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Artificial Intelligence Tools for Joint Airspace Management

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Artificial Intelligence Tools for Joint Airspace Management

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ARTIFICIAL INTELLIGENCE TOOLS FOR JOINT AIRSPACE MANAGEMENT

AIM

1. This aim of this paper is to propose a future Air-Land Integration (ALI) initiative to develop an Artificial Intelligence (AI) decision support tool (DST) for joint tactical airspace management. This paper will provide an overview of ALI tactical airspace responsibilities and how the process of procedural airspace control could be improved through the employment of an Artificial Neural Network (ANN). Though maritime airspace management is a joint responsibility, this paper will focus on airspace integration between the Royal Canadian Air Force (RCAF) and the Canadian Army (CA). To enable future land component dispersed operations and command and control (C2) decentralization, it is recommended that the RCAF support the development of innovative AI-enabled tactical airspace management solutions which could be integrated into ongoing CAF Joint Fires Modernization (JFM) programs.

INTRODUCTION

2. Effective airspace control is critical for supporting joint operations and facilitating the employment of joint fires.[1] Ineffective airspace deconfliction can result in slow response times for target engagement by joint fires platforms and unsafe conditions for aircrew. As a result, limited airspace shared between air and land forces must be efficiently managed in order to promote interoperability, unity of effort, and flexibility in degraded or contested environments.[2] In order to ensure the safe and effective integration of airpower into land force operations, the CAF employs specialized airspace control and coordination elements such as the RCAF Air Support Operations Centre, Tactical Air Control Party (TACP), the CA Airspace Coordination Cell, and Joint Terminal Attack Controllers (JTAC).[3] The control of joint airspace is a shared responsibility between these elements, who employ procedural control measures to maintain separation of manned

[1] Joint Fires is defined as the following: "Fires are the use of weapon systems or other actions to create specific lethal or nonlethal effects on a target," and, "Joint fires are fires delivered during the employment of forces from two or more components in coordinated action to produce desired effects in support of a common objective." United States Joint Chiefs of Staff, *Joint Publication 3-09: Joint Fire Support,* (10 April 2019), I-3, https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_09.pdf.

[2] United States Joint Chiefs of Staff, *Joint Publication 3-52: Joint Airspace Control* (13 November 2014), III-3 – III-4, https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_52.pdf.

[3] Department of National Defence, *B-GA-403-000/FP-001, Canadian Forces Aerospace Shape Doctrine* (Trenton, ON: Canadian Forces Aerospace Warfare Centre, March 2014) 52-53, http://www.rcaf-arc.forces.gc.ca/en/cf-aerospace-warfare-centre/doctrine/ad-b-ga-403-000-fp-001.page; Department of National Defence, *B-GA-402-001/FP-001 Royal Canadian Air Force Doctrine: Command and Control* (Trenton, ON: Canadian Forces Aerospace Warfare Centre, 2018), 30, https://publications.gc.ca/collections/collection_2018/mdn-dnd/D2-393-1-2018-eng.pdf. Accessed 08 Nov 21; Department of National Defence, *B-GL-300-007/FP-001 Fire Support in Land Operations* (Ottawa: Department of National Defence, 2012), 2-9.

aircraft, Unmanned Aerial Vehicles (UAV), and surfaced-based fires.[4] This is accomplished through the use of Airspace Control Means (ACM), which assign aircraft and other weapons systems three-dimensional blocks of airspace to ensure physical deconfliction of airspace users.[5] This process is challenging due to the need to balance tactical responsiveness and safety of flight. The rapid deconfliction of airspace is necessary to support the engagement of targets by joint fires but must also minimize the risk of fratricide or midair collision. If a change in airspace is required – such as when engaging an unplanned target – a series of new ACMs must be established and communicated to all affected airspace users. In order to minimize the risk of accidents and fratricide, aircraft manoeuvre and weapons release is not authorized until the appropriate ACMs have been established.[6] This method of control is employed for its simplicity but can be restrictive due to its reliance upon static airspace corridors, voice communications, and the need for human input to ensure separation of aircraft in a rapidly changing environment.[7] The disaggregated nature of weapons trajectory, friendly force locations, enemy air defence, and aircraft performance characteristics all contribute to the complex decision-making process of dynamically creating ACMs.[8]

