

A SIMULATION OF THE MISSION CREW WORKLOAD IN A MULTI MISSION AIRCRAFT

Phillip Martin
Christopher Watson

CORDA Ltd.
Apex Tower, 7 High Street
New Malden, Surrey, KT3 4LH, UNITED KINGDOM

Andy Skinner

Headquarters Maritime
No 3 Group, Northwood
Middlesex, HA6 3EP, UNITED KINGDOM

ABSTRACT

The increased tasking and reduced manning of a multi mission aircraft put pressures on the mission-crew in terms of their workload, mixture of skill and the training required. This paper describes the simulation undertaken by CORDA for the UK Air Warfare Centre. Within the model, written in EXTEND™ (Imagine That Inc.), the mission is defined in a modular form, which allows the mission tasks to be developed and modified as the study progressed. Workloads are associated with each task which are then distributed amongst the mission-crew. Within the model supervisory roles, relief crew and rest periods are modelled. The design has provided a generic simulation approach to mission-crew loading which allows the analyst to study variations and sensitivities in a controlled manner. This allows the optimum capability to be assessed and the minimum training / manning burden to be associated with the introduction of new aircraft technologies and skills.

1 INTRODUCTION

1.1 Reasons for developing the model

This simulation model was developed as a result of a requirement from the UK Air Warfare Centre to investigate the potential crew workload in a multi-mission aircraft. As the technology improves, the mission crew are required to undertake more varied and complex tasks, but with fewer crewmembers. The study question was: What balance of crew skills would be required to obtain the most utility from the aircraft? The study helped to define the particular skill sets the mission crew may need, and as a consequence, what the training requirements would be. Would the aircraft be better manned with dedicated specialists, a variety of multi-skilled operators, or maybe a combination of both?

This study looked at a future multi mission aircraft. Consequently, the problem is a higher conceptual problem rather than a more detailed problem based on what equipment is to be on board and the ergonomics of the aircraft.

Part of this study was to develop a model to simulate the loadings on the mission crew given various scenarios and crew composition concepts. This paper describes the model, and the rationale behind its design.

1.2 The Method Used

A number of different crewing options had been postulated before the study started, each with different attributes and champions. The model was built to quantify and compare the various options proposed.

The model was written using the simulation environment EXTEND™ by Imagine That Inc. EXTEND had been used before to analyse a similar problem encountered with another aircraft, and it was found to be very useful in:

- the development of prototype models,
- the presentation of the concept to the client,
- the presentation of results.

EXTEND was used in its discrete event mode with both discrete event and continuous blocks being used. A number of customised blocks were created primarily to speed up the simulation and to keep track of data.

The model is time based and a simulation represents a sortie undertaken by the aircraft within a particular scenario. The study consisted of simulating the different crew mixes within a number of scenarios to provide the quantitative comparative data on crew workload.

2 MODEL DESIGN

2.1 Introduction

The model consists of two main sections:

- the generation of the scenario and the crewmember work load data,

- the representation of the aircraft. The aircraft is split into a representation of the mission consoles and of the crewmembers who work at them.

2.2 Defining the Scenario

Each scenario was broken down into smaller parts which could be used as the building blocks for all future scenarios constructed. These building blocks have been defined as events and tasks.

Tasks have a set time period, and have workloads (either constant or varying with time) associated with them.

There are set tasks that will occur during all simulations. For example, the tasks involved during take off and transit, going on task and performing a particular search. These are called the default tasks, and set up the main structure of the scenario. In general, the tasks that the mission crew are required to do will not change from this structure unless an event occurs.

These events are usually some kind of contact received whilst doing a search. The generation of these events during the scenario can occur in one of three ways. They can occur at:

- predefined times during the scenario,
- randomly generated times during the scenario, or
- be triggered by an external simulation.

Events can trigger different tasks, and on completing some tasks others are started automatically. For example, after an initial attack, a follow up attack may occur automatically afterwards.

The tasks generated by the events do not have to be prescribed by the user, as they too can be generated, depending on the type of events that occur – false contacts, enemy submarines, etc. An example of a scenario is shown in Figures 1 and 2. Both refer to the loadings for a single console. Figure 1 shows an example of the default tasks that will occur during a scenario, and Figure 2 an example of the possible tasks occurring when an acoustic contact is made. The relative loadings given to the console is shown in each case.

