun-06		150 Cordite Ave
Specimen I.D.	Nose Cones		MARIBYRNONG Vic 3032
Testing Machine:	SINTECH 60/D		

TEST DETAILS			1	2	3	4
Test Date:		4/06/2006	Dented 1	Dented 2	Half 1	Half 2
Extensometer Gauge Length:	L_e	(mm)	25.00	25.00	25.00	25.00
SPECIMEN DETAILS						
Width:	b	(mm)	5.96	6.00	6.00	5.97
Thickness:	a	(mm)	5.28	5.28	5.35	5.31
Area:	S_o	(mm^2)	31.47	31.68	32.10	31.70
Gauge Length:	L_o	(mm)	24.0	24.0	24.0	24.0
Parallel Length:	L_c	(mm)	27.0	27.0	27.0	27.0
TENSILE PROPERTIES						
Tensile Strength:	R_m	(MPa)	114	112	113	112
Proof Stress:	$R_{p0.2}$	(MPa)	99	98	95	97
Upper Yield Stress:	R_{eH}	(MPa)	N/A	N/A	N/A	N/A
Lower Yield Stress:	R_{eL}	(MPa)	N/A	N/A	N/A	N/A
Post Fracture Elongation:	A	(%)	21	28	24	27
Reduction of Area:	Z	(%)	70	71	72	68

Test Comments:
Tested in accordance with AS 1391-2005



Rodney Wilkie
Authorised Signatory

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E.2. Model Hull Plate – Steel

Table E2. Tensile test results for the steel used in the model hull plate. 2 coupons were cut with their length parallel to the long side of the plate (SC 1 & 2) and 2 with their long side perpendicular to the length of the plate (SP 1 & 2).

Melbourne Testing Services

Unit 1/15 Pickering Road
Mulgrave Vic 3170
Telephone: 9560 2759
Mobile: 0419 116 733

Tensile Test Report

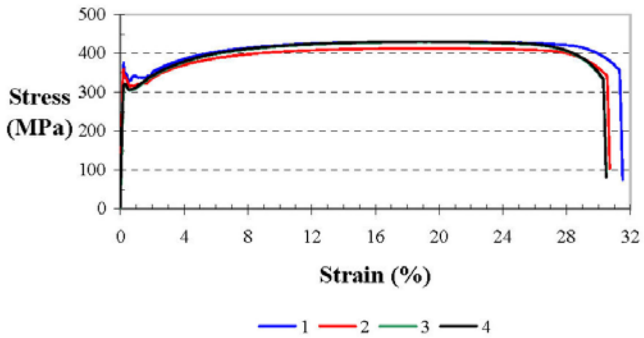
Report No: MT-06/157-D
Report Date: 5-Jun-06
Specimen I.D. Steel Coupons
Testing Machine: SINTECH 60/D

CLIENT: DSTO
150 Cordite Ave
MARIBYRNONG Vic 3032

TEST DETAILS

			1	2	3	4
Test Date:		4/06/2006	SP1	SP2	SC1	SC2
Extensometer Gauge Length:	L_e	(mm)	50.00	50.00	50.00	50.00
SPECIMEN DETAILS						
Width:	b	(mm)	12.53	12.47	12.54	12.53
Thickness:	a	(mm)	2.96	3.10	2.99	2.97
Area:	S_o	(mm^2)	37.09	38.66	37.49	37.21
Gauge Length:	L_o	(mm)	50.0	50.0	50.0	50.0
Parallel Length:	L_c	(mm)	75.0	75.0	75.0	75.0
TENSILE PROPERTIES						
Tensile Strength:	R_m	(MPa)	430	413	429	431
Proof Stress:	$R_{p0.2}$	(MPa)	345	333	312	318
Upper Yield Stress:	R_{eH}	(MPa)	376	360	320	322
Lower Yield Stress:	R_{eL}	(MPa)	329	315	305	306
Post Fracture Elongation:	A	(%)	32	31	34	34
Reduction of Area:	Z	(%)	63	63	65	63

Test Comments:
Tested in accordance with AS 1391-2005



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E.3. Model Hull Plate – Aluminium

Table E3. Tensile test results for the aluminium 6061-T6 model hull plates. 2 coupons were cut with their length parallel to the long side of the plate (AC 1 & 2) and 2 with their length perpendicular to the long side of the plate (AP 1 & 2).

