Canadian Certification of Autonomous Flight Systems Working Group (CCAFS WG): summary report FY19 through FY 22

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Canadian Certification of Autonomous Flight Systems Working Group (CCAFS WG) – Summary Report FY19 through FY22

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1.0 Introduction

1.1 Background

Over the last number of years Remotely Piloted Aircraft Systems (RPAS) operators, manufactures, regulators and researchers alike have been focusing attention on the development of Beyond Visual Line of Sight (BVLOS) operational capabilities. As the potential for true BVLOS operations comes more plausible and possible in Canada (and around the world) it is apparent that operators will look to gain further efficiencies and enhanced capabilities achievable through autonomous aircraft operations. Likewise there is growing interest in the adoption of increasing levels of automation in traditional aviation platforms as well as newly emerging advanced air mobility (AAM) platforms. Although technical and regulatory challenges remain, research, experimentation and development is already rapidly evolving to focus on autonomous operations of RPAS and Optionally Piloted Vehicles (OPV) in the coming BVLOS environment. In the area of certification, "autonomous[1]" aircraft operations present a complex challenge in a number of domains, to which traditional approaches applied to aircraft avionics are not well suited. Recent experience with the certification of rotorcraft fly-by-wire systems, amongst many other examples of advanced technology, have highlighted the need for regulators to better understand and anticipate the technical complexities of these rapidly evolving technologies.

The National Research Council of Canada (NRC) has commenced a large research project focusing on the development of a vertical lift advanced automation (autonomous flight system – AFS) demonstrator through collaborations with the Department of National Defence (DND), the Defence Research and Development Centre (DRDC), Transport Canada (TC), the Directorate of Technical Airworthiness and Engineering Support (DTAES), a major OEM, and a number of Canadian academic institutions and Small to Medium Enterprises (SMEs). The objective of this autonomy-focused project is to demonstrate advanced automation in vertical lift flight technologies, evaluate technology maturity levels, provide insight into concept development and operations of autonomous vehicles, and to create an Autonomous X-Aircraft capability to support on-going development of advanced automation in flight systems in Canada. The project, entitled the Canadian Vertical Lift Autonomy Demonstration (CVLAD)[2] also affords a unique opportunity to gain insight into regulatory considerations applicable to autonomous aircraft, beyond a simple literature survey but rather as part of the research and development of full-scale autonomous flight systems.

1.2 Motivation

Through discussions with staffs at the Transport Canada Civil Aviation RPAS Task Force (RPAS TF) and DND's DTAES, it was recognized that a shared, collaborative discussion with the researchers developing advanced automation flight technologies alongside the regulatory experts would be advantageous to prepare Canada's military and civilian aviation regulator and regulations for the coming autonomous aircraft. The Canadian Certification of Autonomous Flight Systems Working Group (CCAFS WG) was intended to be a forum to discuss

1 The term autonomy is not well defined in the aviation ecosystem. One of the research areas for the CCAFS WG was to establish a taxonomy to help address this issue. In this report the general term 'advanced automation' will be used, although for simplicity and brevity the term autonomy was utilized in early documentation as well as in the CCAFS WG title. When this report refers back to these documents the term 'autonomy' will be utilized but can be interpreted as 'advanced automation'.

2 Internally known as CVLAD (Canadian Vertical Lift Autonomy Demonstration); known as ATHOPeD (Autonomous Tactical Helicopter Operations in Persistent Degraded Environments to DRDC. This document will use the title of CVLAD for the project.

the priority challenges for the certification of advanced automation in flight systems, to steer research activities and to share collective understanding knowledge in the realm of the autonomous flight systems.

1.3 CCAFS WG Objectives and Scope

The objectives of the CCAFS WG were:

a. through consensus, to determine needs, to prioritise and steer research activities related to the certification of autonomous flight systems (thereby taking advantage of on-going autonomy research at the NRC); and

b. to provide an interdepartmental technical forum to share understanding and knowledge around the regulation of autonomous flight systems.

The scope of the CCAFS WG was limited to the regulation and certification of flight autonomy systems (including synthetic world generation and interpretation, path planning, human-machine teaming, and autonomous systems management). It was envisaged that the WG would steer and oversee research related activities completed by NRC but also participate in these activities. For example, the evaluation of means to address system safety of advanced automation may be an area of focused research-based effort, but would also involve direct participation of system-safety experts from TC and DTAES. The Terms of Reference (TOR) for the CCAFS WG are enclosed as Annex A.

The NRC maintained separate work agreements with TC and DTAES, which provided the governing context with respect to sharing of information, including intellectual property. The CCAFS WG did not possess executive or funding authority; all work undertaken by any party was approved in accordance with each parties' own internal processes.

2.0 CCAFS WG Strategy

2.1 Roadmap Development

At the outset of the initial discussions of scope and focus for the CCAFS WG it was recognized that the challenges in adjusting regulations to accommodate increasing levels of automation (i.e. 'autonomy') in flight systems would be a massive undertaking. It was generally accepted that given the diverse implications from certification to operating regulations, there would be a vast requirement for research and studies to help inform the regulator in the creation of new rules and that this would likely out strip the resources available. As the CCAFS WG concept was being formulated, each key member organization conducted an initial assessment of where research focus should be prioritized. These insights were then collated, debated and a preliminary Roadmap was developed. The intent of this Roadmap was that it would be a living document, guiding the focus of the WG discussions and tasks over the coming years.

