DEVELOPMENT OF A NEW CREW SEAT FOR ALL WEATHER LIFEBOATS

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SUMMARY

This paper describes the development of a new design of seat for all weather lifeboats, primarily intended to protect the occupant from the worst effect of extreme wave impacts. The development process began with the collection of lifeboat motions data, both through measurement of existing lifeboats and through computer simulation. Potential crew injury mechanisms were then incorporated and a generic seat suspension system was dynamically modelled to optimise shock absorption and comfort. An innovative seat design concept has now been developed to match these modelled characteristics and a prototype has been built. A series of instrumented experimental trials have been carried out on the prototype seat, initially on a hydraulic test platform under laboratory conditions and subsequently at sea. A production seat design is approaching completion. In addition to describing the design of a new seat, this paper highlights a validated methodology for producing seat suspension units that are optimised for their particular application.

NOMENCLATURE

FNC	Frazer-Nash Consultancy Limited
RNLI	Royal National Lifeboat Institution
VDV	Vibration Dose Value

1. INTRODUCTION

The Royal National Lifeboat Institution (RNLI) is a charitable organisation that exists to save lives at sea. This role necessitates that lifeboats have the capability to operate in occasionally extreme sea states. As the speed of new lifeboat designs increases it is vital that crew seating develops accordingly. Although the suspension seats currently used in 25-knot RNLI lifeboats are the most appropriate on the market, a number of areas have been identified where significant improvements could be made. This paper describes the development of a new crew seat for RNLI lifeboats. The new seat primarily aims to protect the crew from the worst effects of extreme boat motions, but will also provide a safe and stable base for the new integrated control systems under development by the RNLI. It is the design intention to bring the boat and controls to the crewmember, and not the converse. The RNLI has carried out the development of the new seat in collaboration with Frazer Nash Consultancy Ltd.

2. CREW INJURY MECHANISMS

A literature review was undertaken to investigate the effects of vertical vibration and shock on the human body. It was found that spinal injury, in particular lumbar spinal injury, is the major concern in all but the most extreme cases. A programme of bio-fidelic modelling of the human spine was undertaken to generate an understanding of injury mechanisms. Detailed computer models of boat motion, seat motion, and the motion of the human lumber spine were constructed and used to compare the amount and types of injury sustained for different seat designs, seat suspension settings and sea states. The research found that cumulative damage of the spine appears to be dominated by large peaks rather than prolonged exposure to low level accelerations, and that the most injury critical motion of a seated person was found to be in the vertical direction, along the axis of the spine. As such the key to reducing the possibility of injury appears to be to reduce the largest vertical acceleration peaks rather than eliminate the low magnitude accelerations [1].

3. A NEW SEAT DESIGN REQUIREMENT

The seat currently used on 25 knot all weather lifeboats is a variant of a seat primarily designed for use in 'quarry' vehicles. It can be appreciated that the motion inputs for this application are significantly different from those on a lifeboat. Even though this seat is the most appropriate currently available on the market and has been used on RNLI lifeboats for a number of years, it was recognised that an improved solution may be possible.

Although the current seat is comfortable in slight to moderate sea states, it has a tendency to occasionally strike the end-stops ("bottoming-out") in heavy seas. If the crewmember can see that a severe impact is imminent in large seas, he will raise himself out of the seat to isolate himself from the shock load. If the impact cannot be predicted, for example at night, the crewmember may be subjected to severe loading. Any shock load is then transmitted directly into the lower spine. As stated previously it is this type of shock load that has been identified as potentially the most damaging to the human body. In broad terms, it was specified that the new seat should retain the good comfort of the current seat in slight to medium sea states but more importantly it should minimise the transmission of severe shock loads into the crewmember. The main focus of the development of the new seat has been to reduce the frequency and severity of the bottoming-out shock loads.

In addition to designing for shock loading, the design of a new seat can provide an opportunity to address other issues that have arisen from having to use a seat not conceived for a harsh marine environment. For instance weight is often far more critical on high-speed boats than on land vehicles, and any new seat can be designed with this as a high priority. Through life costs can similarly be addressed by designing out areas of potential corrosion.