2.3 Aircraft Representation

The aircraft simulation is confined to the mission crew and the consoles that these crewmembers work at. The tasks have set workloads associated with them. When a task is passed to a console, the workload for that task is generated at that console. This workload is then picked up by the mission crewmember who is at that console at that time.

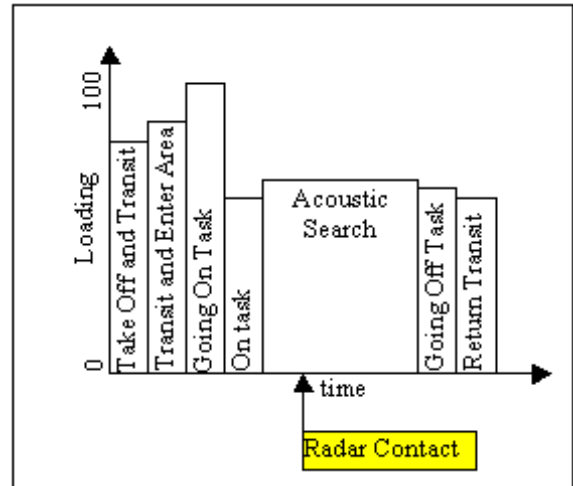


Figure 1: Default Tasks vs. Time

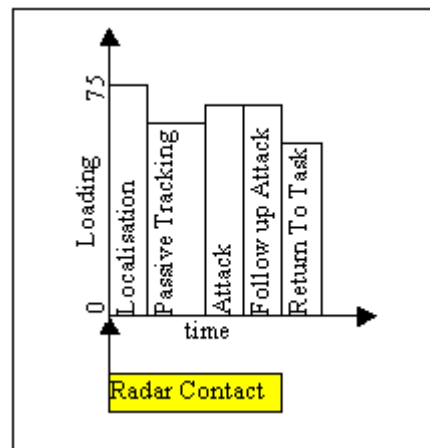


Figure 2: Example of Radar Contact Tasks

In this aircraft, there is also a relief position. Whilst in the relief position, the crewmembers still get a loading from doing various tasks, but not usually to the same extent as when sitting at one of the consoles. Figure 3 shows how the multi mission aircraft is represented in the EXTEND model. In this case the aircraft layout is set up to contain ten consoles (one of which is set up to be the relief position) and ten mission crewmembers (shown separately from the aircraft layout). The connections between the consoles show how tasks and messages are passed between them to set up the required loadings which are in turn picked up by the operators.

The various crewing options define which operators can do which jobs and how well they can do them.

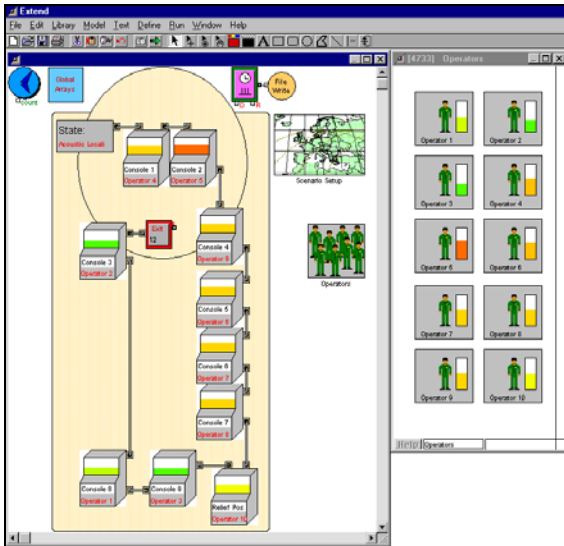


Figure 3: The Multi Mission Aircraft Model

2.4 Crew Rotation

In this model there is one more crewmember than there are work consoles – one crewmember for each of the consoles and one for the relief position. The crewmembers are set up so that the operator in the relief position swaps places after a defined amount of time with one of the other crewmembers. Who the crewmember can replace is decided by which consoles this person can work at, and who has been at their console the longest or which position has the highest priority. The crewmembers then prepare for a change-over (resulting in a slight loading increase for a few minutes), and then swap positions. This results in a relief cycle, giving everyone who can swap positions a rest period. Ideally, this cycle will, depending on the crewing option chosen, result in a more even distribution of the loadings across the consoles and crewmembers.

