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THE APPLICATION OF HUMAN ENGINEERING TO ADVANCED HELICOPTER DESIGN

by

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1 SYNOPSIS

The role of Human Engineering (HE) in the future must not be under-estimated. Investment in tools and methods must continue in order for HE to become better integrated with main stream design. I hope this message is echoed throughout this paper.

2 INTRODUCTION

Quantum improvements in technology combined with demanding customer requirements have promoted systems within which the man himself and the design of the Human Machine Interface (HMI) have become significant considerations in overall system performance.

The optimum integration of man and machine where costs and risks are minimised and performance is maximised, probably lies beyond the mature technology which is available for todays application. The use of aids such as Knowledge Based System (KBS) to support 'optimum' man machine integration is still in the future and as such, HE as a relatively immature discipline, must continue to support 'man-in-the-loop' systems for the foreseeable future making the best of present flight qualifiable hardware and software.

This paper focusses on the Westland Human Engineering experience and available 'Tool box' and identifies some of the cost and technical benefits acrued through the proper integration of HE into the design process. The paper introduces the UK MANPRINT initiative and its impact on HE and finally draws the salient points together by discussing the fundamental problems associated with HE Management.

3 WESTLANDS HE TOOL BOX

Westland's Human Engineering 'Tool Box' has grown throughout the EH101 Development Programme. Its assimilation represents a substantial investment in HE which is evident in the high profile HE has in the company's engineering organisation. The continued development of the Tool Box is part of the company's committment to improved product design and market competitiveness.

The Tool Box at present consists of rapid prototyping tools, full cockpit and mission simulators, workspace design tools, and operator performance modelling tools.

3.1 Rapid Prototyping Tools

Rapid prototyping is a term coined by manufacturers of purpose built software which enables fast and efficient virtual dynamic representation of controls and displays. The term has since been adopted by aircraft manufacturers to refer to almost any form of early design representation. When compared to the more traditional approaches of using hardware prototypes and simulation, which depend on the development of complex system and environmental models, prototype benefits of reduced cost and risk can be gained early in the project life cycle. As projects develop the rapid prototyping approach also offers a distinct advantage by keeping the 'prototyped design' in pace with new or modified customer requirements.

The continued development of EH101 under the Merlin Prime Contract (MPC) has necessitated the very short time scale development of an enhanced HMI which comprises a large increase in functional capability, and the integration of colour electronic displays. This is the main driver at present within Westland for the development of rapid prototyping tools. The tools in current use provide the principle HE means of reducing the risk inherent in continued HMI development.

3.1.1 Prototyping of Integrated Systems Control

A very effective rapid prototyping tool has been developed for the purpose of evaluating the Merlin principal control device for the integrated system, the Common Control Unit (CCU) Figure 1.

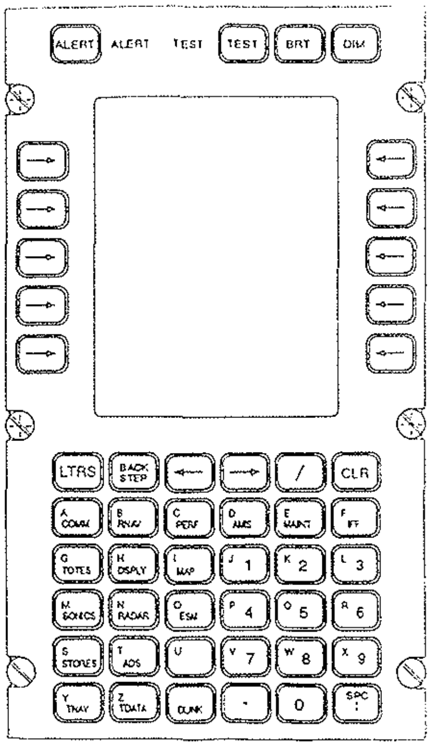

Figure 1 Common Control Unit

The tool is Personal Computer (PC) based, simple in concept and relatively simple in structure but represents a novel application of commercially available data base software. Combined with a good quality graphic representation and a touch sensitive overlay, the user is able to drive an emulated system by accessing a large and exhaustive data base of displayed functions on CCU pages. The pages represent sets of control functions hierarchically arranged for each of the Merlin systems. The evaluation programme involving the customer has not yet started, but the expectation is that the added realism will enable the customer to provide preliminary evaluation from a far better perspective of the end product than would be the case through documentation. The prototype tool provides full display and editing facilities making it useful in both design and evaluation. In addition it uses the full benefits of 'automatic' documentation of the HMI specification and automatic monitoring and traceability back to customer requirements.

Since the prototype is based on a set of software code modules which execute the embedded control characteristics of the input device, there is the possibility to download this software directly into the aircraft simulator and subsequently into the aircraft computer. As a future objective this is an attractive spin off of the application of prototyping tools.

3.1.2 Prototyping of Merlin Mission Displays

The application of colour to the Merlin Mission System Displays brings with it a host of opportunities to improve the former monochrome design. At the same time, it imposes the difficulties of applying a new coding convention to design, and the knock on effects that it might have on the established parts of the system.

The timescales for an early colour definition were driven hard by hardware procurement milestones, in this case, the Symbol Generator. There was an urgent need to take a cost effective approach to the application of colour which would allow the early visualisation of the end product, for customer appraisal and risk reduction.

A proposed colour definition was implemented as a set of accurate but static pictures on the TIGERS Rapid Prototyping System running on Silicon Graphics Workstations. The Workstation was then used to establish the video mixing and overlaying philosophy. Through a process of customer supported design meetings it was possible to review, quickly modify, and re-review the application of colour. The core colour philosophy was thereby established very early on in the programme in order to meet the related hardware milestones.

Acknowledging the limitations of static imagery, a customer based evaluation trial was conducted using a set of dynamic display formats based again on Silicon Graphics hardware but this time 'driving' simulated mission displays in a representative console.

These trials largely confirmed the results from the static imagery tests, but the introduction of dynamics enabled better customer judgement which highlighted a requirement for several further modifications. These trials have been concluded and although some questions still remain, the core definition of colour application has been successfully completed.

3.1.3 Benefits of Rapid Prototyping

There are two main benefits of rapid prototyping which have been proven at Westland, namely, the reduction of design risks, and the transfer of HMI design code to full simulation.

