

Developing ARH Troop Tactics Using Operations Research Constructive Simulation

Chandran A.¹, G. Ibal¹ and Z. Tu¹

¹Defence Science and Technology Organisation, Fishermans Bend, Victoria, AUSTRALIA
E-mail: Arvind.Chandran@dsto.defence.gov.au

Keywords: Defence, Operations analysis, constructive simulation, physical models, decision-making

EXTENDED ABSTRACT

The Australian Armed Reconnaissance Helicopter (ARH) is expected to be introduced into service in 2008. The Defence Science and Technology Organisation (DSTO) supports the Australian Army by using simulation and analysis to develop, explore and optimise mission Tactics, Techniques and Procedures (TTPs) for ARH acquisition.

ARH missions are highly dynamic, involving several interacting land-based and air-based assets. One issue with developing a sophisticated simulation environment for TTP development is gaining an understanding of the level of modelling fidelity required to represent physical systems in an ARH mission. This includes modelling of threat systems in a hostile environment. Studies have focused on regional infra-red (IR) MANned Portable Air Defence (MANPAD) threats; however other threat systems will be examined in future.

Other issues include: creating models of human decision-making appropriate to represent ARH TTPs (which is addressed through consultation with the Australian Army); integrating these models into the simulation; and populating them with measured data.

Several TTP studies have been completed and will contribute to Land Warfare Aviation Combat Tactics. These cover single helicopter procedures, but focus on more realistic teamed tactics.

The results and recommendations are provided to the Australian Army for input into ARH tactical procedures and Concepts of Operations.

This paper focuses on troop evasion against MANPAD threats; MANPAD suppression techniques and escort support to troop-lift helicopters. For each study, a set of Monte-Carlo studies were conducted to explore the impact of different formation configurations and

different tactics on the probability of threat attack.

The lethality of three regional threat systems was examined (Missile A, Missile B and Missile C), and these missiles were launched from a number of randomly selected positions in a grid surrounding the ARH troop. Other parameters that were varied include ARH speed, ARH altitude and flare trajectories. The ARH flare dispensing sequence was fixed based on suggestions by the DACI-A.

Each simulation run recorded Measures of Effectiveness (MOEs) such as:

- Missile launch and missile lock times
- Missile detection time
- Flare dispensing time, and
- Minimum distance between the ARH and missile

There are several limitations and benefits of using simulation to support analysis of ARH operations. The limitations of this approach include:

- A significant amount of time (in the order of months) is required to specify, design, create and test ARH system models.
- ARH system and threat data is often difficult to obtain.

Some benefits of the approach are:

- The simulation can be tailored to exploring tactics for other helicopter operations,
- It provides an engaging environment for the ARH pilot to discuss and explore tactics.
- The analyst and operator have the ability to explore the parameter space quickly.

This approach will be used to provide support to longer term army helicopter requirements, such as the introduction into service of the MRH-90 helicopter and planning for ARH system upgrades.

1. INTRODUCTION

The Defence Science and Technology Organisation (DSTO) uses constructive simulation techniques in addition to analytical OR tools to assist in addressing these military questions. This paper presents an overview of some of the issues that are faced in answering these questions, as well as the method and modelling techniques that are used for both physical systems and decision-making processes.

Project Air87 was established to provide Australia with an Armed Reconnaissance Capability. The Armed Reconnaissance Helicopter (ARH), Eurocopter Tiger, was chosen following tender evaluation in 2001. As of June 2007, the \$1.3 billion project has delivered 8 ARH Tiger aircraft to the Australian Army, with 14 more aircraft to be delivered before the introduction into service scheduled for 2008 (Ferguson 2005). DSTO has been providing OR support to the ARH Tiger acquisition process since prior to tender evaluation

During a reconnaissance mission into a hostile environment, threats to the ARH mission could include a number of different weapons such as small arms, machine guns, anti-aircraft artillery, manned portable air defence (MANPAD), surface-to-air missiles and hostile air-to-air threats. Studies by DSTO have concentrated on regional Infra-red (IR) MANPAD missile threats to ARH survivability. It is expected that other threat systems will be examined through ARH realisation.

