

How do Royal Marines REALLY measure up? Anthropometry in Mission-Critical Design

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SUMMARY

This paper outlines the Human Factors (HF) work done as part of a major design project for a Multi-Role Strike Ship (MRSS), a type of Landing Dock Platform (LDP) capability upon which the Royal Marines (RM) are Embarked Military Forces (EMF). The project consisted of collecting anthropometric data from RMs in support of the MRSS design and comparing the data with the existing LPD capability with a view to ensuring that the assault routes and assembly areas on board are fit for purpose. By applying the findings of this work to the design, the overarching objective of ensuring safe and rapid disembarkation via the assault routes can be maintained and achieved by the new design. The work was delivered by a HF specialist for the Ships Naval Design Partnering (NDP) and the Ministry of Defence (MoD). This aim of this paper is to demonstrate the importance of employing foundational HF assessment and analysis tools and the wide-reaching impact the outcomes can have on a design.

KEYWORDS

Human Factors in Defence, Human Factors Integration, Anthropometry, Ministry of Defence

Introduction

The MRSS will be crewed by the Royal Navy (RN) and will host EMF from the RMs who will launch missions from the MRSS. Preparations for missions take place in the assembly areas on board. RMs bring their personal items to this area and collect weapons and munitions dependant on the mission requirements. They then return to their accommodation and wait for further instructions. Once orders are received to move out, the RMs re-enter the assembly area to pick up their packs and weapons and they then disembark the MRSS. To disembark, EMF travel along designated assault routes which take them to either land, sea or air modes of disembarkation.

Mission demands may require multiple groups of personnel to operate simultaneously from within the MRSS, which leads to certain requirements for the design of the assault routes onboard. One of the driving requirements for this work is that two fully equipped RM commandos must be able to pass each other on the assault route travelling in opposite directions and have appropriate clearance to do so. For the purposes of this paper, “appropriate clearance” is clear, unimpeded access along the full length of the assault route without snag hazards, trip hazards or any other impediment that could limit access.

The Guide to Engineering Activities and Reviews (GEAR) is used by the MoD to facilitate Human Factors Integration (HFI) assurance from an engineering perspective. This paper covers work that falls into the assessment stage of GEAR where a concept (or illustrative) design is developed and presented to the MoD to seek approval to progress to the next stage (the Outline Business Case, OBC), where mature requirement specifications and a solution are approved (the Full Business Case, FBC). This process is outlined in Joint Services Publication (JSP) 912 (UK MoD, 2024).

The purpose of HFI into the illustrative design phase for MRSS was to understand the fundamental size and space constraints that would be placed on the design based on use-case requirements from the EMF when using the assault routes and assembly areas. Obtaining input data at this early stage in the project provided the opportunity to influence the design and ensure the space envelopes were carried through to OBC and FBC and finally through to manufacture and into service. Whilst there are existing sources of anthropometric data available within the defence industry such as the Anthropometry Survey of UK Military Personnel conducted in 2006-7 (Pringle et al, 2011), as well as previous studies having been conducted to inform warship design generally, the specific measurements required for the MRSS design were not available in any known data source. These measurements are outlined in the methodology.

Methodology

The method used for this study was an observational study design. Data was collected across closely scheduled site visits to provide a snapshot of access requirements for RMs when they are traversing the assault routes ready to disembark the ship. This is known as a cross-sectional study which was chosen as a proportionate approach during the early design stage, was cost-effective and yielded immediate results.

The first of two stages involved a visit to “40 Commando” at Taunton to learn from key users and previous user experiences on an LPD platform, including the types of equipment, kit, and clothing RM EMF could be carrying whilst using an assault route. Two serving RM Commandos familiar with operational equipment participated in the study. The limitations associated with sample size are address in the discussion; however, the primary purpose was to derive conservative envelope requirements. The participants were measured using a ruler, tape measure and large bone anthropometer. The anthropometric data of particular interest included stature, bideltoid width, chest depth and waist/hip breadth and depth. These measurements were used to derive maximum static body dimensions, which were then combined with clothing and equipment corrections to generate functional space envelopes.

Measurements of key dimensions of the equipment, kit, and clothing were also taken to further understand clearance requirements This included the impact of wearing webbing, a bergen and/or a Next Generation Light Anti-Tank Weapon (NLAW) has on the space RM EMFs require to ensure appropriate clearance when disembarking. Clothing corrections were applied to ensure that the derived dimensions reflected operational conditions; boot, helmet and jacket corrections were collated.