4. SEAT SYSTEM MODELLING AND OPTIMISATION

4.1 BOAT MOTIONS

An early step in the seat design process was to understand its loading environment. A variety of boat motions data for the new 25 knot 16 metre Tamar class lifeboat was generated using two methods:

- Instrumentation on board the Prototype Tamar lifeboat
- Simulation using HydroDyna [2]

4.2 VIBRATION DOSE VALUE

It was decided that the performance of any new seat would be best judged comparatively, either with the existing seat or with other suspension variants. It was determined that the most appropriate criteria available to compare performance is the Vibration Dose Value (VDV). Vibration Dose Value is an accepted and widely used measure of human exposure to whole body vibration, and is fully described in British and International Standards [3], [4]. VDV takes account of the time period for which the vibration is experienced, and the acceleration level experienced by the subject is weighted to account for the susceptibility of the body to various frequencies.

However, the VDV approach is derived from discomfort tolerances with fairly short exposure times and low magnitudes of acceleration. Its ability to predict injury in the case of this work should be challenged for two reasons: firstly, the relationship between discomfort and injury is unknown, and secondly the low frequency motion and repeated shocks encountered in lifeboats are completely different from the type of motion that has been used to validate the standards. As such although VDV is a useful comparative measure, the merits of any absolute VDV assessment of seat performance are questionable.

4.3 SEAT SYSTEM MODEL

A generic mass-spring-damper seat system model was built using GENDYN, which is a Frazer Nash dynamic spring modelling programme. This allowed key parameters to be easily modified to test various new suspension arrangements. The model, shown in Figure 1, consisted of a two degree-of-freedom system with a human representation [3] supported on a seat consisting of a mass and a spring-damper. The model included elements for the suspension mechanism and the cushion: the stiffness and damping characteristics of both could be changed. The human mass, stiffness and damping characteristics were taken from [5], in which the model has been validated against experimental data for input impedance.

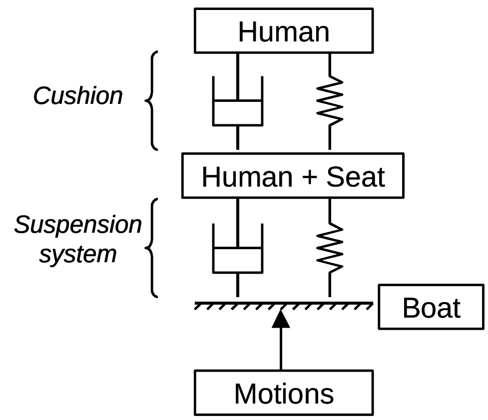

Figure 1: Generic seat suspension system model

4.4 CURRENT SEAT CHARACTERISTICS

In order to provide a baseline the generic seat suspension system model was initially run with the parameters of the current seat, which were measured experimentally. The current seat has a fairly constant spring stiffness of around 8 N/mm over a stroke of approximately 80mm. Beyond this stroke the seat effectively becomes rigid over a very small additional stroke. Damping was in the critical region. Sea states with regular 1.5m, 3m and 6m wave heights and speeds up to the 25 knot design speed were used as motion inputs. The results showed that the seat would exceed its 80mm stroke in a 3m sea state at speeds greater than 20knots, with bottoming out becoming likely beyond this point. Although this is beyond the recommended speed for such conditions, it is not an unfeasible scenario.

4.5 OPTIMISATION OF SEAT SUSPENSION SYSTEM PARAMETERS

A second seat model was generated, and various other stiffnesses and damping rates were tested to comparatively analyse seat behaviour under input accelerations representative of heavy seas. It was found that stiffnesses in between 24N/mm and 400N/mm should be avoided, as they would excite frequencies in the range of 4-6Hz, which are fundamental resonant frequencies of the human body. Although stiffness above

400 N/mm gave theoretically good VDV performance figures, the movement of the seat would be minimal (approximately 7mm total movement) and there would be little scope to isolate smaller motions in less severe sea states. The seat suspension system was thus developed around the lower spring stiffness range, proposing a nominal spring stiffness of around 17N/mm. The need for a spring with a progressive characteristic was found to be vital: rapidly increasing stiffness as the seat approaches its end of stroke is required to lessen the chance of a bottoming out incident occurring. Figure 2 shows the typical spring characteristic that was sought in the new seat design. Critical damping of these spring arrangements was used and was initially selected based on measured or manufacturers' information. It was proposed that damping would be subsequently modified to give a good match to measured seat performance.

