MITIGATING AGAINST THE EFFECTS OF SHOCK

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It is this medium, the marine environment, which has the greatest potential to cause harm to emergency responders.

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This report is intended to be a guide for marine responders and emergency service organisations in Victoria, Australia.

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3.0 Abbreviations

ABDC	American, Australian, British, Canadian and Dutch researchers and defence agencies.
AVCG	Australian Volunteer Coast Guard
BIR	Boat Impact Recorder
ESF	Emergency Service Foundation
ESO	Emergency Service Organisation
EU	European Union
g	Acceleration of gravity
HSC	High Speed Craft
MAIB	Marine Accident Investigation Branch
MIF	Motion Induced Fatigue
RCMR	Royal Canadian Marine Rescue
RIB	Ridged Inflatable Boat
RNLI	Royal National Lifeboat Institute
RS	Repeated Shock
SSR	Swedish Sea Rescue
TBI	Traumatic Brain Injury
USCG	United States Coast Guard
WBV	Whole Body Vibration

4.0 Executive Summary

The demands placed upon emergency service responders in the marine environment are unique to that of other emergency services due simply to the environment that they operate in. Marine responders operate in a dynamic three dimensional environment which can be (mostly) benign however when called upon to carry out their role of rescuing those in distress at sea, it is more often than not undertaken in conditions that first must be over come before help can be rendered to those in need.

It is this medium, the marine environment in which they operate, that has the greatest potential to cause harm to emergency responders. While the effects of operating in this environment have intuitively been understood by marine responders little in the way of research and study has been done in Victoria to fully enunciate the effects of shock on personnel.

This report, sponsored by the ESF scholarship, will look at the current systems used by overseas marine responders and the advantages of using these systems against what is currently employed in Victoria on emergency response vessels. It will also discuss the effects on the human body when it is subjected to shock as well as looking at current off the shelf solutions available.

The conclusion of this research identified that while there is a clearly defined risk to marine emergency service responders being exposed to the effects of shock, there are also a number of ready made solutions that can be both retrofitted to current vessels as well as incorporated into the design of new vessels. It is hoped that this report will be a trigger for all marine response organisations and others within Australia, to move forward with the incorporation of suitable systems to improve the safety of personnel involved in marine rescue.

This report will make recommendations to various emergency marine responder organisations with particular emphases on the volunteer sector.
The key recommendations are:-

- All vessels currently designated as emergency responses rescue vessels are assessed for the suitability for the retrofitting of shock mitigating seating/systems,

- All future rescue vessels are fitted with shock mitigating seating/systems as standard equipment, and
- That the installation of shock mitigating seating/systems is seen not as a stand alone solution but as only one part of a holistic approach encompassing full cabin ergonomics.

This study will demonstrate that not using shock mitigating systems will lead to both short and long term damage to the health of marine responders. It is without doubt that these systems, which are readily available, will protect the state's most valuable asset…its emergency service responders.

RNLI lifeboat at Bembridge station

5.0 Introduction

As an active operational marine rescue responder with the Australian Volunteer Coast Guard I work within a very dynamic and at times dangerous environment: the coastal waters of Port Phillip and Westernport bays as well as Bass Strait. Over the last six years I have been involved in well over 120 calls for assistance ranging from the benign tow of a vessel broken down in calm waters to search and rescue events in conditions which have tested the limits of both the vessel and the crew.

During one particular event the rescue vessel was tasked to respond to a person in the water from an up-turned catamaran in building seas of up to two metres with an onshore wind gusting to 50 to 60 kilometres per hour. During the transit to the datum point the vessel came off a large wave and landed heavily causing a crew member to jar his back. The result of this occurrence had a twofold effect:- firstly, the vessel undertaking the rescue was now limited in it's ability to complete the tasking due to a crew member having been injured and secondly, there was still a person in need of assistance.

It was this event that lead me to start reviewing literature into the effects of shock in the marine environment and how we can better protect crews at sea. Undertaking this course of inquiry ultimately lead me to apply for an ESF scholarship to understand what systems are available to protect crews.

The scope of this report will be

- To identify what effects shock has on the human body in the marine environment
- Identify systems that can protect crews from the effects of shock
- To make recommendations to emergency service organisations that operates in the marine environment how they can mitigate and protect their crews against the effects of shock.

6.0 Methodology

Initially reviewing information online and in reports from around the world it quickly became obvious that there was little or no information available within Australia on either the effects of shock on the human body in the marine environment or indeed systems that can mitigate the effects of shock. Therefore a detailed investigation could not be undertaken without visiting organisations overseas that currently employ systems that mitigate shock.

The method of investigation was to visit leading manufactures of shock seating systems as well as some of the world's major maritime rescue organisations that use these systems. The visit would investigate current best practice in design and use of shock mitigating seating systems as well as gathering data on the effects of shock.

7.0 Findings in Literature

A review of literature on the effects of shock to the human body in the marine environment was sourced from a number of areas with the most relevant being:-

- Incident reports from the Marine Accident Investigation Branch (UK)
- US Navy Health Research Centre
- Industry reports and symposiums

8.0 Discussion

8.1 Organisations visited

For the overseas visit for this research I undertook a comprehensive tour which included visiting England, Sweden, Canada and the United States calling on four marine rescue organisations and two manufacturers of vessels and shock seats. The method used to select the organisations was based upon their international renown in the field of marine rescue as well as personal contacts built up over my years of experience in the field of marine rescue.

The organisations visited included:

RNLI

- The RNLI head office at Poole UK.
- Bembridge lifeboat station UK
- Swanage Lifeboat station UK
- Weymouth Lifeboat station UK
- Inshore RNLI small boat manufacturing facility Isle of Wight UK.

Swedish Sea Rescue

- Head Office Gothenburg
- Rojo Station Sweden
- Bua Station Sweden

Ullman Dynamics (Sweden)

Royal Canadian Marine Rescue

- Naomie Station, Vancouver Island Canada

United States Coast Guard

- Motor Lifeboat School. US

8.2 Effects of shock

Shock is the term used to explain the impact that an object receives as a result of a sudden stop after rapid acceleration/deceleration. Within the marine environment shock occurs when a HSC drops off the top of a wave and hits either the face of the next one or lands in the trough between them. Due to the dynamic nature of the marine environment it is rare that a HSC would be subjected to a single shock event during a given period of operation and therefore the term "repeated shock" (RS) is the more commonly used nomenclature.

The speed of the HSC, the height of the wave and the experience of the coxswain are all variables when a HSC is operating however it is not uncommon for a HSC crew to be exposed to constant shocks in the region of 2g, regular shocks of 6g to10gs and occasional shocks of up to 20g. Short term exposure to these repeated shocks can lead to micro-muscle fatigue (the muscles "twitching" to keep the body in balance) while long term exposure can lead to chronic injuries in the form of skeletal, muscular and tendon damage.

It is these high magnitude impacts (< 10g) as well as long term exposure to low impacts (>10g) that can result in the type of acute injury as described in the High Speed Craft Human Factors Engineering Design Guide which in part reads:

"The risks of acute and chronic injury are manifested in an increase in spinal, knee, arm, or neck injury. This can be from a single high-energy event (e.g. a 20g impact) or the result of a long-term exposure to a large quantity of smaller energy events (e.g. multiple 2g impacts). For example, for predominately military HSC crewmen, there is a significantly higher incidence of back and knee injuries than what is observed in the general military population, who are not typically exposed to the HSC operational environment."

When standing the human spine is at its strongest where it assumes a natural S shape and it is the major load bearing unit of the skeletal system from which head and trunk are supported. The vertebrae are both insulated and cushioned by evenly distributed discs, additional support and strength is provided by the trunk, shoulder and abdominal muscles. This mechanical design is well able to absorb a limited amount of impact provided that it is in the correctly aligned position, the "S" shape.