There is little doubt these days that the HMI plays an important role in bid selection. There is increasing pressure within industry therefore, and particularly on designers, to offer an HMI design for maximum operational effectiveness, whilst at the same time minimising the risk to the programme, and risk to the companies profit margins. The tradeoff between cost and risk reduction is difficult, but it is becoming easier with better workstations, and prototyping software. The application of prototyping tools will ultimately provide the customer with the 'real thing' early enough in the design process to enable either a degree of commitment, or need for change prior to key hardware and software freezes.

By directly sharing HMI software with full man-in-the-loop simulators, the details of the evaluated design can be quickly transferred without duplicating software effort, and without complicating configuration control.

3.2 Simulation Tools

As rapid prototyping increases in sophistication it is becoming more difficult to separate it functionally from full simulation. For the purposes of this discussion, simulation is simply distinguished from rapid prototyping by the sophistication of the systems model and the inclusion of environmental and flight dynamics models.

3.2.1 Development Simulators

Westland has a long history in building and using both development and research simulators for HMI design and evaluation purposes.

The first Sea King Replacement Mission System development simulator was built in the mid 1970's during feasibility studies. Simulator trials, although relatively crude, involved both Westland personnel and RN operators, in a formalised programme of simulated exercises, and was directly instrumental in the decision that two crew could efficiently manage the sensor suite defined at that time.

These simulation exercises were an essential landmark in the development, and were considered at the time to represent a substantial reduction in HMI design risk. In addition, they represented a considerable potential manpower and cost saving to the customer.

As the RN EH101 HMI development programme has progressed over the last two decades, the mission system simulator has been upgraded, and a six axis motion cockpit simulator has been added. Both the cockpit and cabin simulators are continually upgraded and used in a systematic fashion to exercise the HMI and advance the system design.

Mission Simulator

The mission simulator has been used to support a series of trials aimed at either demonstrating the evolving Mission HMI design standard, or measuring crew workload associated with the Anti-Submarine Warfare (ASW) task.

All trials are based on customer subjective appraisal which is controlled by structured questionnaires, checklists, and rating scales where possible. Interestingly, this approach, as opposed to more objective measures of performance such as speed and error, has proven very successful in the context of poorly expressed or non explicit requirements. This success can however be hampered by the inconsistency that can exist between independent crew appraisals over time. This inconsistency can be associated with a change in the customers approving personnel who apply different personal experience to the design solution.

Cockpit Simulator

The HE interest in the cockpit simulator has principally been on flying tasks and the development of display formats for the EH101 Electronic Instrument System (EIS). There have been many other HE uses for the cockpit simulator which include detailed control panel layout, crew comfort, and seat design.

The design of the EIS display formats has proven extremely complex and lengthy due to flight criticality of the system, and the necessarily high standards adopted by military approving, and civil certification authorities in all issues, whether covered by formal requirements or not. All trials and demonstrations depend upon the subjective views of the trial subjects. In the cockpit, controlling the trial is far more difficult since both the military and civil customer insist on managing their own appraisal. Under circumstances where the customer is likely to be far more insistent on the implementation of his own recommendations, early feedback through the application of rapid prototyping techniques is clearly of both cost and risk benefit to the contractor.

An interesting point to note is the extent to which the detailed specification of colour and some fundamental aspects of format design have changed when testing progressed from early static pictures to full simulator dynamics, and for that matter, as simulation dynamics have improved. It is likely that the same effect would be observed in other applications, and highlights the importance of enabling the evaluating pilots to exercise the full 'user model' in the evaluation processes. This is not a criticism of rapid prototyping and does not undermine its value. It is however an indication that the rapidly prototyped product should not be regarded as the final product.

At Westland, attention has been focused on the extensive application of rapid prototyping techniques to assist in simulation. The use of such techniques now forms part of the core Westland approach (Figure 2). The tools and skills developed will enable a rapid response to further simulation requirements by other customers and should substantially reduce simulator development costs on EH101 derivatives such as the Canadian ASW and Air Sea Rescue variants.

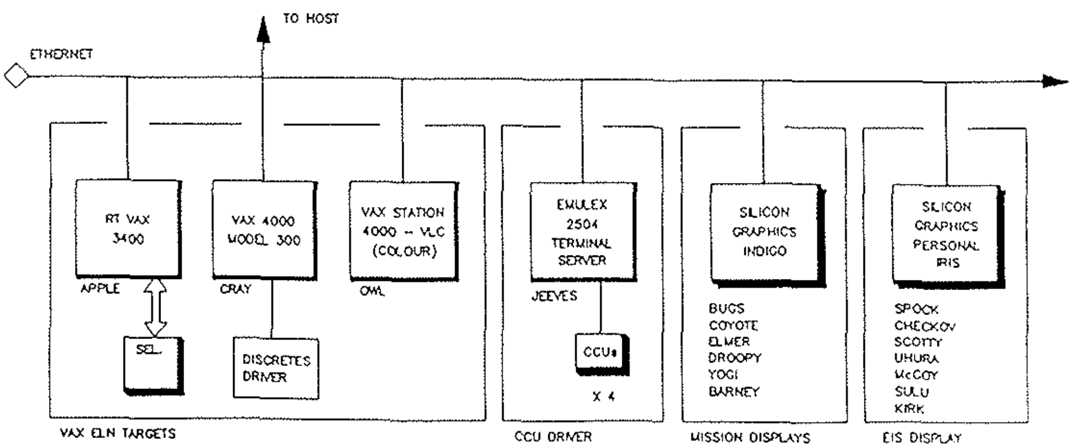

Figure 2 Target Configurations for Limited Cockpit and Cabin Simulators

3.3 Workspace Modelling

The physical design of crew workstations is still one of the largest applications of HE. Traditionally, methods have been based on wooden mockups of varying fidelity using human subjects for evaluation trials. With the advent of powerful computer hardware, the use of computer based modelling techniques is becoming more prolific and several purpose built software tools to enable the graphical 3D representation of workspaces are now commercially available.

