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### Transport Canada RPAS R&D yearly progress report (2021-2022)

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## National Research Council Canada

# Transport Canada RPAS R&D Yearly Progress Report (2021-2022)

LTR-SMM-2021-0194



### Presented to:

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Date: February 3<sup>rd</sup> 2022

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## Record of Changes

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## Introduction and Objectives

This document provides a high-level overview of the R&D activities that were performed by NRC during Fiscal Year 2021-2022 as part of NRC Integrated Aerial Mobility (IAM) Program and Transport Canada RPAS Task Force R&D collaboration. Hyperlinks to the detailed scientific reports are provided in this high-level report. A brief overview of the regulatory research activities history, as of October 2021, is also presented in appendix 2.

It should be noted that the research activities described in this document are performed under the IAM Program, as one of its objectives, is to **“Provide knowledge-based support to Transport Canada to enable sustained and advanced RPAS operations of RPAS in Canadian airspace”**. The IAM program also has for objective, to develop niche technologies, as well as stimulate a stronger Canadian RPAS industry. A brief overview of the IAM program is presented at appendix 3.

## Research Areas and Project Overview

### Fiscal year 2021-2022 research focus

- 1- Air to Air collision severity
- 2- Air to Air collision probability
- 3- Air to Ground (People) collision probability and severity
- 4- Detect and Avoid
- 5- RPAS Traffic Management (RTM)
- 6- Icing
- 7- Urban Flows
- 8- Certification of Autonomous Systems

The following image shows the correlation between IAM regulation related research areas and TC’s R&D plan.

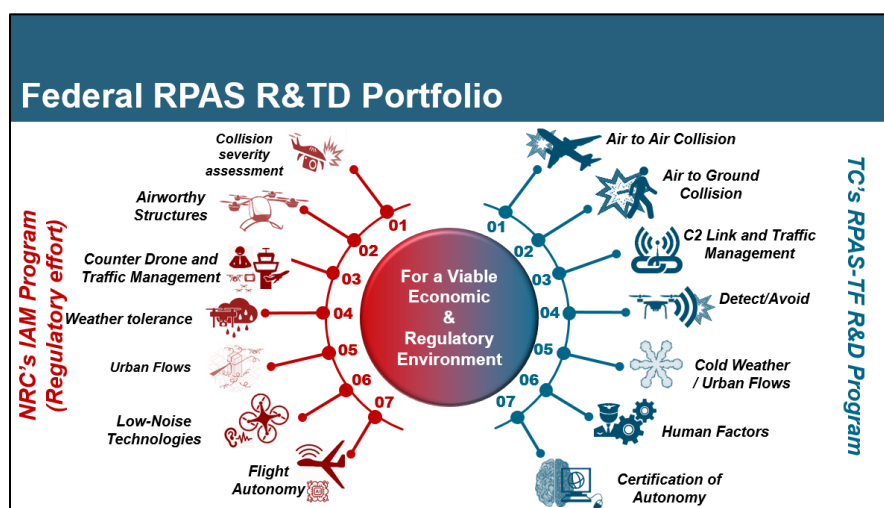


Figure 1 IAM and TC research focus

The following table presents work/milestones achieved, future research and the research projects' regulatory impact. More detailed information on the projects is provided in the subsequent sections of this report.

Research Supporting Regulation Project list					
Research area	#	Projects	Work / Milestones achieved in FY2021-2022	Next Steps	Potential Impact on regulations
Air to Air collision probability and severity	1.1	Canadian Airspace Modeling	Modelling of the Winnipeg area	Canada wide modelling	(Inform the regulatory risk thresholds) Align risk classes with Canadian airspace traffic
	1.2	Drone Impact Assessment (experimental impact testing)	Ongoing planning	AWM 525 - continued	Inform the regulatory risk thresholds
Air to ground collision probability and severity	2.1	Human injury Severity	Injury criteria that encompasses all population and injury Threshold	Various sRAPS scalability	Understanding of injury severity and mitigation requirements Inform the regulatory risk thresholds as well as Standard 922 appendix C.
Detect and Avoid	3.1	DAA system testing	Onboard DAA system integration	Onboard DAA system test and evaluation	inform on the level of performance required in the regulations. Inform Standard 922.09
RTM	4.1	RTM Trials support	Developed technology matrix and supported trials	Simulator development	RTM trials will inform regulatory risk threshold for future Canadian RTM system
Icing and extreme weather	5.1	Investigation of effect of icing on Small rotors	Investigate potential Means of Compliance	TBD	Inform environmental effects, and required monitoring, restriction or measures to be put in place to operate in challenging environmental conditions. Will also inform on standard methods to test system performance in those conditions. Informs standard 922.11
	5.2	Investigation of effect of wind in different environments	Investigated flows in Canadian cities and selected RPAS performance evaluation	More complex urban flows parameters testing on additional RPAS	
Certification of Autonomy	6.1	Certification of autonomous systems	Investigation of thrust in autonomy, and validation and verification techniques	TBD	Certification of autonomy research will inform future regulations

Table 1 Research progress overview

## Air to Air Collision Severity (1)

This project is a follow up investigation on windshield drone strike testing performed in Fiscal Year (FY) 2020. This study considers a real cockpit of an AWM 525 certified aircraft to conduct drone impact tests on windshields at representative speeds such as cruising under 10,000 feet of altitude and during the approach phase. Below are the project objectives

- To perform drone impact tests on Part 25 aircrafts windshields
- To assess damage severity on windshields and cockpit structure
- To assess the lethality of windshield debris on aircraft pilots

To assess the lethality of the windshield debris resulting from the drone impact, two ballistic gel torsos simulating the pilot and co-pilot will be located appropriately within the cockpit. Such dummies are made out of organic materials and include the spine, rib cage, organs, neck and brain/blood in the skull. Other technologies such as the use of special aluminum sheets with various thicknesses simulating the various parts of the upper body and face are considered as well.

In addition, the cockpit is being instrumented with the following:

- 1- Accelerometers to measure structural vibrations during the impact.
- 2- High speed camera to capture the density and distribution of the glass debris as they spall off the windshield and travel towards the test dummies.
- 3- High speed cameras to measure drone speed and record impact sequence with the windshield

The NRC's Super Cannon features a 17-in diameter barrel and allows launching drones at speeds beyond 150 m/s (290 knots). It should be noted that the Super Cannon was modified to accommodate another model of drones, as well as testing of impact on cockpit. A CRJ or Dash-8 cockpit are being considered at the time of writing this report. The actual impact testing should occur in FY2022-2023.