The scope of this Summary Report did not permit a robust handling of the literature survey that was conducted by all members during the CCAFS WG Roadmap formation, however there were a several useful documents and other references that were noted to be particularly useful in the formulation of the CCAFS WG focus and roadmap. Specifically, the following documents were referenced:

a. *Autonomy Research for Civil Aviation: Toward a New Era of Flight* by the National Academy of Sciences' Research Council (reference A). This report provided a robust assessment of the barriers to increased use of "increasing autonomous systems", including: technical, certification and regulation, legal, and social. In each of these areas the report provided significant details of gaps or limitations in current approaches. The report then suggested eight different focus areas and provided a recommended prioritization for the context of the United States of America. These broad eight focus areas resonated with the CCAFS WG membership and were adopted as the organizing structure for the CCAFS WG. However, the work within these areas was further discussed and refined based upon criteria included in the following sections, to arrive at a Canadian relevant approach.

b. *Autonomous Technologies White Paper* from the North Atlantic Council (reference B). This North Atlantic Treaty Organization (NATO) focussed document provided a defence-related perspective on gaps and issues associated with autonomous systems (in all domains: air, sea and land). Although this White Paper was prepared at the high level, it provided linkages to a developing Autonomous Technologies Roadmap (document not publicly releasable), which helped inform the CCAFS WG Roadmap.

c. *NASA Strategic Thrust 6: Assured Autonomy for Aviation Transformation* (reference C). This document provided an overview of NASA' assessment of the research challenges at the time, for future adoption of autonomy. This high-level review provided some additional kernels for follow-on discussion for the CCAFS WG.

d. More Automated, Connected Aviation by 2050 (reference D).

Again, these few documents noted above are an example or sample of the information consulted by the CCAFS WG members. As the CCAFS WG members 'read-into' the challenges of adopting increasing levels of automation in flight systems a long list of considerations were prepared and discussed amongst the team. It was readily evident that the scope of potential tasks for WG action far outstripped the resources available to the WG members. Thus, these considerations and potential Roadmap activities were further discussed and the prioritized using the following considerations:

a. Areas for Potential Collaboration – Given the broad scope of potential activities, which exceeded available resources, a key consideration was to consider ways to enter into collaborations with like-minded organizations such as the FAA, NASA, EASA, etc. With such an approach there would be

areas defined where focus/effort from the CCAFS WG would be placed to work collaboratively with others as well as cases where on-going efforts by others could be leveraged in the Canadian context. One of the specific outcomes of this discussion was to add a specific effort to track relevant international collaborations within the CCAFS WG, to maximize the sharing of information between all parties' participation in external committees, working groups, etc.

b. Canadian unique perspective needed – Given the interest to leverage external and international collaborations as the CCAFS WG Roadmap was initially developed, the WG also noted that there would be cases where a Canadian unique perspective may be needed to balance externally developed information. Areas of potential WG focus, such a Trust in Automation, were noted to likely need Canadian unique study/data and thus such areas were raised in priority accordingly;

c. Expected 'Urgency' for Canadian Regulation modifications – The prioritization of the CCAFS WG focus areas also considered the timeline of expected needs of the Canadian regulators (military and civil). Thus areas of potential more urgent need were prioritized for earlier action and those of a less urgent but more strategic value were also prioritized accordingly.

d. Leverage the opportunity within on-going CVLAD research and development – Finally, the specific areas of AFS research and development was actively on-going at the NRC were considered and also influenced the prioritization of the CCAFS WG Roadmap. In other words, WG areas of interest that mapped into the on-going research and development activities associated with CVLAD were generally increased in priority.

Through the deliberations of the CCAFS WG members and leveraging the definitions created within reference A, the following nine priority research areas were identified with an associated and limited focus (these areas are further defined in the report sections below). It should be noted that the CCAFS WG Roadmap was intended to be 'living document' such that the priorities and activities would be adjusted year-to-year based upon resource availability, on-going collaborations, and the results of previous or lead-in work.

a. Scoping – This general area of activity was identified to 'hold' the overall management activity for the CCAFS WG. Additionally the Scoping activity included the conduct of a Gap Analysis as well as place held external and international collaborative activities;

b. Behaviour of Adaptive/Non-Deterministic Systems – This research area included consideration of an appropriate taxonomy for increasing levels of automation, the development of performance criteria for assessing behaviour of such systems and exploring the human role in limiting such behaviour;

c. Operation without Continuous Human Oversight – This research area was focused upon understanding human supervision of autonomy;

d. Modelling and Simulation – This research area had a specific focus of understanding the use of simulation to train machine learning algorithms;

e. Verification, Validation and Certification (VV&C) – This research area focused on developing flight test techniques applicable for the assessment of AFSs;

f. Non-Traditional Methods & Technologies – This research area was primarily scoped to investigate system safety approaches for AFSs;

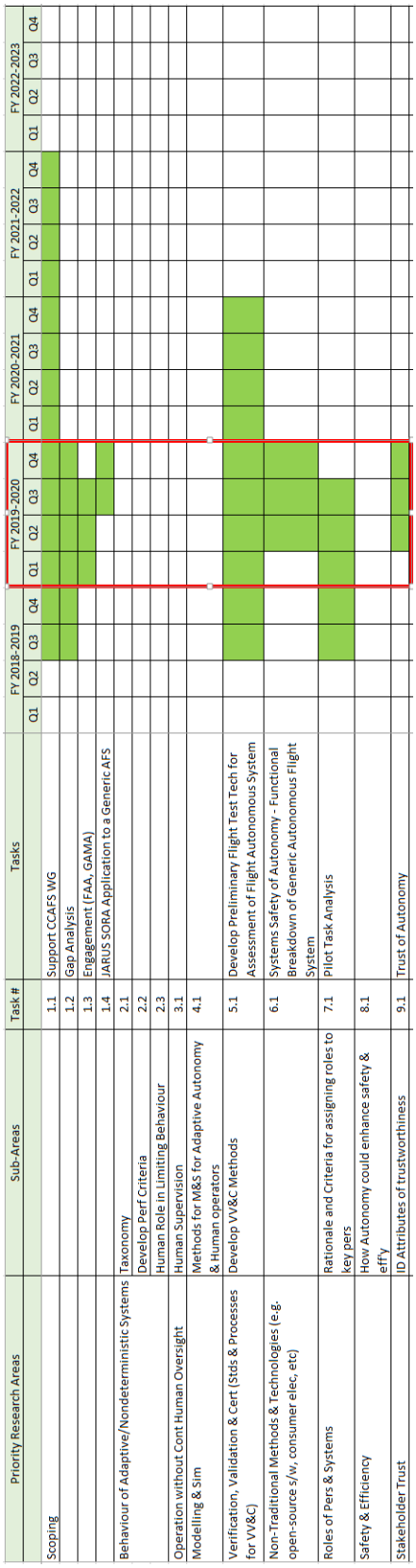
g. Roles of Personnel & Systems – This very broad area of potential research was scoped to better understanding the rational and criteria behind the assignment of roles to personnel and the autonomous agent as part of the implementation of an AFS;

