Modelling of Shock Absorptive Foam using MADYMO to Prevent Injuries in Inflatable Rescue Boats (IRBs)

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DETAILED ABSTRACT

Introduction

Inflatable Rescue Boats (IRBs) are ocean-going vehicles used as rescue vessels by the Australian Surf Lifesavers *(Figure 1)*. The IRBs are used to navigate and patrol the wave-break areas of Australia's popular beaches. They were adopted by Surf Life Saving Australia (SLSA) in 1975 because of their high mobility and rapid response time. The IRBs generally carry a crew of two people, a driver and a crewmember *(Figure 1)*. The surf lifesavers in their IRBs can encounter waves up to and exceeding three metres in height, causing the boat to be subjected to large impact accelerations. This impact can result in a variety of injuries to the crew and patients being rescued.

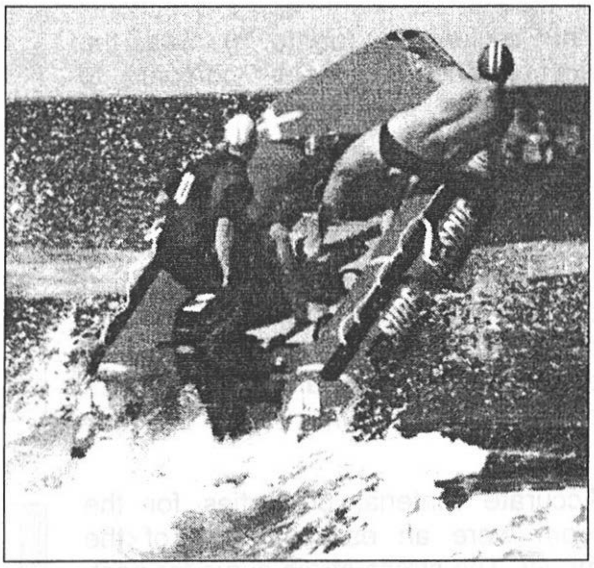

Figure 1: IRB in Use Showing Crew Positions

The increasing frequency and severity of injuries has become a growing concern to SLSA. Research has been undertaken to model the IRB in surf conditions to reduce injuries. Using the available epidemiological data, the injury biomechanics will be investigated to provide a biomechanical engineering input into an otherwise uncharted field. The research outlined in this document, is an investigation into the shock absorptive material located on the floorboard of the IRB.

The objective of the investigation was to determine the optimal density and thickness of foam appropriate for the floorboard of the IRB using modelling techniques. The environmental conditions and general use of the vessel were important considerations. However, the reduction in impact shock for the crew resulting from the impact with a sizeable wave as well as the general ride shock for the passengers that can result from the continuous bouncing over small chop, were the significant factors considered.

Methodolgy

Seven Ethylene Vinyl Acetate (EVA) foams from Ultralon Products Ltd (New Zealand) with densities ranging from 30 kg/m^3 to 190 kg/m^3 were tested for their suitability for this application. EVA foams are used because of their excellent chemical resistance and shock absorbency, prompt recovery, soft 'feel' and high workability.

The foams were modelled using the three-dimensional multibody and finite element package, MADYMO (TNO, The Netherlands). Stress-strain data for the material and/or contact properties were obtained from compression tests on sample foam using an Instron 5500R testing apparatus. The foam model was validated by simulating pendulum impact tests that had been performed in the laboratory on sample foam. The external forces on the impactor and the maximum penetration depth were key factors for validation. The foam models were then tested and qualitatively analysed in the simulation of the IRB floorboard with the acceleration data obtained from the field.

Acceleration data of the IRB travelling out through the waves was gathered as the 'crash pulse' input for the model. The data was collected using a ±50g triaxial accelerometer that was designed and constructed for this specific purpose. A TINY Tiger® data logger sampling the three channels at 1kHz for approximately 60 seconds was used to store the data. This provided a unique data set for the simulation.

Results and Analysis

The acceleration results acquired from the IRB in the field involved 65 seconds of data in the x-, y- and z-directions. The z-direction (up/down) was the major influence on the floorboard to crewperson interaction. Sections of data, like that shown in *Figure 2*, signifying an impact with a wave, were used as the input for the simulation to reduce the computation time that would be required for the full acceleration data set. Furthermore, this reduced data set provided better efficiency during the design and development stages of the model.

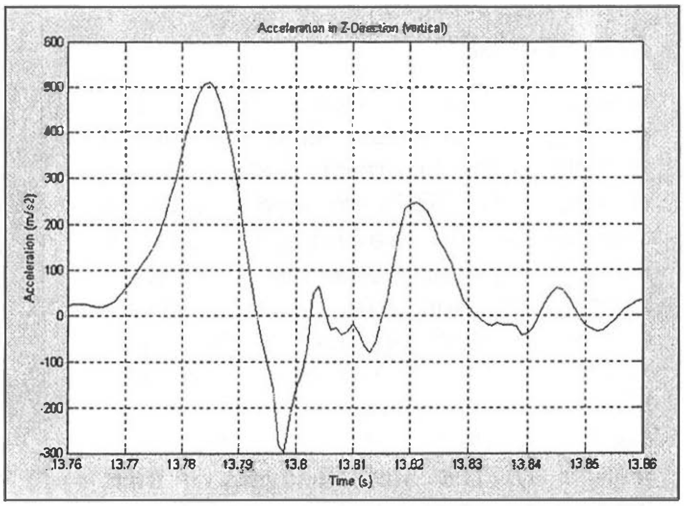

Figure 2: Typical Acceleration Pulse

Accurate material properties for the foam were an essential part of the model. The stress-strain curve for each foam density was established from compression tests. The structure definition and contacts were adjusted to complete the validation without altering the material properties. A typical penetration depth validation curve appears in *Figure 3* for the EVA 190 foam. The truncation of the experimental test was due to the limited range of the proximity probe located on the pendulum impact testing apparatus. The peak values were still obtained for analysis and provided adequate validation results.