### Publications

- Drone impact assessment on aircraft structure: flat plate testing and analysis ([Hyperlink](#))
- Drone impact assessment on aircraft structure: windshield and leading-edge testing and analysis ([Hyperlink](#))
- Drone impact on Part 23 aircraft structures ([Hyperlink](#)).

## Air to Air Collision Probability Project (2)

Near mid-air collision (NMAC) risk is an impediment to the integration of Remotely Piloted Aircraft Systems (RPAS) into non-segregated airspace. Since NMAC rates vary with the airspace density, various regions of Canada are expected to have different safety requirements. The main objective of this work is to develop statistical models of various Canadian Airspaces, which will allow for the assessment of risk when incorporating RPAS with specific performance envelopes into various airspaces in Canada.

In FY 2021-2022, the close collaboration with Carleton University continued and phase 2 of the project focused on the development of methods to analyze and fuse data from various sensors, and then establishes characteristics of the typical intruder aircraft (speed, direction, etc.). Phase 3 will conclude with the development of statistical models across Canada.

## Air to Ground Collision Severity (Injury severity) (3)

The effect of a ground collision between a small RPAS and a human is a concern to the public and government officials. The effects of RPAS impact on humans, more specifically, on head injuries are not well documented. Furthermore, little is known about the effects of RPAS rigidity and mass on the human body during an impact.

In Phase I of this project, the close collaboration with Western University continued, and a small RPAS finite element model (FEM) was developed and both average male and small female skull and brain responses were simulated. Here, the main focus was set on validation of head injuries for the average male model. During Phase I of the project, it was noticed that there is no experimental data in the open literature for the small female and children head responses during an impact with a small RPAS. For this reason, the Phase II work addresses several missing challenges that were not in the scope of the Phase I.

In the FY 2021-2022 project (Phase II), the first objective was to start validation of small female head response during a small Remotely Piloted Aircraft System (sRPAS) impact. While the small female model used in Phase I was validated by scaling the average male model, which is a common safety practice by automotive industry, its application to sRPAS needs further investigation. To address this, an in-depth literature review was conducted and plans are being made for some cadaveric tests at Western University. FEM models are developed and validated based on this experimental data. Then, the small RPAS models are expanded for wider vulnerable populations such as 3, 6, and 10 years-old (YO) children who have weaker necks and more vulnerable brains and skulls. Validation work will be based on scaling the experimental data for male and female, as no experimental work will be performed for children. As part of the project, attempts are being made to simplify the testing process for different sRPAS by using wood or aluminum blocks instead of the real sRPAS, based on the data collected from two sRPAS models with one model to be developed in this project.

**Publications:**

- Phase 1 ground severity report is available online ([Hyperlink](#)).

## Detect and Avoid (DAA) (4)

Transport Canada / NRC have identified several key areas of technology performance evaluation that are required to enable safe BVLOS operations. A specific one is RPAS detect and avoid (DAA) capability. Advancing technology performance assessment in this area will help guide operational risk assessments for future BVLOS SFOC applications as well as inform regulatory developments.

As a result, TC performed a targeted call for participation to industry, which targeted technologies/systems with detection technology onboard of the RPA. This project differs from the previous DAA evaluation project, as mounting each DAA systems onboard a common manned aircraft will ensure known and consistent testing conditions.

National Research Council Canada and Transport Canada obtained participation from 3 airborne DAA systems with different approaches to DAA (1 electro-optical and 2 radar-based). As a result of this project, the selected technologies will be evaluated against the various elements of the DAA performance-based standards after conducting real-time flight tests using NRC aircraft. Those flight tests will give opportunity for airborne DAA system data collection and analysis to inspire future regulatory developments. All three candidate technologies will be installed on Bell 205 helicopter ('own ship', Figure below) with the NRC's Bell 412 acting as an 'intruder'.

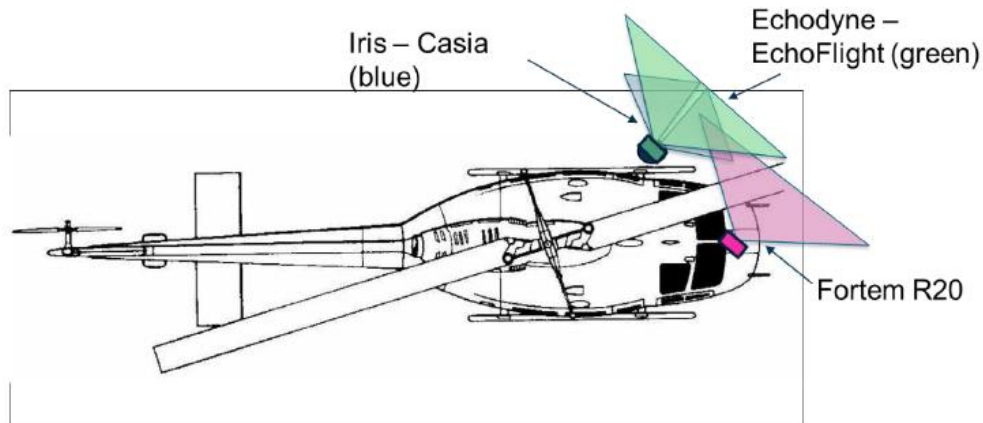


Figure 2 DAA system installation

During FY2021-2022, the following activities are being performed;

- Design/Construct Installation: Includes all the required mechanical design, construction and mechanical installation of the 3 DAA systems on the Bell 205 helicopter, as well as the supporting systems, on the Intruder aircraft for conducting intercepts, which will provide accurate positioning data.
- Identify Test Cases: notional concept for what next FY flight test activities would be in order to fully assess the performance of the systems. Draft test plan including intruder aircraft (size/type), geometries, speeds etc.
- Modify iCollide: NRC's intercept application needs to be modified to account for the different intercept speeds and starting ranges
- System Integration: Perform the electrical and software integration required to operate the 3 DAA systems and store the data they output during proof-of-concept flight tests.
- Shakedown/Airworthiness: Validation that the installed DAA Systems do not adversely affect the airworthiness of NRC's Bell 205 helicopter.
- Proof of Concept Flight Test(s): A flight test will be conducted to ensure all 3 DAA systems are operational and their data is being properly recorded. This will constitute the full performance validation testing.

A follow-on project will conduct two flight test campaigns with extensive intercepts and multiple intruder types.

**Publications:**

Ground based DAA performance evaluation report ([hyperlink](#))

## RPAS Traffic Management (RTM) (5)

Starting 2019, right after initiation of the RTM Action Team, NRC has actively participated and contributed to the meetings and discussions for the roll out of RTM plan and trial selections, effectively taking lead for assessments and gap analysis of the candidate RTM technologies. During the RTMAT meeting participations, NRC has been consulted on a wide range of technology-related issues and questions, and provided high level assessments of the candidate technologies for their potential applications in RTM Foundational and Primary services.

