

UNIVERSITY OF SOUTHERN QUEENSLAND

DEVELOPMENT AND VALIDATION OF A MECHANICAL THORAX SURROGATE FOR THE EVALUATION OF THE BLUNT TRAUMA DUE TO BALLISTIC IMPACTS

A Dissertation submitted by

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Dedication

To my father Late Sri. Venkaiah, my mother Late Smt. Anantha Laxmi and my aunt Narsamma for their divine love and blessings, my wife Smiti and lovely kids Curie and Cura aka Mihir for their love and unconditional support

Abstract

Although fruits of few decades worth of research carried out worldwide by scientists, engineers and researchers, have been available to everybody with a mouse click, engineering problems have not always been easy to accomplish. The complexities of the real life problems are due to lack of resources, lack of applicability of the available data and also due to the increasingly innovative and competitive marketplace. Therefore, engineers always face challenges and strive to accomplish the tasks to obtain desired outcome with continuous research and innovative approach. Two of such challenges, one related to the validation of a closed cell foam material for fabrication of non-lethal munitions and the other related to the development of compliant vehicle front protection systems (VFPS) for modern passenger cars, necessitated extensive research study and led to the development of the finite element (FE) model of thorax surrogate (Mechanical THOrax for Trauma Assessment – MTHOTA) and development a computer aided engineering (CAE) based method for the development of airbag compatible and ADR 69/00 (Australian Design Rule for vehicle occupant safety) compliant multi-variant vehicle front protection systems for a vehicle with multi-variants, with a minimum number of crash tests. These two challenging problems, pertinent research, development, and the outcome, have been presented in this thesis.

Initially, four anthropomorphic test devices (ATDs) were reviewed for their suitability for the evaluation of the blunt trauma. As they were found unsuitable for the intended application, novel concepts for the thorax surrogate were developed and studied for their feasibility. One of the novel ideas was pursued further and developed into a fully correlated (validated) FE model of a thorax surrogate (MTHOTA). Robustness and efficacy of the MTHOTA surrogate was verified for many cases studies from the published literature. Biomechanical responses obtained for the MTHOTA surrogate have shown a correlation with the respective cases. Due to its simplicity, accuracy, easy setup, fast solving and non-ambiguity, the MTHOTA surrogate was successfully used for the evaluation of:

1. the blunt thoracic trauma due to ballistic impacts and the risk of commotio-cordis due to solid sports ball impacts
2. the effect of material, spin and impact speed of the solid sports ball on the thoracic trauma
3. projectile – thorax energy interactions and their relation with the viscous criterion
4. the performance of new non-lethal weapons and foam materials
5. the effect of the energy-absorbing mechanisms on the blunt thoracic trauma caused by Kinetic Energy Non-Lethal Weapons (KENLW)

Concerning the second challenge mentioned above, a systematic procedure based on the non-linear finite element analysis simulations was devised for the development of compliant front protection systems for vehicles with and without airbags. The devised method has successfully been implemented and made commercially non-viable and extremely cumbersome FPS development projects into reality.

By exploiting the non-linear FE simulations expertise and foam material data, effect of foam embellishments on the pedestrian safety characteristics of the FPS was examined highlighting the benefits of garnishing FPS with such semi-rigid foam parts and presented in the thesis. Effect of FPS on the crash compatibility between vehicles was also studied and made recommendations for reaping the benefits of the VFPS.

Certification of Thesis

I certify that the research work and the outcome presented in this thesis are entirely my own work, except where otherwise acknowledged. I also certify that the work is original and has not been previously submitted for any other award, except where otherwise acknowledged.