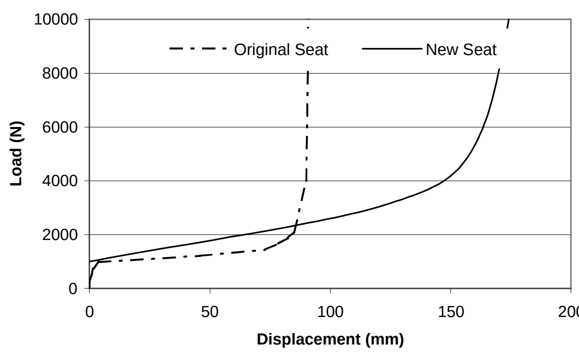

Figure 2: Typical spring characteristic

Having optimised the new seat's suspension characteristics, a number of slam events of varying magnitude were applied to both seats. The model of the current seat was observed to just bottom out for a 62m/s^2 slam and to severely bottom out for slams greater than this. The new design remained within its travel for all slam events, including 93m/s^2, which was the greatest event analysed. Relative levels of potential spinal damage were estimated for a 62m/s^2 slam and it was found that the damage predicted for the current seat model was 10 times greater than for the new seat model. Under higher acceleration input slams this difference would be expected to increase as the current seat bottoms out more severely. An example of the response of the seats is given in Figure 3.

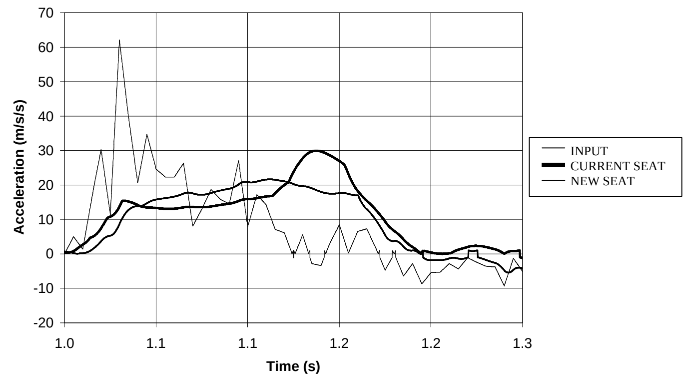

Figure 3: Response of seat models to a 62m/s^2 input

5. CONCEPT DESIGN

A brainstorm was carried out to develop a seat concept capable of supporting the suspension characteristics previously described. Concept development looked holistically at all issues associated with a new design such as adjustability, spring stroke, supporting structure and design flexibility for variant applications. On evaluating the matrix of potential solutions the concept shown in Figure 4 was developed.

The seat is mounted on a number of points (as opposed to the commonly used pedestal), to carry the required loads efficiently. The seat runs on two parallel bars and a single progressive spring/damper unit is mounted centrally. It was observed that vertical impacts experienced on a boat are often accompanied by forward decelerations, and it was postulated that a means to absorb some of this forward impact could enhance the shock absorbing potential of the seat. As such the seat travel has an angle of rake. The footrest remains independent of the seat's motion, allowing bracing to still be possible.

Incorporating an increase in the potential stroke of the seat was identified as being very important in the modelling work for absorbing the shock loads. Armrest mounted controls can allow a larger stoke to be included in the design, by reducing the requirement for the occupant to remain in permanent reach of fixed control systems.

