Sizing up Royal Australian Navy Sailors

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In order to maximise crew performance, anthropometric data, that is, data on the lengths, breadths, depths, and circumferences of the human body, should be incorporated into design for all equipment, and platform spaces involving human life and work at sea. For a military platform an additional imperative is sustainment of the crew's warfighting capability.

In support of the Australian Defence Force maritime procurement program, existing anthropometric datasets were analysed and found to need updating. To ensure relevant anthropometric data are available an Anthropometric Survey of the Royal Australian Navy (ASRAN) was completed in 2015 on 1,322 (232 female and 1,090 male) Permanent RAN personnel aged 18–54 years from Fleet Base East and West. Eighty-seven digital and manual measures required for ship, equipment and clothing design were measured.

This report outlines the basis of sampling for ASRAN, a comparison with other nation's Navies and also the Australian Army. The summary statistics from ASRAN will be optimised for use by the future submarine and future frigate programs, enabling objective accuracy in the use of 3D engineering design technology. In addition, the data will be used to update habitability design guidance documents. This will aim to ensure the safety, working and living conditions are appropriately maintained on what can be severely space constrained platforms.

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1. Background

Anthropometry refers to the measurement of the lengths, breadths, depths, and circumferences of the human body specifically relating to reach, clearance and fit (NASA, 2010). In order to maximise crew performance, anthropometric data should be incorporated into all areas and equipment designed for human work.

Defining crew anthropometric characteristics is recommended to occur in the conceptual design phase of a project to enable the habitable volume requirements and overall architectural layout designs to occur in the preliminary design phase (NASA, 2010). Moreover, there is considerable risk that design decisions taken in the absence of anthropometry guidance will be expensive to change later in the capability lifecycle. Considering such timelines, there are a number of maritime ADF (Australian Defence Force) projects that should consider the anthropometric data options available to them.

The Royal Australian Navy (RAN) has several new platforms to be procured as part of the Defence Capability Plan, including the Future Submarine, Future Frigate, and a Submarine Escape, Rescue and Abandonment System (Australian Government, 2012). Further to this there are a number of platform upgrade projects to sustain and enhance the capability of the current fleet. With these projects there is a prime opportunity to optimise the accommodation and fit of the operators, and ultimately the habitability of the platforms which can affect personnel morale, safety, health and comfort, job performance, and retention (Department of the Navy, 2012; NATO, 1993; Wilcove & Schwerin, 2008).

The last RAN specific anthropometric survey was reported in 2000, and more recently an anthropometric survey of the Australian Army was conducted, referred to as the Australian Warfighter Anthropometric Survey (AWAS) (Edwards, Furnell, Coleman, & Davis, 2014). A review of these anthropometric data options was conducted, and it was suggested that whilst the AWAS data would be the most preferred current dataset to use; it was recommended the RAN collect anthropometric data specific to their population. This paper discusses a review of anthropometric data options, the sampling strategy for the Anthropometric Survey of the Royal Australian Navy (ASRAN), intended uses of the data, and future work.

2. Existing anthropometry data available to the RAN

DST Group was tasked to review the anthropometric datasets available for use by the RAN. Three main questions were investigated:

1. The suitability and quality of the existing RAN anthropometric data (2000).
2. The suitability and quality of the AWAS anthropometric data for use by the RAN.
3. The necessary sample size required for an anthropometric survey to accurately and confidently represent the RAN.

2.1 The 2000 RAN anthropometric reference data

The total sample size of the 2000 RAN anthropometric survey was 302. Of this, 251 participants were males, and 51 were females. The survey was published as a RAN Materiel Requirement Set (MRS) in 2000 (DEFAUST5000, 2000).

Assessment of the current RAN Anthropometric Reference data against international standards (ISO 15535, 2006) suggested that it was not appropriate for the design of a future platform. This anthropometric data posed several risks for current use:

1. Sampling out of date: The data was collected prior to year 2000. Future projects currently underway will not have operational platforms for another decade, therefore the age of the data is a concern. In addition the lack of a more recent dataset hinders the understanding of the demographic, secular, and gender changes in the RAN.
2. Total sample size, particularly of female participants, is too small: Using AWAS data with the sampling formula in ISO 15535 (2006), a sample of 251 males would provide 95% confidence and 1% accuracy for approximately 40% of the dimensions collected in AWAS. The sample of 51 females is not large enough to provide the same confidence and accuracy for any dimension collected in AWAS.
3. There is a risk that the sample is not generalisable to the current RAN population and specifically to submariners: There were presumably very few submariners in the sample due to the data being collected at HMAS Cerberus (Victoria), whereas submariners are based at HMAS Stirling (Western Australia). There were no job category breakdowns provided, therefore if submariners were sampled that is unknown. Furthermore the population sampled represented new recruits with an age range of late teens to late twenties. Therefore the full RAN age demographic is not represented which is problematic for accurately capturing weight and weight affected circumferences (which usually increase with age).
4. The survey data is limited and was conducted using only manual measurements: The data was collected manually, therefore certain data/dimensions that can be generated from 3D scans are not available. Further only the 5th, 50th and 95th percentile data is presented which

may restrict designing to a population beyond this scope, and, identifying risks in design to an accurate percent of the population. In addition minimum & maximum values are not provided, or skewness and kurtosis information. These data are useful to look at extremes for safety critical designs, and understanding the variability and distribution of the data.

For the reasons outlined above the existing RAN Anthropometric Reference Data (2000) was not considered generalisable to the current RAN population, and is not recommended for use in future designs.

2.2 Australian Warfighter Anthropometric Survey

Between 2010 (pilot survey) and 2012, the AWAS data were collected from Army personnel. The survey was undertaken across five Australian Army locations. It used 3D full body scanners together with manual measurements, to measure 2138 personnel. This sample was comprised of 1861 males, and 277 females (Edwards et al., 2014). To determine if the AWAS data would be an appropriate anthropometric dataset to use by the RAN, analysis was conducted on the differences within the ADF 1977 tri-service anthropometric data, and the differences in Army and Navy anthropometric data from different nations.

Significant differences in the means of the 1977 ADF Army and Navy data were found for hip breadth, inter-elbow breadth, palm length, hand breadth and foot breadth. In examining the recent UK and Canadian male Army and Navy anthropometric data a variety of significant differences in the means were found. For the UK data (DEFSTAN 00-250, 2008) these included: hip breadth sitting, vertical functional reach (sitting), buttock – popliteal length, popliteal height, sitting height, and waist circumference (natural). Significant differences found in the Canadian Army and Navy data (DRDC, 2013) included the dimensions: chest circumference, popliteal height, weight, waist circumference (omphalion), elbow rest height (sitting), hip breadth (standing), and buttock – knee length.

In addition to the analysis of Australian, UK, and Canadian Army and Navy anthropometric data, there are additional job selection factors which may create body size and shape differences in the current ADF Army and Navy populations. For example, current ADF pre-enlistment fitness assessment (PFA) standards are different (Billing, Doyle, & Linnane, 2011). The ADF Army also has stricter ongoing physical conditioning requirements than the ADF Navy, which may result in the Army personnel being a different size and shape, particularly in circumferences and mass.

The age breakdowns of the current ADF Army and Navy workforces were also compared to assess any differences in this area of demographics. Certain body dimensions are known to change with age. Therefore if an anthropometric dataset derived from a population other than the target population is used, choosing one with a similar demographic profile is recommended (Gordon, 1996; NASA, 2010).

The AWAS survey was specifically optimised to represent the operationally deployable force, therefore an age limit of 40 was set. Data taken from the Defence Human Resources Database MARS (Management, Analysis and Reporting Solution) in January 2014 indicated that approximately 20% of the age demographics of permanent Navy personnel are not represented in the AWAS survey, this has implications on weight and mass distributions that can fluctuate with age (NASA, 2010).

For the reasons outlined above it was deemed likely that the current ADF Navy population would differ to the current ADF Army population, especially when taking into account the Army age demographics captured in AWAS.

2.3 Summary of current data options

Given the limitations of the 2000 RAN Anthropometric Reference data, the objective differences between Army and Navy populations, together with the size and longevity of the Maritime projects in the Defence Capability Plan, it was recommended that the RAN conduct an anthropometric survey of current personnel.

A new RAN anthropometric survey was agreed upon, funded by both future submarine and surface ship projects. The University of South Australia was engaged to conduct the anthropometric survey under the direction of DST Group.

3. Sample plan for an Anthropometric Survey of the Royal Australian Navy

3.1 Sample size requirements for a RAN anthropometric survey

Guidance on anthropometric survey sample size is provided by scientific and international standards, such as ISO 15535 (2006). Determinations need to be made on the confidence level and accuracy of the data that is required. The Coefficient Variation (CV) of the dimension being measured (that is the degree of variation that characterises a particular dimension in a population) will also impact the number of participants required to meet a certain confidence and accuracy level. A sample size that is too low may capture insufficient variance in the anthropometric data to adequately reflect future populations (NRCC, 2010).