The earlier collaboration project was focused on Phase 1 of the services and trials and the enabling technologies. It also included support for selection of trial candidates and assessment of the trial data upon completion of the tests, through participation in Trial Executive Selection Committee meetings.

This year's work was aligned with that of the earlier project and continues on those efforts. The first objectives were assessing the data obtained from the RTM trials Phase 1 (continued from the earlier project) and updating the technology matrix provided before. This is to systematically identify, categorize and recommend viable existing and emerging technologies for (selected) RTM Foundational, Primary, and Secondary services. Another part of the work involves describing technology performance requirements for the RTM services and recommending measures of effectiveness (qualitative) and measures of performance (high level quantitative). The requirements were shared with the TESC's System Engineering Working Group, where NRC has attended since its inception, and comments were provided. The revised Performance Requirement report was submitted to TC in FY 2021-2022. It is understood that the RPAS Task Force is currently completing the *RTM ConOps* and updating the service descriptions. When completed, this information and related documents will provide the basis for the technology assessments and requirements descriptions.

Below is the list of objectives performed during FY 2021-2022:

- 1) State-of-the art study of enabling technologies and gaps related to RTM services
- 2) Continue updating of NRC Technology Matrix
- 3) Performance characterization and requirements identification and assessment for selected Phase 2 and 3 services
- 4) Design a simulation testbed for use-case and scenario modeling that can support selected RTM service features (e.g., for flight planning and de-confliction) and assist in trial assessments
- 5) Research & technology support to RTM AT, TESC, and System Engineering Working Group for trial selections and evaluations

NRC has engaged in designing a RTM simulation tool with a service oriented architecture (SOA) that will allow for simulating use cases and scenarios.

### **Publications:**

- State of the art in RTM technology for phase 2 trials ([Hyperlink](#))

## Icing (6)

Aircraft encounters with icing conditions during flight are recognized as a major safety hazard, with the resulting accretion of ice on critical surfaces leading to degradation of aerodynamic performance such as increased drag and stall at higher speeds and lower angles of attack. The threat posed by in-flight icing encounters is particularly concerning for RPAS that operate at lower altitudes and lower speeds where the frequency of icing events is increased and the resulting ice accretion enhanced when compared to larger aircraft. In addition, RPAS often lack the ability to detect the occurrence of an icing event from which the risk can be assessed and appropriate corrective action performed.

When a RPAS encounters icing conditions, a particular concern is the degradation in performance of the rotors and propellers. These would tend to collect ice more rapidly, leading to loss of thrust, abrupt increase of power consumption and, with sufficient exposure to the icing environment, may lead to a catastrophic failure of the vehicle.

Phase one of this work (FY 2018-2019) provided an extensive literature review and the acquisition and development of equipment for the simulation of propeller / icing interaction within a wind tunnel environment. Phase two of this project (FY 2019-2020) continued this work with tests being performed on small rotors (i.e., between 10" to 14" diameter) under a range of icing conditions in the NRC Altitude Icing Wind Tunnel (AIWT). This study demonstrated the influence of various icing parameters, e.g., drop size, temperature and Liquid Water Content, on reducing thrust and increasing power input requirements of UAS propellers. This project was then followed by a Phase 3 study (FY 2020-2021) that extended the experimental work on to icing encounters for larger diameter rotors. Testing these systems, however, required sourcing alternative facilities (e.g., Wind tunnels, climate chambers, etc.) that could accommodate the larger rotors while, at the same time, could demonstrate a recognised and traceable calibration of the simulated icing environment. Review of potential test capabilities highlighted that such calibrations were not readily available and any test program would require qualification of the icing environment as part of the overall study. Considering this, it was decided to develop a dedicated RPAS test facility in a cold room at the NRC Montreal Road campus and use this to perform the icing assessment of the larger rotors. This approach had the advantage of providing an icing test facility dedicated to the requirements of the particular environmental conditions to which an RPAS would be exposed and provide readily available facility access for phase 3 and subsequent test programs.

Consequently, phase 3 provided a new test facility for the Investigation of Tolerance for Icing of UAV Rotors / Propellers and delivered data on the performance degradation of larger diameter propellers in icing conditions consistent with the flight envelope of RPAS, e.g., freezing rain and freezing drizzle.

The current follow-on project phase was conducted where further assessment of RPAS rotors in icing conditions was performed. This provides data for the development of guidance material and regulations related to the Means of Compliance for flight in icing. This phase benefits from the work conducted in Phase 3 which enabled such studies to be performed in a calibrated, low cost and accessible facility.

Considering the groundwork that has been performed in the previous 3 phases of this study, the understanding of the impact of icing on RPAS propeller performance can be extended through further testing in the NRC's dedicated icing facility. Testing did evaluate the performance degradation associated with particular icing conditions (e.g., drop size, rainfall (or Liquid Water Content) and ambient temperature) and thereby enabled assessment of the critical operating envelope. As a result, guidance material and/or means of compliance documentation are being developed to qualify candidate RPAS systems for flight within Canadian airspace.

The further demonstration of the NRC RPAS icing facility provides guidance to industry on the acceptable methods that can be employed to demonstrate safe flight in icing. In addition, the work of phase 4 also investigates methods by which propeller icing can be simulated via equivalent means, e.g., use of simulated ice shapes or surface roughness, and whether such an approach can be considered suitable when demonstrating means of compliance.

During FY2021-2022, the following activities were performed;

RPAS Developing Means of Compliance: Testing of propeller blades in icing environments to determine critical environmental conditions related to performance degradation of RPAS. The data provided by this study aids the development of regulations and guidance materials for operations where icing conditions are possible.

Test techniques and simulations for Means of Compliance: Investigation into methods that can be employed by industry to demonstrate compliance to potential future icing requirements. This includes the assessment of "dry" test methods in which simulated ice shapes or roughness are added to blade surfaces to replicate ice accretion and whether such methods offer equivalent performance characteristics compared to those from an actual icing encounter.

**Publications:**

- Investigation of tolerance for icing of small UAV rotors/propellers: phase 1 ([Hyperlink](#))
- Investigation of tolerance for icing of small UAV rotors/propellers: phase 2 ([Hyperlink](#))
- Investigation of tolerance for icing of UAV rotors/propellers: phase 3 test rig development and calibration ([Hyperlink](#))
- Investigation of tolerance for icing of UAV rotors/propellers: phase 3 test results([Hyperlink](#))
- Icing phase 4 ([hyperlink](#))

## Urban Airflows: Effect of wind in different environments project (7)

This is the second year, Phase II, of a multi-year collaboration between TC, NRC and Canadian SME Rowan Williams Davies & Irwin Inc. (RWDI). The first phase of this collaboration included categorization of airflow types within the urban environment that are expected to challenge RPAS operation. Description and illustration of the flow types have been provided to TC by the NRC in video format (Urban Airflow: What Drone Pilots Need to Know). The five urban airflow types identified during Phase I as potentially hazardous to RPAS are: speed, direction, shear, turbulence and vorticity (SDSTV).

