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3D anthropometry: Quantifying the shape and size variability within the UK male offshore oil and gas workforce.

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Abstract:

Background: UK male offshore workers typically increased in weight by 19% since 1985, and are also heavier than the background UK male population.

Aim: To conduct an anthropometric survey on UK offshore workers, employing the latest portable 3D scanning technology, to quantify size and shape change associated with weight increase and identify differing physique groups among the sample.

Method: 588 male offshore workers within seven pre-determined weight categories were scanned, using the Artec L portable 3D scanner, in three different postures; whilst wearing form-fitting clothing and while wearing a survival suit. 404 of the 588 participants also undertook a helicopter window escape task.

Results: The sample population had average weight of 90.5 kg, and matched the weight distribution of the workforce population as a whole (chi squared=11.7; 11df, P>0.05). Five extracted girths (neck, chest, waist, hip and wrist) were found be 13.5% greater than in 1985, with the highest average measurement 17.3% greater at the waist. The 99th percentile of extracted measures had increased more than twice that of the 1st percentile (18.3% v 8.9% increase respectively). The reliability of extracted measures was high with average TEM of 1.15%. 11 distinct physique clusters were identified, across four morphological somatotypes, displaying a tendency towards endomorphic and mesomorphic phenotypes and a predisposition towards obesity (average BMI=28.3 kg/m^2). 51% of the sample successfully passed through the smallest industry standard escape exit, with the best morphological prediction of window egress giving a predictive accuracy of 73.5%.

Conclusion: The dramatic increase in size and shape within the offshore workforce over the last 30 years represents an 'expanding universe' of physique and weight variability. The challenge this presents to designers is considerable in ensuring the on-going ergonomic fit of the industry's working environment for the offshore population.

Keywords: 3D scanning; offshore workers; morphology; ergonomics; anthropometric survey; obesity; 3D anthropometry; size and shape

Contents

Tables

Figures

1. Introduction:

A person's absolute or relative size governs his or her ergonomic fit within the built environment and informs the design and adjustability of infrastructure which aims to maximise the functionality of the workplace. Such size measures of individuals are typically based on an assumed size (e.g. the 95th percentile of male size) which optimises the proportion of the population which can be accommodated. However, due to the general increase in body size which has been widely observed within the western world (Cole, 2002) it is important that the infrastructure and equipment design evolves concomitantly with this size increase to maintain the comfort, productivity and safety of the workforce within their given workplace (Nadadur & Parkinson, 2013). As well as the observed increase in body size from the population as a whole, variability in body size characteristics has been recognised specific to industry employment in certain professional groups (Hsiao, Long and Snyder, 2002). Recruitment and employment regulations may require pre-requisites, such as; restricted heights or attainment of particular strength and fitness targets. Strenuous job-specific tasks may develop distinct muscle hypertrophy or postural alterations. Additionally being immersed in a work space or culture habitually for a length of time may have a significant effect on lifestyle choices such as diet and physical activity. A combination of these factors can lead to an observable body type within a given occupational group.

The absolute size of the adult population is increasing throughout the western world (Cole, 2002), however absolute and relative size do not conform to geometric similarity (Nevill et al., 2006), meaning bigger people are not simply 'scaled up' versions of smaller people, but rather display variability in proportions. This variability suggests that historic anthropometric data and data from other user populations cannot be augmented to describe the current size and shape of a given population. The use of such data could result in sub-optimal ergonomic design with unknown consequences for comfort and safety for individuals working in restricted space environments (Edwards & Jensen, 2014).

The offshore industry is one example where limited space and complex infrastructure prevail. The workforce is absorbed within a culture and restrictive work space, commonly on highly invasive, three weeks on/three weeks off, rotas.

The workforce was last assessed using manual measurement of surface anthropometry in the mid-1980s (Light and Dingwall, 1985). Review of this survey established that overweightness was already highly prevalent within the offshore workforce and that it exceeded that of the age-matched onshore population of the time (Light and Gibson, 1986). By 2010, Oil and Gas UK became aware that offshore workers were getting larger, and commissioned a report on “Big Persons”. This determined that the workforce’s weight had increased by 19% (Aker Solutions, 2010); however as no size data were collected in this initiative, the size increase associated with this remained unknown. Traditional anthropometry, as used in the original sizing survey (Light and Dingwall 1985), provides limited information regarding human body shape and can prove time consuming and costly in large population studies. The use of skinfold callipers and anthropometric tape for measurements made at sites around the body could also be deemed as intrusive. Furthermore, individual variability in shape and size irrespective of health markers deems measures such as body mass index (BMI) inadequate as a description of physique (Wells et al., 2007). Fortunately, the advances in 3D surface anthropometry available via scanning technologies mean that size surveys can take place more rapidly, with greater utility and less cost than conventional anthropometry. The present study is an example of the application of 3D surface anthropometry in a sizing survey of the offshore workforce.

2. Literature Review

2.1. 3D Scanners

A 3D scanner's function is to create a set of geometric data points within an x, y, z coordinate system, known as a point cloud, which represents the external surface of an object. All scanning systems involve a light source, light capturing cameras and dedicated software to process the data (Daanen and Harr, 2013). The two main types of scanner currently in use for human body measurement are laser scanners; such as the Hamamatsu C9036 (Hamamatsu Photonics, Japan) and structured white light scanners; such as the Artec L (Artec-Group, Luxembourg). In producing a 3D mannequin of an individual, post processing software allows for an almost limitless number of volumetric and linear measurements to be extracted in a non-invasive and rapid manner (Li et al., 2009; Bye et al., 2006).

The Hamamatsu scanner uses eye safe lasers (wavelength 690nm), captured by four fixed position high speed digital cameras, creating a surface scan consisting of 16 data points/cm^2 at a 3D resolution of 2.5mm. Each camera picks up reflected horizontal array beam laser light; generating data points located using triangulation algorithms. Processing software then links the points together to form a watertight polygon mesh. The density of the data points determines the resolution of the scan; a total body surface scan can comprise of up to 700,000 data points. Laser scanners such as the Hamamatsu have been commonly used for epidemiological studies due to their ease of use and speed of data acquisition (~10 seconds) in high resolution mode. However, the scanning unit is fixed in position making field work impossible, and clinical work expensive and time consuming, and is required to be situated in an ambient light-controlled environment. Furthermore, the wavelength of the laser precludes users wearing dark coloured clothes, which are not captured optimally.

Structured light scanners project a patterned grid of white light onto a 3D object, and the deformation of the pattern over the geometric surface is registered by the cameras and the distance and position of every geometric point in its field of view is processed. Early structured light scanners such as the TC^2 were fixed units, similar to that of the Hamamatsu, reported accuracies of ~3mm, although more recently portable units have become available with considerably enhanced accuracy. The Artec L portable scanner reports a 3D point cloud resolution of 1mm. The portable nature of the device also negates the issue of camera "grazing angles" where the light beam is tangential to the object surface, a common source of error within static devices which generally capture data only in the horizontal plane. The ability to capture 3D images with a portable device expands the capabilities of 3D scanning as an epidemiological measurement tool. The white light scanners are also much less affected by coloured and reflective surfaces compared to laser scanners.

Despite the advances in portable structured light scanning its use has previously been mostly limited to applications in film animation. Its lack of application in medical and ergonomic fields is perhaps due to its recency and the lack of validation studies. Therefore the need to validate the new technology against its more widely-accepted predecessors and develop a reliable methodological protocol for its use is vital in justifying its deployment in epidemiological studies.

2.2. **Validation Studies**

Recent advances in 3D scanning technology have seen its use in science and industry grow dramatically over the past decade; reductions in costs and increased functionality have driven its increase in popularity. Anthropometric surveys, health measures, documenting artefacts for posterity, accident site recording, ergonomics, clothing design and reverse engineering are just a few applications of 3D scanning (Istook and Hwang, 2001).

As with other measurement methods, for 3D scanning to be an accepted technique for epidemiological shape and size surveys, its validation against criterion methods is essential. Traditional manual anthropometric measurements, such as those developed by 'The International Society for the Advancement of Kinanthropometry' (ISAK) (Stewart et al., 2011), are assumed to be the optimum measure of circumferences, lengths and girths of the human body. Additionally underwater weighing (UWW) is recognised as a highly precise method for assessing total body volume. As 3D scanning conveniently gathers both linear and volumetric measurements in a single assessment, both anthropometry and UWW are acceptable criterion methods to assess its validity as a tool.

A study by Wang et al. (2006) drew comparisons of manual anthropometric techniques and UWW with 3D photonic data, collected using a Hamamatsu C9036 laser scanner, with the measures made on a life sized mannequin. Strong correlations between techniques were observed within all measurements (ICC >

0.98 for volumes; ICC > 0.99 for lengths and circumferences). However, 3D scans were found to significantly over-predict measures compared to the criterion methods, although the differences were proportionally small relative to their mean value, for instance +11.4mm for chest circumference (average chest circumference 897mm (1.27%)). The study also found similarly high levels of correlation between the techniques on human subjects (ICC >0.99) (44 females, 48 males) and was consistent with the Hamamatsu over predicting on all measures. The average overestimation bias, found within the 3D scanning technique for total body volume was +0.46L (+0.56%, p<0.001), while the bias for all circumference measures varied between 4.6-15.9mm.

Earlier studies comparing 3D linear dimensions to traditional anthropometry similarly found significantly greater circumference measures whilst using the 3D scanners (TC^2) over physical measurements (McKinnon and Istook. 2001) (Bias +32.3mm).

The lack of agreement between the techniques may be expected as linear 3D extraction and anthropometric tape measures are fundamentally different measures. It is argued by some that circumference measures using anthropometric tape held at tension produces compression at the skin surface (Wells, Ruto and Treleaven, 2008), something which is not present within 3D scanning. Although following current ISAK methodology, circumference measures require no indentation of the skin and therefore no compression (Stewart et al., 2011). This can be difficult to achieve in practice, with the result that anthropometry does compress a little and therefore underestimates true girth. As many studies have not divulged their anthropometric protocol, skin compression may be one reason for the overestimation reported in many circumference measures using 3D scanners. Furthermore, measurement location heavily influences agreement between methods. This is in large part due to automatic measurement extraction being unable to detect bony structures beneath the skin's surface and therefore having to make assumptions as to the location of skeletal anthropometric landmarks. Manual landmarking has been used in previous studies, showing improved agreement between 3D and traditional measurement extraction (Buxton et al., 2000). This however is in itself a very time consuming and invasive process and is still reliant on the landmarks being placed correctly and the capability of the 3D software to detect the landmarks. One study found that of 35 body dimensions identified by landmarks made by two different anthropometrists (one skilled and one novice), 15 measurements fell out with comparable criterion limits (Kouchi and Mochimaru, 2011).

Similarly, the principal differences between 3D scanning and UWW, along with assumptions associated with volumetric predictions, may underpin the lack of agreement between the two. Postural and breathing artefacts, and hirsutism causing a false surface beyond that of the epidermis, together with the processing software interpolating across gaps and shadows where data are missing are potential errors observed within 3D scanning (Carter and Stewart, 2012).

Work has also focused on the sources of error directly linked with 3D scanning methodology. Postural sway and movement during scanning is one such source of potential error as scans typically take 10-20 seconds to capture the whole body (Daanen et al., 1997). This group quantified postural sway using the Cyberware WB4 laser stripe scanner, a force plate and height sensor. A spring-loaded pointer attached to the subject's head was used to promote better stability and identify head movement. The unaided forward and backward postural sway was measured as 3.6mm and averaged only 0.7mm laterally, whilst wearing the positioning device reduced the forward/backward sway to 1.7mm. The positioning device was also found to entirely remove head rotation. Although its effect was not measured, Daanen's group also suggested subjects should be asked to hold their breath during the scanning process to reduce the breathing artefact.

However, this suggested practice is challenged by work from McKinnon and Istook (2002), which aimed to quantify the effect of respiration on abdominal circumference measures. In the study, 72 subjects were scanned whilst regulating their breathing in three different cycles; full expiration, full inspiration and while breathing normally. Normal breathing gave the least amount of variance between repeated scans, while maximal inspiration/expiration caused variance of up to 1.91cm in the chest circumference measurement.

One of the major issues highlighted with portable scanning is the time in which it takes to complete a whole surface scan (Istook and Hwang, 2001). Preliminary trials using the Artec L scanner have shown scanning times of 1-2 minutes (Ledingham, Nevill and Stewart, 2013). Greater scan duration provides more scope for movement and the potential for breathing artefact, however affords the possibility of creating a much denser mesh from which to extract dimensional data.

The less-invasive nature of the 3D scanner compared to that of underwater weighing (which requires participants to be highly water confident) and anthropometric measures (e.g. for those who have body image issues, (Stewart et al., 2012)), makes it a viable clinical tool for anthropometric and volumetric measurement extraction. Further work is needed to validate new portable body scanners against the fixed scanners currently in use and develop protocols limiting the previously identified sources of error.

2.3. Previous 3D Sizing Surveys

The use of 3D laser scanning in large scale anthropometric population surveys has become common practice with many national sizing surveys adopting the state-of-the-art technologies (Yu, 2004). The Civilian and European Surface Anthropometry Resource (CAESAR 2002) (Robinette et al., 2002) and SizeUK (2004) are contemporary examples of such sizing surveys. The CAESAR study collected and organised data on 2,000 North American and 2,000 European civilians between the ages of 18-65. Each subject was measured using either the Cyberware WB4 scanner (Cyberware, California) in the USA or the Vitronic scanner (Vitronic, Wiesbaden) in Europe; 40 traditional measurements were taken using anthropometry while 60 dimensions were extracted from the 3D scans of three different postures (standing erect with arms abducted 45^0; sitting with knees at 90^0 and arms above the head with the elbows at a 90^0 angle; sitting in comfortable working position). These three postural positions were designed to allow for total coverage of the body surface and present scans that not only allowed for dimensional extraction but represented natural postural positions. The SizeUK survey measured 11,000 members of the British public, extracting 140 measurements from each subject in a standing and seated position using the $[TC]^2$ scanner. The data from both studies were made commercially available, providing large industry and retailers with the opportunity to mine the data in order to tailor clothing and ergonomic design. In addition the data were available for use in health related surveys and studies.

While both studies were comprehensive in their approach and data collection, they remained very time consuming, costly and labour intensive. Both show the potential of 3D scanning as an epidemiological measurement tool, but further work is required to create an efficient tool that can be developed for smaller scale studies, where the sample of interest may differ from that of the host population.

2.4. Previous Anthropometric Surveys

Although the current population surveys (CAESAR and Size UK) are applicable to the general population, surveys on specific populations such as the military (Gordon et al., 2013) and earlier the offshore workforce (Light and Dingwall, 1985) have shown that different occupations attract individuals of atypical physique to that of the general population (Hsiao, Long and Snyder, 2002). Thus self-selection of individuals into professional groups may mandate specific surveys as required.

The most recent comparison of the offshore workforce and general population can be drawn between the 2004 SizeUK survey and the "Big Persons" report conducted on the UK offshore workforce in 2010 (Aker Solutions, 2010). The "Big persons" report collected weight data on 44,495 offshore workers while passing through heliports to offshore installations. The average weight of male offshore workers (90.9kg) was found to be on average 14.2% greater than that of the general male population (79.6kg (SizeUK)). The findings from the "Big Persons" report can also be compared to that of the original anthropometric survey of the offshore workforce when the average weight of workers was 76.6kg, representing a 19% increase in weight over the intervening 28 years. The explanation for this weight increase may well be multifactorial. Work-related tasks, abundance of food and the environment typical of the offshore sector may interact with a culture which attracts and engenders a different physique to that of the general population. In addition to this, the demographics (age, ethnicity, industry experience) of the sample have also contributed to the increased variability in physique over time.

Quantifying the physique difference between offshore workers and the host UK population is an essential prerequisite to determine space requirements and is therefore vital in order to ensure that the restricted space of the offshore working environment can accommodate such individuals. However, body shape and size profiling in itself is not necessarily sufficient. Work by Kozey et al. (2005) demonstrates the need for body size to be measured in clothing common to the workplace in question, as personal protective equipment increases an individual's space requirement and can be the limiting factor for certain movements. The ergonomic fit of the garment itself must also be considered, in order to facilitate common postures and movements related to the working task and environment.

Kozey et al. (2005) assessed the impact of wearing a survival suit has on an individual's minimal space requirement and the effect this has on lifeboat capacities. Subjects were measured whilst in normal work clothing and three leading survival suit brands. Breadth measures were made at the shoulders and the hips (seated and standing). Previous standards set by the International Marine Organization (IMO) stated the mean weight of offshore workers to be 74 kg and the linear space allowance (buttock width) to be 430 mm. By contrast, Kozey and colleagues reported, from a sample of 87 North American offshore workers, an average weight of 89kg and that the limiting linear dimension was the bi-deltoid breadth in all individuals (95^{th} percentile = 575 mm, work clothing condition). Once wearing a survival suit all dimensions were found to significantly increase in non-compressed (standard anthropometric technique) and compressed (pressure applied within the measure to simulate clothing deformation in "packed" conditions) measurement conditions. The mean shoulder breadths ranged from 515-604 mm uncompressed and 441-472 mm compressed, with the 95th percentile of shoulder width being 575 mm. This notable increase in minimal space requirement has been used to propose a change in the IMO Life Saving Code standards for minimum space requirements, reducing lifeboat capacities by ~33% in the USA. Kozey et al. (2005) also suggest that due to shape variability amongst individuals of similar weights an individual's weight cannot be used to determine lifeboat capacities, although average weight should be reconsidered as 89kg. Further research is needed in the other offshore sectors such as those in Europe and Asia where workforce shape and size, and survival suit design may differ.

Despite limited dimensional data collected, the study by Kozey et al. (2005) is the first indication that specific physique proportions have increased alongside weight in the offshore workforce. It is therefore vital not only to consider lifeboat capacities, but the entire ergonomic design of the offshore installation; corridor widths, accommodation quarters, muster stations and emergency escape hatches. A study by Allan and Ward (1986), conducted at the same time as the original UK offshore anthropometric survey, assessed whether the smallest escape hatch on the Super Puma helicopter (432mm–483mm) was large enough to pass through whilst wearing the required survival suit and re-breather of the time. It was concluded that persons up to the 95th percentile of bi-deltoid breadth would be able to pass through the window, as bi-deltoid breadth was considered the limiting anatomical dimension for successful window egress. A recent calculation from the "Big Persons" report has shown that the 95th percentile of the UK offshore population is now 23% heavier than its equivalent in 1986. From this it would be reasonable to expect, as seen in the Kozey et al. (2005) study, that the 95th percentile of bi-deltoid breadth would have also increased substantially. If there is indeed an increase in body dimensions concomitant with the identified weight change, then it would suggest that fewer individuals within the current workforce would fit through the same helicopter escape window, a window that is still in use in the current fleet of helicopters serving the UK continental shelf and other areas (Coleshaw, 2006).

2.5. The need for an up-to-date survey of the offshore workforce.

Knowing that the latest population surveys are not applicable to the offshore workforce and that the original offshore workforce surveys are now out of date, there is an urgent requirement for a follow up anthropometric size and shape survey.

Although determining the actual shape and size of the offshore workforce is an important industry objective, there would be little incentive for individual companies investing in this, which would be costly both in terms of finance and time commitments, to derive a product which would benefit the investor and its competitors equally. As a result the over-arching health and safety body of the offshore industry, Oil and Gas UK, took the initiative to represent the collective needs of the industry. Together with the UK government's Technology Strategy Board, it secured funding via a Knowledge Transfer Partnership for a study which aimed to quantify the size and shape of the offshore workforce, the results of which in turn could be used to assess the suitability of the infrastructure for the current workforce.

3. Research Aim and Objectives

3.1. **Aim:**

To quantify the size and shape of UK male offshore workforce using portable 3D scanning technology for a range of anatomical and ergonomic applications.

3.2. **Objectives:**

Pilot work:

Portable scanning protocol development:

- To calibrate and benchmark a portable 3D scanner against a static device.
- To develop and define an effective scanning procedure and protocol in the required postural positions.

Main work package:

Surveying the sample:

- To complete testing on a representative weight-stratified sample of the UK male offshore workforce.

Modelling the results

- To describe physique using volumetric and linear dimensions, characterising the variation in size and shape of the offshore workforce within specified weight categories.
- To identify and objectively describe groups within the sample displaying similar physique characteristics.
- To assess appropriateness of worker-selected survival suit in relation to measured size.

- To determine the morphological characteristics that best predict egress through an emergency escape window.

On-going capability

- To develop a modularised learning tool facilitating an on-going capability to undertake scanning surveys for a range of industrial applications.

3.3. **Hypotheses**

The study will test the following null hypotheses:-

i. That the increase in space requirement when wearing a survival suit is independent of body size.
ii. That workers select the optimal size of survival suit.
iii. That bi-deltoid breadth is the primary anatomical constraint for window escape.
iv. That physique variability is similar amongst all weight categories.

4. Methods

This study followed the outcome objectives of the Knowledge Transfer Partnership (KTP), following the workflow chart as shown in Appendix 1.

4.1. **Ethical issues**

All subjects were recruited following ethical approval granted by the Robert Gordon University Research ethics committee. All participants were obliged to read the participant information sheet, complete a screening form and provide consent (see Appendix 2, 3, 4) before taking part in the study. Individuals were unable to take part in the research if they met any of the following exclusion criteria:

- Suffer from epilepsy: The 3D scanner uses a strobing flash on the camera, therefore as a precautionary measure individuals who suffer from epilepsy, specifically photosensitive epilepsy, were not able to participate.
- Allergic to talcum powder: The survival suits were treated with talcum powder to increase the visibility in the static scanner, therefore anyone reporting an allergy to talcum powder was unable to participate.

4.2. Pilot work

The Artec L 3D scanner was chosen as the most appropriate tool for the survey after a rigorous selection process, with consideration of the team's skills and the technology available. The resolution, accuracy and usability of the device, as well as the functionality of its software made it stand out amongst the other 3D scanners on the market. A major selling point of the device was its large field of view (H x W = 1196 x 918 mm) compared to all other hand held scanners, allowing for fast scan acquisition of large objects, such as the human body. Quick acquisition time minimises the likelihood of movement within the scans. The portability of the device, however, was the most important factor. Due to the needs of the survey it was vital that measurements could be made at multiple industry locations and that set up time was minimised, therefore the handheld and portable nature of the Artec L was ideal.

An initial study compared the portable scanner (Artec L (Artec-Group, Luxembourg)) to an existing fixed scanner (Hamamatsu BLS 9036-02

(Hamamatsu Photonics, Japan)) presently used for anthropometric measurement extraction. Forty four healthy males were recruited from the university population, with no requirement for offshore employment. Volunteers were aged 31.2 ± 12.2y; BMI: 26.2 ± 4.4 $kg.m^{-2}$ (mean + SD) as determined by stature and mass in form fitting clothing. An appropriately sized survival suit was then provided, following the sizing guidelines specified by the manufacturer (1000 series Helicopter passenger survival suit (Survitec Group, Birkenhead, UK)).