h. Safety & Efficiency – The focus of this activity was to understand how the application of increased automation could enhance safety and efficiency; and

i. Stakeholder Trust – The main focus of this research area was to understand the attributes of trustworthiness in an AFS.

2.2 Roadmap and CCAFS WG Priority Research Areas

The inaugural CCAFS WG Roadmap is presented in Figure 1 with the updated views of the Roadmaps provided at Figure 2 and Figure 3 for fiscal year (FY) 21 and 22, respectively. As can be seen, the content and focus of each priority research area has been adjusted year-to-year based upon the previous year's work, CCAFS WG members' needs, and resource availability. It should be noted that while the Roadmap in the images below indicate a date out to FY23, there are on-going discussions for WG efforts that may go beyond this horizon. Future reports will capture this aspect. Within each of the figures below, the research areas are broken down into sub areas and tasks, with a unique identifier assigned to each task, to help referencing of the associated discussions and documents amongst team members and also within this report.



Priority Research Areas	Sub-Areas	Task #	Tasks	FY 2018-2019				FY 2019-2020				FY 2020-2021				FY 2021-2022				FY 2022-2023			
				Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Scoping		1.1	Support CCAFS WG																				
		1.2	Gap Analysis																				
		1.3	Engagement (FAA, GAMA)																				
		1.4	JARUS SORA Application to a Generic AFS																				
Behaviour of Adaptive/Nondeterministic Systems	Taxonomy	2.1																					
	Develop Perf Criteria	2.2																					
	Human Role in Limiting Behaviour	2.3																					
Operation without Cont Human Oversight	Human Supervision	3.1																					
Modelling & Sim	Methods for M&S for Adaptive Autonomy & Human operators	4.1																					
Verification, Validation & Cert (Stds & Processes for VV&C)	Develop VV&C Methods	5.1	Develop Preliminary Flight Test Tech for Assessment of Flight Autonomous System																				
Non-Traditional Methods & Technologies (e.g. open-source s/w, consumer elec, etc)		6.1	Systems Safety of Autonomy - Functional Breakdown of Generic Autonomous Flight System																				
Roles of Pers & Systems	Rationale and Criteria for assigning roles to key pers	7.1	Pilot Task Analysis																				
Safety & Efficiency	How Autonomy could enhance safety & effy	8.1																					
Stakeholder Trust	ID Attributes of trustworthiness	9.1	Trust of Autonomy																				