To build upon the understanding of the hazardous urban airflow types and their impact on safe RPAS operation, Phase II wind tunnel testing measured urban airflow to determine the extreme magnitudes of each flow type for Canadian cities, and test RPAS flight within the extremes of two flow types; speed and turbulence.

The project objective was to support the TC RPAS Task Force development of regulations for safe operation within urban environments, by providing knowledge on extreme airflows within Canadian cities and the flight response of commonly used RPAS to these airflows.

Impacts on potential regulations and benefits to the RPAS industry include:

Safety of RPAS operations in cities improved by:

- Providing aerodynamic knowledge of RPAS operational limits within typical Canadian urban airflows for the purpose of developing regulations for higher-risk RPAS operations;
- Preparing technologies to inform future amendments to Part IX of the Canadian Aviation Regulations (CARs) for RPAS; and
- Developing methods for assessing RPAS response to representative urban airflow features.

Support the Canadian RPAS industry by:

- Improving knowledge of urban airflows within the RPAS community to promote safe design and product specifications; and
- Enabling Canadian SMEs (RWDI) to develop a Canadian competency in verti-pad assessments for robust Canadian urban infrastructure.

Specifically, Phase II of this project included the following activities:

- Conduct a series of urban flow wind tunnel tests at the NRC's M46 wind tunnel, for four city models representing typical Canadian urban airflow environments including a site in Vancouver, Toronto, Halifax and a modular artificial city. Flow measurement surveys for each city include a large data set encompassing targeted urban canopy and urban roughness layer regions where the SDSTV flow types are found.
- Facilitate and collect data from flight tests of RPAS operated by TC and industry professionals in the NRC 3 m x 6 m Wind Tunnel. TC provided three small RPAS with a range in size from 250 g to 9 kg and an operator. One private company came to operate and test their proprietary small RPAS products. The response of each RPAS to a range in wind speed and wind turbulence was video recorded and time synchronized with wind tunnel flow characteristic data which was used to evaluate stability limits for sustained levels of wind speed with turbulence.

## Publications

- Urban airflow: what drone pilots need to know ([Hyperlink](#)).
- Link to the video ([Hyperlink](#))
- Urban airflow FY2021-2022 report ([hyperlink](#))

## Certification of Autonomous Systems (8)

Over the last number of years Unmanned 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 efficiencies and enhanced capabilities achievable through applying increased automation (a.k.a. autonomy) to aircraft operations. Although technical and regulatory challenges remain, research, experimentation and development are already rapidly evolving to focus on autonomous operations of UAS and Optionally Piloted Vehicles (OPV) in the BVLOS environment. In the area of certification, autonomous aircraft operations present a complex challenge in a number of domains. Certification approaches traditionally applied to aircraft avionics may not be well suited for autonomous systems without modification. For example, the use of Systems Safety analyses and software certification standards may require tailoring for the unique considerations associated with machine-learning, artificial intelligence based autonomous systems. The potential for non-determinism in the decision-making process of autonomous algorithms presents an equally challenging topic for certification. Similarly, with the application of flight autonomy technology, regulations that previously applied to operations and operators may now become linked to system design and testing.

The NRC has commenced a large multi-year research project focusing on the development of a vertical lift autonomy demonstrator through collaborations with other government departments (specifically DND), a major OEM along with a number of Canadian academic institutions and Small to Medium Enterprises (SMEs). This project is entitled the Canadian Vertical Lift Autonomy Demonstration (CVLAD). The objective of the 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 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. As a result, a Canadian Certification of Autonomous Flight Systems (CCAFS) Working Group (WG) has been formed between the TCCA, the Directorate of Technical Airworthiness and Engineering Support (DTAES) and NRC to focus the benefits of this autonomous research into the regulatory domain. The overall objective of this work is to provide information and data to support and guide guidance TC and DTAES in the creation of new, or amending existing, regulations which would support the certification of autonomous flight systems. In particular, this activity should support TC and DTAES in developing a set of performance-based airworthiness requirements for autonomous flight, along with the associated means of compliance. This effort will take multiple years to complete and will be based upon experience and expert knowledge

gained through the development of autonomous flight systems as part of the on-going research at NRC related to autonomous flight systems.

In FY 2021-2022 the autonomous flight system research focused on system design, algorithm development, as well as development of test techniques to assess autonomous flight systems. Under CCAFS, in FY 2021-2022 the NRC focuses on continuing the cooperation established under the CCAFS WG and progress the following tasks under the leadership of the CCAFS WG:

- Co-Lead the CCAFS WG, along with co-chairs from TC and DTAES. In accordance with its Terms of Reference, the WG prioritized research activities and acted as the forum to discuss the specific tasks as well as any certification related issues that arise as a by-product of the development of the research system, thereby raising the technical insight of TC and DTAES specialists and operations staff.
- NRC staff engaged with international authorities and researchers to evaluate the potential for collaboration in support of the CCAFS WG Roadmap.
- Human Role in Limiting Behaviour of Adaptive/Non-deterministic Systems. For FY2021-2022, this activity commenced with a limited scope literature survey to understand the extent of existing research in this area. The literature survey concluded with a summary report which identifies any findings which 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.
- Pilot Intervention Time Study. Following on from the recommendations from the Levels of Attentiveness report (FY 2020-2021), this activity developed an experiment to validate the use of reaction times to provide certification insight for an autonomous flight system in scenarios that require pilot intervention.
- Flight Test Techniques for Assessment of Autonomy. NRC staff continued the development and evaluation of a preliminary set of test techniques designed to enable the assessment of autonomous flight systems. It is envisaged that these techniques will evolve and be refined and developed over several years, in phases with the development of the NRC autonomous flight system itself. In FY 2021-2022, the “open loop” test plan prepared in FY 2020-2021 continued to be executed
- System Safety for Autonomy - The requirement to evolve or adapt traditional systems safety techniques were considered as part of the development of the NRC autonomous flight system. In FY 2019-2020 a generic functional breakdown for a systems safety analysis was completed. Starting in Q4 of FY 2020-2021, this breakdown was applied to the specific NRC autonomy architecture. This analysis continued and was completed in FY 2021-2022.
- Trust of Autonomy. In FYs 2019-2020 and 2020-2021 the NRC developed a tool for the measurement of operator trust of autonomy. In FY 2021-2022 this tool was further refined through its application during open loop and closed loop CVLAD flight test.