The focus of this paper is on how the modelling undertaken in DSTO enhances the development of ARH troop tactics, which involve multiple interacting ARH aircraft. In particular, how effective the ARH troop is in evading a number of MANPAD threats. This extends on work presented previously (Ibal *et al* 2005). Some indicative results from recent ARH OR studies are presented, and a summary of the benefits and limitations of the approach is provided.

2. CHALLENGES TO ARH TACTICS DEVELOPMENT AND MODELLING

The principal issue now faced by DACI-A is how to use the new ARH capability in the Australian context. The ARH is significantly different in structure and capability to other helicopters currently operating in the ADO, and as such will be deployed for very different roles.

The primary role of the ARH is to enhance the effectiveness and tempo of land force manoeuvre through armed reconnaissance and the application of precision firepower as part of the combined arms team (Australian Army Aviation 2003). The ARH consists of a suite of systems including the ARH aircraft, sensors, weapons, countermeasures and communications. Some of the specific systems are highlighted in Figure 1.

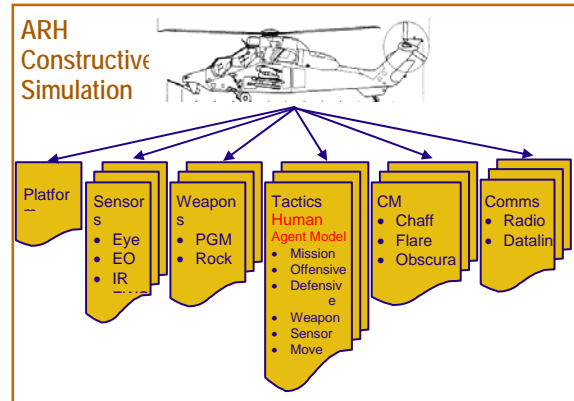


Figure 1. The Physical Systems on-board the ARH Aircraft.

Many of these systems have not been integrated in other army helicopters in the Australian Army (Australian Army 2003).

Threat systems are also an integral part of an ARH mission. During much of an ARH mission, the ARH will attempt to evade threats, such as MANPAD systems, using a mix of manoeuvres and countermeasures in order to achieve mission goals. A MANPAD operator is typically located on land or aboard a surface vessel, and will engage an ARH provided a series of fire conditions are met.

Given that the threat environment the ARH will be exposed to may be similar to that faced by other army helicopters, some tactics, techniques and procedures that have been developed previously may be appropriate, with certain variations. The ARH will operate in a highly dynamic environment involving constant interaction with each other, land forces and enemy targets and threats, often at high speeds and low altitudes. DSTO's role is to provide OR advice in the development of TTPs relevant to ARH functions. This involves investigations of a range of troop operations, scenarios, and includes defensive manoeuvres, offensive manoeuvres and escort roles.

3. REQUIREMENTS FOR OR

Effective OR advice for ARH operations requires, a significant amount of operational and system knowledge. This knowledge must typically include:

- A sound understanding of the ARH strategic environment,
- An understanding of ARH capabilities, both physical and tactical, and how they interact,
- An understanding of threat capabilities and how they potentially interact with the ARH, and
- An ability to explore the complexity of the problem and formulate a method to solve it.

Another issue in conducting an OR study is consideration of the fidelity and timeliness of the response required (Chandran *et al* 2005). In the military theatre, OR support to operations of existing systems generally requires that indicative results to operational questions are provided in days rather than weeks. This means that modelling detail and fidelity is compromised and the number of assumptions is increased to account for this. Often simple techniques such as spreadsheet calculations are sufficient for this level of modelling.

When exploring tactics and capabilities of a new system such as the ARH, a significant amount of time must be taken to understand the environment that the system will be operating in. One approach used in DSTO is to develop a constructive simulation framework to conduct OR studies. Simulation permits exploration of complex military scenarios involving many interacting entities, such as the ARH operating environment. Developing a simulation framework is a complex process that contains many stages, such as:

- Collecting ARH system data and domain knowledge,
- Design, implementation, validation and verification of both physical and decision-making models to the appropriate level of fidelity,
- Integration of these models into the simulation, with the appropriate level of testing,
- Conducting a study with the integrated simulation system, and
- Reporting of findings and results to provide input into ARH TTP documents.