Figure 1 - CCAFS WG Roadmap for FY20

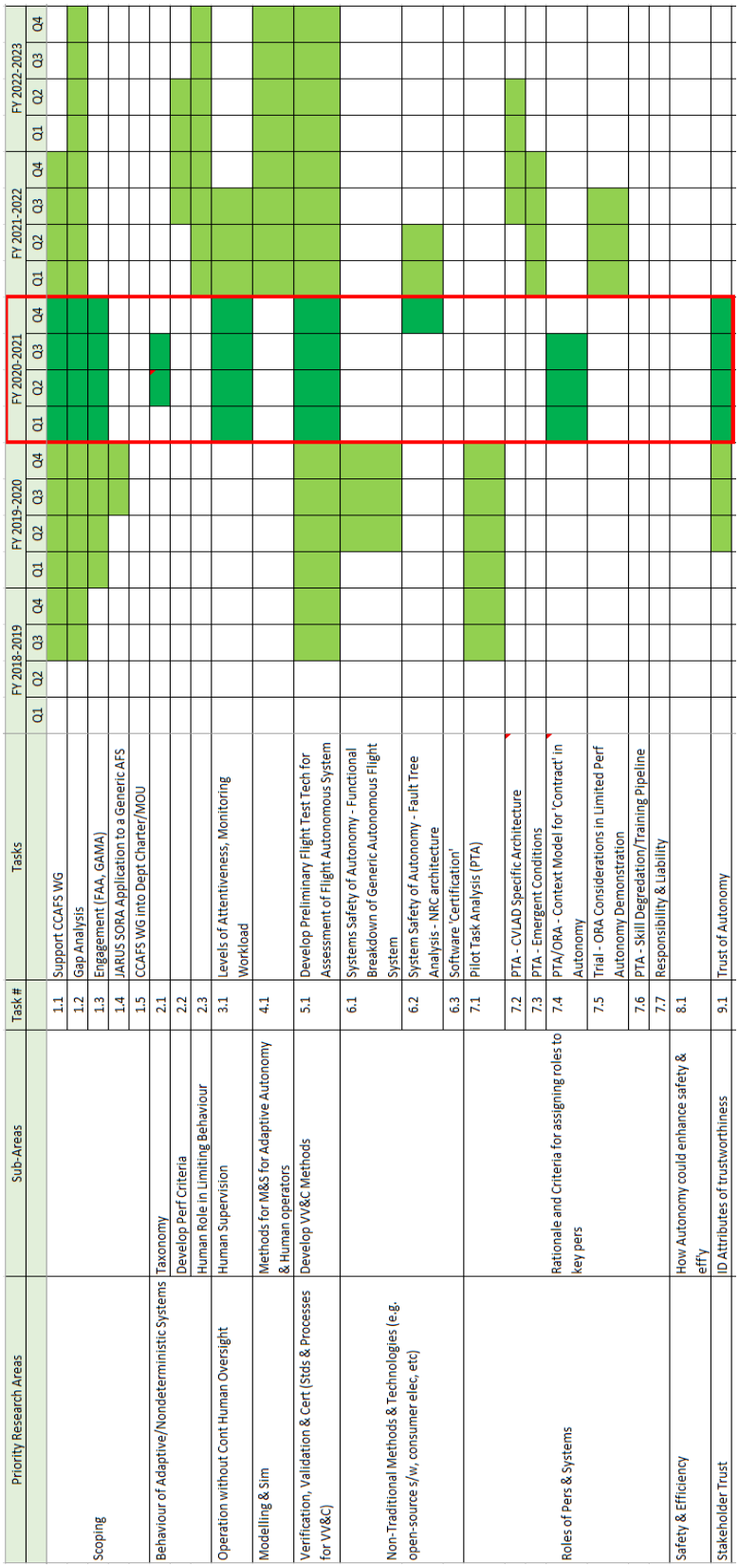


Figure 2 - CCAFS WG Roadmap for FY21

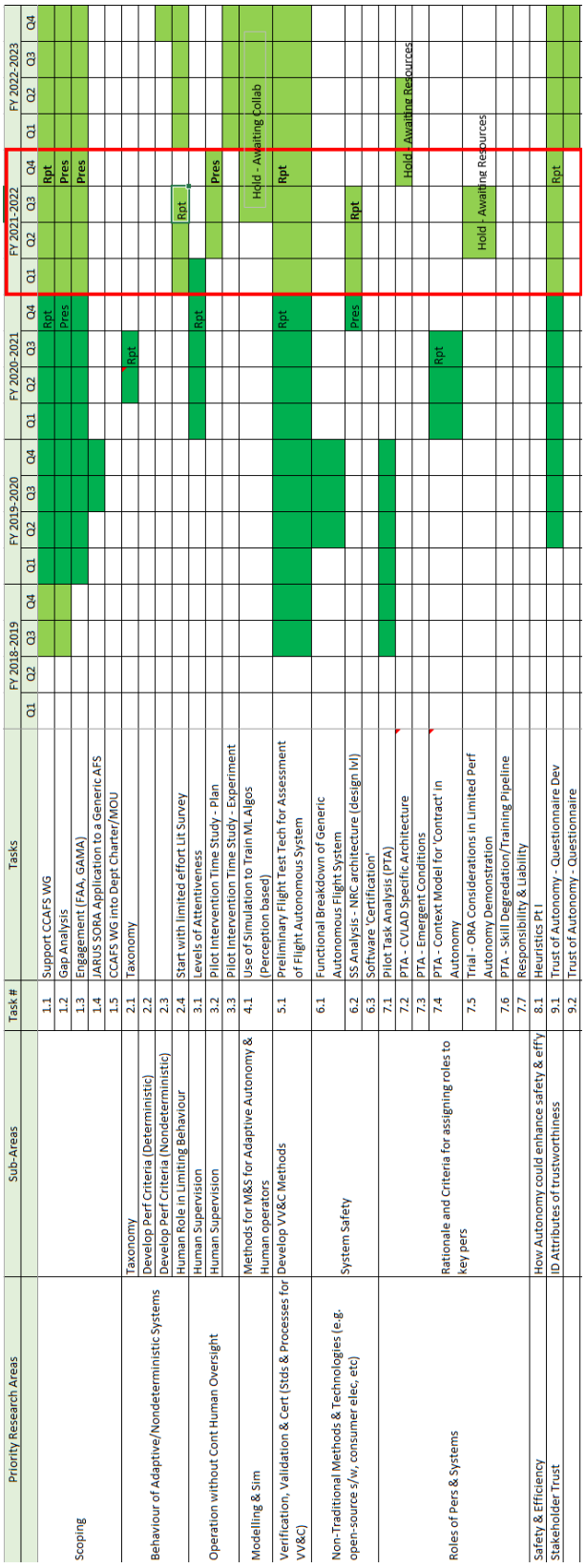


Figure 3 - CCAFS WG Roadmap for FY22

3.0 CCAFS WG Priority Research Areas

In general, the CCAFS WG was executed through the conduct of tasks, which were presented and discussed throughout the work year. The following sub-sections provide an overview of the scope of each task within the identified research areas, broken out by FY where appropriate. As reflected in the Roadmaps above, not all research areas had tasks identified in each fiscal year. The subsections below reflect this fact accordingly.

The CCAFS WG met a number of times each year to address the identified tasks that were active in that year. Each meeting typically focussed on a small number of or a single technical topic. This approach allowed for on-going, concurrent development of the specific research area and associated tasks. Annex B provides a listing of WG tasks cross referenced to discussion/meeting dates as well as the associated documents (presentations from meetings or deliverable reports to the CCAFS WG). Finally, Annex B provides a cross-reference to the public releasability of each document enclosed within this report. Publicly releasable reports will be published individually.

3.1 Scoping (Research Area 1)

This research area was intended to capture the overall management and coordination activities within the CCAFS WG. The research area also captured several on-going tasks which supported the overall CCAFS WG activity.

a. Task 1.1 – Support CCAFS WG. In FY19 this task started with the initiation of the CCAFS WG including the establishment of a TOR and the identification of the necessary skillsets of the WG membership. The subsequent FYs, this task directed the co-execution and co-management of the CCAFS WG in accordance with the TORs including the prioritization of research activities and the coordination of the WG as a forum to discuss the specific tasks thereby raising the technical insight of TC and DTAES specialists and operations staff (as available).

b. Task 1.2 – Gap Analysis. Starting in FY19, this task created a ‘living document’ listing of potential gaps within the airworthiness regulations, as it applies to the adoption of autonomous flight technologies. The task commenced with a preliminary review AWM 529 (based upon the test aircraft to be used for CVLAD) and associated Advisory Material to identify areas where autonomous systems may present a certification challenge, which could otherwise require Special conditions of Airworthiness, Equivalent Safety Finding (ESF) or exemption, etc. (i.e. identify the gaps). The task continued each year to further track/refine the identified gaps and to serve as a placeholder for observations and findings coming out of other task areas, as appropriate.

c. Task 1.3 – Engagement. This task directed the NRC and the WG to engage with international authorities and researchers to evaluate the potential for collaboration in support of the CCAFS WG Roadmap. The outcome of such engagements were reported to the CCAFS WG, the presentations of which included a matrix representation of WG member’s involvement in international committees and working groups.