The most common type of serious injury suffered typically occurs in the lumbar spine area as a result of the vertical loads being applied through the interaction of the HSC with the environment that it is moving through and the corresponding transmission of that energy to the occupants of the HSC. When a person is normally in a seated position they have a tendency to "slump" forward in the seated position (head and neck forward of the bodies' centre of gravity) which allows a degree of forward flexion in the posture which in turn amplifies the effect of the shock load on the skeletal system resulting in a spinal *'wedge'* compression fracture (see Figure1).

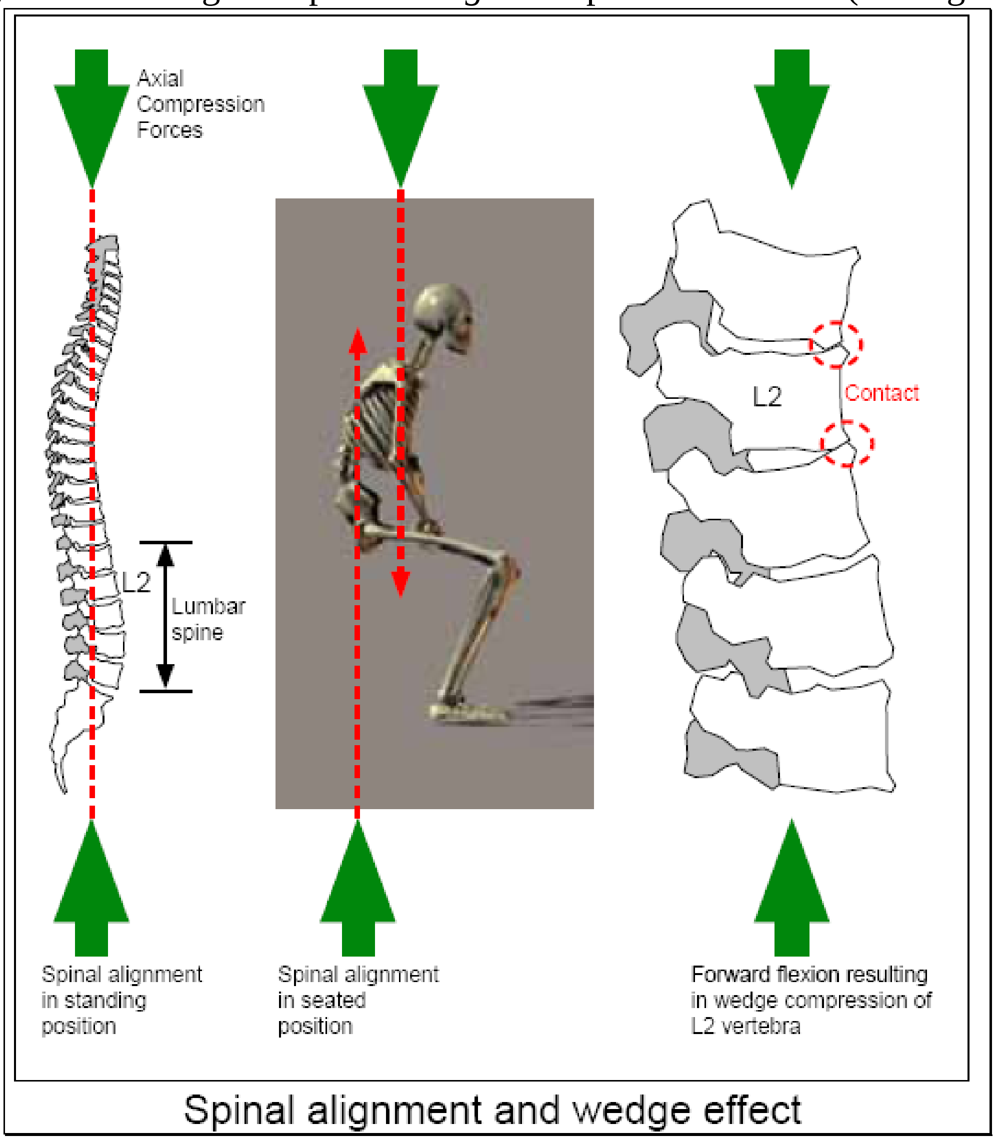

Figure 1[1]

[1] STResearch

Spinal wedge compression fractures are common among people who have been involved in a head on car crash, experienced a violent helicopter landing and are also commonly seen in military pilots who have ejected from an aircraft.

The size of the shocks (g-loading) experienced by people on board a boat are significantly magnified when their bodies leave the seats and then land as the boat rises up towards them. Indeed it is not unusual for a person either seated or standing to be subjected to a higher shock loading than what the actual deck of the vessel has received. This is because even though the deck of a vessel has expended its travel down, the seated and/or standing occupants are still in a vertical downwards trajectory and upon meeting the now stationary deck are still carrying the accumulated energy from the original impact.

Areas of the body that are most at risk of injury due to RS are:-

- Neck
    - Vertebral fractures, Disk herniations
    - Distortion injuries, as in Whiplash trauma
- Spine
    - subject to compressing forces and shear forces
- Lower Back
    - Vertebral fractures (wedge effect), Disk herniations
- Legs
    - Knees are not designed to take up impact in near-stretched positions.
    - Ankles not designed to take up impact on heels.

If a twist or bend is introduced to the lower back region the risk of this type of injury is further increased. Research indicates that the introduction of a twist can reduce the mechanical strength of the vertebra/intervertebral disc unit by up to one third.

8.3 Whole Body Vibration.

Whole body vibration is the transmission of vibration from machinery and or the effects experienced when traveling in a vehicle across uneven surfaces. The effect of this vibration is transmitted to the body either through a seat or if the person is standing, the feet.

The impacts upon the health of an individual subjected to WBV are detailed by Work Safe Australia, a Australian Government statutory agency established in 2009, as follows:

The longer a worker is exposed to WBV, the greater the risk of health effects and musculoskeletal disorders. The most commonly reported disorder from exposure to WBV is low-back pain.

Epidemiological studies of long-term exposure to WBV have shown evidence for risk to the lumbar spine and the neck and shoulder. Results of epidemiological studies also show a higher prevalence rate of low-back pain, herniated disc and early degeneration of the spine in excessive WBV-exposed workers.

Exposure to WBV may also cause or exacerbate other health or safety effects such as:

- *cardiovascular, respiratory, endocrine and metabolic changes*
- *digestive problems*
- *reproductive organ damage*
- *impairment of vision, balance or both*
- *interference with activities and discomfort that could lead to accidents*[2]

However both within Australia as well as overseas, while it is recognized that WBV is a risk to health and that there have been some standards issued to limit the exposure to these effects, all of the standards that have been applied to the marine environment (certainly within the EU) have been simply extrapolated from the mining and industrial sectors with little thought as to how this translates to the marine sector. Indeed this has caused some issues for both the RNLI and SSR in that if they apply the EU standards of allowable exposure to WBV, then their rescue vessels would never be able