3. AI has been recognized by the CAF as an essential military application which must be adopted in the near future.[9] While a variety of digital DST are used to assist controllers by visually representing airspace and aircraft within their area of responsibility, one possibility that has yet to be explored is the automation of ACM generation by using software capable of determining airspace requirements for aircraft and surface-based weapons systems based on minimum separation criteria and weapons attack parameters. One form of AI which could have tactical application in this field is Artificial Neural Networks (ANN). ANN are modeled after the human brain and are

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[4] Procedural Control is defined as: "A method of airspace control which relies on a combination of previously agreed and promulgated orders and procedures. Procedural control includes techniques such as the segmenting of airspace by volume and time, and/or the use of weapon control orders." Department of National Defence, *B-GL-372-001/FP-001 Air Defence Artillery Doctrine* (Ottawa: Department of National Defence, 1999), 85.

[5] Airspace Control Means "segregate, control, and/or reserve airspace for Allied operations, and are a means for positive and procedural ID, thereby reducing the risk of fratricide. In general terms, ACMs can be broken down into the following groups: air corridors and routes, areas, points, and procedures and means." NATO, *AJP-3.3.5 Allied Joint Doctrine for Airspace Control, Edition B Version 1* (NATO Standardization Agency: May 2013), 2-4, https://www.gov.uk/government/publications/allied-joint-doctrine-for-airspace-control-ajp-335b.

[6] Department of National Defence, *B-GA-401-000/FT-000 Royal Canadian Air Force Tactical Air Control Party Tactics, Techniques and Procedures* (Trenton, ON: Canadian Forces Aerospace Warfare Centre, 2017), 4-9 – 4-11.

[7] Department of National Defence, *Air Defence Artillery Doctrine…* 85.

[8] For example, standoff weapons such as the GBU-39 Precision Guided Munition require large volumes of airspace to accommodate their flights paths, which "…may present deconfliction problems depending on the airspace coordinating areas in place." United States Joint Chiefs of Staff, *Joint Publication 3-09.3: Close Air Support* (October 2019), 108; Patrick Chisan Hew, "Distributed Cognition Sheds Light on Munitions Trajectories in Close Air Support," *Ergonomics in Design* 25, no. 2 (2017): 13, https://journals-sagepub-com.cfc.idm.oclc.org/doi/full/10.1177/1064804616675243.

[9] Department of National Defence, *Canadian Armed Forces Pan-Domain Force Employment Concept: Prevailing in an Uncertain World* (Draft, 2020), 23.

capable of being “trained” on data sets to perform specific tasks by assigning “weight” to certain desired parameters.[10] ANN can be used to recognize patterns and conflicts and are currently in use in a variety of activities including Air Traffic Control (ATC) services at civilian airports.[11] As the number of controlled commercial flights increases globally, this has driven researchers to investigate new models of airspace management which could improve efficiency and reduce risk caused by fatigue and cognitive overload on air traffic controllers.[12] In the discussion below, this paper will address the challenges of joint airspace management based in future battlespaces and propose that the RCAF in partnership with the CA and Canadian industry could lead the innovation of an ANN-based tool to support next-generation joint airspace management.

DISCUSSION

4. The RCAF’s procedures for joint airspace control have remained largely unchanged since the war in Afghanistan even though the RCAF acknowledges that such permissive conditions “…simply will not exist in an advanced [Anti-Access/Area-Denial] environment or against a peer adversary.”[13] The contested airspace of near-peer conflict will require a speed of airspace management which will challenge current procedural control methods. In 2009, strategic analyst Dr. Andrew Godefroy predicted that in the future the RCAF would be required to contribute to joint operations within “increasingly constrained environments” characterised by precision fires, semi-autonomous platforms, and highly responsive networks supported by AI.[14] This prediction is proving to be accurate as the recent conflict in Syria has revealed the complexity of joint operations in contested airspace. A lack of clear air superiority by U.S. forces “meant that coalition aircraft could not loiter indefinitely over the battlespace,” and “…there were times when coalition aircraft left the area or limited their time on station as a result of the presence of Russian aircraft.”[15] This was further complicated due to the need to engage targets in close urban fights, supported by howitzer and rocket artillery batteries providing indirect

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[10] Kenneth Payne, *Strategy, Evolution, and War: From Apes to Artificial Intelligence* (Georgetown University Press, 2018), 166-167, https://ebookcentral.proquest.com/lib/cfvlibrary-ebooks/detail.action?docID=5394997; Dursun Delen and Ramesh Sharda, “Artificial Neural Networks in Decision Support Systems,” In *Handbook on Decision Support Systems 1* (Berlin: Heidelberg, 2008), 560-561, https://doi.org/10.1007/978-3-540-48713-5_26.