**Publications:**

Flight Autonomy research summary (hyperlink to come)

## International Committees Engagement

NRC Aero researchers active on the abovementioned projects are currently involved in the following related committees:

- AHS: Handling Qualities
- ASTM: AC377
- ASTM: F38/WK62668 DAA
- ISO TC20/SC16
- NATO: FT 3 Flt Test Tech Team
- NATO: Rotorcraft Modelling
- RTCA: SC-147 TA&CAS
- RTCA: SC-228 MOPS UAS
- RTMAT
- RTMAT System Engineering WG
- RTMAT Supplier Services WG
- SAE: G10 – Aero Behavioral Eng.
- TTCP-AER-TP 12

## Research Funding Mechanisms

R&D funding mechanisms are explored as a way to help encourage research to be done by industry and academia,

### CRIAQ

TC and NRC worked with CRIAQ to perform a third call for RPAS projects in the 2021-2022 fiscal year. The objective was to use CRIAQ'S network, and CRIAQ would sponsor projects to be performed by university and in industry. The research areas proposed by TC-NRC were those in which there was opportunity to complement the research already being performed, namely:

- BVLOS-1: Airborne Collision Avoidance System Qualification: To provide risk mitigation data on specific DAA (detection and avoidance) systems in order to inform the regulator and assist in the issuance of BVLOS Special Flight Operations Certificates (SFOCs).
- BVLOS-2: Robust Communication Links: Provide the regulatory requirements for Command and Control (C2) link characteristics for BVLOS operations at low altitudes (<500 feet) using a small to medium sized RPAS.
- BVLOS-3: Probability of injury: Inform the regulatory requirement on the probability of impact of RPAS on persons, in the event of an accident for low altitude BVLOS operations, by small to medium size RPAS.
- BVLOS-4: Detection & Identification of Drones / Counter UAV Technologies: Stimulate the development of efficient yet affordable drone detection & tracking technologies for airport

environments, to reduce risk to manned aircraft, while informing the regulator on detection & tracking technological capabilities.

In total, 11 Organizations submitted project ideas. An initial technical review of those received projects ideas was performed by a team composed of TC, NRC, NRC IRAP and CRIAQ. Depending on the potential for contribution to regulation development, as well as other eligibility criteria, each project was reviewed and redirected towards the optimal agency. The call for proposals that went out is presented in Appendix 1 of this report.

#### NRC IRAP

Collaboration with the National Research Council-Industrial Research Assistance Program (NRC-IRAP) was significant in the current fiscal year. IRAP Aerospace Sector Team Lead at IRAP were very involved in the CRIAQ Call for Proposals.

## Conclusion

The strategic partnership between TC and NRC continued in FY2021-2022, with the delivery of scientific data supporting regulation development in the priority areas.

This progress report is a living document which has a main objective to provide a yearly high-level update on the TC-NRC collaborative RPAS research effort. For more details, the reader is invited to consult the reports generated by each research project.

## Appendix 1, 2021 CRIAQ-NRC-TC RPAS Call for proposals

### Program Details & Objectives

CRIAQ is organizing a third call for project ideas on Remotely Piloted Aircraft Systems (RPAS) technologies in collaboration with the National Research Council of Canada (NRC) and Transport Canada (TC).

This program aims to identify innovative technology ideas and collect scientific data that will support the development of regulations, test methods and certification methods of compliance that will enable the safe operations of RPAS (also known as UAV or UAS) in Canada.

CRIAQ will support Transport Canada and NRC in the deployment of a research and development program on RPAS, using their networks with the objective of:

- **Promoting collaborative research** activities to support the development of the Canadian regulatory framework.
- **Supporting other key initiatives** as required.

### Call for project ideas

Interested industrial partners are invited to submit a project idea in collaboration with research partners for one of the following themes:

- **BVLOS-1 : Airborne Collision Avoidance System Qualification** :To provide risk mitigation data on specific DAA (Detect and Avoid) systems in order to inform the regulator and assist in the issuance of BVLOS Special Flight Operations Certificates (SFOCs).
- **BVLOS-2 : Robust Communication Links** :Provide data on Command and Control (C2) link characteristics for BVLOS operations at low altitudes (<500 feet) using a small to medium sized RPAS, to inform regulatory development.
- **BVLOS-3 : Probability of injury**: Provide data on the probability of impact of RPAS on persons, in case of an uncontrolled event in low altitude BVLOS operations, by small to medium size RPAS.
- **BVLOS-4 : Detection & Identification of Drones / Counter UAV Technologies** : Stimulate the development of efficient yet affordable drone detection & tracking technologies for airport environments, to reduce risk to manned aircraft, while informing the regulator on detection & tracking technological capabilities.

### Details on project funding

This program does not guarantee access to funding for your project; funding will need to be secured through a specific funding program.

Applicants who receive a positive evaluation of their project idea will be provided with contact information to local funding agencies by CRIAQ.

### Eligibility Criteria:

- Projects must address one of the topics listed above.
- Project ideas must be submitted by an industrial partner.
- Industrial partners must have an R&D presence and/or manufacturing facility in Canada, and operations in Canada must be able to commercialize the R&D results of the project.
- The industrial partner(s) must have an annual sales and/or annual investments of \$500,000.

- Intellectual property arising from the project will be managed by the project participants, as CRIAQ-NRC-TC does not claim or manage intellectual property rights.

**Submission Process:**

For each proposal, please choose a theme and follow the link below to complete the submission form(s) by 14th January, 2021:

- **BVLOS-1: Qualification of Collision Avoidance Systems**
- **BVLOS-2: Communication links**
- **BVLOS-3: Probability of Injury**
- **BVLOS-4: Detection & Identification of Drones / Counter UAV**

**Application submission and approval process**

All project ideas will be evaluated by a joint committee composed of representatives from CRIAQ, the NRC and TC. CRIAQ will act as the contact point for receiving project ideas and coordinating the initiative.

All Quebec-led projects dealing with Technological Readiness Level (TRL) 2 to 6 and meeting CRIAQ criteria will also be invited to follow the CRIAQ process. Project teams may also make direct contact with other Canadian funding agencies if they meet their eligibility criteria.

Depending on the content of the final project plan, Transport Canada may act as an advisor or observer of the project.