In addition to these multi-year tasks, this research area included a single one-year focus task, Task 1.4 which directed the NRC to conduct an analysis of the application of the JARUS Specific Operations Risk Assessment (SORA) to a sample autonomy mission relevant within CVLAD.

In FY23 it is expected that the three on-going tasks identified above will continue. While the approach of have many, short meetings (focusing on a single topic) will continue it is recommended that a semi-annual summary meeting be conducted to allow for strategic prioritization of work and to confirm suitability of the forward looking roadmap.

3.2 Behaviour of Adaptive/Nondeterministic Systems (Research Area 2)

Broadly this research area was intended to focus on developing methods to characterize and bound the behaviour of adaptive/non-deterministic systems over their life cycle. This very broad activity was focused on four tasks (Figure 3), two of which have been initiated within the CCAFS WG. The goal is to generally building an understanding around performance criteria for analysis and synthesis of adaptive/non-deterministic systems.

a. Task 2.1 – Taxonomy of Autonomy (FY21) – The concept of levels of autonomy had been discussed as the CCAFS WG was created and were instrumental in development work conducted with JARUS, based upon TC's invitation for NRC support to that group (Task 1.3). The Pilot Task Analysis (Task 7.1) completed in FY20 provided further consideration of the levels of autonomy. This task captured the latest thoughts of the CCAFS WG as a report for use in collaborative discussions by the CCAFS WG and with external stakeholders.

b. Task 2.4 – Human Role in Limiting Behaviour of Adaptive/Non-deterministic Systems (FY22) – The Figure 3 Roadmap identified an interest in better understanding the role human's play in limiting the behaviour of advanced automation, which leverages adaptive/non-deterministic systems. This activity initiated a limited scope literature survey to understand the extent of existing research in this area. The literature survey will conclude with a summary report in FY23, which identifies any findings that directly relate to potential regulatory gaps as well as considerations that guide future workload and or human interface research under the auspices of the CCAFS WG. It was not expected that the limited scope literature survey would provide specific guidance on changes to regulations or suggest a specific approach to human supervision of autonomy. Rather this work would enable the extension of the current human-machine teaming discussions within the CCAFS WG into non-deterministic domain.

In addition to the completion of the work noted in sub-paragraph (b) above, it is expected that in the coming years the CCAFS WG will focus effort on the development of performance criteria for both deterministic and non-deterministic systems. It is expected that this activity will be closely linked to the Verification, Validation and Certification research area and that this effort will be prioritized to consider applications most likely to be introduced first within civil and military aviation operations. Further, as an outcome of Task 2.4, in FY23 it will be proposed to the WG that research effort be initiated to study the Canadian-focused regulatory considerations of approving adaptive/non-deterministic systems using approaches that include a machine analogy to a pilot 'check-ride'. Such research could potentially be included in Research Area 7.

3.3 Operation Without Continuous Human Oversight (Research Area 3)

Broadly this research area was focused on the evolving paradigm of human supervision of advanced automation as well as human-machine teaming. Areas of interest to the CCAFS WG included human roles, including temporal and workload requirements, for a supervisor of an autonomous system.

a. Task 3.1 – Levels of Attentiveness (FY21) – Following on from the initial Pilot Task Analysis (Task 7.1) completed in FY20, this task initiated research into the concept of levels of attentiveness for a pilot supervising autonomy. This research used the tasks identified in the Pilot Task Analysis as a basis, and drew upon a survey of existing research. The goal of this concept development was to define a construct or model of the spectrum of attentiveness that a pilot supervising autonomy may require as well as the consideration of a framework to describe the transitions required to change from one level of attentiveness to another.

b. Task 3.2 – Pilot Intervention Time Study (FY22) – Following on from the recommendations from the Levels of Attentiveness report (Task 3.1 in FY21), this activity developed an experiment plan to validate the use of reaction times to provide certification insight for an autonomous flight system in

scenarios that require pilot intervention. The study plan was established to examine the variability of reaction time from pilot to pilot and determine the most appropriate value to use as a requirement. The experimental approach proposed under this task leveraged the simulation and flight test capabilities developed under the CVLAD project.

In FY23, it is expected that the first phase of the Pilot Intervention Time Study will be initiated, including simulation based measurement of reaction times for the supervision of an autonomous landing-type task. This research is intended to continue into FY24 with flight and simulation based testing.

3.4 Modelling & Simulation (Research Area 4)

The CCAFS WG had expressed interest in investigating the regulatory implications for advanced automation that included learning algorithms (i.e. Artificial Intelligence, though this is a poorly defined term). A specific task was identified in the Figure 3 Roadmap to evaluate the use of simulation in the training of machine learning algorithms. However, resource limitations have preclude the completion of that task as planned. It is expected that in FY23, the CCAFS WG will host one or more workshops on this topic to raise the overall WG's understanding in this area and that in the following FYs additional research activities will be established based upon the outcome of the workshops.

3.5 Verification, Validation & Certification, Standards and Processes (Research Area 5)

This research area is broadly focused on the building of knowledge to support the establishment of standards and processes to understand the implications of, and approve, the use of advanced automation in flight systems. It is expected that regulators will need to develop new approaches and tools to approve the use of advanced automation and thus this research area is intended to help develop recommendations for such approaches and tools, as well.

