"You don't know Jack": Using 3D anthropometric modelling techniques to identify, assess and aid in the early resolution of safety issues relating to military vehicle design.

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Abstract

Atkins' Advanced Assurance Modelling (AAM) methodology uses the Jack™ 3D anthropometric modelling tool to provide tangible Human Factors (HF) assessments that identify safety issues early in the concept or design and bridge the gap between HF and other engineering disciplines, thus improving integration and facilitating the targeting of limited resources to focus on key project issues.

This methodology has been used to conduct design assessments for new manufacturing facilities, aircraft maintenance tasks, and for both new and in-service vehicles for the UK MoD; specifically focusing on Panther, Bulldog and Scout SV vehicles. The MoD work has been focussed on identifying design issues that will impact on the safe operation and maintenance of, and emergency egress from the vehicles.

This paper describes the work that Atkins has conducted to date to inform and support the MoD in ensuring the safety of current and future vehicles.

The use of AAM enables traditionally complex, time-consuming, imprecise and expensive physical reviews to be conducted quickly, accurately, safely, at significantly lower cost and most importantly, early in the engineering lifecycle. Assessments can be conducted before a physical instantiation of the design has been implemented, requiring minimal MoD resource and intelligently informing trade-off, thus enabling design modifications to include mitigation quickly and at low cost.

This work has resulted in better communication and integration between HF, safety and other engineering disciplines, with the ultimate results of safer vehicles, improved training and safer operations for UK Armed Forces personnel deployed in theatre and cost savings for the MoD, as demonstrated on the Scout SV Initial Assessment Phase 2 and tendering assessments.

1 Introduction

Jastrzębowski first mooted the concept and name of ergonomics in 1857 [REF 1]. However, it was Murrell was the first to define the term "Ergonomics" in 1949 when it was officially proposed at a 1949 meeting of the British Admiralty [REF 2, 3], and then accepted in 1950 as "the scientific study of the relationship between man and his working environment" [REF 4].

Since then, the term is often seen side by side or interchangeable with Human Factors (HF), a term which originated in the USA during World War 2 [REF 5], However, HF is often regarded as the more engineering-based term, with ergonomics being regarded being more focussed on areas of human physiology and health. During the mid-1980s MANPRINT was developed, which defined policy and added process to the field and this subsequently became what we see today in Human Factors Integration (HFI) [REF 6, 7]. Throughout the evolution of ergonomics and HF and their associated processes there have always been issues of misperception, misunderstanding and technical arguments being lost in translation between HF practitioners and the engineering community when they work together. This misunderstanding often results in safety critical and high cost implications.

Traditionally, Systems Engineers or Design Engineers focus on the technical aspects of a capability or a requirement (e.g. structural integrity, ability to withstand over-blast pressure or data transmission rates), often with little or even no consideration for the operator or maintainer. HF practitioners are often excluded in the initial phases of the system design and therefore the design relies largely on other engineering disciplines, particularly safety engineers to consider the impact of human in the system. However, Safety practitioners have traditionally focused on the equipment safety towards the end of the design of a system safe in the world of "10^{-6}" and numbers, leading them to focus more on reliability than true, holistic safety, due to operational safety not being considered. Therefore, it can be surprising to both communities that when the system is used by the human operator, system is neither as safe nor reliable, and does not perform as well as envisaged. It is then the responsibility of the HF practitioners to try to "fit the user around the system" once design has been frozen, which often leads to high training costs.

This is far from an ideal approach, and has resulted in many of the issues that operators complain about when they use a system and many accidents later in a system's use. It is why the operators of a system function at a much lower level than envisaged, significantly reducing the overall performance and safety of the whole system or capability. This is why perfectly safe equipment can become an imperfect and unsafe system.

Within Systems Engineering, the concept of a "system" is not just the technology or the physical structure, but a product of the technology, physical structure, operating environment and the human operator or maintainer, defined by INCOSE as "An integrated set of elements that accomplish a defined objective. These elements include products (hardware, software, firmware), processes, people, information, techniques, facilities, services, and other support elements" [REF9]. Within a system the human is the major constraint, as human limitations can rarely be enhanced by further design, given the other constraints such as time and cost. To enhance the human performance considerably can mean costly, novel and high-risk technology. Therefore within the system the human constraint is a major risk. Alexander Pope aid "To err is human" [REF 10] therefore the emphasis on safety is needed to consider and mitigate the human risk to the system to ensure a "safe" system is delivered. As such, the technology, physical structure and operating environment must be designed to support the human in all of their tasks, thus inherently improving reliability, performance and system safety.