Signature of Narasimha Murthy Thota

Date

ENDORSEMENT

Signature of Dr. Jayantha A Epaarachchi

Date

Signature of Prof. Kin-Tak Lau

Date

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Table of Contents

Dedication	i
Abstract	ii
Certification of Thesis	iv
Acknowledgements	v
List of Figures	xii
List of Tables.....	xix
Notations, Units, and Abbreviations	xxi
CHAPTER-1: INTRODUCTION	1
1.1 Statement of the problem related to thoracic trauma caused by impacts of non-lethal munitions	1
1.1.1 Research goals	2
1.1.1.1 Review of anthropomorphic test dummies	2
1.1.1.2 Development and validation of the FE model for a thorax surrogate	3
1.2 Statement of the problem pertaining to the design and development of the vehicle front protection systems	3
1.2.1 Research goals	4
1.2.1.1 Development of VFPS for non-air bagged vehicles	4
1.2.1.2 Development of VFPS for air bagged vehicles	5
1.3 Specific aims of the research study	5
1.4 Thesis structure.....	6
CHAPTER-2: SUITABILITY OF ANTHROPOMORPHIC TEST DUMMIES FOR THE EVALUATION OF THE BLUNT THORACIC TRAUMA DUE TO BALLISTIC IMPACTS – A CAE BASED SCHOLASTIC STUDY	8
2.1 Introduction	8
2.1.1 Blunt ballistics	8
2.1.2 Thoracic injuries, injury criteria, human tolerance limits	11

2.1.2.1 Force criterion	12
2.1.2.2 Thoracic Trauma Index (TTI)	12
2.1.2.3 Average Spinal Acceleration (ASA)	13
2.1.2.4 Compression criterion	13
2.1.2.5 Viscous Criterion (VC)	13
2.1.2.6 Blunt Criterion (BC)	14
2.2 Methodology	15
2.3 Results and discussion.....	18
2.3.1 LP_20 impact condition	18
2.3.2 LP_40 impact condition	21
2.3.3 SP_60 impact condition	22
2.3.4 Evaluation of VC _{max}	25
2.3.5 Evaluation of p(AIS3+) and p(AIS4+) using maximum rib deflections of ES-2re	28
2.4 Conclusion.....	30
CHAPTER-3: NOVEL CONCEPTS OF MECHANICAL THORAX FOR BLUNT TRAUMA MEASUREMENT – A FEASIBILITY STUDY	31
3.1 Introduction	31
3.2 Novel concepts of thoracic surrogates.....	33
3.3 Methodology devised for validation of the biomechanical surrogate of the thorax.....	34
3.4 Feasibility study	35
3.5 Results and discussion.....	38
3.6 Conclusion.....	42
CHAPTER 4: DEVELOPMENT AND VALIDATION OF A THORAX SURROGATE FE MODEL FOR ASSESSMENT OF TRAUMA DUE TO BLUNT BALLISTIC IMPACTS	43
4.1 Introduction	43

4.2 Existing surrogates of the thorax for blunt trauma applications.....	44
4.3 Methodology.....	46
4.4 Results and discussion	54
4.4.1 Thorax surrogate (MTHOTA) impacted with a long baton of 140 grams with 20 m/s impact velocity (LP_20)	54
4.4.2 Evaluation of blunt thoracic trauma in terms of VC _{max}	56
4.4.2.1 Method-1	57
4.4.2.2 Method-2	57
4.4.3 Thorax surrogate (MTHOTA) impacted with the long baton of 140 grams with 40 m/s impact velocity (LP_40)	57
4.5 Further validation of the FE model of MTHOTA surrogate	63
4.5.1 Sponge nose PVC grenade of mass 41.9 gram and size of 40 mm diameter	63
4.5.2 Rubber ball of 60-cal, 15 mm diameter, 3.7 gram	65
4.6 Conclusion	67
CHAPTER 5: EVALUATION OF THE BLUNT THORACIC TRAUMA CAUSED BY SOLID SPORTS BALL IMPACTS	69
5.1 Introduction	69
5.1.1 Commotio-cordis	69
5.1.2 Historical background	71
5.2 Methodology.....	73
5.2.1 Details of the impact tests	73
5.2.2 Details of the thorax surrogate	73
5.2.3 Finite element model of the solid sports ball	73
5.3 Results and discussion	76
5.3.1 Viscous injury due to solid sports ball impacts and its calculation	76
5.3.2 Energy interactions of the solid sports ball and the MTHOTA surrogate	78