In addition, an ability can be applied to the crewmembers in each of the seats to distinguish between dedicated console operators, those who are multi skilled and those who are less experienced.

2.5 Representation of Load

It had been found in previous work that a non dimensional representation of load provided a convenient method of comparing the relative workloads of the mission crewmembers.

This method was continued in this modelling. A measure of load of 100 units is defined to represent the load an average crewmember could sustain continuously without a degradation in performance. This ability level is varied throughout the crew to provide a rating to show crew with more experience and to define a particular crewmember's ability in different seats. Within the model

another metric is defined as the maximum workload factor (1.5 for example). This is multiplied by the crewmembers ability rating to distinguish a level beyond which any additional load is lost. Between these two levels (ability and maximum) a crewmember works on the tasks but in a degraded way. Figure 4 shows the various work levels in an example where the operator has an ability of 100, and a maximum workload factor of 1.5.

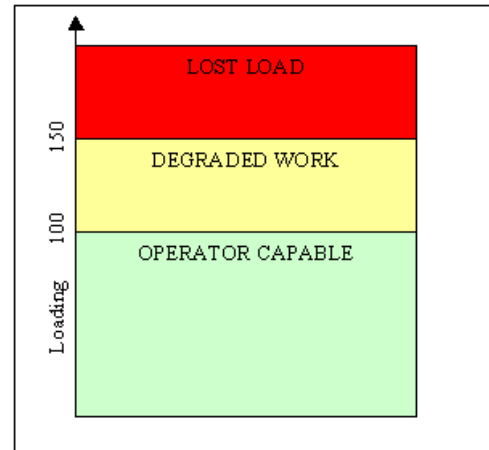


Figure 4: Operator Workload Levels

The “lost” Load is stored and executed when the base load falls below the ability level.

There are also secondary effects that have been implemented, relating to the crewmember workloads.

- The first of these is that of supervisory loadings. The mission crewmembers are split up into various teams, depending on the tasks that they are set to do. The supervisor of each of the teams gets a nominal x% of each of his supervisees current workloads. This supervisory load also increases as the supervisee goes beyond the rating level.
- Another secondary effect is that of briefings. When an operator swaps position, they are re-briefed. This results in an additional loading for the crew executives for a set amount of time as they complete the briefing whilst continuing with their other tasks

3 INPUTS

The model inputs are setup within a Microsoft Excel spreadsheet and are integrated into the EXTEND model via the use of hot links. This not only allowed the data to be readily assimilated but also allowed the model to be run and changed within the EXTEND run time version. There are six main categories of data:

- scenario task definition,
- task / console loadings,

- event details,
- crew abilities,
- crew positioning,
- supervisory roles.

All of this data is based upon consultation with the appropriate subject matter experts to ensure their realism and validity.

3.1 Scenario Task Definition

The scenario is defined by a list of tasks and events which are required during the mission. There are the base tasks which occur due to the mission being undertaken and there are additional tasks which are undertaken if an event occurs. These all have to be defined prior to the simulation, but they may or may not happen depending how the simulation progresses. In the following example (Table 1) Tasks have been defined to represent the consequences of a Radar Contact. The numbers in the last column show the order in which the tasks are undertaken once the contact has occurred. Table 1 has had the columns removed which map other events to the tasks not used in this example. Each task is given a duration, which can be varied during the simulation. Each task is given an ID number which is used by the model to distinguish the tasks and a flag is set to specify if crew changeovers can occur whilst the task is being performed. All this data can be set up by the modeller in consultation with the subject matter experts.