Customer requirement for workspace design are often amongst the few which are explicitly stated. This is not surprising since the body of knowledge in the area of anthropometry and biomechanics apparently is vast. Despite this body of knowledge, it is still difficult to design workspaces even for single populations. Hidden requirements often emerge to consume the available space for man. Such requirements include personal weapons and other 'carry on' equipment. Full combat clothing and detailed NBC requirements are often ignored at the early design stage, but will impact workspace design long after the initial space allocation has been frozen by structural designers.

Even existing anthropometric databases are suspect. Databases are old and mostly out of date despite the fact that we know populations in Northern Europe are getting taller. These considerations in addition to the large anthropometric differences between simultaneous user populations are of special concern to contractors when supplying to a world wide market place.

3.3.1 Workspace Modelling Tools

At Westland considerable emphasis is placed on the design of cockpit, cabin crew and passenger stations as exemplified by the substantial investment made in modelling software and in physical mockups. Over the past five or six years, computer based modelling tools have been successfully applied to workspace design for several EH101 variants, and in other rotorcraft feasibility studies.

Westland has several basic tools. The most fundamental is the traditional CAD system used for structural design. Although not specifically a Human Engineering tool it is used by HE specialists to modify workspace models through formal CAD procedures. Recently, CATIA, the 3D modelling system has slowly taken over from traditional CAD methods and has successfully been used to augment HE designs by generating vision plot diagrams from the workstation design eye positions. The most recent addition to the HE Tool Box is SAMMIE.

3.3.2 Systems For Aiding Man-Machine Interaction Evaluation - SAMMIE

SAMMIE consists of four facilities:

i - Equipment & Workspace Modelling Facilities
ii - Man Modelling Facilities
iii - Viewing Facilities
iv - Ergonomic Assessment Facilities (reach and clearance)

WHL has conducted its own internal validation of the SAMMIE man model using the reach assessment facility. The reach arcs generated by anthropometric trial on the EH101 were compared with reach arcs generated by SAMMIE. Excellent mapping was achieved giving high confidence in the man model fidelity.

The lack of a clothing model in SAMMIE has caused a problem particularly when considering ergonomic compromises incurred through for example, arctic and NBC clothing. The SAMMIE comfort limits are also based on an unhindered joint which does not account for the restrictions imposed by clothing. Existing anthropometric databases are poor at reflecting clothing effects on size and movement. The omission of such databases reduces the utility of the basic tool. For the purposes of our studies, we have measured the crushed dimensions of combinations of clothing and the restrictions imposed on limb movement. This data has been used to supplement the basic SAMMIE manikin and can be implemented easily using present SAMMIE facilities.

Identifying what is a reasonable posture has proven difficult. Westland has appraised different postures by inspection and by photographing subjects, in comfortable and sustainable seating positions. Attention to such detail has enabled the designer to exercise 'discretion' in lieu of live subject trials.

As a future improvement, industry should look towards the integration of a comprehensive man model into present 3D CAD systems. This would offer the advantages of a shared database across engineering disciplines, and reduce or negate the costs associated with separate workspace modelling. The addition of library data representing combinations of clothing and limb restrictions could make the manikin model more realistic. In addition, a biomechanical model representative of dynamic limb feedback would simplify the manipulation of the model and the evaluation of workspace design. See Figure 3.

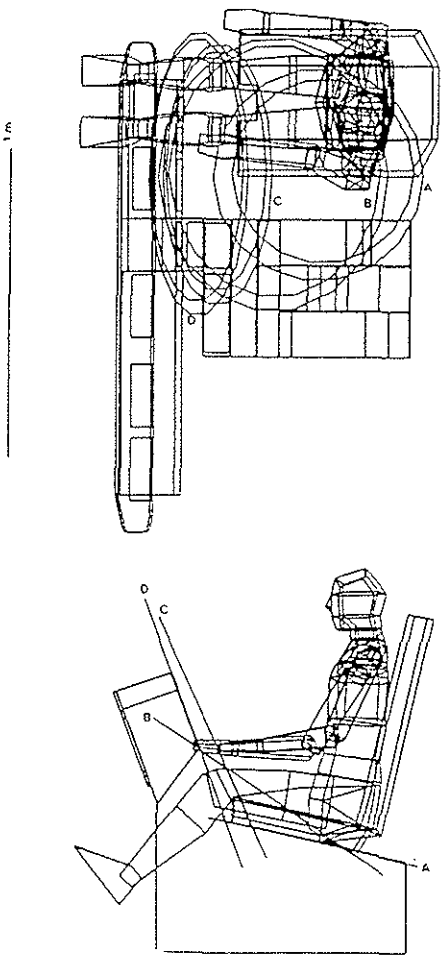

Figure 3 SAMMIE Model Reach Arcs to Control Surfaces

3.3.3 Benefits of Workspace Modelling

The speed of SAMMIE has ensured that HE inputs have been available within the timescales imposed by current contracts without the costs associated with full scale mockups. The clarity of the models and their visual impact has given customers a new confidence. Westland has provided the results of SAMMIE modelling work as deliverables for provisional design acceptance.

Although customer requirements for population anthropometrics are explicit, they are seldom complete. Anthropometric ranges are always given, and occasionally the major anthropometric parameter (or limbs) of interest are specified. However, the customer does not specify the anthropometric combinations, and the scatter diagram data which makes this possible is not always available. In reality, any given individual has combinations of limb dimensions hence the person who is truly 5th or 95th percentile on all dimensions seldom exists. Indeed, Def Stan 0025 specified 5-95th percentile population include a body shape with 5th percentile reach and trunk length and 95th percentile stomach depth. This is one of the most difficult body shapes to accommodate. Our Manikin body of this type is denoted 'G' - Geoffrey.

This issue leaves the contractor potentially very vulnerable since population fit is invariably tested as part of customer design acceptance. Although it might seem advantageous to base design on 5th and 95th percentile 'standard' operators, the operators at the extreme of the specified population must not be ignored. This can be discovered to the contractors cost at customer acceptance trials where 'Geoffrey' might well be the test pilot.

3.4 Operator Performance Modelling Tools

The complexity of present day multi sensor systems has resulted in an HMI which under certain operational circumstances provides the aircrew with both a physically and mentally demanding task. The sensor suite of the RN Merlin, and its operational tasks provides the basis for a contractually mandatory requirement to assess the three man crew performance in the form of 'workload'.