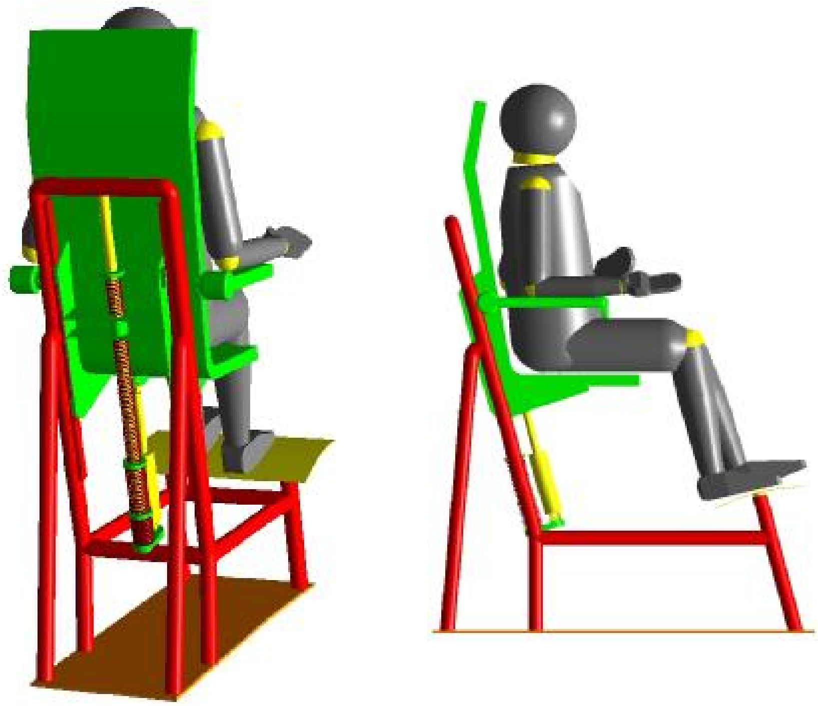

Figure 4: New seat concept design

6. PROTOTYPE SEAT

A prototype seat was developed to test the concept design and to validate the spring, damper and motion stroke suspension characteristics previously determined by analysis. The prototype seat is shown in Figure 5.

Figure 5: Prototype seat front and rear views

The prototype seat structure consisted of twin rails upon which four bearings ran, the seat support structure (attached to the bearings) upon which various seat buckets could be mounted, the base and the back frame. The base and back frame allowed the rake of the stroke to be changed through a series of holes and pins. The main running rails and back frame formed a wide load-bearing base. The seat belt mountings were also attached to the moving seat support structure, and the widest car seat bucket available was used.

The increasing stiffness characteristic was achieved by incorporating a set of springs arranged in series. By arranging a series of spacers in the spring stack and configuring these such that the set of springs are locked in turn from compressing further, the composite spring characteristic can be controlled. The spring elements ran up the back of the seat structure and were set on a threaded rod with nuts at each end. The nuts provided two functions by allowing both pre-compression to be put into the spring stack and the height of the seat to be adjusted independently of the seat structure. The test prototype was designed to allow for up to 180mm of stroke and incorporated a method of changing the rake of the main stroke in the range of 0–30°.

A separate system was incorporated on the underside of the seat for a damping element to be attached. Various dampers were acquired and the attachment system allowed simple interchange to be made between them. Adjustable rate dampers were specified that allowed the damping rate to be modified for both the 'bump' stroke (downwards) and the 'return' stroke (upwards). Dampers were chosen to allow damping ranges to be tested around, above and below critical damping for each spring arrangement.

7. PROTOTYPE SEAT TESTING

7.1 SHORE TRIALS

A series of comparative tests were conducted on both the prototype seat and the current seat. Shore based trials were carried out on the hydraulic test platform shown in Figure 6, in the Institute of Sound and Vibration Research at the University of Southampton. The seats were initially tested with lead shot weights and upon confirmation of safety and performance the seats were tested with human occupants. Tests on the motions platform were limited to a maximum displacement of 1m, maximum velocity of 1m/s and maximum acceleration of $10m/s^2$. As a result of this it was not possible to simulate a bottoming out event and therefore results could only be representative of slight to moderate sea states. Random sinusoidal motion of 1-5Hz and 1-10Hz and actual measured sea motion inputs were used in the tests. Tests were carried out with various damping rates and spring profiles.

It was found that the most comfortable seat spring and damper arrangement reported by the prototype seat occupants was 17N/mm stiffness with a relatively light damping setting (around half critical damping). The performance of the new seat in these slight conditions was broadly similar to the performance of the current seat. The performance of the new seat under the low test motion inputs could be improved by decreasing the damping rate further, but a compromise between comfort at low motion inputs and shock isolation at higher motions is inevitable.