The second part of the study involved a visit to HMNB Devonport to visit HMS Bulwark (current class of LPD) to learn from key users how the assault routes and assembly area are used by crew and EMF. The illustrative design team used HMS Bulwark design as the basis for the new design. Given the requirement to allow two RM EMFs to pass each other along the assault route, the designers needed to make an informed decision on the assault route width based on recommendations from HF. The site visit provided the opportunity to observe the operational environment directly and conduct walkdowns of the assault routes and assembly areas. As well as those mentioned, RM accommodation, vehicle deck, well dock and aircraft deck were also visited.

Assault route dimensions were of specific focus; measurements including corridor width, door apertures, and ladder/stairwell widths, were taken. Bulkhead heights were also measured, which EMFs are required to step over when disembarking. Collecting the measurements allowed suitable clearance requirements to be analysed.

Results

It was important to ensure that the data collected, and application of that data, could be used to optimise EMF performance once given the order to disembark. The safety of the personnel whilst traversing the assault routes and the speed at which they can disembark has a direct impact on the mission they have been called to support. In safety-critical environments, restricted access is typically associated with an increased likelihood of human error or potential injury; in this context, it also translates directly to operational risk.

Anthropometry

Figure 1 provides the anthropometric data collected from the two RM participants, including any observations made at the point of data collection. All measurements are in millimetres (mm) unless otherwise stated.

ID	Description	PPS1	PPS2	Notes
1	Stature (no boots or helmet)	1820	-	PPS 2 not measured as boots and helmet are standard issue and therefore the correction could be ascertained from the measurement.
2	Stature (no helmet, with boots)	1850	-	PPS 2 not measured as per ID 1. Boot correction: 30 mm; Helmet correction: 30 mm.
3	Stature (with boots and helmet)	1880	1850	PPS1 79%ile; PPS2 69.9%ile. Uncorrected statures were used and the measurements compared to British Male adult data from the ages of 18 to 64.
4	Bideltoid width	542	544	Wearing combat gear – light-weight cotton shirt and trousers.
5	Chest depth	320	306	Wearing combat gear – light-weight cotton shirt and trousers.
6	Waist/hip breadth w/ webbing	534	464	The webbing was not packed, however the compartments along the belt have structural integrity and were therefore considered to be representative for the purposes of this study. Webbing is issued as standard, but RMs can buy their own if they choose.
7	Waist/hip depth w/ webbing	391	432	Webbing un-packed as per ID 6.
8	Bergen (pack) + chest depth	670	-	Bergens were appropriately loaded to show the size and shape of the pack. It was noted that the packs can be filled with personal items and equipment weighing up to 60kg which could affect the size and shape when carried. Bergen depth, when moderately packed: 350 mm (inferred from ID 5 and ID 8).
9	Bergen (pack) width when worn	660	-	Bergens were loaded as per ID 8.
10	Bideltoid width w/ jacket	598	-	Jacket used was the standard issue light-weight jacket that is used for warm weather. A heavier jacket would be used for cold weather, particularly in arctic conditions. This was not available during the study due to geographical location. Jacket correction: 56 mm (14 mm per layer) Several layers of the jacket are accounted for in this measurement (around both arms and either side of the chest).
11	Chest depth w/ jacket	333	-	See notes on jacket for ID 10. Jacket correction: 13 mm (6.5 mm per layer).
12	Waist/hip breadth w/ webbing + jacket	554	-	See notes on jacket for ID 10. Jacket correction: 20 mm (10 mm per layer).
13	Waist/hip depth w/ webbing + jacket	401	-	See notes on jacket for ID 10. Jacket correction: 10 mm (5 mm per layer). Jacket will have been more compressed on the bony areas, like the hips/pelvis.
14	NLAW width/length	1000	-	NLAWs are carried by securing it under the flap at the top of the bergen. Due to the shape and configuration of the weapon, the NLAW must be positioned off-centre to the person carrying it. NLAW lengths can vary; the one measured was 1000 mm, but the participants suggested that the lengths could be up to 1500 mm.

Figure 1: Anthropometric Data Collected from Royal Marines

Clothing Corrections

Clothing corrections for boots, helmets and a light-weight warm weather jacket were established or inferred. The following corrections were recommended for use for the MRSS design, and should be added to the unclothed data:

- Boot correction: 30 mm
- Helmet correction: 30 mm
- Jacket correction (per layer): 10 mm

With regards to the jacket correction, based on the variation observed in the measurements taken of PPS1 whilst wearing the jacket (which ranged from 5 mm per layer to 14 mm per layer, see Figure 1), it was inferred that the average jacket layer measures 10 mm. This range gives an average of 9 mm, plus 1 mm for conservatism and ensuring access in tighter spaces.

