SUSTAINABLE GROUND OPERATIONS OF MILITARY TRANSPORT AIRCRAFT WITHIN THE ROYAL CANADIAN AIR FORCE

OPÉRATIONS TERRESTRES DURABLES DES AVIONS DE TRANSPORT MILITAIRE AU SEIN DE L'AVIATION ROYALE CANADIENNE

A Thesis Submitted to the Division of Graduate Studies
of the Royal Military College of Canada
by

Kevin St-Jean
Captain

In Partial Fulfillment of the Requirements for the Degree of
Masters of Applied Science

April, 2024

Acknowledgement

I extend my deepest gratitude to my supervisors, Dr. Nicholas Vlachopoulos, Dr. E.Maria Skordaki, and Capt Kieran Moore, for their unwavering guidance, support, and encouragement over the past two years. Their insights and wisdom have been pivotal in shaping this research project.

My thanks go out to the team at 8 Wing Trenton whose cooperation has been invaluable to my work. I am particularly indebted to Cody Hartwick, Andrew Lumley, and Iain Wilson, whose specialized knowledge regarding their aircraft was crucial in informing my research.

Gratitude is also due to the project sponsors at the Directorate of Operational Sustainability, whose vision initiated this research, and whose ongoing assistance was immensely helpful throughout the project’s duration.

Above all, my partner Jess deserves my most profound appreciation. Her unrelenting motivation and emotional support were the bedrock of my perseverance and accomplishments in my academic pursuits. Her presence was a constant reminder of my purpose and goals. Jess's support was instrumental in my achievements, and it is certain that my success would not have been as profound without her by my side

Abstract

While aircraft engines are efficient at high thrust modes, they are notably less efficient at low-power settings during idling and taxiing. Recognizing the need to address environmental and economic concerns, the civil aviation industry is increasingly exploring sustainable solutions with a view to minimize fuel consumption during ground movements. As the Royal Canadian Air Force (RCAF) advances toward its federal mandate of achieving net-zero emissions in aviation, a key requirement is to determine potential solutions by conducting a comprehensive review of best and/or relevant practices in this regard. As such, within this context, this thesis document examines experiences and insights derived from the global and domestic civil aviation industry, as well as allied air force / military counterparts that could potentially be implemented and incorporated within RCAF operations. The analysis accounts for the specific requirements, constraints, and security considerations faced by military aviation, illustrating how these factors may impact the effective adoption of pertinent sustainable initiatives.

Using Canadian Air Force Base 8 Wing Trenton as a case study, this research study assesses the carbon emissions associated with the transport fleet and their related ground support equipment. The study also includes the feasibility and anticipated fuel savings resulting from the staging of infrastructure (i.e. organizing the location of the various task-tailored buildings that service the aircraft within the air force base) and ground operations optimizations (i.e. taxiing). This comprehensive examination aims to offer practical insights and strategies to enhance sustainability within military aviation. The results of this research study will guide relevant managers within the RCAF and the wider military aviation sector, aiding them in making informed decisions regarding fuel efficiency, carbon emission reduction, and the integration of sustainable practices. This thesis document represents yet another step by DND and the RCAF to continue to be a leader amongst federal agencies concerning sustainability and their efforts to combat climate change while preserving national security and operational effectiveness.

Resume

Bien que les moteurs d’avion soient efficaces dans les modes de poussée élevée, ils sont nettement moins efficaces dans les réglages de faible puissance au ralenti et au roulage. Consciente de la nécessité de répondre aux préoccupations environnementales et économiques, l'industrie de l'aviation civile explore de plus en plus de solutions durables en vue de minimiser la consommation de carburant lors des mouvements au sol. Alors que l’Aviation royale canadienne (ARC) progresse vers son mandat fédéral consistant à atteindre zéro émission nette dans l’aviation, une exigence clé est de déterminer des solutions potentielles en effectuant un examen complet des pratiques exemplaires et/ou pertinentes. Ainsi, dans ce contexte, le présent document examine les expériences et les connaissances tirées de l’industrie de l’aviation civile mondiale et nationale, ainsi que de leurs homologues des forces aériennes et militaires alliées, qui pourraient potentiellement être mises en œuvre et intégrées aux opérations de l’ARC. L'analyse tient compte des exigences, des contraintes et des considérations de sécurité spécifiques auxquelles l'aviation militaire est confrontée, illustrant comment ces facteurs peuvent avoir un impact sur l'adoption efficace d'initiatives durables pertinentes.

En utilisant la 8e Escadre Trenton de la Base de l’Aviation canadienne comme étude de cas, cette étude évalue les émissions de carbone associées à la flotte de transport et à son équipement de soutien au sol connexe. L'étude comprend également la faisabilité et les économies de carburant anticipées résultant de la mise en place des infrastructures (c'est-à-dire l'organisation de l'emplacement des différents bâtiments adaptés aux tâches qui desservent les avions au sein de la base aérienne) et des optimisations des opérations au sol (c'est-à-dire le roulage). Cet examen complet vise à offrir des informations et des stratégies pratiques pour améliorer la durabilité au sein de l’aviation militaire. Les résultats de cette étude de recherche guideront les gestionnaires concernés au sein de l'ARC et du secteur de l'aviation militaire dans son ensemble, les aidant à prendre des décisions éclairées concernant l'efficacité énergétique, la réduction des émissions de carbone et l'intégration de pratiques durables. Ce document représente une autre étape du MDN et de l'ARC pour continuer d'être un chef de file parmi les agences fédérales en matière de durabilité et de leurs efforts pour lutter contre les changements climatiques tout en préservant la sécurité nationale et l'efficacité opérationnelle.

Table of Contents

List of Figures

List of Tables

List of Abbreviations and Acronyms

2 Air Mov Sqn	2 Air Movements Squadron
424 (T&R) Sqn	424 Transport and Rescue Squadron
426 (T) Trg Sqn	426 Transport and Training Squadron
429 (T) Sqn	429 Transport Squadron
436 (T) Sqn	436 Transport Squadron
437 (T) Sqn	437 Transport Squadron
8 OSS	8 Operational Support Squadron
8 MSS	8 Mission Support Squadron
8 AMS	8 Air Maintenance Squadron
AAF	Aircraft Anti-Icing Fluid
ACRP	Airport Cooperative Research Program
ACI	Airports Council International
ADAF	Aircraft De-icing and Anti-icing Fluid
ADF	Aircraft De-icing Fluid
AGPS	Alternative Ground Propulsion Systems
AOI	Aircraft Operating Instructions
APU	Auxiliary Power Unit
ASAR	Airfield Surface and Reconnaissance
ATAG	Air Transport Action Group
ATC	Air Traffic Control
AvPOL	Aviation Petroleum, Oil, and Lubricant
CAF	Canadian Armed Forces
Capt	Captain
CFB	Canadian Forces Base
CFS	Canadian Forces Station
CGSB	Canadian General Standards Board
CIMIC	Civil-Military Cooperation
Civ	Civilian
CO_2	Carbon Dioxide Equivalent
CO	Carbon Monoxide
CH_4	Methane
Cpl	Corporal
DCSS	Defence Climate and Sustainability Strategy
DOB	Deployed Operating Base
DOW	Dry Operating Weight
DND	Department of National Defence
DoD	Department of Defense

DOW	Dry Operating Weight
EGTS	Electric Ground Taxiing System
EI	Emission Index
ERO	Engine Running Onload/Offload
EUSA	European Union Aviation Safety Agency
FCOM	Flight Crew Operating Manual
FDR	Flight Data Recorder
FEGP	Fixed Electric Ground Power
FF	Fuel Flow
FY	Fiscal Year
F-34	NATO Code for Kerosene-Type Aviation Turbine Fuel
F-37	NATO Code for F-34 with S-1749
FOD	Foreign Object Damage
FOM	Flight Operations Manual
GHG	Greenhouse Gas
GPU	Ground Power Unit
GSE	Ground Support Equipment
GWP	Global Warming Potential
HFC	Hydrofluorocarbons
HOT	Holdover Time
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ISO	International Standards Organization
km	Kilometre
kg	Kilogram
LOO	Line of Effort
LTO	Landing and Take-off
Maj	Major
MOB	Main Operating Base
MRPDP	Master Real Property Development Plan
MEEP	Mission Execution Excellence Program
NATO	North Atlantic Treaty Organization
NORAD	North American Aerospace Defence
NO_x	Nitrogen Oxides
NSS	National Safety and Security
N_2O	Nitrous Oxide
O.I.C.	Order In Council
POL	Petroleum, Oil, Lubricant
PFC	Pefluorocarbons
PM	Particulate Matter
Pte	Private
PTNZ	Path to Net Zero

RCAF	Royal Canadian Air Force
RET	Reduced Engine Taxi
RMC	Royal Military College of Canada
RP	Real Property
RP Ops Det Trenton	Real Property Operations Detachment Trenton
RP Ops	Real Property Operations
SAE	Society of Automotive Engineers
SAF	Sustainable Aviation Fuel
SAR	Search and Rescue
SCF	Statistical Contingency Fuel
SET	Single Engine Taxi
SF_6	Sulfur Hexafluoride
SOA	Standing Offer Agreement
SOP	Standard Operating Procedure
SO_x	Sulfur Oxides
SSTC	Strategic Tanker Transport Capability
Sqn	Squadron
S-1749	A thermal stability improver additive
TIM	Time in mode
TRSET	Transport Standardization and Evaluations Team
UAV	Unmanned Arial Vehicle
USAF	United States Air Force
WO	Warrant Officer
WSO	Wing Standing Orders

