Air Operational Research in Support of Helicopter Defensive Tactic Development

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Abstract. DSTO's Air Operations Division (AOD) uses operations research to support Australia's air combat capabilities. Operations research (OR) is used to enhance the Australian Defence Force's (ADF) use of aircraft, weapons, sensors and associated equipments through upgrades, new acquisitions and improved tactical deployment. BattleModel (BM) is a flexible simulation environment suitable for performing operations research. DSTO AOD and KESEM International developed BattleModel, to support a wide range of studies from detailed engagement scenarios to mission level scenarios. BattleModel is used to manage the coordinated integration of sensor, weapon, platform, environment, and operator behaviour models, data collection, scenario specification, and display in an OR study. State Machine (SM) Agent Technology is used to model the decision making of military operators in representative operationally realistic missions, developed in cooperation with the ADF, with mini-scenarios or "vignettes" based on the platform's defined role within the ADF. The SM Agent Technology implements a cognitive model based on the OODA (Observe, Orient, Decide and Act) loop and concepts from BDI (Belief, Desires, Intention) theory. Agile representation of tactical behaviours is a particular strength of the SM Agent approach. This paper describes a research approach undertaken in AOD to explore optimum helicopter defensive tactics against a generic man portable surface to air missile. Results presented here are generic only and does not represent any real system.

1. INTRODUCTION

Man portable air defence systems (MANPAD) are considered highly lethal against war fighting helicopters. From a helicopter pilot's point of view, MANPADs are very hard to detect, avoid, engage and evade. New generation state-of-the-art sensor systems do not help pilots a great deal to detect an enemy soldier on the ground holding a 1 m long, 20cm diameter tube like MANPAD aimed against at them. If there is an undetected MANPAD in the area and it is locked against the helicopter, the only thing that informs the pilot about its existence is a missile-warning receiver (MWR) signal. The MWR system of the helicopter detects incoming missiles through their ultraviolet UV emissions and informs the pilot about their incoming angular direction. Within a very limited time after the MWR warning, the pilot has to follow a pre-defined set of rules (tactics) to avoid the incoming missiles. These include activating counter measure (CM) systems such as ejecting flares or chaff in the air to confuse the missile about whereabouts of its target; or manoeuvring the helicopter.

A successful strike for MANPAD operator is also difficult. Environmental obstacles, such as terrain, trees, hills, clouds, sun etc, prevent a clear view of the helicopter to enable a successful lock on. Since helicopters move fast using terrain cover and shadowing techniques to reduce platform signature, MANPAD operator gets a very short window of opportunity to lock on to the helicopter and fire the missile. Most of the time, they can hear the helicopter noise, but they cannot precisely resolve the direction due to an echoing effect through hills and trees. However, if an operator is informed when and where the helicopter is approaching by other observers, then he or she will have a good chance of locking on and firing the missile at the helicopter.

The purpose of the research work presented in this paper is aimed at finding the optimum defensive tactics that increase the helicopter survivability and consequently reduce the missiles probability of success. In order to study the optimum defensive tactics, it was decided that MANPAD operator should perform with maximum efficiency. For this reasons, we have stressed the test scenarios (vignettes) selected for the study in favour of the MANPAD operator by giving him or her an ability to know the exact position of the helicopter.

Due to time and resource limitations, helicopter defensive tactics including ECM (Electronic Counter Measures) have been left out of the scope of this study. This means the tactics explored here are helicopter platform performance related only and do not contain deployment of flare, chaff or any other measures. Effect of usage of these measures on the defensive tactics explored here is left for future studies.

The following section briefly explains vignettes and the assumptions. Section 3 describes the mathematical models used to represent the vignettes, including the physical system models and human behaviour models. Section 4 describes the simulation tool developed to represent mathematical models defined in the previous section. Section 5 explains the tactic development study undertaken with this tool. Finally, the last section discusses the results.

2. PROBLEM DEFINITION

A generic infrared (IR) guided missile, MANPAD, is assumed to be the main threat in the vignettes defined below. Characteristics allocated to the generic missile system model include a short-range flight performance, a single band first-generation IR seeker and impact fusing capability etc. The helicopter system facing a missile attack is also represented with a generic system with two different physical size and aerodynamic capabilities, a larger platform that moves slower and manoeuvres with a larger time lag compared to a lighter platform.