A key question that has been asked many times is "How best to integrate HF practitioners into a project?" This question is well known, and has been ongoing for decades. Some potential solutions have been proposed, such as HFI, HSI or other similar processes and a plethora of tools and techniques. However, none of these approaches have been as successful as they were claimed or envisaged to be.

According to an old Chinese proverb rejuvenated in 1927 by Fred R. Barnard [11] "a picture is worth a thousand words". Not only does a picture speak a thousand words, but it speaks them across languages. It speaks them across boundaries. It speaks them across cultures. Could a picture achieve what decades of debate and a multitude of methodologies, processes, tools and techniques has failed to do?

2 Context

We are in an age of austerity and our customers cannot spend as they have done in the past. To enable us to continue developing defence (or any other) capability many prefer to take the view of making efficiencies, i.e. getting the maximum out of something and getting it right first time so that costs are reduced by reducing or eliminating rework, waste and retrofitting. Spending what little money there is wisely and efficiently is imperative. However, it is still a common occurrence now to switch on the news and hear that the National Audit Office have found that "Project X" is over budget, or that "Item Y" has been delivered to the troops and is unusable at a cost of "£Z" to the taxpayer.

Combine this with an increase in health and safety legislation, public awareness of health and safety and the explosion of "No-Win-No-Fee" litigation firms over the past 10 years, and a perfect storm is appearing on the horizon.

Eliminating this waste is imperative. Not only to save money, but to ensure safety and that the troops are given the equipment that they really need to support their tasks. But how can this wasted effort be reduced, how can system safety be improved and how can we at least try to get it right first time?

3 The Answer?

Well at least an answer. HFI is viewed by much of the HF community as the best route to integrate the human into a project and ensure that the user's needs are best accommodated and integrated into the design of the system, thus inherently implying improved safety and performance. However, this process already exists, and hasn't proven to be hugely effective over the past 25 years or so that it has been adopted in defence and other high hazard industries. Often this is because of poor uptake and engineers or project managers focussing on technology, meaning that the human component of the system is still ignored until towards the end of a project, resulting in increased cost, poor integration and poor usability at best.

There are many reasons behind the lack of integration, but recurring issues are those of engineers not fully understanding the value or purpose of the outputs of HFI, and HF practitioners not fully understanding the implications of their demands on the engineering. From experience, the "I" in HFI stands for isolation all too often. An overview of other areas that HFI interfaces with is provided in Figure 1.

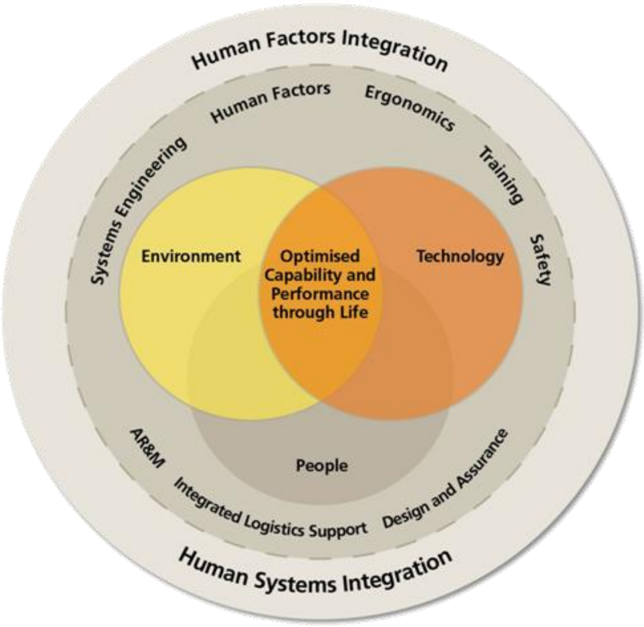

Figure 1. The Relationship of Human Factors Integration to Other Engineering Specialisms.

If followed correctly, the process of HFI can integrate the human in the system effectively, significantly reducing whole life costs, increasing system safety and overall system performance. However, HF as a discipline is not always understood or appreciated by the engineering community. Reasons for this are many, but often the effectiveness of HF is only seen when things go wrong and "human error" is labelled as the cause. When HF has a part in the design of a system, the output of the HF work is often be viewed as intangible, i.e. lots of exploratory research and activity to identify and mitigate human risk, resulting in report writing where the value of the recommendations and the safety critical nature of some recommendations is not clear to the other engineering disciplines.

HFI needs to be inclusive, however as the activities are often done in isolation it is seldom possible to achieve a fully integrated system design.

