

THE ROLE OF SIMULATION IN THE DESIGN PROCESS

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ABSTRACT

This paper discusses the role of real-time simulation in the design process of helicopters and their avionic systems. The nature of the problems facing the helicopter and systems designers are reviewed, and the potential benefits accruing from the timely and effective use of simulation are examined.

The development of simulation as a Westland Helicopters Ltd. (WHL) design tool over the last two decades are reviewed, and the characteristics of the new simulation facilities at Yeovil are described.

1.

INTRODUCTION

Simulators, particularly flight simulators, have been used for many years in both the fixed and rotary wing fields to provide cost effective crew training. Although the helicopter industry has generally lagged behind in applying simulators to the solution of design problems, WHL have been using them in a variety of ways for over 20 years.

However, with technology and techniques evolving at apparently exponential rates - especially with respect to the performance capabilities and reducing cost of digital systems - the nature of the design problems being faced by us and other aircraft and systems designers have changed dramatically in that span of time. With the increases in capability come more demanding requirements, and fresh approaches to the solutions of problems must be examined. WHL, with its involvement in the Sea King replacement project has embarked on a particularly demanding program, with a number of areas of high risk. A major expansion of WHL's simulation facilities has taken place and this paper presents the authors' view of the role these facilities have started to play and will play during the course of this and future projects. Although much of the following discussion revolves around a complex ASW helicopter system, many of the arguments are valid for any modern system, be it military or civil.

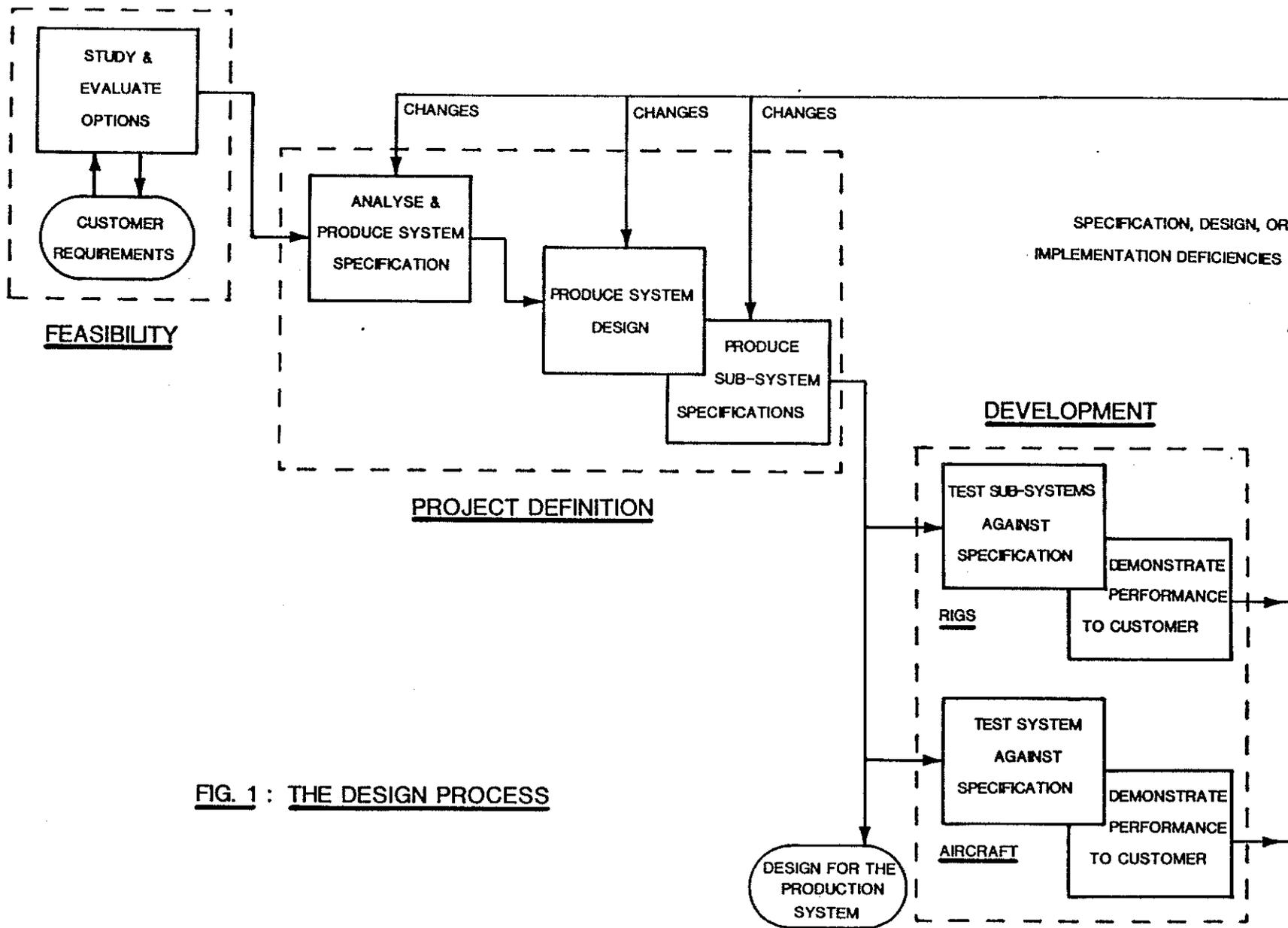


FIG. 1 : THE DESIGN PROCESS

The paper reviews the role of simulation in the current design processes being applied to helicopters and their avionic systems, and discusses the benefits which accrue from the timely and effective use of the simulation tool.