The participants were scanned in duplicate using both the static and portable scanner while adopting three different postural positions and while wearing either form-fitting Lycra shorts, normal indoor clothing or the pre-determined survival suit over regular indoor clothing. The postural positions were defined as the "egress" position (Figure 4.2, arms held tightly against the torso and legs together, standing straight), the "scanner" position (Figure 4.3, arms and legs abducted) and the "seated" position (Figure 4.4, sitting on an anthropometric box (40 cm high) with knees together and hands clasped on lap). In total each participant underwent 24 scans within the one measurement appointment. The scan acquisition time was ~ 10s and ~60s for the static and portable scanners respectively. Due to the prolonged scan time for the portable scanner, participants were provided with four-point orthopaedic walking aides to stabilise the arms and minimise postural movement during the scanner position pose.

4.3. Main Work Package (Offshore Workforce)

4.3.1. Population and Sample

This study follows a quantitative cross-sectional design, measuring a total of 588 UK male offshore workers, stratified within pre-determined weight categories. The sample size of 588 provides the required power for representing the actual weight of the workforce with a 95% CI of 1.1 kg, a value which may be anticipated by diurnal fluctuations. To ensure that the sample represents the weight frequency distribution, established by the “Big Person” report (Aker Solutions, 2010), the sample was stratified into 7 weight category groupings; <76.4; 76.5 - 82.4; 82.5 - 87.4; 87.5 - 91.4; 91.5 - 97.4; 97.5 - 104.4; >104.5kg. The sample size exceeds that of Light and Dingwall (1985) whose study included 419 male subjects, and was used for direct comparison. A larger sample size accounts for the larger and more diverse offshore workforce currently in operation.

4.3.2. **Measurement location and recruitment**

Subjects were recruited and scanned within various industry locations, including; heliports, industry offices, occupational health centres, offshore installations and survival training providers. The locations were identified due to their high workforce footfall and the ease with which the volunteers could participate. Heliports proved to be the most convenient location for measurement due to the large centralised throughput of workers and abundance of waiting time when participants were freely available.

Recruitment was carried out using various media. Flyers (Appendix 5) and posters were distributed throughout measurement locations along with participant information sheets. Through engagement with various large oil and gas industry employer’s recruitment material was also disseminated by mail and company bulletins to thousands of UK based personnel. Owing to industry and public interest in the Size and Shape survey over £222,000 worth of media coverage was generated throughout the study helping raise its profile further.

During the recruitment and measurement process the study team and industry sponsors were eager to reiterate the purpose of the study as a means to improve safety offshore. Particular effort was made to reassure the workforce that the study outcomes would not affect their work requirements or employment rights.

4.3.3. **Protocol**

Each participant attended a single measurement session which took no longer than 20 minutes. All measurements were made in a private room. Due to the various measurement locations all rooms were required to have a minimum of 2 m x 2 m free space for scanning, an area for private changing and a 240 volts mains power supply.

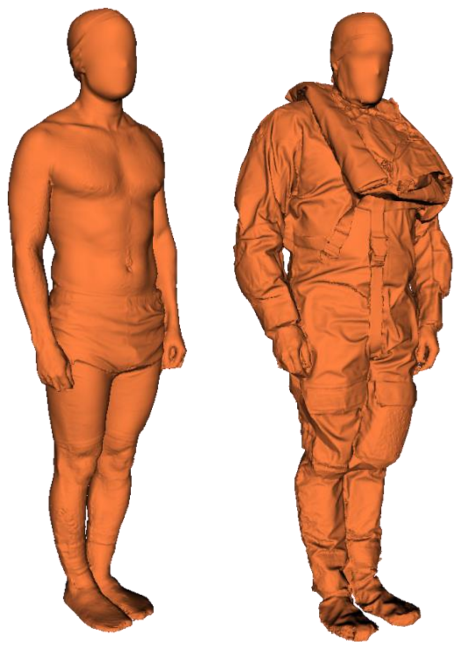
There were minor protocol amendments during the measurement acquisition phase which arose from dialogue with the Civil Aviation Authority (CAA) representatives following a fatal helicopter crash in August 2013. As a result, some individuals undertook slightly modified measurement sessions with extra measures. Below is the complete protocol with additional components highlighted along with the number of individuals that participated in each section. All amendments to the protocol were approved by the Robert Gordon University Research ethics committee.

All measurement sessions included four direct measures; stretch stature (with shoes removed)) and three body mass measurements under three different clothing conditions (wearing normal indoor clothing, survival suit and re-breather, form fitting clothing (all with shoes removed)). Each participant undertook between six and eight 3D scans using the Artec L portable 3D scanner, specifications provided in Appendix 6. The minimum number of six scans included three different postural positions while wearing form fitting clothing and then a survival suit ((1000 series Helicopter passenger survival suit (Survitec group, Birkenhead, UK)) plus re-breather lifejacket over normal indoor clothing) (Figure 4.1).

Figure 4.1. A study volunteer wearing the 1000 series survival suit and re-breather

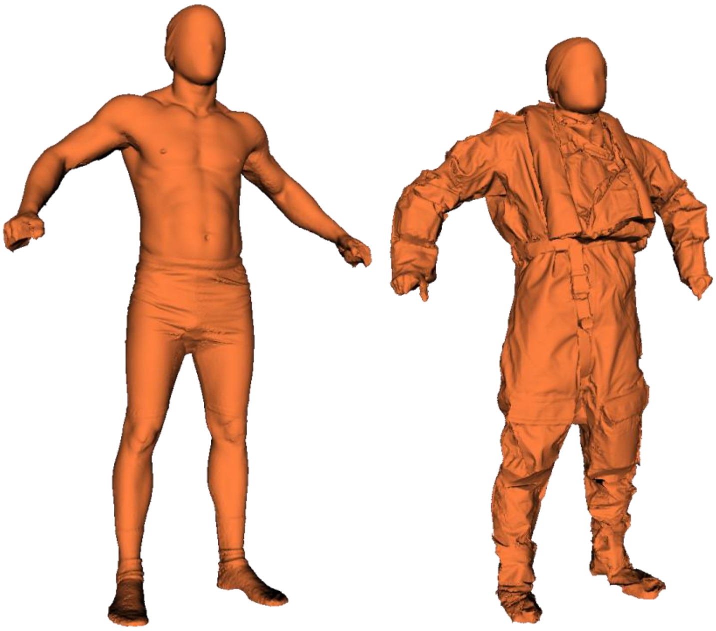
The three standard postural positions were as follows: standing (Figure 4.2, egress position) erect with feet together and arms against sides; standing (Figure 4.3, scanner position) straight with feet 30cm (shoulder width) apart, upper arms abducted to 45° and forearms perpendicular to the floor holding onto four point mobility aides to assist balance; sitting (Figure4.4, sitting position) on an anthropometric box (50cm tall) with feet and knees together, hands clasped on lap, back straight and facing directly forwards. The two supplementary 3D scans were added due to industry relevance and equipment development; the “window egress position” required the participant to stand with their right arm extended directly above their head with their left arm held tightly against the side while standing up straight in form clothing (Figure 4.5) (404 individuals) and a secondary “egress position” in survival suit while wearing the new Emergency Breathing System (EBS) (life jacket) over the survival suit (38 individuals).

An accompanying window egress task was performed by all participants, which involved passing five wooden window frames over themselves while wearing the survival suit and re-breather. The windows frames where accurate representations of in use helicopter underwater emergency escape windows. Due to industry significance an extra, smaller, window frame was added to the test, completed by 404 participants. The additional window was a suggestion arising from discussion with the CAA, and represents the smallest aperture anyone aboard a helicopter in the UK offshore area could conceivably attempt to exit through.



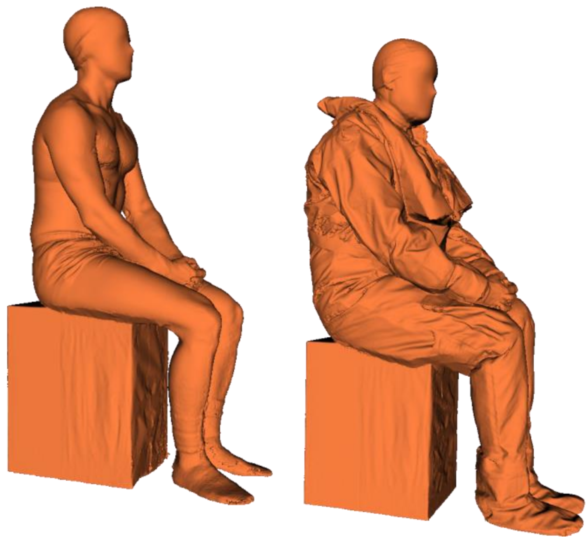
A. **B.**

Figure 4.2. Egress position (A. Form and B. Survival Suit)



A. **B.**

Figure 4.3. Scanner position (Form and Survival Suit)



A. **B.**

Figure 4.4. Sitting position (Form and Survival Suit)

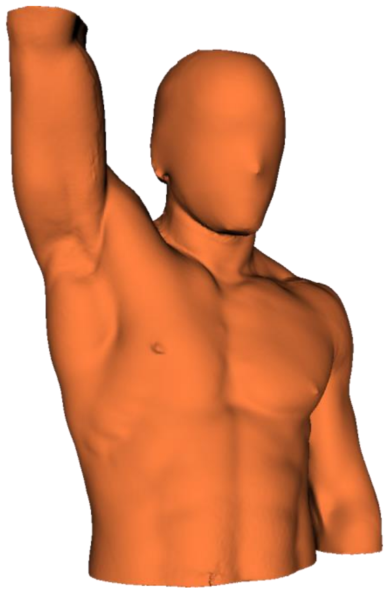


Figure 4.5. Window egress position (Form)

The sequence of the measurement protocol was as follows;

- Body mass measured wearing regular indoor clothing with footwear removed.
- Stature measured with footwear removed.
- Survival suit and re-breather worn over regular clothing. Correct survival suit size selected, based on prior selection or in accordance with the sizing proforma.
- Body mass measured wearing survival suit and re-breather.
- SCAN 1. Standing in a standard scanning position wearing survival suit (Figure 4.3, B)
- SCAN 2. Standing with arms by sides wearing survival suit and lap-jacket (Figure 4.2, B)
- SCAN 3. Sitting wearing survival suit (Figure 4.4, B)
- Additional Scan (New EBS system). Standing with arms by sides wearing survival suit with EBS system. (38 individuals)

- Egress task through 5 window frames of different apertures.
    - A. CAA PUSH OUT (483 X 432mm)
    - B. Super Puma Push Out (440 x 500mm)
    - C. JAR/FAR Type IV Min (660 x 483mm)
    - D. Super Puma Type IV (680 x 510mm)
    - E. Bell 412 (686 x 559mm)
- Additional Egress Task
    - Small Window S92 – (432 x 356mm) (404 individuals)
    - Egress task through 6 windows while wearing survival suit and EBS-jacket (38 individuals).
- Change into form-fitting clothing (lycra shorts)
- Body mass measured wearing form-fitting clothing.
- SCAN 4. Standing in a standard scanning position in form-fitting clothing (Figure 4.3, A).
- SCAN 5. Standing with arms by side in form-fitting clothing (Figure 4.2, A).
- SCAN 6. Sitting wearing form-fitting clothing (Figure 4.4, A).
- Additional Scan (Window egress position). Standing with right arm directly above head and left arm held tightly against the side (Figure 4.5)

4.4. **Measurement Extraction**

All measurements were extracted from the scans manually. As no physical landmarks were placed on the body prior to scanning all anatomical landmarks were identified visually and landmarked digitally using the Artec Studio 9 software package. Once landmarks had been placed on visually identifiable anatomical features cut planes were created allowing for dissection of the 3D scans. These planes ensured that all measurements made around a placed landmark were within the same x, y, z coordinates. From these, cut planes, linear, girth and volumetric measurements could be made. The planes also allowed for the identification of maximum and minimum widths and depths. The extracted measures were as follows; Shoulder girth, bi-deltoid breadth, height of deltoid, chest depth at deltoid, max chest depth, neck girth, chest depth at deltoid in survival suit, maximal depth in survival suit, maximal breadth in survival suit, chest breadth (axilla), chest girth (nipple), chest breadth (nipple), waist girth (minimum), waist girth (umbilicus), abdominal depth, hip girth, hip breadth, crotch height, wrist girth, total volume, abdominal volume, arm volume, leg volume, total volume in survival suit, hip breadth sitting, buttock to front of knee, deltoid to thorax, body mass in form clothing, body mass in normal clothing, body mass in survival suit and stature. For the measurement extraction protocols refer to Appendix 7. Where possible measurement extraction protocols followed that of the International Organization for Standardization methodology (BS EN ISO 20685: 2010)

4.5. Data Manipulation and Statistical Analysis

SPSS Statistics V21 (Inc, Chicago, IL) was the statistical package used.

Microsoft excel was used to structure and record data as well as produce tables and figures.

4.5.1. Pilot Study – Validation and Reliability Statistics (Volume extraction)

The %TEM (Percentage Technical Error of Measurement) statistic was used to assess the reliability of duplicate volumetric measures within each technique (defined in 4.5.2).

Bland and Altman analysis was used to analyse agreement between the two 3D scanners; identifying the bias and systematic error present within the data.

- Bias was defined as the mean difference between the two measures (Hamamatsu measurements minus the Artec L measurements), reported in litres (l).

4.5.2. **Main Work Package**

Measurement extraction reliability (volumetric and linear)

TEM (Technical Error of Measurement) and %TEM (Percentage Technical Error of Measurement) was used to assess the reliability of repeat volumetric and linear measures extracted from the same post-processed scan. The use of the TEM statistic is an accepted ISAK practice (Norton and Olds, 2000)

$$TEM = \sqrt{(\Sigma d^2/2n)}$$

$$\%TEM = 100(TEM/M_{overall})$$

Where d is the difference in replicated measures, and n is the number of paired measurements.

Characterisation of space requirements

Two methods in which to describe physique and space requirements have been used:

- The "Box" method
    - The minimum space required by an individual, drawn by their maximal height, anterior, posterior and lateral anatomical points; both in survival suit and form fitting clothing.

    - Comparison of space requirements whilst wearing the LAP jacket and the new EBS-system was made using maximal width and depth measurements.
- Volumetric analysis
    - Segmental volumes (legs, arms, torso) as a proportion of total body volume.

Cluster analysis and physique classification

- K-means cluster analysis has been used to identify a subset of representative physiques that best describe the common physique groups within the entire population.
    - Physique of caricatures assessed and characterised by an ISAK accredited photoscopic somatotype rater.
- Characterise the variation in size and shape of the offshore workforce within specified weight categories.

Survival clothing fit mismatch

Appropriateness of worker-selected survival suit has been identified through comparison of sizing chart guidelines and matching extracted body measurements.

Equipment adaptations

Difference in space requirements between wearing the LAP jacket and EBS jacket were assessed by extracted measurement dimensions.

Predicting emergency egress

Binary logistic regression analysis has been used to identify which measurement variables factor best predict an individual's ability to egress through a simulated helicopter window and to quantify predictive accuracy.

5. Results – Pilot Study

5.1. Reliability Statistics

Both scanners demonstrated good reliability with the Artec L scanner showing better precision with survival suit scans; whereas the Hamamatsu scanner was more reproducible with form-fitting scans.

Table 5.1. %TEM volumetric measures

Posture	Form fitting clothing		Survival Suit	
	Hamamatsu	Artec	Hamamatsu	Artec
Egress	0.79	1.28	1.54	1.03
Scanner	0.85	1.48	1.03	0.97

N = 38, Calculation based on replicate scans after repositioning

The average volumes extracted by each scanner, in differing postures and clothing conditions are indicated in Table 5.1, along with the measurement bias expressed as the difference between the Hamamatsu and Artec scanners. This shows the Artec scanner to be a reliable alternative, to be used in the main survey, compared to the Hamamatsu scanner.

Table 5.2. Mean and SD of body volumes (l)

	Hamamatsu	Artec	Bias	95% CI of difference	%CV	P
Form-fitting egress	86.9 ± 15.3	84.2 ± 14.2	-2.7	-3.497, -1.992	2.68	< 0.0001
Form-fitting scanner	87.6 ± 15.2	84.8 ± 14.4	-2.8	-3.533, -2.003	2.70	< 0.0001
Survival suit egress	142.7 ± 15.8	142.3.0 ± 15.0	+0.4	-1.269, 0.478	1.86	0.365
Survival suit scanner	144.3 ± 15.7	142.2 ± 15.5	-2.1	-3.151, -1.203	2.07	< 0.0001

n = 38; volumes in litres; paired t-test used for comparison

5.2. Volumetric analysis

Volumetric measures were made on 43 individuals while wearing form fitting clothing, indoor clothing and survival suit. The graph (Figure 5.1) below shows the step change in volume between form fitting clothing and survival suit and form fitting clothing and regular indoor clothing; +71.3% and +27.7% respectively.

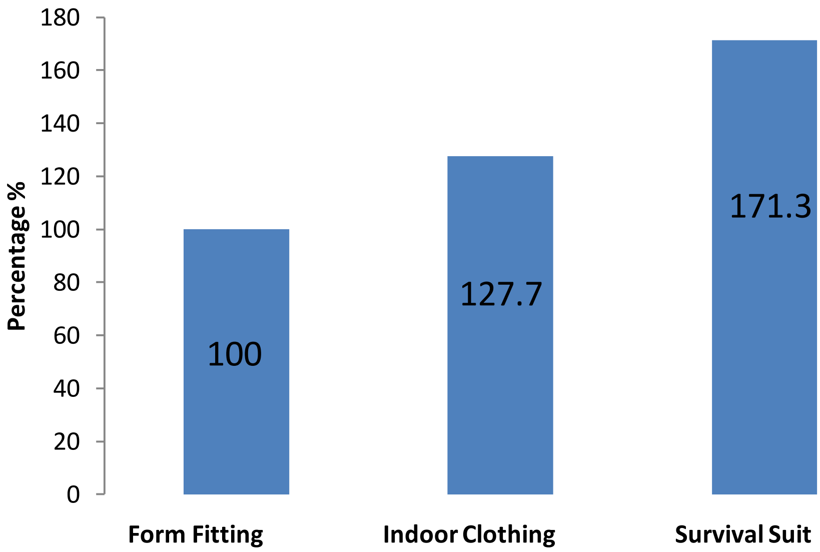


Figure 5.1. Volumetric effects of different clothing assemblages.

6. Results - Offshore Sample

6.1. Descriptive statistics

A total of 667 individuals took part in the study. An over sampling of individuals was an inevitable consequence of the protocol whereby participation was agreed prior to body weight being measured. This was a deliberate policy to compensate for participants being called for flights before all scans were complete and also, the possibility of incomplete scans due to unsatisfactory quality, usually due to movement. Furthermore, a substantial amount of scanning sessions while in heliports were cut short as participants were called away for flights resulting in incomplete data. Each of the seven weight categories required 84 individuals, resulting in a total sample population of 588. In categories where oversampling occurred participants with incomplete and/or poor quality scans were removed and 84 individuals were randomly selected from the remaining participants. Within groups five and six there was no oversampling however eight individuals within these two groups exhibited incomplete/unusable scans. These missing data accounted for 1.4% of the entire data set. In these cases regression analysis was used to generate the missing measurements. A comparison of using the data from those subjects from the weight category itself, or the entire sample revealed the latter to have a much smaller standard error of the estimate, hence the entire sample was used to generate imputed data. Weight category and total population descriptive statistics are detailed in Table 6.1.

Table 6.1. Participant Characteristics (Mean ± SD)

Weight Category	Age (y)	Weight Clothing (kg)	Weight Survival Suit (kg)	Weight Form (kg)	Stretch Stature (cm)	Body Mass Index (kg/m^2)	Years in Industry (y)
1. (84) <76.4kg	36.95 ± 11.18	72.21 ± 4.32	77.73 ± 4.31	70.88 ± 4.35	174.09 ± 6.03	23.45 ± 1.92	8.11 ± 8.29
2. (84) 76.5-82.4kg	40.46 ± 11.09	81.04 ± 1.92	86.63 ± 1.99	79.57 ± 1.73	175.44 ± 5.87	25.93 ± 1.76	10.11 ± 9.09
3. (84) 82.5-87.4kg	39.37 ± 10.28	85.92 ± 1.86	91.46 ± 1.93	84.64 ± 1.68	178.03 ± 6.12	26.80 ± 1.94	11.20 ± 9.29
4. (84) 87.5-91.4kg	39.73 ± 10.28	90.60 ± 1.74	96.31 ± 1.72	89.56 ± 1.09	180.37 ± 5.82	27.62 ± 1.86	11.19 ± 9.98
5. (84) 91.5-97.4kg	42.81 ± 10.98	95.31 ± 1.69	100.93 ± 1.74	94.07 ± 1.70	179.45 ± 5.72	29.30 ± 1.92	11.61 ± 11.04
6. (84) 97.5-104.4kg	43.76 ± 9.58	101.78 ± 2.41	107.48 ± 2.52	100.52 ± 2.24	180.53 ± 6.19	30.96 ± 2.32	12.49 ± 10.26
7. (84) >104.5kg	41.14 ± 10.18	115.26 ± 8.30	121.15 ± 8.28	114.13 ± 8.04	183.01 ± 7.39	34.24 ± 3.62	11.33 ± 9.66
Total (n = 588)	40.61 ± 10.68	91.73 ± 13.65	97.38 ± 13.76	90.48 ± 13.68	178.70 ± 6.79	28.33 ± 3.98	10.86 ± 9.72

Seven weight categories each containing 84 individuals, were identified, each with a unique range to ensure the sample population matched the weight demographic of the population as a whole. The seven weight categories were as follows; <76.4, 76.5 - 82.4, 82.5 - 87.4, 87.5 - 91.4, 91.5 - 97.4, 97.5 - 104.4, >104.5kg. The graph below shows the weight distribution of the sample population versus the offshore population obtained in 2009, the sample matching almost perfectly (chi squared value = 11.7; 11df, P > 0.05).

