CHAPTER 7

Military helicopter flight mission planning using data science and operations research

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Abstract
Military helicopter flight mission planning consists of many aspects ranging from for instance route selection, helicopter configuration design, opponent modelling to personnel to platform allocations. In this chapter we will survey recent algorithmic techniques from the fields of operations research, data science and aircraft trajectory optimisation that can aid in military flight mission planning automation and optimisation. We will present examples and describe potential uses with a specific focus on the Dutch Ministry of Defence. As such this chapter provides a first approach to military helicopter mission optimisation.

Keywords: *Helicopter performance, Mission planning, Route selection, Search games, Trajectory optimization*

7.1. Introduction

The nature of modern conflict varies among four archetypes of fight, ranging from counterterrorism, grey-zone and asymmetric fights to high-end conflict fights.[1] Air power provides unique opportunities to create a wide range of effects at all possible levels, ranging from the strategic to the tactical level. In the Nicaraguan intervention of 1927, aircraft supported ground troops at close range in such a manner that they were being actively coordinated toward their targets whilst at the same time being deconflicted from fire and movement of friendly ground forces. Offensive Air Support was born. Initially coordination was done by ground troops only, later however airborne platforms also started to incorporate this coordinating function.[2]

Even though we have come a long way since 1927, offensive air missions are in large part still being planned manually, e.g., battle positions are picked by hand and analysed by a large group of experienced aviators, load planning is done by load masters who do weight and balance calculations (using simple calculation tools) and route allocations are determined by visual inspection of maps and

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terrain data. In this chapter we introduce a methodology that can help to optimise components of helicopter mission (planning), using the key elements of the strike coordination and reconnaissance (SCAR) mission. SCAR is a typical counter-land mission that gained prominence during the Gulf War and in theatres such as Iraq and Afghanistan.

7.1.1. Strike coordination and reconnaissance

Offensive Air Support (OAS) consists of a variety of missions and can be divided into deep air support missions (DAS) that prematurely disrupt the enemy's operational cycle at a distance from friendly forces and close air support missions (CAS) providing flexible and responsive fire support against hostile targets in close proximity to friendly forces (see Figure 7.1). One key DAS mission, the use-case of this chapter on helicopter flight mission optimisation, is the so-called strike coordination and reconnaissance (SCAR) mission. It is flown in a specific geographic area with the purpose of locating, reporting and coordinating the attack of targets of opportunity and to perform battle damage assessments (BDA). See Figure 7.1 for an overview of the various types of OAS missions and SCAR's position in this taxonomy.

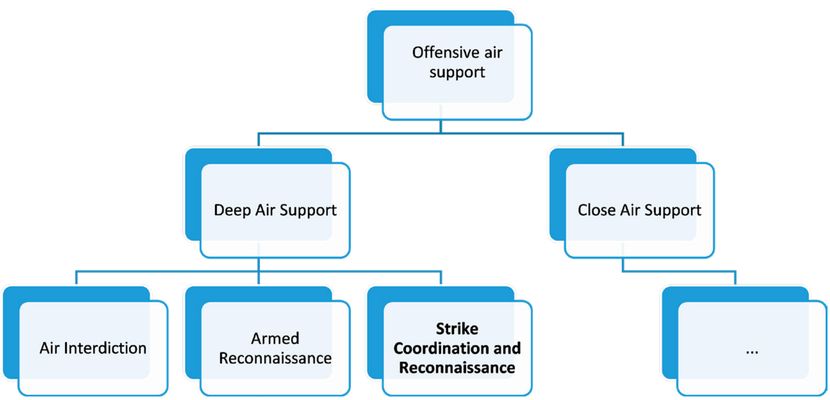

Fig. 7.1. A taxonomy of offensive air operation mission types according to Marine Corps Doctrinal Publication 3-23 Offensive Air Support.[3]

SCAR missions differ from Air Interdiction (AI) in the sense that they do not respond to targets that are known and briefed in advance. SCAR platforms discover and mark targets and/or verbally talk-on other attacking flights through the target area. Additionally, they provide prioritised targeting guidance including the location, description and threat type of targets. SCAR missions prevent redundant targeting

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and assist in ensuring the flow of aircraft through an assigned area of operations. Typically, a SCAR mission consists of searching for targets, target discovery, identification and tracking and finally attack coordination and execution. The key elements of SCAR type missions can therefore be summarised as follows[4]:

- Targets are not known in advance.
- Conducted by combat aircraft able to detect, mark and interdict targets including the neutralisation of enemy air defences.
- Conducted in a specified geographic zone (so-called surface kill boxes).
- SCAR aircraft are part of command-and-control interface and can cycle multiple attacking flights through the target area.
- SCAR aircraft can provide battle damage assessments (BDA).