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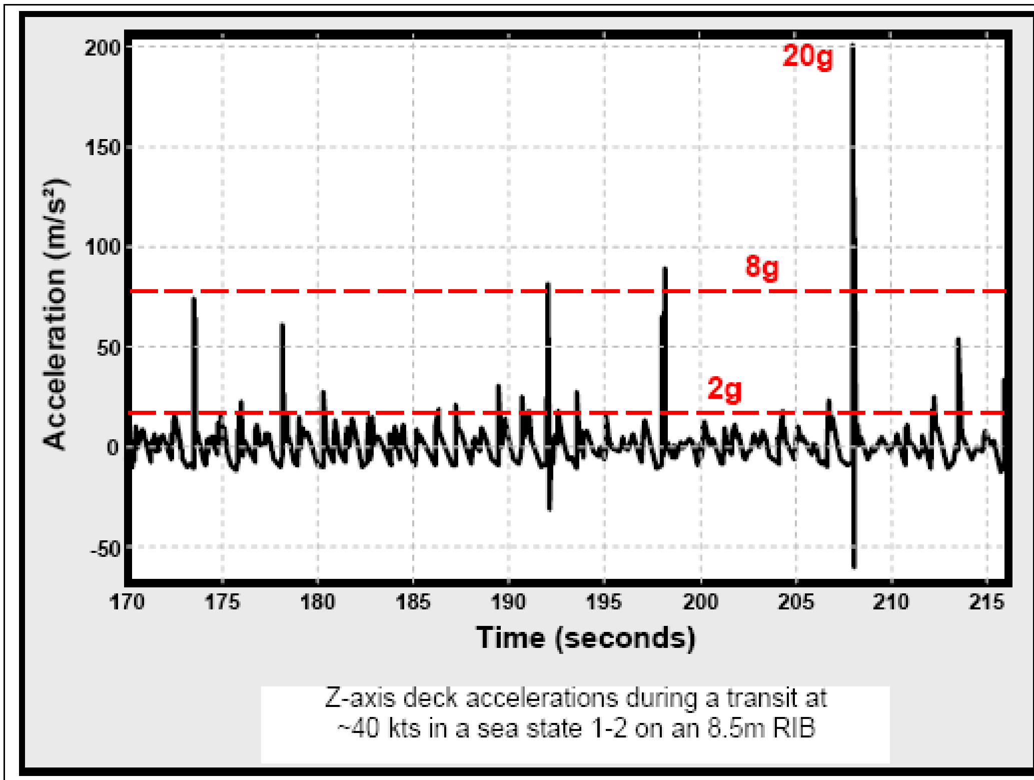
2 http://www.safeworkaustralia.gov.au/sites/swa/AboutSafeWorkAustralia/WhatWeDo/Publications/Pages/Whole-body-vibration-fact-sheet.aspx

to put to sea in anything but the calmest conditions (sea state 1) and at speeds not exceeding 20 knots.

The RNLI has sought and gained exemptions from the EU regulations and the EU is currently reviewing the standards for marine operations.

The ABDC working group undertook research to gather base line measurements for WBV and RV which was then used in its publication *"High Speed Craft Human Factors Engineering Design Guide"*. This experiment was specifically undertaken to quantify data measurements of RV and WBV from a HSV during operations in calm conditions. A graph of the results of the trial (see figure 3) show that within the first 15 minutes of the transit a person would have exceeded the 8 hour European Union allowable limits for WBV. A person would have, after 1 hour, been exposed to 7.5 times the allowable limits.



Magnitude and frequency measurements for shock recorded on board an 8.5m RIB [3] Figure 3

[3] Graph taken from the "Celtic Pioneer Report" page 18 Marine Accident Investigation Branch (UK)

The quandary is that the current EU requirements for WBV exposure limits are in place because of the known proven chronic effects of long term exposure to WBV (albeit for terrestrial operations) however these same standards mean that even a limited exposure in mild to moderate conditions exceed safe operating limits for crews.

Another insidious effect of WBV is the effect of fatigue on crews known as Motion Induced Fatigue (MIF). The term MIF was first coined by the ABCD working group after trials conducted to test the existence of MIF.
These trials were conducted by Myers, Dobbins and Dyson[4] building upon previous work carried out by the US Navy.
The existence of MIF was proven by using test subjects who were first required to undertake a running test (beep test) from which the results were used as a base line. The subjects were then required undertake a transit of less than two hours in a RIB in calm conditions and then undertake a second running test.

The results of the second running test showed a reduction of 26% from the original baseline run test, supporting the existence of MIF. While the at sea trails were taking place the subjects oxygen intake was also measured, to calculate energy expenditure. However this could not account for the reduction in post sea run tests results as the subjects, while at sea, where seated were not observed to be to as highly aerobic as the run test. So what was causing the degradation in the post sea trail performance?

It was thought that the physical work that the body was doing to try and protect itself from the effects of WBV and RS were of a type that was similar to micro-muscle damage, and so this was tested in trails where a biochemical marker of muscular damage was measured. This biochemical marker, known as creatine kinase (CK) was tested in the subjects before a sea transit, and up to 72 hours after the transit. The results showed that there was an elevation of CK markers indicating that micro-muscular damage had occurred, and it was this that was in fact the root cause of the MIF. The most surprising aspect of these trails were that the transits were over a time period of not more than three hours and in sea states not exceeding 2 (see figure 4).

[4] The majority of this work was conducted as part of a UK Engineering & Physical Sciences Research Council (Project No.EP/C525744) project conducted at the University of Chichester with additional support from the UK MOD.

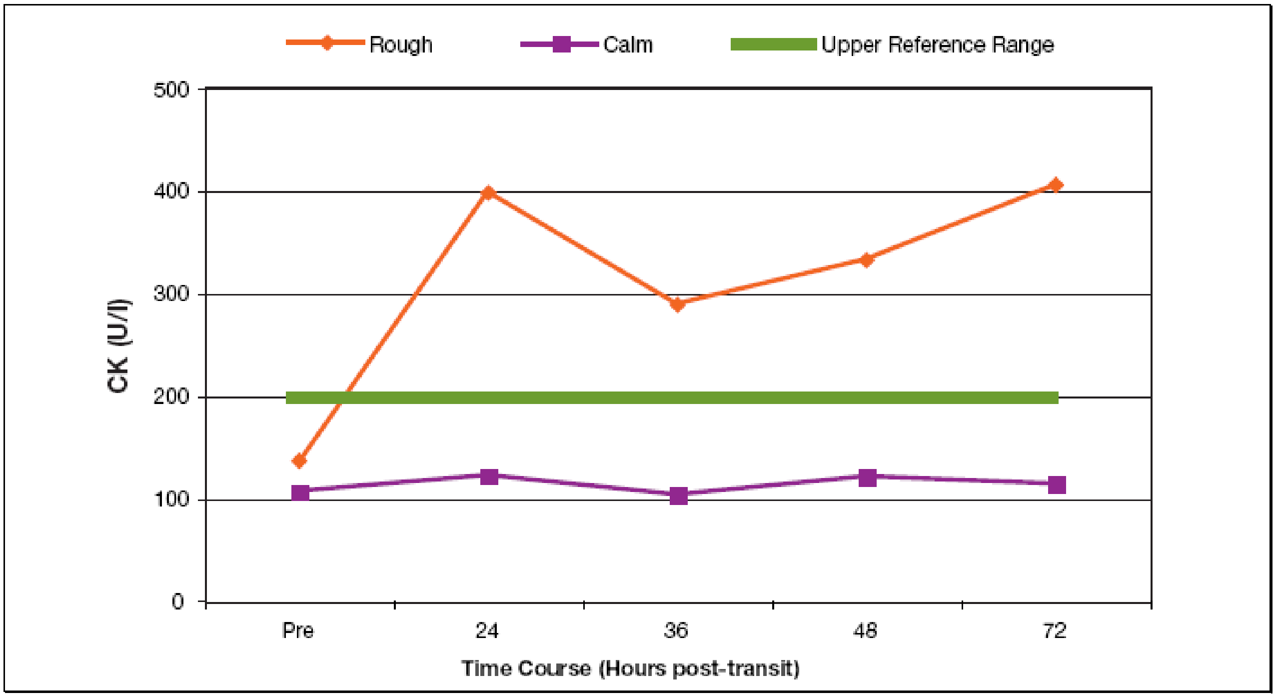


Figure 4 **The mean (+/- SD) time course response (n=12) of a biochemical marker of muscle damage (CK) following a 3-hour transit in a 28' RIB in a Sea-State 1-2.**[5]

Time spent in on water operations by marine organisations in Victoria usually exceed the trials conducted above in time spent on the water by 100% to 200% and it is not unusual for extended searches to have responders on the water for 8 to 10 hours. Given the information above it can be deduced that marine responders within Victoria are being routinely exposed to micro-muscular damage, which as a consequence means that crews are routinely fatigued to a point where their operational effectiveness must be questioned.

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[5] Graph from page 15 of the "*High Speed Craft Human Factors Engineering Design Guide*". Myers S, Dobbins T, Hall, B., Ayling, R., Holmes, S., King, S. and Dyson R.

A SSR vessel located at Gothenburg Sweden

8.4 Injury Statistics

Before exploring how to mitigate these effects it is important to look at statistical data for injuries to crews and passengers operating HSC.