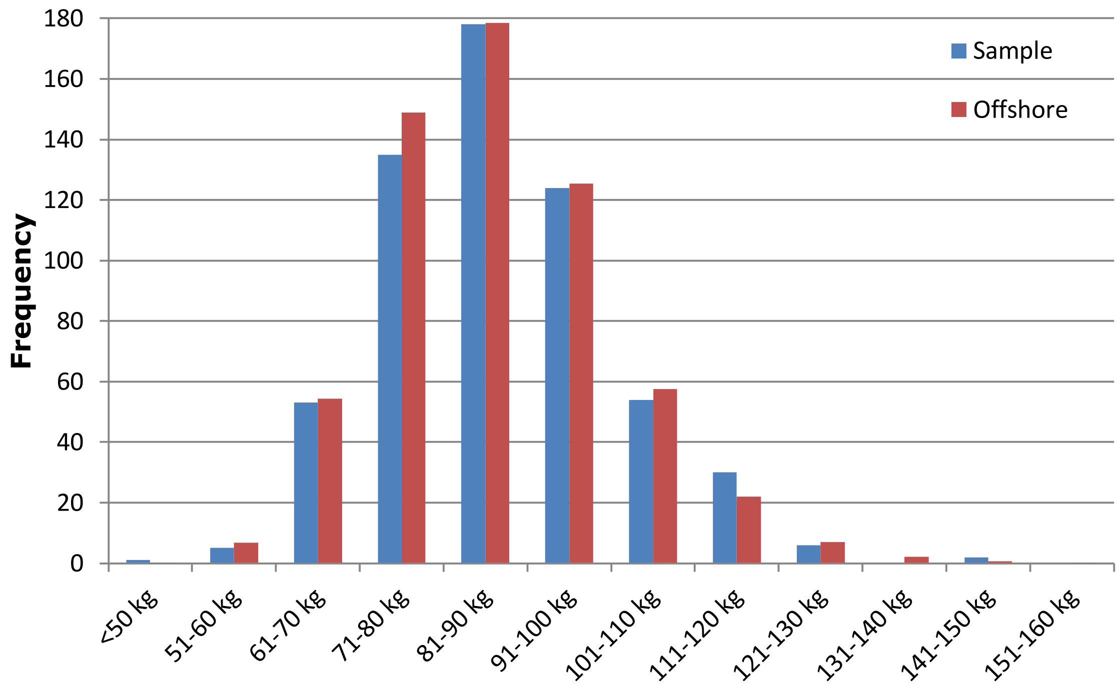


Figure 6.1. Sample population VS Offshore population (Weight Demographic)

Table 6.2, provides the average extracted measures from each weight category. All but adjacent weight categories were found to provide significantly different average measurements within all extracted measures.

Table 6.2. Descriptive statistics - Extracted Measures

	1	2	3	4	5	6	7	Total
	Mean (84)	Mean (84)	Mean (84)	Mean (84)	Mean (84)	Mean (84)	Mean (84)	**Mean (588)**
Shoulder girth (cm)	118.5	124.5	126.7	129.4	131.8	134.5	141.0	**129.5**
	4.8	5.7	4.2	5.2	4.8	5.5	6.9	**6.7**
Bideltoid (cm)	47.9	50.0	50.9	51.8	52.6	53.7	56.3	**51.9**
	1.7	1.8	1.5	1.7	1.5	1.6	2.5	**2.5**
Chest depth at deltoid (cm)	23.4	24.6	25.5	26.2	26.8	27.8	29.3	**26.2**
	1.6	1.5	1.7	1.6	1.5	2.1	2.2	**2.1**
Max chest depth (cm)	24.7	26.4	27.4	28.1	28.8	30.4	32.0	**28.3**
	1.7	1.4	1.8	1.6	1.8	1.8	2.1	**2.8**
Neck Girth (cm)	38.8	40.5	40.6	41.8	43.1	44.1	45.7	**42.1**
	1.6	1.8	2.1	2.1	1.9	2.4	2.7	**2.7**
Chest breadth axilla (cm)	36.5	38.2	38.9	39.5	39.9	41.0	42.7	**39.5**
	2.0	1.8	2.5	2.0	1.7	1.8	2.3	**2.5**
Chest Girth nipple (cm)	95.2	100.5	104.4	106.3	109.5	114.4	120.6	**107.3**
	4.9	4.1	4.2	4.3	4.1	4.5	6.2	**6.2**
Chest breadth nipple (cm)	33.1	34.7	35.8	36.5	37.4	38.9	41.0	**36.8**
	1.7	1.5	1.3	1.6	1.5	1.7	2.7	**6.3**
Waist girth minimum (cm)	84.7	91.5	93.4	96.2	100.8	105.6	112.8	**97.9**
	6.2	5.4	6.3	5.2	6.1	5.6	7.9	**7.9**
Waist girth umbilicus (cm)	88.9	95.5	98.1	101.1	104.9	110.6	119.0	**102.6**
	7.1	5.2	6.4	5.1	5.8	5.2	8.6	**8.6**
Abdominal depth (cm)	23.0	24.9	25.7	26.5	28.0	30.0	32.8	**27.3**
	2.6	2.1	2.5	2.0	2.4	2.4	3.3	**3.3**
Hip girth (cm)	97.1	100.2	103.0	105.4	107.5	110.4	116.9	**105.8**
	3.2	2.1	2.7	2.9	2.8	2.9	6.0	**6.0**
Hip breadth (cm)	35.1	36.0	37.0	37.6	38.1	39.1	40.8	**37.7**
	1.1	1.1	1.2	1.3	1.2	1.4	1.9	**1.9**
Wrist girth (cm)	17.5	18.1	18.6	18.7	19.1	19.6	20.0	**18.8**
	0.9	1.0	1.3	1.1	1.3	1.2	1.4	**1.4**
Hip breadth sitting (cm)	36.4	37.8	39.0	40.1	40.6	41.5	43.8	**39.9**
	1.4	1.3	1.6	1.6	1.3	1.7	2.6	**2.6**
Buttock to front knee (cm)	59.9	60.6	62.0	62.7	62.6	63.6	65.2	**62.4**
	2.1	2.2	2.2	2.2	1.9	2.4	2.6	**2.6**
Deltoid to thorax (cm)	42.0	43.8	44.6	45.1	46.1	46.7	49.1	**45.5**
	1.7	1.4	1.3	1.4	1.2	1.5	1.9	**1.9**
Total volume (l)	72.6	80.5	85.2	90.5	94.8	101.5	115.5	**91.5**
	4.7	2.7	3.0	2.7	2.2	3.1	8.7	**8.7**
Abdominal volume (l)	38.7	44.2	46.4	49.5	52.9	58.0	67.4	**51.0**
	3.5	2.5	3.4	3.1	3.1	3.5	7.4	**7.4**
Arm volume (l)	3.4	3.8	4.0	4.2	4.3	4.5	5.0	**4.2**
	0.3	0.3	0.3	0.4	0.4	0.4	0.5	**0.5**
Leg volume (l)	10.4	11.2	12.1	12.8	13.2	13.6	15.1	**12.6**
	1.1	1.1	1.3	1.2	1.2	1.4	2.1	**2.02**
Total volume SS (l)	123.6	132.1	136.7	141.9	145.7	153.6	164.8	**142.68**
	7.1	6.6	6.6	6.9	7.7	5.8	8.2	**.27**

In all cases measures differed significantly between weight categories other than between directly adjacent weight categories. All values shown with standard deviation.

6.2. Centile charts – Extracted measures

Centile charts have been created for all measurements and are contained within a publication that will be made commercially available to the industry. Examples of the centile chart outputs can be found in Appendix 8.

6.3. Population size and shape change (Current Sample vs. 1985 Light and Gibson Sample)

Neck girth, chest girth, waist girth, hip girth and wrist girth were the five extracted measurements which allow for direct comparison between the current study and the Light and Dingwall (1985) study (Table 6.3). An average measurement difference of 13.5% can be seen across the population, with the greatest average difference of 17.3% at the waist. Not only has the population as a whole increased in size across all matching extracted measurements but the 99th percentile has increased more than twice that of the 1st percentile; 18.3% increase and 9.0% increase respectively. The observed sample average weight of 18.3% is slightly lower than the weight increase of 19%, as expected from the "Big Persons" report (Aker Solutions, 2010). Thus the dimensional differences observed within the current sample may slightly under predict the actual dimensional measurements in the population as a whole.

Table 6.3. Extracted measurement increase (Current Sample vs. Light and Dingwall, 1985)

	Percentile									
	1	**5**	**10**	**25**	**50**	**75**	**90**	**95**	**99**	**Average Percentage Measurement Increase (%)**
Neck Girth (cm)	9.4	10.2	10.2	12.6	14.3	15.1	16.3	18.2	19.8	14.0
Chest Girth at nipple (cm)	9.0	10.2	11.1	11.6	13.3	14.1	14.7	15.8	15.8	12.8
Waist girth minimum (cm)	10.3	13.9	16.1	17.2	18.6	19.3	19.4	21.3	19.9	17.3
Hip girth (cm)	10.5	11.2	10.5	9.6	11.0	11.6	13.3	13.6	15.9	11.9
Wrist girth (cm)	5.6	5.8	7.7	8.5	10.9	12.9	15.9	14.7	20.2	11.4
Average Percentage Measurement Increase (%)	**9.0**	**10.3**	**11.1**	**11.9**	**13.6**	**14.6**	**15.9**	**16.7**	**18.3**	**13.5**

Table 6.4. Height and weight increase (Current Sample vs. Light and Dingwall, 1985)

	Percentile									
	1	**5**	**10**	**25**	**50**	**75**	**90**	**95**	**99**	**Average Percentage Measurement Increase (%)**
Weight (kg)	13.9	13.7	14.6	17.3	17.7	19.1	22.9	24.4	20.7	18.3
Height (cm)	2.2	2.3	1.9	2.3	1.9	1.8	2.2	1.8	2.0	2.0

6.4. Reliability Statistics (extracted measures)

Duplicate measurements were made on 28 randomly selected individuals within the final 588 population, 4 from each of the seven weight categories. Table 6.5 shows TEM and %TEM statistics for all extracted measurements while wearing both form fitting clothing and a survival suit. Table 6.6 shows the %TEM for the different measurement types.

Table 6.5. TEM and %TEM for extracted measurements.

Postural Position	Extracted Measurement	Technical Error of Measurement (TEM)	% Technical Error of Measurement (%TEM)
Form Egress	Shoulder girth	1.16	0.89
	Bi-deltoid	0.37	0.70
	Height of deltoid	0.92	0.68
	Chest depth at deltoid	0.33	1.28
	Max chest depth	0.37	1.30
	Neck girth	0.33	0.78
Form Scanner	Chest breadth(axilla)	0.45	1.15
	Chest girth(nipple)	0.50	0.47
	Chest breadth(nipple)	0.22	0.59
	Waist girth (minimum)	0.59	0.60
	Waist girth (umbilicus)	0.39	0.39
	Abdominal depth	0.26	0.96
	Hip girth	0.38	0.36
	Hip breadth	0.27	0.72
	Crotch height	1.28	1.28
	Wrist girth	2.50	2.50
	Total volume	1.21	1.21
	Abdominal volume	2.17	2.17
	Arm volume	2.88	2.88
	Leg volume	3.47	3.47
Form Sitting	Hip breadth sitting	0.52	0.52
	Buttock to front of knee	0.92	0.92
Arm Raised	Deltoid to thorax	0.62	0.62
	Average Form	**0.96**	**1.15**
Survival Suit Egress	Chest depth at deltoid SS	0.90	2.30
	Maximal depth SS	0.66	1.42
	Maximal breadth SS	0.64	0.93
Survival Suit Scanner	Total volume SS	0.03	0.03
	Average Survival Suit	**0.56**	**1.17**
Total Average		**0.90**	**1.15**

Table 6.6. Measurement type %TEM

	% Technical Error of Measurement (%TEM)
Girths	**0.65**
Lengths	**1.03**
Lengths Survival Suit	1.55
Lengths Form	0.86
Heights	**0.98**
Volumes	**0.96**
Volume Form	0.00
Volume Survival Suit	0.03
Segmental Volumes Form	2.84

6.5. Space requirements and physique characterisation

The space requirement of individuals has been defined as their maximal extracted depth and width described as a two dimensional box (Ledingham and Stewart, 2013). A considerable increase in space requirement as a result of wearing a survival suit is shown in Table 6.7. The space requirement increase associated with wearing a survival suit can be seen to have a diminishing effect in larger/heavier individuals.

Table 6.7. Space requirement (Box method)

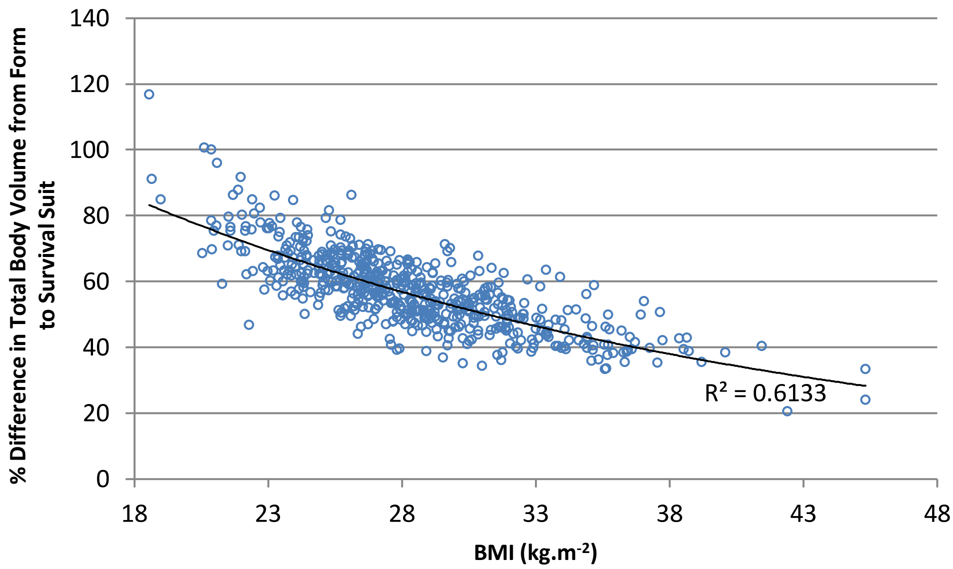
Weight Category (84/category)	Space Requirement Form (cm^2)	Space Requirement Survival Suit (cm^2)	Difference (cm^2)	Percentage Difference (%)
1	1184.7	2883.6	1698.9	143.4
2	1320.2	3045.3	1725.1	130.7
3	1395.5	3126.0	1730.5	124.0
4	1455.3	3170.8	1715.5	117.9
5	1514.8	3275.1	1760.3	116.2
6	1631.2	3358.1	1726.9	105.9
7	1806.1	3531.2	1725.1	95.5
Total (588)	**1472.5**	**3198.6**	**1726.0**	**119.1**

Total body volume and the effect of wearing a survival suit on total volume can be seen in Table 6.8. As with space requirements it can be seen that wearing a survival suit adds proportionally more volume to lighter/smaller individuals than larger heavier individuals, despite the suits being size specific.

Table 6.8. Total body volume (clothing effect)

Weight Category (588/category)	Total Volume Survival Suit (l)	Total Volume Form (l)	Volume Difference (l)	% Volume Difference
1	123.6	72.6	51.0	70.7
2	132.1	80.5	51.6	64.2
3	136.7	85.2	51.5	60.5
4	141.9	90.5	51.5	56.9
5	145.7	94.8	50.9	53.8
6	153.6	101.5	52.1	51.4
7	164.8	115.5	49.3	43.0
Total (588)	**142.6**	**91.5**	**51.1**	**57.2**

The relationship between BMI and increases in total body volume as a result of wearing a survival are shown below, Figure 6.2. The graph shows that larger individuals increase in size proportionately less than their smaller counterparts as a result of wearing a survival suit.



Sample size: 588, y = 175.9e$^{-0.04x}$.

Figure 6.2. Effect of BMI on total body volume increases

6.6. **Cluster analysis**

A total of 11 clusters were generated using k-means cluster analysis of 19 extracted variables, calculated using z-scores. Z-scores were used to normalise the data, expressing the group's differences above or below the population average as standard deviations. The z-score averages within each cluster are shown in Table 6.9 and selected z-scores are displayed graphically in Figures 6.3 and 6.4. The 11 clusters were decided upon firstly through hierarchical cluster analysis, used on an exploratory basis. The resulting dendrograms established using factoring variables providing 11 well populated clusters. Secondly, due to there being 11 standard survival suit sizes in regular use for the entire workforce, it was deemed sensible to create clusters which would allow for a similar sizing scheme to be developed around their identified shapes. Centroids were identified from each group by selecting the individual with the smallest Euclidean distance from the cluster mean for all measured variables. Cluster centroids were somatotyped through visual inspection of the individuals 3d scans by a qualified ISAK photoscopic somatotype rater. The somatotypes according to the cluster centroids are displayed in Table 6.10 and the cluster phenotypes are depicted in Figure 6.6.

Cluster 1 (10.7% of population) comprises relatively slender and linear individuals compared to their weight-matched colleagues, described as ectomorphic-mesomorphs. Their average BMI is the lowest of all clusters and falls within a healthy range, with all z-score statistics (apart from % segmental volumes) falling well below the offshore sample average. Above average percentage limb volumes suggests less of their mass is centrally located and is more uniformly distributed. They are also the youngest group within the population.

Clusters 2, 4 and 7 (37.1% of population) include individuals displaying equal muscularity and adiposity; described as mesomorph-endomorphs. The average weight of these groups is the closest of any to that of the entire sample.

Clusters 3, 5, 6 and 9 (41.5% of population) represent a morphology of muscularity while displaying a certain level of adiposity; described as endomorphic mesomorphs. They exhibit comparatively lower abdominal girths at the waist and chest measurement sites which suggest less centralised fat distribution than their weight matched counterparts. On visual inspection the proportions of abdominal and thoracic volumes appear similar, representative of a uniform muscle to fat deposition (Carter and Heath, 1990).

Clusters 8, 10 and 11 (10.7% of population) are examples of mesomorphic endomorphs. They are by far the heaviest group within the sample and are classed as obese, exhibiting an average BMI level of 37.6kg/m^2. Volumetric measures suggest that the vast majority of weight is centrally located with below average limb volume to total body volume percentages, while torso to total body volume is well above average; represented by an average z-score of 1.5. They all express well above average z-scores for all torso girths and depths, with a greater proportion of torso volume located abdominally. All three centroids fall well out with the original somatochart limits, as originally designed by Sheldon and colleagues (Sheldon et al., 1940), suggesting that they represent an extreme phenotype.

All clusters, with the exception of cluster 1, appear to group towards the mesomorph-endomorph axis of the somatochart. This may partly related to the skewedness of the weight demographic towards the heavier end of the spectrum and suggests that it is largely attributed to greater adiposity within the workforce, especially evident within the mesomorphic endomorph group.

Table 6.9. Descriptive statistics - Z-scores across assigned clusters

	Final Cluster Centres										
Z-score	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Bideltoid	-1.3	-1.0	-0.2	-0.3	0.3	0.2	0.9	0.8	2.5	1.9	2.6
Shoulder girth	-1.3	-1.0	-0.2	-0.3	0.4	0.2	0.8	0.9	2.6	1.7	2.3
Chest depth at deltoid	-1.4	-0.7	-0.4	-0.3	0.4	0.2	0.6	1.1	2.2	1.8	1.9
Max chest depth	-1.5	-0.6	-0.6	-0.1	0.5	0.1	0.8	1.3	1.7	1.8	2.4
Neck girth	-1.2	-0.6	-0.7	0.0	0.4	-0.1	0.6	1.5	1.2	1.7	1.9
Chest breadth axilla	-1.3	-0.6	-0.4	-0.1	0.4	-0.1	0.7	0.9	2.0	1.6	3.0
Chest girth nipple	-1.6	-0.7	-0.7	-0.1	0.5	0.1	0.8	1.4	2.0	1.9	2.7
Chest breadth nipple	-1.4	-0.7	-0.5	-0.2	0.3	0.1	0.8	1.2	2.1	2.0	2.8
Waist girth minimum	-1.5	-0.4	-0.8	0.0	0.5	-0.2	0.8	1.6	1.3	1.9	2.8
Waist girth umbilicus	-1.5	-0.5	-0.8	0.0	0.4	-0.1	0.8	1.5	1.1	2.0	3.2
Abdominal depth	-1.4	-0.3	-0.9	0.0	0.4	-0.2	0.7	1.7	1.1	1.8	2.9
Hip girth	-1.3	-1.0	-0.5	-0.1	0.0	0.4	1.0	1.0	0.8	2.0	4.1
Hip breadth	-1.2	-1.0	-0.4	0.0	-0.1	0.4	1.1	0.7	0.5	1.6	3.9
Wrist girth	-0.8	-0.8	-0.3	0.1	-0.1	0.1	0.8	0.8	0.5	1.2	1.5
Hip breadth sitting	-1.2	-0.9	-0.4	0.0	0.0	0.4	1.1	0.6	0.1	1.7	3.9
Buttock to knee	-0.7	-1.1	0.0	-0.2	-0.4	1.0	0.8	0.0	0.3	1.1	2.0
Abdominal of total volume	-1.1	0.3	-0.8	-0.1	0.8	-0.7	0.2	1.6	0.8	1.5	1.3
Arm of total volume	0.7	-0.5	0.9	-0.1	-0.3	0.4	-0.3	-1.2	0.3	-0.9	-1.6
Leg of total volume	0.8	-0.4	0.8	-0.1	-0.8	0.8	-0.1	-1.4	-0.5	-1.1	0.1
Average Z-score	**-1.1**	**-0.7**	**-0.4**	**-0.1**	**0.2**	**0.2**	**0.7**	**0.8**	**1.2**	**1.4**	**2.3**
Average weight (kg)	**71.6**	**76.5**	**83.5**	**88.4**	**92.6**	**94.6**	**104.6**	**104.8**	**112.8**	**118.5**	**138.3**
Average Height (cm)	**176.4**	**171.8**	**180.4**	**178.1**	**176.4**	**185.0**	**182.8**	**175.8**	**181.0**	**180.4**	**181.0**
Average BMI	**23.1**	**26.0**	**25.7**	**27.9**	**29.8**	**27.7**	**31.4**	**34.0**	**34.4**	**36.5**	**42.4**
Number	**63**	**69**	**96**	**74**	**74**	**66**	**76**	**39**	**7**	**20**	**4**