1. Introduction

1.1 Purpose of Study

Aviation fuel is the largest single emission source within the federal government, contributing to approximately one-fifth of the government's total emissions (Strong, 2019). Given that the majority of the Canadian Armed Forces (CAF's) Greenhouse Gas (GHG) emissions are from aircraft, the pathway to decarbonization certainly warrants further investigation (Canada, 2022b). Furthermore, many of the aircraft currently in use, that rely heavily on fossil fuels, will continue to be in service until 2050 and onwards (DND, 2023). The RCAF recognized that no single measure can be relied upon to achieve net zero emissions by 2050, thus, a multifaceted approach is required. In line with Line of Effort (LOO) 1, which focuses on Operational adaptations for fuel efficiency, the purpose of this study was to monitor and analyze aircraft ground operations and airfield infrastructure to create a baseline of energy usage, identify efficiencies that can be achieved, and quantify their potential GHG emission reductions. This initial study utilizes a case study approach to examine the transport fleet at 8 Wing Trenton. By creating a baseline of energy usage, identifying achievable efficiencies, and quantifying potential GHG emission reduction, this study provided actionable insight that can be used to inform future policy, paving the way for the identification, analysis, and implementation of sustainable practices for Royal Canadian Air Force (RCAF) aircraft, supporting equipment, and infrastructure.

1.2 Thesis Objectives

The objectives of this thesis are further amplified in subsequent sections and are summarized as follows:

1. Establish a baseline of fuel consumption for ground operations;
2. Provide a re-design option for the airfield and infrastructure
3. Assess Feasibility and Projected Fuels Savings of Reduced Engine Taxi;
4. Assess Strategies to Reduce APU Fuel Consumption;
5. Optimize Aircraft De-icing;

6. Identify Types of GSE, Fuel Consumption, and Provide Sustainable Alternatives;
7. Assess Mission Fuel Planning;
8. Assess Ground Traffic Management; and
9. Assess the Culture of Fuel Efficiency.

Objective 1: Establish a Baseline of Fuel Consumption for Ground operations.

While the RCAF meticulously tracks overall fuel usage, objective 1 sought to enhance the understanding of fuel consumption during ground operations for aircraft in the transport fleet through during engine idling, taxiing, and APU usage, and through the use of Ground Support Equipment (GSE) such as Ground Power Units (GPUs). To achieve this objective, data on taxi times, APU run times, and average fuel flow rates were gathered through a combination of interviews and direct measurements. These observations were validated by attending and observing local training flights for the CC-177, CC-150, and CC-130J. Fuel logs and historical departures and arrivals were analyzed to determine the average fuel consumption per flight and the fuel consumption by GSE. Furthermore, this study explored the fuel allocation for initial engine start-up and taxiing, using planning figures from ForeFlight for each airframe. This comprehensive approach combining qualitative and quantitative data, sought to provide a detailed overview of estimated fuel consumption during ground operations.

Objective 2: Provide a re-design option for the airfield and infrastructure.

The design of an airfield can reduce GHG emissions by improving traffic flow and minimizing delays on the ground (Norton, 2014). Additionally, designing runways and taxiways to reduce on-ground distances reduce the associated fuel usage. This study projected forward operational and sustainability requirements 25 years into the future with a view to provide redesign options for the airfield and infrastructure at 8 Wing Trenton that meets the requirements of the RCAF while adhering to industry best practices. Objective 5 included redesigning and optimizing the airfield to address deficiencies such as taxiway Papa limitations, and the need for a new hangar in support of the arrival of the CC-330 as part of the Strategic Tanker Transport Capability. This included reviewing the current site layout, identifying future infrastructure projects derived from Canadian Forces Base (CFB) Trenton’s Master

Real Property Development Plan (MRPDP), and incorporating best practices to enhance the sustainability and operational effectiveness of the site.

Objective 3: Assess Feasibility and Projected Fuels Savings of Reduced Engine Taxi

The aim of this objective was to evaluate the operational feasibility and projected fuel savings of Reduced Engine Taxi (RET) for airframes in the transport fleet at 8 Wing Trenton. This was achieved through a detailed analysis of current taxi practices and comparison with best practices in both civil and military aviation. A key aspect of this evaluation was the examination of Flight Crew Operating Manuals (FCOMs), to discern if engine start and shutdown checklists include modified versions to support RET. Lessons from other studies were incorporated to include technical and operational considerations that may impact the implementation of RET such as technical feasibility, safety risks, and pilot workload. Projected fuel savings from RET were calculated using data on average engine fuel flow during taxi, average taxi-in times, and the number of sorties capable of performing RET. This calculation aimed to quantify the potential reduction in fuel consumption, and GHG emissions. Staff from 8 Wing Staff, including air crew and ground crew, were engaged to understand their attitudes towards RET, uncover any concerns they might have, and gather their general thoughts on the efficacy of RET as a fuel saving mechanism. By establishing a baseline of fuel consumption and GHG emissions for ground operations, the RCAF will be better positioned to manage and optimize resources more effectively. This baseline will serve as a valuable benchmark for future improvements, allowing the RCAF to make informed decisions regarding changes to operational procedures, equipment upgrades, and future procurement.

Objective 4: Assess Strategies to Reduce APU Fuel Consumption

This objective aimed to evaluate strategies for reducing Auxiliary Power Unit (APU) fuel consumption. This involved establishing scenarios under which APUs are activated, their operational durations, and the factors guiding the selection between APU and GPU use. Data collection was carried out through informal and formal interviews with staff, validated by firsthand observations on local training flights involving the CC-130J, CC-150, and CC-177. This assessment encompassed aircraft specific technical limitations and operational factors such as challenges posed by remote locations, GPU reliability, APU-generated noise, and its impacts.

Additionally, the investigation determined the type of GPUs in use, their fuel types, their deployment frequency, including the use of air start and heater carts. Recommendations were formulated to enhance APU usage tracking and propose greener alternatives, like electric GPUs and Fixed Electric Ground Power (FEGP). This objective intended to support managers in accurately gauging APU fuel consumption and formulating strategies to reduce their use.

Objective 5: Optimize Aircraft De-icing

This objective aimed to understand and optimize the de-icing process, focusing on the use of Aircraft Deicing and Anti-Icing Fluids (ADAFs) at 8 Wing Trenton. This objective was achieved by gathering information on the types and quantities of ADAFs employed, which was sourced from 8 Operational Support Squadron (8 OSS) records. An assessment was made on how ADAF is stored, how it is released into the environment, treated, and disposed after use. An in-depth examination of the de-icing process was conducted, encompassing stages of the de-snowing, de-icing, and anti-icing. This assessment aimed to understand the entire workflow and identify areas for optimization. The investigation also covered the extent to which preventative measures, such as sheltering aircraft and hangars to minimize the need for ADAF, were being utilized. Factors included operational limitations like the availability of hangar space and logistical challenges that may impeded these preventative practices. Data collection involved interviews with pilots and direct observations of the de-icing process including observing the CC-177 undergo de-snowing and de-icing during a local training mission. The firsthand observations were compared to the procedures outlined in the 8 Wing Flying Orders to identify discrepancies or areas for improvement. Based on the findings, recommendations were formulated aimed at reducing the consumption of ADAFs.

Objective 6: Identify Types of GSE, Fuel Consumption, and Provide Sustainable Alternatives

This objective focused on identifying the types of Ground Support Equipment (GSE) used at 8 Wing Trenton, analyzing their fuel consumption, and suggesting sustainable alternatives. This approach involved taking an inventory of the GSE utilized by each unit/squadron along with the type of fuel used. A detailed categorization of GSE present at 8 Wing was provided. To determine fuel consumption, diesel and AvPOL logs were examined, offering a unit/squadron breakdown of GSE fuel consumption over a year. Site visits were conducted to observe the GSE in operation, noting which equipment was used, its application, and frequency of use. Interviews with squadron personnel responsible for operating and maintaining the GSE help identify potential issues with the current GSE fleet and gather insights into the types and quantifies of fuel consumed by these assets. The objective also including formulating recommendations for sustainable GSE alternatives, such as electrically powered equipment. This involved considering the upfront investments require for upgrading the electrical grid capacity, installation of charging stations, and managing the lifecycle transition of existing equipment towards more sustainable alternatives.

Objective 7: Assess Mission Fuel Planning

Objective 7 focused on evaluating the mission fuel planning process at 8 Wing. It aimed to understand the methodology behind fuel allocation for aircraft, distinguishing between planning for missions and local training exercises. The objective involved assessing the quantity of fuel loaded into aircraft for various operations. The evaluation also explored the tools available to pilots, such as ForeFlight, assessing their effectiveness in facilitating accurate fuel load calculations for mission planning. The investigation also extended to analyzing instances where pilots exceeded minimum fuel requirements specified in the Flight Operations Manual (FOM), aiming to comprehend contributing factors behind such decisions. A comparison of 8 Wing’s current fuel planning tools and procedures against industry best practices was conducted to identify areas for improvement. The practical aspects of fuel planning strategics was validated through direct observations of local training flights on the CC-130J, CC-150, and CC-177. Through this assessment, this objective aimed to uncover practical insights into the state of mission fuel planning at 8 Wing Trenton, identifying opportunities to enhance fuel efficiency while maintaining operational effectiveness.