Melbourne Testing Services

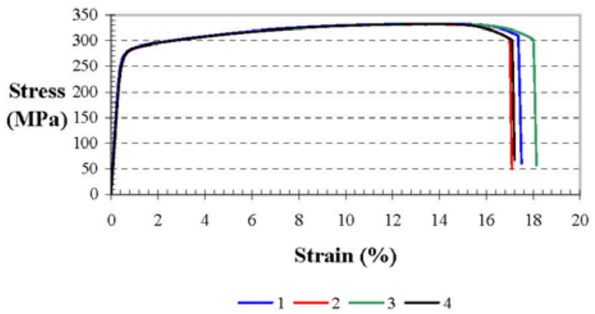
Unit 1/15 Pickering Road
Mulgrave Vic 3170
Telephone: 9560 2759
Mobile: 0419 116 733

Tensile Test Report

Report No:	MT-06/157-B	**CLIENT:**	DSTO
Report Date:	5-Jun-06		150 Cordite Ave
Specimen I.D.	Aluminium Coupons		MARIBYRNONG Vic 3032
Testing Machine:	SINTECH 60/D		

			1	2	3	4
TEST DETAILS						
Test Date:		4/06/2006	AP1	AP2	AC1	AC2
Extensometer Gauge Length:	L_e	(mm)	50.00	50.00	50.00	50.00
SPECIMEN DETAILS						
Width:	b	(mm)	12.49	12.43	12.49	12.51
Thickness:	a	(mm)	4.70	4.73	4.71	4.70
Area:	S_o	(mm^2)	58.70	58.79	58.83	58.80
Gauge Length:	L_o	(mm)	50.0	50.0	50.0	50.0
Parallel Length:	L_c	(mm)	75.0	75.0	75.0	75.0
TENSILE PROPERTIES						
Tensile Strength:	R_m	(MPa)	333	332	332	332
Proof Stress:	$R_{p0.2}$	(MPa)	273	272	272	272
Upper Yield Stress:	R_{eH}	(MPa)	N/A	N/A	N/A	N/A
Lower Yield Stress:	R_{eL}	(MPa)	N/A	N/A	N/A	N/A
Post Fracture Elongation:	A	(%)	18	18	20	19
Reduction of Area:	Z	(%)	27	36	38	31

Test Comments:
Tested in accordance with AS 1391-2005



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E.4. Model T-Stiffeners

Table E4. Tensile test results for two coupons of the model T-stiffener steel.

Melbourne Testing Services

Unit 1/15 Pickering Road
Mulgrave Vic 3170
Telephone: 9560 2759
Mobile: 0419 116 733

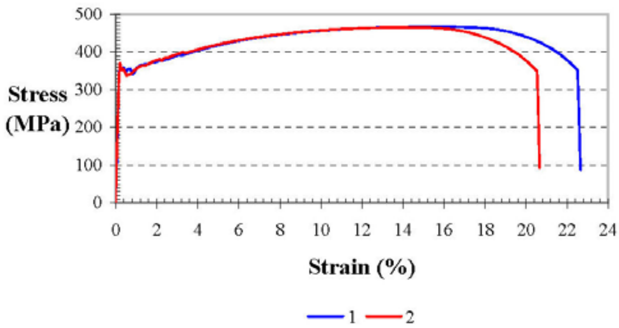
Tensile Test Report

Report No:	MT-06/157-C	**CLIENT:**	DSTO
Report Date:	5-Jun-06		150 Cordite Ave
Specimen I.D.	T-Stiffener		MARIBYRNONG Vic 3032
Testing Machine:	SINTECH 60/D		

TEST DETAILS

			1	2
Test Date:		4/06/2006		
Extensometer Gauge Length:	L_e	(mm)	50.00	50.00
SPECIMEN DETAILS				
Width:	b	(mm)	12.42	12.51
Thickness:	a	(mm)	4.99	4.90
Area:	S_o	(mm^2)	61.98	61.30
Gauge Length:	L_o	(mm)	50.0	50.0
Parallel Length:	L_c	(mm)	75.0	75.0
TENSILE PROPERTIES				
Tensile Strength:	R_m	(MPa)	467	466
Proof Stress:	$R_{p0.2}$	(MPa)	358	352
Upper Yield Stress:	R_{eH}	(MPa)	354	371
Lower Yield Stress:	R_{eL}	(MPa)	341	337
Post Fracture Elongation:	A	(%)	25	24
Reduction of Area:	Z	(%)	57	59

Test Comments:
Tested in accordance with AS 1391-2005



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Paul van der Schaaf

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506 Lorimer St
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Practice torpedo impact

19. ABSTRACT

A small scale drop tower arrangement was used to simulate the dynamics of a practice torpedo impacting a submarine's pressure hull. This experiment provides a set of reference data against which numerical impact models can be tested. To ensure structural similarity, the model hull form used in the experiment is of a T-stiffened cylindrical section. The hull form and the impacting nose shell of the model torpedo have both been designed to deform under drop tower impact loads. To broaden the parameter range of this experiment and thus present a stronger test for numerical impact models, three impact velocities were used with three model hull forms - steel plate with and without stiffeners and aluminium plate without stiffeners. A qualitative comparison of the results for the three model hull forms shows that stiffeners tend to limit the extent of the dent, that aluminium plate has a greater elastic response than that of both stiffened and unstiffened steel plate, and that the nose is flattened for impact against the steel hull form but dimpled for impact against the aluminium hull form. Experimental data presented in this report includes the tensile properties of the nose, hull and stiffener materials, dimensional scans of the deformed noses and hull plates, cross-sections taken through the impact dents, and high speed video and kinematic data of the fall, impact and rebound of the model torpedo nose from the hull form. A supplementary digital data-set is available for the numerical modelling of this experiment.

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