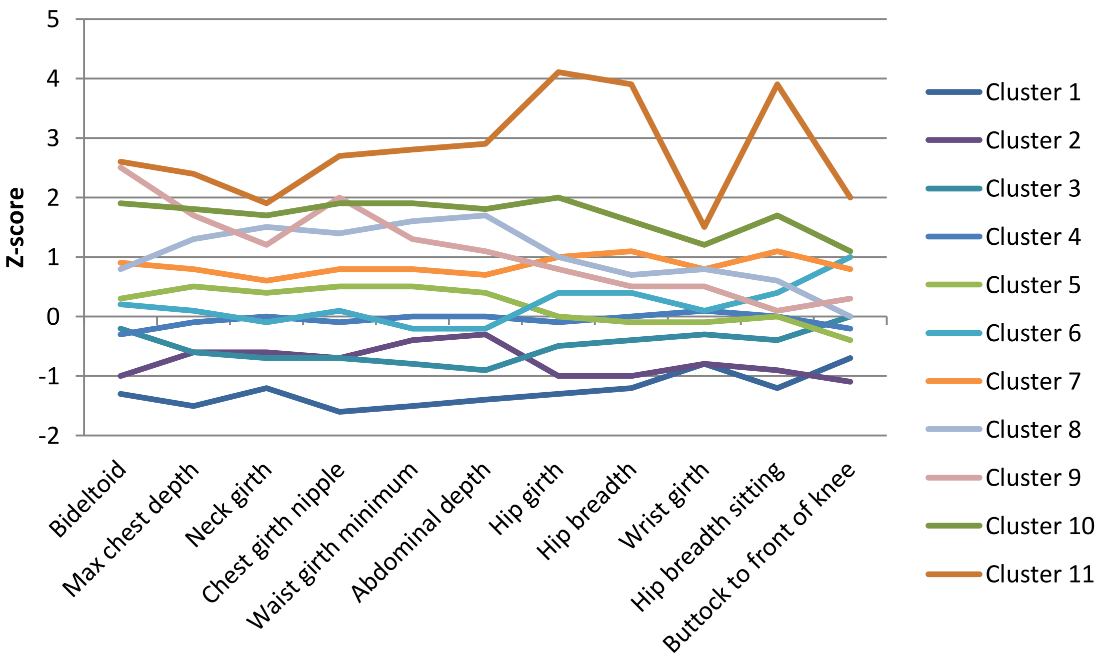


Figure 6.3. Z-scores - Selected extracted linear measures

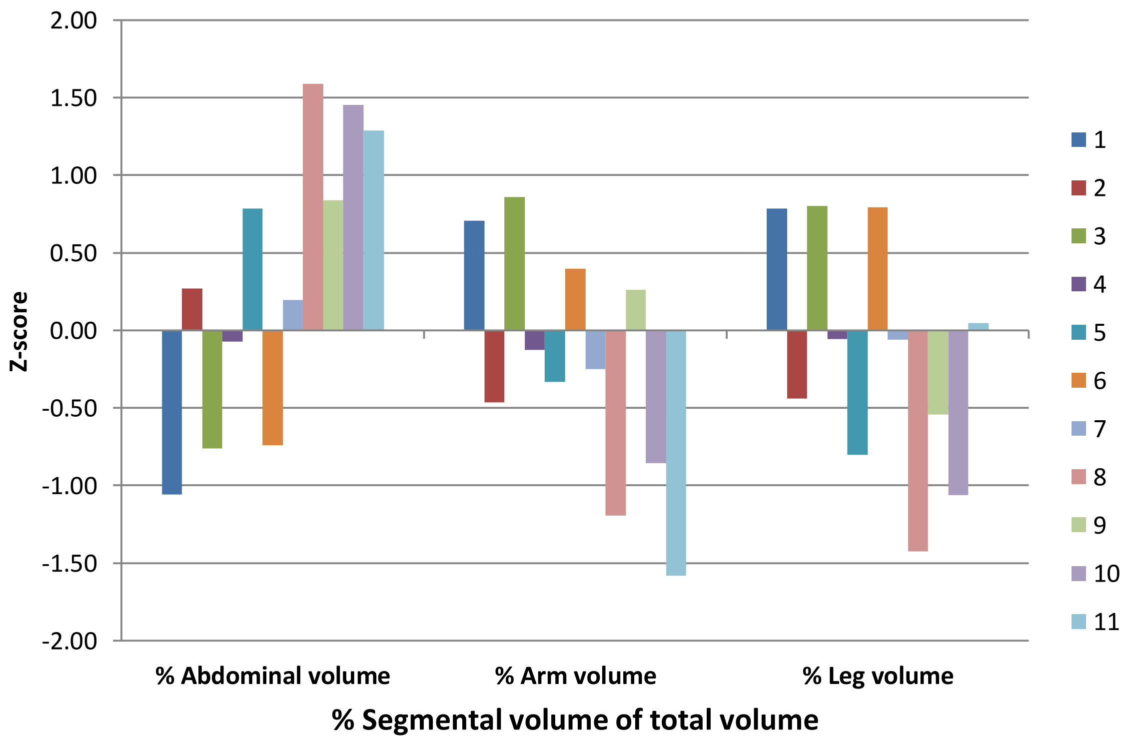


Figure 6.4. Z-score - Segmental volumes as a percentage of total volume

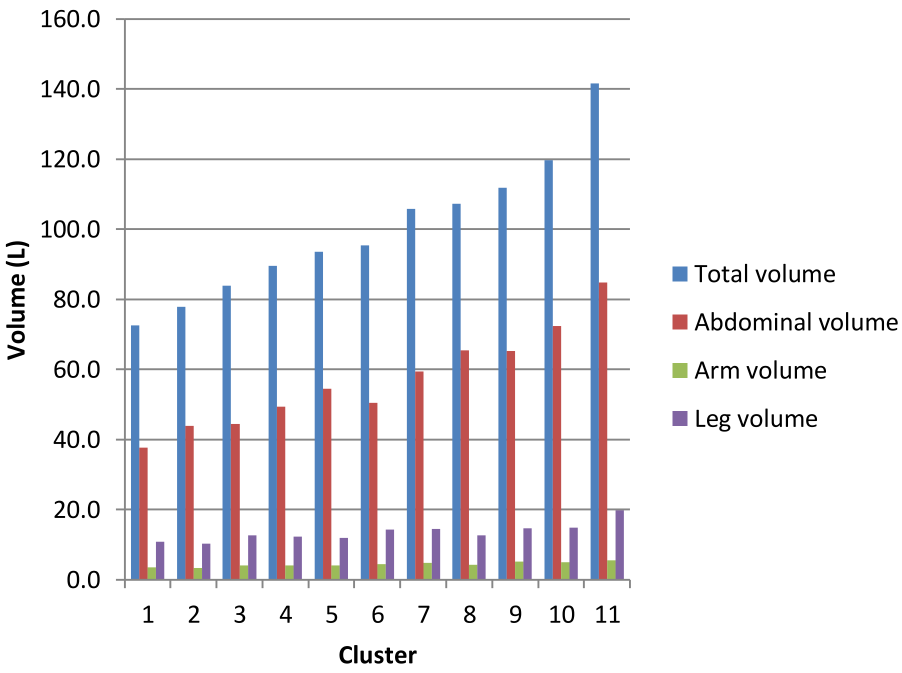


Figure 6.5. Total and segmental volumes by cluster

Table 6.10. Cluster somatotypes

	Somatotype	Endomorphy	Mesomorphy	Ectomorphy
1	Ectomorphic Mesomorph	2	4.5	3.5
2	Mesomorph Endomorph	5	4.5	2.5
3	Endomorphic Mesomorph	3.5	6.5	2
4	Mesomorph Endomorph	5	5	2
5	Endomorphic Mesomorph	5	6.5	1
6	Endomorphic Mesomorph	4.5	6.5	1
7	Mesomorph Endomorph	5.5	6	1
8	Mesomorphic Endomorph	7	6	1
9	Endomorphic Mesomorph	6	7	1
10	Mesomorphic Endomorph	8.5	5.5	1
11	Mesomorphic Endomorph	8	5	1

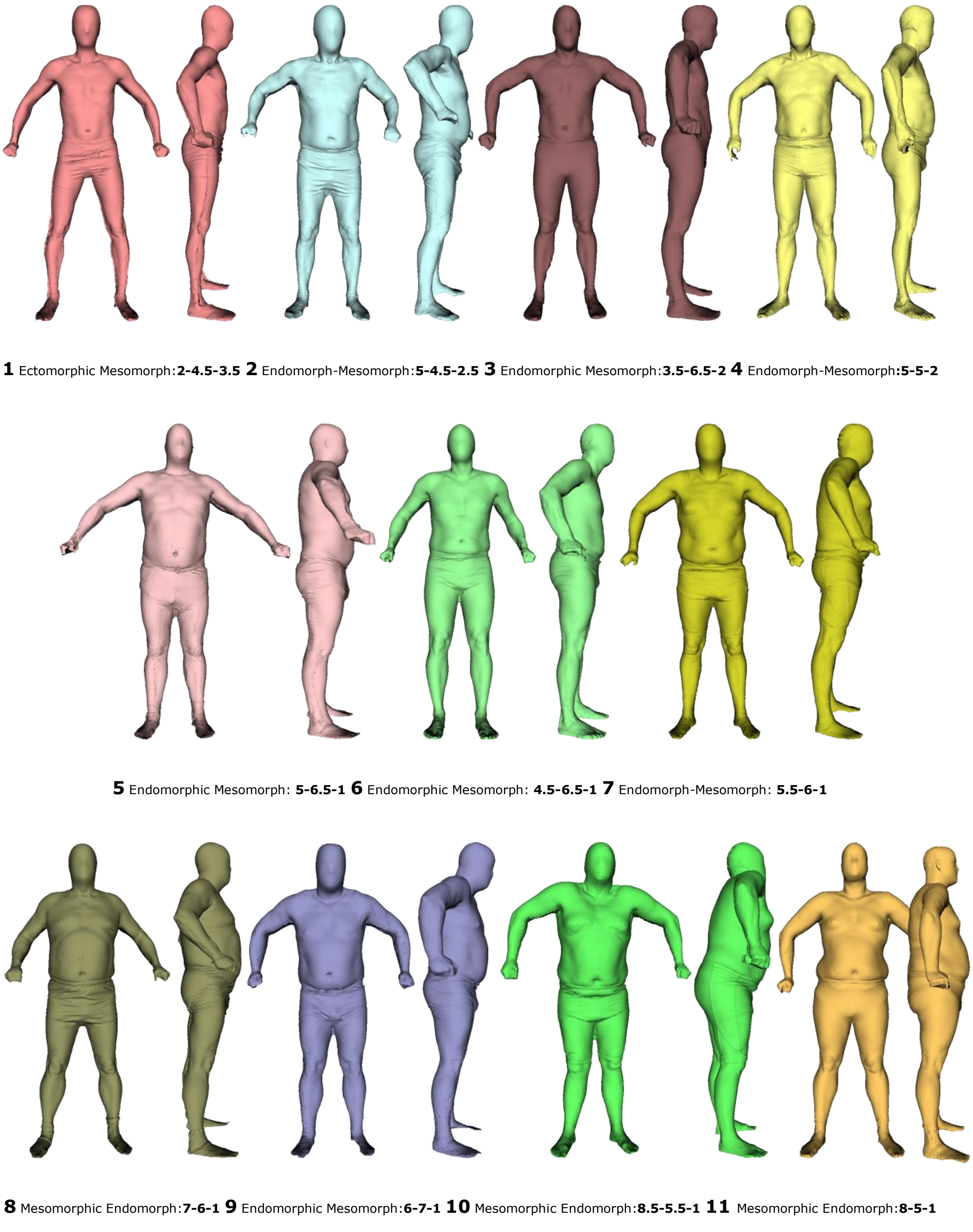
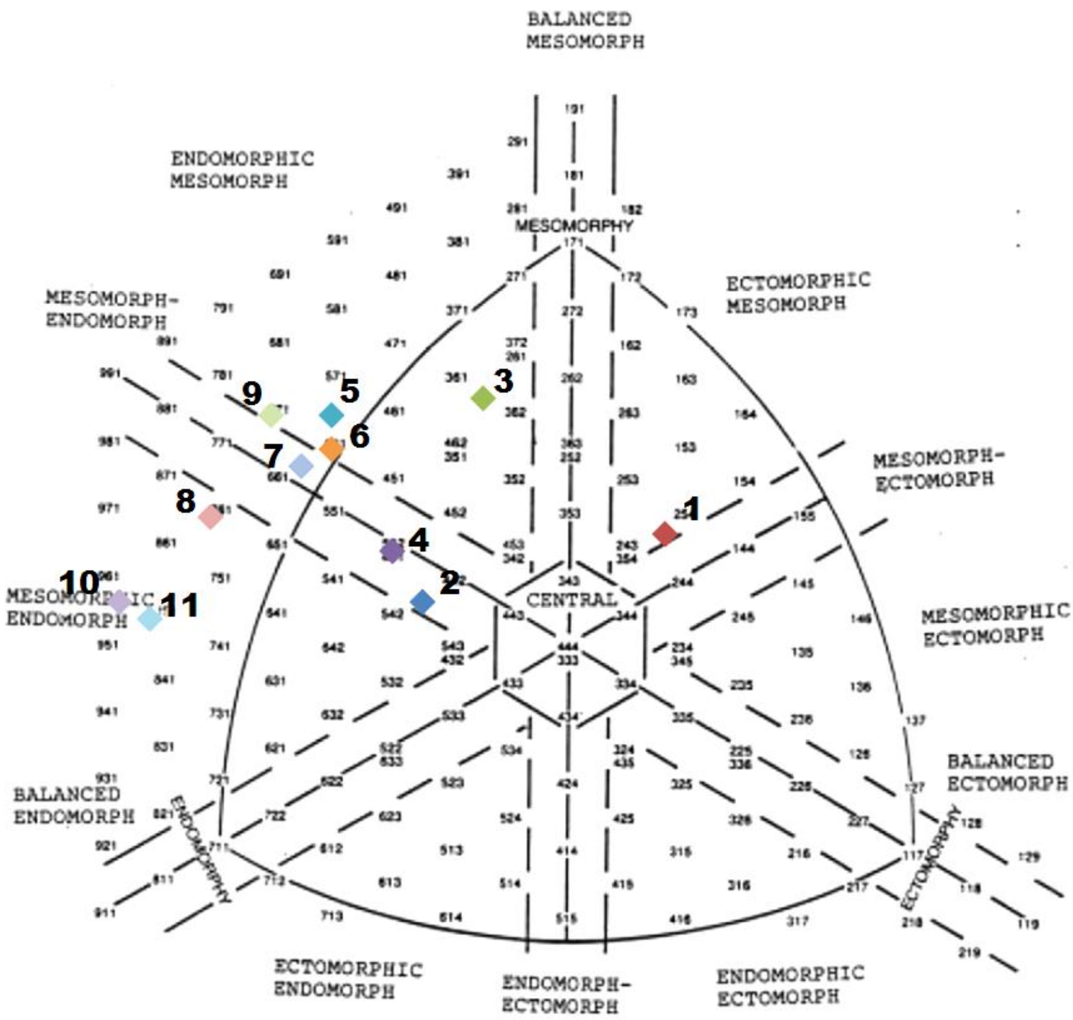


Figure 6.6. Cluster centroid phenotypes

Below is a somatochart, Figure 6.7, showing the physique centroids amongst the offshore workforce. A tendency towards the Mesomorph – Endomorph region of the chart is apparent. The annotated numbers correspond to the cluster centroids depicted in Figure 6.6.



Somatotype – plotted by coordinates X and Y. X-coordinate = ectomorphy - endomorphy, Y-coordinate = 2 x mesomorphy – (endomorphy + ectomorphy).

Figure 6.7. Somatochart - Cluster Centroids

The descriptive statistics for each cluster are shown in Table 6.11 and the descriptive statistics of the four identified somatotypes are given in Table 6.12.

Table 6.11. Cluster descriptive statistics

Cluster	Age (Y)	Weight Form (kg)	Height (m)	BMI	Number
1	32.2	71.6	176.4	23.1	63
2	43.9	76.5	171.8	26.0	69
3	35.1	83.5	180.4	25.7	96
4	43.8	88.4	178.1	27.9	74
5	44.9	92.6	176.4	29.8	74
6	38.3	94.6	185.0	27.7	67
7	41.9	104.6	182.8	31.4	75
8	49.9	104.8	175.8	34.0	39
9	37.0	112.8	181.0	34.4	7
10	41.4	118.5	180.4	36.5	20
11	36.8	138.3	181.0	42.4	4
Average	**40.6**	**90.5**	**178.7**	**28.3**	**588**

Table 6.12. Somatotype descriptive statistics

Somatotype	Age (Y)	Weight Form (kg)	Height (cm)	BMI	Number	% of pop
Ectomorphic mesomorph	32.2	71.6	176.4	23.1	63	10.7
Endomorph mesomorph	43.2	89.8	177.6	28.4	218	37.1
Endomorphic mesomorph	38.8	95.9	180.7	29.4	244	41.5
Mesomorphic endomorph	42.7	120.5	179.1	37.6	63	10.7

6.7. Survival suit fit

All participants selected survival suits, from a choice of 11 sizes, which they would usually wear for offshore helicopter travel. If the individual was unaware of his usual survival suit size the most appropriate size was selected as per the survival suit sizing chart. Table 6.13 and 6.14 show the proportion of individuals whose extracted chest and height measurements concur with their selected survival suit sizing (not provided due commercially sensitive nature). 29.9% of cases both extracted chest and height measurements matched the selected survival suit size, while 20.6% of cases neither measurement fell within the sizing guideline. However, according to the manufacturers the sizing chart is purely as a guide and a starting point for individuals to try on suits. If the individual does not find the survival suit comfortable or it is not deemed appropriate by ground staff, the suit can be changed before a flight. Due to a certain amount of ease and give within the suit fit, it is feasible that a taller thinner individual could fit inside a suit which also fits shorter but broader individual.

Table 6.13. Breakdown of survival suit fit

	Survival Suit Size										
	SR	**MR**	**MT**	**LR**	**LT**	**XLR**	**XLT**	**2XLR**	**2XLT**	**3XLR**	**3XLT**
Both (%)	0.0	29.2	28.6	33.0	30.7	42.2	29.9	16.0	14.7	0.0	0.0
Height (%)	66.7	19.4	42.9	24.5	29.9	32.8	28.9	24.0	29.4	0.0	33.3
Chest (%)	33.3	27.8	14.3	20.8	19.7	14.1	17.5	40.0	20.6	66.7	0.0
Neither (%)	0.0	23.6	14.3	21.7	19.7	10.9	23.7	20.0	35.3	33.3	66.7
Subjects	3	72	49	106	127	64	97	25	34	3	3

Table 6.14. Survival suit fit agreement

	All Survival Suits
Both (%)	29.9 (174)
Height (%)	28.6 (167)
Chest (%)	20.6 (120)
Neither (%)	20.9 (122)
Number of Subjects	**583**

Figure 6.8 shows the non-uniform step change in variables between participants wearing different suit sizes.

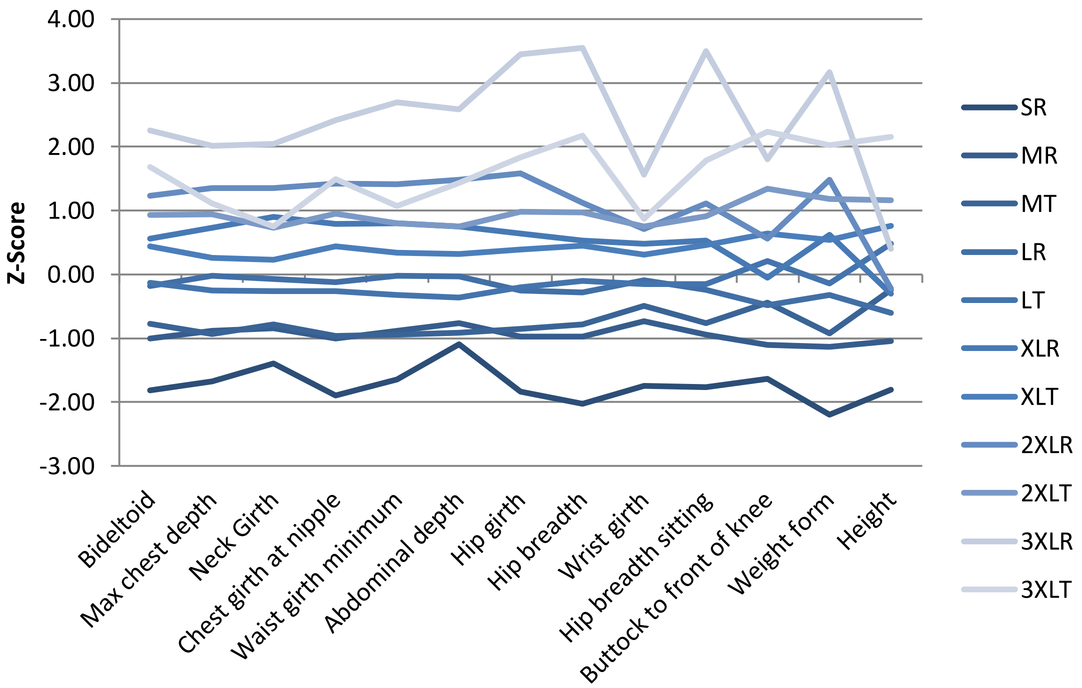


Figure 6.8. Z-score average for selected survival suits

6.8. Equipment adaptations - effect on space requirements

The change in chest depth at deltoid in the transverse plane and maximal chest depth associated with wearing the survival suit and either the original re-breather life jacket or the new emergency breathing system life jacket is shown below, Table 6.15.

Table 6.15. Difference in extracted chest measurements while wearing different lifejacket systems.

	Chest depth at deltoid transverse plane (cm)	Maximal chest depth (cm)
Re-breather	39.2 ± 3.04	46.5 ± 2.92
Emergency Breathing System	43.2 ± 2.6	49.5 ± 3.04
Difference	4.0cm[a] ± 3.0	3.0[a] ± 3.9
Percentage difference	10.3%	6.4%

N=31, [a] = $p<0.05$

6.9. **Window Egress**

A total of 404 individuals of the 588 attempted a small window egress task, with 51% successfully passing themselves through the frame. Figure 6.9 shows the average Z-scores for selected variables of those who passed or failed to egress through the small window frame. The variables have been organized in a descending order from the greatest Z-score average for individuals that failed to pass through the window frame. It is shown that individuals that pass successfully through the window are typically smaller than the offshore sample average, whereas the individuals that failed are typically larger than the offshore sample average, across all variables.