One of the most surprising aspects of the tour was that with the exception of the USCG, none of the other marine rescue organisations visited had recorded any form of detailed analysis of injuries sustained by their HSC operators. Part of the reason for this can possibly be explained by the fact that the RNLI, SSR and RCMR manpower is drawn mostly from volunteers where as the USCG is 100% career staff as well as having a substantially large support arm to the operational side of the organisation in comparison to the other named organisations.

Thankfully some statistics are available from other sources but the main data reported here is that undertaken by Antonio B. Carvalhas, Ph.D. of the USCG human resources department.

In October 2004, Antonio B. Carvalhas presented a report detailing the *"Incidence and Severity of Injuries to Surf Boat Operators"*. The purpose was to:

- Quantify anecdotal reports of the incidence of high injury rates for crews operating in surf and heavy weather conditions
- Identify the types of injuries sustained as well as the severity
- Look at factors that may contribute to the injuries (Operational and Personnel)
- Provide recommendations to mitigate the incidence of the reported injuries.

One of the main data collection sources for the report was to gather data from a survey of 100 Coast Guard personal who at ranked as "Surfman", a USCG ratings for those that they are qualified to operate HSC in off shore rescue operations.

The demographic of the respondents were as follows:-

- Average age of the respondents 38.2 yrs
- Years in Coast Guard 18.2 yrs
- Average years conducting rescue operations 8.9 yrs
- Hours per week conducting rescue operations 5.3 yrs
- % of time in seas 6 -15 feet 71.3%
- % of time in seas >21 feet 4.0%

INJURY DEMOGRAPHICS

Experience a surf-related injury	52%
Total number of surf injuries in career (average)	1.7
Length of time at unit before injury (in months)	21
Experience pain from injury	59.6%
Experience pain in general	35.9%
Currently being treated	15.8%
Injury resulted in 'lost workday' or 'restricted duty'	12%

Respondent estimates of exposure, incidence, severity, and consequence of surf injuries

[6]

The table above shows that of the 100 respondents 52% had experienced a injury while undertaking "at sea" duties. Interestingly this figure correlates with an unofficial poll undertake at the Australian Volunteer Coast Guard unit (Safety Beach) in which the 54% of the respondents also reported an injury while engaged in on water activities.

ERGONOMIC SYMPTOMS

Body region	CG Follow-Up	NMLBS	ST Cape D
Neck	17%	38%	25%
Shoulder	19%	63%	25%
Elbow/Forearm	6%	25%	0%
Hand/Wrist	9%	38%	0%
Fingers	3%	38%	0%
Upper Back	9%	50%	25%
Lower Back	39%	63%	50%
Thigh/Knee	32%	63%	25%
Lower Leg	3%	13%	0%
Ankle/Foot	13%	38%	25%

Percent of respondents who experience 'pain' or 'discomfort' by body region

[7]

The table above show the percentage of injuries reported by respondents to the poll from the National Motor Life Boat School (NMLBS) measured against respondents from the Cape Disappointment station. The NMLBS is where all prospective Surfman and crews do their initial and advanced

[6] Carvalhas October 20, 2004
[7] Carvalhas October 20, 2004

training and as such it would be expected that a slightly higher incidence of injuries are reported. However it is also important to note that those respondents from the Cape Disappointment station, who are experienced crews, still showed a high incident of lower back issues. It is also interesting to note that the crews from the Cape Disappointment station reported no issues with elbows, hands, wrists or fingers however the incidence of issues with neck shoulder, upper and lower back as well as legs was still quite high by percentages.

One of the most interesting points to come out of the report is that Carvalhas found that age does not increase propensity for injuries nor do physical fitness programs prevent or reduce injuries.

Four recommendations came out of the report that applies to engineering, human resource, medical and physical solutions to the identified problems. The recommendations were as follows:-

- ***Engineering Changes***
    - *Shock dampening seats*
    - *Handholds*
- ***Exposure Limits and Underway Guidelines***
    - *Identifying operational conditions with greatest impact stresses and limiting exposure to these elements*
    - *Exercise and Physical Conditioning Programs*
- ***Target body regions most prone to injury (lower back, knee, etc.)***
    - *Use of protective or support equipment to limit exposure*
- ***Medical Screening and Pre-existing Conditions***
    - *Identify medical and physical conditions that predispose members to injury to limit/avoid exposure*[8]

Upon the release of this report the USCG undertook to install shock mitigating seating on all new vessels introduced into the fleet.

Further historic data on shock related injuries appear in reports form the Marine Accident Investigation Branch (UK).

[8] Carvalhas October 20, 2004

The MAIB notes in it's report on the investigation of injury to a passenger on board the RIB vessel "Celtic Pioneer" that:

"*The MAIB is aware of* ***28 accidents that have resulted in lower back compression injuries*** *on board RIBs since 2001. Of these, 21 occurred in the last 3 years, 12 were confirmed as spinal fractures and 16 occurred during thrill type boat rides.*
As in this case, many of these accidents were not reported to the MAIB by the vessel operator, and include an injury to a female passenger in 2007 in the vicinity of the Rannie buoy in a RIB owned by another operator, and two injuries on board a UK coded RIB, operating in Spain in 2008. Several other shock related injuries during high speed and thrill type boat rides have been reported to the MAIB, such as leg fractures and facial injuries." [9]

9.0 Mitigating WBV, MIF and RS

With the compelling evidence that WBV, MIF and RS can and does lead to chronic and in the most severe cases debilitating acute injuries to the musculoskeletal system and further, that injuries to the lumbar spine is often cumulative as a result of exposure to the impacts of the HSC transiting within a water environment, there is a clear need to introduce systems that can offer protection to crews.

While the effects of WBV, MIF and RS can never be completely nullified they can certainly be mitigated to the point the crews can undertake missions with a level of protection against the known hazards
Broadly there are two approaches that can be undertaken.

Engineering:-

- Hull design
- Suspended deck
- Seating design
- Cabin layout

Human resources:-

- Limiting exposure to the issue
- Education

[9] Report on the investigation of injury to a passenger on board a
Delta 8.5m RIB. River Thames, London 6 May 2010.Marine Accident Investigation Branch

Hull design

Hull design can mitigate against some of the effects of RS and WBV through the choice of using different materials such as GRP, composite-material, mono vs. multi-hull and dead rise angle which may assist in reducing slamming and vertical accelerations. However while the design of the hull to incorporate mitigating effects of RS and WBV is a potential solution, it should be noted that the mission profile for the hull design will always be a tradeoff and may not necessarily be able to be accommodate designing out the effects of RS and WBV in which case additional engineering solutions above the hull should be considered such as the location of the cabin/wheelhouse.

Positioning the wheelhouse/console further to the rear of the vessel will build in a mitigating factor as the rear third of the hull receives less shock loading than the forward two thirds of the hull. Further engineering solutions could also include cabin isolated from the hull as demonstrated in the French Pantocarene pilot boat design used by Port Phillip Pilot Services (see figure 5).

Figure 5

Suspended Deck

One of the interesting features of this design is the suspended cabin which allows for isolation from the hull which would give a level of protection to the crew for WBV and MIF.

Along similar lines is the development of the ICE-2 system from Shockwave Seats where the entire console and seats are isolated from the hull on a Multi Axis suspension system. This system allows for retro-fitting to existing hulls and in talks with operators (The Royal Canadian Mounted Police) during my visit to Vancouver Island B.C. reported that the mitigating the effects of the ICE-2 (Figure 6) for MIF "where significant" and that officers where no longer as fatigued from sea duties as they were in the past before the fitting of the system. The only note of caution in regards to this type of system is that the design introduces "pinch" points between the console and the hull under some conditions.

Figure 6

Ride control

Systems such as those developed by Maritime Dynamics (USA) can further assist in mitigating some of the effects of RS, WBV and MIF by automatically adjusting (fully automated) for dynamic roll, pitch and heave motions of the vessel. Trials of this system have documented a 70% reduction of pitch angle and a 57% reduction of roll angle of the vessel while underway. This has the potential to reduce vertical, longitudinal and lateral impacts to the vessel occupants. While time did not allow for ride control to be fully investigate these types of systems and the benefits claimed would certainly warrant further investigation and consideration for the retrofit of current vessels and inclusion for future vessel designs.