Objective 8: Assess Ground Traffic Management

Objective 8 focused on analyzing ground traffic management at 8 Wing Trenton, with an emphasis on determining whether congestion, a prevalent issue at major civilian airports, also affected military installations characterized by a lower volume of flights. Data collection include direct observations from the Air Traffic Control (ATC), enabling a first-hand view of ground traffic patterns, including taxi in and out times, which were measured ruing site visits. Formal interviews with pilots provided insights into their experiences and perceptions of congestion during ground operations. Further insights were gained through informal discussions with ATC staff in the tower. These conversations aimed to understand the decision-making process behind the selection of taxi routes and gauge the ATC staff's perception of congestion levels. The assessment extended to evaluating the current effectiveness of ground traffic management practices. A key component of this evaluation was determining whether the integration of additional tools, such as ground traffic management software, could enhance operational efficiency and reduce ground congestion.

Objective 9: Assess the Culture of Fuel Efficiency

Objective 9 aimed to assess the culture of fuel efficiency within 8 Wing Trenton by exploring how deeply fuel efficiency principles are ingrained in the staff practices and attitudes, and the overall leadership messaging. Through interviews with staff members from various units and squadrons, insights were gathered on their perspectives towards fuel efficiency. The interviews were analyzed, and quotes were categorized into the themes of data reporting, confidence building, awareness, and training, and balancing operational priorities with fuel efficiency. This objective sought to understand the extent to which fuel efficiency is prioritized and embedded into the culture of 8 Wing. It involved examining if and how fuel efficiency considerations might potentially conflict with operational priorities. It also explored staff awareness if fuel saving measures, their integration into training, and the frequency of their application in daily operations. Identifying potential resistance to adoption fuel efficient practices was another critical area. This including uncovering any reservations staff might hold towards implementing sustainable measures and understanding the general sentiment among staff about the importance and feasibility of fuel efficiency. This objective also drew from other studies on fostering a culture of fuel efficiency, aiming to both map the current state of fuel efficiency culture at 8 Wing and identify strategics that could enhance the integration of fuel efficiency into the organization.

1.3 Scope of Research

Due to its proximity to Kingston and the type of aircraft operating at the location, the scope of this research focuses on the transport fleet at 8 Wing Trenton with the intent of expanding the scope to additional fleets in future research. Selecting 8 Wing as a case study for this research presents several advantages, greatly enhancing the depth and utility of the study. By focusing on a specific wing and fixed-wing transport aircraft, the research gains access to first-hand experiences and on-the-ground insights that are key for a comprehensive analysis.

The choice of 8 Wing Trenton allowed for direct engagement with personnel involved in air operations, creating opportunities for interviews and discussions. This qualitative approach enabled the researcher to amass first-hand perspectives from personnel actively engaged in the day-to-day operations of the Wing. These interviews and site visits provided valuable context, revealing current practices, challenges faced, and the overall operational environment. This qualitative approach can also bridge the gap where quantitative data is either unavailable or not easily accessible; presenting an opportunity to pinpoint areas where data should be collected. Furthermore, the study at 8 Wing Trenton allowed for an exploration of the attitudes and beliefs held by relevant personnel regarding sustainability initiatives. Understanding the perspectives of those involved directly in air operations is key for gauging the feasibility and acceptance or resistance of proposed sustainability measures.

This study strategically focused on the transport fleet outlined in Table 1.1 and illustrated in Figure 1.1, which included the CC-130J Hercules, CC-150 Polaris, and the CC-177 Globemaster III. Figure 1.1 also features the CC-330 Husky, which was not analyzed because its procurement was still ongoing during the study period. Additionally, it was uncertain which location would be selected as the main operating base for the CC-330. Nevertheless, it was identified as the critical aircraft influencing the redesign of the airfield and infrastructure. The choice to study the transport fleet was primarily driven by the similarity of these airframes to the extensively studied passenger aircraft in both academic research and the airline industry. Passenger aircraft have been a primary focus when it comes to sustainable aviation research, given their prevalence in commercial aviation and their environmental impact. By studying the RCAF’s transport fleet, which shares characteristics with commercial passenger planes, this study can leverage existing knowledge and sustainable practices established in academic research and the airline industry. Insights gained from this analysis will contribute to a broader understanding of sustainable measures that can be applied across the RCAF's aircraft fleets.

Figure 1.1: 8 Wing Trenton Transport Fleet Modified from (RCAF, 2017; RCAF 2023)

Table 1.1. Specifications for the transport fleet at 8 Wing Trenton

Aircraft	CC-130J	CC-177	CC-150
Quantity in CAF	17	4	5
Cruising Speed (km/h)	660	950	535
Empty Weight (kg)	40, 823	125, 645	80, 014
Max Gross Weight (kg)	79, 380	265, 350	157, 000
Fuel Capacity (kg)	20, 519	82, 125	19, 758
Height (m)	11.81	16.79	15.8
Wingspan (m)	40.38	51.74	43.9
Aircraft Group Number	IV	IV	IV

In contrast, the literature on sustainable measures for rotary wing fleets and fighter fleets has been relatively limited. This is particularly true within the realm of optimizing infrastructure and operations to decrease GHG emissions. Studies about GHG reduction measures for these fleets have mainly targeted the use of sustainable aviation fuels (SAFs), rather than changes to infrastructure and operations. These aircraft have unique operational profiles and challenges that differ significantly from traditional passenger and transport aircraft. Therefore, the decision to concentrate on the transport fleet allows this study to address a current gap in literature, providing valuable insights into sustainable practices that have not been extensively studies within the context of rotary wing and fighter fleets.

1.4 Limitations

The limitations to this study are expanded in subsequent sections and include the following:

1. Depth of Study;
2. Temporal Limitations;
3. Access to Historical Data; and
4. RCAF-specific studies.

Depth of Study

The broad scope of this study encompassed various aspects of the optimization of infrastructure and operations across three aircraft, presenting a limitation of depth in certain areas that were studied. Due to the breadth of this study and time constraints, certain aspects were not explored in depth. As such, certain areas certainly necessitate further, more targeted investigations for a more comprehensive understanding. These have been cited and expanded upon within the Recommendations Section at the end of this thesis.

Temporal Limitations

The study's temporal limitations should be acknowledged, as the information gathered reflects a snapshot in time. As operational circumstances, technologies, and policies evolve, the findings may not cover all possible scenarios or future developments. Furthermore, the study involved selective personnel interviews and the views expressed by these individuals may not be entirely representative of the broader population of relevant staff at 8 Wing. As a result, the conclusions drawn should be contextualized within the timeframe of the study and the perspectives of the personnel that were interviewed.

Access to Historical Data

The availability and accessibility of historical data, particularly in areas such as historical flight data, presented challenges during the research. In certain instances, data was available but not easily accessible or entirely unavailable. In these cases, the researcher had to rely on assumptions, as outlined throughout the thesis document. To address these gaps, qualitative information obtained from interviews and site visits were utilized in order to provide context and insights, although this does not entirely replace the depth and accuracy that historical quantitative data can offer.

RCAF Specific Studies

The shortage of RCAF-specific studies in the literature on sustainable aviation practices presented a significant challenge in this research, requiring the researcher to make certain assumptions about the applicability of sustainable measures. With limited precedent and context-specific to the RCAF, the study had to draw on broader sustainable aviation literature and adapt findings from commercial aviation and other military contexts. The assumptions, outlined in the thesis, are necessary to bridge the knowledge gap and develop initial insights into potential sustainable measures for the RCAF fleets. These assumptions introduce a level of uncertainty, which can be challenging to quantify without empirical data. The lack of RCAF-specific studies underscores the need for future research that dive deeper into the intricacies of the RCAF's current and projected operations.

1.5 Research Site Overview

CFB Trenton is situated in the town of Trenton in the Quinte West region of Ontario, Canada, along the shores of the Bay of Quinte (DND, 2022). CFB Trenton is the overall military base in Trenton, Ontario, encompassing all infrastructure, units, and services, including operational and support facilities. 8 Wing Trenton is the specific air force unit within CFB Trenton, responsible for managing and executing air mobility missions and search and rescue operations. CFB Trenton serves as Canada's main operating base (MOB) for deployable expeditionary forces, search and rescue

(SAR) operations, and air mobility. The CC-130, CC-150, and CC-177 fleets are primarily supported by CFB Trenton, which serves as the RCAF’s primary transportation hub. The Canadian Armed Forces (CAF) receive supplies and assistance from CFB Trenton for both domestic and international missions. CFB Trenton is a deployed operating base (DOB) that supports Canadian Forces Station (CFS) Alert and tactical fighter operations for the RCAF and North American Aerospace Defence (NORAD) missions.

1.5.1 Runway and Airfield Layout

Despite being the main air mobility hub for the CAF, runway 06-24 is the sole runway at CFB Trenton (DND, 2022). The lack of runway redundancy creates an added strain on operations considering that CFB Trenton cannot operate without around-the-clock access to the airfield. Furthermore, a total shutdown of runway 06-24 often necessitates the relocation of 8 Wing squadrons to Mirabel or Mountainview airfields. The south side of the taxiway, Papa, which is parallel to runway 06-24, also functions as a runway for the CC-130 and CC-177 during training and emergency scenarios. Even as an austere runway, taxiway Papa does not meet the criteria for runway classification, thus, it operates under a waiver. The CC-150, CF-18, and CC-144 are not permitted to use taxiway Papa as a runway and rely solely on runway 06-24 for take-offs and landings.