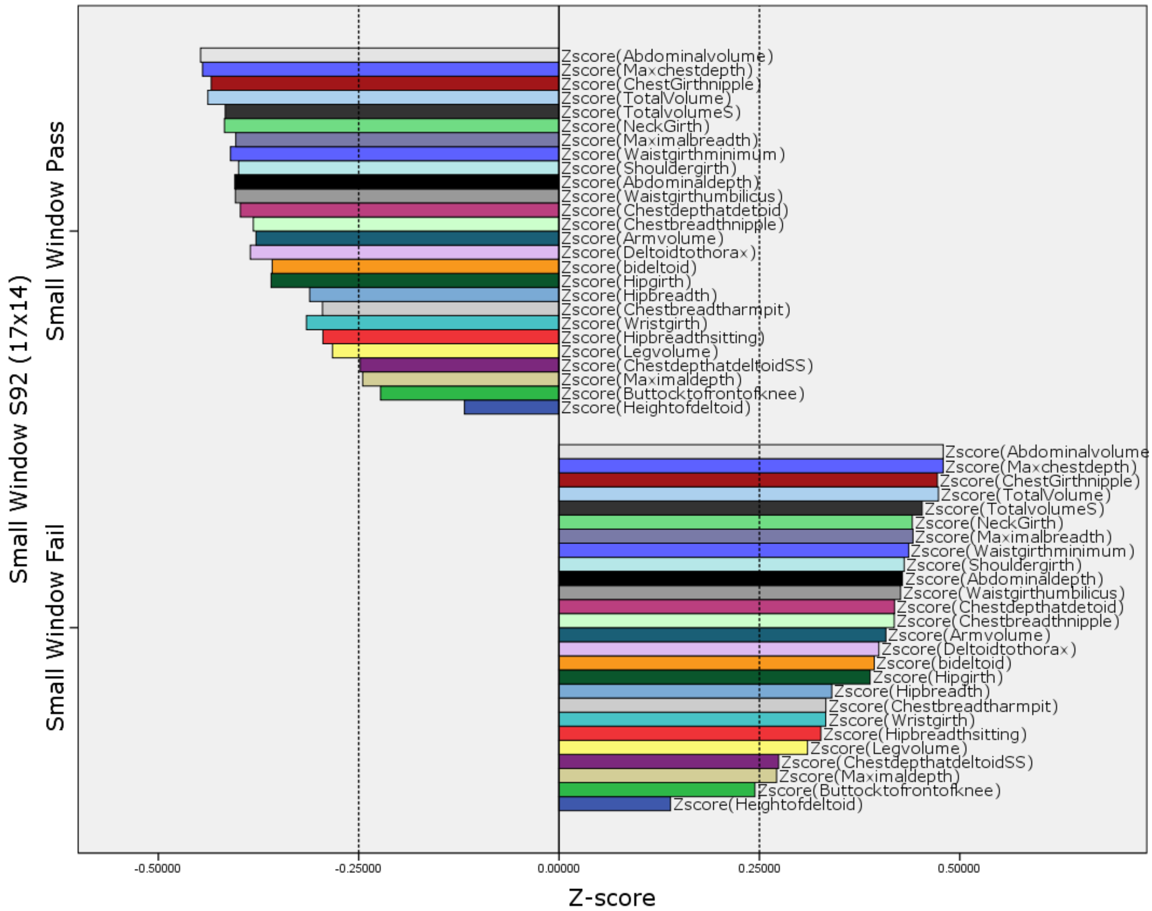


Figure 6.9. Z-scores of selected variables for window passes and fails.

As identified in Table 6.16, a 10 variable equation, selected using backwards regression from all 29 variables, best predicted a person's ability to pass through the window (73.5% predictive accuracy). Selecting nine easily acquired measurements, again using backwards regression, it was identified that a combination of max chest depth, hip breadth and weight in clothing gave a predictive accuracy of 70.8%. The best single measurement was max chest depth representing a 68.6% predictive accuracy outperforming bi-deltoid breadth.

Table 6.16. Logistic regression showing predictive accuracy of ability to pass through an aperture.

Model	Variables included	Predictive Accuracy (%)
1. All 29 variables (backward elimination)	Shoulder girth, bideltoid, Neck girth, maximal breadth, waist girth minimum, abdominal depth, hip girth, abdominal volume, arm volume, leg volume	73.5
2. 9 measurements easily extracted at heliport (backward elimination)	Max chest depth, hip breadth, weight (clothing)	70.8
3. Weight (clothing) and max chest depth	Weight (clothing), max chest depth	70.0
4. Height and weight (clothing)	Height, weight (clothing)	69.6
5. Maximum depth and width in Survival suit	Max depth (suit), max width (suit)	69.6
6. Max chest depth and bideltoid width	Maxchest depth, bideltoid width	68.8
7. Max chest depth	Max chest depth (form)	68.6
8. Bideltoid width	Bideltoid width (form)	64.4

N = 404

Table 6.17. Logistic regression predictive test outcomes

Model	True –ve	False -ve	True +ve	False +ve
1. All 29 variables (backward elimination)	141 (35%)	50 (12%)	156 (39%)	57 (14%)
2. 9 measurements easily extracted at heliport (backward elimination)	132 (33%)	52 (13%)	154 (38%)	66 (16%)
3. Weight (clothing) and max chest depth	130 (33%)	53 (13%)	137 (35%)	75 (19%)
4. Height and weight (clothing)	128 (32%)	56 (14%)	150 (35%)	70 (17%)
5. Maximum depth and width in Survival suit	129 (32%)	54 (13%)	152 (38%)	69 (17%)
6. Max chest depth and bideltoid width	128 (32%)	56 (14%)	150 (37%)	70 (17%)
7. Max chest depth	130 (32%)	59 (15%)	147 (36%)	68 (17%)
8. Bideltoid width	123 (30%)	69 (17%)	137 (34%)	75 (19%)

The predictive test outcomes are detailed in table 4. Misclassification occurs in 22% or more cases, with more false positives (predicted to fail, but pass) than false negatives (predicted to pass, but fail) in all cases.

7. Discussion

7.1. **Key findings - Size increase:**

The study has demonstrated that the size increase in offshore workers has increased profoundly and dramatically, and evidence suggests that as a professional group, the disparity between their size and that of UK males as a whole is increasing. The increase in weight of the UK offshore workforce over the last 30 years has been well documented. However, this study is the first, since the original anthropometric survey in 1985 (Light and Dingwall, 1985), to quantify the morphological size and shape changes associated with this increase in weight.

The average weight (90.5 kg) and distribution (chi squared value = 11.7; 11df, P = 0.613) of the sample closely mirrors the weight of the entire offshore population, measured in 2009 (average weight in 2009 was 90.9 kg). Due to the stratified sampling strategy used in this survey this conformity is unsurprising and supports the basis that the sample closely resembles the population demographic as a whole (Figure 6.1). Light and Dingwall, (1985) sampled the offshore workforce through a single survival centre, assuming that their sample was representative of the workforce as a whole at the time, the current weight of 90.5kg signifies an increase in weight over the last 30 years of 18.3%, from 76.6 kg.

Along with this 18.3% increase in average weight a dramatic change in body shape has also been quantified. If body size increase followed principles of geometric similarity and was made of uniform tissue it could be hypothesised that the theoretical dimensional increase would be the $\sqrt[3]{18.3}$, which is 2.6%, and yet we have strong evidence that the increase at these fleshy sites averages five times this. Neck girth, chest girth at nipple, minimum waist girth, hip girth and wrist girth were five measurements taken which allowed for direct comparison of extracted measurements between the current study and the Light and Dingwall (1985) survey. An average measurement increase in 13.5% can be seen across the measurements, with an average measurement increase as high as 17.3% for minimum waist girth. A more profound increase is evident amongst the largest individuals, the 99th percentile has increased more than twice that of the 1st percentile; +18.3% and +8.9% respectively. Therefore, not only has the population as a whole become larger, but the largest individuals have become proportionally even larger. This positive skew towards larger morphological features is demonstrated across all measurements and the positive skew is mirrored in the weight demographic shown in the frequency graph (Figure 6.1). The difference between the hypothesised 2.6% increase in body dimensions versus the measured average increase of 13.5% is dramatic and highlights how mass distribution is not geometrically similar. As highlighted by the Foresight Report (Butland, et al. 2007), the World is suffering an obesity epidemic and it is clear that the offshore workforce has not escaped this, with an average BMI of 28.3kg/m^2. This rise in obesity has also been forecast to increase at similar rates, with only 10% of UK males by 2050 falling within healthy BMI norms. If current size trends were to be extrapolated a further 30 years, then by 2045 we could expect the average weight of the offshore workforce to be 106.9kg, with the 95th percentile reaching levels of 144.3kg. Even without these extreme extrapolations from limited data, it is certain that super-sized individuals are becoming less rare, and will present serious challenges to ergonomic design, safety and health in the future.

Assessment of extracted measurement reliability can leave us assured that our measurements compare favourably with accepted manually extracted anthropometric measurements. An average percentage technical error of measurement (%TEM) of 1.15 (Table 6.5), surpasses an accepted %TEM of 1.5% for an accredited instructor from the International Society for the Advancement of Kinanthropometry (ISAK). This average %TEM is also skewed by including volumetric measures which were poorer across the board than all girth, length and height measurements. A breakdown of the different measurement types and their %TEMs are illustrated in table 6.6.

No anthropometric landmarking was used within this survey due to time constraints associated with this; an average %TEM for form girths, lengths and heights of 0.9% is comparable however to an intra-tester technical error of 0.7% found in a similar study which used landmarks (Olds et al., 2013). Poorer reliability was found within the extracted segmental volumes compared to the Olds et al. (2013) study, most probably due to an accumulation of errors associated with visual landmarking as the planar slice required for extracting segmental volumes needs to be defined by at least three landmarks. The protocols used for extracting segmental volumes within this study are described in the measurement handbook (Appendix 9).

7.2. **Why has the offshore workforce increased in size?**

An increase in weight and skewedness towards larger and heavier individuals is something that has become prevalent throughout the western world (Cole, 2002). However members of the UK offshore population are not only larger than their UK general population counterparts, but also larger than the equivalent US population (Peebles and Norris, 1998), judged as the largest nation in the world (UK offshore: 90.5kg , UK general: 83.9kg, US general: 86.2kg).

The offshore working regime and environment is dissimilar to most other working environments in regards to their combined influences on lifestyle and drivers for size and shape change. The apparent difference between onshore and offshore populations in regards to size and shape demonstrates either a self-selection process, where offshore work appears to attract a particular morphology of worker, or alternatively that the offshore working lifestyle manifests and promotes certain exaggerated morphological characteristics. Both may be equally true of this population. In support of a self-selection process, the offshore workers appear to be taller than their onshore counterparts. Stature at a population level is unlikely to be influenced by post growth nutritional status. In support of the work environment promoting a particular morphology, a combination of muscle hypertrophy, and positive energy balance would both explain the observed enlarged dimensions in soft tissue measurements.

Offshore work has long been seen as a male dominated environment where only 3-4% of the current UK offshore workforce is female. The majority of work has been strenuous while being concurrent with a limitless and unrestricted diet of energy rich food (Mearns and Hope, 2005). Mearns and Hope, (2005) also suggest the social function of meals has a strong relationship within the offshore community. Offshore a vast majority of social activity is based within the canteen, where uncontrolled quantities of highly appetising and energy dense food may encourage over-eating. Offshore work remains strenuous for many offshore workers providing a training stimulus that is significant enough to incur muscular hypertrophy especially in the upper body and torso. Anecdotal evidence suggests training stimulus through work tasks is often augmented through self-regulated strength training, which is the most readily available form of exercise offshore, and which has a strong culture amongst the workforce. This is evident in a large number of the 3D scans, where extreme muscularity appears prominent. More recently however, through the mechanisation of many loadbearing tasks offshore, an increasing proportion of the population's work tasks has become progressively more sedentary over recent decades, during which time individuals were still being exposed to an environment where three or more cooked meals a day are very much the norm and exercise is largely the choice of the individual. It is likely that this routine has a different if not greater effect on body size and shape, removing much if not all training stimuli from the working day for many employees. Following recent alterations to roster patterns, workers frequently find themselves immersed within this environment for three weeks at a time followed by three weeks of free and unregulated time onshore. This time onshore remains mostly unobserved and adverse lifestyle health risk factors are reportedly commonplace and of higher prevalence than with their onshore counterparts (Mearns and Hope, 2005). Exposure to this potentially obesogenic lifestyle and environment within the present sample has been over a significantly longer period of offshore employment compared to the Light and Dingwall (1985) sample (on average 10.9 years versus 4.3 years respectively, $P<0.001$).

In the 1980s the oil and gas sector in the UK was in its youth yet already had a population of around 30,000 individuals working offshore. Comparisons between anthropometric measures from both the offshore (Light and Dingwall., 1985) and onshore populations (Dietary and Nutritional Survey of British Adults, as reported in Scarborough et al., 2010) show the two populations to be very similarly matched in both height and weight (Onshore: 174 cm, 76.2 kg; Offshore: 175 cm, 76.6 kg). The current picture however is very different. It would appear neither population has escaped the global obesity epidemic with both dramatically increasing in weight; however the increase in weight has been vastly more prevalent within the offshore workforce. While this might be explained by the training load of a strenuous job, perhaps a more likely explanation is a positive energy balance where work based activity has decreased while energy intake has remained extremely high (Mearns and Fenn, 1994). Since the 1970s the male onshore population has increased in weight by 10.1% (to 83.9 kg) (Sutton, 2011), whereas the offshore population is increased by 18.3% (90.5 kg), while height has remained comparatively stable within each population. Whereas muscular hypertrophy will be expected to be specifically located in certain body regions such as arms, shoulders and upper torso, excess fat associated with obesity can accumulate and has the potential to enlarge all regions of the body increasing all body dimensions, but is possibly most apparent at fleshy sites, especially the abdomen.

Body composition was not measured in this survey, however the location of some comparable measurements allow for some speculation as to what has had the greatest effect on the increase in body weight and size; fat or muscle? The minimum waist circumference has been found to have increased by 17.3% across the entire population, with the 1^{st} %ile and 99^{th} %ile increasing by 10.3% and 19.9% respectively. A measure of waist circumference has long been used as a measure of health due to measurement increases being largely due to regional adiposity rather than muscle deposition (Janssen, Katzmarzky, and Ross 2004). It can therefore be supposed that for the vast majority of the UK offshore population the increase in body weight and size is more likely due to greater adiposity at this site than muscle mass increases. The similarity in buttock to knee and hip breadth (sitting) measures between the current onshore and offshore population, measures more related to skeletal size than adiposity, lends support to the suggestion that the increase in weight is soft tissue related rather than an increase in skeletal size.

The offshore workforce has certainly increased in size and weight over the last 30 years, yet the change has been exaggerated compared to their onshore equivalents. On the face of it, such a disproportionate increase in body size of offshore workers, especially relating to fatness, has occurred, which is most probably attributed to lifestyle choices and energy balance. Recruiting of larger individuals may be down to the work tasks associated with offshore employment and a pre-disposition to weight gain may be due to recruitment from a demographic who also less risk adverse than the general population, so may be less receptive to health messages. Mearns and Hope (2005) have shown that smoking prevalence offshore is considerably higher than onshore, 32% of offshore workers smoke compared to 22% in the male onshore population. The identified changes in the body shape strongly implies that the majority of the offshore workforce has increased in weight due to deposition of fat tissue particularly around the abdomen, attributed mainly to the lifestyle they lead off and on shore.

7.3. Size and shape variability – Cluster analysis and somatotyping

We know that the workforce has become heavier and larger; however, as highlighted by Nevill et al. (2004), increases in body size and shape do not conform to geometric similarity. Using cluster analysis 11 clusters were identified and somatotyping was used for the quantification of the 11 cluster centroids physiques.

From these clusters it was possible to identify the most commonly observed body morphologies within the offshore workforce, something which could be of great importance and use in ergonomic and equipment design. The 11 clusters have been numbered in weight order from lightest to heaviest with four distinct somatotype groups being identified. The characteristics of the cluster centroids are shown in Table 6.9 and their 3D scans along with somatotype ratings displayed in Figure 6.6.

The four distinct somatotypes identified within the population highlight the variability in body shape present across the workforce demographic. However, interrogating the actual cluster centroids extracted measurements may prove more useful as a tool for ergonomic and equipment design, allowing for sizing charts and adjustments to be made for the known shapes and sizes of the workforce.

Interestingly these four distinct somatotype groups, raises further questions as to the susceptibility of different individuals offshore to obesity. Cluster 1 shows that even within an obesogenic environment some individuals appear to stay resolutely lean and a further four clusters present a more muscular than fat physique. This apparent resistance to weight gain and fat accumulation in a proportion of the population provides evidence to a hypothesis made by Speakman (2008), that not all individuals are susceptible to weight gain. Previously the “Thrifty Gene” hypothesis suggested that due to natural selection individuals that were susceptible to storing fat would have a better chance of surviving and reproducing during famines. However, Speakman argues that even within the United States of America, regarded as the fattest national population, 30% of the population are not obese, yet if obesity were naturally selected we would expect >99% of the population to be obese in such a environment. Speakman therefore suggests a “Drifty Gene” hypothesis, that genes for obesity were not positively selected rather random mutations occur in genes and it is due to these that some people are susceptible to obesity rather than it being the norm within modern society. Future research might usefully consider a strategy for identifying those susceptible to fat gain, and combine 3D scanning and a biological and genetic approach.

7.4. Size and shape increase: the effect on ergonomic and equipment design.

The identified weight increase and evident variability in shape could have a considerable knock on effect to offshore safety, particularly associated with the tendency towards larger heavier individuals. Within most ergonomic design a tolerance for the 95th percentile of size is usually used to ensure that the majority of the user population will be accommodated. However, the use of aging infrastructure within the UK offshore oil and gas sector is widespread. Many installations built as early as the 1970’s are still in use, these being designed around the then current workforce and not anticipated to be in service for the next 30+ years. Despite on-going updates and modifications to meet current health and safety regulations, designers and companies can only make changes so far as is reasonably practicable and based on best estimates of worker size due to lack of current data. Knowing now that the offshore workforce has changed dramatically over the past 30 years and not in parallel with the general onshore population, ergonomic design needs to be reassessed to ensure it is fit for purpose. In seeking to accommodate as large a proportion of the offshore population as possible, ergonomic design will affect every facet of working infrastructure and equipment (Vries and Parkinson, 2014). In this study the focus has been specifically on helicopter egress, mustering, survival suit fit and confined space passing ability.

7.5. The effect of personal protective equipment on size and ergonomic fit

Evidence based on the pilot data prior to the present survey (Ledingham and Stewart, 2013) identified a vast increase in volumetric and space requirements associated with wearing occupational specific equipment, specifically the helicopter passenger immersion suit. Volumetric measures indicated a 71.3% increase in total body volume over form-fitting clothing, and the combined maximal depth and width measures implied a 101.9% increase in standing area requirements. Repeat analysis within the complete (588) offshore sample has provided similar results; a 119.1% increase in space requirement and a 57.2% increase in total body volume. Interestingly, the increase in both space requirement and body volume is inversely correlated to an individual's weight, with lighter individuals requiring a greater relative increase in space and volume requirements than their larger colleagues, identified in both studies. While passing ability (defined as the ability for two individuals to pass one another in a restricted width, without touching) is compromised in bigger people, the implied looseness of fit in the suits especially in smaller individuals could present a snag hazard in the pipework infrastructure, especially in an emergency. The lesser increase in body volume within the main sample is most likely due to the sample being heavier (Offshore survey (588) = 90.5kg, Pilot study (43) = 84.1kg).

However the heavier sample population does not explain the increase in space requirements, potentially due to more stringent protocol controls regarding three layers of clothing being worn under the immersion suit in the main offshore sample.

An increase in total body volume was expected due to the bulk associated with the immersion suit and re-breather required for helicopter travel over cold water environments, such as that found in the North Sea. However, the disparity in volumetric increases between weight categories, with smaller individuals increasing in total body volume proportionally more than their larger counterparts raises concerns about survival suit fit. The greater volume associated with smaller individuals was first expected to be due to poor fit of survival suits. Visually the poorer fit appeared to be due to excess ease across the chest and abdomen in smaller individuals. This may well be true, however, assessing the immersion suit sizing charts (height and chest girth) versus extracted body dimensions it appears that larger individuals are more likely to be smaller than recommended survival suit fit for chest. This may be due to larger individuals finding the neck and wrist seals uncomfortable (too tight) and therefore sizing up their suit to accommodate for this. Anecdotally many individuals, at the time of data collection, suggested sizing up suits to get a more comfortable fit. In fact, across the sizing chart, it is surprising that more did not fit the sizing chart guidance; with only 29.9% of individuals meeting both the height and chest circumference criteria provided by the suit manufacturers, 28.6% and 20.6% fitting only height or chest circumference respectively and 20.9% of individuals meeting neither criteria. Further work may be required in assessing the volume of trapped air within the suits due to lack of fit, suit specifications EASQA ETSO-2C503 (Appendix 10), states that the suit must not provide any more than 150N of buoyant force and allow for no more than 200ml of water ingress.

The disparity between survival suit size and fit could have major negative effects on their functionality and performance. The inherent buoyancy of a survival suit is dependent on its composition and capacity to trap air. A standard for inherent buoyancy has been designed for survival suits, ensuring that buoyancy is kept below 146N (Brooks, 1988). Excessive buoyancy levels have been attributed to failed inverted underwater helicopter escape due to passengers being unable to swim down towards emergency exits. With 31.1% of the measured population within this study displaying extracted chest measurements below that of the design parameters of their chosen survival suits; it is feasible that the capacity of the suits to trap air is above that of the original design specifications. The survival suits are designed with one way air valves on the shoulders that expel air once under-pressure, exerted though submersion, however it is possible that once inverted the trapped air could accumulate at the feet and legs where no valves are located. This occurrence has already been identified through previous functionality testing (Coleshaw, 2006), yet further work to recognise the effect of poor survival suit fit on inherent buoyancy would be prudent.

With the lack of contemporary anthropometric data for equipment designers to work from it may be no surprise that the survival suit fit may not be ideal for the current workforce. The percentile data arising from this study is to be made commercially available, providing up-to-date anthropometric data to the industry, presented in a similar format to the original survey. Further to the percentile data, the cluster analysis carried out in this study may therefore prove useful for designers. The 11 identified physiques could be used as design templates for future sizing schemes, a strategy implemented by Hsiao et al, (2015) when developing a new sizing structure for fire-fighter's gloves.

The striking increase in space and volumetric requirements associated with personal protective equipment raises further questions regarding the suitability of the current infrastructure. In addition to the fact that the workforce has increased in morphological size, the infrastructure design cannot have anticipated the personal protective equipment worn by today's offshore workforce. Changes have already been made to lifeboats in regard to increases in individual's space requirements (Kozey, et al. 2005); increasing allocated seat spacing based on 95th percentile of bi-deltoid breadth from 430mm to 575mm, decreasing lifeboat capacities by 33%. As well as lifeboat capacities further consideration must be made to other situations and infrastructure where an individual's space requirement is a limiting factor for personal safety, productivity and comfort. These include mustering stations, helicopter capacities, helicopter egress windows, confined space working environments, corridors and living stations.

7.6. **Window Egress**

Of the 404 who attempted the egress task 206 successfully passed through the window, representing a 51% pass rate. As identified in Table 6.16, the best predictive test for window egress ability based on morphology worked 73.5% of the time; 70.8% of the time for easily acquired morphological measurements; and 68.6% of the time for a single measurement, max chest depth. This suggests that in at least 26.5% of cases, egress capability is unrelated to morphology.

Looking at all variable z-scores individually for passes and fails, individuals that failed were typically larger than the population average and individuals that passed were typically smaller than the population average in all extracted measurements. Chest and abdominal, depth and girth, measurements appear to have the greatest disparity between passes and fails. Interestingly height was a particularly poor predictor of passes and fails and varied very little between the two groups. It has been previously observed that fat is more uniformly distribution over a larger frame (Nevill et al., 2010), as shown by the inverse relationship between stature and waist circumference in UK males, this may improve the ability of a tall heavy individual to egress through a window over a shorter heavy individual.