Given that a main research objective of the CVLAD project is to develop test methods and techniques for assessing the performance and behaviour of AFSs, the CCAFS WG established an on-going task (Task 5.1) to develop and evaluation of a set of test techniques designed to enable the assessment of autonomous flight systems. It was envisaged that these techniques would evolve, be refined and developed over several years, in phases with the development of the NRC autonomous flight system itself. Through FYs 19 through 22 this task included the development of test plans and reports in synch with the developments of the CVLAD architectures. Additionally, in FY 22 a summary report (included within a flight test report) was created to describe the NRC's approach to an 'autonomy envelope' and the heuristics within which the NRC identified the acceptable limits of autonomy performance for the CVLAD AFS.

It is expected that this task will continue into FY23 and beyond. Further, investigation of the concept of autonomy heuristics will be continued under Task 8.1 in future FYs.

3.6 Non-Traditional Methods & Technologies, Enabling Adoption (Research Area 6)

The full scope of enabling the adoption of non-traditional methods and technologies was found to be quite broad and in excess of the resource capacity of the CCAFS WG membership. Additionally aspects of this research area, such as enabling the adoption of open-source software and consumer grade electronics was being addressed elsewhere within the regulatory members of the WG. Therefore the CCAFS WG elected to focus on systems safety within this research area, with several linked tasks executed from FY20 through to FY22.

a. Task 6.1 - System Safety for Autonomy (FY20) – The need to evolve or adapt traditional systems safety techniques was considered as part of the development of the CVLAD AFS. As a first step, this task supported the development of a functional breakdown for a generic autonomous flight system based upon the concept behind NRC's autonomous flight system research.

b. Task 6.2 – System Safety for Autonomy (FY21, FY22) – In FY20 a generic functional breakdown for a systems safety analysis was completed. In FY21 and continuing into FY22, this breakdown was applied to the intended NRC Build III autonomy architecture. This task will also include a summary assessment of the potential benefits and challenges of applying the systems Theoretical Process Analysis (STPA) approach as a parallel system safety assessment technique.

In FY23 it is expected that the CCAFS WG will seek to further investigation of the application of STPA to advanced automation of flight systems. This may include the contracting of a STPA course, tuned for CCAFS WG membership, to be delivered by researchers at the Massachusetts Institute of Technology.

3.7 Roles of Personnel and Systems (Research Area 7)

The roles of personnel and systems as a research area was a topic of foundational interest to the CCAFS WG and was the area of research that originally spawned the interest of the membership to form the WG in FY19. Again, this broad area of research internet was considered to be substantially greater that the resources of the WG could manage. Specific, Canadian relevant areas of interest were identified as the CCAFS WG was established and included the study of pilot task allocation and workload in the supervision of advanced automation as well as consideration of skill degradation within the established pilot training 'pipeline'.

a. Task 7.1 – Pilot Task Analysis (FY19 and FY20) - A task-based analysis of piloting functions was be performed, which led to an assessment of which tasks could be incorporated into autonomous functions based upon an initial definition of autonomy. The analysis evaluated the baseline tasks (two pilots) and the tasks breakdown for a supervised-autonomy based flight system. The potential for this analysis to predict the associated workload changes was also be investigated (i.e. to verify if the simulation capability of the analytical tool IPME was adequate to provide workload predictions).

b. Task 7.2 - Context Model for the Pilot 'Contract' in Autonomy (FY21) - The Pilot Task Analysis completed in FY20 included the identification of a new concept, that of a pilot-autonomous agent 'contract'. This concept was further refined to develop a construct or model for discussion within the CCAFS WG. The development included the consideration of normal operations as well as emergent conditions and aircraft emergencies and how these would be treated within the 'contract' concept. The development also considered risk as a factor within the contract in addition to the constraints of position and time.

With the on-going development of the CVLAD AFS, it is planned to extend the Pilot Task Analysis (Task 7.1) into the CVLAD specific architecture in FY23 (Task 7.2). Additionally, if resources permit in FY23 a flight trial could be conducted to evaluate the operational risk assessment considerations associated with limited performance advanced automation such as is presently functioning in the CVLAD Build I AFS (Task 7.5).

3.8 Safety and Efficiency (Research Area 8)

To date the CCAFS WG has not allocated resources to address potential tasks within the safety and efficiency research area, which primarily focused on 'how autonomy could enhance aviation safety and efficiency'. A new task (Task 8.1) was identified within the VV&C research area, which focuses on further understanding the potential benefits of establishing an autonomy fight envelope. This task could be initiated in FY23, pending resource approval of the WG membership.

3.9 Stakeholder Trust (Research Area 9)

This research area was selected to support the generation of knowledge to assess and further develop stakeholder trust in advanced automation applications in aviation. Within the CCAFS WG this effort was initially focused on the trust of pilots in advanced automation. A separate, parallel research activity, measuring public trust of autonomy and autonomous aircraft was underway at the NRC, with results being reported to the CCAFS WG.

a. Task 9.1 – Trust of Autonomy (FY20 to FY22) – The goal of this task was to develop a tool with which trust in autonomy could be evaluated for a variety of stakeholders. The initial scope and framework of the study was presented to the CCAFS WG, following which the WG directed a pilot-trust oriented focus. Subsequently a tool was developed an exercised with pilots conducting autonomous flights as part of the CVLAD Build I open-loop flight tests.

In FY23 it is expected that the developed tool will be further exercised and refined in parallel with CVLAD Build I closed-loop flight tests and demonstrations (including a wider pilot survey group, which may be available through demonstration flight tests). This work has been identified as Task 9.2.

4.0 Summary and Results

The objectives of the CCAFS WG were to determine needs, to prioritise and steer research activities related to the certification of autonomous flight systems (thereby taking advantage of on-going autonomy research at the NRC) as well as to provide an interdepartmental technical forum to share understanding and knowledge around the regulation of autonomous flight systems. This summary report provided an overview of these activities as well as curated all the associated presentation/discussion material and reports overseen by the CCAFS WG from FY19 through to FY22. The summary report also highlighted expected activities for FY23, resource approval pending. It is expected that with FY23 research activities, the next several years of CCAFS WG Roadmap will also be ratified. The work completed and FY23+ roadmap will be reported in a Summary Report for FY23.