SCAR missions are normally part of the command and control (C2) interface to coordinate multiple flights, detect and strike targets, neutralise enemy air defences, and provide battle damage assessment. Typical tasks include cycling multiple attacking flights through the target area and providing prioritised targeting guidance to maximise the effect of each sortie.

Platforms like remotely piloted aircraft can perform specific SCAR tasks such as locating, verifying, and cross-cueing other assets to positively identify targets and pass target updates. These platforms may also be able to engage targets on their own, buddy lase for manned aircraft, and provide BDA for the same mission.

7.1.2. Overview of the chapter

We illustrate how scientific methods can be used to optimise elements in helicopter mission planning in general with the SCAR mission as a particular use-case. After the collection and analysis of data concerning the mission, the geographical situation (data analysis) and the defence options of the enemy (data analysis, machine learning (ML) about locations of for example surface to air missiles (SAMs)), one enters the deployment phase, consisting of routing toward the kill-box and neutralising enemy air defence, prioritising detected targets and assigning platforms to those targets (operations research), trajectory optimisation (flight mechanics and human factors) and finally the realisation and execution of the mission (Military, data science, ML, flight guidance, scheduling). Each of these elements will be taken up in the sections below. In Section 7.2 a general overview and decomposition of helicopter mission planning is given. Optimal routing towards the kill-box and trajectory optimisation is discussed in Section 7.3. Section 7.4 deals with the methodology to optimise search patterns for target discovery inside the kill-box together with target prioritisation and allocation to platforms. Finally, we present our conclusions in Section 7.5.

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7.2. Helicopter mission planning

The current helicopter mission planning process consists of several steps. It starts with a mission order. Next, information is gathered, and a plan is made. Once the plan is complete, the mission is prepared. If permitted by time and resources, pilots can practice the mission. The process ends with the take-off and the execution of the mission. This process has several shortcomings. First of all, it is time consuming since it is largely a manual process. As a consequence, it is also prone to errors and it will most likely lead to suboptimal solutions. Furthermore, it can be an inflexible process if the situation changes during the mission. In case of relatively straightforward missions, the above-mentioned shortcomings are acceptable. However, when complex missions are planned with multiple helicopters in a contested environment it would be highly beneficial to have a mission planning process in place that automatically creates optimised mission plans from which the end user can select the most appropriate one. A new mission planning process for future helicopter operations is therefore proposed. This process is summarised in Figure 7.2.

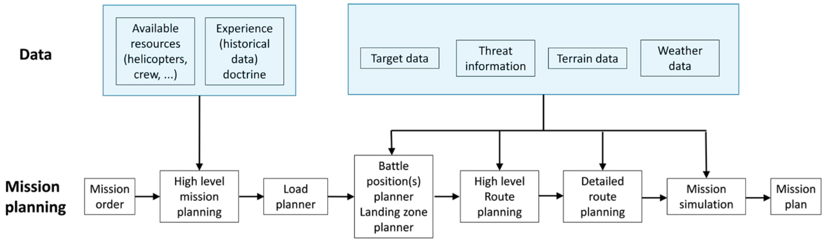

Fig. 7.2. Proposed future helicopter mission planning process based on multi-level optimization.