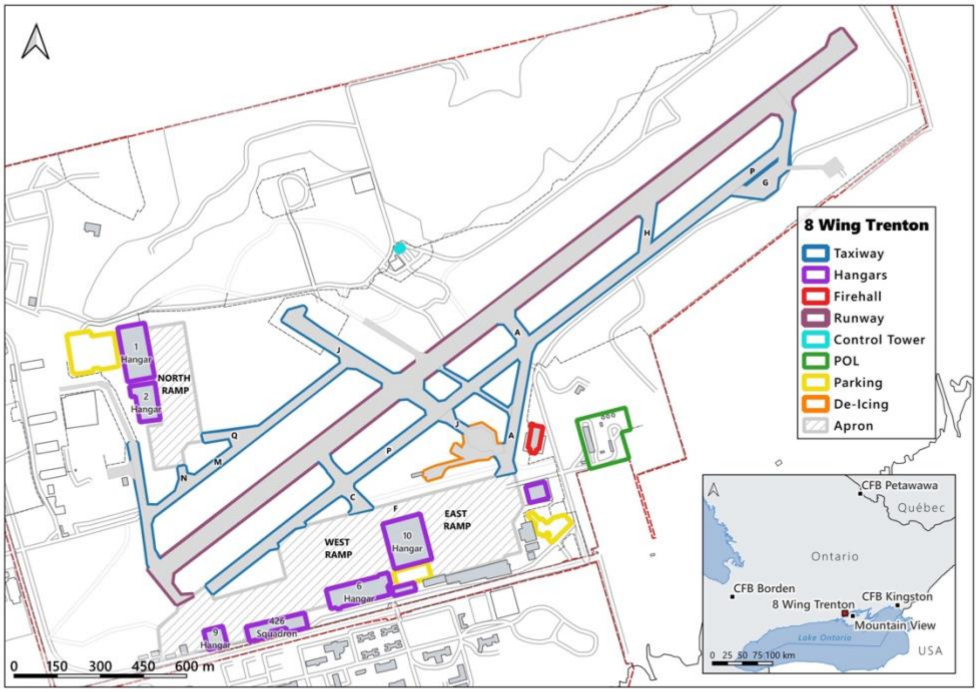


Figure 1.2: 8 Wing Trenton Airfield Site Map

1.5.2 Overview of Aircraft

Fixed-wing transport aircraft at 8 Wing Trenton include the CC-130, CC-150, CC-177, CC-144, and CC-145. Figure 1.1 only the CC-130, CC-150, and CC-177 have been considered for this study, as illustrated in Figure 1.1. Across the RCAF, the CC-130, CC-150, and CC-177 consume approximately 50.3% of all aviation fuel consumed, whereas the CC-144 and CC-145 consume approximately 2.4% (RCAF, 2023). The specifications for the transport fleet at 8 Wing Trenton are summarized in Table 1.2.

Table 1.2. Specifications for the transport fleet at 8 Wing Trenton (St-Jean et al., 2023)

Aircraft	CC-130J	CC-177	CC-150
Quantity in CAF	17	4	5
Cruising Speed (km/h)	660	950	535
Empty Weight (kg)	40, 823	125, 645	80, 014
Max Gross Weight (kg)	79, 380	265, 350	157, 000
Fuel Capacity (kg)	20, 519	82, 125	19, 758
Height (m)	11.81	16.79	15.8
Wingspan (m)	40.38	51.74	43.9
Aircraft Group Number	IV	IV	IV

1.5.3 GHG Emissions

The use of fossil fuels at 8 Wing Trenton, is by far the biggest contributor to GHG emissions. A study undertaken by the RMC Green Team (2020), revealed that jet fuel (F-34 and F-37) produces the highest GHG emissions, accounting for approximately 80% of total emissions on the base. The second largest contributor is the burning of natural gas, accounting for approximately 16% of total emissions. Given that these emissions are used to heat water and buildings, they can be grouped into total building GHG emissions. The remaining activities, contribute to approximately 4% of GHG emissions and include the burning of diesel, gasoline, incineration, and wastewater treatment plant (WWTP) off-gassing. The distribution of GHG emissions recorded at 8 Wing Trenton is presented in Figure 1.3.

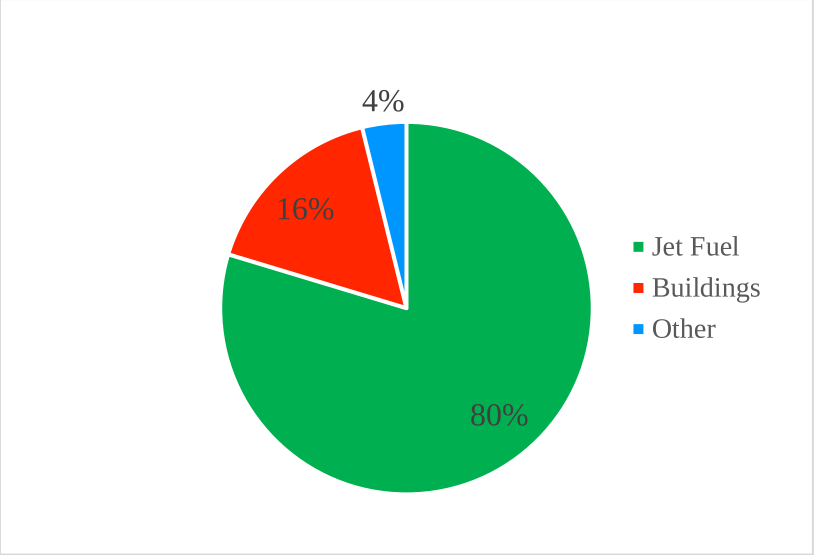


Figure 1.3: 8 Wing Trenton GHG emissions. modified from (RMC Green Team, 2020)

1.6 Thesis Organization

This thesis was prepared in accordance with the RMC's *Thesis Preparation Guidelines* (2015). This thesis follows the traditional format. A summary of the content by chapter is as follows:

Chapter 1 – Introduction. This chapter provides the purpose of the study, thesis objectives, thesis scope, limitations, site overview, and thesis organization.

Chapter 2 – Background. This chapter examines the governing strategic direction, DND progress on climate change, civil aviation progress on climate change, and civil aviation targets.

Chapter 3 – Literature Review. This chapter examines the relevant literature on aspects related to greenhouse gas (GHG) emissions in aviation, including estimated fuel burn and emissions, GHG emission scopes, and net zero contributions. It also examines sustainable measures for aviation including aircraft taxiing, sustainable aviation fuels, reducing auxiliary power use, ground support equipment, de-icing, and training. It also compares the differences between military and civilian aviation within the context of sustainability.

Chapter 4 – Methodology. This chapter outlines the methodology that was employed for this research project. It expands on the literature review, questionnaire development, interviews, site visit results, and analysis methodology.

Chapter 6 – Site Overview and Redesign. This chapter presents 8 Wing's organizational layout, and the layout and uses existing of the airfield and infrastructure. It identifies airfield deficiencies and forecasted infrastructure projects derived from Trenton's MRPDP. Best practices for airfield design focused on reducing aircraft fuel consumption and enhancing operational efficiency were considered, leading to a comprehensive redesign of the airfield. The new layout is designed with sustainability in mind, aiming to accommodate forecasted operational requirements over the next 25-30 years, ensuring the airfield's effectiveness and efficiency while addressing current deficiencies and future needs.

Chapter 7 – Qualitative and Quantitative Analysis. This chapter presents investigations into several key measures related to sustainable ground operations such including ground fuel consumption, fuel management practices, ground traffic management, reduced engine taxi (RET) practices, mission fuel planning, de-icing processes, use of ground support equipment, the culture of fuel efficiency. Data gathering included use of secondary and primary data, such as interviews and site visit, allowing for a comprehensive overview of current practices and the identification of potential areas of improvement in fuel efficiency. This chapter also draws from best practices and lessons learnt from other studies and how they could be applied to enhance fuel efficiency in the RCAF.

Chapter 8 – Outcomes and Recommendations. This chapter summarizes the major findings, recommendations, and future research recommendations in this field.

2. Background

2.1 Strategic Direction

Examining policies from DND, CAF, and RCAF is critical to ensure that this research aligns with the strategic direction laid out by these organizations. The policies serve as foundational frameworks that dictate the overarching goals and priorities relating to sustainability and net zero policy. By contextualizing the research with these policies in mind, the research seeks to gain valuable insights into the strategic objectives set out by the department and the government of Canada and come up with feasible, implementable solutions.

Federal Government Strategic Direction

In 2017, the Canadian government released the Greening Government Strategy, which set targets to reduce GHG emissions from operations by 40% from 2005 levels by 2030, and subsequently 80% by 2050 (TBS, 2020). As part of the aforementioned targets, certain government GHG emissions were excluded from the government's reduction targets for safety and security reasons (ECCC, 2021). The National Safety and Security (NSS) exemption applies to operational missions within the DND and consequently, emissions from RCAF aircraft are omitted in the federal GHG reduction targets (ECCC, 2021).