5.0 References

A - National Research Council, “Autonomy Research for Civil Aviation: Toward a New Era of Flight”,; Washington, D.C., The National Academies Press, 2014.

B – North Atlantic Council Deputies Committee, “Autonomous Technologies White Paper”; DPRC-N (2020)0070, 20 September 2020.

C – Balin, M., “ARMD Strategic Thrust 6: Assured Autonomy for Aviation Transformation”, National Aviation and Space Administration, 24 May 2016.

D – Academie de L’Air et de L’Espace, “Les Dossiers: More Automated, Connected Aviation by 2050”, AAE Dossier #42, 2018.

Annex A - CCAFS WG Terms of Reference

CANADIAN CERTIFICATION OF AUTONOMOUS FLIGHT SYSTEMS (CCAFS) WORKING GROUP

TERMS OF REFERENCE

Version 3, 25 March 2019

1.0 BACKGROUND

Over the last number of years Unmanned Aircraft Systems (UAS) operators, manufactures, regulators and researchers alike have been focusing attention on the development of Beyond Visual Line of Sight (BVLOS) operational capabilities. As the potential for true BVLOS operations comes more plausible and possible in Canada (and around the world) it is apparent that operators will look to gain further efficiencies and enhanced capabilities achievable through autonomous aircraft operations. Although technical and regulatory challenges remain, research, experimentation and development is already rapidly evolving to focus on autonomous operations of UAS and Optionally Piloted Vehicles (OPV) in the coming BVLOS environment. In the area of certification, autonomous aircraft operations present a complex challenge in a number of domains, to which traditional approaches applied to aircraft avionics are not be well suited. Recent experience with the certification of fly-by wire systems, amongst many other examples of advanced technology, have highlighted the need for regulators to better understand and anticipate the technical complexities of these rapidly evolving technologies.

The NRC has commenced a large research project[1] focusing on the development of a vertical lift autonomy demonstrator through collaborations with DND, a major OEM, and a number of Canadian academic institutions and Small to Medium Enterprises (SMEs). The objective of this autonomy-focused project is to demonstrate autonomous vertical lift flight technologies, evaluate technology maturity levels, provide insight into concept development and operations of autonomous vehicles, and to create an Autonomous X-Aircraft capability to support on-going development of autonomy in Canada. The autonomy demonstration project also affords a unique opportunity to gain insight into the certification considerations applicable to autonomous aircraft, beyond a simple literature survey but rather as part of the research and development of full-scale autonomous flight systems.

2.0 MOTIVATION

Through discussions with staffs at the Transport Canada Civil Aviation RPAS Task Force (TC) and DND's Directorate of Technical Airworthiness and Engineering Services (DTAES), it was recognized that a shared, collaborative discussion with the researchers developing autonomous technologies alongside the regulatory experts would be advantageous to prepare Canada's

[1] Internally known as CVLAD (Canadian Vertical Lift Autonomy Demonstration); known as ATHOPeD (Autonomous Tactical Helicopter Operations in Persistent Degraded Environments to DRDC. This document will use the title of CVLAD for the project.

military and civilian aviation regulator and regulations for the coming autonomous aircraft. This working group (WG) is intended to be a forum to discuss the priority challenges for the certification of autonomy, to steer research activities and to share collective understanding knowledge in the realm of the autonomous flight systems.

3.0 OBJECTIVES, SCOPE and DELIVERABLES

The objectives of the Canadian Certification of Autonomous Flight Systems (CCAFS) Working Group are:

a. through consensus, to determine needs, to prioritise and steer research activities related to the certification of autonomous flight systems (thereby taking advantage of on-going autonomy research at NRC); and

b. to provide an interdepartmental technical forum to share understanding and knowledge around the regulation of autonomous flight systems.

The scope of the CCAFS WG is limited to the regulation and certification of flight autonomy systems (including synthetic world generation and interpretation, path planning, human-machine teaming, and autonomous systems management). It is envisaged that the WG will steer and oversee research related activities completed by NRC but also participate in these activities to an extent. For example, the evaluation of means to address system safety of autonomous may be an area of focused research-based effort, but will also involve direct participation of system-safety experts from TC and DTAES.

The NRC will maintain separate work agreements with TC and DTAES, which will provide the governing context with respect to sharing of information, including intellectual property. The Working Group does not possess executive or funding authority; all work undertaken by any party must be properly approved in accordance with each parties' own internal processes.

The CCAFS deliverables are expected to be copies of presentations made to the CCAFS membership and minutes of meetings. Minutes will be prepared by the NRC participants (as part of separate work tasks approved by TC and DTAES). Any additional deliverables will be agreed upon as part of the CCAFS work.

4.0 ORGANIZATION

4.1 Leadership

The CCAFS WG be led by three Co-Chairs, one each representing TC, DTAES and NRC. Each organization will identify/approve their own co-chair. At the inaugural CCAFS WG, the following Co-Chairs were identified (these assignments may be adjusted at each organization's discretion):

a. DTAES; Yann Moffet, DTAES 6;
b. RPAS TF: Enzo Diodati; and

c. NRC: Derek (Duff) Gowanlock

Secretarial duties will be handled by NRC staff, including preparation and distribution of meeting agendas and minutes (in accordance with the Co-Chairs).

4.2 Duties of the Co-Chairs

The Co-Chairs will:

a. moderate meetings, approve minutes;

b. steer the focus of the CCAFS WG;

c. serve as arbiters for CCAFS WG decisions, if needed; and

d. coordinate activities of specialists, as required.

5.0 MEETINGS

The CCAFS WG will nominally meet four times per year, or as requested by the Co-Chairs.