Maximum width of EMF

Based on all measurements taken during the Taunton visit, when considering a space envelope for RM EMF the following maximum was recommended for the MRSS design. These dimensions are inferred from the data in Figure 1, ID 9.

- Maximum width (RM wearing a jacket, body armour, and bergen): 660 mm

A clothing correction is not required for this measurement because the bergen's width is wider than the bideltoid width. Having consulted the RM Anthropometric Data survey (Pringle et al, 2011), the 95th percentile male bideltoid breadth is 568 mm. With four jacket layers added to this measurement to correct it, the result still falls short of 660 mm by 52 mm, making 660 mm an appropriately conservative working maximum for clearance design.

Maximum height of EMF

Based on the data collected during the Taunton visit, when considering a space envelope for RM EMF the following maximum was recommended for the MRSS design. These dimensions are inferred from the data in Figure 1, ID 3, the corrections given in sub-section "Clothing Corrections", and the RM Anthropometry Survey (Pringle et al, 2011).

- Maximum height (RM wearing boots and helmet): 1960 mm

This measurement is made up of 95%ile RM stature (1900 mm) from the anthropometry survey (Pringle et al, 2011) and the boot and helmet clothing correction ($30 + 30 = 60$ mm). The stature measurement was taken from the survey rather than the data collected in Taunton as the tallest participant (PPS1) was around 80%ile for stature, and therefore the maximum was used.

The maximum width, maximum depth and the maximum height of RM EMF was based on data collected at Taunton, and clothing corrections were established or inferred based on the collected data.

Anthropometry and Space Constraints Onboard

Figure 2 provides the anthropometric data collected from onboard HMS Bulwark, including any observations made at the point of data collection. All measurements are in millimetres (mm) unless otherwise stated. Based on the collected data, further observations were made:

- Based on a doorway width of 870 mm (BULW1), EMF can travel through the door forwards (660 mm) or sideways (690 mm).
- When EMF are carrying weapons, travelling through doorways (including stepping over bulkheads) may become challenging depending on how the weapon is carried and the type of weapon carried.
- Based on an assault route width of 1480 mm (BULW2), EMF can travel side-by-side, moving in opposite directions either forwards ($2 \times 660 = 1320$ mm) or sideways ($2 \times 690 = 1380$ mm).

- EMF will be wearing body armour as well as carrying their bergens and weapons, which will add depth to the measurements.

ID	Description	Measurement	Notes
BULW1	Doorway width from assault route-accommodation corridor into the assembly area	870	No weapons are carried through this door, which leads to the accommodation from the assembly area. Weapons remain in the assembly area until EMF are ready to leave their accommodation and carry out their mission.
BULW2	Assault route (green mile) corridor width	1480	The measurement was taken at the widest point, noting that any "furniture" on the corridor walls is kept to a minimum along all assault routes to allow as much access and free movement of EMF whilst wearing their bergens. The assault route is known as the green mile as the floor covering is green which distinguishes it from other corridors and routes on the ship.
BULW3	Bulkhead height	460	The bulkhead measured was situated on 4-Deck (the vehicle deck) and located at the bottom of two assault route ladders. Two doors must be moved through at this point in quick succession. The measurement was taken from the floor to the top edge of the bulkhead. EMF (and anyone else travelling through this aperture) is required to step over this bulkhead to continue forward progress.
BULW4	Doorway width (vehicle deck)	870	This measurement was taken from the same door as the bulkhead measurement in BULW3.
BULW5	Doorway height (vehicle deck)	1370	This measurement was taken from the same door as the bulkhead measurement in BULW3 and BULW4. Top of door height from floor: 1830 mm (inferred from BULW 3 and BULW5).
BULW6	Assault route ladder (vehicle deck)	920	This measurement was taken from one of the assault route ladders, rail to rail. It should be noted that this is not a vertical ladder. The ladder measured was in the same area as the doors measured in BULW3, 4 & 5.