The solution is to enable engineers to see the value of HF and one way of doing this is through demonstration. At Atkins we have discovered a tool that can offer engineers a view of the system from an HF perspective to assist in trade-off decisions. This tool is Jack™.

You don't know Jack

Based on more than 6 years of experience in using the Jack™ 3D anthropometric modelling tool on a wide range of projects, it has become clear that there are huge benefits in deploying this technology on a project, but specifically at an early stage in the project lifecycle in the support of both HF, design and requirements capture activities.

Jack™ is not an Atkins product. Jack™ is a 3D anthropometric and biomechanical modelling tool produced by Tecnomatix (a Siemens PLC company), and distributed by Simulation Solutions in the UK. Atkins uses Jack TM because it solves our problems. It integrates with commercial CAD packages and facilitates significant cost and time savings by enabling design quality to be improved and process feasibility to be assessed early in the product lifecycle, often before anything has been built or a design finalised. Jack™ enables biomechanically and anthropometrically accurate human models to be sized to match required user populations, e.g. from little Lisa Simpson through to the great Homer Simpson with the entire Simpsons cast in between. It can be used to test designs for multiple factors including injury risk, manual handling, user comfort, reach, line of sight, energy expenditure and fatigue as well as spatial fit. It seamlessly integrates Human Factors and Ergonomics into the planning, design and validation stages of a product lifecycle.

However, no matter how capable and advantageous Jack™ is, no matter how powerful a visualisation tool it is, it is still only a tool and the outputs of any tool are only as good as the inputs of its human operator. At Atkins we have found that using qualified HF practitioners with a sound understanding of engineering and design to operate Jack™ provides the best results. Over the years, we have developed our experience of using Jack™ into an integrated approach that we call Advanced Assurance Modelling.

The Benefits of a Combined and Integrated Approach

Advanced Assurance Modelling (AAM) integrates HF, CAD and engineering disciplines into a single approach based around Jack™. We have found that AAM provides a powerful communication and translation link between HF and engineering disciplines on projects.

AAM is a six-stage process, and is now in a relatively mature stage of development, but there is always the potential for improving the process, with new projects providing the opportunity to refine the methodology. An overview of the AAM process is shown below in Figure 2.

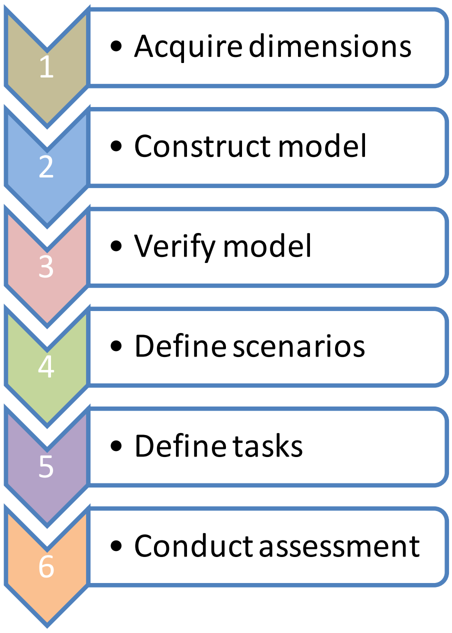

Figure 2. The Six Stages of Advanced Assurance Modelling.

The first stage of the process is to create a new, or acquire an existing CAD model. Creating a CAD model requires access to what is being assessed then taking dimensions and a number of reference photographs. Dimensions, photographs and any available engineering drawings allow the CAD model to be produced to the specifications required.

Gaining a full understanding of the tasks for the assessment is the next stage, which is best done with subject matter experts on hand. Tasks are assessed under different scenarios, with each scenario depicting the variables involved with each of the assessment tasks. In order to define and fully understand these tasks, a task analysis is conducted.

Once the assessment is fully understood, the tasks derived from the above phase need to be assessed against each of the relevant scenarios within the Jack™ environment. Each task (and any relevant sub-tasks) are then methodically simulated using Jack™ for each scenario. Human Factors issues that are identified through this process are recorded for later analysis with subject matter experts.

Alternative processes (usually non simulator) are available, including user trials, fitting trials and overlaying 2D manikins on orthographic drawings. These methods are not as capable as AAM, are limited in terms of accuracy and validity and in the case of the former two methods, are significantly more expensive and time consuming than AAM.

Through the use of Jack™ in Advanced Assurance Modelling, we have found that the visualisation of a problem is an invaluable tool to aid communication and the understanding of issues between HF practitioners and engineers. It helps to clearly identify the HF issue and put it in an engineering context, presenting it in a way that is both tangible, accurate and easy to comprehend. A picture truly does speak a thousand words and those unspoken words do cross cultural boundaries, enabling HF and engineering disciplines to work more closely together and understand each other in a clear and unambiguous way.