## Appendix 2, NRC Aero - TC RPAS TF collaborative research



Transport Canada / Transports Canada



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## RPAS R&D Projects Reports Summary

Overview of FY 20-21 research activities

*Carlos Ruella, R&D Manager, TC RPAS Task Force*  
*Charles Vidal, Integrated Aerial Mobility Program Lead(Interim), NRC*


*With contributions from: Azzedine Dadouche, Iryna Borshchova, Javad Gholipour, Iraj Mantegh, Kris Ellis, David Orchard, Hall Barber, Derek Gowanlock*













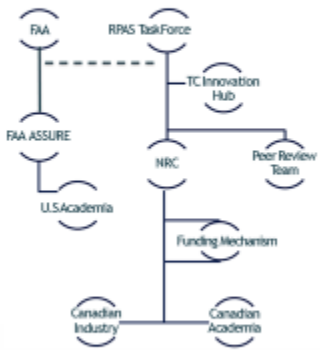



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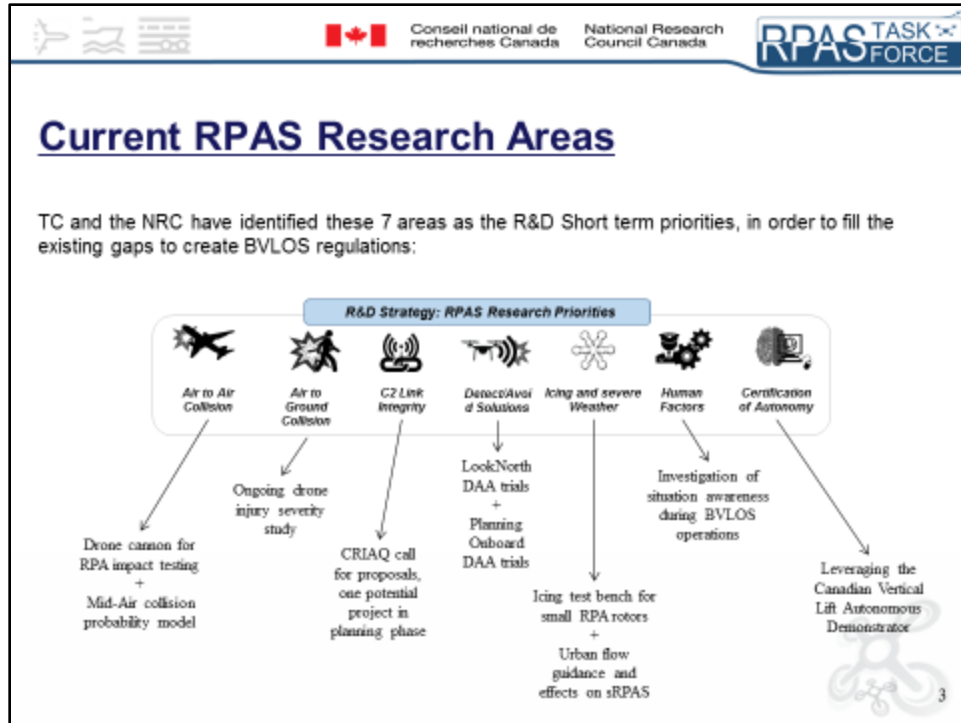


## R&D Mandate and Partners

- Provide R&D data that supports regulatory and policy framework development.
- TC is collaborating with the FAA and FAA Assure to share R&D data and reduce duplication of research.
- TC have engaged with the 'National Research Council Canada' (NRC) to execute R&D to support the regulatory development for RPAS operations.
















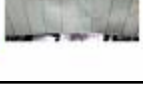
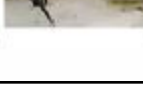






**Drone Impact Assessment (Part 23)**





- General Description:**  
 Impact severity assessment of a quadcopter shot from a drone cannon at various components of a Part 23 representative aircraft.
- Testing executed:**
  - 1.2kg drones shot at various components of the aircraft:
    - Wing leading edge
    - Horizontal stabilizer leading edge
    - Vertical stabilizer leading edge
    - Wing strut
    - Flaps when fully deployed
    - Propeller
  - Impacts speeds of 100kts and 160kts


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## Drone Impact Assessment (Part 23)

Test ID	Severity	Selected damage pictures	
T1WSTAB-CS	Level 3		
T2HSTAB-AS	Level 2		
T3HSTAB-CS	Level 3		
T4-STRUT-AS	Level 1		
T5-STRUT-CS	Level 2		
T6-FLAP-AS	Level 3		

T7-SENG-CS	Level 4		
T8-WING-CS	Level 4		

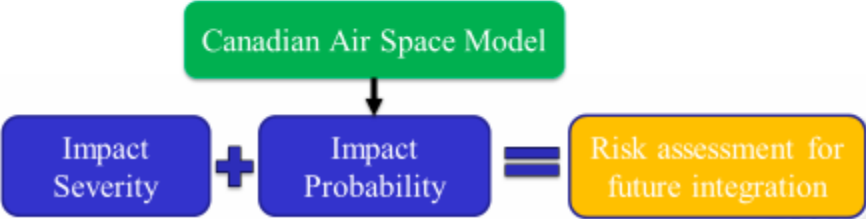
Severity	Description	Example
Level 1	<ul style="list-style-type: none"> <li>Audible rattling</li> <li>Small deformations</li> </ul>	
Level 2	<ul style="list-style-type: none"> <li>Extensive permanent deformation or removal of fibers</li> <li>Small deformations in internal structure</li> <li>No failure of skin</li> </ul>	
Level 3	<ul style="list-style-type: none"> <li>Skin breach</li> <li>Detachment of at least one component into the airflow</li> </ul>	
Level 4	<ul style="list-style-type: none"> <li>Penetration of UAV into airflow</li> <li>Failure of parts of the primary structure</li> </ul>	

\* FAA ASSURE proposed level of severity index. 5


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## Airspace Modeling


- General Description:**  
 To design and develop statistical models of the airspace in Canada using aircraft tracks data provided by NAV Canada. The project is comprised of 3 phases to be completed by March 2023.  
 In parallel we are looking at developing a low altitude air risk model based on qualitative data obtained from manned aviation operators. The outcome of this air risk study will be used as an input to the overall Canadian airspace model.



```

            graph TD
            A[Canadian Air Space Model] --> B[Impact Severity + Impact Probability]
            B == C[Risk assessment for future integration]
            
```

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## Human Injury Severity

**Organizations Involved:**  
 TC RPAS Task Force – Research coordinator  
 NRC – Research coordinator  
 Western University – Project Execution

- **General Description:**  
 To support the development and amendment of injury criteria for small RPAS to human impacts. Also to investigate how different populations (average male/female) respond differently during RPAS head impacts.

- **Testing executed:**
  - Simulated impacts from drones for THUMS 50% male and 5% female
  - Compared with ASSURE's cadaveric testing
  - Head injury criterion and brain injury criteria were calculated







## RTM trial support



NRC is supporting the execution of the ongoing RPAS Traffic Management (RTM) trials.