The measurement of crew workload is becoming one of the fast growing and exciting technical areas of HE. With increasing HMI sophistication, workload is now a major overall system performance issue. A definition by HART (1982) corresponds to the Westland view as applied to the Merlin Programme.

"Workload is a subjective experience caused by external and internal factors, such as motivation, ability, expectations, training, timing, stress, fatigue and circumstances in addition to the number, type and difficulty of tasks performed, effort expended, and success in meeting requirements".

It is only recently that modelling tools have become available to industry. Models of human performance which underpin all todays 'tools' have been generated by Psychologists over the past decade but can be traced back to the earliest studies of 'Time and Motion'. Most workload tools have been developed under US DOD funding and are now becoming available outside the US. The UK is slow to develop its own.

3.4.1 Operator Performance Modelling

For Merlin, Westland in consultation with AeroSystems International has developed a suite of two highly successful predictive modelling tools, based on commercially available spread sheet and networking software. These tools have been used to conduct a predictive workload analysis study which has been undertaken in two complementary parts.

1 Task Network Modelling (Static Analysis)

This used a time line based 'snap shot' approach considering the time required versus the time available to undertake crew activities, and the workload related with these activities.

2 Decision and Error Analysis (Dynamic Analysis)

This approach used a novel technique examining task related decision processes and their associated errors.

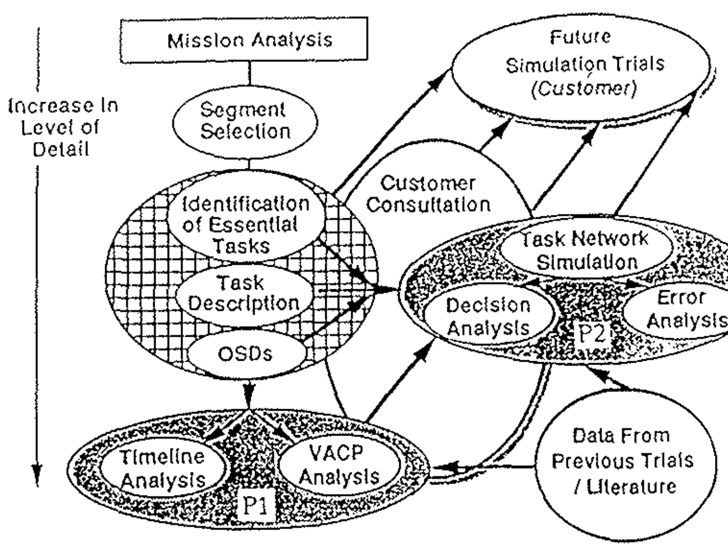

Figure 4 Summary Diagram of Predictive Workload Analysis

P1 = Task Network Modelling Study
P2 = Decision and Error Analysis

A necessary aspect of both the analyses was an emphasis throughout on the importance of customer participation in the conduct of the study. Both studies relied on basic mission scenarios. A substantial amount of time was spent with the Royal Navy (RN) generating three scenario models which were considered 'representative'. This stage in the process was essential since the value of study results are completely dependant upon the suitability of the basic mission scenario model. In the case of Merlin where the HMI and the operating procedures for the aircraft are evolving, a 'representative' scenario was difficult to establish. This is a fundamental limitation to all predictive studies of this kind, and exemplifies the need for a 'tool' based study where amendments can be quickly implemented, and results quickly recalculated. The description of these tools is more detailed because the application in the UK is novel.

3.4.1.1 Task Network Modelling

The Task Network Modelling Study was based on three components.

i) Time Line Analysis (TLA)

This was based on traditional techniques which are already well established. Mission milestones were identified, and placed on the timeline running the duration of the mission. These were based on aircraft, target, and weapon performance and other user defined characteristics. Operational Sequence Diagrams representing crew activities were generated and mapped onto the mission milestones. These tasks represented the activities the crew were expected to undertake, and the mission milestones represented the time available within which the crew were expected to complete these activities.

ii) Time Synthesis Modules (TSMs)

TSMs were derived in three stages. The first stage identified discrete crew activities which were numbered and divided into a sequence of subactivities which were typically 'reach', 'press' 'focus' etc. The second stage allocated times to each activity. The third stage allocated a scale value to each of the human senses for each crew activity. These scale ratings are referred to as Attentional Demand Ratings (ADRs).

By joining TSMs together it was possible to calculate the total time for the task, and it was also possible to generate an ADR profile over the whole mission timeline.

iii) Attentional Demand Analysis (ADA)

The ADA analysis algorithm was embedded using commercially available LOTUS 123(TM) spreadsheet software. The algorithm has two components based on the techniques described below.

Concurrent Effect

The first technique was developed in the US and Canada on the basis of the original work undertaken by MacCracken and Aldrich as part of the LHX Programme (Reference 1) and is based on a tradeoff matrix for each of the human senses,, (ie vision, hearing, cognition and psychomotor activity). Each crew task requires the use of the senses. Parallel or concurrent tasks require the simultaneous use of the senses. Where the senses are used concurrently, the tradeoff matrices can be used to judge the effect on each sense in terms of an 'Acceptable' effect, a 'Marginal' effect, or an 'Unacceptable effect' on workload. Figure 5 illustrates one of the matrices. Whereas the allocation of ADR is relatively straight forward for psychomotor, auditory and visual modalities, the use of the matrix probably oversimplifies the specification of the cognitive load.

Combined Effect

The 'Combined Task Rules' are further products of the US and Canada and enable the assessment of overall workload based on the combination of values derived from the trade off matrix for each sense.

The tool developed at Westland requires the analyst to manually input the task sequences for the crews showing both serial and concurrent activities. It also requires the analyst to identify the dependencies crew members have on each other for the start and finish of specific activities.

Given this information, the analysis tool is able to select the relevant task from the TSM database (which includes subcomponent times and associated ADR's) in the order defined by the analyst, and calculate what the overall related workload will be for each crew member under conditions when tasks occur both serially and concurrently. The ADA will also calculate the extent to which the time needed to complete the task corresponds with the time available to do the task.

In the Merlin programme the tool has been able to predict the specific sequences of crew activities which could be associated with workload peaks.