DND Strategic Direction

Despite the exemption of aviation fuel from the NSS considerations, the RCAF is adopting a proactive stance by exploring various avenues to decarbonize its fleets. In 2023, DND introduced the Defence Climate and Sustainability Strategy (DCSS), which served to enhance the strategic direction outlined in the Defence Energy and Environment Strategy (DND, 2023). Concerning NSS Fleets, Target 9 pledges to support the Canadian government's commitment to achieve net-zero emissions by 2050 from the NSS fleet, considering factors such as availability, affordability, compatibility, and operational feasibility. Specifically related to aircraft, Target 12 commits to the review of operational procedures intending to identify efficiencies that would effectively reduce greenhouse gas emissions for selected aircraft within the RCAF NSS fleet.

RCAF Path to Net Zero Strategy

The RCAF Path to Net Zero Strategy (PTNZ) presents vectors to attain net zero emissions, consistent with the overarching objectives of the government of Canada (RCAF, 2022). While the PTNZ is anticipated to undergo several changes throughout the span of the strategy, due to shifts in policy, technology, and resources, it aims to direct and shape preliminary endeavours at all levels. As illustrated in Figure 2.1, the PNTZ strategy delineates LOOs that are intended to be sustained across a period of 30 years to achieve net zero emissions by the year 2050.

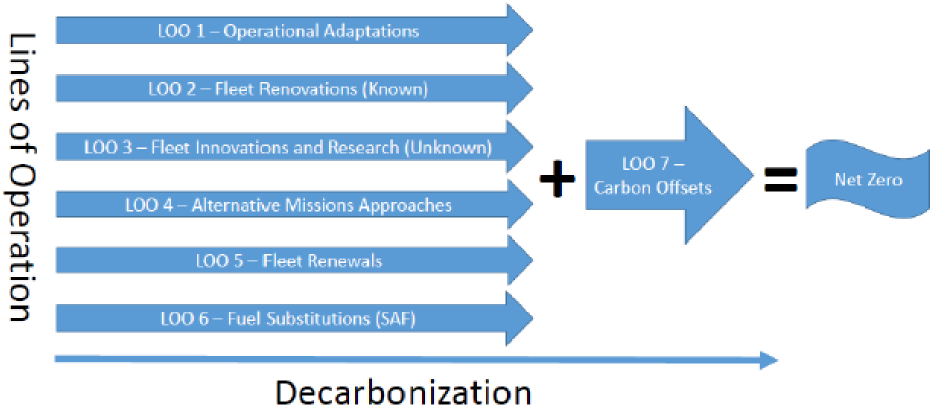


Figure 2.1: RCAF Path To Net Zero Strategic Outline Plan (RCAF, 2022)

Descriptions of each LOO and examples of preliminary activities that were incorporated into this research study are as follows (RCAF, 2022):

LOO 1: Operational adaptations for fuel efficiency
Wherein policy, doctrine, training, and procedures are scrubbed for efficiencies, decisions made on compromises, and changes are applied to the RCAF mission. This will include a comprehensive Best Practice Review; wherein global and domestic civil industry and allied military's experience with fuel efficiency is aggressively investigated against, and applied with discipline to, the RCAF mission.

LOO 2: Fleet renovations
Wherein known technologies are applied across the various fleets to improve fuel efficiency or operational efficiencies affecting the RCAF mission.

LOO 3: Fleet innovation and research
Wherein unknown or unproven technologies or procedures relating to efficiencies are actively investigated for application to the RCAF mission and applied where feasible.

LOO 4: Alternative Mission Approaches
Wherein different actions are explored to accomplish the RCAF mission – such as simulations, smaller Unmanned Aerial Vehicles (UAVs), space-based systems, and Civil-Military Cooperation (CIMIC) leveraging.

LOO 5: Fleet Renewals
Wherein airframes or major components will be replaced with modern efficient technologies over the 30-year timeline of the path.

LOO 6: Fuel Substitutions
Wherein traditional hydrocarbon fuel is progressively replaced by accepted alternative sustainable aviation fuels as they become available worldwide. The RCAF will contribute to market development initiatives and adopt new fuels as technically, commercially, and economically feasible within the RCAF mission.

LOO 7: Carbon Offsets
Wherein any remaining carbon contributions are balanced off with the purchase of carbon credits outside of the RCAF system. Progressing this LOO is dependent on evolving federal policies and is largely independent of the RCAF's influence. No action is required under current policies.

2.2 DND Progress on Climate Change

In recent years, DND has made significant progress in curtailing emissions due to operations. As discussed in the DCSS, DND is currently on track to meet its commitment to reduce GHG emissions by 40% below 2025 and achieve net zero emissions by 2050 (DND, 2023). Illustrated in Figure 2.1, as of fiscal year (FY) 21-22, DND realized a reduction of 36% compared with FY 05-06. Notably, 81% of NSS fleet emissions came from aircraft.

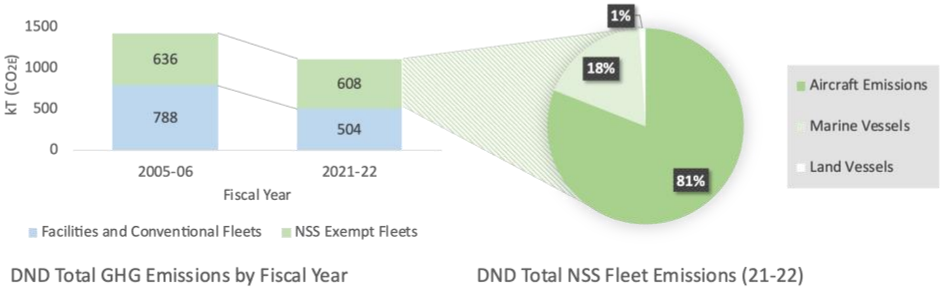


Figure 2.1: DND GHG Emissions Breakdown (St-Jean, 2023)

However, despite these targets, there is a discernable gap between targets and actual progress, particularly, within the NSS fleet. For instance, within the same period, emissions reductions over the same period amounted to a mere 4.4%, a figure that falls short of broader emissions targets and underscores the challenges of reducing emissions from aircraft (see Figure 2.2). Within the NSS fleet, aircraft GHG emissions have only seen a marginal decrease of 0.3% since the fiscal year 2005-06. This stark contrast highlights the complexity and difficulty of progressing towards climate targets for aviation. This discrepancy between targets and modest progress within the NSS fleets signals that there remains significant work that still needs to be done. The RCAF must continue to innovate and implement more effective measures to bridge this gap and meet emissions targets.

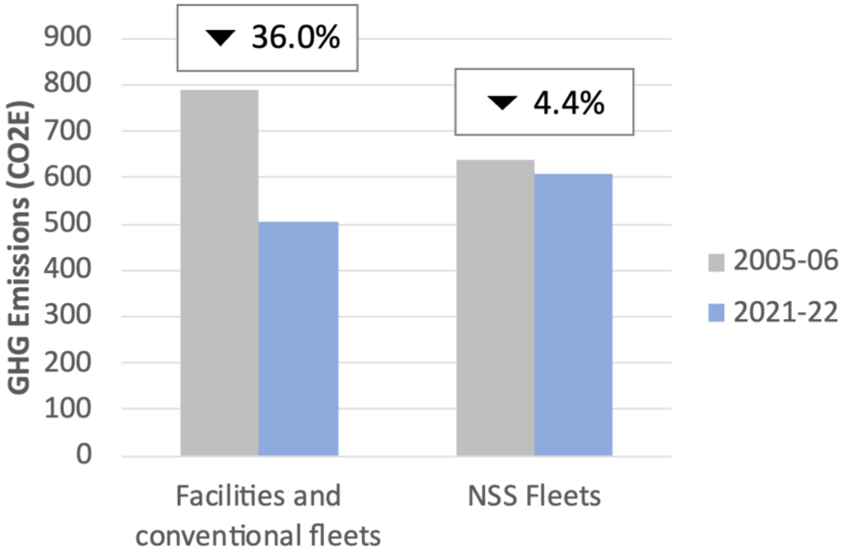


Figure 2.2: GHG Emission Reduction Progress (St-Jean, 2023)

2.3 Civil Aviation Targets

Although the civil aviation industry and the RCAF have distinct characteristics, there are lessons from the civil aviation sector that can be beneficial to the RCAF. This is particularly true for the shared measures necessary to attain net zero emissions, despite differences in their respective structures and mandates. Overall, both sectors can draw from common strategies to achieve net emissions zero by 2050. The subsequent sections will explore the aviation industry’s projected path to net zero emissions and emissions target.

2.3.1 Civil Aviation Targets

To address its significant impact on climate change, the aviation industry, under the guidance of the International Air Transport Association (IATA), set forth three ambitious voluntary targets in 2009 aimed at mitigating its environmental footprint. First, the industry committed to achieving a 1.5% annual average increase in fuel efficiency between 2009 and 2020, a goal aimed at reducing fuel consumption and, consequently, emissions per kilometer flown. Following this period, the second target stipulates a move towards carbon-neutral growth post-2020, ensuring that any increase in aviation's carbon footprint is offset by equal carbon-reducing activities elsewhere. Lastly, the sector has pledged to drastically reduce its CO_2 emissions, aiming for a 50% reduction from the levels recorded in 2005 by the year 2050. These targets represent the industry's proactive approach to contribute to global efforts in combating climate change (IATA, 2022). These three voluntary targets can be summarized as per the following:

1. A 1.5% annual average increase in fuel efficiency from 2009 and 2020;
2. Carbon neutral growth after 2020; and
3. A reduction of 50% in CO_2 levels from 2005 level by 2050.