However, the 26.5% of egress capability unrelated to morphology remains unknown. Using 3D scanning the body is treated as if it was a rigid object and therefore these predictions cannot take into account physical factors, such as tissue compressibility and flexibility. An individual's body composition could affect the compressibility of body tissue. Large measurements due to adiposity may not prove as much of a hindrance as measures mainly composed of muscle, measures of adipose tissue made with a slight force have shown measures to decrease by up to 37% (Toomey et al., 2011). Flexibility, especially across the shoulders and back could also affect the ability of the individual to assume the optimal posture for fitting through the window. Other non-physical factors such as motivation to complete the given task and technique may also have contributed to egress ability.

In reaction to recent offshore helicopter incidents the UK Civil Aviation Authority (CAA) carried out a helicopter safety review in 2013, announcing a large number of changes in April 2014 (Civil Aviation Authority, 2014). One action (A9) within the review was to ensure the morphological compatibility of offshore helicopter passengers with their nearest available emergency exit. Preliminary data from this study along with old aviation data (Allan and Ward, 1986) were utilised to inform an approach for characterising individuals into those who do and those who do not require a larger window for underwater emergency egress. Bi-deltoid breadth was selected as the characterising measure of egress success as suggested in a 1986 Royal Air Force report into the minimal acceptable size of helicopter secondary escape windows (Allan and Ward, 1986) and the limit with which it was set was assigned through use of preliminary data produced from this study. Individuals were assigned by a cut off value for bi-deltoid breadth, identifying them as either "extra broad" (XBR) (requiring a seat beside a larger escape window) or "non-extra broad" (non-XBR) (can sit anywhere on the helicopter).

The CAA directive (Civil Aviation Authority, 2014) was to be put in place by the 1st April 2015, leaving four months to measure the bi-deltoid breadth of all offshore workers currently flying offshore (around 62,000). Step Change in Safety, a member-led health and safety organisation for the UK's oil and gas sector, coordinated the measurement protocol along with RGU. To ensure 62,000 individuals could be measured within the tight time frame a system of "train the trainers" and "train the measurer" courses were conducted creating more than 1000 individuals capable of taking the bi-deltoid breath measurement. 3-4% of the offshore population measured XBR which is significantly less than the availability of seating beside larger windows on all offshore helicopters currently in use and therefore a considerable size contingency is available.

As discussed, it is now known that chest depth out performs bi-deltoid breadth as the best single predictive measure of helicopter window egress success; as well as composites of extracted measures and body weight. Chest depth was also not deemed useable for the measurement programme because it was considered problematic to measure in women and may vary more with breathing artefact. Composites of measurements were not used due to the time constraints associated with the implementation of the CAA's directive the full data set was not available at the time of the decision.

Questions have been raised about the validity of the original Royal Air Force report (Allan and Ward, 1986) in relation to the offshore workforce both then and now. The study only used four individuals who completed a total of 22 underwater escapes through a simulated window. The occupation and water confidence of the subjects was not reported, it being reasonable to suggest that four healthy Royal Air Force personnel would not accurately represent the UK offshore workforce in terms of physical and mental capacity underwater. Furthermore, despite the subjects carrying out the underwater escapes wearing typical immersion suits for the time, dramatic changes in design and composition of immersion suits have taken place since 1984. In fact the lifejacket (Lifejacket Air Pocket Plus (LAP jacket)) used in the current study is already out of date. Another action of the CAA (Civil Aviation Authority, 2013) was to replace it with the new EBS jacket (Emergency Breathing System). Preliminary tests were carried out on 31 individuals, each individual being scanned in both the LAP jacket and the EBS over a survival suit. It was found that the new EBS life jacket added an average of 4.0 ± 3.0 cm (10.3%) to chest depth measured at the deltoid transverse plane and 3.0 ± 3.9 cm (6.4%) at the maximal extracted chest depth. Through visual inspection of the corresponding scans it is apparent that the additional depth is caused by the placement of the compressed air bottle used in the EBS protruding from the chest. These findings may raise cause for concern in regards to helicopter egress with the new EBS jacket, in particular the potential for snagging the bottle on the window frame. While the additional time the EBS system affords the escaping person may outweigh the disadvantages of its increased depth and potential for snagging, further research is clearly warranted in this area as an urgent priority.

Defence for the use of the bi-deltoid measure, however, is still strong. The present survey only measured the male offshore population where the chest measurement may be valid, however it does not account for the 3-4% of the offshore population that is female. Moreover, bi-deltoid measurements were found to be more reliable to measure within this survey, providing a lower %TEM than extracted chest depth measurements. Further inaccuracies may transpire within the chest depth measurement when the breathing cycle affects manual anthropometric measurement extraction reliability, something which is not quantifiable within the static snapshot provided by the 3D scanner. Finally, the limit at which the bi-deltoid breadth was set for XBR passengers was matched to the diagonal aperture of the smallest underwater escape window. Theoretically all passengers with a bi-deltoid width less than that of the XBR limit should be able to go through the diagonal aperture of the window with both arms at their sides, however the flexibility across the shoulder girdle and ability to raise one or both arms above the head to reduce their shoulder profile will provide substantial margin for successful egress. The present study sought to measure the anatomical difference between bi-deltoid breadth and perhaps a more realistic posture for window egress (window egress position, with one arm elevated). The window egress position reduced the shoulder width by a mean of 6.4 cm across the population. In addition the larger individuals shoulder width profile decreased to a greater extent than their smaller counterparts, this reduction providing even further leeway for the most 'at risk' individuals, 7.2 cm and 5.9 cm respectively.

7.7. Corridor passing

Access, egress and transit offshore are obviously not limited to helicopter windows. Being a highly functional environment; stairways, corridors, gangways, emergency exits and rooms are designed to maximise space for plant and process and not necessarily for aesthetics and comfort.

Preliminary published analysis carried out using 210 individuals, selected from this study, compared the theoretical probability of two randomly selected current offshore workers being able to pass one another without touching in a confined corridor 100 cm and 80 cm wide, compared to the UK general population in a theoretical model (Stewart, et al. 2015). Their size was described as width (shoulder) and depth (chest). Comparing the present study with the most recent size survey data available with the required measurements (Peebles and Norris, 1998) it was found that while passing front to front and side to front, offshore workers were 28% and 35% less likely to be able to pass than their UK onshore counterparts respectively. Furthermore, the addition of personal protective equipment was estimated to reduce the ability of randomly selected offshore workers passing in a 100cm corridor by 89%, in a front-to-side configuration. While personal protective equipment will vary greatly between occupational groups offshore, the survival suit and re-breather used in this case is PPE used by all, and likely represents the worst case scenario in terms of size effects. One such scenario where this finding would be relevant would be the need to abandon the platform, where the abandonment suits are essentially the same as the survival suit, but one size fits, with friction tighteners used to expel air.

From this it is clear that not only are UK norms for size unacceptable for ergonomic design offshore, due to the distinct working population, but accommodation of equipment and safety apparel commonly worn offshore must be factored into design also. Of particular concern should be the speed of egress in emergencies and the accommodating space of muster stations. Without costly alterations to infrastructure, possible changes in protocol, practice and routes of egress may suffice, and ensuring narrow corridors are not used in both directions in emergency situations.

8. Summary

8.1. Strengths

The current study in comparison to the original anthropometric survey (Light and Dingwall, 1985) recruited a greater number of participants; 588 and 419 respectively. The greater diversity and size of the current offshore workforce deemed it necessary for this larger sample size. Furthermore, it has been shown that this larger sample size closely matches the population as a whole and represents not only the average worker but encompasses the extremes equally as well, shown in table 6.1.

After much deliberation the Artec L 3D scanner was selected as the measurement tool of choice for this survey, as discussed in methods 4.2. Its large field of view allowed for faster data acquisition than the more accurate scanners on the market, however, its accuracy and density of data points represents scan quality unmatched in the majority of similar large scale surveys. This quality of scan related to highly reliable extracted measures, with reliability statistics well within the required norms of criterion manual anthropometrists. The quick scan acquisition time also allowed measurement sessions to be vastly shorter than full anthropometric profiles, limiting disruption to participants and on-going business function.

The advantages of having a portable and efficient 3D scanner were more than just reliability and quick scans however. The ability to travel with the device to locations of high workforce footfall allowed for selectivity of participants, ensuring that they were regular offshore staff and fulfilled the criteria to match the population demographic as a whole. Measurements were made mainly in heliports serving the UK continental shelf; however scanning was also taken offshore, to Apache's Forties Alpha, in order to measure individuals at their place of work. Ensuring the sample was made up of a majority of 'core crew' offshore workers was important as it is expected that the offshore lifestyle and culture is different to any other and promotes an atypical body size and shape to other populations. Any dilution of the sample through onshore-based personnel who travel offshore only occasionally may have changed the outcomes and not represented the true workforce currently working offshore.

The surveys focus on the male workforce can also be seen in a positive light. In most ergonomic design applications, the 95%ile of male population morphological size is used, ensuring that the vast majority of the population is accommodated comfortably within the infrastructure. Female anthropometric data as published by Peebles and Norris. (1998) confirms that it is highly improbable that including females in the sample of the current study would have increased the centile chart dimensions for any variable other than chest depth. Males also accounts for over 96% of the entire workforce and therefore producing specific anthropometric data directly associated to them is important for specific equipment design.

8.2. **Limitations**

Due to the large sample size required in the survey the study design precluded the use of fixed scanner units, manual landmarking and extensive anthropometry.

The use of fixed scanners is predicated on the expectation that all participants would report to a given location, and this was deemed unfeasible within this sample. The workforce while onshore is widely scattered throughout the UK and beyond, limiting the opportunity for them to be assessed centrally in one location. Originally, as with Light and Gibson, the study plan was to measure the majority of the workforce within survival training centres. However, this was judged to be ineffective for recruitment due to inflexible course timetables, the ability of the scanner to be portable and be based in a range of locations was viewed as strategically advantageous. The use of fixed scanners is common practice within the majority of other large-scale 3D anthropometric surveys; the benefits of fixed scanners being a known reliability and accuracy, with reduced scanning and post-processing time.

Post-processing time was something that was underestimated within this study. The proprietary software that comes with the Artec L 3D scanner requires manual construction of scans and does not have automatic landmark recognition or measurement extraction features. This has considerable advantages for the trustworthiness of extracted data, but therefore required each scan to be registered manually, then measurement sites located and extracted individually for each scan. With a minimum of six scans per person, it is estimated that it required almost two hours per person to process scans and extract measurements. Fortunately, support grated by the Health and Safety Executive funded a paid honours computing and graphics placement student to assist in the registration of scans. To ensure measurement reliability was not affected and intra-observer error of measurement was avoided the placement student did not carry out any measurement extraction.

The greater scan time associated with the portable scanner, over most fixed scanners, increases the chance of postural movement within the scan, which can affect the overall quality of the resolved image. Extra work was needed in post processing to reconstruct such scans were movement was prevalent and added to the already lengthy process. Despite the longer scan acquisition time the scan reliability, as measured by extracted volumetric measures of repeat scans, was deemed to be similar if not better than that of previous surveys using fixed scanners and extracted measures correlated well with fixed 3D scanner measurement in the pilot study (Ledingham, Nevill and Stewart, 2013).

Finally, due to many of the measurements being made at heliports, in eight cases individuals were called for their flights prior to measures being completed. This meant that eight datasets out of the 588 were imputed using regression analysis from the sample as a whole. This represents only 1.4% of the scanned data.

8.3. Implications

Taken together, this study can make a significant contribution to the legal framework, work practices, and awareness of body size as an issue affecting equipment and clothing design offshore, as well as other aspects of health and safety. For the first time in 30 years this study provides anthropometric data to the industry and supply chain companies that is specific to the current offshore workforce.

The data have already contributed to industry decisions involving changes made in the allocation of helicopter seating, with body size identified as a limiting factor for safe helicopter egress. Bi-deltoid breadth being used as the predictor of window egress success, and individuals over a predetermined shoulder width must be seated close to larger allocated windows. Similar size-related issues may also be identified and require amendments to regulations and safety practices once the full data set is available to the industry. The physical infrastructure itself is unlikely to be changed subsequently due to the cost implications, however its use and the safe systems of work put in place may need to change to ensure that the infrastructure is best used to maintain safety. Corridor widths, lifeboat capacities and muster station capacities are just a few ergonomically limited environments that may be identified as safety concerns once the known workforce size and shape can be taken into account.

The data can also provide useful information to survival suit and other equipment manufacturers. Use of the data set as a whole or using the identified cluster groups as sizing norms could allow for manufacturers to make equipment specifically designed around the known sizes and shapes of the current offshore workforce. With the identified mismatch between selected survival suit size and actual body size, this could potentially improve equipment design greatly, allowing the sizing charts to be tailored to the specific population rather than based on generalisations. For instance, identifying appropriate neck and wrist seals to fit actual sizes in a suit otherwise grouped by stature and chest girth.

A general trend of weight increase has been seen across the western world over the last 30 years, has been termed an 'obesity epidemic' in which co-morbidities such as diabetes and heart disease are associated with increasing fat content are becoming more and more prevalent (James, et al. 2001). However, as identified, the offshore workforce has actually increased in weight even more than the general. The balance of evidence points to this being attributed to adipose tissue. It can therefore be assumed that the health of the offshore workforce has deteriorated greatly over the last 30 years concomitantly with their increase in weight (although data on health outcomes and clinical conditions for UK offshore workers are not in the public domain). If true, this assault on the health of offshore workers is something that needs to be addressed urgently, if disease incidence is to plateau or decrease.

Health promotion initiatives including information about healthy food choices and quantities and exercise regimes need to be provided to the offshore workforce in order to change the current obesogenic culture and environment prevalent offshore. Not only would such initiatives oppose the weight increase and enhance health outcomes, healthier individuals would be less likely to have adverse health events offshore and would be better able to respond to medical or operational emergencies. This also relates to the existing offshore infrastructure that is already at its limits of ergonomic accommodation of the workforce, which could be further stressed if workers' size increase continues, requiring costly adaptation to existing plant and equipment to ensure its safe use for all. Fundamentally, this study has underscored the need to regularly survey the workforce and has facilitated this through the provision of protocols and publications detailing procedures for scanning and measurement extraction.

This survey and associated data set is an opportunity for the industry and supply chain companies to set a new standard for design and ergonomic safety offshore. The use of the study's digital archive should be encouraged for future analysis and design work, ensuring that the offshore workforce is treated as the unique population has been demonstrated to be.

8.4. Further studies and recommendations

This survey only concentrated on the male workforce. Future work should look to identify the specific size and shape requirements of the female offshore workforce; such as equipment and ergonomic fit. The female workforce however only consists of around 4% of the offshore workforce as a whole and therefore a targeted survey would be required in order to reach sufficient numbers of participants. Furthermore, measurement techniques and researchers may need to be adapted for the different needs of the female participants, especially for clothing assemblages, and the acceptability of participation will need to comply with ethical procedures.

The window egress analysis within this study was limited by the fixed window frames used for testing. A window egress test using an adjustable window would allow for regression analysis of pass/fail ability and identify more succinctly the anatomical dimensions that hinder window escape. Furthermore, many other factors that could influence window egress were not measured within this study such as flexibility, trainability, equipment assemblages and body composition.

These need to be measured and their function in successful window egress determined.

The identified size mismatch of suits sizes and extracted body measurements also highlights recommended further study. The use of cluster analysis to identify common phenotypes amongst the offshore workforce is one way to create a sizing chart that suit design could be based around. Further analysis and collaboration with fashion, textile and design experts may produce more accommodating clusters suitable for purpose. The identified size mismatch also raises concerns around the inherent buoyancy of the suits. There are current standards for inherent buoyancy, yet, some of the calculated volumetric increases associated with wearing a survival suit point to unsafe levels of trapped excess air especially amongst smaller individuals. Further work needs to be done to quantify the trapped air remaining after the venting procedure, and the effect water submersion has on total inherent buoyancy. Specific interest may be paid to survival suit fit and whether excess inherent buoyancy is due to poor suit selection or poor accommodation within available sizes.

It may also be of interest to the industry to use the data to forecast the size and shape changes that can be anticipated in the coming decades of continued oil production. Current trends can only be assessed through comparison of the original sizing survey and the present survey, however, increases in average age of the workforce or trends towards less manual jobs offshore may have an effect on the overall morphology of the workforce. These factors may be able to be predicted by closer analysis of age effects within the sample.

Moreover, a study of offshore culture and its capacity to influence body shape and health would be of interest. Identifying individual susceptibility in terms of why some of the population have stayed thin while the majority have increased in weight and size particularly in the larger end of the spectrum would be especially valuable, so individuals and companies could make informed choices of suitable work and occupational tasks.

Overall, the data set and raw scan images generated in this study could lead to a wealth of additional studies. From ergonomics and equipment design to health and fitness, the opportunities to develop the work appear to be unlimited. Continued industry support and interest will remain vital in terms of making the most of the data set and ensuring that the lessons learnt and information available cascades down into everyday improvements in the comfort, safety and efficiency of offshore infrastructure and equipment. It is also imperative that the industry heeds the warning signs of the obesogenic environment that is currently prevalent offshore and ensures that the current trend towards increased size and weight is addressed and accounted for.

9. Conclusions

UK offshore workers are substantially heavier and larger than the UK general population and have increased in size dramatically over the last three decades, with evidence suggesting that much of this is attributed to adiposity. Furthermore, the biggest individuals are getting disproportionately bigger, signifying an ‘expanding universe’ of physique and weight, which if allowed to continue will have many implications for health and safety.

The current offshore workforce takes up more space and is less likely to be able to pass one another in confined spaces than both their predecessors and the UK general population.

Close to three quarters of window egress cases can be predicted by morphological dimensions, with the remainder explained by other factors such as flexibility, compressibility, technique and motivation.

11 natural clusters of physique prevail within the workforce. This information could be vital for future survival suit and equipment design and provides an interesting technique for assessing and comparing physiques in the future.

Re-surveying in a much shorter time interval, as well as including females, and undertaking a programme of related ergonomic studies would be prudent in order to maximise the effectiveness of the fit of the offshore environment to those working in it.

References

Aker Solutions., (2010). *Safety issues concerning big persons travelling and working offshore. Work group.* Presented: Oil and Gas UK - Work Group Meeting 2. 1st June 2010. United Kingdom.

Allan, J.R. & Ward, F.R.C., (1986). *Emergency exits for underwater escape from rotorcraft. Aircrew equipment group.* Report no. 528. Royal Air Force Institute of Aviation Medicine, Farnborough, Hampshire.

Brooks, C. J., (1988). Maximum acceptable inherent buoyancy limit for aircrew/passenger helicopter immersion suit systems. *Applied Ergonomics* (1988), pp. 266-270.

BS EN ISO 20685 : 2010 BSI Standards Publication 3-D scanning methodologies for internationally compatible anthropometric databases. (2010).

Butland, B., (2007). Foresight. Tackling Obesity: Future Choices - Project report. Government Office for Science, London.

Buxton, B. et al., (2000). Reconstruction and interpretation of 3D whole body surface images. London: UCL.

Bye, E., Labat, K. L., & Delong, M. R. (2006). Analysis of Body Measurement Systems for Apparel. Clothing and Textiles Research Journal.

Civil Aviation Authority (2013). *Development of a technical standard for emergency breathing systems*. Report CAP 1034.

Civil Aviation Authority (2014). *Safety review of offshore public transport helicopter operations in support of the exploitation of oil and gas.* Report CAP 1145.

Carter, J. E. L., and Stewart, A. D., (2012). Physique: Phenotype, somatotype and 3D scanning. *Body Composition in Sport, Exercise and Health.* (2012) chapter 4, pp. 64-86. Oxon: Routledge.

Carter, J. E. L., and Heath, B. H. (1990). *Somatotyping: Development and applications*. New York: Cambridge University Press.

Cole, T. (2002). The secular trend in human physical growth: a biological view. *Economics and Human Biology*, 1, pp. 161-168.

Coleshaw, S. R. K., (2006). Investigation of removable exits and windows for helicopter simulators. Aberdeen: OPITO.

Daanen, H. A. M., Brunsman, M. A. and Robinette, K. M., (1997). Reducing movement artefacts in whole body scanning*. IEEE*. 97, 262-265.

Daanen, H. A. M., and Ter Haar, F. B. (2013). 3D whole body scanners revisited. Displays, 34(4), 270–275.

Edwards, K. and Jensen, P. L., (2014). Design of systems for productivity and wellbeing. *Applied Ergonomics ,* 45 (2014), pp. 26-32.

Gordon, C. C. et al., (2013). *2010 anthropometric survey of U.S. Marine Corps personnel: Methods and summary statistics.* Natick, MA: U.S. Army Natick Soldier Research, Development and Engineering Centre.

Hsiao. H. et al., (2015). Firefighter hand anthropometry and structural glove sizing: A new perspective. *Human factors and Ergonomics Society* [Epub ahead of print]

Hsiao, H., Long, D. and Snyder, K., (2002). Anthropometric differences among occupational groups. *Ergonomics*. 45:2, 136-152.

Istook, C. L. and Hwang, S-J., (2001). 3D body scanning systems with application to the apparel industry. *Journal of Fashion Marketing and Management*, 5, pp. 120-132.

James, P. T., et al., (2001). The worldwide obesity epidemic. *Journal of Obesity Research,* 9, pp. 228-233.

Janssen, I., Katzmarzky, P. T. and Ross, R., (2004). Waist circumference and not body mass index explains obesity related health risks. *American Journal of Clinical Nutrition*, (2004), pp. 379-384.

Kouchi, M. and Mochimaru, M., (2011). Errors in landmarking and the evaluation of the accuracy of traditional and 3D anthropometry. *Applied Ergonomics,* 42 (2011), pp. 518-527.

Kozey, J. et al., (2005). The impact on immersion suit use on lifeboat capacities. Presented: 36th Annual Conference of the Association of Canadian Ergonomists.

Ledingham, R. J., Stewart, A. D., (2013). Volumetric and space requirements of the offshore workforce: the effects of donning a survival suit. *Proceedings of the 4th 3D Body Scanning Conference*, Long Beach California (November 2013), pp. 317-322

Ledingham, R. J., Nevill, A. M. and Stewart, A. D., (2013). Reproducibility of body volume assessments in survival clothing in fixed and portable scanning systems. *Proceedings of the 4th 3D Body Scanning Conference*, Long Beach California (November 2013), pp. 355-359.

Li, Z., et al., (2009). 3D clothing fitting based on the geometric feature matching. *IEEE*. 74-80.

Light, I. M. and Dingwall, R. H. M., (1985). Basic anthropometry of 419 offshore workers (1984). In: Offshore Survival Centre. Robert Gordon's Institute of Technology.

Light, I.M. & Gibson, M. (1986). Percentage body fat and prevalence of obesity in a UK offshore population. *British Journal of Nutrition*, 56, pp. 97-104.

McKinnon, L. and Istook, C., (2002). Body Scanning: The effects of subject respiration and foot positioning on the data integrity of scanned measurements. *Journal of Fashion Marketing and Management*, vol. 6 (2002), pp. 103-121.