Figure 2: Measurements Collected from onboard HMS Bulwark

- The height of the door aperture from the floor of the ship is 1830 mm (BULW5) and the maximum height of the EMF is inferred to be 1960 mm, meaning there is a negative clearance through the doorway of 130 mm. When considering male stature, a stature of 1830 mm with clothing corrections removed, gives an inferred measurement of 1770 mm ($1830 - 30 - 30 = 1770$ mm). Using PeopleSize 2020 as a guide (Open Ergonomics, 2020), recognising it does not contain specific military data, a stature of 1770 mm is around 54th percentile. This means that nearly half (46%) of the RM population will have to adjust their posture to pass through the doorway when wearing their boots and helmet. This alteration in posture may increase the RMs' effective dynamic envelope, resulting in wider clearance requirements than would be needed if they could maintain a neutral posture while passing through.
- The width of the assault route ladders (920 mm) is sufficient to accommodate a single EMF (660 mm).
- It is acknowledged that not all EMF will be carrying NLAWs when moving along the assault routes onboard. However, given the width of the NLAW when stowed in the bergen is a minimum of 1000 mm, if two EMF pass each other with one carrying an NLAW, they will not be able to pass through the space with adequate clearance when travelling in a forward direction ($660 \text{ mm} + 1000 \text{ mm} = 1660 \text{ mm}$ space requirement). The assault route width is only 1480 mm, meaning there is a negative clearance of 180 mm ($1480 - 1660 = -180$ mm). However, the individual carrying the NLAW can turn sideways to pass another person, which allows for two people to pass with appropriate clearance. This is also true should two individuals carrying NLAWs need to pass each other.

Discussion

This study has several limitations that should be considered when interpreting the results. An existing source of UK Forces anthropometric data and UK population data was used in support of

this study (Pringle et al, 2011 and Open Ergonomics, 2020). The MoD have recognised that the anthropometric data available is not fully representative of today's Armed Forces; that is particularly evident for women and minority ethnic groups (Evans et al, 2024). The MoD has issued a survey for a more comprehensive dataset, and initial samples have been collected but these measurements were not available when this study was conducted.

The study involved a small number of participants; however, the intent was not statistical generalisation but the derivation of space envelopes including conservative clothing and equipment corrections, to support the illustrative design for the MRSS assault route. It should be noted that static dimensional compatibility does not guarantee adequate clearance under dynamic movement, particularly when personnel are load-bearing and moving at speed.

When considering chest depth, the body armour that the participants had available to wear during the study did not have the chest plates in the front or back. These plates increase the thickness of the body armour and therefore will add depth to the chest measurements. This is of particular importance when the EMF are carrying their bergens along the assault routes and need to pass other EMF travelling in the opposite direction. Using the current dimensions and the data collected, if two members of the EMF were to pass each other moving sideways (as opposed to forwards), there is 100 mm of clearance that allows this (1480 mm assault route width – 2 x 690 mm chest depth carrying bergens (1380 mm) = 100 mm). Adding the increased depth for the chest plates, and the potential for bergens to be packed beyond the size used in the study, passing someone becomes challenging and full clearance is not achievable. Given this could reduce the speed of travelling along the assault routes, this could also have increase operational risk.

Whilst the weapons and equipment that EMF could be carrying has been considered, this was not covered in detail by this study. Participants were able to provide an example of an NLAW and an assault rifle to give an indication of what they could be carrying when travelling along the assault routes. As assault rifles are hand-carried and can be repositioned dynamically, static dimensional measurement was not considered appropriate as the EMF can manoeuvre the weapon to an appropriate position that will allow for them to pass another person when travelling along the assault route. It is acknowledged that there are multiple other weapons that could be carried by the EMF, all of which could impact someone's ability to move freely along the assault routes, particularly when it comes to traversing the ladders, and therefore increase journey time to disembarkation.

For this study, it was not possible to access the arctic clothing and cold weather attire that the RMs would wear if located in northern locations. This equipment and the personnel who use it are based outside of the UK and therefore fell outside of the scope of this study. The clothing corrections established during this study only apply to the warmer weather attire and therefore do not give a worse case measurement that can be applied to the MRSS design. The absence of cold weather attire means that a worst-case operational envelope has not yet been validated. It is assumed that all clothing corrections and operational envelope sizes would increase if the participants were wearing cold weather attire, and it is acknowledged that the RMs would have different equipment with them for cold weather missions (for example, skis). This could then impact the minimum clearance requirements for the assault routes to allow EMF to move along them, through doorways, and up/down ladders.

When it comes to the webbing worn by the RMs, it is noted that there is variation in where the RMs choose to wear the belts around their hips/waist. This could be due to comfort, fit of the belt, the type of belt, and what is packed into the webbing. This variation is not captured in this study due to the small sample size and due to the variety of different webbing belts that could be used by RMs given they can, and do, purchase their own equipment down to personal preferences. The lack of

data surrounding measurements of RMs whilst wearing webbing is not considered to have a significant impact on this study because the width and breadth measurements are smaller than those collected at chest height when carrying a bergen.