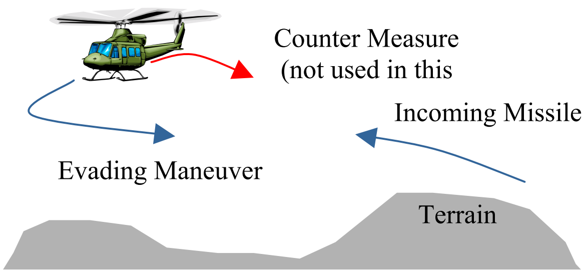

Figure 1: Simple drawing of vignette

The MANPAD operator first detects the helicopter, identifies it as a threat, locks the seeker on and then launches the missile. The helicopter pilot is informed about the incoming missile and its approach angle from the MWR display of cockpit. In order to evade incoming missile, the pilot performs an evading manoeuvre.

3. MATHEMATICAL MODEL

Representing the above vignette with a mathematical model is a very time consuming and a complicated process. There are quite a large number of physical and cognitive systems involved. The level of fidelity required for each system has to be considered carefully and then an appropriate mathematical model needed has to be defined accordingly. Some of the main physical systems involved here include: the helicopter platform; the missile platform; the missile seeker; the missile guidance system; the missile propulsion system; the missile warning receiver; the terrain; the counter measure systems; etc. The operator model is a representation of the helicopter pilot who had to react to the threat and decide on how to fly the helicopter. Because of the space limitation, one example from each system type, helicopter platform model and helicopter pilot cognitive model, will be briefly discussed in the following paragraphs.

The helicopter platform had to be modelled with a high level of fidelity, as the manoeuvrability of the platform was a key focus of the study. Therefore, linearised helicopter equations of motion for the full six degrees of freedom (6DOF) was selected to represent helicopter motion.

Helicopter equations of motion can be described in nonlinear form as

$$\dot{\mathrm{x}}=\mathrm{F}(\mathrm{x},\mathrm{u},t)\ .$$

Linearised equations describing perturbed helicopter motion about a general trim condition, is given [1] below

$$\dot{\mathrm{x}}=\mathrm{A}\,\mathrm{x}+\mathrm{B}\,\mathrm{u}(t)+\mathrm{f}(t)\ .$$

The additional function *f(t)* represents atmospheric and other disturbances. A and B (system and control matrixes respectively) are defined as

$$\mathrm{A}=\left(\frac{\partial \mathrm{F}}{\partial \mathrm{x}}\right)_{\mathrm{x}=\mathrm{x}_e}$$

$$\mathrm{B}=\left(\frac{\partial \mathrm{F}}{\partial \mathrm{u}}\right)_{\mathrm{x}=\mathrm{x}_e}$$

where x_e is the equilibrium value of the state vector. In 6-DOF form, the motion states and controls are

$$\mathrm{x}=\{u,w,q,\theta,v,p,\phi,r,\psi\}$$

$$\mathrm{u}=\{\theta_0,\theta_{1S},\theta_{1C},\theta_{0T}\}$$

where *u, v* and *w* are the translational velocities along the three orthogonal directions of the fuselage fixed axes system, *p, q* and *r* are the angular velocities about x-, y- and z-axes, θ,ϕ and ψ are the Euler angles, defining the orientation of the body axes relative to the earth axes. θ_o, θ_{Is}, θ_{Ic} and θ_{oT} are respectively main rotor collective, longitudinal cyclic, lateral cyclic and tail rotor collective terms of the control vector, u.

The helicopter flight dynamic model uses a number of generic characteristic data tables including large sets of aerodynamic stability and control derivatives. The model receives a desired velocity vector as input from the helicopter pilot operator model and uses the helicopter’s current kinematic state vector, and then outputs the new kinematic state vector for the helicopter.

The missile model was also modelled to a high level of fidelity, as the interactions between the manoeuvring helicopter and the missile were considered significant. The missile model used similar equations of motion to the platform although it was limited to five degrees of freedom, with roll being ignored.

The helicopter pilot behaviour was implemented using SM Agent Technology based on an OODA framework and concepts from BDI theory [2]. Agile representation of tactical behaviours is a particular strength of the SM Agent approach. When specifying and creating a model of a human operator, it is a desirable objective that the model should reason in a way that is accepted as intuitive by analysts, domain experts, operators and lay people. The OODA loop is a widely known and accepted model within the military domain that characterises military decision making as a four part looping process. The four parts of the OODA loop are: Observe, Orient, Decide and Act. The Air Operations Division (AOD) of DSTO has mapped the OODA loop onto a four box model as: Situation Awareness (Observe), Situation Assessment (Orient), Tactics Selection (Decide), Tactics Execution (Act).