To determine a sample size for the RAN survey, the AWAS data was used to calculate the CV. Predicted sample size requirements were then calculated at 95% confidence at both 1% and 2% accuracy, for certain dimensions considered critical for design. For the dimensions considered, a sample size of 500 males and 500 females was estimated to provide 95% confidence at 1% accuracy for 56% of measures examined. A sample size of 1000 males and 1000 females was estimated to provide the same confidence and accuracy for 80% of the measures.

3.2 Target population and sampling

In order to capture a high level of confidence and accuracy for most dimensions, whilst accommodating funding and demographic constraints, the intention of ASRAN was to sample 1000 males, and 500 females.

The sampling strategy included decisions on: 1) employment category, 2) exclusion criteria, 3) age, 4) gender, and 5) site location. See Figure 1 for the full list of activities undertaken as part of the survey planning.

3.2.1 Employment categories

RAN employment categories include Permanent, Reservist and Foreign Service personnel. Permanent navy personnel were the preferred participants to sample. Reservists are more likely to be based in shore positions and less likely to have sea going tasks, and it was unknown as to what effect these positions have on body size. Reservists also have a much different age profile to the Permanent Navy. Foreign Service individuals were excluded to prevent demographic confounds in the data.

3.2.2 Exclusion criteria

The main exclusion criteria for participation related to medical fitness. Being medically unfit for duty covers a wide variety of conditions, some which may impact ability to take part in a survey and/or the representativeness of sea going personnel. On this basis it was recommended to exclude medically unfit personnel who met the criteria of:

- Unfit for operational deployment and joint exercises or,
- Determined to be medically unfit for further service

3.2.3 Age categories

Age is important data to collect in anthropometric surveys for several reasons. The occurrence of secular trends where the size and shape of individuals change from one generation to the next (Cole, 2003) is best examined by matching age (among other factors) in anthropometric surveys of a population.

In addition, anthropometry changes as a function of age. Humans typically gain adiposity (body fat) and lose muscle mass as they get older (Janssen et al., 2000). This can affect all measures taken in a survey, but most notably the circumferences (Furnell et al., 2014). For this reason the overall age distribution of a survey should be similar to that of the overall target population.

3.2.4 Gender sampling

In the interests of data confidence and accuracy, sampling 1000 females would be ideal, but realistically an extremely difficult target to meet. More feasibly a sample size of 500 females was proposed. The same sample size target of 500 females was planned for AWAS, with a sample of 277 achieved (Edwards et al., 2014). Whilst the female sample was still judged usable, confidence was reduced from an accuracy of 1% to 2% for some measures. Therefore targeting and marketing the ASRAN survey to females was considered particularly important to maximise the ASRAN sample size as well as the overall ADF sample of females.

3.2.5 Location of data collection

ASRAN survey sites were chosen where participation from surface fleet and submarine force personnel would be maximised. Important also to consider was ensuring appropriate facilities were sourced. This required attention to space requirements (for example the 3D scanners required a building with a 3m ceiling height), whilst also ensuring an appropriate level of privacy could be maintained for participants. The sites chosen for data collection were HMAS Stirling in Western Australia, and HMAS Kuttabul in New South Wales.

3.3 Measures to collect

The 85 measures used in AWAS were taken as a baseline starting point for refinement. This decision was taken for the following reasons:

- Efficiency: the protocols for the measurements have already been established in Australia and overseas.
- Validity: DST has invested in research to validate the accuracy of the scanned measurements.
- Logistics: The flow of personnel through the survey is highly predictable based on the AWAS experience.

The AWAS measures were then examined in light of the RAN needs and requirements for anthropometric measures. For example, a primary requirement in AWAS was the collection of dimensions for clothing and body armour design. The RAN however had requirements that prioritised habitability and platform design. Stakeholder interviews and consultation together with publication reviews were conducted. Following these reviews 87 measures were selected, comprising of 43 manual, and 44 digital measures.

Desired encumbrance ensembles to collect Personal Equipment and Clothing Correction Factors (PECCF) were also identified, which were: 1) Military cleanskin (Disruptive Pattern Navy Uniform (DPNU), 2) Firefighting and damage control, 3) Submarine escape and rescue suit, 4) Surface ship boarding party and amphibious operations.