This approach has been used in the design of new equipment, workstations and facilities, for assessing bids to help aid decision making and inform the customer of future implications of their selection, to assess emergency escape and casualty evacuation routes from in-service military vehicles and to then design potential solutions and improvements.

Using this integrated approach on projects, including FRES UV, Scout SV, Panther, Bulldog, Bradwell nuclear power station and the A350 XWB, we have leveraged significant savings for customers and improvements in performance and safety through the following factors:

- The use of Jack™ 3D anthropometric modelling enabled what were previously complex, time-consuming and expensive reviews to be conducted quickly, accurately, at lower cost and most importantly, early in the engineering lifecycle where they can add most benefit.
- The ability to conduct assessments before a physical instantiation of the design has been implemented or finalised informs trade-offs and enables engineers to modify the design to include mitigation quickly and at low cost.
- Where the physical design already exists or it is not practicable to modify a design, the use of the Advanced Assurance Modelling approach enables the clear identification of the specific nature of an issue and enables non-engineering based solutions to be developed in conjunction with training and amending operating procedures.

Case Study: Panther

Atkins successfully used their Advanced Assurance Modelling approach to conduct an assessment of emergency egress and casualty evacuation from the British Army's Panther vehicle. The requirement for this assessment stemmed from an incident in Afghanistan in 2010 involving a Ridgeback vehicle that resulted in a tragic loss of life [REF 12].

The original requirement from the MoD was for a traditional-style moveable and rotatable full scale physical mock-up to be built and used in live trials with troops being used to conduct egress and casualty evacuation activities.

Atkins did not see a great deal of value in this. Building physical mock-ups of the required type takes time and is expensive. Using troops to conduct activities is time consuming, a drain on overstretched resources, exposes the troops to an unnecessary risk of injury and provides only very limited, often biased and subjective data.

Instead, Atkins proposed the use of the Advanced Assurance Modelling approach. We proposed that Jack™ should be used to take the place of the troops, and a 3D CAD model should take the place of the full scale physical mock-up. Based on our initial calculations, this approach was approximately 60% cheaper than the traditional mock-up approach. It also offered additional flexibility and benefits including the ability to control the size and shape of "participants" by tailoring them to 3rd and 97th percentile values as required, and assessing postural loading – two things that would not be possible using the traditional mock-up approach.

Our novel approach was accepted and we conducted the assessment. We assessed three orientations of the vehicle and 13 scenarios for emergency egress and casualty evacuation. The output of the assessment was not just a set of clearly defined issues based on tangible findings, but also a set of proposed solutions to these issues, either modelled in Jack™, or defined as procedural or training changes backed up by the tangible findings. The whole assessment, including building the CAD model of the vehicle from scratch, conducting the assessment and writing the final report, was conducted in less than three months of effort, which was two months less than expected for the traditional approach.

The ability to produce tangible, accurate and easily comprehended issues and solutions through the use of Advanced Assurance Modelling (AAM) proved invaluable on this project. This work has resulted in better communication and integration between Human Factors, Safety and other engineering disciplines, with the ultimate results of safer vehicles, improved training and safer operations for UK Armed Forces personnel deployed in theatre and a cost saving for the MoD.

Summary

As a discipline, Human Factors (or ergonomics) is not new, it has been around for centuries and as an engineering process has been utilised on defence projects since the 1940s [REF 3].

Additionally, 3D CAD models are not new, nor is anthropometric modelling; they have been around for over 20 years. The concept of combining HF, 3D CAD and anthropometric modelling is not new either. So what is new?

Nothing. It is not a matter of currency; it is a matter of experience and taking a risk to adopt an approach that is in essence quite obvious and simple. It is having developed and honed that approach to be able to deliver cost and time savings coupled with safety enhancements to customers and to produce designs and design recommendations that are high accuracy, repeatable, tangible and agreed by all disciplines.

Atkins saw a means for improving communication and understanding between the HF and engineering communities to help make system solutions more usable and safer, so we adopted it. This approach can be applied across all domains; air, land, maritime and space. It can be applied across industries and across all products and systems. Whilst it does have limitations and can't do everything, what it does do, it does exceptionally well, and can make a significant difference to the acceptance or rejection of a vehicle, system, facility or piece of equipment.

There may be many reasons why others have chosen not to adopt an approach similar to Advanced Assurance Modelling, but Atkins only needed one reason to do it: to deliver the best value service to its customers in support of the goal of getting it right first time.

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