The key SM Agent behaviours for the purpose of this study include: (i) Situation Awareness - the operator observes the environment including the helicopters speed, position, orientation and the sensors including eyesight and MWR output, (ii) Situation Assessment - having observed the MWR issues a warning that a missile is approaching the helicopter, the operator concludes that he is under threat and needs to be defensive, (iii) Tactics Selection - based on the operators defensive posture and the missile approach information provided by the MWR, the operator chooses an appropriate evasion tactic. The evasion tactic chosen depends upon a number of parameters including the helicopter's speed and altitude, and the approach angle of the missile. (iv) Tactics Execution - given an appropriate evasion tactic has been chosen, the Tactics Execution component executes a series of manoeuvres according to the planned evasion tactic. While maintaining the evasion tactic, the operator issues flight control commands to the helicopter.

For the purpose of this study the MWR was modelled to a lower level of fidelity than the other components. The MWR detections of IR emissions were not directly modelled, but rather the movement of the missile model triggered the detection by the MWR model. The underlying assumption was that the MWR would always detect missiles launched in the area of interest and modelling of the actual IR effects would not contribute to the study results.

4. SIMULATION TOOL

The models discussed above are executed within the BattleModel simulation environment. BattleModel is a flexible simulation environment suitable for performing operations research. DSTO AOD and KESEM International developed BattleModel to support a wide range of studies from detailed engagement scenarios to mission level scenarios. BattleModel is used to manage the coordinated integration of sensor, weapon, platform, environment, and operator behaviour models, data collection, scenario specification, and display in an operations research study.

BattleModel has been designed to provide an infrastructure that allows models to be integrated and pass data between each other in a modular way. By decoupling the models from the infrastructure in this way, models of varying fidelity, even for the same type of component, can be included in a single simulation. Figure 2: presents a conceptual view of the BattleModel infrastructure as the mechanism by which all components in a scenario communicate.

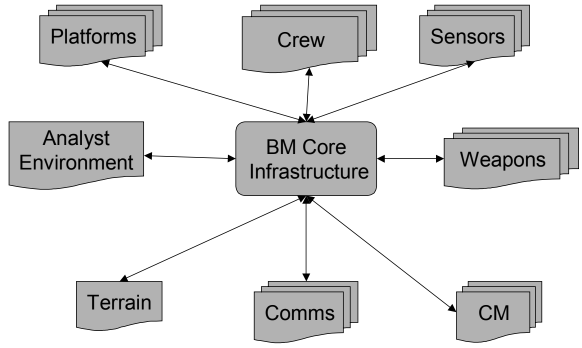

Figure 2: BattleModel Infrastructure

This allows a study to start with a basic BattleModel scenario composed of generic low or medium fidelity models and then extended the scenario with specific high fidelity models appropriate to the particular simulation requirements of the study. For example, a basic missile model was initially used to define and test the scenarios of interest for the current study. This model was then replaced with a model of greater fidelity for performing the actual studies.

BattleModel also supports varying time fidelity. Models in a simulation may be executed at different simulation time fidelities. For example, initial studies were executed with a 0.5 second simulation frame time, which was found to be inadequate and the simulation frame time was then changed to 0.1 seconds.

5. STUDY

As illustrated earlier in the paper, the main purpose of the current study is to explore optimum helicopter defensive tactics. For this reason, a number of test cases based on the vignettes described in section 2 have been investigated in detail using the BattleModel simulation tool described above.

The following entitles have been defined in the BattleModel simulation environment: (i) a large and less manoeuvrable generic helicopter platform (Platform 1), (ii) a small and highly manoeuvrable generic helicopter platform (Platform 2), (iii) a generic IR Missile (MANPAD), (iv) missile operator and (iv) helicopter pilot. For eliminating the terrain type effect on the simulation results, terrain has been represented with a flat ground.

The dot points in figure 3 show god's eye view of each missile launch positions inputted to the simulation tool, the black circle at the centre is the actual helicopter position at the time of missile launch. Initial test runs indicated that the missile operator model was not able to lock on smaller helicopter (Platform 2) from long ranges due to the reduced IR cross section of the helicopter. Therefore, a finer missile launch position grid covering short ranges was used for this helicopter. For the same reason, a course launch grid covering longer ranges was used for larger helicopter (Platform 1) due to its larger physical size and IR cross section.