2.3.2 Path to Net Zero

The Air Transport Action Group (ATAG) is a global association representing organizations in the aviation industry including airlines, airports, suppliers, and manufacturers (ATAG, 2021). The Waypoint 2050 report is a collaboration between over 70 industry experts and stakeholders in the broader aviation industry. It explores scenarios on how the industry can achieve net zero by the year 2050. It covers efforts required over the next 30 years in commercial aviation. Notably, it does not include military or private aircraft, however, there are certainly themes that can be applied to the military.

The report covers four scenarios including a baseline scenario, prioritizing technology, and operations, prioritizing sustainable fuel deployment, and an aspirational and aggressive technology perspective (ATAG, 2021). The baseline scenario offers insights into the potential consequences of inaction, where emissions reductions are largely due to carbon offsets. Further, the report’s analysis of various scenarios demonstrates the dynamic nature of the industry’s path to net zero. Likewise, the RCAF will need to be flexible in its approach as new fuels, technologies, and novel measures come online.

Traffic Growth

A primary challenge with reducing GHG emissions in commercial aviation is that improvements in fuel efficiency have been largely outpaced by increased consumer demand (ATAG, 2021). Although this phenomenon is not entirely applicable to the military, it is important to keep in mind that it is a significant driver of increasing emissions in the commercial aviation industry given that increased consumer demand has largely outpaced gains in fuel efficiency. Figure 2.3 illustrates how while increased consumer demand have historically driven up emissions, improvements in fuel efficiency have avoided over 11 Gt of CO_2 emissions since 1990. Furthermore, investments in technology, operations and infrastructure, fuels, and carbon offsets will be required to achieve net zero emissions by 2050.

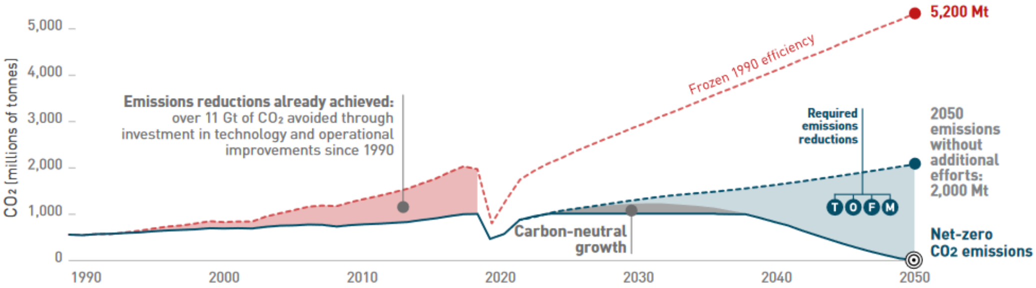


Figure 2.3: Historical CO2 emissions and projections moving forward (ATAG, 2021)

Technology

Compared to their predecessors, today's aircraft are already very efficient (ATAG, 2021). This is particularly true when considering their speed and operating conditions. Each new generation of aircraft consumes 15-20% less fuel than the aircraft that they replaced. Technology plays a significant role in improving the fuel efficiency of aircraft and can be primarily classified into the subcategories of airframe and propulsion systems. The airframe involves aspects like aerodynamics, the use of lightweight materials, advancements in equipment, new configurations, energy management and electrification. Whereas propulsion systems include factors such as engine architecture, thermal and propulsion efficiency, combustor technologies, advanced materials, and electrification.

Infrastructure and Operations

Although emissions reductions due to optimization of infrastructure and operations on their own are not sufficient to achieve net zero emissions, they can be implemented at a scale more rapidly than technologies and sustainable aviation fuels (ATAG, 2021). Infrastructure improvements include changes in air traffic management, and energy savings at the airport such as limitations on the use of auxiliary power units, reduced engine taxi, and reduced taxi times. On the other hand, operational improvements include basic weight reduction, improvement of the aerodynamics of in-service aircraft, and the use of systems to improve efficiency during the operation of aircraft.

Sustainable Aviation Fuels

Sustainable aviation fuel (SAF) is a term for a broad class of non-fossil-derived aviation fuels (ATAG, 2021). They are derived from a variety of sources other than fossils such as biomass, waste residue, and synthetic pathways (ATAG, 2010). The certification for SAFs is the same as conventional jet fuel. They are drop-in fuels, meaning that they can be blended with conventional jet fuels in different proportions, utilize existing infrastructure, and do not require any modifications to the aircraft. To be permitted to use the term sustainable, they are subjected to sustainability standards including reducing lifecycle carbon emissions, minimizing fresh water usage, not interfering with food production, and avoiding deforestation (ATAG, 2021). Compared to conventional fuels, they are estimated to reduce CO_2 emissions by approximately 80%, although this figure varies depending on the type of SAF. The largest barriers to the widespread adoption of SAFs include production and costs. ATAG estimated that production would need to double for SAFs to reach 2% of all aviation fuels consumed by 2025. Additionally, the cost of SAFs are currently 1.5 to 6 times higher than conventional jet fuels (EASA, 2023). It is expected that as production of SAFs ramp up in future years, prices will become more cost effective (ATAG, 2021).

Carbon Offsets

In each of the scenarios, ATAG has identified the requirement for 90% of the aviation section’s fuel requirements to be met using SAFs (ATAG, 2021). However, the remaining emissions reductions would still need to come from out-of-sector carbon offsets. Broadly speaking, carbon offsets are a mechanism that allows organizations or individuals to compensate for their GHG emissions by investing in projects or activities that reduce or remove an equivalent amount of CO_2 from the atmosphere. Other mechanisms include taxation or exchanging of carbon credits. This approach is often used as a temporary measure to compensate for emissions that are challenging or expensive to eliminate directly, allowing for an immediate impact on GHG reduction efforts. It has been noted by the IATA that as emerging technologies like SAF become more prevalent, the requirement for offsets is likely to decrease (Ellerbeck, 2022).

3. Literature Review

3.1 GHG Emissions

The environmental impact of the aviation industry is primarily attributed to the release of greenhouse gas (GHG) emissions (Alonso et al., 2014). As illustrated in Figure 3.1, emissions originating from airport activities can be characterized as either exhaust emissions, produced by aircraft or ground support equipment (GSE), or evaporative emissions, arising from activities like aircraft refuelling and de-icing (Cokorilo, 2016). These emissions include carbon dioxide (CO_2), sulphur oxides (SO_x) carbon monoxide (CO), and soot and are a function of operating conditions such as aircraft taxi times, thrust settings, and the number of engines utilized (Benito & Alonso, 2018; Deonandan & Balakrishnan, 2010; Macintosh & Wallace, 2009; Waitz et al., 2005).

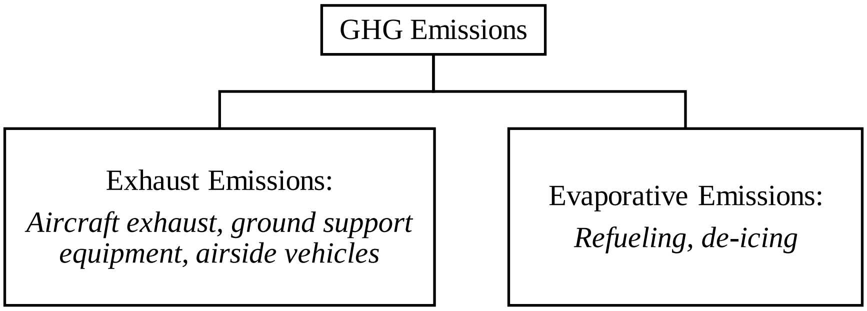


Figure 3.1: Characterization of Airport GHG Emissions

As presented in Table 3.1, the Airport Cooperative Research Program (ACRP) defines three levels of GHGs that airports can be addressed by airport operators (ACRP, 2009). The GHGs included in this list are reflective of those included in the Kyoto Protocol. For the majority of airports, CO_2 is the most crucial GHG to inventory (ACI, 2009). Despite having the least potent greenhouse effect among the Kyoto Protocol gases, CO_2 is by far the largest contributor to global emissions.

Table 3.1: Three Levels of pollutants that airport operators can address (ACRP, 2009)

Level 1	CO_2 only
Level 2	Gases covered by the Kyoto Protocol including CO_2, CH_4, N_2O, HFC, PFC, and SF_6.
Level 3	All six Kyoto pollutants, precursors, and any other pollutants exerting a GHG effect

For level 2, the remaining 5 Kyoto Protocol gases are not often emitted at airports (ACI, 2009). Additionally, at level 3, there may be NO_x, SO_x, particulate matter (PM), ozone, hydrocarbons, and water vapour. Due to their effects on local air quality, several of these pollutants are tracked at airports.

However, their exact contributions to climate change are not well understood. GHG inventory assessments are performed in order to calculate the overall amount of CO_2, typically, annually (ACI, 2009). To facilitate comparison, the masses of other GHG emissions are usually transformed into a comparable mass of CO_2 by employing a conversion factor, commonly referred to as the Global Warming Potential (GWP) of the pollutant. The GWP is determined for each GHG based on its atmospheric lifespan and heat-absorbing capabilities (RMC Green Team, 2020). GHGs with higher GWP can capture more energy per unit weight compared to those with lower GWPs. Table 3.2 provides an overview of GWPs of common GHGs.