Just as in the current process, future mission planning starts with a mission order. In the high-level mission planning step, it is decided how many helicopters and of which type are required. This step also includes the selection of weapons and payload. Next, the payload must be distributed over the helicopters, taking into account weight and balance constraints. The load planner phase includes the determination of the required amount of fuel. In case of an attack mission, feasible locations for battle positions must be identified and from this set the most optimal location should be selected. This step can also be replaced by a landing zone planner in case the objective is to transport payload or personnel to a specific location. With the battle position known, the route planning can start. The different steps in the process require data, ranging from information about the available resources to threat information and detailed digital terrain maps. Regardless of the

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mission, it will consist of different phases. A part of a mission is given as an example in Figure 7.3. In this example three phases can be identified. The helicopter first performs a nap of the earth terrain following flight in order to evade enemy air defences. This flight will follow several pre-determined waypoints. Near the final destination, a manoeuvre is executed to decelerate the helicopter. Finally, the helicopter performs its intended manoeuvres at the destination.

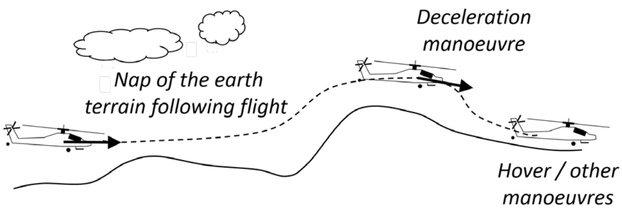

Fig. 7.3. Example elements of a military mission.

The route planning for a mission can be decomposed in two levels. High level route planning in order to determine waypoints with for example the objective to maximise survivability and minimise flight time or fuel burn. The second level pertains to the trajectory optimisation between waypoints. In this second step a more refined analysis of survivability, mission effectiveness and flight-time and fuel burn can be made, taking into account helicopter limitations and external factors such as wind. Cheng and Menon and Kim decomposed helicopter missions in a similar fashion and identified a third level designated near field guidance which is intended to provide a least expected deviation path from the nominal flight path.[5] A third level could be useful for future operations with unmanned aircraft. The route planning is described in detail in Section 7.3. Finally, if permitted by time and resources, pilots can practice the mission in the mission simulation phase.

7.3. Route planning

7.3.1. Route towards the area of operation (high level planning)

Given a mission, the helicopter has to find an optimal route towards the area of operation, and once arrived has to determine an optimal search pattern inside the kill-box. *En route* it may encounter several threats in the form of (mobile) SAM installations, interceptors/radar. A chosen route has to balance time (duration of the route) and survivability (non-detection). When an aircraft is required to

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penetrate air defences, it is necessary to select an optimum route that will ensure a minimum exposure to enemy fire and achieve the maximum probability of survival in accomplishing the specified mission.

To this end, the region that has to be traversed to reach the area of operation is represented by a network, where the nodes form the set of possible waypoints. For this it is necessary that (electronic) maps and terrain data are available. Intelligence may provide information about positions of SAM installations, radar, etc. Given such information, one may use simulation techniques to assign the probability of intercepting a traversing helicopter on a path between two consecutive nodes. This enables optimising a route from entry point A to target B that has the largest probability of survival and non-detection.

One may use linear programming techniques to find this route: given the probability of detection p_{ij} on a path from node (waypoint) i to node (waypoint) j, the following optimisation problem finds the route with minimum detection probability. The route can be identified from the optimal solution in terms of the variables x_{ij}, which is 1 if the optimal route contains the path from i to j.

$$\min \sum_{i \to j} -\ln\left(1 - p_{ij}\right) x_{ij}$$

subject to

$$\sum_{j:i \to j} x_{ij} - \sum_{j:j \to i} x_{ji} = 0, \; i \neq A, B$$

$$\sum_{i:A \to i} x_{Ai} = 1$$

$$\sum_{i:i \to B} x_{iB} = 1$$

with all variables binary.

The airspace between points A and B is defended against any penetrating aircraft and the probability of kill over any segment of flight within that space will be assumed to be known, as in the linear program above, either in terms of the actual probabilities or probability densities per unit distance or unit time. To ensure a minimum exposure to enemy fire and achieve the maximum probability of survival in accomplishing the specified mission for aircraft, one may also use this linear program to identify on which paths a reduction of probability of detection is most rewarding. In other words, one may try to identify the installation whose destruction or degradation is most rewarding in terms of survivability of a penetrating aircraft. Analogous to this problem, the enemy may try to maximise this probability of interception by placing its installations (mobile or fixed) at optimal

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locations from a set of possible locations. These two problems then become a so-called max-min or min-max problem, for which several solution procedures exist.[6] One may also use game-theory to devise optimal interdiction plans for a flow of helicopters that try to penetrate the area.[7] In many cases, one may use genetic algorithms to solve these problems. Results of these analyses provide the waypoints that are input to the trajectory optimisation phase.