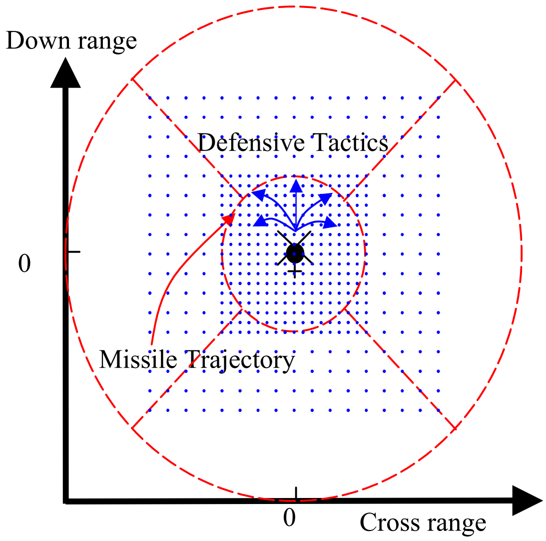

Figure 3: Missile lunch positions in simulation

Monte Carlo simulation runs have been performed for missile launches from each dot point (total of 288) shown in this figure. Each simulation run has consisted of main events such as: missile operator acquires target, missile lock on, missile launch, MWR detection of missile, helicopter pilot's decision cycle, pilot performs evasive manoeuvre, missile hits (or not) the target and damage assessment of the platform. The platform has been assumed to be damaged if one of the main components, such as engine, tail rotor, cockpit etc., becomes non-functional. As seen in the figure, the helicopter pilot model has been tasked to try a number of different manoeuvring tactics for each Monte Carlo simulation set to evade the incoming missile. These simulation sets have been repeated by changing the parameters such as; helicopter altitude and forward speed. The following chapter will discuss only two of the helicopter manoeuvring tactics considered at low altitude and slow forward speed and present the results in a comparative manner for each platform.

6. RESULTS

Figures 4,5,6 and 7 below show the overall study results. The probability of damage by missile on the helicopter has been presented for each tactic type selected. As defined in figure 3, helicopter is located at the centre of the dotted circles at the time of missile launch.

White areas in the figures show that the MANPAD operator model targeting from these areas (i) could not get a lock on the helicopter or (ii) was able launch but none of the simulation runs hit the helicopter.

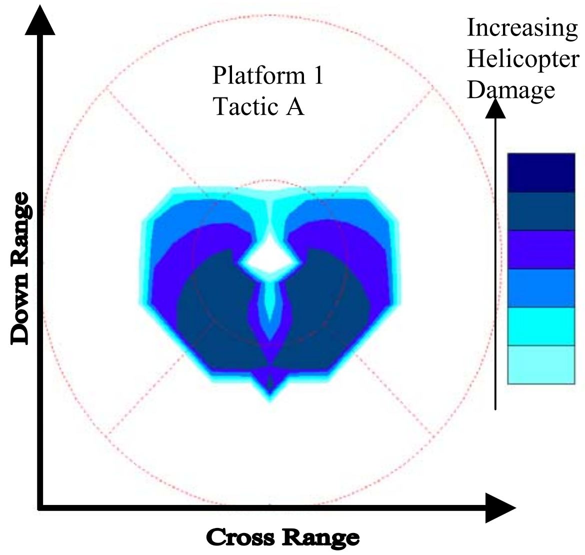

Figure 4: Probability of damage distribution for Platform 1 when Tactic A is employed.

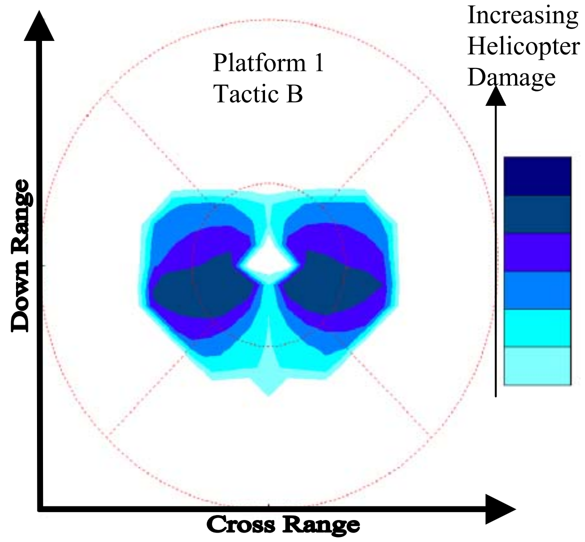

Figure 5: Probability of damage distribution for Platform 1 when Tactic B is employed.

Shaded areas in the figures show that the missile operator model targeting from these areas had achieved lock and some percentage of the simulation runs have been able to achieve missile damage on the helicopter.

Darker shaded areas indicate that the missile operator model targeting from these areas had achieved lock and a higher percentage of the missiles launched from these regions had hit and damaged the helicopter as compared with launches from lighter shaded areas.