Seating design

Over the last 15 years there has been a large amount of work and testing to develop seating systems that will mitigate the effects of RS and WBV and MIF. Indeed it is these systems that are the main line of defense against the effects of RS and WBV and MIF.

Benefits of shock mitigating seat against normal seats in protecting against RS, WBV and MIF have been proven in a number of trials conducted over the last few years. In the study carried out by the ABDC working group for its publication *"High Speed Craft Human Factors Engineering Design Guide"* during which test subjects were first required to undertake a running test (beep test) before and after a transit in a HSC it was observed that those test subjects using a shock mitigating suspension seat actually recorded improved running tests results as measured against those test subject who undertook the transit in a RIB using a normal (non-mitigating fixed) seat (refer to page 14).

The graphed results (see figure 8) show the recorded differences between the use of a suspension seat and a fixed seat in the ability of the test subject to perform a run test and record that those using the suspension seat returned a 1% increase in the post transit run test measured against the pre transit run test demonstrating a reduced effect of MIF.

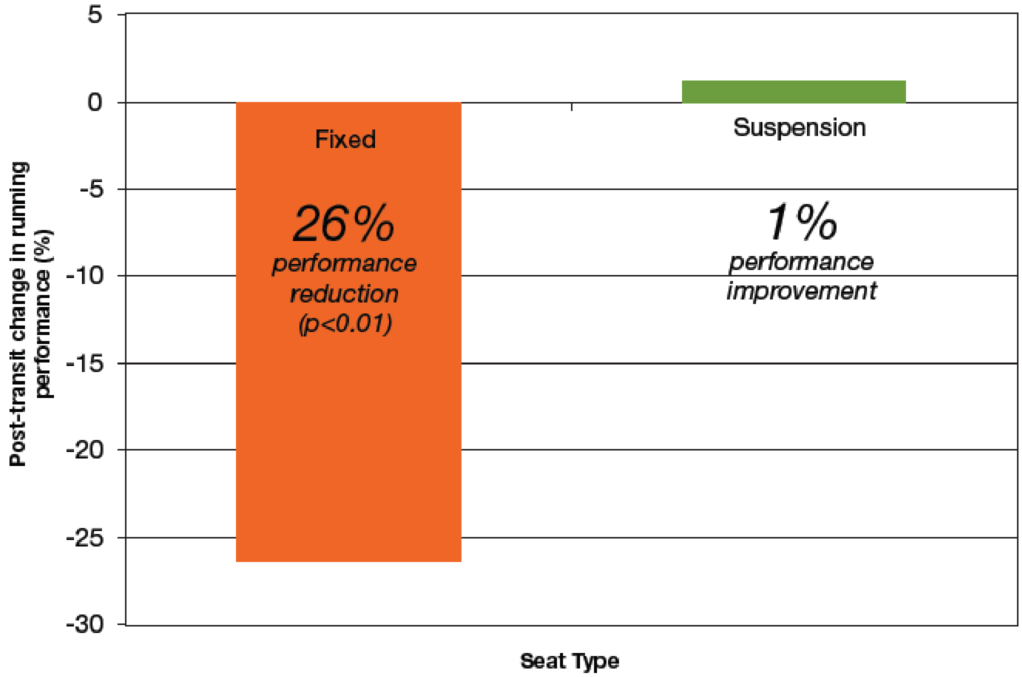

Figure 7

10

In a further trial undertaken to study HIGH SPEED CRAFT MOTION ANALYSIS to quantify the motion measure of RS exposure in relationship to HSC it was observed that "*use of a suspension seat substantially reduces both the frequency and the magnitude of the impacts compared to the HSC deck.*"[11]

The graphs in figures 9 and 10 demonstrate the effectiveness of suspension seating as measured against the HSC deck and (in figure 10) a fixed seat.

In percentage terms a suspension seat returned a 53% difference against a fixed seat in a 5.8g impact event and a 62% difference in a 12g impact (where the fixed seat recorded a 12g impact the suspension seat recorded a 4.6g impact for the same event).

[10] Graph from page 14 of the "*High Speed Craft Human Factors Engineering Design Guide*". Myers S, Dobbins T, Hall, B., Ayling, R., Holmes, S., King, S. and Dyson R.

[11] HIGH SPEED CRAFT MOTION ANALYSIS – IMPACT COUNT INDEX (ICI)
Trevor Dobbins, Stephen Myers and Rosemary Dyson; University of Chichester, Chichester, UK.
Tom Gunston; SIG SCP, Southampton, UK.Stuart King; QinetiQ, Farnborough, UK.Reginald Withey; Alverstoke, UK.

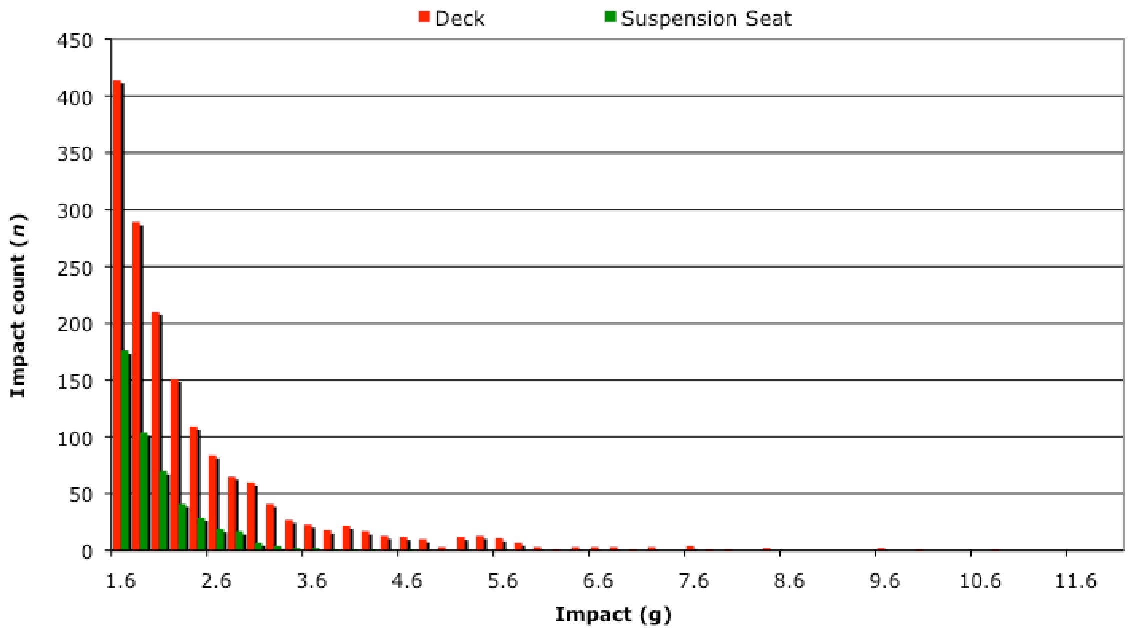

Figure 8
[12]