These stages are detailed in the sections below.

3.1 Collecting Data and Knowledge

Knowledge elicitation in the ARH environment involves two aspects. The first is gaining an understanding of the scenarios in which the ARH troop will be operating, and the tactics that the allied and opposing force operators will be employing. This information is gathered through detailed discussions with operators and subject matter experts in the military domain, such as representatives from DACI-A. The second is obtaining ARH system data that can be used by modellers to estimate the capabilities of the ARH systems to the appropriate level of fidelity (Chandran 2005). In the past, data on ARH system performance has been provided by Aerospace Australia and Eurocopter.

3.2 Modelling the ARH Environment

Many of the physical systems identified in Section 2 have been computationally modelled for analysis of ARH operations, including an ARH aerodynamic platform model, missile models, Missile Warning Receiver (MWR) model and flare model. This involves: developing specifications of the models with subject matter experts; designing the characteristics of the model; and creating the model so that it satisfies its specifications through assessing the inputs, processes and outputs.

The threat systems are an integral aspect in the ARH environment. DSTO has been tasked to examine the impact of a number of regional missile threats on the ability of the ARH to achieve mission success. The models used to represent these threat systems have incorporated critical aspects of their capability and their effect on ARH effectiveness and survivability. The level of model fidelity and validity has been deemed acceptable through DSTO for OR studies. For example, the flare rejection logic of the different missile models has been based on hardware-in-the-loop tests for these missiles. The output of these tests has been integrated into the missile seeker model in a tabulated data format. This is used to represent missile seeker interactions with flares, targets and the environment where background illumination is ignored.

Modelling ARH operator and opponent decision-making processes encounters complexities due to operators interacting with each other and their environment. The development approach used by DSTO is to use artificial intelligence technologies (Heinze *et al* 2002) to represent operator behaviours. Currently finite state machines, which models behaviour as transitions between a finite

number of states and actions resulting from these, are used to characterise ARH pilot and MANPAD operator decision-making. Some of the behaviours developed for analysis of ARH operations include: evading threats through manoeuvring and using countermeasures; manoeuvring the ARH through difficult terrain and co-ordination with team members.

Validating these operator models is difficult given that the ARH is not yet in operation. Much of the validation takes place through discussions with operators who provide the knowledge of their experience. This forms the basis of proposed tactics. The tactics are then refined through the use of human-in-the-loop (HIL) simulation exercises prior to introduction into service. This is explored in greater detail in Section 3.6.

The models have been developed stand-alone, and can therefore be integrated into and removed from the simulation environment when required. Each model has its own individual rate of processing – within the simulation, the ARH physical models process information at a rate of 10 Hz, whereas the operator models receive information and process it every second. Further, some models, such as the aircraft and missile models, are 6 degree-of-freedom (6 DOF) and 5 degree-of-freedom (5 DOF) representations requiring greater processing capability. This means that as a greater number of higher fidelity physical models are included in the simulation framework, a greater amount of processing capacity is required to maintain real-time and greater simulation performance.

3.3 Integrating/Testing ARH Models

When the physical and decision-making models for the study have been developed and individually tested, they are then integrated into the simulation environment. The interactions between models are examined, to ensure that the correct data is being passed between models that are related. This is a part of the verification process to ensure that the software is 'bug free'. For example, it is critical that the ARH pilot model has access to data from its Missile Approaching Warning System (MAWS), so that the pilot model can react to an approaching missile by manoeuvring and dispensing countermeasures.

During the build up to an OR study, constant liaison takes place between Australian Army operators and DSTO, relating to models of ARH systems and decision-making processes. As new

information becomes available, this is provided to DSTO and models are incrementally enhanced.

3.4 Conducting an ARH Study

The OR studies conducted by DSTO to support ARH operations are based on two aspects; the first is a requirement directly from DACI-A to provide input into TTPs. This is typically identified through gaps in tactics documents which have not been examined due to operator unavailability or time constraints. The second is based on output from the ARH Synthetic Environment Research Facility (SERF) experiments, which are a series of Human-in-the-loop simulation experiments co-ordinated by DSTO (Pratt and Tregenza 2005). During these experiments, ARH pilots control the aircraft through a series of missions and explore a number of aspects of aircraft operations, such as suppressing a threat, troop manoeuvres and threat evasion. Following these experiments, issues are highlighted by DACI-A which require further investigation through OR, leading to an ARH study into the issue being conducted.