The paper includes an overview of the Flight Dynamics, Cockpit and Mission Avionics Simulators which constitute the new simulation facility recently commissioned at WHL.

2. A VIEW OF THE DESIGN PROCESS

Before any discussion of how simulation fits in to the design process one must define some terms, in particular that of 'the design process'. Figure 1 shows us a simple (and perhaps somewhat idealised) model of the traditional process linking the original specification of the customer's requirements to the production of series aircraft. It is possible to trace an evolution of the design from the extreme abstract to the very concrete, corresponding to the phases termed Feasibility Studies, Project Definition and Development.

Feasibility Studies

The task here is to examine the customer's aspirations expressed in the form of a target specification, and by assessing the feasibility of various options assist him to produce a more refined specification expressed as a requirement. During this phase extensive use is made of modelling techniques, and little or no hardware is produced. The result of this phase is an Outline Requirement Specification on which both supplier and customer agree.

Project Definition

Continuing on from Feasibility, the task in this phase is to analyse the specification and its implications, and produce a detailed specification of the overall system requirements. From this an initial system partitioning and design evolves, together with detailed specifications for the sub-systems. Once again, the prime tool in this phase is the mathematical model rather than tests with hardware, but boundaries with the next phase become blurred as progress is made faster in some areas than in others.

Development

In this phase, the design is in principle complete and the task is to demonstrate by initially using early model hardware in ground rigs, and later using "production" standard equipment in prototype aircraft, that

- . The design is satisfactory in that the subsystem or system design is capable of meeting the requirements of the appropriate specification.
- . The design has been satisfactorily implemented, in that the subsystem or system performs as designed.
- . The performance meets the needs of the customer i.e., the system or subsystem specifications correctly interpreted the original customer specification.

In practice of course this is a strongly iterative process with deficiencies leading to revisions in the design or specification, or both. Of course, the customer is usually very involved in this process, particularly where trade-offs occur with system cost, performance and timescales.

On the completion of this phase the design has reached a stage where production can begin, which for the purposes of this analysis marks the end of the design process.

Of course the customer is seldom completely satisfied with the delivered system, and product improvements continue throughout the life of the project, but that's another story!

The traditional main tools visible in this analysis of the design process are - mathematical models - ground rigs - flight test aircraft (prototype). It is our contention that simulation can and should play a major role alongside these tools in all phases of the design process.

The requirement for real time simulation stems principally from the need for tools to address the interactions of a man with some system, rather than the inter-system interactions which can equally well be studied using non-real time models. In the case of the pilot, for example, the interactions he has with the aircraft may be categorised as involvement either with the control of the flight path of the helicopter or with the control of the on-board systems (both basic aircraft and mission

related). The non-flight control systems still need to be assessed in the context of the flight control task however, as the requirements for the pilot to interact with them must not compromise his ability to carry out his prime task. There is in addition a secondary requirement for real time simulation which stems from the need to demonstrate system performance, (be it with or without a man in the control loop) in a meaningful way - graphical representations of response characteristics have their place, but can be difficult to interpret.

3. THE ROLE OF SIMULATION

The primary reasons for using simulation on any project are to demonstrate the viability of some concept - which can range from that of the total system to some mode of operation of a subsystem - and to reduce the cost and timescales of the design and development programmes. It will be seen from the following sections that where simulation is used to augment the traditional tools of mathematical models, rigs and hardware prototypes, the emphasis on the differing contributions made by simulation varies according to the phase of the design. In general, however, benefits will always accrue wherever simulation is used to address those problems which would otherwise be avoided or postponed, e.g. the analysis of flight dynamics under system failure conditions, the assessment of crew performance when confronted with demanding workloads, and the prediction of operational performance in complex scenarios.

The role relative to traditional tools

Simulation is used both to extend, validate, or simplify the use of the traditional design tools, and to augment them by providing a means of addressing issues which would otherwise defy analysis as being too costly (in time or money) or too complex. These issues, of course, arise from the vastly extended system capabilities which modern technology offers and the customer naturally demands, and include system integration, human factors, complex scenarios etc. The role of simulation in this sense is shown in Fig. 2.