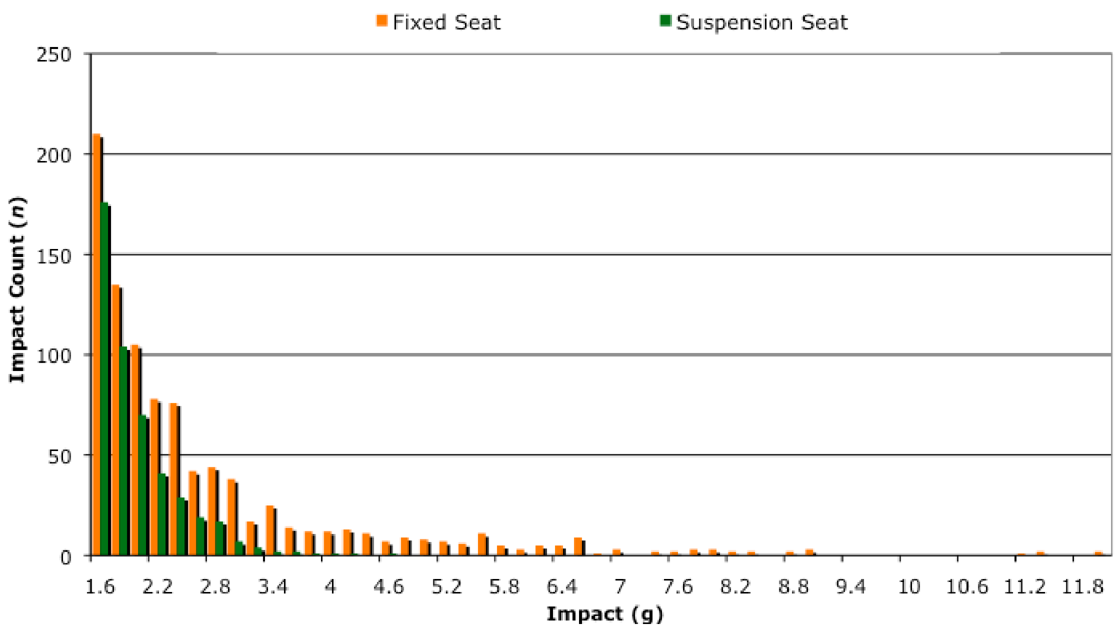

Figure 9
[13]

[12] HIGH SPEED CRAFT MOTION ANALYSIS – IMPACT COUNT INDEX (ICI)
[13] HIGH SPEED CRAFT MOTION ANALYSIS – IMPACT COUNT INDEX (ICI)

This graphical evidence clearly shows the demonstrated differences in shock mitigation performance between fixed seats and suspension seats leading to the conclusion that the use of a shock mitigating seat will lead to a demonstrable reduction in effect of MIF, WBV and RS thus reducing the potential for acute and chronic musculoskeletal injury.

Shock mitigating seats come in a variety of styles that can be broadly broken up into two main categories, the "Jockey" seat and the "Full" seat.

The jockey style of mitigating seats was pioneered by Ullman Dynamics and is most commonly used on RIB boats (see figure 10 & 11).

Figure10

Figure 11

The design is intended for the operator to "straddle" the seat and use the legs to help support and steady the body while the seat itself looks after and protects the spine. The author tested this design on two differing vessels in and around Gothenburg while on the Swedish leg of the tour. While the seat provides excellent vertical support there is a feeling of lack of support for lateral motions. Further it was also found that while the concept of using the legs was sound the author's legs became fatigued over a period of time.

While I understood that further training in the use of this type of suspension seat would ameliorate this, it is felt that the seats should be of a design that requires little or no training and that the seat should be capable of providing full protection to the uneducated. Having said that this design does have its advantages in areas of limited deck space such as that on small RIBs or where there is the need to transport large numbers of personnel with limited deck space.

The full seat style (figure 12, 13 & 14) is produced by a growing number of manufactures. Generally all seats produced by reputable manufactures will provide a level of protection from the effects of MIF, WBV and RS. The choice of what seats are most suitable will largely come down to cost, ascetics and suitability for the specific vessel.

Figures 13 &14

Pictured in figures 12 to 14 are three different styles of full seats which the author tested. The advantages of the full seat over the jockey seat is that the user does not have to actively "participate" as the seat will do all of the work without any conscious thought of the user. Further the seats offer a higher feeling of “security” and an increased level of comfort over and above jockey style seats.

However it is important to note that within Victoria due to a lack of understanding by ESOs of the effects of RS, WBV and MIF, some organisations have chosen to purchase seats that provide a level comfort (and therefore perceived protection) over the normal seats that are generally supplied with the vessel upon purchase. Typically these seats are of a similar if not the same as those found in large trucks.

Disturbingly some of these suppliers have made claims that these seats are suitable for marine applications and while they do offer some limited value in protecting the user against the effects of MIF and WBV in calm conditions, they provide no protection against MIF, WBV and most importantly RS in conditions above sea state 1 and are generally not capable of protecting the occupant from shocks greater than 3g. As demonstrated in the trials noted on page 13, (See figure 3) g-loadings in excess of 8g can routinely be experienced in sea state 1 & 2. Therefore it is important that the claims of manufacturers are verified.

Regardless of which brand of seat is chosen, the fact remains that a seat produced specifically to mitigate against the effects of RS, WBV and MIF is measurably more beneficial to the end user than not using a suspension seat at all, and there are a number of reputable companies that can provide both off the shelf as well as whole of concept solutions.

Interestingly the RNLI made the decision to design and produce their own suspension seat rather than purchase an off the shelf design. While visiting the headquarters in Poole the author queried this decision. In general the RNLI did not have any issues with designs currently on the market at the time. However the RNLI design team wanted to adopt a more holistic approach of full ergonomic layout for their off shore rescue vessels and it was felt that (the then) seat designs could not be incorporated. Having an in-house design team and the resources to undertake the project was also an influencing factor into designing a tailored suspension seat. The RNLI understood that the ergonomic lay-out of the cabin plays just as an important role in mitigating the effects of RS, WBV and MIF as does hull design and seat selection.

Dr. Dale Bass of the University of Virginia, (Center for Applied Biomechanics) notes that: - "*Operator posture is as critical as any design consideration for shock mitigation. The human spine is designed to compress during a fall and can absorb a considerable amount of impact provided that it is aligned with the direction of force. As the human spine becomes misaligned (i.e. more perpendicular) to the force vector, a shearing effect is imparted between vertebras, which can lead to injury. This 'poor posture' is often observed on HSC where the location of the controls force the operator to lean forward in their seat/bolster.*" and has estimated that, *"poor posture can reduce the effectiveness of a suspension seat by as much as 30%"*.

As discussed on page 9, the human spine is at its strongest when it is in the standing position. Seated position the body tends to slump forward (see figure1) exacerbating the alignment of the spine. Suspension seats correct this by encouraging the occupant to sit in a more upright position as well as taking up and mitigating (any) shock-load.
However if operator does (or is not able) to sit correctly then the protective capacity of the seat will be compromised potently leading to an injury for the occupant.

Poorly designed console and cabins can lead to a reduction in the effectiveness of suspension seats as demonstrated in the picture below (figure 15) in increasing the risk of injury.

Figure 15

The operator pictured (figure 15) is fully leaning forward and if the vessel was to take a shock load event of 5g then his neck would be bearing the weight of 25kgs (given that a normal person's head weight is an average of 5Kgs).

Within the military, car and aircraft industries there are already a number of ergonomic design standards[14] that have been in place for many years. Having already identified the increased risk to users health (as well as operational effectiveness) operating HSC in marine environments there are many lessons that are easily transferred.

This is already well understood by the RNLI and as shown by the picture below demonstrates a fully integrated cabin layout where the users have full

[14] ASCC AIR STD 61/116/13, The Application of Human Engineering to Aircrew Systems.
NATO STANAG 3994: Application of Human Engineering to Advanced Aircrew Systems.
NASA-STD-3000, Man-Systems Integration Standard.
FAA Human Factors Design Standard (HF-STD-001)
DSTAN 00-25 Part 14: 2000. Military Land Vehicles Design.
US Federal Motor Vehicle Safety Standards Part 571:
Standard No. 101 – Controls and Displays.
Standard No.123 – Motorcycle Controls and Displays.
Standard No. 207 – Seating Systems.

access to the all of the vessels controls and systems without moving from their suspension seats (see figure 16).

Figure 16

To encompass a holistic approach to ergonomics and crew safety the RNLI developed a system called Systems and Information Management System (SIMS) which allows the crew to monitor, operate and control many of the boat's systems directly from their suspension seats without compromising the safety of the operator. Access to all communications (VHF, MF, DF, intercom), navigation (radar, chart, GPS, depth and speed) as well as being able to monitor the engineering systems is done via the trackball (seen in figure 16 just to the right of the throttles).