3.5 Reporting of Results

The statistical output obtained from constructive simulation runs is used to form the basis of results. DSTO uses a mix of tabular and graphical representations to provide the results to the Australian Army, however, visualisation is a critical tool employed by DSTO to better understand results and anomalies. Numeric representations of the position and attributes of an ARH is difficult to comprehend in a virtual environment, however visualisation tools, such as that shown in Figure 2 provide a natural representation of the same data.

In addition to the display of entities in the virtual environment, abstract notions such as line-of-sight and tactic planning can be visualised to assist DSTO analysts and DACI-A to understand the results better.



Figure 2. The Visualisation Tool Displaying an ARH Evasion Tactic.

3.6 Exploring Technical Options

The recommendations associated with these results are assessed by DACI-A, and have influenced the tactical procedures documents.

The ARH is yet to be introduced into service, and as such these recommended tactics have not been used in the real life. In order to explore and refine tactics, HIL simulation is currently used. This form of simulation allows computational operator models to be replaced by human operators who interact with the simulation. The HIL experiments have been conducted in association with the military, who call on their experience to examine new tactics and to provide input into the simulation capabilities.

As new tactics are explored and their effectiveness measured¹, operators will identify changes required to the models and tactics, resulting in further analysis being conducted. This will be continued until the ARH is used operationally. The cycle is known as the Generic Analysis Cycle as shown in Figure 3.

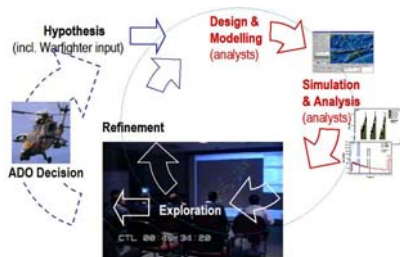


Figure 3. The Generic Analysis Cycle Using Constructive Simulation to Support OR.

4. TWO CASE STUDIES: ARH TROOP OPERATIONS

This section provides two examples of how troop operations have been examined in DSTO.

4.1 ARH Troop Evasion against MANPAD Threats

When a transiting ARH comes under threat from a MANPAD IR missile, the pilot employs both manoeuvring and flares deployment to evade the threat. When two ARH aircraft are operating in troop formation, a flare dispensed by a threatened ARH may be sufficient to deter the missile from itself, and thus eliminating the possibility of ‘primary attack’. However, that dispensed flare may guide the missile toward

¹ Through the data collection capability of the simulation framework

the unsuspecting team-mate, resulting in an undesirable ‘secondary attack’. A representation of this scenario is shown in Figure 4.

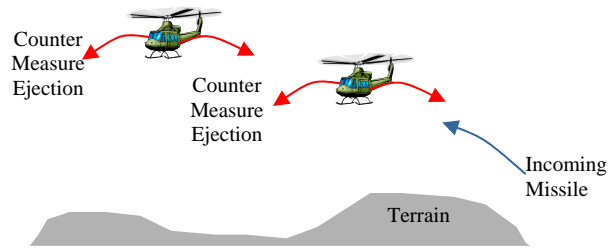


Figure 4. ARH Flare Ejection When Attacked by an IR Missile.

Three regional threat systems (Missile A, B and C), were launched from a number of positions in a grid around the ARH troop, and the lethality of these missile systems was examined. Other parameters that were varied include ARH speed, ARH altitude and flare trajectories. The ARH flare dispensing sequence was fixed based on direction by DACI-A.

Each simulation run recorded Measures Of Effectiveness (MOEs) such as:

- Missile launch and missile lock times
- Missile detection time
- Flare dispensing time, and
- Minimum range from the ARH to missile

A number of different formations were examined. The cases tested were ARH separation distances ranging from 50 metres to 1000 metres, and ARH separation angles ranging from 0° (side by side) to 60°. MOEs were collected for each of the cases. Figure 5 shows the region of danger for *one* particular ARH within the troop. The left-hand side of the graph shows the region of primary attack against the ARH on the left-hand side, and the right-hand side of the graph shows the region of secondary attack also against the ARH on the left-hand side (the flares dispensed by the ARH on the right-hand side have guided the missile towards the ARH on the left-hand side). The white areas in the graph represent regions where the ARH is out of the MANPAD range.