[11] Frank Wolfe, “How Searidge Uses Artificial Intelligence to Revolutionize Airports, Air Traffic Management,” https://www.aviationtoday.com/2020/06/29/how-searidge-uses-artificial-intelligence-to-revolutionize-airports-air-traffic-management/, accessed 23 Jan 2022.

[12] Biyue Lo et al., “A Deep Unsupervised Learning Approach for Airspace Complexity Evaluation.” *IEEE Transactions on Intelligent Transportation Systems* (2021): 1, https://ieeexplore-ieee-org.cfc.idm.oclc.org/stamp/stamp.jsp?tp=&arnumber=9531558.

[13] NATO, *Allied Joint Doctrine for Airspace Control…,* 5-20 – 5-25; Department of National Defence, *Future Concepts Directive Part 2: Future Air Operating Concept* (Ottawa: Department of National Defence, 15 August 2016), 20, http://www.rcaf-arc.forces.gc.ca/en/cf-aerospace-warfare-centre/elibrary/future-concepts-directive-part-2-future-air-operating-concept.page.

[14] Andrew Godefroy, *Projecting Power: Canada’s Air Force 2035.* (Trenton: Canadian Forces Aerospace Warfare Centre, 2009), 43, 65.

[15] Becca Wasser et al., *The Air War Against the Islamic State: The Role of Airpower in Operation Inherent Resolve* (Santa Monica, CA: RAND Corporation, 2021), 189, https://www.rand.org/pubs/research_reports/RRA388-1.html.

fires. As a result, airspace needed to be carefully partitioned as quickly as possible while minimizing coordination.[16] This will prove even more challenging when facing an adversary capable of launching complex aerospace attacks, such as the employment of loitering munitions and manned attack aircraft seen during the 2020 Nagorno-Karabakh War.[17] The increasing automation of allied and adversary weapons systems will drive the need for a faster tactical airspace deconfliction system; for example, the F-35 can locate targets using the AN/AAQ-47 Electro-optical Distributed Aperture System and relay that information to other surface or aerial fires platforms "autonomously without requiring an additional workload from the pilot."[18] In future air warfare, the ability for manned and unmanned aircraft to engage threats will be mostly limited by the speed of information processing and decision making, of which airspace management remains a limiting factor.

5. The CA's pivot towards dispersed operations in response to near-peer threats will also disrupt the traditionally centralized process of procedural airspace control. In *Close Engagement: Land Power in an Age of Uncertainty,* the Canadian Army Land Warfare Centre identifies the need to shift land battlespace focus on a posture of "Adaptive Dispersion" to be able to influence a wider operational footprint while reducing vulnerability to weapons systems such as rocket artillery.[19] Land forces must be capable of operating in a dispersed fashion, while "still retaining those dispersed element's ability to aggregate rapidly to concentrate combat power."[20] Smaller combat formations would operate with greater autonomy over wider distances, with the capacity to "access all land and joint enablers through an integral lethal and non-lethal effects coordination cell."[21] While air power's characteristics of speed, reach, and elevation enable it to support dispersed land operations by rapidly massing effects in support of manoeuvres, this could result in airspace congestion if sufficiently agile tactical air traffic management procedures are not employed. Helicopters, UAV, logistical supply vehicles, and attack aircraft are all predicted to be employed in support of Company-level manoeuvre with limited time for coordination in a contested electromagnetic environment.[22] The necessary speed of airspace deconfliction in such a conflict would outpace the capacity for procedural control due to its reliance on centralized human decision-making and verbal communication. An airspace control system which enables decentralization and

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[16] Wasser et al., *The Air War Against the Islamic State…,* 191.

[17] While autonomous unmanned aircraft have been the the focus of media and scholarly attention during the 2020 Nagorno-Karabakh War, the Azerbaijan Air Force also employed SU-25 aircraft and attack helicopters throughout the conflict to engage ground targets. Ministry of Defense of the Republic of Azerbaijan, "Video footage reflecting airstrikes of the Su-25 attack aircraft and combat helicopters inflicted on the enemy during the Patriotic War," https://mod.gov.az/en/video-archive-047/?vid=35003, accessed 23 Jan 2022.