Table 1: Scenario Set-up Example

Task	ID	Changeover Possible? (0/1)	State Length (minutes)	Radar Contact Program Block Order		
Acoustic Search	5	0	300			
Radar Search	31	0	300	6		
Radar Localisation	32	0	10	1		
Return To Task	35	0	10	5		
Overt Shadow	36	0	10			
Covert Shadow	37	0	10			
SelfTac	38	1	10			
Follow Up SelfTac	39	0	10	4		
Rapid SelfTac	40	1	10	3		
OTHT Report	41	0	10			
OTHT Attack	42	1	10			
Radar ID	43	1	10	2		

3.2 Task Loadings

Table 2 is an extract from the Microsoft Excel spreadsheet showing task loading inputs for three tasks. Each of these tasks is specified by a pair of columns. The first column is the time from the start of the task and the second is the non dimensional load. During Take Off and Transit for example, console 1 is given a loading of 50 units for the first 4

minutes of the simulation, then it drops to 20 units, and then progressively increases to 40 units at 7 minutes. The last time of 20000 minutes is simply a large number put in to ensure the input data covers to the end of the task. All timings are relative to the start of the task and not simulation lapse time.

Table 2: Console Loadings Example

	Take Off & Transit	Transit & Enter Area	Going On Task
Console 1	0 50	0 50	0 70
	4 20	20000 50	10 70
	5 30		12 65
	6 30		14 60
	7 40		16 65
	20000 40		18 70
			20 60
			20000 60

3.2 Event Details

The event details are a list of the possible events that may occur during the scenario, and prescribed times at which they will occur (if the user wants to control when these will happen). Alternatively, events can be set to occur randomly. The example below (Table 3) shows that at 100 minutes into the scenario, an acoustic contact is received. Other times are inputted for all of the other contacts that occur. If a contact is not required to occur during a scenario, then it is simply set to occur after the end of the simulation run time (as in this example with the ASW Radar contact).

Table 3: Contact Times Example

	Contact Times:	
	Possible Contacts:	Time (minutes)
ASW:	Acoustic Contact1:	100
	Radar Contact:	20000
	Acoustic Contact2:	400
ASuW:	Radar Contact:	300
	Visual Contact:	500

3.3 Crew Abilities

Table 4 shown below is the definition of the crew abilities. For each crewmember an ability is set for each of the console positions. In this example, Operator 1 in console 1 has a greater ability than Operator 2, who has a greater ability than Operator 3. The last column is the maximum workload factor, which in this example has been set to 1.2 for all operators.

Table 4: Abilities of the Crew Input Table

	Console 1	Console 2	...	Console n-1	Relief Position	Maximum Workload Factor
Operator 1	120	110	...	0	100	1.2
Operator 2	90	100	...	0	100	1.2
Operator 3	85	85	...	0	100	1.2
...
Operator n	0	0	...	100	100	1.2

3.4 Crew Positions

The starting positions of the crew, their job title and which consoles each of the crewmembers can sit at are set up as in Table 5 shown below. In this example, the table entries with a number 1 and a shaded background mean that that crewmember can sit at that position. The table entries with a 0 means that crewmember cannot operate that console. Below, Operators 1, 2, and 3 can all do the tasks coming into consoles 1 and 2. This means that they will rotate between sitting at these consoles and being in the relief position. Also defined are the mission crew starting positions.

Table 5: Crew Positions Example

	Starting Position	Console 1	Console 2	...	Console n-1	Operator Job Title
Operator 1	1	1	1	...	0	Crew 1
Operator 2	2	1	1	...	0	Crew 2
Operator 3	n	1	1	...	0	Crew 3
...
Operator n	n-1	0	0	...	1	Crew n

3.5 Supervisors

The supervisory loads are also set-up in a similar table shown in Table 6. This example shows that Operator 1 supervises those people working at consoles 1 and 2, and Operator n supervises those at consoles n-2 and n-1. This also shows that each of the supervisors get 5% of the supervisee’s loading added to their own load.

Table 6: Supervisory Input Table

	Console 1	Console 2	...	Console n-2	Console n-1
Operator 1	1	1	...	0	0
Operator 2	0	0	...	0	0
Operator 3	0	0	...	0	0
...
Operator n	0	0	...	1	1
Percentage to Supervisor	5	5	...	5	5

4 OUTPUTS

The following figures show the types of output that can be extracted from the model. The exact outputs will vary depending upon the questions being answered, but the nature of the EXTEND environment allow graphs and output tables to be easily created.

Figure 5 shows the load supplied to a particular console as a function of time. The peaks and troughs in load show differences in work during localise, attack and follow up phases (the peaks) when compared to that of a simple search (the troughs).