Within the aviation industry this type of system is known as HOTAS (Hands On Throttle And Stick) and allows pilots to effectively control the aircraft regardless of the attitude of the aircraft or the g that the pilot is being subjected to.

[15]

Figure 17

As demonstrated in figure 17, the seats enhance crew safety by incorporating essential controls such as throttles and joystick within easy reach while the operator is being fully restrained within the suspension seat thus not compromising safety or the ability of the suspension seat to fully mitigate and protect against the effects of RS.

The ergonomic concepts can also be applied to smaller vessels such as RIBs as evidenced by the design below (figure 18) from Shockwave seats.

[15] Author siting in an RNLI "Tamar" Class lifeboat operated by the Bembridge Lifeboat Station.

Limiting exposure to the issue is another potential solution to the identified issues of the effects of RS, WBV and MIF. While placing operational time limits for personal on HSC would assist in ameliorating the effects of MIF and WBV (but would have no impact on reducing the effects of RS). Moreover this solution then places further strain on what is already (within Victoria) a limited pool of both career staff and volunteers. However certainly in instances of extended searches where in the past crews have been known to be on the water for periods of up to 14 hours this could be reduced to more acceptable limits of 4 hours. This needs to be balanced against operational capacity and needs as well as the understanding and willingness that by those controlling the event that more resources would need to be used than may have been the practice in the past.

Education is another factor that must be considered. Currently (generally speaking) there is little or no understanding within the Victorian Marine Rescue community about the dangers and ongoing chronic and potential acute effects of RS, WBV and MIF. By raising the awareness of users to the effects of shock and vibration, small changes in the way vessels are used can be introduced, such as speed of the vessel and the way the vessel is steered into and across varying types of sea conditions to reduce the effects of RS, WBV and MIF on the crew.

Additional educational tools that can be used to raise the awareness of HSC operators are Boat Impact Recorders. Recently Ullman Dynamics have introduced a portable BIR (see figure 17) which allows users and organizations' access to data that measures and records:-

Figure 17

- Human impact exposure
- Route tracking and analysis
- Driving performance evaluation
- Accident investigation
- Warranty monitoring
- Complying with standards

The BIR also produces graphical representations of the total exposure of the vessel and occupants as well as showing where during a voyage that the impacts occurred (see figures 18 and 19).

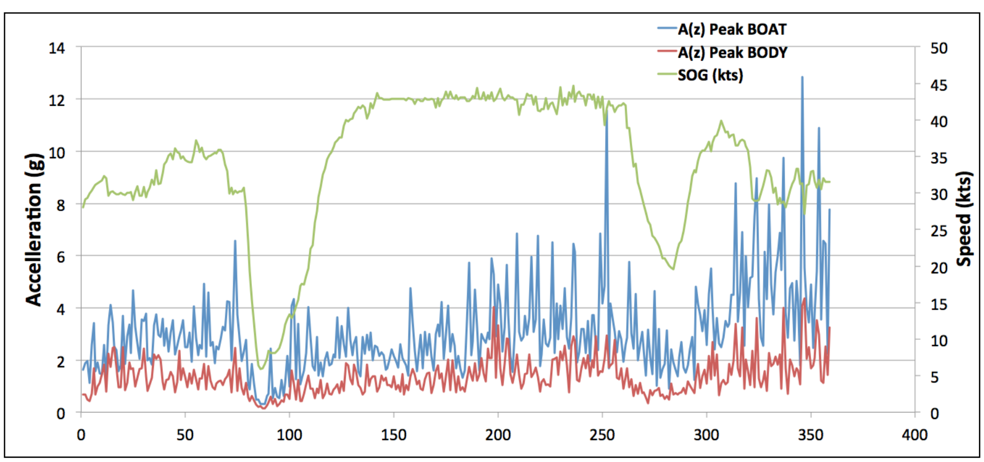

Figure 18

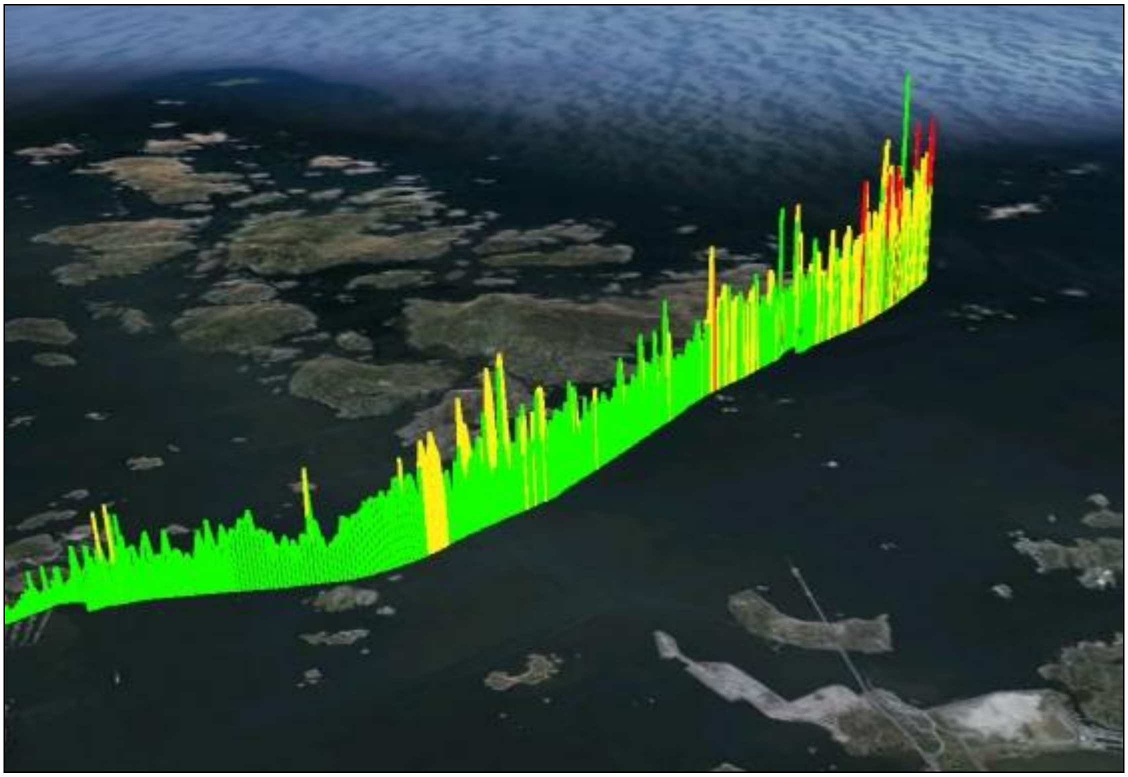

Figure 19

This data can be used as an educational tool to assist the HSC operators to make better informed choices on how to in the future operate the vessel for given conditions and operational requirements. Figure 19 (above) shows how the BIR linked with GPS can illustrate and record impact data over a given graphic area.

10 Conclusions

The evidence gather from the study tour is compelling and demonstrates that not only is the effects of RS, WBV and MIF quantifiable, but more so has a measurable impact upon the health and safety of marine emergency responders. In summation exposure to RS, WBV and MIF without any form of mitigation will have the following impacts upon the human body:-

- Exposure to repeated shocks has the potential to lead to chronic and acute injuries to the neck, spine, lower back and legs.
- Exposure to whole body vibration has the potential to lead to chronic
    - cardiovascular, respiratory, endocrine and metabolic changes
    - digestive problems
    - reproductive organ damage
    - impairment of vision, balance or both
- Exposure to motion induced fatigue will result in a measurable reduction in crew operational efficiency

The overseas experience shows a much more mature understanding of these effects and therefore a much more reasoned solution to the identified problems. In comparison the level of knowledge in Victoria specifically and Australia in general is of a lower standard at organizational level, however there is a growing awareness amongst individuals that RS and WBV is something that needs to be addressed . The evidence gathered in this report will go towards helping alleviate any gaps in knowledge on this subject and will provide a baseline from which further investigations and studies can be undertaken.

