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Airspace management: Some challenges for automated decision support

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Abstract

A critical component of current and emerging airspace management problem complexity lies on airspace deconfliction (AD), which consists in predicting and resolving conflicts between multiple users sharing a common airspace. Yet, current military and civilian decision support solutions for AD which could benefit the Canadian Air Force have been largely ignored so far, not to mention the absence of any explicit doctrine, and recent international efforts and exploration on advanced capabilities and decision support systems to support a growing demand. This report presents the AD problem, identifies decision support requirements at planning and execution monitoring levels for a targeted military organization, highlights and discusses the main findings of a limited survey of existing civilian and military systems and solutions to tackle AD, outlines decision support deficiencies and limitations, and emphasizes benefits and strengths expected from suitable automated decision support capability. The study also describes current trends and future challenges, and presents some limited recommendations for near-future investigations of technological solutions and avenues.

Résumé

Une composante critique de la complexité du problème actuel et émergeant de la gestion de l'espace aérien réside dans la déconflictualisation de l'espace qui consiste à prédire et résoudre les conflits entre les multiples usagers partageant un espace aérien commun. Pourtant, les solutions existantes de systèmes d'aide à la décision militaires et civils ont été largement négligées à ce jour, sans compter l'absence de doctrine explicite ainsi que des efforts internationaux récents et l'exploration de capacités avancées et d'aide à la décision pour appuyer une demande croissante. Ce rapport présente le problème de la déconflictualisation de l'espace aérien, identifie les exigences d'aide à la décision au niveau planification et exécution pour une organisation militaire particulière, met en évidence et analyse les principaux résultats issus d'une revue de littérature limitée sur les systèmes d'aide à la décision civils et militaires existants ainsi que les solutions proposées, souligne les déficiences et limites de ces systèmes, et insiste sur les bénéfices et les forces auxquelles on pourrait s'attendre d'une capacité d'aide à la décision automatisée. L'étude présente également les tendances et les défis futurs anticipés, et offre quelques recommandations pour l'étude de solutions et d'avenues technologiques dans un futur proche.

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Executive summary

In the Canadian Air Force context, airspace control refers to theatre airspace management during operations. It consists in providing airspace management flexibility in order to ensure safe air defence operations. The recent adoption of the US Theater Battle Management Core System (TBMCS) by the Canadian Air Force Command and Control Information System project (AFCCIS) to support some basic functions offers partial solutions to this problem. It provides some resource management authoring tools to support planning and execution tasks. However, as no survey of existing military and civilian decision support solutions for airspace management has been conducted and no explicit doctrine has been established, enhancements and requirements for advanced capabilities are still being explored to support the growing demand for airspace management around the world.

The objective of this work is to examine the expected benefits of automated intelligent decision support tools, clarify the main decision support requirements to support planning and execution monitoring, and provide guidance and directions as to suitable technological solutions for the Canadian Air Force. Given time constraints, the study more specifically investigates automated decision support requirements and challenges with a view to addressing the airspace deconfliction problem. Airspace deconfliction (AD) consists in resolving conflicts and maintaining collision avoidance conditions by dynamically (re-)assigning airspace variables (time, space, user refusal, risk acceptance), while sharing flight activity information between key military organizations and aviation agencies. This effort is sponsored by DAR 4-2 in order to investigate the relevance of intelligent decision aid tools to tackle AD in the context of Canadian Air Force operations.

Results indicate that the civilian systems examined are primarily designed for air traffic control functions and are not necessarily or directly applicable to military air operations, due to their complexity. On the other hand, current military-based systems are limited by their differing emphasis and granularity. Such systems reflect abstraction level variability in metrics for conflict detection definitions over space and time intervals regarding airspace mission requirements (e.g. single aircraft and route-based vs. complex volumetric mission-dependent conflicts) or provide incomplete decision support (e.g. no conflict resolution mechanism and/or limited capability for on-line deconfliction). Additional deficiencies associated with current military AD systems relate to the gap between off-line and on-line deconfliction requirements to smooth the integration of planning, execution and monitoring, and the increasing demand for airspace management.

Preliminary observations suggest there is some merit in the short-term development of tailored decision support components with conflict detection and resolution mechanisms compatible with and built upon the legacy systems in current use. However, increasing airspace demands (user density, diversity, manned and unmanned air vehicles, additional capacity, service level, risk mitigation, dynamic airspace allocation and enroute uncertainty management, coordination with a mix of military and civilian organizations, restricted theatre or reduced operation airspace); growing user/organization relationships, interdependencies (joint/combined operations, coalitions) and complexity; as well as asymmetric threats (e.g. terrorism and urban battlespace) impose additional pressures and call for new solutions. This is happening as airspace is increasingly perceived as a shareable resource and no longer as a private property or commodity.

Despite the current situation of the Canadian Air Force dealing with its limitations, revised roles (border and in-land protection), addressing critical future capabilities, and gracefully transitioning toward net-centricity while going through transformation, the AD problem is likely to grow in complexity. Innovative centralized and/or decentralized AD solutions applicable to a variety of operations such as surveillance/reconnaissance and antiterrorism, or target search, time-critical targeting and fire support missions might have a significant impact. The findings of this study are

intended to guide military managers in prioritizing future efforts and appreciating critical issues with a view to mandating research and development activities or roadmap, building knowledge and expertise, and improving AD decision support capabilities over various time horizons. This work is also relevant to DRDC applied research programs on Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) and to the international TTCP C3I/AG1 action group on “Dynamic Planning and Execution”.