Table 3.2: Global Warming Potentials for Various GHGs (RMC Green Team, 2020)

Greenhouse Gas	**GWP (CO_2e)**
Carbon Dioxide (CO_2)	1
Methane (CH_4)	25
Nitrous Oxide (N_2O)	298
Hydrofluorocarbons (HFCs)	124 – 14,800
Sulfur Hexafluoride (SF_6)	22,800
Nitrogen Trifluoride (NF_3)	17,200

3.2 Estimating Fuel Burn and Emissions

Estimation of fuel burn plays an important role in calculating the environmental impact of air traffic operations and has been a topic of interest for several years (Collins, 1982). The total amount of GHG emissions is directly proportional to the quantity of fuel consumed (Waitz et al., 2005). The International Air Transport Associated (IATA), estimates that 3.16 kg of CO_2 is produced per kg of jet fuel combusted(IATA, 2022). While the quantity of GHG released is dependent on operating conditions (i.e. aircraft maintenance and efficiency, distance travelled, load, and atmospheric conditions), estimated combustion by-products per kg of jet fuel combustion are presented in Table 3.3.

Table 3.3: Estimated combustion by-products per kg of jet fuel consumption (Benito & Alonso, 2018; IATA, 2022)

Combustion by-product	**Estimated quantity per kg of jet fuel**
CO2	3.16 kg
H2O	1.239 kg
NOx	6-20 g
SO2	1 g
CO	0.7 – 2.5 kg
UHC (Unburnt Hydrocarbons)	0.1 – 0.7 g
Soot	0.02 kg

According to the International Civil Aviation Organization (ICAO), emissions from an individual aircraft are primarily a function of three variables: time-in-mode (TIM), main engine emissions indices (EI), and main engine fuel flow (ICAO, 2020). The three variables are defined as follows (ICAO, 2020):

a. Time-in-mode (TIM): the duration during which an aircraft’s engines operated at a specified level of power, commonly associated with one of the landing and takeoff (LTO) modes within the operational flight cycle(s);
b. Emission Index (EI): The mass of pollutant emitted per unit mass of fuel for a specific engine (g/kg of fuel); and,
c. Fuel Flow (FF): Fuel flow for the mode (e.g. take-off, climb-out, idle, and approach) each engine used on the aircraft type (kg/s).

The process of certifying aircraft engines to obtain EIs and FFs is determined using the aircraft's LTO cycle, consisting of four modes of operation: approach, idle, take-off, and climb (ICAO, 2022). The engine emissions certification information from ICAO pertaining to emissions, along with corresponding fuel flow rates, are published with the four modes of operation along with reference times (i.e. time-in-mode) at each of the power settings (ICAO, 2021). While the reference TIMs are not representative of actual TIM in real-world scenarios, they can be used to provide a conservative estimate of time spent in each mode of operation when airport-specific TIM data is not available. Figure 3.2 illustrates the LTO cycle and corresponding reference thrust and TIM values.

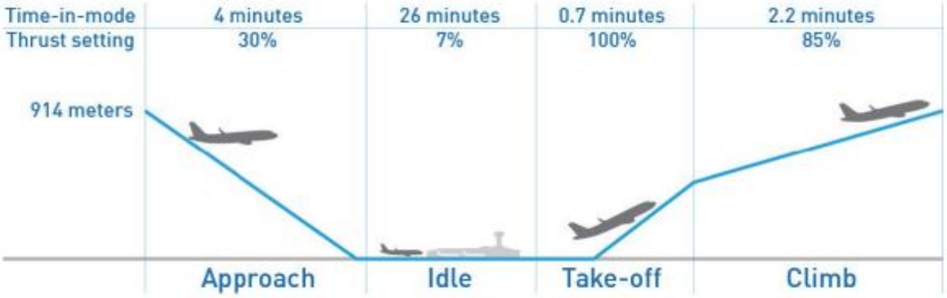


Figure 3.2: ICAO engine emissions certification LTO cycle (ICAO, 2022).

3.3 GHG Emission Sources

Airports Council International (ACI) categorizes GHG emissions into three scopes and recommends that each should be reported separately (ACI, 2009). Understanding the three scopes of GHG emissions is key for developing strategies to reduce emissions across different sectors. As illustrated in Table 3.4 and expanded in subsequent sections, GHG emission sources can be broadly characterized as either Scope 1, Scope 2, or Scope 3 emissions.

Scope 1 emissions are direct GHG emissions generated from sources owned or controlled by the government. Examples of Scope 1 emissions include government facilities, vehicles, and aircraft. Scope 1 emissions are the most controllable by the government because they are produced directly by their assets and activities. For example, the government can directly reduce scope 1 emissions by transitioning to electric vehicles in their fleets, improving the energy efficiency of buildings, or by transitioning from fossil fuels to renewable energy sources.

Scope 2 emissions cover GHG emissions produced indirectly from the purchase of electricity, heat, or steam that the government consumes. These emissions are tied to the local power grid and how the power is produced. For example, if the grid relies heavily on fossil fuels for power generation, Scope 2 emissions will naturally be higher. The government can partially control these emissions by minimizing the use of purchased power or by leveraging onsite renewable energy in lieu of purchased utilities.

Scope 3 emissions include all other direct emissions that occur because of the activities of the government but occur from sources not owned or controlled by them. These can include items such as business travel, employee commuting, waste disposal, and supply chain emissions of procured goods and services. Scope 3 emissions are the hardest to quantify and control because they involve actions of third-party suppliers. Scope 3 emissions are not always reported due to the complexity and lack of control over the sources. Nevertheless, understanding scope 3 emissions is important to understand the entire scope of GHG emissions. They can also be used to engage with suppliers and stakeholders to reduce the overall carbon footprint.

Table 3.4: Emissions scope for airport activities (Canada, 2022b)

Scope 1	GHG emissions are produced by sources that are owned or controlled by the government.
Scope 2	GHG emissions are those generated indirectly from the consumption of purchased energy
Scope 3	GHG emissions are indirect such as the emissions produced in the supply chain of the goods and services

GHG Emissions: Aircraft Taxi

Taxiing refers to the movement of an aircraft on the ground, using taxiways to navigate between the terminal gate and the runway (Guo et al., 2014). Under most circumstances, taxiing involves both pushback and engine-powered movement. Pushback is when an aircraft is moved backwards from the gate, typically with the help of ground support equipment (GSE) such as pushback tractors or tugs. During most of the taxi-out and the entirety of the taxi-in phase, the aircraft is propelled using its own power.

The use of ICAO for taxi fuel burn estimation requires the assumption that all ground operations occur entirely at 7% thrust (ICAO, 2021). While this simplifies the estimation process, there is no differentiation between the various taxi phases such as ground idle, constant speed, taxi, breakaway, and perpendicular turns. Khadilkar & Balakrishan (2012), identified different thrust values during the taxi phase, as illustrated in Table 3.5.

Table 3.5: Approximate thrust from fuel indices during the taxi phase of aircraft (Khadilkar & Balakrishnan, 2012)

Taxi Phase	Ground Idle	Constant Speed Taxi	Breakaway	Perpendicular Turns
Thrust	4%	5%	9%	7%

The ICAO fuel burn indices can frequently vary from the values derived from the Flight Data Recorder. (Khadilkar & Balakrishnan, 2012; Patterson et al., 2009). For many aircraft models, the fuel burn calculated using the ICAO method tends to be higher than what is recorded by the FDR. Fuel indices can provide a general estimation of fuel consumption, but their reliability depends on several factors including the accuracy of the data used to create the indices, the similarity of the aircraft and the operational conditions being compared. It is always recommended to use actual fuel consumption data, when available, for more accurate results but fuel indices are useful as a rough guide, particularly if flight data is not readily available.

3.4 Sustainable Ground Operations

Flight phases can be categorized into two segments: en-route cruise and the landing and take-off (LTO) cycle (Guo et al., 2014). Decreasing fuel consumption during the en-route cruise is particularly challenging as safety regulations take precedence over environmental and economic factors. The LTO encompasses all activities in close proximity to the airport, typically limited to activities below 3000 feet. Given that there is less flexibility in controlling fuel consumption during the en-route cruise phase, the aviation industry is growingly seeking more sustainable alternatives for aircraft ground movements.

3.4.1 Aircraft Taxi

When aircraft operate at low power settings, such as during taxiing, they are less fuel efficient than when at cruising power, resulting in increased emissions at airports and surrounding areas (Guo et al., 2014). During aircraft taxi, landing gear brakes are used, leading to further loss of energy. Given the inefficient nature of the taxi phase, novel approaches and fuel-efficient technologies have arisen in recent years to reduce fuel usage and emissions. There are mainly two methods to reduce fuel consumption and emissions during aircraft taxi. The first method involves adopting operational practices such as reduced-engine taxiing (RET). The second approach centres on advancing technologies, which include alternative ground propulsion systems and designing more fuel-efficient engines. Aircraft taxi fuel consumption reduction measures are summarized in Figure 3.3.

