CHAPTER 1: Introduction

This dissertation documents the work done during a master's study entitled the multidisciplinary design and optimisation of liquid containers for sloshing and impact.

The advent of modern computing capabilities, their dramatic reduction in cost and their widespread integration into the modern engineering design office have changed the way the design process is approached by the modern engineer. Computer aided design packages, solid modelling tools, finite element method packages, computational fluid dynamics software, and more recently numerical optimisation software are just some of the highly technical software solutions provided to the modern engineer. Any one of these commercial software packages may be used in the design process and, in more recent history, may in fact be used in combination. The aim of this study is to evaluate some of these tools within the context of the design of a specific type of equipment, i.e., liquid containers.

Liquid containers are items that are found throughout the engineering design environment, across all engineering disciplines. The design of certain of these containers command high levels of research and development. Fuel containers for aeronautic and astronautic applications are examples that traditionally have enjoyed the pinnacle of design efforts in this field. It is largely thanks to many of the related high level research institutions that many of the above mentioned engineering design tools were developed. There are endless applications where many of these tools are tragically under utilised. In principle, the design challenges experienced in all liquid container applications are very similar, and this means that many of the advanced design techniques developed are universally applicable.

The aim of the study is to examine the available techniques in a generic sense as an exploratory evaluation of their corresponding contributions and effectiveness in the design of liquid containers. A quantitative measure of sloshing will be presented, and experimental tests will qualify the use of the numerical methods used to model sloshing. The development of methods for modelling sloshing by using Computational Fluid Dynamics (CFD) and the modelling of liquid container impact using Finite Element Methods (FEM) will form part of the study. The combination of numerical modelling techniques, like CFD and FEM, with a number of the available mathematical optimisation methods, like Response Surface Methods (RSM), will be presented and the results will be evaluated. As a final contribution, the use of CFD, FEM and mathematical optimisation will be combined in an automated cycle and presented as a tool with which to tackle the optimal design of a simple liquid container structure. The study as a whole is aimed at presenting the use of multiple mathematical design tools in the design of liquid containers. The work will collectively provide a platform from which future academic research may emanate in a subject field that suggests a number of possibilities for further development. The combination of multiple disciplines, optimisation, and multiphase unsteady free-surface behaviour is regarded as new work, in that it has not been studied, to the knowledge of the author, at an academic level or published in any known scientific journals.

Chapter 2 of the dissertation covers a literature study of work in the field of liquid container design and the understanding of transient liquid motion. The work done on liquid motion is mostly confined to linear oscillatory motion of shallow and deep waves. Other more historical methods of liquid motion representation are presented, including Equivalent Mechanical Systems. These simplified systems are analysed and their advantages and short comings identified. The chapter also provides a description of the various engineering design tools that are utilised in the study. The tools presented include the simulation packages used for Computational Fluid Dynamics and Finite Element Analysis and an overview of some of the more significant models included in these packages and how they may be utilised in liquid container design. An overview of experimental methods outline some of the criteria used in modern time to define the safety regulation that control the design of liquid containers used in the automotive environment. Finally the later sections of the chapter cover available mathematical optimisation techniques and how they may be used in a design process.

Chapter 3 documents the modelling of sloshing and the methods employed within the simulation tools utilised. The chapter covers automated methods of using the simulations tools so that they may later be incorporated within a mathematical optimisation routine. To gain confidence in the techniques chosen, several experimental verification methods are presented. The experimental results include both a qualitative analysis provided through free-surface images and a quantitative analysis of pressures in a liquid container in the time and frequency domain.

The optimisation of the liquid container for sloshing is presented in Chapter 4. To incorporate the Computational Fluid Dynamics modelling techniques into an inherently quantitative mathematical optimisation environment, a method for quantifying the level of sloshing in a liquid container is proposed. The behaviour of this quantification is analysed within the spectrum of sloshing phenomena expected. The bulk of the chapter provides documentation of a systematic comparison of the setup and results of the various optimisation techniques available. The strengths and weaknesses of the various methods are identified and further means of analysing the data available from an optimisation process are presented.

Mathematical optimisation for impact is covered in Chapter 5 and provides an overview of the Finite Element Analysis techniques used to simulate the fluid structure interaction that results in the deflection of the baffles in a liquid container. The ensuing stresses are used to formulate an automated optimisation routine that reduces the mass of the liquid container while adhering to predefined constraints on structural integrity.

Chapter 6 brings together a number of the methods investigated into a single optimisation routine. It covers the multidisciplinary optimisation of liquid containers for both liquid sloshing and structural integrity during impact. The chapter demonstrates the results one can expect while performing a multidisciplinary optimisation process. The idea is that one could adapt the methods utilised to any specific combination of geometry, input load curves and constraints, structural or otherwise, and the same principles will apply. It should for this reason be noted that the geometries and load curves have been simplified throughout this study so as to effectively demonstrate as many techniques and combinations as possible within the available time frames.

The dissertation is concluded with a chapter containing conclusions and suggestions for future work.