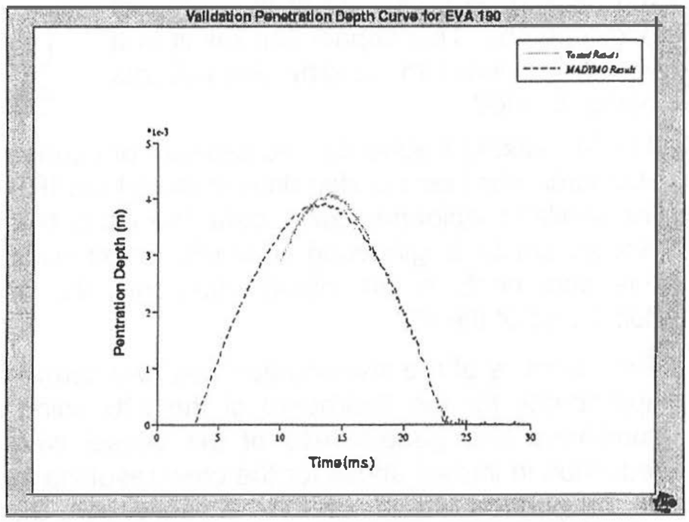

Figure 3: Typical Penetration Curve

After applying the acceleration profiles to the validated foam in the MADYMO model for simulation, the final results were analysed. As expected, they showed that a decrease in density improved the general ride comfort (external forces/accelerations) for the patients in the IRB, but it reduced the absorption capacity and stability for the crew standing in the IRB. The smaller surface area of contact for the standing crew meant that the foam reached consolidation too easily and therefore did little to absorb the impact. The differing contact areas and therefore stress distributions between standing and sitting/lying in the boat indicate that reasonably different densities and/or thickness are required to find the optimal solution for each case. Materials varying from 60 kg/m^3 to 120 kg/m^3 could be favoured depending on the relative importance given to the safety of the sitting/lying patient and the standing crew in the boat. Foam densities around the 60 kg/m^3 are more suited to the sitting or lying patient while the foams around the 120 kg/m^3 are more appropriate for the safety of the crew operating the vessel.

There were some other important factors to consider when analysing the results. A decrease in density also reduces the wear resistance of the floor covering therefore reducing the cost effectiveness for that material. Conversely, an increase in density increases the abrasion effects for the patients in the IRB. Therefore a compromise must also be made with respect to the reduction in wear resistance and the decrease in abrasiveness for the patients.

This led us to other possible solutions to the problem. Rather than keeping a single homogeneous foam layer, a multi-layer or laminar foam covering with a high density surface and a low density base was put forward to help eliminate some of the previous mentioned problems but abrasions would still occur. Alternatively, a multi-sectioned foam covering was proposed that consisted of the crew footing areas made with a higher density foam and the patient contact areas with a lower density foam. Also, a new product known as Foam-Grip may be equally useful. Foam-Grip is a durable, highly flexible, UV resistant, fire retardant, non-slip membranous coating that can be applied to EVA foams and could be effectively added to the areas around the crew footings. However, these solutions all rely heavily on the cost associated with their manufacture for the volunteer organisation.

The study did not undertake a comprehensive analysis of the wear resistance and aging effect of each material. Funding and the availability of materials have also limited the comprehensiveness of the research.

Conclusions

A range of potential solutions to the problem of reducing the impact transferred to the patients and crew from the floor of an IRB have been suggested. The final solution will depend on the relative importance of occupant safety and cost factors that will be finalised after discussion with SLSA. The initial approach was to establish a single foam layer similar to that currently in use. A lower foam density (closer to 60 kg/m^3) should be chosen for increased patient safety, while higher density foam (closer to 120 kg/m^3) is preferred for crew safety. Using this approach, a compromise of some proportion within these two extremities is required. A different resolution to the problem is given by a laminar structure featuring a higher density surface and a lower density substrate. Otherwise, a sectioned surface with higher density foam at the crew footings and lower density foam throughout other areas could be implemented. Finally, a new Foam-Grip material could be incorporated into any of the previous options at the crew footings to increase stability.

This research involving injury biomechanics, is a pioneering investigation into the world of watercraft safety for the volunteer men and women who risk their lives to save ours. A total of 12,948 rescues were completed by surf lifesavers in the 1998/99 season around Australia. This study will help to improve the safety of the IRB to enable it to continue to be effectively used as one of the most prominent rescue tools for Australian Surf Lifesavers and throughout different parts of the world.