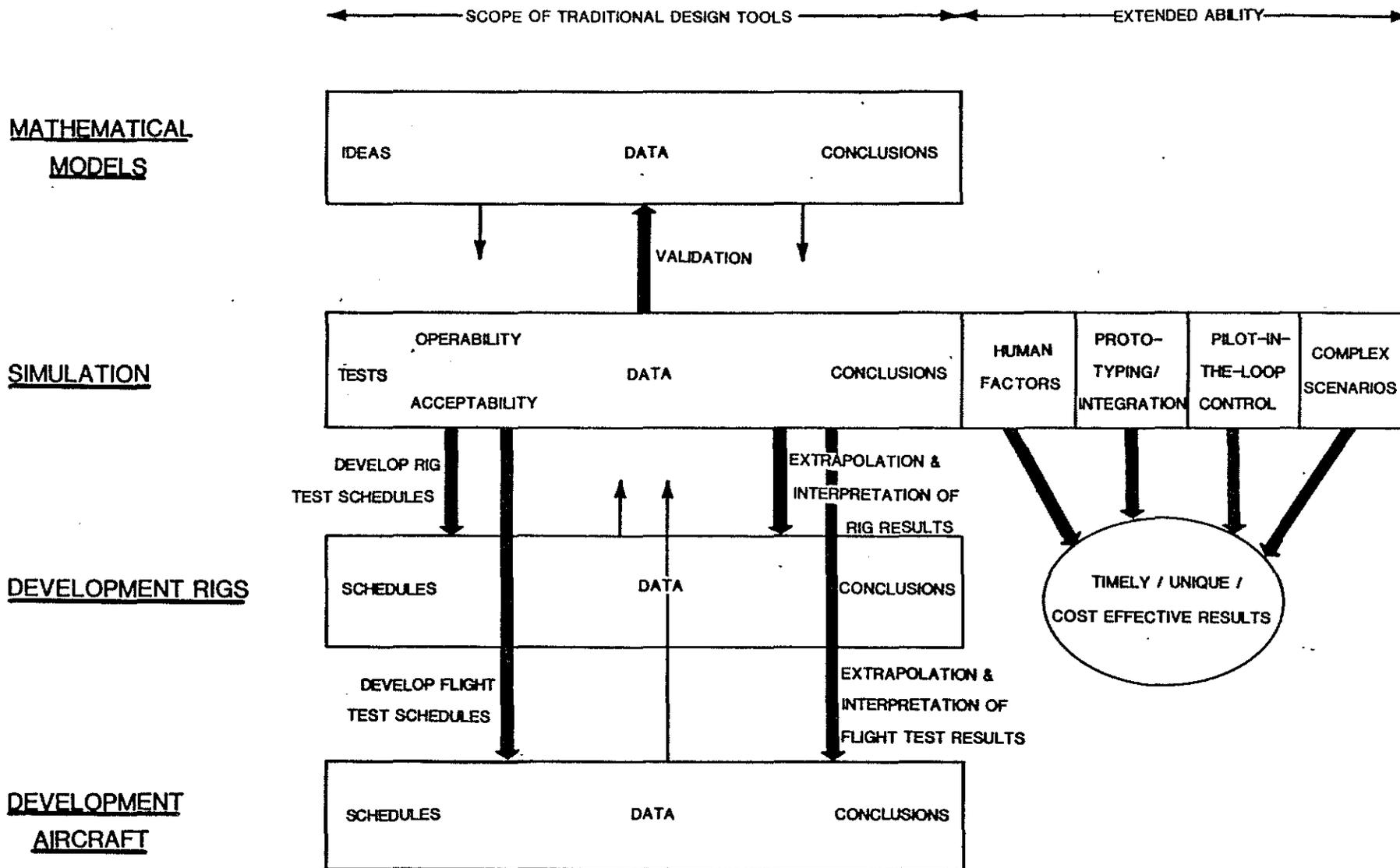


FIG. 2 : THE ROLE OF SIMULATION

The role during Feasibility Studies

The role during this earliest phase of a project is mainly concerned with two problems arising from the pilot and crew operations. The first of these concerns the feasibility of using any new, unproven technology which may be considered for the crew interface, e.g. multi-axis miniature controllers and cockpit CRTs, and the second is that of the human factors relative to overall System Management. This latter category is usually the more demanding, as it considers not only the problems of operator efficiency under high workload (and stressful) conditions, but also the likely performance of the complete system in what might be a very complex environment. It is at this stage that the crew complement and the necessary avionic system to fulfil the customer requirements are considered - and doubtless reconsidered!

Where completely new systems are being considered (as was the case with the Sea King Replacement), and the timescales short, there is clearly no possibility of using rigs or flight trials to address these problems. Although paper studies (i.e. mathematical models) can answer many of the performance problems, albeit to a limited depth, the use of simulation at this stage is invaluable. Not only can many technical problems be answered, but simulation may also give the customer the necessary confidence in the proposed solutions to enable him to authorise the following phase, where otherwise a project might be abandoned or postponed.

The role during Project Definition

The prime use of simulation as a design tool at this stage is again where design concepts run up against the limitations of the mathematical models available - either in terms of system complexity, or in terms of the involvement of the human operators. Simulation's function is to test these concepts for acceptability or operability. It provides a tool which allows designers to analyse the implications of their design options in the proper context; such a tool will help to understand interactions between the crew and aircraft systems as well as between the systems themselves and thus help to produce better designs. Secondly, it will provide a tool which will assist with the development of these designs into an acceptable final product; by supporting the "tuning" of parameters, and by the demonstration of system performance at an early

stage without recourse to costly hardware. A consequence of having simulation at this stage is that of having an ability (as provided by rigs and prototype aircraft later on) to demonstrate to the designers of sub-systems and most importantly to the customer, aspects of the system performance in a meaningful form. This provides opportunities to assist the customer to refine his specification at a much earlier stage than would otherwise be possible (confusion over the interpretation of a customer's requirements can be a recurrent problem).