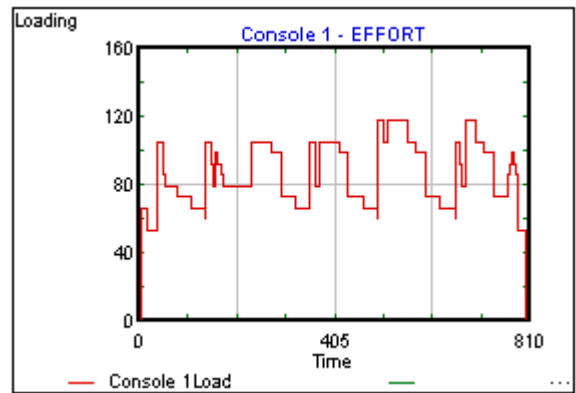


Figure 5: Console Loading Example

Figure 6 shows a similar presentation of the load on a particular operator. The gross load shows the total input load to the operator (console, supervisory and briefing loads), the net load shows the amount of gross load the operator can complete (based upon operator ability), the stored load shows the amount of load that could not be completed by the operator, and the worked load shows the actual amount that was completed (the net load plus any of the stored load that can be worked off).

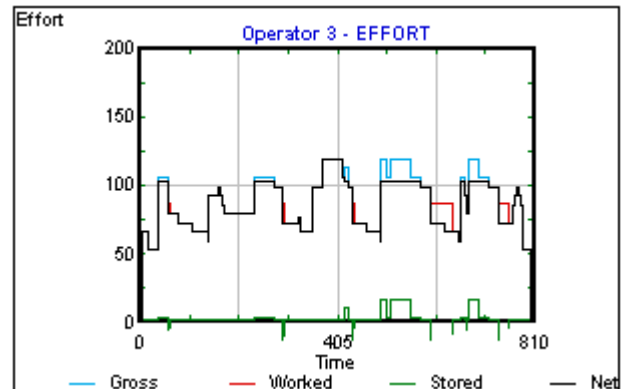


Figure 6: Operator Loading Example

The loading versus time data for both the operators and consoles are extracted into Excel for further manipulation.

For each of the mission crew in the aircraft, there are other useful metrics that can easily be obtained. The amount of time each of the operators spent in each of the seats shows how the crew rotation effects the individual operators. Figure 7 below shows this. In this example, there are three operators who rotate between two consoles and being in the relief position. Looking at Figure 7, it would be expected to see each operator spending approximately a third of their time in each of the seats. However, it can be seen below that Operator 1 was at Console 2, Operator 2 was in the relief position, and Operator 3 was at Console 1 for a lot longer than they were in any other seat. This is due to the fact that when performing certain tasks, the operators are not permitted to rotate seats. Whether the tasks allow or do not allow rotation is a user input into the model.

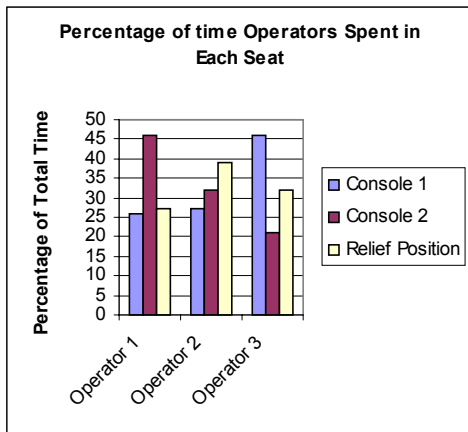


Figure 7: Time Operators Spent at Consoles

The percentage of time each of the operators spent doing certain levels of work is also useful. An example of this is shown in Figure 8. This example shows what effect allowing crew rotation (compared with not allowing it) has on the levels of work operator 1 had to do.