The validity of the underlying techniques of the Attentional Demand Analysis is presently subject to debate (eg Reference 2) which centres at least in part, around the subjective allocation of ADR scale values to real tasks. It will be interesting to note how that debate is resolved since the tools beginning to emerge from the US are based on similar (if not the same) underlying theory. From a Westland perspective however, and from the point of view of having to perform the analysis now and not at some unspecified time when the theoretical debates are resolved, the tool is a valuable asset provided that results are viewed as indicative rather than definitive. There is a further rational basis for Westlands commitment to the technique. Prior to the award of the Merlin contract, Westland had undertaken a similar man-draulic study which was subsequently validated using man-in-the-loop simulation. Validation results did not show a perfect correlation but the number of instances where the theoretical analysis failed to predict a problem were few. Even these omissions could be overcome by better modelling.

Rating

		1	2	3	4	5	6	7
Automatic (stimulus - response)	1	A	A	A	A	A	A	A
Sign, Signal, Recognition	2	A	A	A	A	A	A	M
Selection (choose alternative)	3	A	A	U	M	A	M	M
Encoding/decoding, Recall	4	A	A	M	U	M	M	U
Planning (project actions etc)	5	A	A	A	M	U	U	U
Evaluate (consider aspects)	6	A	A	M	M	U	M	U
Estimate, Calculate, Conversion	7	A	M	M	U	U	U	U

Figure 5 Cognitive Sensory Modality, Rating Scale, Description and Conflict Matrix

3.4.1.2 Decision and Error Analysis (DEA)

Operator decisions are required when there is more than one possible course of action. The operators ability to make the correct decision is directly related to the quality of his work performance. Every decision includes the scope for making error, although it is possible to make errors without making decisions.

The ability to make the correct decision is based on experience, training, and the HMI itself. It is also based on events beyond the control of the operator. These events include environmental effects, the working environment, organisational influences, and certain imbedded personality characteristics.

To help all operators become good decision makers, procedures sometimes referred to as Standard Operating Procedures or SOPs are defined as part of the training regime. Such procedures where ever possible, decompose decision opportunities into simple bipolar choices, and if possible, decompose them far enough such that any given bipolar choice is not in itself critical to mission success. Departure from SOPs for whatever reason will increase the difficulty of making the correct decision thereby increasing the likelihood for error. As incorrect decisions compound themselves the likelihood of mission failure increases. Decisions and errors alike reflect human judgement which is wholly a cognitive process. The Decision and Error Analysis (DEA) helped to provide a better representation of the effect of cognition on overall mission success.

The DEA was the second part of the approach to Merlin workload analysis and was intended to complement the Task Network Modelling (TNM) Study. Results would indicate:

i) A distribution of times for task and mission completion.

ii) Probability of following alternative sequences of crew activities other than those defined in the TNM study.

iii) The effect of operator error on subsequent decisions and its effect on overall mission success.

iv) The areas of operator performance most critical to mission success.

The TNM and DEA models used data from the common Time Synthesis Modules and were based on the same mission scenarios. The two studies in conjunction were therefore able to provide a dual perspective on HMI effectiveness.

Decision and Error Analysis Model Components

The DEA was based on a model of operators decisions and associated errors related to the mission scenario under test. The DEA model is comprised of three components which are largely empirically based.

i) Operator Task Components (Figure 6 Major Task)

The analysis was based on blocks of operator task components which were derived from collections of TSM. Both total time duration and time distribution were used in the model.

ii) Decision Model (Figure 6 Decision Node)

The decision model was empirically based and modelled three forms of bipolar decisions at each mission model node. The basic mission model reflected the scenario used for the TSM Study but also modelled alternative decision paths which would cause the aircrew to deviate from the prescribed sequence of activities.

iii) Error Model (Figure 6 Decision Node)

The error component represented the cause of incorrect decisions. It was therefore modelled as an integral part of each decision. A number of different error forms which appear to be common to all human operators were modelled:

- Deliberate breach of rules. (Conscious departure from rules)
- Incorrect application of rules. (The operator believes that he is applying correct procedure but is not)
- Slips and lapses. (Unintended error caused by a lapse of attention)
- Mistake. (Performance contrary to correct intention)
- Incorrect perception of evidence. (Influenced by system design, quality of training and experience)

Error severity was also accounted for in the model in terms of low to catastrophic effect on mission success.

An error 'knock on' effect was also provided in the model by carrying over error effects into the subsequent task. This was dealt with by use of an algorithm which calculates the size of the knock on effect according to error severity and time between tasks.

MicroSAINT for Windows (TM) network analysis software (MSW) was used to network the decision and error models. The use of MSW allowed the study of critical decisions and errors through the dynamic simulation of various possible combinations of crew task through to mission completion using monte carlo rules. The tool supports a pragmatic but stochastic approach to the problem of studying operator performance. Empirically collected performance data can be utilised and models can be behaviourally oriented to reflect crew interrelationships and the effects of extraneous mission events on operator performance. Furthermore, MSW allows the presentation of a map of the model in a form easily understood by the customer.