There is, of course, a powerful interaction between the simulations, and the other mathematical models being used at this stage. The simulators provide important data to validate or refine assumptions made in the models, particularly with respect to operator performance, and the models provide the ability to extrapolate and interpret the simulation results.

A further capability, dependent on the simulation design, that may come into play at this stage is based on the ability of the simulator to provide a representative environment for particular subsystems. This may be capitalised on in a number of ways.

For systems with much embedded software, it is possible to use the simulation to support a software prototyping approach towards the final system design. Here a version of the software, designed to implement the kernel of a particular subsystem's functions, is produced to run on a processor interfaced directly to the simulator. Ideally the language used, the structure of the program, the operating system, and the computer and its I/O hardware would be targetted at the final system. However, these are secondary issues to the central concept of producing an early version of the software which can evolve as the project proceeds. Such an approach reduces the technical risks involved in developing the subsystem, and also provides valuable and relevant experience to the project team at relatively low cost. Invaluable data can also be gathered regarding the necessary processor storage capacity and throughput, the data flows in the total system, and the performance of tracking or control law algorithms.

Again where the simulator design provides a suitable environment, it may be possible to 'grow' the simulator into a form of an early system integration rig. Here prototype versions of the avionic systems, including any software or firmware, can be provided at an early stage

with signal flows representative of the final aircraft system. This approach, which allows added confidence to be built up in high-risk or safety critical areas, has typically been used previously for flight control system design and development.

It would be easy to disregard the involvement of simulation in the basic design process beyond this point (other than for the design of variants), with the major traditional impact to come many years on in the support of in-service aircraft. However, we feel that there is an equally important role for simulation to play once the design has progressed into the development phase of a project.

The role during Development

Firstly, with complex systems, there is a real problem in the design of suitable rig or aircraft trials programmes once the basic engineering trials have been completed. Where dynamic variation of many input parameters is required in a co-ordinated fashion to simulate system functions in a way usefully related to its operational use, the determination of the appropriate set of stimuli to achieve a given end can become a mammoth task. Simulation can provide useful assistance to the trials designer in this context, by identifying the essential stimuli, and by performing a sensitivity analysis so that trials are directed at the most critical areas.

More importantly, provided always that a vigorous programme of simulator validation/refinement is pursued in parallel with the aircraft development programme, the simulator can probably make it's most substantial contribution to the progress of the project in other areas. These are allied to the two main reasons for having a development programme - proof of design and performance.

Firstly, a substantial proportion of both rig and aircraft trials programmes throw up problems, either of deficiencies in the design or its implementation, or of deficiencies or misinterpretations of the specifications. In many cases the fault will be obvious and the matter can be referred back to the appropriate authority without delay. In many other cases however, and especially where complex and interdependent systems are involved, it will not be always be obvious what causes a problem, and much valuable flight and/or rig time will be used in tracing the problem. Simulator time is much cheaper in comparison (at least ten times less than development aircraft flight time), and

hence the simulator provides a useful option for analysing observed behaviour without disruption to the main flight or rig programmes.

Again, the customer requires that the flight and rig programmes demonstrate to him that the weapons system he is procuring satisfactorily achieves his specified performance. As weapon systems become more complex, this too becomes more and more difficult to achieve. The cost and logistic difficulties of arranging trials that are capable of demonstrating to any convincing extent the performance of, for example, a multi-sensor, multi-weapon aircraft intended to operate from a sea borne platform in co-operation with other surface and airborne units against a variety of surface and sub-surface targets are prohibitive. However, if flight and rig data is used to bench mark a validated simulator, then trials using the simulator permit at least interpolation between, and with luck extrapolation beyond the flight test data, giving either a quicker/cheaper demonstration programme, or better visibility to the customer, or both. The times ten cost factor relating simulator hours to development aircraft flight hours might easily be factored by ten again for work which would require trials on instrumented ranges or with weapons. We believe that by providing simulator back-up to a flight trials programme a more cost effective and thorough exploration is possible.

Finally, the exposure of crew and aircraft to hazardous flight regimes during the exploration of boundary conditions can be minimised by the effective use of simulation during the development phase. Although crew safety is of paramount importance, any major incident resulting in the prolonged unserviceability of a development aircraft could have a catastrophic effect on the project timescales, or indeed continuation.

4.

SIMULATION AT WHL

WHL have been committed to the use of simulators within the framework of the overall design process for over 20 years, and during that period have reacted to both the changing simulation requirements and the 'technology push'. Throughout this period the scale and capability of the simulation facilities has been tailored to the needs, as described in the following sections.

Review of Simulator developments

WHL's first exposure to the use of simulators came in the early 60's with the purchase of time on an analogue 'bureau' machine, rapidly followed by the purchase of an EAL 23IR/1 analogue computer to support a growing Flight Mechanics research programme. The system was enhanced in 1964 with an EAL 23IR/5 computer, and subsequently with a logic system, special purpose axis transformation hardware, and a helicopter cockpit mock-up to become a powerful Hybrid computer based Flight Dynamics Simulator.

In 1971, the first Digital Equipment Co. PDP11 had been introduced for simulation purposes, and by 1974 a dual 11/34, 11/55 system was being used to support an ASW Mission Avionics Simulator during Feasibility Studies.