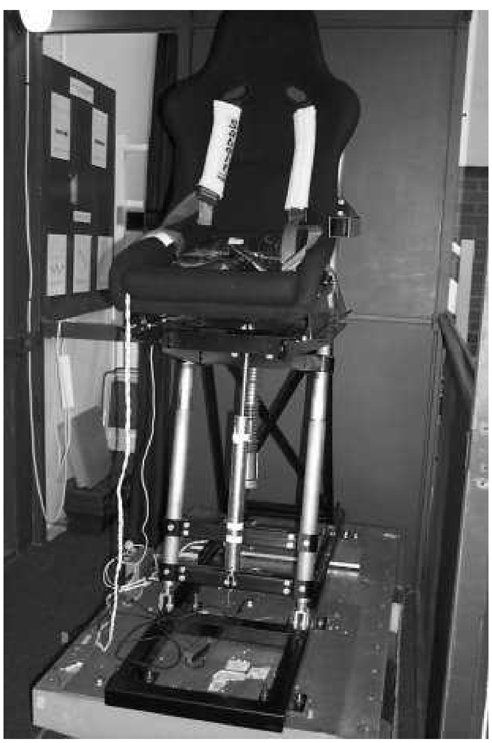

Figure 6: New seat undergoing hydraulic platform tests

7.2 SEA TRIALS

A set of sea trials was devised to test higher input motions. A formal safety assessment of both seat designs and proposed trials operations was carried out as an integral part of developing the sea trials plan. A 13m rigid inflatable boat was used to carry out both instrumented and subjective comparative trials on the two seats. An interface was built and fitted to the foredeck of the trials boat onto which the current and new prototype seats were mounted. A series of accelerometers were positioned on the boat and seats to measure vertical input to the boat and to occupants of both seats. Additional accelerometers were positioned between the suspension element and the seat cushion of each seat. The current seat had a more substantial seat cushion than the thin soft cushion on the bucket seat.

Trials were initially carried out with weighted mannequins occupying the seats as shown in Figure 7. Upon analysis of these initial tests and confirmation of the safety of the trials equipment, RNLI trials personnel were substituted for the mannequins. Tests were carried out into and away from the prevailing seas. Typically one-minute runs were made in each direction. A wave-buoy was deployed in the vicinity of the trials to log the sea conditions during the trial. Runs were made at increasing speeds from 15 knots to 35 knots. Measured wave heights were in the range of 0.8m to 1.5m. Typical impact events were measured with accelerations of between $20m/s^2$ and $70m/s^2$. The significant events were typically of 0.3 to 0.5 seconds duration.

Both seats gave a broadly similar response to the moderate events. However the new seat with its less substantial seat cushion gave less isolation of high frequency input. Nevertheless, both seats gave a good degree of isolation of high frequency input from the vessel. The current seat used the majority of its stroke in absorbing the more severe slam events, and the increased capability of the new seat was highlighted by displacement markings indicating significant stroke remaining to absorb more severe events.

Although not a primary area of study on the prototype seat the bucket seat was universally accepted as being very comfortable, giving a feeling of security when subjectively assessed by a series of occupants. The bucket included hip and shoulder support, as well as a moulded head support. The occupants varied in height and weight, and wore appropriate clothing and equipment. In contrast the current seat gave a feeling of insecurity, and trials personnel were far more reluctant to use it in extreme conditions. This appears to be a result of significant side-to-side movement: although the mountings remain fixed the seat moves up to +/- 100mm.

Figure 7: Weighted mannequin trials

8. PRODUCTION SEAT DEVELOPMENT

Having used the prototype seat to prove both the seat concept and the chosen suspension parameters, a production seat design in currently being developed. The development of the production seat is addressing the following issues:

Weight	The production seat is being designed to weigh 40kg or less. In order to achieve this, the bucket seat and its support structure is being designed using lightweight composite materials. Similarly the seat runners, base and back supports are to be a combination of composite materials and Aluminium.
Cost	The cost per production seat aims to be equivalent to the current seat.
Structural loading	The production seat is being designed to withstand the following static loadings: • Forward and aft, +/-10g • Side, +/-8g • Down, 10g • Up, 5g Proof loads are to be 1.5 times these figures, and ultimate loads 3 times greater.
Flexibility for alternative applications	In addition to being able to customise the suspension system, the seat can be mounted on any base structure to allow flexible interface with the boat.
Batch manufacture	The small number of parts requiring assembly, and the use of composite moulding techniques allow the seat to be easily manufactured in large numbers.
Through life costs	Maintainable parts are few, cheap, standard and easily replaced. The seat is not susceptible to corrosion, and upholstery is to be simple and easy to replace.
Ergonomics	The internal seat shape is based on a combination of positive features from existing bucket seats. An ergonomic mock up has been built and evaluated.

On completing the production seat design process, a single pre-production seat will be built and tested at sea. Following this a suite of production seats will be fitted to the pre-production Tamar class lifeboat for further in service operational assessment.