The helicopter damage level bar at the right side of the figures indicates, in relative terms, the percentage variation of the probability of helicopter kill by missiles launched from these areas.

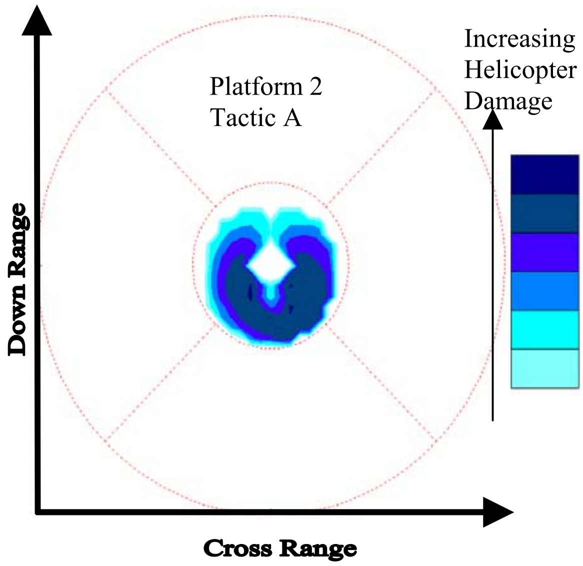

Figure 6: Probability of damage distribution for Platform 2 when Tactic A is employed.

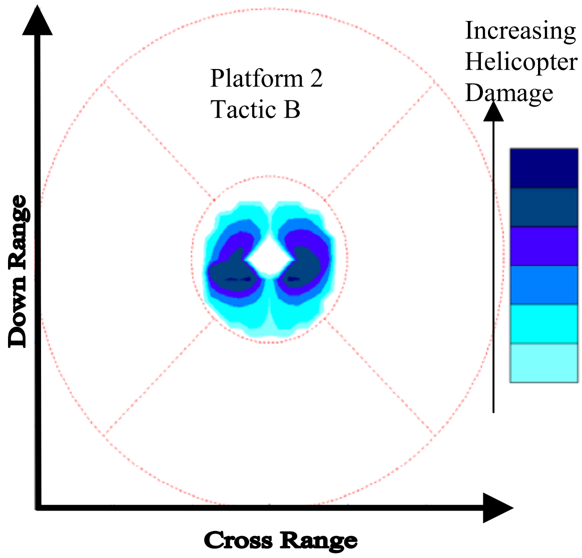

Figure 7: Probability of damage distribution for Platform 2 when Tactic B is employed.

If we compare survivability of the two platforms, the smaller and more manoeuvrable platform, Platform 2, had performed better, as expected. It gave very little area of opportunity for the MANPAD operator model to lock-on and fire. Conversely, the larger IR signature of Platform 1 assisted the missile seeker in achieving lock from long ranges and made the missile more effective and lethal.

If we compare two selected tactics, Tactic A and Tactic B, for both platform types, Tactic B appears to consistently help the pilot model to reduce the probability of platform damage and increase survivability as compared with Tactic A. With Tactic B, darker areas indicating high probability of helicopter damage is reduced in size and shifted to the sides by making helicopter less vulnerable against missile shots from rear. Note that Tactic A and Tactic B are deliberately left undefined here to avoid any misinterpretation of the result.

For situations where (i) the helicopter platform does not have a counter-measure system, (ii) the counter-measure system is non-operational (damaged or no flare left for use) or (iii) the incoming missile has an effective counter measure (flare) rejection system, the current simulation model offers a very fast and cost effective way for finding the optimum helicopter defensive tactics.

These tactics may also be applicable for cases where the counter measure system is successfully used and the missile guides on the flare. In cases that the flare is positioned between missile and helicopter during an engagement, the missile may fly through the flare and hit the helicopter. If the pilot were not performing the optimum manoeuvre to evade the missile at the time of impact, the probability of helicopter damage would be relatively increased, as shown in figures 4 to 7.

As stated earlier, the effect of defensive counter measure deployment is not yet studied here. But, two points worth making would be that: (i) if the optimum defensive tactics (optimum manoeuvre) and counter measures (flares) are both employed at same time against any IR missile attack, the pilot would most likely have a better chance to survive, (ii) regardless of whether flares are in use or not, the optimum helicopter evasive manoeuvre (tactic) would increase survivability.

The simulation model described in this paper can easily be tailored for use in studying tactics for real helicopter and threat systems. The generic data files of the model are structured in such a way that only a minimal effort is need for modification. If this is required, the main effort would be on gaining access to the real system data that is usually classified and time consuming to acquire.

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