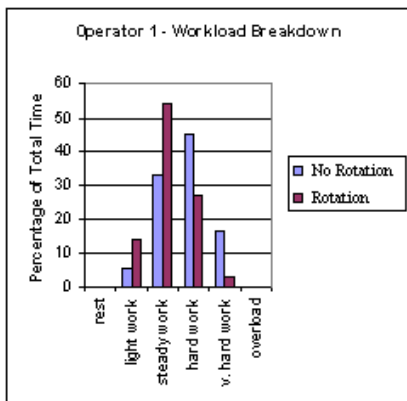


Figure 8: Workload Breakdown Example

Looking more closely at Figure 8, it can be seen that within this particular scenario, the rotation has resulted in an overall decrease in the amount of work having to be done. The operator completes more light (<50 units) and steady (<75 units) work whilst doing less hard (<100 units) and very hard (<125 units) work when rotation is permitted.

This kind of output is also useful when looking at the way in which the teams within the mission crew work. If one team works considerably harder than another, is there a crew composition that will result in some of this load being transferred to the team doing less?

5 LESSONS LEARNED

It is important to note that this model does not give “the answer”. It is a tool that is used by the analyst to compare the various crew composition options proposed. These comparisons are made by a number of metrics, some of which are mentioned above. Questions that can be answered with the model are:

- How long did each of the mission crewmembers spend in each of the positions?
- How long did the crewmembers wait until they moved into a different position?
- Did any of the crewmembers lose any tasks, and if so how much and how does it compare to the other mission crewmembers?
- What was the overall distribution of tasks over the whole crew?
- Were certain crewmembers doing significantly more work than others?

The balance of results from these metrics helps the analyst to distinguish the differences between each of the various concepts.

The reason for using a non dimensional level of load is that it was needed to keep a balance between the data being used and the simulation. When developing a model, it is very easy to get into the weeds of the problem. Moreover, at the early stages this high level of fidelity is not required and cannot be supported with the available data whilst there is often a significant body of information available at more conceptual level backed by extrapolation from past experiences and best military judgement.

The majority of the input data is based upon military experience of existing aircraft, systems knowledge and early trials impressions. This data is by its nature subjective for the new aircraft and the study needed to investigate the sensitivity of the results to changes to the inputs. The model design, and the EXTEND environment provided a robustness which allowed this to be investigated.

Likewise, after the initial comparison of results from this model, refinements were simple to incorporate, giving a higher fidelity into the model. The “What if?” questions

are easily covered by the existing model by manipulation of the input data or addition of blocks to the model. For example, if another console was required and an extra mission crewmember was to be added to the model, dragging down from the model libraries both of these custom blocks is a straightforward task to complete.

6 CONCLUSIONS

The model was successfully used to investigate the crew mix and training requirements, within a tight timescale.

The nature of the simulation environment allowed a close interaction of the military client with the development of the model. The graphical user interface allowed non-modellers (the client) to understand the model and to visualise any problems, thus enhancing the customers input into the model development.

The non dimensional “load” kept a balance between the fidelity of the model and the detail of the inputs.

The design provides a high level of reusability in the model for further investigations with this aircraft or alternative aircraft.

AUTHOR BIOGRAPHIES

PHILLIP MARTIN is a senior analyst and consultant within the Centre for Operational Research and Defence Analysis (CORDA), a wholly owned subsidiary of BAE SYSTEMS. He is a graduate of Aeronautical Engineering from Bristol University, and has been an Operational Analyst for over twenty years. During this time he has been involved with projects for all the UK Armed Services. He is currently responsible for the front line analysis undertaken by CORDA staff for the UK MoD and was himself a front line analyst working for the Maritime Warfare Centre (Fleet OA Staff) for six years. His email address is <Phillip.Martin@corda.co.uk>.

CHRISTOPHER WATSON is an analyst within the Centre for Operational Research and Defence Analysis (CORDA), a wholly owned subsidiary of BAE SYSTEMS. He is a graduate of Mathematics from the University of Warwick, and has worked within CORDA for three years. His email address is <Christopher.Watson@corda.co.uk>.

ANDY SKINNER is a Squadron Leader within the RAF. He is a graduate of Aeronautical Engineering from Southampton University and the RAF Aerosystems Course. He has served 2 tours on 201 Squadron at RAF Kinloss, a tour on the Nimrod Operational Evaluation Unit and as a Trials Officer at Boscombe Down responsible for navigation, acoustics, communications and self defence systems trials on RAF and RN helicopters. Currently, he is the RAF desk officer responsible for the introduction of the Nimrod MRA4 into UK service.