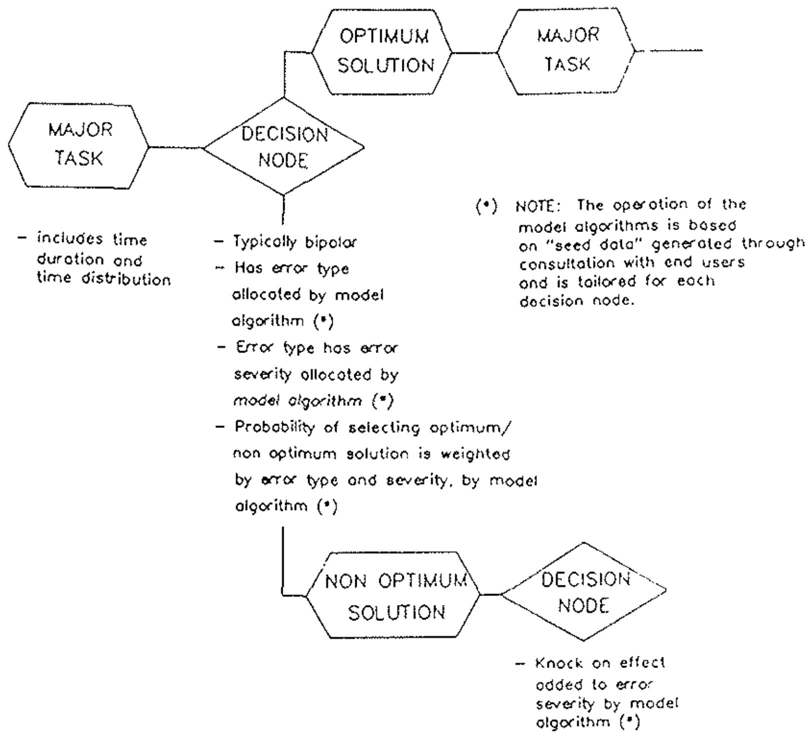

Figure 6 Implementation of Model Components

At the time of writing this paper, the results from the Decision and Error Analysis has not been fully generated. However, preliminary results appear in general to correspond to those obtained from the TNM Study. As expected, the more comprehensive attention to the crews cognitive process (decisions and errors) in the DEA study has indicated areas of concern which were missed in the Task Network Modelling Study.

3.4.1.3 Benefits of Workload Analysis

For any large complex system, the crew must be considered as an essential part of the operational performance calculation.

Crew workload has long been a customer concern, and 'design for minimum workload' now appears as a common requirement. It is also a significant issue in HE since workload is a central consideration in the customers judgement on HMI fitness for purpose. It is however a mixed blessing. Analysis of the kind described, if conducted early enough in the development programme, and if maintained as part of the progressing design, can provide customer confidence and can provide early indications of HMI related problems. However, analytical techniques are still in their infancy and no HE practitioner could on balance instigate requirements for extensive and expensive change to the HMI on the basis of indicative results.

The real benefits are probably to the end user himself who in the final analysis is probably the best judge of the effectiveness of the HMI. It is often observed that the analysis points to areas of high workload which the customer is well able to predict for himself, or has already expressed concern over. This is invariably interpreted by HE specialists as confirmation of the effectiveness of the analysis but often by others as more unnecessary cost and effort. I believe that the charge of 'unnecessary cost and effort' is misguided. If one accepts that the reduction of risk is a central product of progressing development, then workload analysis which provides added weight to specific concerns, or added weight to existing confidence is of considerable value. Even to the contractor who has enormous investment in an existing design, early workload concerns can be offset not by launching into expensive redesign, but by working with the customer towards improved 'Operating Procedures', better allocation of tasks between crew, or even by consideration of crew training. If conducted from an early enough stage, the continued reiteration of workload assessment as the HMI develops can actually be used as a measure of continued HMI improvement.

4 MANPRINT AND HUMAN ENGINEERING

It is not possible to talk about Human Engineering in the UK these days without talking about MANPRINT. Some practitioners confuse Human Engineering and MANPRINT. Although HE is an integral part of MANPRINT it is only one part.

MANPRINT is an acronym for MANpower and PeRsonnel INTegration, in system acquisition. It is a philosophy applied to the UK MOD procurement process which covers six major technical areas:

Manpower:	The number of human resources, military and civilian, required and available to operate and maintain military systems.
Personnel:	The aptitudes, experience, and other human characteristics necessary to achieve optimal system performance.
Training:	The requisite knowledge, skills, and abilities needed by the available personnel to operate and maintain systems under operational conditions.
Human Engineering:	The comprehensive integration of human characteristics into system definition, design, development, and evaluation to optimize the performance of human-machine combinations.
System Safety:	The inherent ability of the system to be used, operated and maintained, without accidental injury to personnel.
Health Hazard:	Inherent conditions in the operation or use of a system (eg vibration, fumes, radiation, noise) that can cause death, injury, illness, disability, or reduce job performance of personnel.

The philosophy behind MANPRINT is that each of the above domains should be systematically considered during the procurement of any new manned system. Examination of these areas is not new, what is new is the explicit recognition that these areas are all interrelated and potential trade-offs exist between them.

MANPRINT in the UK is not new. In the late 1980's, based on a model of the US MANPRINT program and encouraged by US DOD reverse engineering cost trade off studies, the British Army adopted the MANPRINT philosophy into its procurement process. As of 1992, MANPRINT became tri-service. At present it is mandatory to call-up MANPRINT procedures for the procurement of all "major land systems". In effect, this means all Army Systems with a development cost of >£5M or a production cost of >£10M. This does not preclude the use of MANPRINT for air, sea, or lower value programmes if the MOD feels that there are advantages to be gained from doing so. This places future rotorcraft procurement programmes such as the Attack Helicopter (AH) and future major updates to EH101 Merlin in the category of programmes likely to be covered by MANPRINT.

4.1 Consequences For Industry

The cost of military manpower has not traditionally been considered in the procurement process. The increasing cost of personnel compared to equipment is now being recognised by the UK Government as a major factor in equipment life cycle costs.

Commitment to its "Options for Change" initiative has forced the government to consider the personnel aspects of equipment it wishes to introduce as a means of reducing the MPT (manpower and training) costs of such systems.

Industry cannot ignore the UK MOD initiative if they seriously wish to bid for UK MOD contracts. In all future MOD procurement programmes industry will be required to produce a MANPRINT plan. This plan will identify industry expertise and also demonstrate that the MANPRINT framework will be used effectively during the design process. While there is no agreed format, or specific MANPRINT item description, the plan should address the company's overall MANPRINT structure, including the qualifications of domain experts, their interface with other programme elements for the considered system and the level to which the Company's MANPRINT organisation reports to the system's program manager. The plan needs to indicate a means of ensuring that MANPRINT requirements will be fully met.

Proposals received from industry in response to Invitation To Tenders (ITTs) will be assessed by a team of experts, probably drawn from a MANPRINT Working Group. They will examine proposals for evidence of MANPRINT planning, management, reporting, test and evaluation expertise, analysis of MANPRINT costs, preliminary trade-offs and understanding of the MANPRINT goals and constraints. Specific MANPRINT issues highlighted in the ITT must also be adequately covered.