5.3.3 Influence of the deformation velocity of the MTHOTA on the injury	81
5.3.4 Effect of the impact velocity on the thoracic injury	82
5.3.5 Effect of the ball spin on the thoracic injury	82
5.3.6 Kinematics of the impacting ball and evaluation of the risk of commotio-cordis	84
5.4. Conclusion.....	86
CHAPTER 6: DEVELOPMENT AND VALIDATION OF A NON-LETHAL PROJECTILE USING MTHOTA FE MODEL SURROGATE – A CASE STUDY	
6.1 Introduction	89
6.2 Requirements for the scholastic study.....	90
6.3 Methodology	91
6.3.1 Quasi-static compression tests for the foam material data preparation	91
6.3.2 Selection of the suitable foam for the projectile	93
6.3.3 Concepts of the energy absorbing mechanisms for the foam nosed projectiles	95
6.4 Results and discussion.....	96
6.4.1 Development of foam nosed projectile equivalent to XM 1006	96
6.4.2 Effect of EA mechanism on the blunt thoracic trauma	99
6.4.3 Head damage characteristics of the projectile	101
6.5 Conclusion.....	105
CHAPTER-7: DESIGN AND DEVELOPMENT OF FRONT PROTECTION SYSTEMS FOR NON-AIR BAGGED PASSENGER VEHICLES – A SYSTEMATIC METHOD	
7.1 Introduction	106
7.2 Specifications for the design and development of the vehicle front protection systems	107
7.3 Methodology for the development of VFPS	108
7.4 Results and discussions	112

7.4.1 Mass setting calculations of the Ute under consideration	112
7.4.2 Selection of the mounting points for the fitment of the FPS	116
7.4.3 Simplified crash simulations to finalize the FPS mounts for the Ute	117
7.4.4 ADR 69/00 full frontal vehicle crash tests	122
7.5 Conclusion	122
CHAPTER-8: VEHICLE FRONT PROTECTION SYSTEMS: A SYSTEMATIC CAE BASED METHOD TO ACHIEVE AIR BAG COMPATIBILITY	124
8.1 Introduction	124
8.2 Various other methods in use and their limitations	124
8.2.1 Pendulum test	125
8.2.2 Barrier crash test	126
8.3 Airbag compatibility	126
8.4 Methodology.....	128
8.4.1 Baseline design of the VFPS	128
8.4.2 Simplified crash simulations for finalization of the baseline design of the FPS mounts	129
8.4.3 Development of the correlated FE model of the vehicle	130
8.4.4 Whole vehicle crash simulations for finalization of the FPS design	131
8.4.5 Full vehicle physical crash tests for the development of ADR 69 compliant VFPS	132
8.5 Results and discussion	135
8.5.1 Whole vehicle (Ute) FE model correlation	135
8.5.2 Full vehicle crash simulations	136
8.5.3 Problem associated with the development of multi-variants of FPS for multi-variants of the vehicle model	139
8.5.4 Physical vehicle crash tests	141
8.6 Energy absorption of the VFPS from the non-linear FEA simulations.....	145

8.7 Pedestrian safety and crash compatibility aspects of the VFPS	146
8.7.1 Pedestrian safety – Head Injury Criterion	146
8.7.2 Crash compatibility	149
8.8 Conclusion.....	151
CHAPTER-9: CONCLUSION AND FUTURE WORK.....	153
9.1 Thesis summary	153
9.2 Recommendations for the future work	154
REFERENCES.....	155
APPENDIX – I.....	170