7.3.2. Trajectory optimisation (detailed planning)

The waypoints determined in the high-level route planning process provide the global path which the helicopter has to follow in order to optimise a combination of survivability and flight time. The geometric distance between the nodes (waypoints) in the high-level route planning process should be small enough to capture the most important features of the terrain and the threat. At the same time, the geometric distance should not be too small for two reasons. First of all, a denser grid increases the computational effort. Second, if the grid is too dense, solutions may be found which are infeasible when taking into account the dynamics and physical limitations of the helicopter. In practice, waypoints are expected to have a distance which typically requires flight times ranging from 15 seconds up to 5 minutes. At this stage, the optimal path of the helicopter in three-dimensional space between the waypoints is not yet determined. This optimal path consists not only of positions in space but also of the groundspeed of the helicopter as a function of time. The performance of a helicopter in terms of manoeuvrability and fuel burn depends primarily on airspeed, flight altitude and the current weight of the helicopter. External factors such as wind and atmospheric conditions also play an important role. For the analysis of optimal trajectories, one has to take into account the limits of the helicopter such as engine and drivetrain limitations, the maximum load factor and airspeed limits. The technique to solve this type of problem is called trajectory optimisation. It is essentially a problem within the field of optimal control theory which has a wide variety of applications in the aerospace domain such as space flight, missile guidance and the calculation of environmentally friendly trajectories for transportation aircraft.

1. Problem definition and numerical methods

When applied specifically to helicopters, Bottasso defines trajectory optimisation as:[8]

> *"The process of computing the optimal control inputs and the resulting response of a model of a helicopter which minimizes a cost function (or maximizes an index of performance) while satisfying given constraints which specify for example, the vehicle flight envelope boundaries and/or safety and procedural requirements for a manoeuvre of interest."*

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An example path of a helicopter between two waypoints is visualised in Figure 7.4. This finite-time transition from condition 1 to condition 2 is called a manoeuvre.[9]

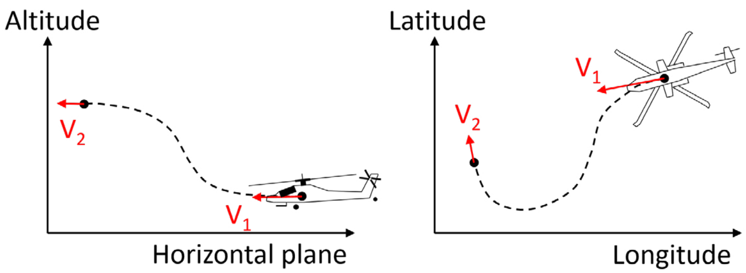

Fig. 7.4. Example manoeuvre.

2.Numerical methods to solve the trajectory optimisation problem.
In mathematical terms the optimal control problem can be defined as follows:

$$\min_{\underline{u}(t)\,\in\,U} \int_{t_0}^{t_1} L[\underline{x}(t), \underline{u}(t), t]dt$$

$$subject\ to : \dot{\underline{x}}_i = f_i[\underline{x}(t), \underline{u}(t), t]$$

Where the objective function depends on the control usage *u(t)*, the state of the helicopter *x(t)* and the time (*t*). The control usage *u(t)* is subject to rate limits and maximum deflections. It therefore belongs to a closed and bounded set *U*. The performance index is expressed as an integral of a function (*L)* of the state variables, control usage and time. Hence, survivability, mission effectiveness, fuel burn and flight time can be incorporated in the objective function. The set of first order nonlinear differential equations represents the dynamics of the helicopter which is a function (*f*) of its state variables and control variables. There is a large variety of numerical methods which can be used to solve the trajectory optimisation problem. The methods which are most widely used for trajectory optimisation problems in the aerospace domain are summarised in Table 7.1. This summary is based on the studies by Betts, Rao and Ben-Asher.[10]

The primary two classes of numerical methods are direct and indirect methods. Indirect methods rely on the analytical derivation of adjoint equations and their gradients. This can be very challenging if the physical model of the vehicle is complex and nonlinear as is typically the case for helicopter simulation models. The analytical derivation is not required for direct methods. Direct methods are based

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on a parameterisation of the control function. For sake of completeness, ‘other’ methods are also included in the table. Both dynamic programming and heuristic methods have been applied successfully to trajectory optimisation problems, but they are computationally more expensive than direct and indirect methods.

Table 7.1. Numerical methods to solve the trajectory optimisation problem

Direct methods	**Indirect methods**	**Other methods**
Single shooting	Single shooting	Dynamic programming
Multiple shooting	Multiple shooting	Heuristic (usually genetic algorithms)
Collocation (transcription)	Collocation (transcription)	
Pseudospectral		

3. Helicopter flight simulation models

In order to solve the trajectory optimisation problem, a simulation model of the helicopter is required as well. The helicopter can be modelled with different levels of fidelity, ranging from basic point mass models to high fidelity flight dynamics models. Padfield proposed a classification of different levels of model fidelity.[11] An overview of the classification, extended with a *Level 0* model is presented in Table 7.2. The *level 0* model is a point mass model of the helicopter. Performance charts such as those listed in a helicopter flight manual can serve as an aerodynamic database for such a model. Alternatively, simple aerodynamic models based on momentum theory can be used in conjunction with a point mass model.

Table 7.2. Classification of helicopter models used for trajectory optimisation (extension of classification by Padfield[12])

Model designation	**Equations of motion (fuselage)**	**Rotor dynamics**	**Aerodynamics**
Level 0	Point mass model or performance constraints	Not included	Look-up tables with power required for complete helicopter or momentum theory combined with look-up tables for fuselage aerodynamics. Aerodynamics are not included in case the helicopter is modelled based on performance constraints.
Level 1	Rigid body	Quasi steady or rigid blades with flap and possibly lag and torsional degrees of freedom	Linear 2-D dynamic inflow or local momentum theory. Analytically integrated loads

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Model designation	Equations of motion (fuselage)	Rotor dynamics	Aerodynamics
Level 2	Rigid body	Rigid blades with flap and possibly lag and torsional degrees of freedom	Nonlinear (limited 3-D) dynamic inflow or local momentum theory. Local effects of blade vortex interaction. Unsteady 2-D compressibility. Numerically integrated loads
Level 3	Rigid body or elastic body	Elastic blades	Nonlinear 3-D full wake analysis, unsteady 2-D compressibility numerically integrated loads

Hence, different types of simulation models and numerical methods for optimisation can be used. The overarching question is which combination of numerical method and helicopter simulation model is most suitable in the context of helicopter mission planning considering all operational constraints. In the next section, a comprehensive literature survey is presented of helicopter trajectory optimisation applications in scientific literature.

4. Survey of helicopter trajectory optimisation applications

Research in the field of helicopter trajectory optimisation with military relevance dates back to the early 1980s. Falco and Smith investigated the influence of manoeuvrability on helicopter combat effectiveness.[12] This method was intended to be used for short term manoeuvres in the context of helicopter conceptual design. Slater and Hertzberger used an indirect method to optimise a complete mission of a civil helicopter with the aim to minimise fuel burn.[13] Menon and Kim performed a variety of studies where the objective was to maximise a linear combination of terrain masking and flight time. Terrain masking is defined as the integral of the altitude above the terrain over the complete trajectory. An indirect method was used in combination with a level 0 model of a military helicopter (AH-1S Cobra).[14] Dynamic programming techniques were later used by Nikiforova to find optimal terrain following trajectories for attack missions.[15] More than 10 years later, a similar method was used by Toupet and Mettler to optimise trajectories of an unmanned military helicopter in obstacle avoidance flight.[16] A key difference in the latter study is that the algorithm was used for online computation on-board the unmanned helicopter. The studies described above all made use of low fidelity (level 0) helicopter simulation models. Bottasso performed various studies in which higher fidelity simulation models were successfully used to optimise specific short-term manoeuvres both in the civil and military domain.[17] Higher fidelity simulation models are typically black box models developed by specialists. For this reason, direct methods were applied

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in the studies by Bottasso. Since noise and emissions are becoming more and more important to the helicopter community, several studies were performed in the last years with the aim to minimise helicopter noise for approach and departure trajectories of civil helicopters.[18] It is a challenge to accurately predict helicopter noise. A key aspect in these latest research efforts was the inclusion of accurate noise models within the helicopter simulation model. The literature survey of trajectory optimisation specifically for helicopters is summarised in Table 7.3.

5. Proposed trajectory optimisation approach for the Royal Netherlands Air Force
The Royal Netherlands Air Force operates various helicopter types. The mission planning process should therefore accommodate missions in which different helicopter types are used simultaneously. In the future, one could even include (unmanned) fixed wing aircraft and rotorcraft in this process. Of each helicopter type, the performance and its limitations are known in detail based on flight manuals and technical manuals. Detailed flight simulation models are available for pilot training. However, these models are typically black box models provided by helicopter manufacturers in combination with the flight simulator hardware. Therefore, these models cannot easily be integrated within an automated mission planning and optimisation process. Altogether, it is recommended to create dedicated *level 0* or *level 1* helicopter simulation models for the mission planning process. These models should be combined with direct methods for trajectory optimisation as demonstrated in the studies by Hartjes and Visser.[19]

7.4. **Detect, mark and interdict targets**

In this paragraph we discuss techniques from operations research and game theory that can help to optimise other elements of helicopter missions, in particular regarding the strike coordination and reconnaissance mission.

7.4.1. Prioritising targets in areas of operation / situation awareness / coordinating multiple flights

Intelligence reports, based on historical analysis of data using common data scientific techniques, might indicate (or predict) the presence of specific targets in the kill-box designated to SCAR platforms prior to their mission. This a priori information can be used even though targets are not known in advance in a typical SCAR mission, e.g., the platforms conducting the SCAR mission in a designated geographic area are searching for unknown targets that may be static or dynamic in nature. A research field of particular use in this domain is the field of search games

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Table 7.3. Survey of trajectory optimisation studies for helicopter applications

Helicopter category	Manoeuvre/mission phase	Timescale (seconds)	Objective(s)	Numerical method	Flight simulation	Special features	References
Military utility	Hover depart	15	Flight time	Direct collocation	Level 1		Bottasso et al. 2008
	Lateral reposition	20					
	Pirouette	60					
	Slalom	30					
Civil tiltrotor	Continued and rejected take-off	20	Safety and flight time	Direct multiple shooting and direct single shooting	Level 2		Bottasso et al. 2012
Military utility	Minimum time turn	15	Flight time	Direct collocation	Level 1		Botasso et al. 2010
	Pirouette	60					
	Slalom	30					
	Continued take-off	20	Safety and flight time				
Civil tiltrotor	Minimum time turn	15	Flight time	Direct multiple shooting	Level 2		Botasso et al. 2010
Military utility	Lateral reposition	20	Flight time	Direct multiple shooting and direct collocation	Level 1	Inclusion of pilot model	Bottasso et al. 2009
	Pirouette	60					
	Slalom	30					
	Rejected take-off	20	Safety and flight time				
	Engine off landing	10	Safety				
Civil	Descent	150	Noise	Genetic algorithm	Level 0	Noise source and propagation models	Cruz et al. 2012
Military attack	Air-to-air missile avoidance	30	Survivability	Stochastic learning method	Level 0	Missile and gun models	Falco 1982
	Air-to-air gun combat	30					

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Civil utility	Flight over populated area	1000	Noise	Heuristic	Only performance constraints	Acoustic database	Greenwood 2019
Civil utility	Approach trajectories, Climb to cruise, Course change	300	Minimal accelerations (smooth flight)	State Dependent Ricatti Equation technique	Level 0 and Level 2	Automatic flight path vector generation and tracking	Halbe et al. 2018
Civil utility	Approach trajectories	300	Noise and fuel burn	Pseudospectral	Level 0	Basic noise model	Hartjes et al. 2009
Civil utility	Approach trajectories	300	Flight time, fuel burn and NO_X emissions	Pseudospectral	Level 1	Basic noise model	Hartjes et al. 2011
Civil utility	Approach trajectories	400	Noise, flight time and fuel burn	Pseudospectral	Level 1	Noise source, noise propagation and nonstandard atmosphere models	Hartjes & Visser 2019
Military attack	Nap of the earth terrain following flight	60	Altitude and flight time	Various indirect methods	Level 0	Wind included	Menon and Kim, 1990
Civil small unmanned	Obstacle avoidance in urban terrain	60	Flight time	Various	Level 0	Standardised approach for comparing guidance systems	Mettler & Kong 2010
Military attack	Nap of the earth terrain following flight	300	Altitude and flight time	Dynamic programming	Level 0		Nikiforova 1995
Civil transport	Climb, cruise and descent	3600	Fuel burn and flight time	Indirect method based on energy height approach	Level 0	Helicopter performance based on flight manual	Slater & Ertzberger 1984
Military unmanned	Obstacle avoidance	variable	Flight time	Dynamic programming	Level 0	Online trajectory optimisation for obstacle free elements of the flight	Toupet &Mettler 2006

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which stems from search theory.[20] The focus of search theory is to find optimal ways to search for targets in a plethora of settings that occur between searchers and targets (often called 'hiders'). If one also has information in terms of heat maps or has intelligence of how targets move around in the area, specialised search and detection theory techniques may be employed to find a target as soon as possible and with the highest probability. These methods are based on meta-heuristics and discrete Markov chains for instance.[21] Table 7.4 presents an overview of the most common search games (as found in literature).[22]

Table 7.4. Search games classification[23]

		Searcher's strategy		
		Special	**Moving**	**Resource distribution**
Hider's strategy	**Special**	Smuggling game		Inspection game
	Stationary	Binary search game	Linear search game Hide-search game	Hide-allocation game
	Moving	Path constrained search game	Evasion-search game Princess-monster game	
	Resource distribution			Search-search game Blotto game Attack-defence game

Consider for instance platforms observing a fixed location known for possible illicit activity. If due to resource constraints (budget, personnel, platforms) the platforms could observe the location only for m times in a fixed time-window whereas the opponent has n opportunities ($n > m$) to conduct its illicit activity (smuggle weapons for instance), then this situation can be modelled as an inspection game and optimal strategies for both players determined. On the other hand, if the opponent is dynamic and aware of being searched for in a continuous space and time, the

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evasion-search game is more suited to model and find optimal strategies (continuous search paths for the helicopters).

Once targets are within sensor range of SCAR platforms, one may use neural networks and data science to classify and mark the objects using techniques from image recognition.[24] Multiple SCAR platforms active in a given kill-box can use their datalink to communicate about found targets and use onboard target prioritisation algorithms to rank them. Techniques like the orienteering problem can then be used to plan and coordinate a route that visits the set of targets that maximise the total profit, while also giving a final classification.[25] There are several OR techniques that can be used in this regard. These include methods for online planning and planning with time windows. Online planning may be very important to take into consideration new targets that appear. In that case the sequence of visiting the targets can be interrupted and a new optimal route has to be computed. To minimise the effect of these interruptions, one uses meta-heuristics and robust planning techniques to also take into consideration these online events in advance.

Additionally, network models can be used to assess the situation awareness in coordinated attacks. The intelligence reports regarding the targets (combined with the results of neural networks) may be combined with availability and capability of individual helicopters, resulting in an assignment problem at the operational level that can be represented as an integer linear programming problem. It gives a deployment plan that may serve as input at the tactical level of a mission.

7.4.2. Battle position planner

Even though battle positions are generally not an element of a typical SCAR mission we include them in this paragraph as they are important to (attack) helicopter missions in general. To determine battle positions and route to a mission essential enemy targets in an area of operation, one may utilise game theory, that models the situation of conflicts with opposing interest. It has, for example, been applied to attacking or defending a ship that coordinates and executes a mission in a coastal area by a submarine. The essential ship has frigates, helicopters with dipping sonar to protect itself. In such a situation, movements of some friendly assets are detectable by the enemy (like the movement of a frigate), and some are only detectable when it is too late (like the dipping sonar of a helicopter). In these situations, one may find an optimal plan for the deployment of friendly forces, as well as an optimal attack plan. The same approach may be used to determine optimal battle positions and attack plans.[26] An optimal configuration of, say four helicopters to attack an enemy wave of aircraft can be found using war game simulations, neural networks and heuristics.[27] If the configuration consists of unmanned aircraft, the results become even more interesting, as some of the aircraft in an optimal

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configuration serve as decoy and are attacked. Such configuration with a very risky position for one aircraft is less likely to be flown in the case of manned aircraft.