[18] Stephen T. Davis, "Type 4 Close Air Support," *Marine Corps Gazette* 102, no. 3 (03, 2018): 35, https://www.proquest.com/trade-journals/type-4-close-air-support/docview/2008819986/se-2?accountid=9867.

[19] Department of National Defence, *Close Engagement: Land Power in an Age of Uncertainty* (Kingston: Canadian Army Land Warfare Centre, 2019), 16-18, http://www.army-armee.forces.gc.ca/assets/ARMY_Internet/docs/en/close-engagement.pdf.

[20] Department of National Defence, *Close Engagement…,* 16-18.

[21] Department of National Defence, *Close Engagement…,* 23-24.

[22] Department of National Defence, *Close Engagement…,* 30-32.

automated decision-making would be necessary to enable air support operations in a rapidly changing battlespace, particularly at low altitudes which will see high concentrations of aircraft and weapons.

6. The RCAF should prepare for future joint aerospace operations by investing in an ANN-enabled DST with the capacity to dynamically generate ACMs with minimal need for human input. While software such as the Windows Tactical Assault Kit and TacView currently employed by the CAF can be used to display airspace information and allow users to manually input new ACMs, this proposed DST would be capable of automatically generating ACMs based on aircraft and weapon requirements to provide joint fires coordinators with airspace solutions at greater speeds.[23] The US Defence Advanced Research Projects Agency (DARPA) has already begun the process of developing such a joint airspace management system between the US Army and US Air Force. The Air Space Total Awareness for Rapid Tactical Execution (ASTARTE) program aims to "enable efficient and effective airspace operations and de-confliction in a highly congested future battlespace," and while the output of that program will likely be specific to US capabilities, its conceptualization provides an accurate depiction of the need to modernize the airspace deconfliction processes.[24]

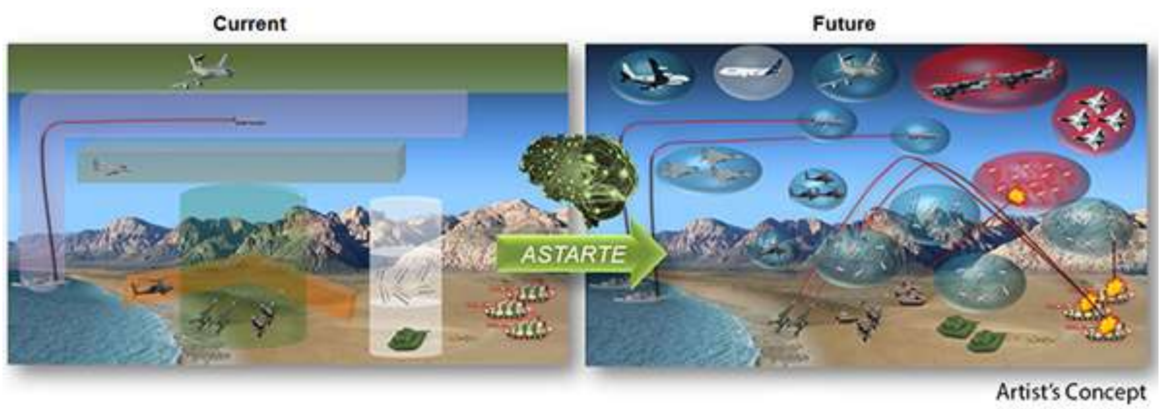

Figure 1 – Air Space Total Awareness for Rapid Tactical Execution (ASTARTE)
Source: DARPA, "Real-time Airspace Awareness and Deconfliction for Future Battles."

7. Tactical airspace management would be an ideal opportunity for the RCAF to experiment with AI technology, as there is already established research supporting the use of AI for airspace control and suggesting that an ANN DST may be achievable in the near future. Dalmau and Allard developed an ANN capable of deconflicting aircraft based on a reward and penalty system associated with aircraft speed, separation criteria, and deviation.[25] Mollinga and van Hoof employed Deep Reinforcement Learning to train an

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[23] For more information on WinTAK and TacView, see their product pages: https://tak.gov/solutions/military, https://www.tacview.net/product/about/en/.