McKinnon, L. and Istook, C., (2001). Comparative analysis of the image twin system and the 3T6 body scanner. *Journal of Textile and Apparel, Technology and Management*, vol 1, Issue 2, 1-7.

Mearns, K. and H, L., (2005). *Health and well-being in the offshore environment: The management of personal health*. Health and Safety Executive Books (2005). Caerphilly, Wales.

Mearns, K., and Fenn, C. (1994). *Diet, Health and the Offshore Worker - A pilot study*. Suffolk: HSE Books.

Nadadur, G. and Parkinson. M. B., (2013). The role of anthropometry in designing for sustainability. *Ergonomics*, 56 (2013), pp. 422-439.

Nevill, A. M., Stewart, A. D., olds, T. and Holder., (2004). Are adult physiques geometrically similar?: the dangers of allometric scaling using body power laws. *American Journal of Physical Anthropology*, 124 (2004), pp. 177-182.

Nevill, A. M., Stewart, A. D., Olds, T. and Holder, R., (2006). Relationship between adiposity and body size reveals limitations of BMI. *American Journal of Physical Anthropology*, 129, 151-156.

Nevill, A.M., Stewart, A.D. and Olds, T. (2010). A simple explanation for the inverse association between height and weight in men (letter). *American Journal of Clinical Nutrition,* 92(6), 1535.

Norton, K., Olds, T, editors. Anthropometrica. Sydney: University of New South Wales Press (2000).

Olds, T., Daniell, N., Petkov, J. and Stewart, A. D., (2013). Somatotyping using 3D anthropometry: a cluster analysis. *Journal of Sports Sciences.*

Peebles. L. and Norris. B., (1998). *Adult data: the Handbook of Adult Anthropometric and Strength Measures.* Department of Trade and Industry, UK (1998)

Robinette, K. M. et al., (2002). Civilian American and European surface anthropometry resource (CAESAR) final report, volume 1: Summary. Interim report 1997-2002. Warrendale, PA: SAE International.

Scarborough, P., et al., (2011). Increased energy intake entirely accounts for increase in body weight in women but not in men in the UK between 1986 and 2000. British Journal of Nutrition, 105 (2011), pp. 1399-1404. Sheldon, W. H. et al., (1940). *The Varieties of Human Physique.* New York: Harper and Brothers

Speakman, J. R., (2008). Thrifty genes for obesity, an attractive but flawed idea, and an alternative perspective: the 'drifty gene' hypothesis. *International Journal of Obesity* 32, pp. 1611-1617.

Stewart, A., Marfell-Jones, M., Olds, T. & de Ridder, H. (2011). *International Standards for Anthropometric Assessment.* International Society for the Advancement of Kinanthropometry, Lower Hutt, New Zealand

Stewart, A.D., Klein, S., Young, J., Simpson, S., Lee, A.J., Harrild, K., Philip Crockett, P. & Benson, P.J. (2012). Body image, shape, and volumetric assessments using 3D whole body laser scanning and 2D digital photography in females with a diagnosed eating disorder: Preliminary novel findings. *British Journal of Psychology,* 103, pp. 183-202.

Stewart, A., et al., (2015). Body size and ability to pass through a restricted space: Observations from 3D scanning of 210 male UK offshore workers. *Applied Ergonomics,* 15 (2015), pp. 358-362.

Sutton, R., (2011). Adult anthropometric measures, overweight and obesity. *Health Survey England* 2012, Volume 1, Chapter 10, pp. 1-37.

Toomey, C., McCreesh, K.,Leahy, S. & Jakeman, P. (2011). Technical considerations for accurate measurement of subcutaneous adipose tissue thickness using B-mode ultrasound. *Ultrasound*, 19, pp. 91–96.

Vries, C. de., and Parkinson, M. B., (2014). Limiting disproportionate disaccomodation in design for human variability. *Ergonomics*, 51:1, pp. 52-65.

Wang, J., Gallacher, D., Thornton, J.C., Yu, W., Horlick, M. & Pi-Sunyer, F.X. (2006). Validation of a 3-dimensional photonic scanner for the measurement of body volumes, dimensions and percentage body fat. *American Journal of Clinical Nutrition*, 83, pp. 809-816.

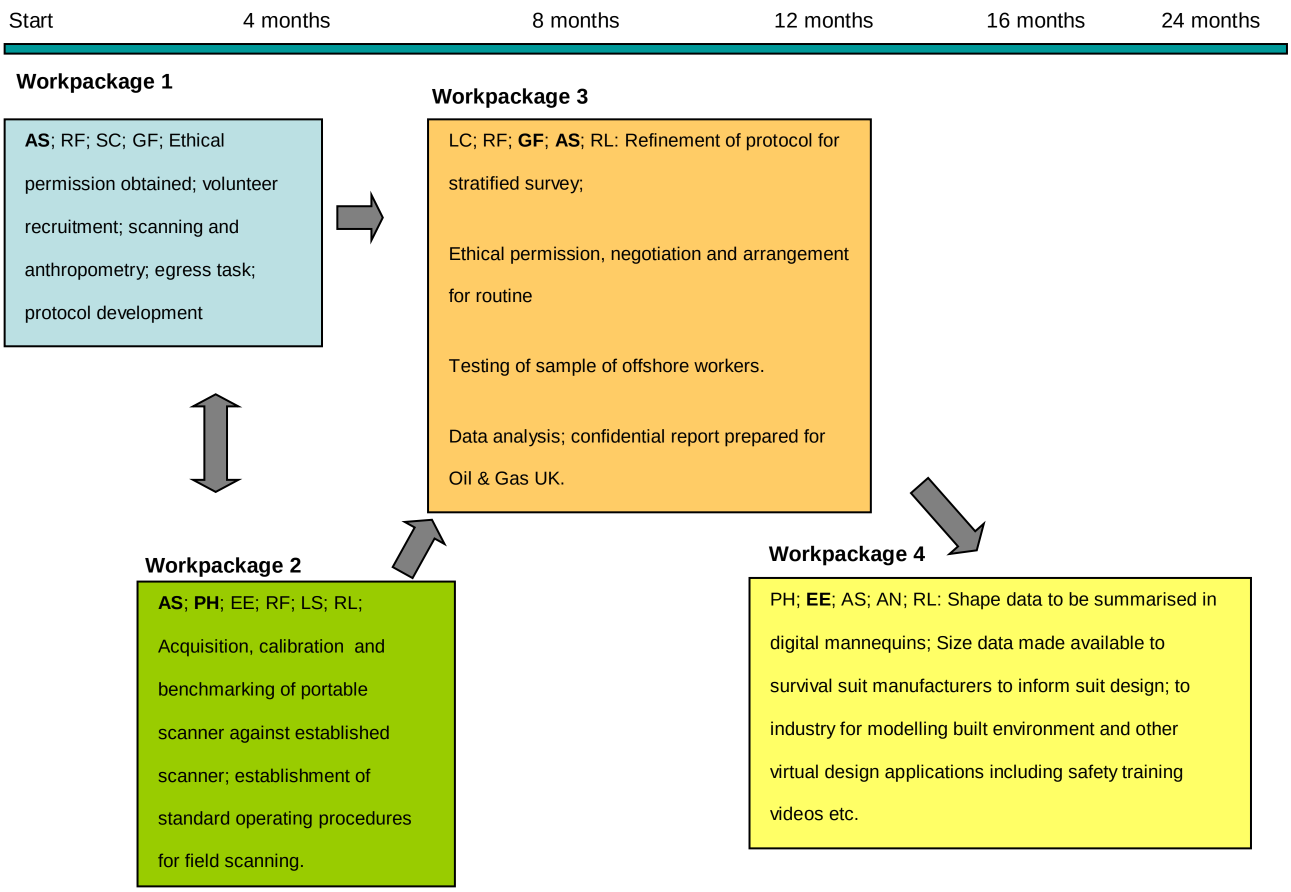
Wells, J. C. K., Treleaven, P. and Cole T. J., (2007). BMI compared with 3-dimensional body shape: The UK national Sizing Survey. *American Society for Nutrition*. 85, pp. 419-425.

Wells, J. C. K., Ruto, A. and Treleaven, P., (2008). Whole-body three-dimensional photonic scanning: a new technique for obesity research and clinical practice. *International Journal of Obesity*. 32, pp. 232-238.

Yu, W. (2004). Human anthropometrics and sizing systems. In Journal of Fashion, W. Yu, & L. Hunter (Eds.), *Clothing appearance and fit: Science and technology* (pp. 169–195). Cambridge: Woodhead.

Appendices

1 Work Flow Diagram



2 Participant Information Sheet (1+2)

ROBERT GORDON UNIVERSITY•ABERDEEN

Participant Information Sheet [version 1; 21/09/2011]
Workpackage 1 and 2

Principal Investigator: Dr Arthur Stewart (RGU: CORE) Co- Principal investigator: Dr Graham Furnace (Oil & Gas UK); Prof. Patrik Holt (RGU Computing) ; Dr Eyad Elyan (RGU, Computing) Dr Susan Coleshaw (Independent survival consultant)

You are invited to participate in this research study. Before you decide whether or not you would like to, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether you wish to take part. Thank you for reading this.

Introduction - Why is the study taking place?

Since 1985, when the last survey of the offshore workforce was carried out for body size, the weight of male workers has risen by 19%, but the extra size and space requirements which accompany this extra weight are unknown. Understanding the size of today's workforce is important because their clothing, transportation and work environment has been designed to fit the workforce as it was a quarter of a century ago. This introduces an unknown additional risk into the offshore environment, and in order to protect its workforce, it is important to establish the size of a representative sample. Since the 1985 survey, the development of 3D laser scanning has enabled much more rapid acquisition of size data, which makes a survey not only timely, but more affordable in financial terms.

The study involves four different phases, which relate to the 'work packages' involved.

Phase one involves quantifying the space requirements in sitting and standing, when wearing the survival suit, standard clothing, and form fitting clothing. It also involves an egress task,
simulating a dry escape through the window of a helicopter, which will enable the study team to identify critical anatomical dimensions to predict helicopter escape.

Phase two involves a smaller number of scans, but enables the study team to assess the performance of a portable scanner against that of the fixed scanner.

This information sheet refers to Phase One and Two only. It is possible to volunteer for both phase one and two if you so wish, because the work for each can be carried out simultaneously.

Phase three involves the actual offshore workforce itself, and involves the egress task, and scans in regular and survival clothing using the portable scanner.

This information sheet is not to be used for Phase Three. (Phase four involves detailed analysis of the data, and no new data acquisition).

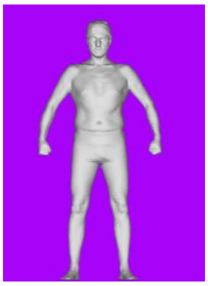
Phases one, two and four take place at Robert Gordon University, while phase three takes place at a survival training organisation.

Am I eligible to take part?
In order to be eligible for this study you must be between the ages of 18 and 60, be in good general health. If you suffer from epilepsy or are allergic to talcum powder you may also be unable to take part in the study.

Do I have to take part?
No, taking part is voluntary. If you would prefer not to take part you do not have to give a reason. Also, if you take part but later change your mind you can withdraw at any time.

If you do participate, you can be assured that the information that you provide will be treated with confidentiality and securely stored, and that the study has been approved by RGU's Research Ethics Committee.

What will I have to do if I take part?
If you decide to take part, you will be asked to attend the scanning facility at N516E (RGU Garthdee campus) on one occasion. This will involve being shown the laboratory, and where to get changed into the required clothing.


If you are volunteering for Phase One you will be measured for height, weight and then for shape using the fixed scanner (above L; which takes about 10 seconds/scan) for nine different scans. Also, you will be asked to perform a simulated dry helicopter escape wearing the survival suit, through window apertures of varying sizes. The measurement sequence will be as follows:

- Weight measured wearing regular indoor clothing.
- Height measured with shoes off.
- Scan 1 standing in standard position (see above, centre) wearing regular indoor clothing.
- Scan 2 standing with arms by sides wearing regular indoor clothing.
- Scan 3 sitting wearing regular indoor clothing.
- Over regular clothing, don survival suit and re-breather

- Weight wearing indoor clothing, survival suit and re-breather
- Scan 4 standing in standard position wearing survival suit
- Scan 5 standing with arms by sides wearing survival suit
- Scan 6 sitting wearing survival suit.
- Egress task through various window apertures.
- Change into light coloured form-fitting clothing
- Weight measured wearing form-fitting clothing
- Scan 7 standing in standard position (see above R) wearing form fitting clothing.
- Scan 8 standing with arms by sides wearing form fitting clothing.
- Scan 9 sitting wearing form fitting clothing.

These measurements will take 45 – 60 minutes to complete

If you are volunteering for Phase Two you will be measured for height, and then for shape using the fixed scanner and also the portable scanner (see R; which takes about 2 minutes) for four different scans. If undertaking stage 1 and 2 simultaneously, repeat measures will not be required. The measurement sequence will be as follows:

- Weight measured wearing form fitting clothing.
- Scan 1 (fixed scanner) standing in standard position wearing form fitting clothing.
- Scan 2 (fixed scanner) standing with arms by sides wearing form fitting clothing.
- Scan 3 (portable scanner) standing in standard position wearing regular form fitting clothing.
- Scan 4 (portable scanner) standing with arms by sides wearing form fitting clothing.
- Over regular clothing, don survival suit and re-breather
- Weight measured wearing indoor clothing, survival suit and re-breather
- Scan 5 (fixed scanner) standing in standard position wearing survival suit.
- Scan 6 (fixed scanner) standing with arms by sides wearing survival suit.
- Scan 7 (portable scanner) standing in standard position wearing survival suit
- Scan 8 (portable scanner) standing with arms by side wearing survival suit.

These measurements will take 30 – 45 minutes to complete

If volunteering for both phases one and two, measurements will take approximately 65–70 minutes. Three dimensional body shape (from which other measurements are extracted automatically) will be determined using both fixed and portable 3D scanners. The fixed scanners uses eye-safe lasers (certified class 1 laser), to capture shape while the portable scanner uses structured light (L). These processes are safe, and do not require the researcher to physically touch the participant in order to make the measurements which are obtained from a digital file of the body shape. For scans you are required to wear light coloured indoor clothing, and also light coloured form fitting clothing (which can be provided if necessary).

What are the possible risks of taking part?
There are no risks known to the researchers of the measurements involved in taking part in this study. For instance, the fixed scanner uses a class 1 laser which means that you can stare at the light beam with eyes open with no ill effect. The portable scanner (Phase two only) involves capturing shape using structured light, and as a precaution, individuals with known epilepsy are excluded (The manufacturers of the Artec L scanner have had no known incidents of epilepsy as a result of its use).

Are there any possible benefits?
There are no direct benefits, other than a greater understanding of shape and space requirements, and an introduction to novel technology and offshore survival via a simulated dry egress.

Who is funding the research?
Oil and Gas UK, along with individual named offshore partners are funding the research.

What do I do now?
Please contact Dr Stewart or Robert Ledingham if you have any questions related to any aspect of this pilot study or if you are willing to take part in the study. Direct phone line is 01224 262850, and email is r.ledingham1@rgu.ac.uk or contact Arthur Stewart on a.d.stewart@rgu.ac.uk

Thank you very much for considering taking part in this research.

Participant Information Sheet (3)

Participant Information Sheet [version 1.1; 07/05/2013]
Work Package 3

Principal Investigator: Dr Arthur Stewart (RGU: CORE) Co- Principal investigator: Dr Graham Furnace (Oil & Gas UK); Prof. Patrik Holt (RGU Computing); Dr Eyad Elyan (RGU, Computing) Dr Susan Coleshaw (Independent survival consultant); Robert Ledingham (KTP Associate)

You are invited to participate in this research study. Before you decide whether or not you would like to, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether you wish to take part. Thank you for reading this.

Introduction - Why is the study taking place?
Since 1985, when the last survey of the offshore workforce was carried out for body size, the weight of male workers has risen by 19%, but the extra size and space requirements which accompany this extra weight are unknown. Understanding the size of today's workforce is important because their clothing, transportation and work environment has been designed to fit the workforce as it was a quarter of a century ago. This introduces an unknown additional risk into the offshore environment, and in order to protect its workforce, it is important to establish the size of a representative sample. Since the 1985 survey, the development of 3D laser scanning has enabled much more rapid acquisition of size data, which makes a survey not only timely, but more affordable in financial terms.

Phase one/two involves quantifying the space requirements in sitting and standing, when wearing the survival suit, standard clothing, and form fitting clothing. It also looks to assess the performance of the portable scanner and develop an efficient scanning protocol.
Phase three involves the actual offshore workforce itself, and involves an egress task, and scans in form fitting and survival clothing using the portable scanner.

This information sheet refers to Phase Three only.

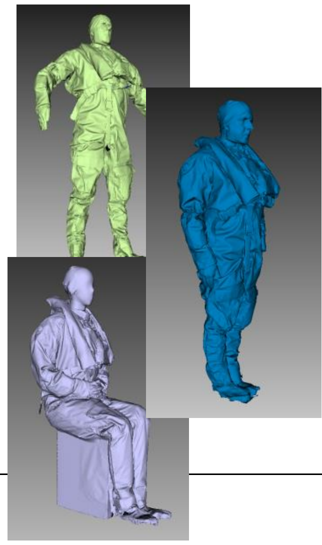
Am I eligible to take part?
In order to be eligible for this study you must be between the ages of 18 and 60, be in good general health. If you suffer from epilepsy or are allergic to talcum powder you may be unable to take part in the study.

Do I have to take part?
No, taking part is voluntary. If you would prefer not to take part you do not have to give a reason. Also, if you take part but later change your mind you can withdraw at any time.

If you do participate, you can be assured that the information that you provide will be treated with confidentiality and securely stored, and that the study has been approved by RGU's Research Ethics Committee.

What will I have to do if I take part?
If you decide to take part, you will be asked to attend a pre-determined location within the facility. There will be a brief introduction to the study and you will be shown where to get changed into the required clothing.

You will then be measured for height, weight and then for shape using the portable scanner for 6 different scans. You will also be asked to perform a simulated dry helicopter egress task wearing the survival suit. This will involve passing through window apertures of varying sizes. The measurement sequence will be as follows:



- Weight measured wearing regular indoor clothing.
- Height measured with shoes off.
- Over regular clothing don survival suit and re-breather.
- Weight measured wearing survival suit.
- Scan 1. Standing in standard position (see right, top) wearing survival suit
- Scan 2. Standing with arms by sides wearing survival suit (see right, middle).
- Scan 3. Sitting wearing survival suit (see right, bottom).
- Egress task through various window apertures.
- Change into form-fitting clothing.
- Weight measured wearing form-fitting clothing
- Scan 4. Standing in standard position wearing form fitting clothing.
- Scan 5. Standing with arms by sides wearing form fitting clothing.
- Scan 6. Sitting wearing form fitting clothing.

These measurements will take 15-20 minutes to complete

Measurements will take approximately 15-20 minutes. Three dimensional body shape (from which other measurements will be extracted automatically) will be captured using a portable 3D scanner. The process is deemed safe and does not require the researcher to physically touch the participant in order to take the measurements. For the survival suit scans you will be required to wear three layers of clothing underneath the suit, as would be expected while travelling offshore. For the form fitting scans; tight fitting shorts must be worn for men and tight fitting shorts and top for women (form fitting clothing can be provided if necessary).

What are the possible risks of taking part?
There are no risks known to the researchers of the measurements involved in taking part in this study. The portable scanner involves capturing shape using structured light, and as a precaution, individuals with known epilepsy are excluded (The manufacturers of the Artec L scanner have had no known incidents of epilepsy as a result of its use).

Are there any possible benefits?
There are no direct benefits, other than the industry gaining a greater understanding of the space and ergonomic requirements of the offshore environment, potentially improving health, safety and comfort of offshore working.

Who is funding the research?
Oil and Gas UK, along with individual named offshore partners are funding the research.

What do I do now?

Please contact Robert Ledingham if you have any questions related to any aspect of this study or if you are willing to take part in the study; direct phone line 07792818894, email r.ledingham1@rgu.ac.uk.

Thank you very much for considering taking part in this research.

3 Screening Form

Participant Identification Number for this trial:__________

Screening Form

Date of Birth: **Gender:**

Years in industry: **Survival Suit Size:**

Please tick the boxes that apply.

	Yes	No
Do you suffer from photosensitive epilepsy?		
Do you suffer from any other form of epilepsy?		
Do you have an allergy to talcum powder?		

***If you have answered yes to any of the questions you may not be able to continue with the measurement process*.**

4 Consent Form

Version 1.1- 07/05/2013

Participant Identification Number for this trial:__________

CONSENT FORM

Title of Project: **The Size and Shape of Offshore Workers – Work Package 3**

Principal Investigator: Dr Arthur Stewart

Please initial box

1. I confirm that I have read and understand the information sheet dated 07/05/2013 (version 1.1) for the above study. I have had the opportunity to consider the information, ask questions and if I have done so, have had these answered satisfactorily. ☐
2. I understand what is involved in the phase of the study I am volunteering for. ☐
3. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my medical care or legal rights being affected. ☐
4. I understand that my anonymised data may be seen by academic researchers from RGU and the members of the research team, and that such data may be disseminated in academic media in a way that does not reveal my identity. ☐
5. I agree to allow my anonymous scans to be used for research and teaching purposes, in a manner that will conceal my identity to others. ☐
6. I agree to take part in the above study. ☐

________________________	______________	____________________
Name of Participant	Date	Signature

I confirm that I have explained to the participant named above, the nature and purpose of the procedures to be undertaken.

__________________________	______________	____________________
Name of Person taking consent	Date	Signature

5 Recruitment Flyer

Knowledge Transfer Partnerships

ROBERT GORDON UNIVERSITY ABERDEEN

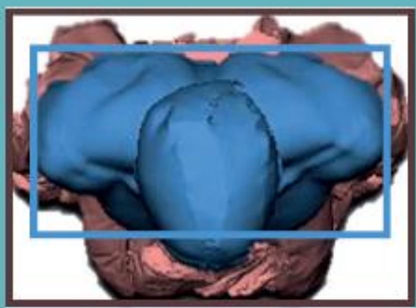
Oil & Gas UK

THE SIZE AND SHAPE OF THE OFFSHORE WORKFORCE

Why is the size and shape study taking place?

Since the last size and shape survey of the male offshore workforce, almost 30 years ago, the average body weight has increased by 19 per cent.

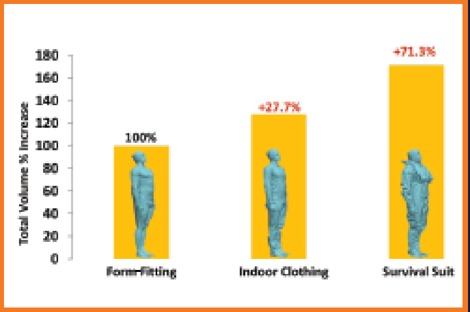
This study will be used to inform the future design and adjustability of offshore equipment and infrastructure including corridor widths, accommodation quarters, muster stations and emergency facilities.