7.5. Conclusions

In this chapter, we investigated how Operations Research, Trajectory Optimisation and Data Science may be utilised in helicopter mission planning. In particular, we focused on SCAR missions to identify where optimisation techniques may improve the planning of such missions. The blue part of figure 7.2 (terrain and target data) lends itself for applications of modern AI techniques and image recognition. In the figure below, which illustrates a part of figure 7.2, we highlight the multi-level optimisation approach that we explored in more depth in this chapter, using OR techniques, including artificial intelligence and machine learning.

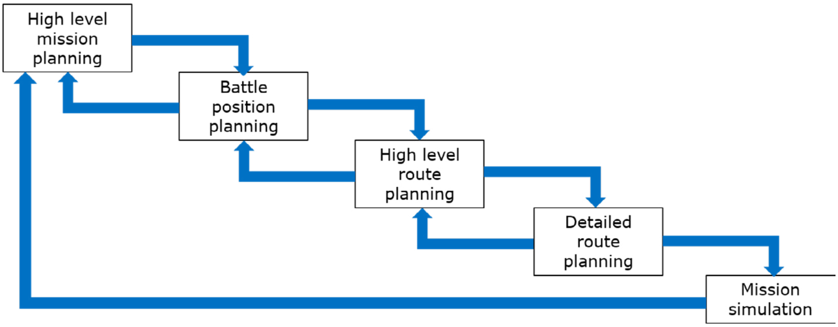

Fig. 7.5. Multi-level optimization approach.

As stated in the introduction, offensive air missions are in large part still being planned manually, e.g., battle positions are picked by hand and analysed by a large group of experienced aviators, load planning is done by load masters who do weight and balance calculations (using simple calculation tools) and route allocations are determined by visual inspection of maps and terrain data. In this approach experienced military personnel play a significant role.

Valuable as this is, we propose to add to this the application of OR techniques. As explained, the battle position planning, the route planning and the prioritising of targets in the area of operation can be supported by already existing scientific methods. The same holds for coordinating multiple flights. Applying these methods and using the outcomes of these analyses can be used as decision support. It serves as a platform for discussion to improve the situation awareness of the whole

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mission with all its aspects, tests tacit assumptions, and reveals the various subjective opinions. We conjecture that, using field testing in a simulated environment, one may already prove the added value of applying existing OR tools as described in the previous three sections. This may hold for the various aspects of a mission in isolation, as well as for planning and evaluating the mission as a whole. All the different elements can be automated to avoid a time-consuming manual process. It also avoids operator fatigue, especially in the case of a SCAR helicopter mission consisting of more than one wave, generating additional tactical situations.

Given the complexity of the interacting processes (terrain information, weather, routing, neutralising, prioritisation, coordinating) as shown in the figure above, classical OR techniques may be used in an iterative manner to generate an optimal or even suboptimal solution that takes into account all these interacting processes in a balanced way. Combined with modern image recognition techniques regarding terrain and target data, and AI/ML, one may develop a comprehensive approach to mission planning.

Tactical problems (like battle position planning, prioritising targets, etc.) become (only) difficult when there is a scarcity of helicopters and other means. This scarcity may be due to operational considerations that assigns just a few helicopters to the mission but may also be the result of maintenance issues, operational reserve and logistic reserve. Given the number of targets and the influence of enemy air defence, this scarcity poses several other problems in the planning process, from planning for battle positions to prioritising targets. For example, a tactical issue may be: do we distribute our means evenly over the targets or do we create excess situations for just a few targets. Here a game-theoretic approach may be beneficial as it is able to generate and identify dominating strategies.

Notes

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