[24] Defense Advanced Research Projects Agency, "Real-time Airspace Awareness and De-Confliction for Future Battles," https://www.darpa.mil/news-events/2020-04-07, accessed 23 Jan 2022.

[25] Ramon Dalmau, and Eric Allard, "Air Traffic Control Using Message Passing Neural Networks and Multi-Agent Reinforcement Learning," (*10th SESAR Innovation Days,* 2020), 6, https://www.sesarju.eu/sites/default/files/documents/sid/2020/papers/SIDs_2020_paper_26red.pdf.

ANN to automate three-dimensional air traffic management, concluding however that its "performance deteriorates when the traffic density increases."[26] While the technical and ethical limitations of ANN will likely prevent the full automation of airspace control, this capability could alleviate the cognitive load on controlling agencies and reduce the risks of fatigue and information overload which negatively impact the speed of airspace deconfliction. Instead of relying upon procedural control, this would facilitate "supervisory control" of airspace, only requiring human intervention in exceptional circumstances.[27] Using tactical data links, AI-generated ACMs could be relayed to aircrews as quickly as they are generated, further reducing task load on airspace managers. This is particularly important as the RCAF and CA rely on teams of specialized personnel who have historically been difficult to generate due to the resources require to be trained to international certification.

8. For such an ANN to provide useful ACM recommendations it would need to be trained on sufficient volumes of airspace, aircraft performance, and controller operations data. Numerous studies have developed analytical frameworks for assessing airspace complexity in ways that could assist in DST modeling of combat airspace. Hew's research into Close Air Support as a form of "distributed cognition" identified the relationship between JTAC, aircrew, and aircraft influence upon weapon trajectories, concluding that the ability to calculate such trajectories and rapidly develop and display appropriate airspace measures in real time would greatly improve the efficiency of airspace management.[28] Mao *et al.* developed a three-dimensional airspace modeling method for aircraft attacks against surface targets while taking wind, manoeuvres, and pilot error into account.[29] This data-driven airspace modeling method could be used to develop more accurate dynamic ACMs requiring smaller volumes of airspace. Lee, Feron, and Pritchett's research on ATC sought to model complex air traffic as a measure of disturbances in airspace patterns, where a "closed-loop controlled system" of airspace could be subjected to disturbances such as weather and increased traffic, measuring the degree of intervention required by a controller to prevent collisions.[30] This kind of complexity mapping has value in modeling tactical airspace, which is complicated not only by aircraft and weather, but also by munitions and friendly ground force locations. While there is still work to be done to tie these concepts together into a viable product, this research shows that the intellectual foundation currently exists for the tactical application of automated airspace management.

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[26] Joris Mollinga and Herke van Hoof, "An Autonomous Free Airspace En-route Controller using Deep Reinforcement Learning Techniques," (International Conference on Research in Air Transportation, 2020), 8, https://www.icrat.org/9th-international-conference/papers/.

[27] Hew, *Distributed Cognition…,* 14.

[28] Hew, *Distributed Cognition…,* 13.

[29] Mao, Houchen, Guhao Zhao, Wenming Gao, and Tianchi Sun. "Research and Simulation on Division Attack Airspace." *MATEC Web of Conferences* 114, (2017): 3015, https://www.proquest.com/docview/2039241893.

[30] Keumjin Lee, Eric Feron, and Amy Pritchett, "Describing Airspace Complexity: Airspace Response to Disturbances," *Journal of Guidance, Control, and Dynamics* 32, no. 1 (2009): 210-211, https://arc-aiaa-org.cfc.idm.oclc.org/doi/abs/10.2514/1.36308.

9. The development of an ANN airspace tool would provide the RCAF with an opportunity to lead airspace innovation in the CAF and contribute to its strategic objectives of interoperability and technological collaboration.[31] In a recent article in *RCAF Today*, LGen Meinzinger extolled the importance of innovation culture, describing the efforts being made to "build a digital backbone" for the RCAF to include technologies such as machine learning.[32] AI-enabled joint airspace management is the kind of technological innovation that would support the "systems of systems approach" required to promote interoperability through air power mastery.[33] The RCAF, as the steward of air power in the CAF, should invest in this project due to both its eminence in the air domain and the RCAF's interest in assuring safety of flight for aircraft in joint operations.[34] Improvements to joint airspace management systems would also contribute to the several Force Development concepts identified in the RCAF *Future Air Operating Concept,* including "[defining] requirements and initiate projects for distributed C2 applications and [DSTs] across all RCAF capabilities from tactical to operational."[35] The RCAF would not need to undertake this project alone as the CA sees AI as a tool which could help automate tactical decision-making and intends to undertake research into AI as part of its Priority Initiatives for Army modernization in cooperation with Defence Research and Development Canada.[36] The opportunities for civilian partnership are substantial as Canada's AI industry is considered to be global leader of AI development.[37]