6.0 MEMBERSHIP

The CCAFS WG membership will contain an equitable balance of representation across the participant organizations. It is expected that technical specialists from DTAES and TC will be requested to participate. These requests will be managed by each co-chair in their internal organization. Specific experiential and competency requirements of the membership will be determined by the WG (i.e. determination of skillsets that should be represented on the WG will be determined by the WG membership).

Membership of the CCAFS WG will be limited to members of DTAES, TC and NRC (including contractors to these organizations). External personnel may be permitted, with consensus approval of the co-chairs, to attend meetings and present information, but these personnel will not form part of the WG.

At the time of writing, liaison responsibilities with other governmental working groups (e.g. DronExchange) have not been defined.

7.0 GOVERNANCE AND CHARTER

This TOR may be amended by the consensus agreement by the Co-Chairs.

Annex B - CCAFS WG Summary of Meetings and Deliverables

Working Group #	Meeting Date	Task Number	Topic of Discussion	Publicly Releasable (see Note 1)
0	13 Mar 19	1.1	Kick-off Meeting, Terms of Reference	Y
		1.2	Gap Analysis (See Note 2)	
		2.1	Taxonomy (Intro)	N - Work in Progress
		5.1	Pilot Task Analysis (Intro)	N - Work in Progress
1	25 Apr 19	1.1	Kick-off Meeting, Terms of Reference Discussions	Y
		1.1	RPAS TF Intro	N (Releasability with TC)
		2.1	Taxonomy Discussion	N - Work in Progress
		5.1	Pilot Task Analysis Update	N - Work in Progress
		1.2	Gap Analysis Intro	N - Work in Progress
-	25 Jun 19	1.3	Artificial Intelligence Automation and Autonomy in Aviation Briefing from FAA (Kathie Abbott)	N (FAA Material)
-	3 Jul 19	6.1	System Safety Kick-off Discussion Presentation by Jim Marko, TC	N (TC Material)
2	18 Jul 19	1.1	Terms of Reference and Roadmapping Discussion	Y
		9.1	Trust in Autonomy Questionnaire Intro	N - Work in Progress
-	6 Sep 19	6.1	System Safety Discussion	N - Work in Progress
-	16 Sep 19	1.3	JARUS WG Engagement	Y
-	23 Sep 19	1.1	Roadmapping Discussion	Y
3	4 Nov 19	1.1	Task & Roadmap Review	Y
		1.3	ASTM Pillars of Autonomy – Engagement Update	N (ASTM Material)
		7.1	Pilot Task Analysis Status Update	N - Work in Progress
		6.1	System Safety Analysis Update	N - Work in Progress
		5.1	VV&C – Initial Concepts	N - Work in Progress
4	24 Feb 20	7.1	Pilot Task Analysis Update	N - Work in Progress
5A	31 Mar 20	6.1	System Safety Discussion	N - Work in Progress
5B	16 Apr 20	9.1	Trust In Autonomy Discussion	N - Work in Progress
5C	17 Apr 20	1.4	ORA Analysis	Y
		1.2	Gap Analysis Presentation Deliverable	Y
		7.1	Pilot Task Analysis Report	Y
		5.1	VV&C – Captive Carriage Flight Test Plan (Note: This Test Plan was updated in FY21, this updated version included herein)	N (IP Embedded)
		9.1	Trust In Autonomy Report and Presentation	Y
-	17 Jun 20	1.3	NASA Engagement on Autonomy Research in Support of FAA	
-	24 Aug 20	6.2	System Safety Scope Discussion	
6A	19 Jan 21	1.1/1.3	Task & Roadmap Review; External Collaboration Summary	Y

		2.1	Taxonomy	N - Work in Progress
		1.3/6.2	UL4600 Standards for Safety	N (DTAES Release Authority)
6B	21 Jan 21	7.4	Pilot-Autonomy Contract Presentation	N - Work in Progress
		9.1	Public Trust in Autonomy Presentation	N - Work in Progress
		5.1	CVLAD/ATHOPeD Development Update	N (IP Embedded)
7A	24 Mar 21	5.1	Flight Test of Autonomy	N (IP Embedded)
		1.2	Gap Analysis Update	N - Work in Progress
7B	25 Mar 21	3.1	Levels of Attentiveness Update & Discussion	N - Work in Progress
		9.1	Trust in Autonomy Update	N - Work in Progress
		6.2	System Safety Update & Discussion	N - Work in Progress
		5.1	VV&C – Open-Loop Flight Test Plan	N (IP Embedded)
		7.4	Pilot-Autonomy Contract Report	Y
		2.1	Taxonomy Report	Y
8	21 Apr 21	3.1	Levels of Attention	N - Work in Progress
-	28 Oct 21	3.1/3.2	Levels of Attention Update	N - Work in Progress
9	2 Nov 21	5.1	Flight Test of Autonomy	N (IP Embedded)
10	16 Dec 21	6.2	System Safety	N - Work in Progress
-	17 Jan 22	6.2	System Safety	N - Work in Progress
11	24 Feb 22	3.2	Pilot Intervention Time Study	N - Work in Progress
12	XX Mar 22	2.4	Status of Research – Human Role in Limiting Non-Deterministic Behaviour Presentation	N - Work in Progress
13	XX Mar 22	9.1	Trust in Autonomy	N - Work in Progress
-		1.2	Gap Analysis – Latest Summary Listing	N - Work in Progress
-		3.1	Levels of Attention Report	Y
-		6.2	System Safety Report – FHA Study of NRC architecture	Y
-		5.1	VV&C – Closed-Loop Flight Test Plan	N (IP Embedded)
-		5.2	VV&C – NRC Build I AFS Flight Test Report	N (IP Embedded)
-		9.1	Trust in Autonomy Report	Y

Notes: 1. Releasability identified is from the NRC perspective. Documents generated by NRC that are approved for public release are identified as "Y". Otherwise a "N" is indicated along with a brief description.

2. The Gap Analysis was a work in progress that was incrementally over several years of work.

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