List of Figures

Figure 2.1	TASER gun, Pepper spray gun, M32 grenade launcher, M79 grenade launcher	9
Figure 2.2	Rubber bullets, foam baton, rubber buckshot, bean bag, DIRECT IMPACT foam nosed grenades	9
Figure 2.3	Difference between automotive collisions and the blunt ballistic impacts as far as mass and speeds are concerned	11
Figure 2.4	Procedural steps to evaluate the suitability of the ATDs	16
Figure 2.5	Impact points selected on the thoraces of ATDs	17
Figure 2.6	Dynamic chest deflection of the Hybrid III dummies (LP_20 impact condition)	19
Figure 2.7	Stages of the impacting projectile and the cross section of the deflecting thorax	20
Figure 2.8	Dynamic force response of the ES-2re dummy (LP_20 impact condition)	20
Figure 2.9	Dynamic deflection response of the ES-2re dummy (LP_20)	20
Figure 2.10	Dynamic deflection response of the ES-2re dummy (LP_40 impact condition)	21
Figure 2.11	Dynamic deflection response of the ES-2re dummy (LP_40 impact condition)	22
Figure 2.12	Thick black line shows the area that provide adequate loading surface for the projectile	23
Figure 2.13	Stages of skidding projectiles due to inadequate loading surface	23
Figure 2.14	Stages of the deflecting thorax – when adequate loading surface was available to the projectile	24
Figure 2.15	Dynamic force response of the ES-2re thorax (SP_60 impact condition)	24
Figure 2.16	Dynamic deflection response of the ES-2re thorax (SP_60 impact condition)	25
Figure 2.17	VC_{max} values for LP_20 impact condition	26
Figure 2.18	VC_{max} values for LP_40 impact condition	27
Figure 2.19	VC_{max} values for SP_60 impact condition	27

Figure 2.20	ES-2re subjected to LP_40 impact condition (impact point P1 on the lower rib)	28
Figure 2.21	Deflection-time response for 3 impact conditions	29
Figure 3.1 a	Thorax surrogate made up of a hollow corrugated Aluminum cylinder	33
Figure 3.1 b	Thorax made up of stacked foam sheets	33
Figure 3.2	Methodology devised for theoretically validating the surrogate	35
Figure 3.3	Impact points P0 – P5	37
Figure 3.4	Thorax surrogate with foam nosed projectile	38
Figure 3.5	Force-time response of the Hybrid III thorax when impacted at P1	38
Figure 3.6	Peak impact forces for all impact cases	39
Figure 3.7	Stages of the projectile impacting with 100 m/s at P1	39
Figure 3.8	Comparison of peak impact forces obtained from the Hybrid III thorax and the target	41
Figure 3.9	Projectile impacting the target at various impact times	41
Figure 3.10	Force – time response of the target (surrogate) after 25 th design iteration.	42
Figure 4.1	Reusable thorax surrogate 3-RCS.	45
Figure 4.2	Reusable thorax AUSMAN and the rib cage	46
Figure 4.3	Details of the concept of MTHOTA	47
Figure 4.4	Process flow chart for validation of the thorax surrogate using human response corridors	48
Figure 4.5	Cross section of the MTHOTA concept and design variables	49
Figures 4.6	Cross section and FE model of the baseline configuration of the MTHOTA surrogate	50
Figure 4.7	Force – time response of the MTHOTA (LP_20 impact condition)	54
Figure 4.8	Deflection response of the MTHOTA (measured using the node on the impact plate – LP_20 impact condition)	55

Figure 4.9	Deflection response of the MTHOTA (measured using the node on the impact plate with respect to plate-3, LP_20 impact condition)	55
Figure 4.10	Force response of MTHOTA (LP_40 impact condition)	58
Figure 4.11	Deflection response of the MTHOTA (measured using a node of the impact plate, LP_40 impact condition)	58
Figure 4.12	Deflection response of the MTHOTA (measured using the node on the impact plate with respect to plate-3, LP_40 impact condition)	59
Figure 4.13	Variation of the total energy of the projectile and the surrogate during the impact	59
Figure 4.14	Force response of the MTHOTA (SP_60 impact condition)	60
Figure 4.15	Deflection response of the MTHOTA (measured using a node of the impact plate, SP_60 impact condition)	60
Figure 4.16	Deflection response of the MTHOTA (measured using the node on the impact plate with respect to plate-3, SP_60 impact condition)	61
Figure 4.17	Stress contour plots in the thorax surrogate (SP_60 impact condition)	61
Figure 4.18	Comparison of VC_{max} values obtained from MTHOTA with cadaver tests and 3-RCS surrogate	62
Figure 4.19	Sponge nosed projectile impacting the thorax surrogate at 73 m/s. Stages of the projectile and the thorax.	63
Figure 4.20	Sponge nosed projectile impacting the thorax surrogate at 73 m/s. Cross-sectional view of the initial and final stages of the projectile and the thorax.	64
Figure 4.21	Dynamic deflections of the impact plate, w.r.t. plate-3 when MTHOTA impacted with a sponge grenade at 37 and 73 m/s	64
Figure 4.22	Comparison of the VC_{max} values obtained by using MTHOTA with those obtained from cadaveric tests. Adjusted 3-RCS model and FE thorax model	65
Figure 4.23	Stages of the thorax surrogate during the impact with 0.60 caliber rubber bullet impacting with speed of 326 m/s	66
Figure 4.24	Dynamic deflection of the impact plate with respect to the plate-3 (MTHOTA subjected to the stinger rubber ball projectile)	67

Figure 5.1	Location and time of impact for the occurrence of commotio-cordis	70
Figure 5.2	Heart rhythms obtained by impacting the porcine models with the projectiles at different phases of heart cycles	70
Figure 5.3	Pathophysiology of the commotio-cordis	71
Figure 5.4	Finite element model of the solid sports ball used in the simulations	75
Figure 5.5	Stages of the MTHOTA when subjected to the soft core baseball impact with 30 m/s	77
Figure 5.6	Deflection – time response of the MTHOTA subjected to soft-core baseball (measured using the node of the impact plate)	77
Figure 5.7	Influence of the material, weight and the impact speed of the solid sports ball on the VC_{max}	78
Figure 5.8	Energy interactions of the soft-core baseball and MTHOTA	79
Figure 5.9	Influence of the rate of maximum total energy on the VC_{max}	80
Figure 5.10	Influence of the rate of maximum kinetic energy on the VC_{max}	80
Figure 5.11	Influence of the deformation velocity on the VC_{max}	81
Figure 5.12	Influence of the impact speed of soft-core baseball on VC_{max}	82
Figure 5.13	Stages of the MTHOTA with spinning baseball impact	83
Figure 5.14	Dynamic force response of the MTHOTA (soft-core baseball impact)	85
Figure 5.15	Correlation of commotio-cordis with the cardiac load	85
Figure 5.16	Correlation of probability of commotio-cordis with the maximum peak LV pressure follows Gaussian distribution	86
Figure 6.1	Foam specimen in the test condition (block diagram)	92
Figure 6.2	Preparation of foam material data and the FE model of the projectile	92
Figure 6.3	Load curve obtained for the foam	93
Figure 6.4	Selection of the candidate foam for the projectile	94
Figure 6.5	Foam projectile and MTHOTA surrogate in the non-linear FEA simulations	95