CONCLUSION

10. The CAF must update its joint airspace deconfliction process for future battlespaces which will not be as permissive as those within which the CAF has previously operated. Dispersed land forces will be reliant upon air support for joint fires, resulting in complex airspace problems as aircraft and weapons systems rapidly converge to deliver effects during fleeting windows of opportunity. The increasing automation of information-sharing within the joint battlespace will require airspace solutions to be generated at the speed of machine processing. To achieve this, the RCAF should take advantage of Canada's position as a global leader in AI technology to capitalize on

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[31] Department of National Defence, *Air Force Vectors: Agile, Integrated, Reach, Power* (Ottawa: National Defence Headquarters, 2014), 37-38, https://publications.gc.ca/site/eng/9.697371/publication.html.

[32] Al Meinzinger, "Innovation, Always," *RCAF Today* 12, (2021): 8-10, https://issues.skiesmag.com/554/766/1704/RCAF-Today-2021/.

[33] Meinzinger describes the "systems of systems" approach as "… a focused effort to build a digital backbone for our platforms to ensure integration and compatibility within the Canadian Armed Forces, and with our Five Eyes and NATO partners." Meinzinger, "Innovation, Always," 10.

[34] The RCAF TACP TTPs describe Routing and Safety of Flight (RSOF) as "the single most important direction a TACP gives to aircrew." Department of National Defence, *Tactical Air Control Party TTPs,* 6-3.

[35] Department of National Defence, *Future Air Operating Concept…,* 26.

[36] Department of National Defence, *Advancing with Purpose: The Canadian Army Modernization Strategy,* 4th ed. (Ottawa: Canadian Army Headquarters, December 2020), 52, http://www.army-armee.forces.gc.ca/assets/ARMY_Internet/docs/en/national/2021-01-canadian-army-modernization-en.pdf.

[37] University of Toronto, "Canada's AI Ecosystem: Government Investment Propels Private Sector Growth" (Toronto: University of Toronto Government Relations Office), 4, https://research.utoronto.ca/media/541/download, Accessed 23 Jan 2022.

disruptive technologies which could revolutionize our joint airspace control systems. This paper suggests that a solution could be developed in partnership with the CA and Canadian industry to produce an ANN capable of automatically identifying the airspace deconfliction. Such a system would support the speed of airspace deconfliction required to rapidly converge joint fires in dispersed operations, and while reducing the cognitive load of airspace controllers during tactical engagements.

RECOMMENDATIONS

11. This paper recommends that the RCAF to nominate an ALI AI liaison to begin the process of identifying stakeholder requirements in joint airspace management. The RCAF Aerospace Warfare Centre (RAWC) could be a source for this liaison, as the RAWC hosts the RCAF Innovation Lab and is currently recruiting machine learning specialists.[38] Once a liaison is identified, an AI Working Group should be formed to include the Director Land Requirement's (DLR) JFM project, which is responsible for the digitization of the CAF joint fires capability but currently lacks RCAF participation.[39] Establishing a relationship between the relevant RAWC, JFM, and ALI Working Group members would connect the technical and professional joint fires experts in order to develop a business case for an AI airspace management tool. Subsequently, the AI Working Group could identify the requirements of a minimum viable product for AI airspace management, to include a data collection plan and future research requirements. This would be followed by assessment from DRDC for viability and cost-analysis, before being brought to industry for development.

[38] Artemis Canada, "Machine Learning Specialist – Royal Canadian Air Force (RCAF)," https://www.artemiscanada.com/machine-learning-rcaf, accessed 23 Jan 2022.

[39] Bryan Hunt and Leonard Wappler, "Record of Decisions: Air-Land Integration Steering Committee (ALI SC) 16 Jun 21," Canadian Forces Base Kingston: file 3185-1 (SO TACP), 19 July 2021, 7-8.

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