The main task are:

- Provide SME support and recommendations for the development of the Canadian RTM strategy
- Analyze the data coming out of the trial participants to validate it and provide the Task Force with a summary report






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## DAA: LOOKNorth / NRC / TC trial (FY 19-21)



- **General Description:**  
The purpose of these trials is to evaluate the performance level of **Non-Cooperative** DAA systems. Specifically systems used by Canadian RPAS operators/manufactures, both ground based and onboard systems.

Three Canadian companies were selected to participate in this trial:

- [Drone Delivery Canada](#)
- [Canadian UAVS](#)
- [Pegasus Imagery](#)


[TC trial announcement](#)



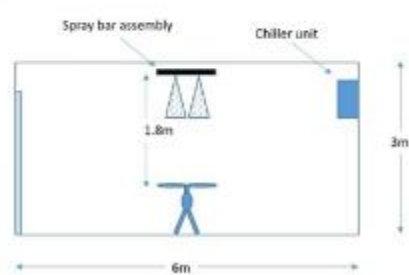
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## Drone Propeller Icing Tolerance


- **General Description:**  
Study on how larger diameter propellers (22") perform in icing conditions. This constitutes an extension of work done last FY on propellers of 8" to 14" in diameter. Development of a new and larger RPAS specific icing testing ring.











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## Drone Propeller Icing Tolerance


- **Testing executed:**
  - Cold room testing facility with calibrated spray system
  - Propellers mounted on a motor with a dynamometer and a load cell
  - Temperature, droplet size, liquid water content, and flow rate varied
  - Thrust, torque and power requirements measured for rotor and motor




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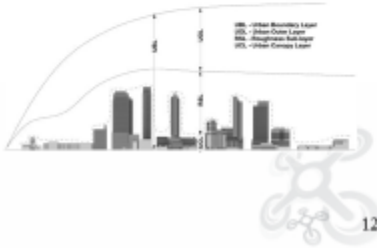

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## Urban Airflow

- **General Description:**  
To investigate urban airflow and its impact on RPAS operations. Also to introduce RPAS pilots to the wide range of urban flow types within the urban environment.
- **Work executed:**
  - Literature Review
  - RPAS operator awareness video, in both official languages:
    - [English](#)
    - [Français](#)





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## Certification of Autonomy

- **General Description:**
  - Study on how would be accredited and/or certified flying systems with higher level of autonomy
  - Long term project 2018-2023
  - Multi-disciplinary working group.
  - **Development of Flight Test Techniques to assess autonomous flight systems capabilities/performance**
  
- **Organizations Involved**

TC RPAS Task Force – Research coordinator / SMEs  
 TC NAC – SMEs  
 DND DTAES – SMEs  
 NRC – Project Execution  
 FAA – SME participating in working groups  
 NASA– SME participating in working groups



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## CRIAQ / NRC / TC calls for projects

- **1<sup>st</sup> call for projects was launched in June 2019**
  - 30+ project ideas received.
  - Down selected to 12 full project proposals.
  - 2 projects ongoing with CRIAQ:
    - Savinte: RTM solution based on transponders.
    - Humanitas: Realistic simulation environment to help assess the probability of an RPAS colliding with a pedestrian.
  
- **2<sup>nd</sup> call for projects was launched in September 2020**
  - This call focused of the following areas:
    - DAA system qualification;
    - C2 link robustness;
    - Human injury probability;
    - Pandemic response.
  - 1 project was accepted and is completing the CRIAQ process:
    - Detect and Avoid (DAA) system demonstration for safe deployment of remotely piloted aircraft system (RPAS)



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## Publicly available reports

- An important element of the R&D program is to publish the results and share them nationally and internationally to avoid duplication of effort.
  
- Reports/papers already published online:
  - [Part 25 drone impact assessment report](#)
  - [RPAS icing literature review](#)
  - [Small RPAS propeller icing tolerance report](#)
  - [RPAS specific icing test rig development and calibration report](#)
  - [Urban Air Flow Report \(Operator guidance video\)](#)
  - [Modelling sRPAS system to head impact for investigating craniocerebral response](#)
  - [Transport Canada RPAS R&D yearly progress report - NRC Publications Archive - Canada.ca](#)
  
- The following reports are under review and should be published soon:
  - Medium RPAS propellers icing tolerance report
  - Part 23 drone impact assessment report
  - Ground impact injury severity report




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## RPAS TF – NRC R&D potential projects for FY22-23


Green = Completed, Blue = Active, Yellow = Planning Stage

	FY18-19	FY19-20	FY20-21	FY2021-2022	FY2022-2023
<b>Air to Air Collision</b>	Drone Impact Assessment Part 25	Drone impact Part 23	Traffic density model - Phase 1 of 3	Traffic density model - Phase 2 of 3	Traffic density model - Phase 3 of 3
<b>Air to Ground Collision</b>		Human injury severity Phase 1		Human injury severity Phase 2	Human injury severity Phase 3
<b>RTH C2 Link Integrity</b>			RTH Trials support	RTH 2nd Trials support	RTH (TRC) C2 Link reliabilities in complex environments
<b>Detect/Avoid Solutions</b>			DAA Performance Evaluation Trials	Onboard DAA Systems Perf. Eval.	Onboard DAA Systems Perf. Eval.
<b>Icing / Severe Weather</b>	Icing of Small Rotors		Icing of larger Rotors Urban Wind Flow - Operator guidance	Icing testing guidance Urban Wind Flow - Wind resistance	Icing Wind Flow testing guidance
<b>Human Factors</b>	Situation Awareness				
<b>Certification of Autonomy</b>			Certification of Autonomous Flight Systems		Certification of Autonomous Flight Systems



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## Appendix 3, NRC Aero IAM Program presentation



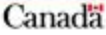
NRC.CANADA.CA

# INTEGRATED AERIAL MOBILITY PROGRAM

Charles Vidal, Eng.  
Program Leader



National Research Council of Canada / Conseil national de recherches Canada



## The National Research Council of Canada

The NRC is Canada's largest federal R&D organization

**3** GOALS

1. Support business innovation
2. Advance scientific and technical knowledge
3. Deliver policy solutions for government

<b>3,700</b> scientists, engineers and technicians	<b>1,000</b> companies with R&D collaborations	<b>\$1B</b> annual budget	<b>7,500</b> SME clients
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**100s**  
of national and international partners



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## Aerospace Research Center Laboratories - Programs



A grid of nine circular icons representing different laboratories and programs at the Aerospace Research Center. The icons are arranged in two rows: five in the top row and four in the bottom row. Each icon is accompanied by a text label below it.