Any company ignoring MANPRINT issues will be heavily penalised at the bid assessment stage. The MOD recognise that contractors will be reluctant to incorporate MANPRINT into proposals or designs unless MANPRINT elements are seen to influence MOD decisions. Therefore the MOD have specified that MANPRINT should be a top level assessment criterion and should be accorded the same level of importance as technical management, cost, or logistic assessment at the proposal assessment stage.

In the UK, lessons are to be learned from the US DOD treatment of LHX bids. Superiority in the maintainability and MANPRINT Human Engineering areas were reported (Reference 3) as the factors responsible for the Boeing/Sikorsky First Team's victory over their McDonnell Douglas/Bell Super Team competitor.

4.2 Industry's Response

As yet, there is no formalised MOD approach to the integration of the MANPRINT domains into the procurement process which industry can use as a model. It is not clear which of the MANPRINT domains will actually become the responsibility of the equipment contractor. The UK military, Manpower, Personnel and Training domains are less familiar to industry for two reasons; less is known about them, and traditionally, they are domains which fall within the remit of the MOD itself or contracted to specialist organisations.

It is not unreasonable to assume that all these domains will become more significant to industry irrespective of who retains the principal responsibility (MOD or industry). In addition to the traditional subject matter of these domains, there are related factors which will continue to have a direct bearing of HE in its application to design. Under the Merlin programme, there are 'Manpower' requirements which specify number of crew (2 mission crew, single pilot). Although these requirements are based at least in part on very early feasibility work undertaken at Westland, they are viewed by the MOD as 'foundation stones' in the HMI design irrespective of the expansion of sensor capability and HMI complexity which the present Merlin requirements impose. Although comprehensive crew workload studies are being undertaken, it has been made clear to industry that the addition of a fourth crew member is not an attractive solution if workload related problems are discovered. Industries attitude to accepting the HMI design risks and potential cost deltas associated with such indirect requirements under MANPRINT contractual conditions might well change. This will occur not only because of the MOD recognised trade offs which exist between domains but because industry will need to adopt a programme of activities which continually service these requirements throughout the development cycle.

4.3 Costs to Industry

It remains of great interest to witness how HE MANPRINT requirements will be expressed to industry and how industry will respond in the climate of fixed price contracts.

There will be the inevitable process of industry best guessing the relative level of importance the customer placed on the HE content of MANPRINT. Human Engineering considerations will also be made in the context of industries own commercial needs and objectives, present and desired strengths, marketing strategy and perception of how and to what extent competitors will respond.

Industries response to HE MANPRINT requirement is difficult to quantify. Improved HE practices and the improved standing of HE in any existing design organisation must come primarily from the design organisation itself through its industrial strategy of product improvement which will (in part) be based on a clear view of the values of HE and its place in a multi disciplinary approach to product design.

The strategy adopted for the application of HE to Merlin development under the Human Engineering Programme Plan carries many of the MANPRINT hallmarks required for successful integration into an upgrade programme (see Figure 7). Given the present state of the defence industry and the much welcomed peace dividend, this might represent the working model for some time to come. A technical model which might be more appropriate for a new aircraft programme would be well founded on the already existing and well defined requirements of STANAG 3994 and Mil-H-45655.

5 THE MANAGEMENT OF HUMAN ENGINEERING

The struggle between customer and contractor over poorly defined HE related requirements, and continual debates over the relative merits of diverse design solutions, all of which can be technically correct, is characteristic of any sizable HE programme.

The apparently unresolvable problems become far clearer, if two premises are accepted:

i) That the contractors main motivation is to reduce corporate risks associated with a proposed technical solution and keep the cost of contracted development activity to a minimum.

ii) That the customers main motivation is to ensure that he can 'live with' the product in service and that the best value for money is achieved by consideration of full life cycle costs.

Any successful HE programme must cater for both perspectives. The solution probably lies in a balance between clear and concise specification of requirements, and demonstration of the process within which rational (not necessarily compliant) decisions are made.

A typical process diagram is shown at Figure 7. The key component is the Human Engineering Plan (HEP). The HEP must contain a clear and concise statement of intent by the contractor. This will be achieved by concentrating on three factors.

i) Requirements
ii) Risks
iii) Processes

5.1 Human Engineering Requirements

HE requirements are typically described to varying degrees of specificity. Requirements contained in standards such as STANAG 850, Mil-Std-1333 and Mil-Std-250 cover design of the physical interface and crew workstations and are reasonably well defined. Requirements for integrated systems which are software intensive are much less explicit but do exist in standards such as Def-Stan-0025 and Stanag 3705. Requirements which cover crew or HMI effectiveness do not exist as anything other than customer requirements for 'low workload' and 'usability'.

As systems become more software intensive, poor requirements will inevitably compromise HE acceptance testing. Despite the fact that explicit customer requirements might not exist, the implicit requirements play a full and active part in customer evaluation. This is not meant as a criticism of customer requirements, it just reflects the 'state of the art'. For future systems which depend on a 'symbiotic' relationship between man and machine, the problem associated with poor HMI effectiveness requirements will be exacerbated. The cognitive capabilities which presently reside in man are conveniently swept up in the requirement for a manned crew. When these capabilities are integrated with the machine they become part of the software specification which will be subject to acceptance testing. Establishing this set of testable requirements is a formidable challenge for customer and contractor alike.

For present development programmes, it is essential that all HE agreed contractual requirements are exhaustively listed and redefined in specific implementable terms wherever possible. From the contractors perspective, this will enable costs to be closer defined and will provide a checkable list which can be used as part of the customer acceptance process.

For present software intensive system design, industry is perhaps better served by looking at the effectiveness of similar applications or by depending heavily on the Human Computer Interaction (HCI) literature which provides firm HE guidelines on central design principles. These are some, of the sources for rational design. They can be applied to design and demonstrated to the customer, through rapid prototyping for example, even if they cannot always be expressed in explicit terms. The embodiment of these rational rules can provide direct input into the design process through HE design philosophies. Under the Merlin programme, several such philosophies have been developed.