11 Recommendations

It is the recommendation of this report that:-

- All vessels currently designated as emergency responses rescue vessels are assessed for the suitability for the retrofitting of shock mitigating seating/systems.

- All future rescue vessels are fitted with shock mitigating seating/systems as standard equipment (with reference made to the "High Speed Craft Human Factors Engineering Design Guide" during the drafting of the tender document/research phase for a new vessel).

- That the installation of shock mitigating seating/systems is seen not as a standalone solution but as one part of a holistic approach encompassing full cabin ergonomics for crew protection.

12 Acknowledgments

The Emergency Services Foundation plays an important and world leading role in providing support and sponsorship for the benefit and betterment of emergency service responders in Victoria. Everybody who is related to this important institution should be justifiably proud of the results that the scholarships produce and I can only hope that my small part in this initiative is worthy of those who have gone before me.

It would also be remiss of me not to acknowledge my parent organisation, the Australian Volunteer Coast Guard, in both supporting my application and undertaking to action the findings.

The physical and mental effects of injury to emergency responders is by and large a hidden scar upon our community of responders who with an unwritten code expects and at times demands acts of selflessness as we rush to render aid to those most in need. As leaders of these average people who undertake extraordinary acts, it is incumbent upon us to, for not only legal and moral reasons, but to honour these deeds, by providing them with the best protection available so that they may return home safely and injury free.

The brotherhood of the marine responders was something brought home to me with clarity during one particular event during my trip. I was undertaking a trip on a Swedish Sea Rescue vessel (just myself and the SSR Coxswain) in the Kattegat Sea evaluating a jockey style suspension seat when we received a call for a vessel in distress. There was never any question about whether we would or would not respond. We arrived on scene and undertook to tow the vessel to a safe harbour. The most interesting aspect to this was how well the two us of worked together never having met before and the fact that I was on an unfamiliar craft in unfamiliar waters. The task was completed without any issues and it is a compliment to the training that we undertake here in Australia that I was able to fit in and work so seamlessly with a foreign agency.

My study tour took me around the world to the UK, Sweden, Canada and the US and it would be impossible to single out any one agency as being above any other. While each agency had its own culture and outlooks, all were willing to share and also just as importantly learn, interested in trends in

other countries as well as my experiences in Australia. The comradely experienced when visiting volunteers in other countries is something that I will remember and cherish and it goes without saying that the hospitality that was extended to me was one of the highlights of the tour.

Additionally the opportunity to visit a range of other marine organisations has exposed me to many other important elements of marine rescue that are in need of further investigation in Victoria such as design philosophies for dedicated marine rescue vessels. Whereas by and large local marine organisations have been using off the shelf recreational vessels to fill the role of emergency response vessels, overseas organisations take the view that it is critical to ensure that the correct crew safety features should be designed into a vessel rather than adapted to an existing one.

USCG vessels from the NMLBS Cape Disappointment

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United Sates Coast Guard http://www.uscg.mil/

Work Safe Australia
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RCMR rescue vessel located at Naomie Vancouver Island Canada

14 Appendix 1 Helmets

Throughout my trip it was an interesting safety point to note that all marine rescue organisations have now mandated the use of protective head gear for crews on HSC. The head is the most susceptible component of the human body to injury and when combined with the working environment of a rescue vessel the potential risk for injury is high: operating at night in dynamic environment, working on a wet deck, sudden and unexpected vessel movements due to sea conditions.

Injuries to the head can range from a minor bump to the more serious traumatic brain injury (TBI) and in extreme cases even death. Even the most acute injury from exposure to RS will not kill and so it can be recognised that TBI is a risk that must be mitigated.

An injury to the head either through a fall or blow and produces a TBI can lead to impairment of the individual expressed as:-

- cognition -- concentration, memory, judgment, and mood
- movement abilities -- strength, coordination, and balance
- sensation -- tactile sensation and special senses such as vision
- TBI sometimes results in seizure disorders (epilepsy).

About 1 percent of persons with severe TBI survive in a state of persisting unconsciousness.

It is noteworthy that the study undertaken by Carvalhas in October, 2004 (see page 18) had no reports for head injuries. The author can only conclude that this is due to the current operational requirement of all USCG HSC operators that protective head gear (helmets) must be worn while participating in rescue events.

The Australian Institute of Health and Welfare reports *"The most common causes of brain injury in cases with TBI as principal diagnosis were falls (42%), transportation (29%)"* [16] While there is no data reporting that any of these incidents were as a result of accidents in a water environment and indeed it could be safely assumed that the majority of the transportation

[16] Hospital separations due to traumatic brain injury,
Australia 2004–05. Yvonne Helps, Geo Henley and James Harrison

accident were as a result of traffic accidents, the statistics are still useful as an indicator of the prevalence for this type of injury.

The RNLI, SSR, RCMR and USCG all have varying levels of requirements for when a helmet must be worn, with the RNLI being the most stringent stating that they must be worn at “all times”. Interestingly the RNLI volunteers have no problems with this ruling and even embrace the wearing of helmets as part of their PPE. Indeed within our own jurisdiction (Victoria) land based ESOs such as the MFB, CFA and SES also have stringent requirements and standing orders surrounding the use of helmets, with little or no issues over the wearing of these items from either career staff or volunteers. This suggests a high level of safety awareness by these land based ESOs (both career and volunteers) that marine organizations could easily transpose to the marine environment.

With the wealth of data available concerning the effects of TBI and more importantly the reduction of incidents of TBI as a result of legislative mandates (the required wearing of helmets for road users such as motorcycles and bike riders) it is difficult to carry an argument subscribing to not using helmets in the marine environment.

Purely from a risk perspective, let alone a health and safety stand point; this is a subject that will require further investigation by all marine response organizations within Victoria.

14 Appendix 2 Self Righting Vessels

One of the most striking aspects of my tour was that ***all*** of the organizations that I visited will only employ vessels into their fleets that have the ability to self-right. That is, if the vessel becomes involved in a knock down event (which will find it either on its side or upside-down) it will either self-right to the correct upright position or have the ability of the crew to activate a self-righting system. Further, the engineering (propulsion system) will be able to survive such an event and have the ability to restart.

In Victoria the current ESOs have not had a recent historical event where they have lost a member due to drowning as a result of a rescue vessel foundering and as such the priority to have such a capability engineered into the current fleet has been low or no existent.

Overseas organizations however, do have historic precedents, of which there have been many, and in some cases have had this ability to self-right in their vessels going as far back as the 1940's. Such knowledge has been hard won, and the cost to the organizations in learning these lessons has been high, namely the loss of life of an emergency responder.

The type of sea conditions faced by marine responders within Victoria is no less dangerous than those faced by organizations overseas, and yet within the Victorian marine responder community, self-righting vessels are viewed as either a luxury item or "would be nice to have" rather than a (organizationally) mandated safety requirement.

Within Victoria there is only one organisation that currently mandates that its vessels have the ability to self-right and this is the Port Phillip Pilots Service (see figure 5 Page 21). This requirement is a direct result of the lessons learned from the loss of life when three crew members of a pilot boat over turned in the Port Phillip heads.

This is a subject that will require further investigation by all marine response organizations within Victoria.

Within the aviation industry the motivating factors for changes in safety is known as the "tombstone imperative", in that change will only occur after the loss of life, rather than bringing in change to prevent the loss of life before the fact. In Victoria inquires and reports into the loss of life of emergency responders almost always result in improvements to vehicles and equipment, with the most notable of these inquiries in recent times being the coronial inquest into the Linton bush fire where five volunteers from the Country Fire Authority lost their lives after their fire trucks engulfed in fire following a wind change. One of the enduring outcomes is that all Country Fire Authority tankers are now fitted with a crew protection system that is designed to preserve life should a truck be exposed to a burn over.

Organizationally, ESOs within Victoria need to take note of what is being done overseas, and take heed of local institutional knowledge gained at great cost to apply the appropriate levels of safety and protection of the States most valuable asset…its marine emergency service responders.