9. ERGONOMIC WHEELHOUSE DESIGN

It is vital that any seat is fully compatible with its operational environment and as such the new seat has not been designed in isolation. Although the seat design is flexible for a variety of marine applications it has been designed concurrently with the Tamar class lifeboat. The Tamar design and development process has involved an extensive amount of investigation into the ergonomics of operation. The design of the seat has been assessed as part of the ergonomic design of the boat, which has addressed issues such as console design, boat systems control and internal wheelhouse layout. An example of how this process has informed the design of the seat can be seen in Figure 8, which shows arm mounted controls that are to be fitted to the new seat: where possible the boat is being brought to the crewmember. The use of a full-scale wheelhouse mock up has assisted the ergonomic design process considerably.

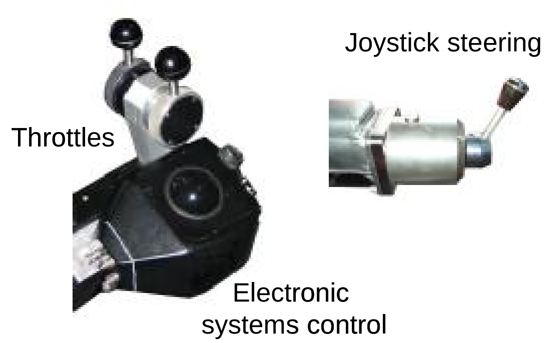

Figure 8: Arm mounted controls

10. TAILORED SEAT SUSPENSION SYSTEM METHODOLOGY

In addition to designing a new seat for the RNLI, this project has developed and validated a methodology for tailoring a suspension system to any particular application, marine or otherwise. Throughout the design of the new seat, flexibility for other applications has been a high priority. This is critical for the RNLI both in terms of fitting the seat to other classes of lifeboat, and also because there are further reaching commercial implications. This methodology is summarised in Figure 9.

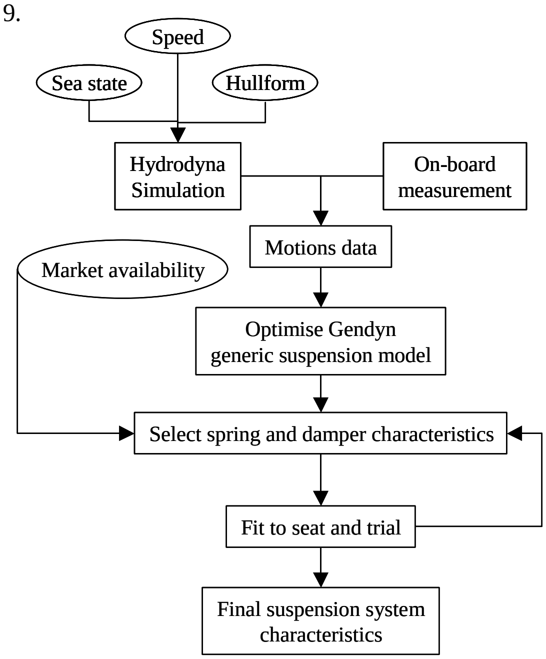

Figure 9: Tailored seat suspension system methodology

11. CONCLUSIONS

This paper describes the development of a new design of seat for high-speed rescue craft, intended to protect the occupant from the most extreme types of wave impacts. Possible injury mechanisms have been investigated, as were methods for their prevention. A generic seat suspension system has been dynamically modelled, and on applying motions data the sprung and damped characteristics of the generic system have been optimised. A new concept seat design has been developed and a prototype built and tested. Experimental and theoretical outputs have now been combined to develop a production seat that addresses requirements for crew safety, comfort and operational efficiency. The seat is being developed in parallel with the ergonomic design of a new all weather lifeboat wheelhouse, and in addition to providing a safe and comfortable workstation, the seat will fully integrate the crew with the operation of the boat. Finally this paper describes a validated methodology for the development of seat suspension systems that can be tailored to a particular application.

12. REFERENCES

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13. AUTHORS BIOGRAPHY

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David Richards is a Senior Consultant at Frazer-Nash Consultancy, with specific expertise in concept design and design development. Previous examples of his work include the design of a novel six degree of freedom motion platform for use in a wind tunnel, design and test of a friction brake device for a Mars space mission landing system and the design, development and support of large outdoor mobile and static video screens.