Conclusion

The purpose of this study was to collect anthropometric data from RMs to inform the MRSS assault route design and compare these data to the existing LPD capability. Although the study has limitations, meaningful data were derived and applied to the design. By grounding clearance requirements in measured user and equipment dimensions, a direct link was established between design decisions, personnel safety during disembarkation, and operational risk. Four design recommendations were made, in addition to a recommendation for future work, that would enhance the outcome of this study and better inform the MRSS design. The recommendations are detailed in Figure 3.

ID	Recommendation	Notes
REC1	Doorway width shall be no less than 870 mm.	Consider weapons and equipment carried through the doorway when determining the appropriate doorway apertures.
REC2	The assault route throughway width shall be no less than 1480 mm.	Consider the different weapons and equipment that will be carried along the assault routes when determining the appropriate assault route width.
REC3	Doorway aperture height shall be maximised where possible, and be no lower than 1830 mm.	Existing doorway heights do not accommodate the full target audience, with approximately half of the RM population needing to adjust (reduce) their stature to pass through the doorways when wearing their boots and helmets.
REC4	Assault route ladder useable width (between rails) shall be no less than 920 mm.	Consider the different weapons and equipment that will be carried up/down the ladders when determining the appropriate usable ladder width.
REC5	The additional work outlined [in this paper] shall be completed to close the gaps identified by this study.	The recommended future work considers arctic weather clothing and cold weather attire, weapons, and equipment, and goes on to compare the updated space envelope requirements with the assault route dimensions, and usability of the assembly area onboard the MRSS. It would also take account of any updated anthropometric data sets produced by the MoD which contain Forces-specific data.

Figure 3: Recommendations

The early inclusion of an anthropometric study within this large-scale design project ensures that the MRSS design reflects the specific needs of the intended users, particularly regarding access requirements and space constraints. This simple study provided data that directly supports the timely, smooth, safe and rapid disembarkation of EMF in a mission-critical scenario and timeframe. It also highlights the meaningful impact early HF integration can have during a large-scale design project such as this.

Beyond the immediate design benefits, the study demonstrates the value of grounding pertinent space envelope requirements and accessibility decisions in real user data rather than assumptions or legacy measurements (even if the sample size is small). Undertaking the study at an early stage in the design process made it possible to identify potential user-equipment mismatches before they became embedded in the design, avoiding later rework and ensuring that design trade-offs were informed by evidence. The process also reinforced how even small variations in user size and movement patterns can have significant operational consequences when speed, safety and coordination are critical.

It is proposed that anthropometric data collection should be embedded as a planned and resourced activity early in the project lifecycle, rather than being treated as an optional validation step, to ensure maximum benefit to the design. As always, close collaboration between HF specialists,

designers and engineers is essential, as it ensures that the data gathered is relevant and usable and aligned with key design requirements. This study demonstrates that small, focused anthropometric assessments can provide significant value when undertaken at the appropriate stage of the design process. By integrating measured user and equipment envelopes early, potential mismatches between personnel and platform were identified before they became embedded in the design baseline. In mission-critical environments, even small dimensional incompatibilities can have disproportionate operational consequences. Focused HFI activities can ensure that such risks are identified and addressed while design flexibility remains.

Implications for Future Work

Further anthropometric measurements are needed to capture the space envelope requirements for EMF when wearing arctic clothing and cold weather attire and taking account of the range of equipment and weapons the RMs could be carrying and using in these colder climates. It is suggested that this study is repeated, with a larger sample size and with the full body armour available (with chest plates) to mitigate most of the limitations identified in this study. These data should then be compared to the existing LPD assault route measurements taken during the original study to understand if the recommended minimums in this paper are still tolerable for the MRSS design. Any future study should take account of any updated anthropometric data sets published by the MoD which contain Forces-specific data to ensure the most up-to-date information is used to inform the MRSS design.

Once the repeat study has been completed, it is suggested that the updated space envelope requirements are then directly compared to the existing LPD assembly area size and the size that has been proposed in the MRSS illustrative design. This additional work should consider how the assembly area space is used, how many people will be using the space, and whether there are new and emerging technologies available that could support with the smooth and rapid dispatch of EMF to disembarkation. Such technologies could include intelligent lighting systems to identify the most suitable route a team of RMs should take, use of electronic tagging of EMF to check then in and out of certain areas around the ship, and the use of portable electronic devices to support the guides that work alongside the EMF in the assembly areas. More research is required to identify which technologies would be of benefit, and how they are then integrated into the procedures and ways of working onboard.

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