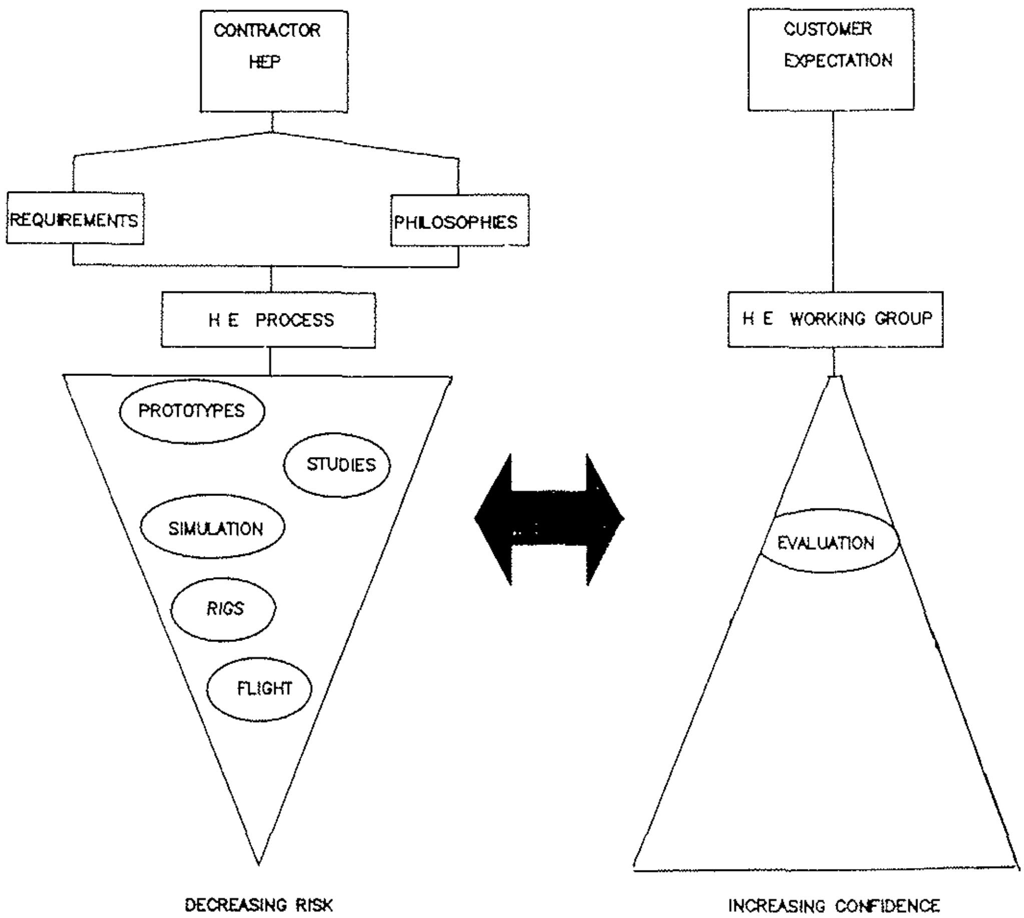

Figure 7 HEP Strategy

5.2 Human Engineering Risks

Human Engineering risks are simply a subset of risks associated with the overall programme. As such, they must be treated as an integral part of the project cost/modification/ timescale trade offs. If the HE risks are identified as high project drivers, then these are the risks which should be given high profile within the overall programme and should formulate the main thrust of the Human Engineering Plan (HEP).

5.3 Human Engineering Design Processes

The HEP must describe the process of design, test, and evaluation. The processes give the customer access to the design cycle through their involvement in the whole range of rapid prototyping simulation trials and demonstrations and analytical workload analyses which have already been discussed. The processes however give the customer far more than early insight into design. They demonstrate that the diverse range of requirements (sometimes contradictory and non explicit despite the contractors prior attempt to define them in context) are being managed in a rational manner and that the eventual design solution can be justified. Further, the defined processes will give confidence to the customer that the timing of the HEP activities and the remainder of the design activity are appropriate for the management of high risk areas.

Where crew workload is considered a high risk area for example, a well defined process for investigating workload, and the timing of the study with respect to major system software freeze dates, will give the customer considerable confidence in both the management of the problem, and the cost/performance trade offs which might subsequently need to be made.

In the UK, the interface between the contractor and customer is usually through an HE working group. The working group is usually chaired by the Project Manager (customer) and attended by the customers own nominated technical and programme authorities, together with the contractors technical experts. Difficulties arise where this exercise is seen by the contractor as an opportunity to gain approval of the design. It is difficult to get consensus on whether the current solution is acceptable (there may be a better one). The contractors intent is to stop looking once he has found one solution whereas the customer needs to satisfy himself that they have selected the best available at contract cost.

MANPRINT and its relations elsewhere in Europe are frameworks for thinking about design problems and decisions which are aimed at generating confidence in the contractor by ensuring decisions are justified based upon life-cycle costs of both equipment and personnel. If future HE efforts are closer aligned to customer expectations, then Human Engineering Working Groups may concentrate rather more on the process of design and justification of design decisions rather than on the details of design itself. This shift in emphasis might reduce the concern often expressed over poorly defined requirements, but will most certainly require a far greater emphasis on the application of formal processes and demonstration through the kinds of prototyping tools discussed in this paper.

6 CONCLUSIONS

This paper has addressed a broad variety of technical areas and tools central to the application of Human Engineering to rotorcraft design. It has considered some of the major difficulties Westland has experienced in applying Human Engineering to mainstream design, and more generally considered some of the more important issues related to the management of Human Engineering in industry, and the possible implications of MANPRINT.

The following key summary points can be made.

i) Product complexity particularly HMI complexity cannot be successfully managed without the application of HE.

ii) Poor attention to HE will undoubtedly lead to unacceptably high programme risks and poor customer confidence.

iii) HE although a relatively immature discipline has a formidable tool set which can and does complement those already well established within other more mature disciplines.

iv) For HE to be successfully integrated into the design process it must become a mainstream activity programmed into the critical design path.

v) The adoption of MANPRINT by the UK MOD will make HE a mandatory requirement which will necessitate a more formalised set of requirements on the part of the customer, and a formalised management structure on the part of the contractor.

vi) A proven HE track record is a significant part of the companies capability profile and will help to maintain a competitive position certainly under future UK MOD procurement policy.

The role of HE in the future must not be under estimated. Investment in tools and methods must continue in order for HE to become better integrated with main stream design. I hope this message has been echoed throughout this paper.

7 REFERENCES

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Reference 3 Flight International 17-23, April 1991.