Figure 6.6	Energy absorbing mechanisms conceptualized for the study	95
Figure 6.7	Procedural steps to evaluate the effect of EA mechanisms	96
Figure 6.8	Stages of the projectile and MTHOTA (impact speed 100 m/s)	97
Figure 6.9	Dynamic deflection plots useful for the evaluation of VC_{max}	97
Figure 6.10	Dynamic force response plots for all impact cases	98
Figure 6.11	Dynamic deflection response of the impact plate	100
Figure 6.12	Dynamic force response plot for all impact cases	100
Figure 6.13	Projectiles of same KE with Alloy foils of 2.5 mm and 4 mm	101
Figure 6.14	Force – time response obtained from the rigid wall impacts	103
Figure 6.15	Head damage curve obtained for the new foam	104
Figure 7.1	Bumper replacement FPS and over the bumper type FPS	106
Figure 7.2	Bumper replacement FPS, non-compliant with the Australian standard AS 4876.1-2002	108
Figure 7.3	Inputs and procedural steps for the development of compliant FPS for non-air bagged vehicles	109
Figure 7.4 a	Flat plate mounts along with their mounting points	110
Figure 7.4 b	Folded plate mounts and their mounting points	110
Figure 7.4 c	Box section mounts with their mounting locations	110
Figure 7.5	Procedural steps to select the suitable FPS mounts	111
Figure 7.6	ADR 69/00 test protocol	112
Figure 7.7	GAW-FRONT AXLE allowance for all accessories of 1 and 2 variants of the vehicle	115
Figure 7.8	Baseline design concept of the bumper replacement type FPS	116
Figure 7.9	Mounting locations selected for the fitment of the VFPS	117
Figure 7.10	Set up of the simplified crash analysis	118
Figure 7.11	Stages of the collapsing crash can and cross member assembly	119
Figure 7.12	Configurations of the FPS mounts	120

Figure 7.13	Stages of crushing steel bull bar with a plate with a fold mounts	121
Figure 7.14	Deceleration pulses elicited from the simplified CAE simulations	121
Figure 8.1	Pendulum test rig for dynamic testing of the bull bar	125
Figure 8.2	Details of the velocity thresholds for the airbag deployment	127
Figure 8.3	Procedural steps and input data requirements for the baseline design of the FPS	129
Figure 8.4	Procedural steps for simplified crash simulations	130
Figure 8.5	Procedural steps for whole vehicle model correlation	131
Figure 8.6	Protocol for the whole vehicle crash simulations	133
Figure 8.7	Protocol for the physical crash tests of the vehicle with FPS	134
Figure 8.8	Stages of the vehicle during the crash (15 km/h ORB test)	136
Figure 8.9	Stages of the impacting vehicle fitted with bumper replacement type FPS	137
Figure 8.10	FPS mounts used in simulations with air bag no fire test conditions	138
Figure 8.11	Mounts designed for the over the bumper type FPS	139
Figure 8.12	Stages of impacting vehicle fitted with nudge bar	140
Figure 8.13	Deceleration pulse obtained from ECU sensor (CAE and physical crash tests)	141
Figure 8.14	Deceleration pulse obtained from the front sensor (CAE and physical crash tests)	142
Figure 8.15	Velocity –time plots obtained from ECU sensor (CAE and physical crash tests)	142
Figure 8.16	Velocity –time plots obtained from the front sensor (CAE and physical crash tests)	143
Figure 8.17	Displacement – time plots obtained from the ECU sensor (CAE and physical crash tests)	143
Figure 8.18	Displacement – time plots obtained from the front sensor (CAE and physical crash tests)	144
Figure 8.19	Energy absorbed by the bumper replacement type FPS	145

Figure 8.20	Adult headform impacting the Steel FPS at vulnerability points 1,2 and 3	147
Figure 8.21	Foam tubing to cover the tubular section of the FPS	148
Figure 8.22	Small car seated with USSID impacted with the Ute fitted with the Steel FPS	149
Figure 8.23	Stages of small car crash during the impact with the Ute fitted with the Steel bull bar	150
Figure 8.24	Stages of small car crash during the impact with the Ute fitted with the Alloy Nudge bar	151

List of Tables

Table 2.1	Relation between chest compression and thoracic injury	13
Table 2.2	Impact cases and details of the projectile	15
Table 2.3	Scale factor and Deformation constant for all ATDs	26
Table 2.4	VC_{max} values for all important impact cases	26
Table 2.5	Probabilities of AIS3+ and AIS4+ injuries	29
Table 3.1	Details of the impact points	36
Table 3.2	Peak impact forces (Hybrid III and surrogate)	40
Table 4.1	Impact conditions	47
Table 4.2	Details of the MTHOTA finite element model	51
Table 4.3	Mechanical properties of materials of MTHOTA surrogate	52
Table 4.4	Load curve data of the TPE foam used in MTHOTA	52
Table 4.5	Contact interfaces in the FE model of the MTHOTA	53
Table 5.1	Material data and material models of the baseballs	74
Table 5.2	Details of the FE model of the solid sports ball	75
Table 5.3	MOONEY_RIVLIN_RUBBER material data	76
Table 5.4	Rate of change in KE and TE of the surrogate	83
Table 5.5	Effect of the baseball spin on the VC_{max}	84
Table 5.6	Percent risk of commotio-cordis due to the baseball impacts from MTHOTA's force response	86
Table 6.1	Foam material data obtained from the experiments	93
Table 6.2	VC_{max} values evaluated for all impact cases of the candidate foam	98
Table 6.3	EA mechanisms of constant KE and their foil thicknesses	99
Table 6.4	VC_{max} values evaluated for the projectile impacts	101
Table 6.5	Human head tolerance limits (blunt ballistic impacts)	102
Table 6.6	Rigid wall impact test results	104

Table 7.1	GVM allowance for all accessories (for 1 and 2 variants)	114
Table 7.2	Loads on the front and rear axles due to all accessories	114
Table 7.3	Suitability of the FPS fitment based on the GAW-FRONT AXLE allowance	115
Table 7.4	Material data and material models used in the crash simulations (both simplified and full vehicle crash)	118
Table 8.1	ADR 69/00 test specifications and performance criteria	128
Table 8.2	ADR 69/00 test results	144
Table 8.3	Crash energy absorbed by the FPS assembly with various mounts	146
Table 8.4	HIC values obtained from the simulations and experiments	148

Notations, Units, and Abbreviations

Notations and Abbreviations

3-RCS	3 Rib Chest Structure
AIS	Abbreviated Injury Scale
ASA	Average Spinal Acceleration
ATD	Anthropomorphic Test Dummy or Anthropomorphic Test Device
BC	Blunt Criterion
CAE	Computer Aided Engineering
COR	Coefficient of Restitution
D	Dummy constant (measured in length dimension)
DSTO	Department of Science and Technology Organization
EA	Energy Absorbing
ECU	Electronic Control Unit
FEA	Finite Element Analysis
GAW	Gross Axle Weight
GVM	Gross Vehicle Mass
HSTM	Human Surrogate Torso Model
KENLW	Kinetic Energy Non-Lethal Weapons
LSTC	Livermore Software Technology Corporation
LP	Long Projectile
LV	Left Ventricle
MTHOTA	Mechanical THOrax for Trauma Assessment
P(AIS3+)	Probability for level 3 or more injuries on AIS
P(AIS4+)	Probability for level 4 or more injuries on AIS

PMHS	Post Mortem Human Subject
PVC	Poly Vinyl Chloride
S	Scale factor of the ATD (a dimensionless multiplication factor)
SP	Short Projectile
TPE	Thermo Plastic Elastomer
TTI	Thoracic Trauma Index
VC	Viscous Criterion = Product of the instantaneous 'Velocity of chest deformation' and instantaneous 'Chest compression'
VC _{max}	Max of Viscous Criterion
VF	Ventricular Fibrillation
VFPS	Vehicle Front Protection System

Units

g	9.81 m/s ²
GPa	Giga Pascal
kgf	kilogram-force
kPa	kilo Pascal
kN	kilo Newton
m	meter
m/s	meter per second
ms	millisecond
N	Newton
s	second