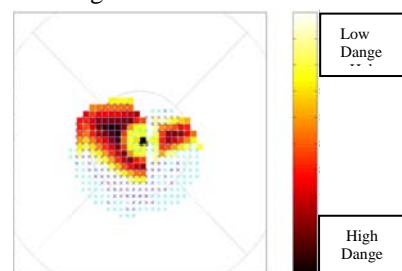


Figure 5. MANPAD Launch Regions against the ARH on the Left Hand Side.

The analysis shows that a smaller safety range can be employed when the troop is threatened by missile B. A larger range is required against missile C to eliminate the probability of secondary attack, as shown in Figure 6.

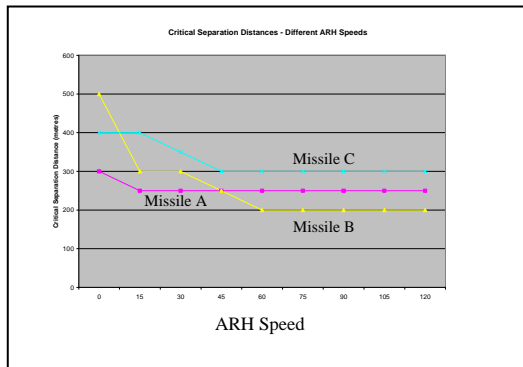


Figure 6. Safe Separation Ranges for Various ARH Speeds against 3 MANPAD Threats.

4.2 ARH/Blackhawk Escort Operations

One of the primary roles of the ARH troop will be to safely escort a team of troop lift aircraft to and from an area of operations. This mission consists of two phases: the first part involves the ARH troop escorting the Blackhawk team to an Ingress Point (IP) in formation I; the second part involves the formation transiting from the IP to the Landing Point (LP) in formation II. These two formations are represented in Figure 7 and Figure 8.

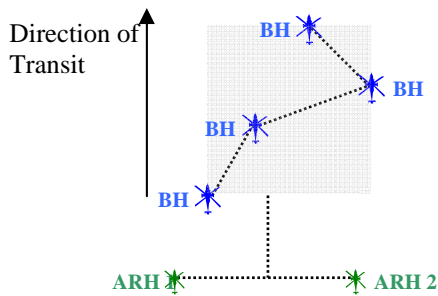


Figure 7. The Attached Escort Formation transiting to the Ingress Point.

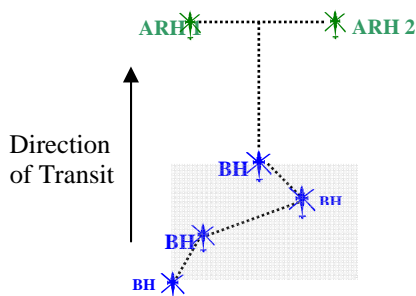


Figure 8. The Escort Formation transiting from the Ingress Point to the Landing Point.

This escort formation may come under attack from an IR MANPAD threat during either of these phases. The pilot will employ both manoeuvring and flares deployment to evade the threat.

The aim of this study was to examine the effects of the two formations and two tactics (Tactic 1 and Tactic 2) on the likelihood on primary and secondary attack by three regional threats (Missiles A, B and C). For each scenario, 3,000 launch positions were randomly generated, and six missiles were fired from each position; one at each of the six helicopters in the scenarios. Each missile can result in primary attack against its intended target and secondary attack against the five other helicopters in the formation.

There is a significant increase in the likelihood of secondary attack by all missiles when the helicopters are transiting in formation II, as shown in Figure 9.

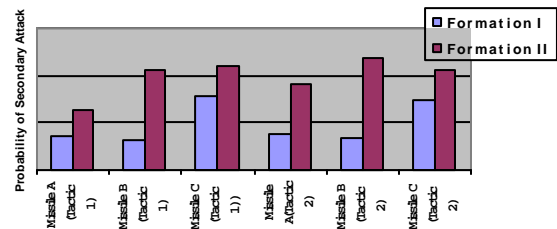


Figure 9. Comparing the Probability of Secondary Missile Attack for each Formation.