Donning a survival suit almost doubles your space requirement

Who is collaborating on the study?

Oil & Gas UK with the Health and Safety Executive and facilitating partners is collaborating with Robert Gordon University to undertake a survey of a sample of 600 male offshore workers using state-of-the-art technology.



Clothing has a direct influence on an individual's size and shape

What is involved?

Using a portable 3D scanner you will be scanned in a survival suit and whilst wearing form-fitting clothing in three different postural positions, as shown in the images below:

Height and weight will be measured to ensure data are collected from across the offshore demographic. You will also be asked to perform a simple egress task, which involves passing five frames of varying dimensions over your body whilst wearing the survival suit.

All measurements will take no longer than 20 minutes.

Knowledge Transfer Partnerships

ROBERT GORDON UNIVERSITY ABERDEEN

Oil & Gas UK

Who can take part?

This study will focus on male offshore workers within the UK Continental Shelf who are between the ages of 18 and 60. As a precaution, individuals with photosensitive epilepsy are not permitted to take part in the study due to the 3D scanner flash.

How do I get involved?

If you would like to volunteer to be part of this study, please contact Robert Ledingham who can provide you with an information pack and further details: *r.ledingham1@rgu.ac.uk*

Any questions can be directed to:

Robert Ledingham
E: r.ledingham1@rgu.ac.uk

Moira Lamb
E: mlamb@oilandgasuk.co.uk

FAQs

Q. What do I need to wear for form-fitting clothing, and why?
A. Form-fitting clothing scans involve wearing cycling shorts only (which will be provided). This allows for the measurement of minimum space requirements without the obstruction of additional clothing.

Q. Why do you need to measure my weight and height?
A. Height measurements allow us to correctly identify survival suit size whilst weight measurement ensures we select individuals from across the workforce demographic.

Q. Why only the male offshore workforce?
A. As males are likely to be largest in size and shape and make up a large proportion of the offshore workforce, they provide the most influential data set for designing future offshore infrastructure and equipment.

Q. What does the scanner pick up?
A. The 3D scanner only detects the body surface shape and unlike an ultrasound or X-ray scanner it does not measure within the body.

Q. Are there any risks involved in taking part?
A. There are no risks involved in taking part in this study. The 3D scanner works like a normal digital camera in the way it collects images and gives no radiation dose.

Q. What happens to my 3D scanned image?
A. All scans will be anonymised in order to fully protect individuals' identities.

Q. Can I have a copy of my 3D scan?
A. An electronic copy can be made available on request if you are happy to leave an email address.

Q. What is the purpose of the egress test?
A. The test allows us to identify which body dimensions best predict an individual's ability to pass through a given space.

6 3D scanner specifications

Artec L -specifications	
Ability to capture texture	No
3D resolution, up to	1.0 mm
3D point accuracy, up to	0.2 mm
3D accuracy over distance, up to	0.15% over 100 cm
Texture resolution	n/a
Colors	n/a
Light source	flash bulb (no laser)
Working distance	0.8 – 1.6 m
Linear field of view, HxW @ closest range	598 x 459 mm
Linear field of view, HxW @ furthest range	1196 x 918 mm
Angular field of view, HxW	41 x 32°
Video frame rate, up to	15 fps
Exposure time	0.0002 s
Data acquisition speed, up to	288,000 points/s
Multi core processing	Yes
Dimensions, HxDxW	353 x 114 x 70 mm
Weight	2.3 kg / 5.1 lb
Power consumption	12V, 36W
Interface	1x USB2.0
Output formats	OBJ, STL, WRML, ASCII, AOP, CSV, PLY
Processing capacity	40'000'000 triangles/1GB RAM
Supported OS	Windows 7 or Windows 8 - x64
Minimum computer requirements	I5 or I7 recommended, 8Gb RAM, NVIDIA GeForce 400 series
Calibration	no special equipment required

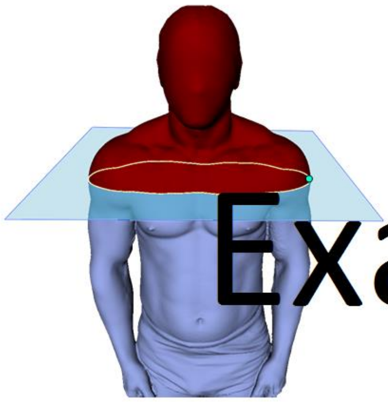
7 Table of Measurements

Measurement	Definition	Scanning Posture
Shoulder Girth	The circumference of the chest identified as a transverse plane at the maximal protuberance of the deltoids	Egress Form
Bi-Deltoid Breadth	The linear distance between the most lateral surfaces of the right and left deltoid muscles	Egress Form
Height Of Deltoid	The vertical height of the greatest protuberance of the deltoid muscle.	Egress Form
Chest Depth at Deltoid	Maximal anterior-posterior distance in the sagittal plane across the thorax at the height of the deltoid.	Egress Form
Max Chest Depth	Maximal anterior-posterior distance in the sagittal plane across the thorax.	Egress Form
Neck Girth	The circumference of the neck, with the place perpendicular to the long axis of the neck.	Scanner Form
Chest Depth at Deltoid in SS	Maximal anterior-posterior distance in the sagittal plane across the thorax at the height of the deltoid, while wearing a survival suit.	Egress SS
Maximal Depth in SS	Maximal anterior-posterior distance in the sagittal plane across the thorax, while wearing a survival suit.	Egress SS
Maximal Breadth in SS	The maximal horizontal distance across the scanned figure in the coronal plane.	Egress SS
Chest Breadth (Axilla)	The horizontal distance in the transverse plane between the most lateral points on the thorax, at the level of the axilla.	Scanner Form
Chest Girth (Nipple)	The circumference of the thorax at the level of the nipple.	Scanner Form
Chest Breadth (Nipple)	The horizontal distance in the transverse plane between the most lateral points on the thorax, at the level of the nipple.	Scanner Form
Waist Girth (Minimum)	The minimum circumference of the waist, measured in the transverse plane.	
Waist Girth (Umbilicus)	The minimum circumference of the waist, measured at the level of the umbilicus.	
Abdominal Depth	The distance in the sagittal plane between the most anterior and posterior point at the level of the umbilicus.	Scanner Form
Hip Girth	The circumference of the hips in the transverse plane at the level of the greatest posterior protuberance of the gluteal muscles.	Scanner Form
Hip Breadth	The horizontal distance in the transverse plane between the most lateral points at the level of the greatest posterior protuberance of the gluteal muscles.	Scanner Form
Crotch Height	The vertical distance between the standing surface and the notch of the	Scanner Form

	crotch.	
Wrist Girth	The minimum circumference of the wrist, perpendicular to its long axis.	Scanner Form
Total Volume	The volume of the unclothed body.	Scanner Form
Abdominal Volume	The volume of the torso, excluding the arms, legs and head.	Scanner Form
Arm Volume	The volume of one arm.	Scanner Form
Leg Volume	The volume of one leg.	Scanner Form
Total Volume in SS	The volume of the suited body, including life jacket.	Scanner Survival Suit
Hip Breadth Sitting	The horizontal distance in the transverse plane at the most lateral points of the hips.	Sitting Form
Buttock to Front Of Knee	The greatest perpendicular distance between the most posterior aspect of the buttocks and the most anterior aspect of the knee.	Sitting Form
Deltoid to Thorax	The horizontal distance in a transverse plane between the most lateral points on the deltoid and opposing thorax, at the level of the axilla	Window Egress Position
Body Mass	Mass measured in minimal clothing	Form clothing
Body Mas in Normal Clothing	Mass measured in normal clothing	Normal clothing
Body Mass in SS	Mass measured in survival suit and life jacket	Survival suit
Stature	Stretch stature measured with the head in the Frankfurt plane.	Normal clothing, no shoes.

8 Centile Charts

3. Deltoid height



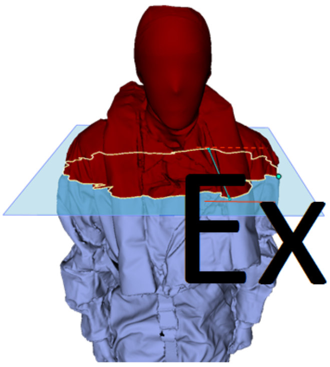
Subject position: Egress

Definition
The vertical distance of the lateral and inferior aspect of the deltoid from the standing surface.

			Percentiles								
N = 588	min	max	1	5	10	25	50	75	90	95	99
Deltoid height (cm)	117.81	153.52	123.10	125.40	127.54	130.79	134.69	139.16	142.97	144.97	150.21

19

7. Chest depth at Deltoid (survival suit)



Subject position: Egress

Definition
Maximum anterior-posterior distance in the sagittal plane across the chest at the deltoid section (see marked location L).

			Percentiles								
N = 588	min	max	1	5	10	25	50	75	90	95	99
Chest depth at deltoid in Survival Suit	30.73	55.47	33.53	34.51	35.19	36.57	38.26	39.95	41.37	42.75	46.14

23

9 Measurement Protocol

Above image acts as hyperlink to full document.

Size and shape of
the offshore workforc

Please find a hard copy of the measurement protocol for your information along with the thesis submission.

10 **Survival Suit – European Technical Standard**

ED Decision 2006/04/R
11/07/2006
Annex I

European Aviation Safety Agency

ETSO-2C503

Date: 18.07.06

European Technical Standard Order

Subject: HELICOPTER CREW AND PASSENGER IMMERSION SUITS FOR OPERATIONS TO OR FROM HELIDECKS LOCATED IN A HOSTILE SEA AREA

1 - Applicability

This ETSO gives the requirements which immersion suits for use on helicopters operating to or from helidecks located in a hostile sea area (as defined in JAR-OPS 3.480(a)(12)(ii)(a)), that are manufactured on or after the date of this ETSO, must meet in order to be identified with the applicable ETSO marking.

2 - Procedures

2.1 - General

Applicable procedures are detailed in CS-ETSO Subpart A.

2.2- Specific

This ETSO and the appendices refer to JAR-OPS 3 at Amendment 2 dated 1 January 2002.

3 - Technical Conditions

3.1 - Basic

3.1.1 - Minimum Performance Standard

Standards set forth in Appendix 1 to this ETSO.

3.1.2 - Environmental Standard

None.

3.2 - Specific

None.

4 - Marking

4.1 - General

Marking is detailed in CS-ETSO Subpart A paragraph 1.2.

4.2 - Specific

As given in Appendix 1.

5 - Availability of Referenced Document

See CS-ETSO Subpart A paragraph 3.

EN documents may be purchased from the European Committee for Standardisation (CEN), Rue de Stassart 36, B-1050 Brussels, Belgium or any CEN member.

JAA documents may be purchased through Information Handling Services. Addresses of the worldwide IHS offices are listed on the JAA website (www.jaa.nl) and IHS's website (www.global.ihs.com)

APPENDIX 1. EASA STANDARD FOR HELICOPTER CREW AND PASSENGER IMMERSION SUITS FOR OPERATIONS TO OR FROM HELIDECKS LOCATED IN A HOSTILE SEA AREA

1. Purpose

   1.1 This specification prescribes the minimum standard of design and performance for helicopter crew and passenger immersion suits that are designed to be used with an approved lifejacket.

2. Scope

   2.1 This standard covers immersion suits for use on helicopters operating to or from helidecks located in a hostile sea area (as defined in JAR-OPS 3.480(a)(12)(ii)(a)).

   2.2 The immersion suit shall comprise at least the following:-
   a) A dry coverall
   b) Hand and head coverings

   2.3 Where applicable any additional or optional items designed to be used with the suit (but excluding the lifejacket) e.g. thermal liner, shall be considered as part of the immersion suit as far as this specification is concerned.

3. Donning

   3.1 It is assumed for the purpose of this specification that the suit is donned prior to boarding the aircraft and is worn with an approved lifejacket.

   3.2 The immersion suit and any attached equipment shall be capable of being donned without assistance and shall be capable of being sealed and adjusted by the wearer without assistance prior to boarding the aircraft.

   3.3 Air retained inside the suit after donning which could adversely affect egress, the manoeuvrability or flotation attitude, shall be capable of being exhausted, either automatically or by the wearer.

   3.4 It must be possible to complete all actions required to don the head covering required by paragraph 2.2(b) and seal the suit within 10 seconds. These actions shall be possible both when seated with harness fastened and wearing the uninflated lifejacket and when in the water while wearing the inflated lifejacket.

   3.5 The wearer shall be able to complete all actions required to don the hand covering required by paragraph 2.2(b) when tested in accordance with paragraph 3.11.6.5 of EN ISO 15027-3:2002 except that this shall be demonstrated by each subject after immersion in water at a temperature no higher than 10°C (50°F) for a period of 3 minutes.

4. Freedom of movement

   4.1 The immersion suit shall be designed to a standard which will allow the wearer to carry out all normal and emergency functions and movements necessary for the operation of a helicopter and its equipment.

4.2 The design of the immersion suit shall allow tailoring to fit the individual wearer or, where suits are not individually tailored, the size range must be satisfactory for all wearers whose significant body dimensions range from the 5th percentile female to the 95th percentile male, and adequate for most of the 5% at each extreme.

4.3 The immersion suit, when correctly donned and adjusted, shall not prevent the wearer from having an acceptable field of vision. This shall be demonstrated by testing to paragraph 3.7 of Appendix 2.

4.4 The immersion suit when worn with the inflated lifejacket shall allow the wearer to turn from a face down position into a stable face up floating position within 5 seconds. This shall be demonstrated by testing to paragraph 3.2 of Appendix 2.

5. Comfort

5.1 The design of the immersion suit shall minimise any discomfort to the wearer so as to avoid jeopardising safety. Particular attention should be given to the level of thermal comfort afforded the wearer on long into-sun flights in summer.

6. Compatibility

6.1 Approval of an immersion suit to this specification shall take into account the compatibility between the suit and any approved lifejacket and sprayhood that is intended to be worn with it. The performance of the suit and lifejacket combination shall be tested in accordance with Appendix 2 of this specification.

6.2 The immersion suit shall be tested with each type of lifejacket that the suit is designed to be compatible with. If it is to be approved for use with more than one type of lifejacket, the performance testing of Appendix 2 shall be repeated with each additional type of lifejacket.

6.3 The immersion suit shall be designed, and the materials used in its construction chosen, to have no features which would be likely to have any detrimental effect on the operation of any helicopter or its equipment. In particular any part of the suit which might pose a snagging hazard during flight, emergency egress or recovery, shall be suitably covered, protected or restrained. All materials used shall be compatible with materials used in the construction of the appropriate approved lifejacket, sprayhood or liferaft.

6.4 Any attached equipment shall not compromise the basic survival function of the immersion suit by causing puncturing, fretting or distortion of the material, or changes in its mechanical properties.

7. Materials

7.1 All materials used shall be to an acceptable specification which shows the material to be suitable for its intended application. The materials used shall meet the requirements of paragraph 4.14 of EN ISO 15027-1:2002, with the exception of paragraph 4.14.3 of EN ISO 15027-3:2002 Resistance to illumination test.

7.2 The immersion suit and its equipment shall be so designed and constructed as to remain serviceable for the period between scheduled inspections. The choice of materials used shall be such that, when stowed in accordance with the relevant instructions, neither the immersion suit nor its attached equipment shall be liable to become unserviceable through material deterioration or chafing, or from any other cause. Due consideration shall be taken of the possible temperature variations during stowage which may range between -30°C and +65°C (-22°F and +149°F). This shall be demonstrated by testing to paragraph 3.9 of EN ISO 15027-3:2002. The normal operating temperatures for the immersion suit shall be -5°C to +40°C (23°F to 104°F).

7.3 The outer fabric used in the construction of the suit shall be of low flammability. It shall not have a burn rate greater than 100mm/min (4in/min) when tested in accordance with the horizontal test of JAR-25 Appendix F Part 1 or other approved equivalent method.

8. Buoyancy

8.1 The trapped buoyancy due to the suit and recommended clothing, with the suit fully vented, shall be no more than 150N (33.7lbf) when measured in accordance with paragraph 3.11.7.2 of EN ISO 15027-3:2002.

9. Thermal protection

9.1 The suit shall provide the user with thermal protection in the water that at least satisfies the test requirements of paragraph 3.8 of EN ISO 15027-3:2002 as a class B suit system.

10. Water ingress

10.1 The immersion suit shall be so constructed that not more than 200g (7oz) of water shall leak into the suit when measured in accordance with paragraph 3.7 of EN ISO 15027-3:2002.

11. Conspicuity

11.1 Passenger Immersion Suits
To facilitate search and rescue operations, those parts of the suit which will be visible when in the water shall be of a highly conspicuous colour and comply with paragraph 4.5 of EN ISO 15027-1:2002.

11.2 Crew Immersion Suits
Where possible immersion suits for crew use shall meet the requirements of 11.1. However, the choice of suit colour may vary to minimise the risk of the suit reflecting on surfaces within the flight deck.

11.3 A passive light system of retro-reflective material shall be provided. This shall conform to the technical specification detailed in IMO SOLAS 83, Chapter III, Resolution A.658(16), Annex 2 or equivalent. A minimum area of 300cm2 (46in2) shall be provided, distributed in accordance with paragraph 4.12 of EN ISO 15027-1:2002.

12. Inspection Testing and Repair

12.1 The procedure for inspecting, testing and repairing immersion suits shall be established by the manufacturer and shall be capable of ensuring that all suits satisfy the requirements of this specification throughout their service lives.

As part of the procedure, suits shall be inspected at intervals to ensure they are always ready for immediate and effective use in the water. Special attention shall be paid to seals and fasteners. Suits shall be required to be immediately removed from service for repair or replacement if damage or deterioration is discovered that may lead to the suit failing to satisfy a routine leak test when one is next carried out.

12.2 The procedures for servicing, inspection, repair and testing shall be described in the manufacturer's manual.

12.3 The frequency of servicing and inspections shall be agreed with the manufacturer holding design approval for the suit.

13. Marking

13.1 Each detachable part of the immersion suit assembly shall, where reasonably practicable, be marked with:-

(a) The manufacturer's approved inspection stamp.
(b) The part number.
(c) Date of manufacture or batch record.
(d) Serial number

13.2 In the case of passenger immersion suits, the immersion suit shall be marked with:-

(a) Suit model designation
(b) The manufacturer's name and address
(c) Date of manufacture and Serial Number
(d) Date at which next scheduled service and overhaul are due
(e) Modification standard

13.3 In the case of crew immersion suits, the immersion suit shall be marked with:-

(a) The name of the crew member to whom it has been allocated
(b) Rank of crew member marked externally, e.g. epaulettes.
(c) Suit model designation
(d) The manufacturer's name and address
(e) Date of manufacture and Serial Number
(f) Date at which next scheduled service and overhaul are due
(g) Modification standard

13.4 When marking is not practicable alternative means must be agreed.

APPENDIX 2. IMMERSION SUIT / LIFEJACKET SYSTEM PERFORMANCE TESTING

1. Purpose

1.1 These tests are to demonstrate satisfactory performance of the specified immersion suit/lifejacket combination which together make a unique safety system. They shall be carried out for every immersion suit/lifejacket combination for which approval is required to ensure compatibility for that combination.

2. Test conditions

2.1 The following tests shall be conducted in calm water. The water temperature shall be 25±2°C (77±4°F).

2.2 Pass/fail criteria
All samples shall pass all objective tests for the entire system to meet the requirements of ETSO-2C503 Immersion Suits and ETSO-2C504 Lifejackets. However, due to the high variability between subjects and the difficulty in assessing some subjective measures, it is permitted that an immersion suit / lifejacket combination does not completely meet the requirements of the following subjective tests in a single example and in no more than in one test subject. In these circumstances, two other subjects within the same weight category and with the same sex, should be subjected to the same test. If this additional test is still not clearly passed then the immersion suit / lifejacket combination shall be deemed to have failed, whilst if it is clearly passed then both items may be deemed to have passed the test overall when used in the tested combination.

3. Performance tests

3.1 Jump Test.
Each test subject shall perform a jump test in accordance with paragraph 3.11.6.1 of EN ISO 15027-3:2002.

3.2 Turning Test
Each test subject shall perform a turning test in accordance with paragraph 3.11.6.3 of EN ISO 15027-3:2002.

3.3 Escape Test Underwater
Each test subject shall be required to swim through an opening not greater than 430mm x 355mm (17in x 14in) (minimum acceptable size of helicopter escape window) positioned with the top of the opening at least 300mm (12in) below the surface of the water wearing the uninflated lifejacket. At least one of the subjects for this test shall be required to have a shoulder width measurement of at least 500mm (19.7in).

3.4 Swim Test
Each test subject wearing the immersion suit, clothing and inflated lifejacket shall swim on their back for 20 minutes. The hands and arms shall be kept in the water even if not being used for propulsion. Each test subject shall then board a liferaft fitted with boarding facilities, without undue effort and without assistance, with the suit sealed, the lifejacket inflated and the sprayhood deployed. The pool used shall

be of sufficient size and depth to prevent the subject gaining assistance by "pushing off" from the side or bottom while performing this test.

3.5 Freeboard
Immediately following the swim test, the clearance of each test subject's face above the water shall be measured, with the subject behaving normally and when simulating unconsciousness. The clearance of the mouth (mouth freeboard) shall be a minimum of 120mm (4.7in) above the waterline in both cases. It shall be established that the nose freeboard is not less than the mouth freeboard.

3.6 Floating position
The angle of the test subject's body shall be measured by an appropriate method. The angle between the body and the horizontal shall be recorded and shall not be greater than 60°.

3.7 Field of vision
The wearer's field of vision shall not be unduly restricted when tested in accordance with paragraph 3.11.6.6 of EN ISO 15027-3:2002

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11 Measurement Proforma

Participant Identification Number for this trial:__________

Proforma

	1	2
Weight measure wearing regular clothing (kg).	.	
Height measured with shoes off (cm).	.	
Over regular clothing don Survival Suit and re-breather.		
Weight Measured Wearing Survival Suit and Re-breather (kg).	.	
Scan 1. Scanner Position, Survival Suit.	.	.
Scan 2. Egress Position, Survival Suit.	.	.
Scan 3. Sitting Position, Survival Suit.	.	.
Change into form-fitting clothing.		
Weight measured wearing form-fitting clothing (kg).	.	
Scan 4. Scanner position, form-fitting.	.	.
Scan 5. Egress position, form-fitting.	.	.
Scan 6. Sitting position, form-fitting.	.	.
Window Egress Task	**Pass**	**Fail**
A. CAA Push-out minimum 483 x 432mm		
B. Super Puma Push-out 440 x 500mm		
C. JAR/FAR - Type IV Minimum 660 x 483mm		
D. Super Puma - Type IV 680 x 510mm		
E. Bell 412 – Type IV 686 x 559mm		
F. Smallest		

Notes: