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

List of Figures

List of Tables

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

9	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