3.4 Anthropometrist criteria

To ensure accurate and robust data the anthropometry team were required to be trained to at least Level 2 by the International Society for the Advancement of Kinanthropometry (ISAK). Acceptable thresholds of precision and accuracy were set using ISAK standards at 1) an intra-tester Technical Error of Measurement (TEM) of 1.5% for precision, and 2) an inter-tester TEM of 2.0% for accuracy (Tomkinson, Daniell, Dale, & Wachowicz, 2015).

4. Outcomes of ASRAN & future work

Overall 1322 RAN personnel participated in ASRAN, comprising of 232 females and 1090 males. The ASRAN data is being used to update the current Anthropometric Reference Data for the RAN. The update includes information on secular trends, and encumbered PECCF data. The anthropometric data will also inform the development of a new habitability standard for the RAN. This will be used to tailor habitability recommendations to the size and shape of RAN personnel, including appropriate secular trend adjustments. This is of particular importance for diesel electric submarine design where the size of the platform leads to difficulty in accommodating standards which have been designed for surface ships, or nuclear submarines. Diesel electric submarines are often much more space constrained than other maritime platforms, largely due to the trade-off between size and power requirements.

Future work to extend and maximise the results of ASRAN include the development of boundary manikins representing the range of anthropometric extremes for different work tasks; and integrating these into Digital Human Modelling (DHM) tools. The collection of additional PECCF data, furthering understanding of the implications of different PECCF ensembles on range of motion, and the representation of such in DHM tools is also of interest.