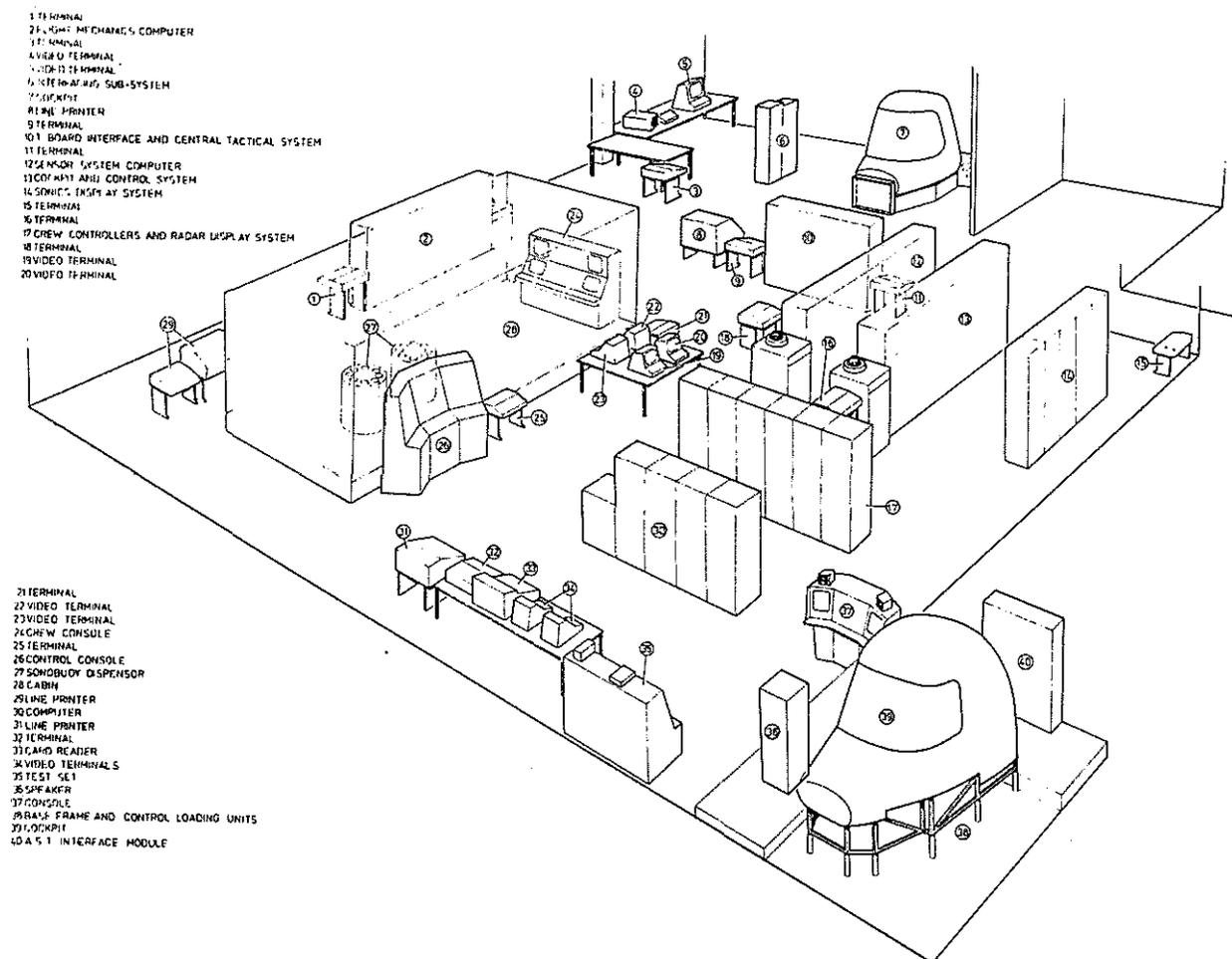
These machines were used extensively throughout the early and mid 1970's, but by 1978 the requirements for more powerful, flexible and integrated simulation facilities were becoming evident. In particular, the Sea King Replacement programme (now EH101) was entering a project definition phase, and the complexities of cockpit and cabin operations, together with the comprehensive flight control system options being considered, dictated that a substantial programme of simulator development should be undertaken. Consequently, WHL began modifying buildings to accommodate the simulation centre, recruited additional engineers to expand the existing hardware and software teams, and orders were placed for the necessary hardware.

This hardware (detailed below) was installed in December 1979, and the Flight Dynamics, Cockpit and Mission Avionics simulators commissioned in January 1980, March and April 1981 respectively.

Overview of Current Facilities

The layout of the simulation centre is shown in Fig. 3. From this it is apparent that a multi-processor approach was taken, generally favouring PDP 11/34 and 11/70 machines, although an SEL 32/77 minicomputer was selected as the basis for the Cockpit Simulator, and an AP120B array processor augments the Flight Dynamics Simulator. Standardisation was continued wherever possible into the software systems, with extensive use being made of CORAL 66 and the MASCOT design approach. The philosophy taken with each of the simulators was to cater not only for eventual linked operation, but also to build in additional flexibility and computing capacity so that support could be given in future to the foreseeable range of project activity.