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Sommaire

Dans le contexte des Forces aériennes canadiennes, le contrôle de l'espace aérien réfère à la gestion de ce dernier en théâtre d'opérations. Celle-ci consiste à procurer la flexibilité requise pour assurer la sécurité des opérations. L'adoption récente du système US TBMCS (Theater Battle Management Core System) par le projet Canadian Air Forces Command and Control Information System (AFCCIS) visant le développement d'un système d'information de commandement et contrôle pour les Forces aériennes afin d'appuyer quelques fonctions de base présente des solutions partielles à ce problème. Il procure des outils d'édition de gestion de ressources soutenant des tâches de planification et d'exécution. Toutefois, comme aucune revue des solutions actuelles d'outils d'aide à la décision civiles et militaires de la gestion d'espace aérien pouvant bénéficier aux Forces aériennes n'a été effectuée, et qu'aucune doctrine officielle explicite ne soit connue, l'exploration d'améliorations et d'exigences de capacités avancées pour souitenir une demande croissante de la gestion de l'espace aérien sont toujours en cours.

L'objectif de ce travail sur la gestion de l'espace aérien est d'obtenir une meilleure évaluation des bénéfices potentiels d'outils d'aide à la décision automatisés, en clarifier les principales exigences pour le soutien à la planification et l'exécution ainsi que de guider et donner des directions de solutions technologiques appropriées pour les Forces aériennes. Étant donné les contraintes d'échéance, l'étude s'est orientée en fonction des exigences et défis d'aide à la décision automatisée pour le problème de déconflictualisation de l'espace aérien. Ce problème consiste à résoudre des conflits et maintenir l'évitement de collision en affectant dynamiquement les variables d'espace aérien (espace, temps, refus, risque) tout en partageant l'information de vol entre organisations militaires et agences d'aviation. Cet effort est parrainé par DAR 4-2.

Les résultats indiquent que les systèmes civils explorés sont principalement orientés vers le contrôle du trafic aérien et ne sont pas nécessairement directement applicables au domaine militaire en vertu de la complexité des opérations caractérisant ce domaine. En contrepartie, les systèmes militaires répertoriés demeurent limités, avec différents accents et granularités. Ces systèmes montrent une variabilité de niveau d'abstraction dans les métriques définissant la détection de conflits sur les intervalles d'espace-temps pour des exigences de mission (par exemple simple avion et routes Vs conflits de nature volumétrique et dépendant des missions), ou proposent des aides à la décision automatisés incomplets (par exemple, aucun mécanisme de résolution de conflits, ou capacité limitée pour la déconflictualisation en temps réel). La demande croissante de gestion de l'espace aérien, ainsi que l'écart entre les exigences de déconflictualisation de nature délibérative et réactive dans les systèmes militaires actuels pouvant faciliter à la fois l'intégration de planification, exécution et monitoring, constituent des déficiences supplémentaires.

Les observations préliminaires semblent suggérer le développement à court terme de composantes d'aide à la décision adaptées, intégrant la détection de conflits et des mécanismes de résolution compatibles et cohérents avec les systèmes actuellement utilisés. Cependant, l'augmentation de la demande pour l'espace aérien (densité et diversité d'usagers, véhicules aéroportés autonomes et non-autonomes, capacité additionnelle, niveau de service, réduction du risque, allocation dynamique de l'espace aérien et gestion de l'incertitude en vol, coordination d'organisations militaires et civiles, théâtre restreint et espace aérien réduit), les relations croissantes entres organisations et usagers, les interdépendances (opérations conjointes/combinées, coalition) et la complexité, ainsi que les menaces asymétriques (par exemple, terrorisme) imposent une pression supplémentaire et nécessitent de nouvelles solutions. Ceci s'opère au fur et à mesure que l'espace aérien est progressivement perçu comme une resource partageable plutôt qu'une propriété privée ou une commodité.

Malgré la situation actuelle des Forces aériennes devant composer avec ses contraintes, la revision des rôles (protection du territoire et des frontières), les capacités futures critiques et la transition vers la

réseau-centricité durant la transformation des Forces, le problème de déconflictualisation de l'espace aérien va continuer de croître en complexité. Des solutions innovatrices centralisées et/ou décentralisées applicables à une multitude d'opérations, telles la surveillance/reconnaissance et l'antiterrorisme, ou des missions de recherche de cibles, de ciblages critiques dans le temps ou de tirs, pourraient avoir un impact significatif. Les résultats de cette étude devraient contribuer à guider les gestionnaires militaires à prioriser les efforts à venir et mieux apprécier les éléments critiques afin de proposer des activités appropriées de recherche et développement, développant connaissance et expertise, et améliorant les capacités d'aide à la décision de déconflictualisation de l'espace aérien pour différents horizons temporels. Ce travail présente un intérêt pour le programme de recherche appliquées de RDDC lié au domaine Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) ainsi qu'au groupe international TTCP/C3I/AG1 sur la «planification dynamique et exécution».

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1. Introduction

Airspace management is key to successful air operations in civilian and military environments. It consists in successfully managing and coordinating airspace utilization by a variety of users to ensure flight safety, defence, security, monitoring and air traffic management safety. Increasing demands on airspace utilization, the conflicts arising from the multiplicity and diversity of users and operations, and the participation of heterogeneous organizations in dynamic and uncertain environments require further attention to face emerging challenges.

In the military context, airspace control refers to theatre airspace management during operations. It is aimed at providing airspace management flexibility to ensure safe air defence operations. The recent adoption of the US Theater Battle Management Core System (TBMCS) by the Canadian Air Force Command and Control Information System project (AFCCIS) to support some basic functions offers partial solutions to this problem. It provides some resource management authoring tools to support planning and execution tasks. However, system enhancements and requirements for advanced capabilities to support airspace management are still being explored.

This work investigates automated decision support requirements and challenges for limited airspace management. Limited to a regional AD setting, this preliminary study examines the requirements, potential and challenges of automated intelligent decision support technologies to assist end-users in the mission planning process. Current civilian and military system limitations/deficiencies and requirements for automated capability to support military operations are explored, and potential technology solutions to support relevant AD tasks are reported.

The document is structured as follows. A limited survey of state-of-the-art centralized AD systems is summarized in Chapter 2. It introduces the basic problem, presents decision support requirements and outlines the main strengths and weaknesses of current AD system solutions. Chapter 3 offers an overview of current distributed AD efforts around the world. Current trends are first described, followed by a discussion. Finally, some conclusions and comments are given in Chapter 4.

2. Centralized airspace deconfliction

2.1 Problem

2.1.1 Generic description

Airspace management refers to the coordination, integration and regulation of the use of airspaces of defined dimensions. Airspace management prevents interference between airspace users, facilitates air defence and identification, and accommodates the safe flow of all air traffic [1], [2]. Given the complexity of the multi-level airspace management problem, specific attention is first devoted to the AD problem. It consists in resolving conflicts and maintaining collision avoidance conditions by dynamically (re-)assigning airspace variables (time, space, risk level), while sharing flight activity information between key organizations and aviation agencies. A variety of definitions for related problems including air traffic management, traffic flow management and relevant subproblems may be found in [3].

AD involves conflict prediction/detection, conflict resolution and conformance monitoring functions. A characterization of the conflict detection and resolution decision-making process was recently proposed by Kuchar [4] as displayed in Figure 1. Informative in nature, conflict detection consists in deciding *when* action should be taken (e.g. volumetric overlap, eminent predicted separation loss) in predicting potential conflict. It ascertains when conflict notification to the user should take place. Advisory in nature, conflict resolution determines *how* or *what* action should be performed notifying or assisting the user in delivering a suitable response. Conformance monitoring determines the degree to which a mission or flight is adhering to its assigned trajectory or to what extent the plan execution deviates from the expectations considered during plan construction.

The objective of a conflict detection and resolution (CDR) system is to predict potential conflicts in the near future; alert, inform and notify the user (human operator); and assist the user in taking appropriate action to resolve the conflict. The prediction, notification and resolution decision-making process may involve multiple elements as shown in Figure 1. The environment is first monitored based on sensors and communication systems providing state information from which a situation assessment is derived (environment state estimation). Then, using an environment model (dynamic model and behaviour) to anticipate/project possible future state transitions along with predetermined metrics (e.g. minimum aircraft separation, estimated time to closest point of approach) to characterize significant deviations from expectations, conflict prediction/detection and resolution components may be sequentially carried out involving passive or active participation, feedback and collaboration of the human operator, ultimately modifying the environment state. The interaction between the conflict prediction and detection elements is primarily dictated by the nature and granularity of possible actions and reaction times, leading to tightly or loosely coupled components.

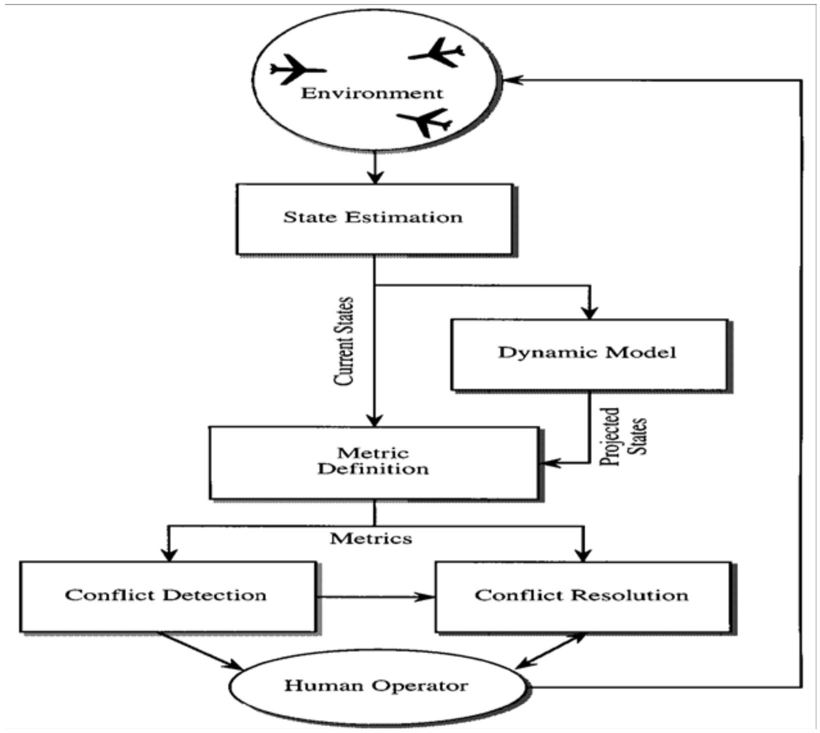

Figure 1 – Conflict detection and resolution process after Kuchar [4].

AD may occur at the strategic or tactical abstraction levels, depending on the timescale of the targeted problem. Strategic deconfliction typically takes place ahead of time (off-line) during the planning phase and primarily relies on coarse-grain conflict definition. Tactical deconfliction arises during the plan execution phase in real-time or near real-time (on-line) using fine-grain conflict definition. On-line deconfliction introduces additional complexity to the problem, including for example, dynamic routing of air vehicles, developing or revisiting new routes for close air support or against mobile targets, artillery operations, firing zones, enroute tactical mission replanning or redirection of aircraft around hostile activity zones.

2.1.2 Case study – MACP

In a military context, AD is defined as a process aimed at reducing risk and enhancing the application of airpower via management and control of a volume of airspace and the objects in and about to enter the airspace under management and control. AD pursues a variety of objectives, such as expediting airborne missions to/from their duty stations and mission objectives, avoiding harmful interaction between airborne objects, enhancing the monitoring/controlling of current and projected airborne objects, and optimizing resource allocation.

This section gives a high-level description of a limited case study focusing on selected AD activities at Maritime Air Component Pacific (MACP) located at Esquimalt, B.C. In the current problem setting briefly presented to the author during a visit in March 2005, operational (off-line) AD is primarily emphasized. In a nutshell, the problem consists in deconflicting mission requests over limited littoral sectors of B.C.'s west coast involving partially segregated airspaces. Deconfliction typically includes a variety of military patrol mission requests as well as some civilian patrol activities (e.g. illegal fishing or oil polluter detection), namely from the Department of Fisheries and Oceans and Transport Canada. Conflict prediction for military missions is achieved using an automated AD system (ADS-TBMCS) presenting all potentially conflicting mission pairs based on some conflict detection definition. Conflict resolution is then handled manually for each pair through altitude deconfliction rules. An iterative process progressively eliminates remaining conflicts accordingly. Tactical conflict resolution is handled procedurally to lower planning echelons (dialogue between the units concerned, mediated or not via Wing Operations or MACP staff, briefings and pilot discussions prior to the mission). As for real-time AD, once units are airborne, visual flight rules (VFR) apply, and it is the pilot's responsibility to maintain separation. If there is any change to the conflicting conditions (e.g. patrol cancellation) then either MACP or Wing Operations advises the aircraft. Likewise, if the crew has any questions, they contact Wing Operations for further clarification. Conflict resolution between military patrols and known civilian contractor flights and known other government department flights is achieved procedurally.

In the TBMCS adopted by AFCCIS to support air operations planning, current airspace planning is achieved using two components, namely, the Airspace Control Order/Air Tasking Order Tool (AAT) and the Airspace Deconfliction System module of TBMCS (ADS-TBMCS). An Air Tasking Order (ATO) specifies flying unit tasks to carry out missions, whereas an Airspace Control Order is an airspace control plan specifying airspace attributes (usage, location, time interval, altitude, controlling authority, configuration of the targeted area, etc.) of approved requests for given Airspace Control Measures (ACMs) in support of the ATO. It may be published as part of the ATO or separately. ACMs descriptions include zones, areas, sectors and airspace corridors, and indicate airspace restrictions, access and control and coordination procedures. AAT is an authoring tool allowing the user to manually construct, revisit and store Air Control Orders (ACO), which contain airspace allocations to missions defining static air corridors over a period up to a month prior to mission execution. The ADS-TBMCS component is primarily used to detect airspace conflicts, allowing the user to:

- Create and manipulate ACMs, ACM groups, types and usages.
- Specify criteria to identify a conflict between ACMs.
- Detect conflicts between ACMs and generate a conflict report.
- Perform AD over multiple ACMs.
- Display a graphical map of ACMs and modify them as required.
- Monitor execution and publish modifications to the ACO.

Generally speaking, airspace allocation may be summarized according to the following ACO generation process:

- Users submit ACM requests prior to a published deadline.
  A request defines airspace volumes, routes and rules for the use of the airspace partitions.
- Airspace managers build plans and deconflict ACMs (resolve conflicts with users).

2.2 Decision support requirements

2.2.1 Generic requirements

This section mainly reflects some of the requirements generally encountered for conflict detection/resolution capability in systems designed for air traffic control and is based partly on [4]. The identified decision support requirements are aimed at supporting planning (conflict prediction/detection/resolution) and execution monitoring (conformance monitoring) tasks and are applicable to both on-line and off-line AD. These first include mission/flight safety based on domain-dependent acceptable standards, performance maximization on airspace utilization in static and dynamic environments/settings in terms of optimization and flexibility. Optimization objectives typically involve trading off separation loss maintenance and false-alarm generation; maximizing system capacity to satisfactorily respond to the demand in managing space-time distribution and route efficiency; and minimizing response time, service denial, and energy and resource consumption. Suitable decision support systems should handle multiple objectives; offer assistance to supplement manual conflict resolution associated with appropriate measures of performance; integrate or interoperate with other information sources (hazards, terrain proximity warning systems, weather, notices to airmen (NOTAMs), alert monitoring systems); and provide automated capabilities for uncertainty management (enroute and off-line), concurrent multiple conflict handling, coordination with alternate systems or organizations, and human-computer interaction issues. In that regard, decision support systems should be consistent and supportive in addressing cognitive needs for critical tasks allowing user observability and directability to mitigate the negative impact of severe user workload, look-ahead or limited planning horizon, and combinatorial complexity, while focusing on solutions to maximize probability of success for user acceptance and trust. Real-time requirements for an adaptive decision support system include speed, responsiveness, timeliness, graceful adaptation and scalability.

2.2.2 Case study – MACP

In this section, we summarize the highlights reflecting deficiencies and decision support requirements for AD tasks as drawn, perceived and interpreted from the feedback obtained from MACP A3 staff members (Capt Mark Mombourquette and Capt John McKinnon), in a meeting at MACP in March 2005. Additional information is provided in [5].

2.2.2.1 System deficiencies

The nature of off-line AD, the time horizon and the volume of related requests typically handled at MACP usually allow sufficient reaction time for the user to achieve pairwise ACM deconfliction and call for repair. However, even though the AD component currently used (ADS-TBMCS module) may detect conflicts and notify the user accordingly, the basic authoring capabilities offered to achieve detection and resolution appear very limited.

Deficiencies include the absence of automated conflict resolution capability and unsuitable metrics for conflict detection definition which could limit conflict resolution and system capacity to satisfactorily manage concurrent ACMs. Thus, the ADS-TBMCS module defines high-level potential conflicts considering separate dimensions independently, such as global volumetric overlap and ACM time intervals intersection, rather than explicit space-time airspace utilization and any key ACM characteristics (flying object, purpose, kinematic parameters, etc.). Although simple in nature, this approach provides over-conservative aircraft separation assurance, while generating high rates of false alarms unnecessarily.

Conflict resolution is achieved manually using standard deconfliction procedures, relying on domain-dependent expertise, overlooking the impact of more appropriate measures of performance. Potential additional limitations relate to the absence of automated advisory decision support capabilities (e.g. alternate solutions, advice and recommendations, updates) to either supplement manual user intervention or optimize airspace allocation based on user preferences or multiple criteria (resource utilization, risk mitigation, mission requests coverage).

Alternate deficiencies have to do with combinatorial complexity stemming from problem size, no automated resolution capability, and real-time constraints and limited user reactivity/capacity making problem-solving possibly unmanageable for a single user when restricted to pairwise deconfliction only (as opposed to global). The impact on the decision-making process of capacity, performance, demand and airspace boundaries are also primarily unknown. Another shortcoming involves the lack of system integration with other information sources (e.g. procedural deconfliction rules with AD component, hazards, warning and weather systems). On-line or tactical AD is achieved through morning briefings and pilot communication before missions, and also using visual and instrument flight rules. In certain conditions, better integration with off-line deconfliction systems might be suitable.

2.2.2.2 Decision support requirements

This section summarizes and discusses some of the anticipated decision support requirements perceived for the MACP environment. These mostly revolve around conflict resolution and capability improvements. On the one hand, an advisory decision capability assisting the user in resolving conflicts would first be a significant and useful enhancement alternative to the currently used standard deconfliction rules, as no automated mechanism is available to the user. This capability would also be useful for training and learning purposes. A global AD procedure capability represents a potential value-added over pairwise methods, providing additional user options and opportunities for optimization or performance comparison. On the other hand, mission/task heterogeneity and underlying uncertainty call for more sophisticated rules for conflict detection in order to improve deconfliction solution quality. Accordingly, conflict detection rules might be further refined or specialized, exploiting space and time mission variable dependencies, safety zones, kinematic features and model behaviours whenever deemed applicable, and revising over-conservative threshold values based on mission characteristics and specific constraints. These refinements would reduce false alarms, speed up conflict resolution, possibly improve service/capacity (mission coverage), and reduce computational effort while yielding a satisfactory solution through iterative pairwise deconfliction.

General decision support capability requirements mentioned in section 2.2.1 also apply to a certain extent, namely conformance monitoring, uncertainty management, coordination (MACP handles some Transport Canada and Fisheries and Oceans patrol flight deconfliction requests), adaptive due to limited reaction time, human-computer interaction (decision support capability user acceptance, consistent and supportive, cognitive), integration with other information sources (hazards, weather, etc.) and performance improvement in minimizing false alarms.

Additional extensions to conflict detection/resolution might be beneficial for cases involving many constraints, critical numbers of airspace users, reduced airspace involving high contention or deconfliction pressure, and more sophisticated or adjustable conflict definition. But this ultimately depends on the precise situation-dependent objectives pursued. If the goal is to increase capacity (i.e. handle and accommodate a large number of ACMs), better conflict detection and resolution mechanisms are needed. The potential benefits of using intelligent tools would be improved service levels, airspace capacity and operator flexibility.

2.3 Solution perspectives

2.3.1 Summary

This section briefly summarizes high-level results of a survey of the feasibility, benefits and limitations of potential and existing solutions to the case study problem described in Section 2.1.2. The aim of the study was to provide an overview of promising civilian and military approaches to support AD. However, mainly due to time constraints, the identification, characterization and evaluation or exploration of suitable approaches remained high-level and partial, yielding brief descriptions of concepts, paradigms and some major deficiencies in decision support technologies. The results of this limited survey [3] are augmented by some observations drawn from the recent literature [4] on civilian and military systems.

The study reported in [3] refers to strategic (off-line) and tactical (on-line) planning, which may correspond to air traffic flow management (off-line planning), and air traffic control (on-line during execution). Air traffic flow management mainly relates to a deliberative planning activity. Air traffic control, however, involves reactive planning and execution over a shorter timescale. The limited study reports on three civilian or non-military systems and four military systems. The non-military systems are the User Request Evaluation Tool (URET) developed by MITRE, Tactical Separation Assisted Flight Environment (TSAFE), and Canadian Automated Air Traffic Control System (CAATS). The military systems are the airspace management (ASM) component of the NATO-based Integrated Command and Control (ICC) system, the AD module of TBMCS, the Analysis Tools (RAT) suite of the Portable Flight Planning System (PFPS), and MAATS, the Canadian military counterpart of CAATS. The main findings indicate on the one hand that the civilian systems examined are intended primarily for air traffic control and are not necessarily or directly applicable to military aviation owing to the complexity of military air operations. On the other hand, current military-based systems are limited by incomplete decision support capability (e.g. no conflict resolution mechanism and/or limited capability for on-line deconfliction), and variability of emphasis and abstraction over metrics for conflict detection definitions dictated by space, time intervals and airspace mission requirements (e.g. single aircraft and route-based Vs complex volumetric mission-dependent conflicts). Hence, ASM-ICC shows similar functionality to ADS-TBMCS while offering superior user interfaces, both focusing on a coarse-grain conflict detection definition, whereas RAT-PFPS places more emphasis on tactical flight planning presenting some finer-grain conflict detection definition (e.g. route-based), having more commonality with conventional air traffic control for commercial aviation. These military authoring system components are designed to assist mission planners in detecting conflicts among air control measures or planned routes. However, none of them seem to explicitly provide or include conflict resolution and conformance monitoring capabilities. More details on system descriptions and high-level analysis may be found in [3].

The study conducted by Kuchar on conflict detection and resolution modelling methods appears to be the most complete and valuable report available. A large number of solutions, mainly related to air traffic control, are examined, analyzed and classified, primarily referring to tactical or on-line AD. Systems rely on various key technologies such as optimization, genetic algorithms, etc. The 68 system solutions examined are very domain-specific and mostly attempt to trade off false-alarm rates and loss of separation maintenance, as a solution to the conflict detection or prediction problem. An excellent survey, analysis, capability description and comparison are reported in [4] and [6]. Concerning conflict detection/resolution models to trade off false-alarm rates and loss of separation maintenance, few of the current systems under investigation satisfactorily address the requirements mentioned in section 2.2.1.

A brief analysis and description of existing AD systems both in military and civilian domains reveal system deficiencies. Shortcomings associated with existing civilian systems, as potential military solutions, naturally emerge. As current systems have been mainly designed to operate in a commercial air traffic setting involving known or nearly predictable flight trajectories, their applicability to military vaiation is quite limited, as granularity definition for conflict detection may differ significantly, addressing potential non-tactical deconfliction levels (e.g. operational), or involving various sources of uncertainty and additional complexity due to the nature of the operations and missions. For instance, corridors and lines usually describing commercial flight requirements and considered by conflict detection and resolution models for the civilian domain, may translate and expand to airspace volumes and complex spatio-temporal requirements for a military domain while making concepts of conflict detection thresholds and models, multi-dimensional and domain-dependent. Likewise, protection and safety zone concepts normally used for aircraft to predict conflicts in civilian air traffic control, as well as the goals pursued and the spectrum of tasks to be carried out, may introduce significant differences in the definition of a conflict for a military domain.

Another deficiency associated with the specialized military modules of ICC, TBMCS and PFPS relates mainly to the gap between off-line and on-line deconfliction requirements to harmonize the integration of planning, execution and monitoring. As the volume of operations, requests and airspace users increases, the additional workload and higher stress levels are transferred to the system operator, resulting in longer reaction times and decreased performance. In that case, current systems available providing assistance in detecting and resolving conflicts at various levels of granularity reach their limitations, failing to gracefully adapt when transitioning from low-demand (off-line) to high-demand (on-line) situations or from operational to tactical levels. It also appears that real-time (on-line) system deconfliction capability is quite limited, forcing the user/operator to resolve conflicts manually using prescribed procedures or rules, possibly at the expense of solution quality. Current automated deconfliction capabilities of military systems tend to define simple high-level conflict detection mechanisms or rules, restricting unnecessarily the set of possible solutions, and reducing conflict resolution system robustness in high-demand situations. Consequently, it is very unlikely that existing civilian and military solutions or systems can satisfactorily meet all general decision support requirements for specific military domains. This observation is consistent with the conclusion reached for URET regarding its applicability to military domains as reported in [3].

2.3.2 Discussion and recommendations

Given current civilian and military systems, the probable high cost of adapting existing solutions to partial needs, and currently known Canadian military domain requirements, the author proposes a domain-dependent specific solution, accounting for key AD problem attributes such as timescale (on-line vs. off-line deconfliction requirement), airspace user density and diversity. The advocated short-term recommendation is mainly based on the expected benefits of reusing legacy systems while maintaining simplicity and user understanding to incrementally build trust and usability.

The off-line (planning phase) deconfliction nature of current MACP procedures calls for short-term solutions improving on current conflict detection capabilities and assisting users in improving conflict resolution by extending user options from pairwise to complete conflict detection and resolution over a single cycle, while strategically relieving the operator and reducing workloads. Consequently, we recommend the development of a tailored advisory or mixed-initiative decision support component to support conflict resolution and augment automation to improve performance in complementing the ADS-TBMCS conflict detection module for achieving non real-time (off-line) AD. Gradually incorporating knowledge from the user and a Recognized Air Picture component (under development) to improve situation assessment/recognition, a resulting knowledge-based decision support component could generate a valuable intelligent assistant, demonstrating advisory and learning capabilities. Suitable recommendations on specific technological content defining conflict resolution solution and capabilities nonetheless require further investigation, creating unique opportunities for close collaboration between the Department of National Defence, civilian and military entities and university research programs.

As for short-term on-line (plan monitoring/execution phase) AD requirements (if any), we recommend the development of a tailored decision support component including conflict detection and resolution mechanisms compatible with and built upon the currently legacy system (ADS-TBMCS).

A detailed roadmap for the delivery of timely general technological solutions for the Canadian Air Force is still elusive and lies beyond the scope of this study as a larger spectrum of Air Force requirements for AD based on doctrine must be thoroughly analyzed and considered. However, AD solutions might be significant for specific operations such as surveillance, target search, antiterrorism and time-critical targeting.

3. Toward distributed airspace deconfliction

3.1 Trends

Generally speaking, three approaches may be used to achieve coordinated AD. The first and easiest way consists in eliminating any need for coordination (implicit or policy-based scheme). Segregating airspaces and preventing any conflict from happening beforehand using ad-hoc uncertainty management policies for any possible situation represents such an example. Although useful for mitigating problem dynamics, that scheme may nonetheless prove inefficient and expensive, limit capacity unnecessarily, and reduce service levels. The second approach proposes an explicit centralized coordinator (centralized scheme), but this assumes timely accurate information, sufficient computational resources to dynamically meet variable demands and real-time constraints, and no bottlenecks. Finally, an alternate way relies on mechanisms or protocols governing user interaction (distributed scheme). It is well-suited to address high tempos of operations, demand pressures, short reaction times and uncertainty.

Traditional AD systems have mainly been based on implicit and centralized coordination schemes or combinations of the two. Ultimately, the choice was dictated by multiple factors and objectives, depending on demands, state estimation accuracy, event density and environment predictability. However, increasing airspace demands (user density, diversity, manned and unmanned air vehicles, additional capacity, service levels, risk mitigation, dynamic airspace allocation and enroute uncertainty management, coordination with a mix of military and civilian organizations, restricted theatre or reduced operation airspace boundaries); growing user/organization relationships and inter-dependencies (joint/combined operations, coalitions) and complexity; and the nature of evolving threats posed to homeland security impose additional pressures and call for new innovative solutions, as airspace is increasingly perceived as a shareable resource and no longer as a private property or commodity.

Major international civilian and military efforts have been initiated to tackle some of these problems. In the US, the Air Force Rome Laboratory, Boeing, NASA and universities have been active players. The recent US Air Force Rome Laboratory Joint Airspace Management and Airspace Deconfliction (JASMAD) initiative is investigating new joint coordination concepts for time-critical targeting tasks. The scope of this effort is to "develop, demonstrate and transition technology that can be used to create, manage and deconflict airspace during Air Tasking Order and Airspace Control Order planning and execution for current and advanced platforms"[7]. Boeing is heading for an Integrated Air Traffic Management System[1] to satisfy future air traffic contingencies and demands proposing a network-enabled air traffic system relying on networked satellites and distributed systems to efficiently operate on reliable information in a timely manner. NASA has suggested a shift in paradigm to accommodate ever-

[1] http://www.boeing.com/news/releases/2003/q2/nr_030616d.html

increasing demands and emerging constraints. Based on the ‘free flight’ concept NASA, is looking at alternate technological solutions relying on a distributed scheme to enable autonomous flight management. This new “autonomous flight management” concept is definitely addressing key distributed AD issues. Many universities including the Stanford Research Institute[2] are also working on AD and dynamic coordination problems proposing hybrid centralized/distributed supportive system architectures. In Europe, Eurocontrol, the organization tasked with harmonizing civilian and military co-operation and needs in air traffic management across Europe, is moving away from the traditional concept of segregated airspaces. Eurocontrol recently introduced the concept of “Flexible Use of Airspace”[3] targeting a more efficient and flexible use of a shared airspace responding to a variety of contingencies through multi-level coordination policies and mechanisms. Research projects on distributed conflict resolution for air traffic management using a variety of approaches including multi-agent negotiation have recently been proposed, as reported in [8].

3.2 Discussion and recommendations

The military is expected to evolve in an environment with increasing demand and service levels, additional airspace capacity, dynamic airspace allocation, and where better coordination with other civilian and military organizations is required to carry out airspace management. In effect, increasing air traffic, multiplicity and diversity of aircraft deployed by various organizations will cause segregated airspace practices to be revisited and then create opportunities to define the necessary synergy and coordination between airspace management players. Evolution toward distributed airspace management to handle deficiencies, demand-dependent space management and space overlaps, timely coordination, common and separate objectives, different regulations, constraints and requirements, to ensure better use of the airspace at some selected levels, is progressively becoming a real challenge. Related civilian/military cooperation issues were recognized in Europe some years ago (Flexible Use of Airspace concept).

Despite the current situation of the Canadian Air Force dealing with its current limitations (e.g. no explicit doctrine on AD), facing some revised defence roles (border and in-land protection), addressing critical future capabilities, and gracefully transitioning toward net-centricity while going through transformation, the AD problem is likely to grow in complexity. Therefore, it is imperative for the Air Force to value and prioritize multiple targeted objectives to be pursued over various time horizons on that front. The specification of additional measures of performance and criteria against those goals would be useful as well.

In the meantime, our short-term recommendations to meet emerging AD challenges are to initiate some research activities oriented toward future likely or anticipated needs on coordination issues (e.g. decision support capability to enable learning multi-agent coordination, mechanisms and protocols, multi-level coordination) in order to progressively develop basic expertise, build knowledge and provide guidance and directions on suitable technological solutions in the near future. First limited to a single level, the employment of unmanned air vehicles (alone, swarms) along with a mix of new and traditional heterogeneous airborne resources, platforms and systems in restricted airspaces and applicable to a variety of domestic, contingency, urban and coalition operations for projected scenarios (e.g. cooperative search for surveillance/reconnaissance, emergency management, logistic) could represent a promising case study to develop pertinent knowledge. Coordination involving cooperation among civilian and military organizations (e.g. MACP, Transport Canada for oil pollution, and Department of Fisheries and Oceans) represent an alternate example to address risk mitigation in AD. The

[2] http://www.ai.sri.com/project/UAMS
[3] http://www.eurocontrol.int/eatmp/mil/why1.html

resulting body of knowledge on hybrid (centralized/distributed) and distributed AD may then be further extended or specialized with growing problem complexity.

4. Conclusion

Airspace deconfliction, a critical component of airspace management, consists in predicting and resolving conflicts between multiple users sharing a common airspace. This work was an attempt to gain some insight on expected benefits of automated intelligent decision support tools to support AD, clarify the main decision support requirements to support planning and execution monitoring tasks, and provide guidance and directions on suitable technological solutions for the Canadian Air Force. It introduced the AD problem, identified MACP decision support requirements, summarized and discussed the main findings of a limited survey of existing civilian and military systems and solutions supporting AD, reported strengths and weaknesses of current AD decision support system solutions, and stressed expected benefits from suitable automated decision support capability. Trends and anticipated AD challenges were also presented. Finally, limited recommendations were proposed.

Limited to a regional AD problem setting, this preliminary effort was aimed at investigating the need, potential and challenges of automated intelligent decision support technologies to assist end users in carrying out AD during the mission planning process. Mainly oriented toward an on-line air traffic control conflict detection and resolution process, most systems involve known or nearly predictable flight trajectories, with limited applicability to military domains, as definition granularity for conflict detection and metrics may differ significantly, potentially introducing non-tactical deconfliction levels (e.g. operational) and various sources of uncertainty and additional complexity due to the nature of the operations and missions carried out. Given the state of the art in current civilian and military systems, the probably costly option of adapting existing solutions that would at best only partially meet the identified needs, must be rejected. As a result, a recommendation was proposed to build an adapted decision support capability based on expected benefits drawn from reusing legacy systems. It relies on the development of a tailored advisory or mixed-initiative decision support component to assist the user in improving conflict resolution capabilities and augments automation to improve performance in complementing conflict detection, and then further incorporating adapted Recognized Air Picture components to improve situation awareness. Alternatively, a recommendation was to initiate some research activities oriented toward future likely or anticipated needs concerning coordination issues (e.g. decision support capability to enable learning multi-agent coordination, mechanisms and protocols, multi-level coordination).

The richness and complexity shown by centralized, decentralized and distributed decision-making to ensure airspace management for military problem domains, offer new challenges and opportunities to be explored, from current decision support concept extensions and refinements to the emergence of totally new ones. Findings of the limited study are expected to provide some guidance and directions in exploring new advanced decision support technology concepts.

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A critical component of current and emerging airspace management problem complexity lies on airspace deconfliction (AD) which consists in predicting and resolving conflicts between multiple users sharing a common airspace. Yet, current military and civilian decision support solutions for AD that could benefit the Canadian Air Force have been largely ignored so far, not to mention the absence of any explicit doctrine, and recent international efforts and exploration on advanced capabilities and decision support systems to support a growing demand. This report presents the AD problem, identifies decision support requirements at planning and execution monitoring levels for a targeted military organization, highlights and discusses the main findings of a limited survey conducted on existing civilian and military systems and solutions to tackle AD, outlines decision support deficiencies and limitations, and emphasizes benefits and strengths expected from suitable automated decision support capability. The study also presents current trends and future anticipated challenges to take on, and delivers some limited recommendations for near future investigations of technological solutions and avenues.

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