There is a significant rise in the likelihood of secondary attack for missiles A and B when the formation employs Tactic 2, as shown in Figure 10.

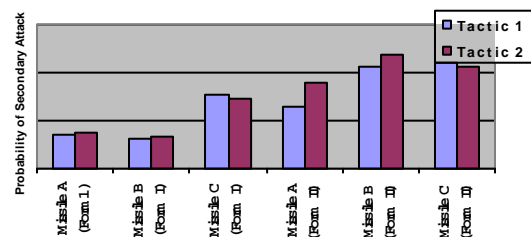


Figure 10. Comparing the Probability of Secondary Missile Attack for each Defensive Tactic.

5. LIMITATIONS AND BENEFITS OF SIMULATION FOR OR

There are some limitations of using constructive simulation approach for OR studies.

Firstly, the framework requires ARH system models to be specified, designed, created and tested, which can take months. This does, however, provide more detailed and realistic results than

other OR tools used for analysis such as spreadsheets in general.

Another limitation is that sufficiently detailed ARH system data is often difficult to obtain, which can lead to the fidelity of the models being compromised.

There have been a number of benefits of using the constructive simulation method described for OR of ARH operations. These benefits are:

- The simulation can be tailored to exploring tactics for other helicopter operations (eg MRH-90) and threat systems with minimal effort.
- The analyst and operator have the ability to explore the parameter space for tactical effectiveness quickly, and cost-effectively.
- It provides an engaging environment for the ARH pilot to discuss and explore tactics (Results can be provided graphically).
- Constructive simulation provides an environment for analysing the impact of many interacting entities on the effectiveness of a military operation.

6. CONCLUSIONS AND FUTURE WORK

The method described in this paper is one that is used extensively throughout the Air Operations Research capability of DSTO. It has been endorsed as a valuable technique in supporting TTP development by DACI-A. With the imminent ARH introduction into service, there is still a significant amount of work to be done to provide ARH operational advice to DACI-A in other areas. Some of these include:

- Examining the effect of different countermeasures on the survivability of the ARH.
- Examining ARH offensive tactics, including weapons usage, against a number of threats and targets
- Examining the use of ARH sensors, such as forward looking IR sensors, to detect and track threats.

The intention is that this constructive simulation approach will be used to provide support to longer term army helicopter requirements, such as the introduction into service of the MRH-90 helicopter and planning for ARH system upgrades.

7. REFERENCES

- Ferguson, G. (2005), First Australian-built Tiger ahead of schedule, *Australian Defence Magazine*, Volume 13, Issue 7.
- Ibal, G., Tu, Z., Harvey, H., Siemienowicz, I., Selvestrel, M., Patterson, T. (2005), Closed Loop Simulation Model Development Process For Helicopter Air Operations Research, presented at SimTecT 2005.
- Australian Army Aviation (2005), Armed Reconnaissance Helicopter Eurocopter Tiger Statement of Operating Intent (Restricted), *Version 3.1*.
- Australian Army (2003), Concept of Employment of the Armed Reconnaissance Helicopter Capability 2003 (Restricted).
- Chandran, A., Ibal, G., Tu, Z., Harvey, H., Patterson, T. (2005), Development of Low-Level ARH Tactical Procedures Using Constructive Simulation for Operations Research, presented at the Land Warfare Conference 2005.
- Chandran, A. (2005), Complex Simulation Supporting OR for Military Decision-Making, presented at the 18th National Conference of the Australian Society for Operations Research, 2005.
- Heinze, C., Goss, S., Josefsson, T., Bennett, K., Waugh, S., Lloyd, I., Murray, G., Oldfield, J. (2002), Interchanging Agents and Humans in Military Simulation, *AI Magazine*, Volume 23, No. 2.
- Pratt, J., Tregenza, M. (2005), Advancing ARH TTP Development and the Six Tenets of Problem Definition and Experiment Design, presented at SimTect 2005.