FIGURE 3: WESTLAND HELICOPTER SIMULATION COMPLEX



Flight Dynamics Simulator

The Flight Dynamics Simulator (Fig. 4) focusses on the task of predicting and analysing flight dynamic characteristics.

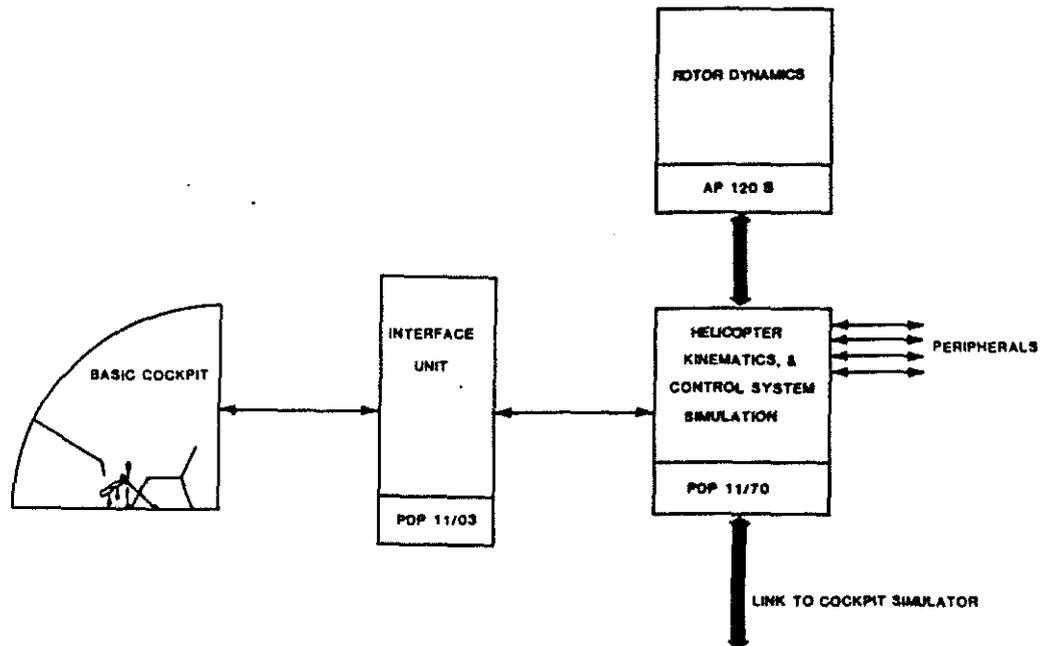


FIG. 4 : FLIGHT DYNAMICS SIMULATOR

It is based on a number of detailed mathematical models of the aircraft and its flight control system. To obtain accurate and stable results from these models it is necessary to iterate at high rates, in some cases many times the rates of loops in conventional training simulators. To achieve this in real-time (so that pilot inputs may be made in response to flight instrument displays) an extremely powerful computing resource is needed.

Although a large modern mainframe computer, such as a CDC 7600, would have the necessary power and word-length, the general inadequacy of mainframe machine architectures and operating systems with respect to real-time computing, coupled to the high cost of ownership, mitigate against their

use in this type of application. WHL opted for a much more satisfactory solution based on an AP120B array processor interfaced to a PDP 11/70 (see Figure 4). For the mixture of program constructs and functions typically required, the AP120B has a throughput which equals or betters that of a CDC 7600, whilst the 11/70 architecture and operating system are ideally suited to the real-time environment.

The calculation of main and tail rotor forces and moments, and the modelling of fuselage effects, are carried out by the AP120B at high iteration rates. The PDP 11/70 is used to solve vehicle kinematics, environmental modelling, manages the cockpit display and control data transfers, and handles the various peripherals. The software for the 11/70 is written in CORAL 66 and runs in conjunction with a MASCOT kernel hosted by the DEC RSX-11M operating system, whilst the array processor is programmed in assembler.

The cockpit contains sufficient controls and displays to permit real-time inputs by the engineers, and uses a mixture of actual aircraft instruments and rig hardware.

Cockpit Simulator

The Cockpit Simulator takes the form of a fully representative cockpit interior, with all displays and controls functioning, and is used for human factors assessments relating to instrument choice and layout, the integration of sub-system control panels, and of the piloting task in general. To extend the capabilities of the simulator with this last task, the Flight Dynamics or Mission Avionics Simulators may be linked to the Cockpit Simulator so that the pilot may fly the fully representative Flight Dynamics model, or he may make contributions to the ASW task in a realistic scenario. The simulator is based on an SEL 32/77 computer which interfaces with the traditional cockpit displays and controls via a Link-Miles (who produced the majority of the system hardware and software) AST multiplex data transmission system (see Fig. 5).

The SEL computer is interfaced directly to a raster graphics display generator (using a PDP 11/34 and a Micro Consultants Ltd. Intellect system) which produces the pilot's CRT displays, to the cockpit CRT based keyboards, and to the display systems being used by the Simulation Controllers.

The cockpit stands on a base frame which contains mountings for three control loading sub-frames for the yaw, cyclic and collective controls. Each sub-frame contains hydraulic control loading servos and linkages for both the pilot's and co-pilot's controls, and space is provided to cater for different control geometries.