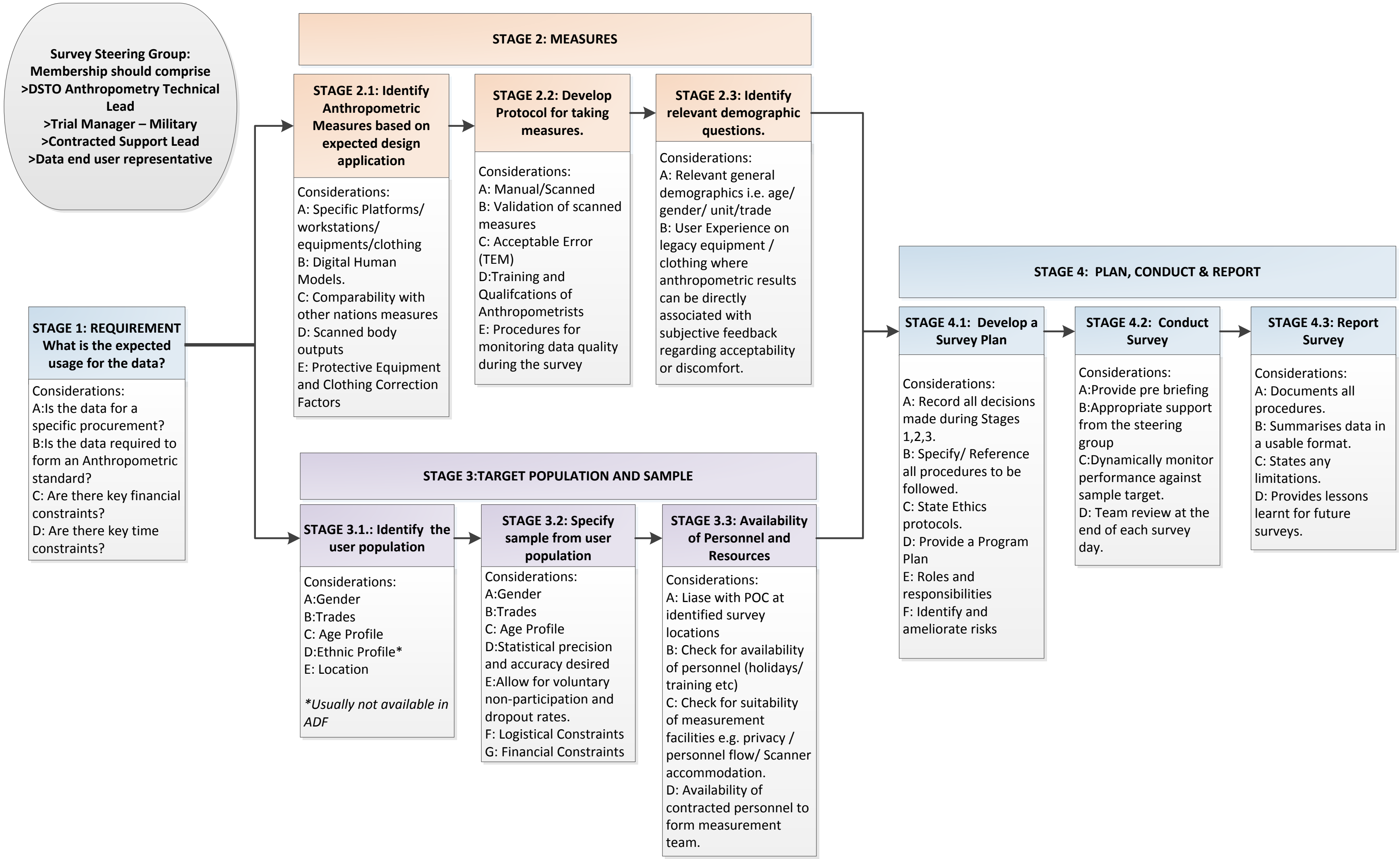

Figure 1. Survey planning flowchart (Furnell et al., 2014).

References

Australian Government. (2012). *Defence capability plan public version.* Department of Defence: Canberra.

Billing, D., Doyle, T., Linnane, D. (2011). *Back-casting applicant and recruit standards from job related physical employment standards for incumbents* (DSTO-CR-2011-0502). Australia: Defence Science and Technology Organisation (unpublished report).

Cole, T. J. (2013). The secular trend in human physical growth: a biological view. *Economics and Human Biology, 1*(2), 161-168.

Defence Australia (DEF(AUST))5000. (2000). *Materiel Requirements Set (MRS), Royal Australian Navy anthropometric reference data* (Volume 2, Part 25) (A016451). Commonwealth of Australia.

Defence Standard (DEFSTAN) 00-250. (2008). *Human factors for designers of systems*, Part 3: Technical Guidance, Section 9 – People characteristics. UK: Ministry of Defence.

Defence Research and Development Canada (DRDC). (2013). *2012 Canadian forces anthropometric survey traditional measures summary report* (DRDC CR-2013-147). Toronto, Canada: Department of National Defence.

Department of the Navy. (2012). *OPNAV Instruction 9640.1B: Shipboard habitability program*. Retrieved 15 May, 2015, from http://www.med.navy.mil/sites/nmcphc/Documents/nepmu-6/Environmental-Health/SSCP/References/OPNAVINST-9640-1B.pdf.

Edwards, M., Furnell, A., Coleman, J., Davis, S. (2014). *A preliminary anthropometry standard for Australian Army equipment evaluation* (DSTO-TR-2014-3006). Australia: Defence Science and Technology Organisation.

Furnell, A., Coleman, J., Ponton, K., Cockshell, S., Fletcher, K. (2014). *Sample plan for the Anthropometric Survey of the Royal Australian Navy* (DSTO-TN-2014-1380). Australia: Defence Science and Technology Organisation.

Gordon, C. C. (1996). *U.S. Army anthropometric survey database: Downsizing, demographic change, and validity of the 1988 data in 1996* (Technical Report 97/003). U.S: Army Soldier Systems Command Natick Research Development and Engineering Center.

International Standard (ISO) 15535. (2006). *General requirements for establishing anthropometric databases* (2nd Edition). Switzerland: The International Organization for Standardization.

Janssen, I., Heymsfield, S. B., Wang, Z. M., Ross, R. (2000). Skeletal muscle mass and distribution in 468 men and women aged 18–88 yr. *Journal of Applied Physiology, 89*(1), 81-88.

National Aeronautics and Space Administration (NASA). (2010). *Human integration design handbook (HIDH)* (NASA/SP-2010-3407). USA: NASA.

North Atlantic Treaty Organisation (NATO). (1993). *Guidelines for shipboard habitability requirements for combatant surface ships.* Allied Naval Engineering Publication - 24 (ANEP-24). Retrieved 15 May, 2015, from http://infostore.saiglobal.com/store/details.aspx?ProductID=464260

National Research Council Canada (NRCC). (2010). *Review of the statement of operational requirement for the fixed wing search and rescue aircraft – final report* (CR-FRL-2010-0025). Canada: NRCC.

Tomkinson, G., Daniell, N., Dale, M., Wachowicz, T. (2015). *ASRAN methods, summary statistics, time trends and comparisons*. Australia: University of South Australia.

Wilcove, G. L., Schwerin, M. J. (2008). Shipboard habitability in the US Navy. *Military Psychology, 20*, 115-133.