- Aerodynamics Lab
- Aerospace Manufacturing Technology Center
- Flight Research Laboratory
- Structures and materials Performance Laboratory
- Gas Turbine Laboratory
- Integrated Aerial Mobility
- Low Emission Aviation Program
- Aerospace Product Development & Certification
- Defence Technologies

## Aerial Mobility Application Spectrum

Mobility of:

 Services	 Cargo	 People
Commercial and Security/Defence		
IAM - INTEGRATED AERIAL MOBILITY		

## Integrated Aerial Mobility - IAM

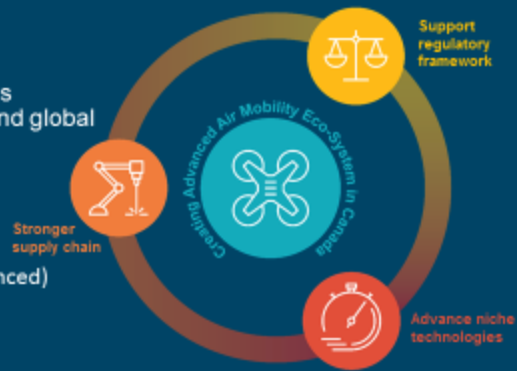
### Goal and Objectives

Create an ecosystem to grow Canada's industrial capabilities in the strategic and global Advanced Air Mobility market.

Some statistics, in Canada:

~60,000 drones registered

~60,000 pilot certificates (Basic and Advanced)



## IAM Program Scope

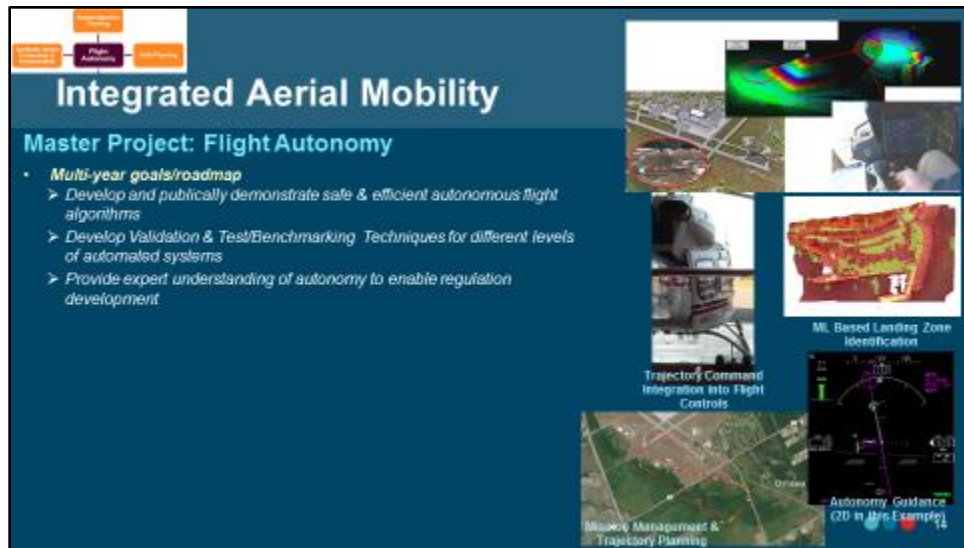




**Integrated Aerial Mobility**  
**Master Projects - Operating Environment**

- **Multi-year goals/roadmap**
  - Develop testing and computational M&S capabilities/tools for RPAS (icing/rain/snow, urban flows, air-to-air & air-to-ground collision)
  - Characterize RPAS icing and develop effective ice detection and ice protection technologies suitable for RPAS operations in icing conditions
  - Evaluate extreme airflows within Canadian cities and investigate stability limits of RPAS within urban flows and suitability of novel control systems for their safe operations in urban environments
  - Determine small RPAS air-to-air and air-to-ground collision impact for safe operations in civilian airspace and populated areas


Visuals include: a flowchart at the top left; a cockpit view; a diagram of 'Differing crash scenarios'; a 'Shall Stress' diagram; 'Urban Flows' and 'Air-to-Ground' test images; 'Air-to-Air Collision' test images; 'Flight test specimens' (C-223 A/C); and 'RPAS prop. icing and captohic coatings'.



**Integrated Aerial Mobility**  
**Master Project: Flight Autonomy**

- **Multi-year goals/roadmap**
  - Develop and publically demonstrate safe & efficient autonomous flight algorithms
  - Develop Validation & Test/Benchmarking Techniques for different levels of automated systems
  - Provide expert understanding of autonomy to enable regulation development

Visuals include: a flowchart at the top left; a 3D visualization of a city with a flight path; a 'Trajectory Command Integration into Flight Controls' diagram; 'ML Based Landing Zone Identification' map; 'Mission Management & Trajectory Planning' map; and 'Autonomy Guidance (2D in this Example)' diagram.



## Integrated Aerial Mobility

### Master Project: Integrated Aerial Services

*Multi-year goals/roadmap*

**Aerial Robotics**




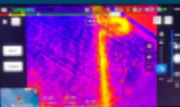

- > **-Multi-year Goal:** Develop aerial robotics technologies for inspection and maintenance of elevated structures and security applications.

**Counter Drone and RPAS Traffic Management (RTM)**

- > **-Multi-year Goal:** Develop and validate advanced AI-enabled Counter drone technologies, and develop/implement new capabilities to enable RTM in Canada and support regulation developments

**Advanced Remote Sensing**

- > **-Multi-year goal:** Have an integrated system of sensors (e.g. hyperspectral, LIDAR, aeromagnetics and thermal-IR) on a high payload UAV and develop BVLOS applications. Implement advance analytics (e.g. data fusion) for different applications for natural (e.g. peatlands) and man-made systems (e.g. railway infrastructure, heating systems).

## Integrated Aerial Mobility

### Master Project: Integrated Design

*Multi-year goals/roadmap*

**Integrated UAM Cabin Project**


Multi-objective optimization and prototype manufacturing of a subfloor and side floor cabin structure

**Urban Air Mobility Propulsor Aeroacoustics**

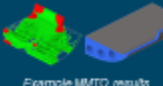
Develop and demonstrate low-noise UAM propulsion.

**Low-order simulations of flying taxi solutions**

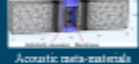
Prediction of aerodynamic performance of UAM configurations and rotors





Multi-Material Lattice



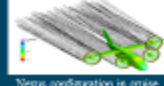
Example MTO results




Acoustic meta-materials

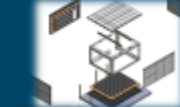

Drone acoustic test facility



Nexus configuration in cruise



Slipstream one propeller

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