The software is written in FORTRAN 77 and uses a proprietary Link executive hosted on the SEL RTM operating system.

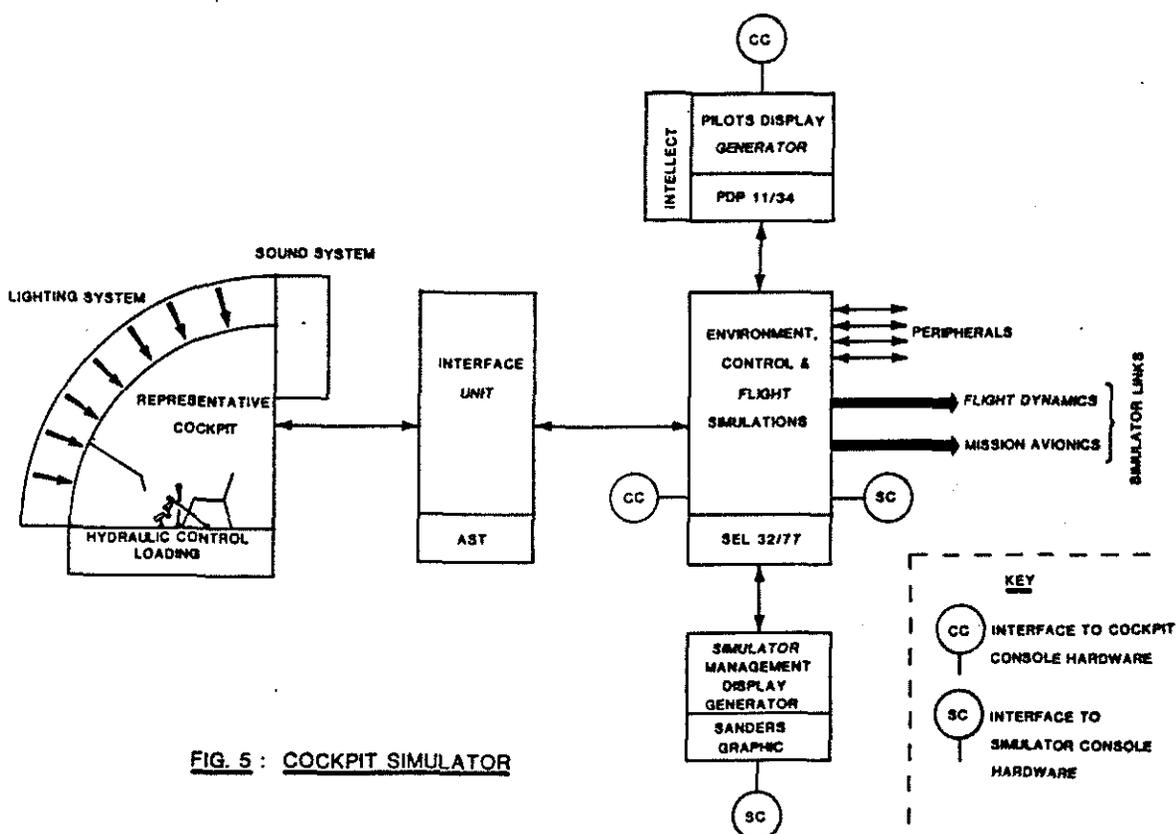


FIG. 5 : COCKPIT SIMULATOR

Mission Avionics Simulator

The Mission Avionics Simulator (see Fig. 6) provides a tool to examine the interfaces between the crew and the ASW avionics systems, in particular the format and contents of the displays and the refinement of interactive control

techniques. Other systems design activities which have already been supported (with considerable success) are software prototyping of certain systems and the verification of other non-real time mathematical performance models.

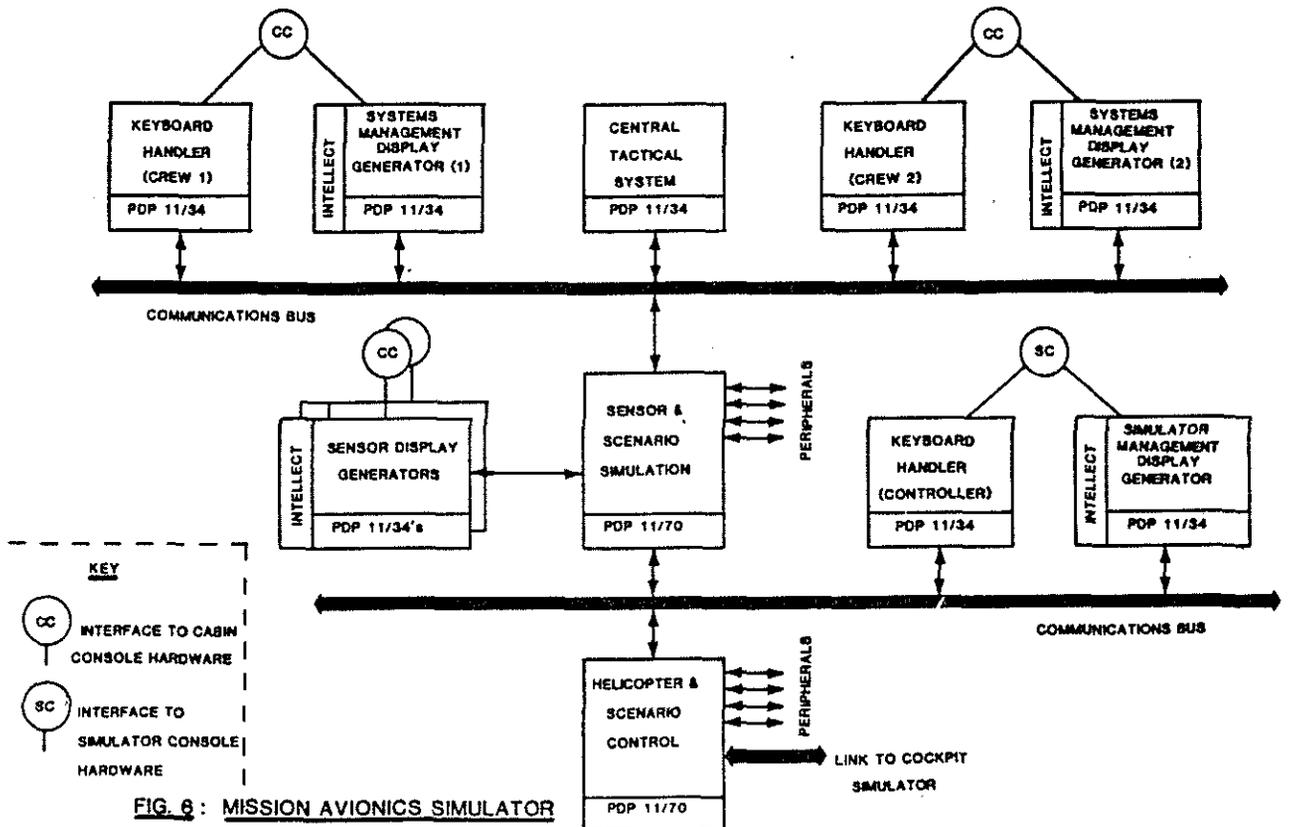


FIG. 6 : MISSION AVIONICS SIMULATOR

It is based on a large array of PDP 11/34 and 11/70 computers partitioned in such a way that the man-system interaction can readily be traced to sub-system level. Models of the avionic systems are interfaced with a simulated external environment (the scenario) and displays are based on the same raster graphic generators as used by the Cockpit Simulator.

The software has been written in CORAL 66, and runs with a MASCOT kernel hosted on either an RSX11-M or RSX-11S operating system. Several sub-contractors have been involved in the production of the various software systems.

The inadequacy of training simulators in the design context

From the foregoing discussion it can be seen that the requirements for, and the consequent usage of, simulators in the design process evolve in step with the overall programme. This is particularly relevant when considering the nature of the necessary simulation facilities, as it results in simulator designs which may depart radically from those of crew training simulators bought "off the shelf". It is the pressure to maintain flexibility, modularity, and margins of computing power in order that aircraft system changes may be readily assimilated which has dictated the approach taken to the WHL simulator designs. Briefly, the simulation design problems arise from a single source - the passage of time.

In the earliest phase of a project (for a new system), so little is known of the ultimate characteristics that a comprehensive simulation would be futile, and probably harmful. What is required is an intelligently animated mock up of the crew station which can be added to in terms of breadth and depth of coverage as the system evolves. As the design proceeds, and the weapon/sensor fit is defined, so more and more representative models are required, and the fidelity of the crew stations and the observed characteristics become more important.

Where piloting issues are concerned, the need for visual and motion cues to augment the cockpit instruments becomes ever apparent as development proceeds and as the customer takes an ever increasing interest in the efficiency of the aircraft and its systems. Likewise the crew who manage the mission system will have started to scrutinise the apparent performance more closely, and the emphasis will change from the refinement of subsystem management to the operation of the complete system. Thus it is during development that skilled operational crews, seeking additional fidelity, start to use the simulators alongside the engineers, and linked operation of Cockpit, Mission Avionics, and Flight Dynamics simulators becomes important.

It is this essential evolution of the simulation facilities in step with the design process which prevents the use of a standard training simulator to fill the Cockpit requirement, and of course the Flight Dynamics and Mission Avionics Simulation requirements present unique problems.

5.

SUMMARY

This paper has outlined the nature of the design process of complex helicopter systems, from the earliest stages through to production, and has illustrated the role of simulation alongside the more traditional design tools during the evolution of a typical programme. The nature of the simulation tools used in this context are very different to that of the training simulator, and the facilities which have been recently commissioned at WHL have been reviewed.

It is our belief that simulation provides an extremely efficient and cost effective means of reducing overall project costs and timescales, and indeed may sometimes tip the balance when the future of a project is being considered by demonstrating feasibility and reducing technical risks.

Although the scale of simulation used in this context must clearly be tailored to the requirements of individual projects (remembering that this is primarily for design assistance rather than research or training) it is imperative that a long term view be taken when developing a new facility. With the steady technological push, and the seemingly constant extension of the customer requirements, the usefulness of a particular simulator as a design tool could easily vanish in a 5 year period. Thus the standard of the simulators must be continually reviewed, and maintained in accordance with the nature and phases of the projects being supported.

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