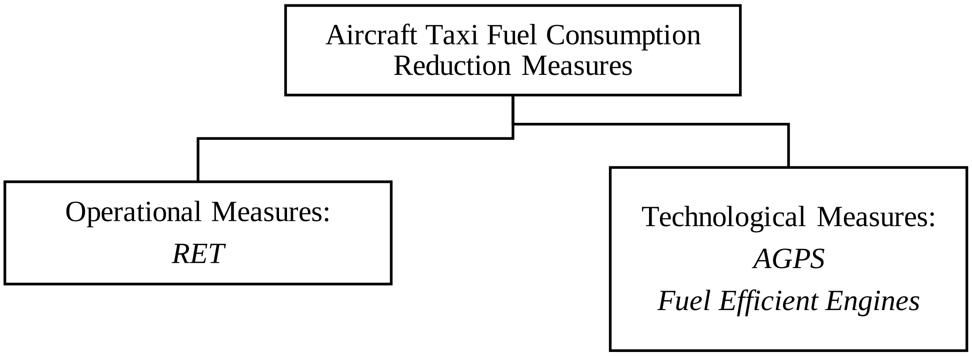


Figure 3.3: Aircraft Taxi Fuel Consumption Reduction Measures

Reduced Engine Taxi

RET, is a method to reduce fuel consumption and emissions during taxiing using only half the installed number of engines for the majority of the taxiing time (Stettler et al., 2018). It is the most feasible operational measure, offering immediate implementation benefits without the need for infrastructure modifications or upfront investments (Khammash et al., 2017). Depending on aircraft type and operating conditions, RET is expected to yield reductions of 20% to 40% in CO_2 and 10% to 30% in NO_x (Heathrow Airport, 2012).

Though effective in fuel and emissions reductions, RET has several additional considerations compared to conventional taxiing. The most critical consideration for RET operation lies in the aircraft's design (Kameníková et al., 2022). For RET to be considered, the aircraft must have sufficient residual thrust, which can only be achieved up to a specified maximum gross weight. For certain aircraft, emissions reductions may be minimal due to the increased thrust requirement on the operative engines (IFALPA, 2016). Moreover, aircraft engines require warm-up and cooldown periods ranging from 2 to 5 minutes (Airbus, 2004; Deonandan & Balakrishnan, 2010; Di Mascio et al., 2022). Thus, RET can only be considered when the taxiing phase exceeds the time necessary for the engines to warm up or cool down. RET is also advised against in the case of sloping taxiways, unfavourable weather conditions, and in areas with tight turns, as they could result in power overloads for the operational engines (Di Mascio et al., 2022). As a broad consideration, RET can negatively impact the aircraft's performance, particularly in terms of its maneuverability and balance (AEON, n.d.). Pilots have reported challenges when making tight turns on narrow taxiways during RET, particularly when asymmetric thrust is present, as is the case with twin engine-aircraft (Deonandan & Balakrishnan, 2010). RET also removes redundancy, increasing the likelihood of losing braking capability and nose wheel steering. As RET requires more thrust per engine to taxi, particularly, during breakaway and to navigate tight turns, caution should be exercised to prevent jet blast and foreign object damage (FOD) (Guo et al., 2014; IFALPA, 2016). Given the aforementioned considerations, RET should only be performed based on the pilot's judgement, following a thorough assessment of local and operational conditions (IFALPA, 2016). A summary of the considerations for using RET are presented in Table 3.6.

Table 3.6: Summary of Considerations for Using RET

Consideration	Rationale
Aircraft design	The aircraft must have sufficient residual thrust for RET to be considered. Emissions reductions may be minimal for certain aircraft.
Engine warm up and cool down	The taxiing time must exceed the time necessary for engine warm up or cool down time.
Unfavourable taxiway conditions	Sloping taxiways in unfavourable conditions, and areas with tight turns could result in power overloads for the operational engines
Reduced Redundancy	Reduced redundancy during RET increases the risk of loss of braking capability and nose wheel steering

Consideration	Rationale
Reduced manoeuverability	RET can negatively impact the aircraft's maneuverability and balance
Safety Concerns	Caution must be exercised as the greater thrust per operational engine may result in jet blast and FOD

As illustrated in Figure 3.4, RET can be further divided into two sub-types, pre-departure taxiing 'reduced engine taxi out' (RET-out), and post landing taxiing 'reduced engine taxi-in' (RET-in) (Pillirone, 2020). While both RET-out and RET-in are employed to a certain extent in the airline industry, RET-in is much more common. Pillirone (2020) estimated that RET-out is used on about 50%, while RET-out is used in less than 10% of departures. Furthermore, RET-out is not a recommended procedure in most airlines, primarily due to the increased workload associated with the engine start-up procedure.

The workload during RET-out is significantly greater compared to RET-in, mainly due to the engine start procedure (IFALPA, 2016). As it could compromise safety in certain situations, RET-in is used as the predominant procedure in commercial air transport aircraft operations (Kameníková et al., 2022). Whereas taxi-in times are more predictable, uncertainty regarding taxi-out time dissuades pilots from initiating RET-out procedures (Pillirone, 2020). During taxi out, the aircraft is typically following a more complex route, with more turns and intersections, which can make it harder for pilots to maintain control and monitor their speed and position on the ground. Due to fuel burnt during flight, post-flight aircraft weigh much less than pre-flight and can typically taxi in using RET on idle power (USAF EATF, 2018). Moreover, mechanical problems can occur during the start-up of the remaining engines, necessitating a return to the gate for maintenance (Airbus, 2004). In contrast, if a mechanical problem occurs at the gate, it can be promptly address without the added complication of having to taxi back to the gate.

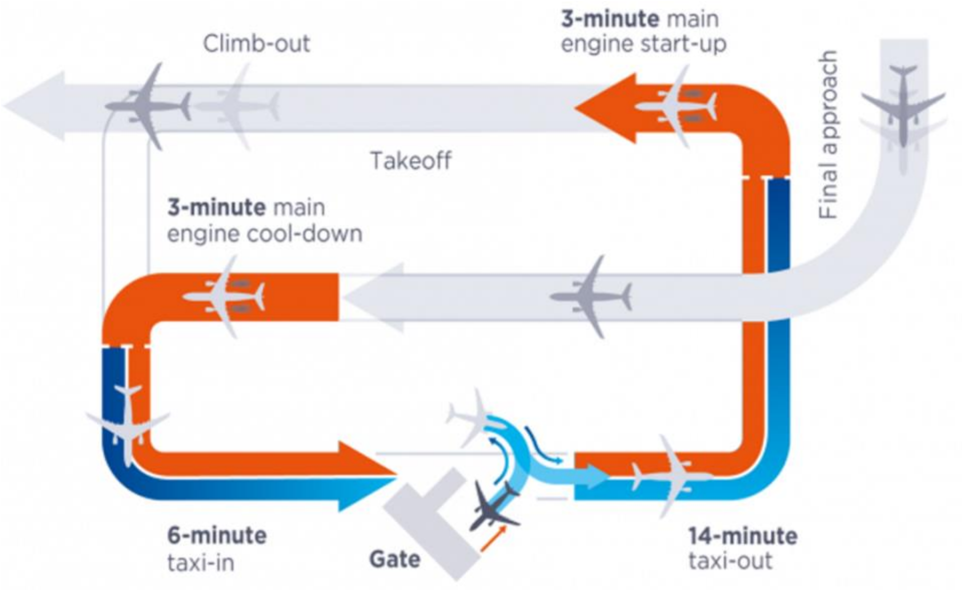


Figure 3.4: RET-out and RET-in Procedures (AEON, n.d.)

Table 3.7: Summary of Challenges of RET-Out

Challenge	Justification
Increased Workload	The workload is significantly higher during RET-out due to the engine start procedure
Taxi time	Taxi out times can be unpredictable which may dissuade pilots from employing RET-out
Taxi route	Taxi out routes tend to be more complex, making it harder to monitor speed and position on the ground
Weight	Due to fuel burnt during flight, pre-flight aircraft weigh much more than pre-flight and may be unable to taxi out on idle power
Mechanical Problems	Mechanical problems encountered during start-up of remaining engines may necessitate a return back to the gate

External AGPS

External Alternative Ground Propulsion Systems (AGPS) mainly include dispatch towing systems. Dispatch towing is an alternative taxiing method, where aircraft are towed from the gate to the runway by a tug powered by diesel, gasoline, or an electric battery (Di Mascio et al., 2022). Aircraft dispatch towing systems are estimated to reduce CO_2 emissions by up to 82% during taxiing (Van Oosterom et al., 2023). Common AGPS, as summarized in Table 3.8, include TaxiBot and SAFE tug.

Table 3.8: External Alternative Ground Propulsion Systems

External AGPS	Application
Taxibot	Hybrid diesel-electric tractor
SAFE Tug	Autonomous self-driven towing system

Guo et al. (2014) noted the drawbacks of dispatch towing systems that restrict their widespread adoption with the main concern being the significant wear and tear on the aircraft's nose, potentially reducing the longevity of the landing gear. Moreover, it was suggested that the use of dispatch towing systems may need additional roads and dedicated parking areas to allow tows to safely return after they have detached from the aircraft. Dimasco et al (2022) reported that dispatch towing occurs at a speed of 40% of full-engine taxiing. This could lead to additional delays, particularly in an already congested airport. As described by Moulton et al. (2015), another drawback to AGPS is the need for additional personnel, ranging from 9 to 11 additional staff, depending on the aircraft type and configuration. The numerous drawbacks of dispatch towing have limited its widespread adoption by airports and airlines.

Dispatch towing involves several additional safety considerations to avoid collisions (SKYBrary, n.d.a). The ground crew must maintain situational awareness while adequately communicating with the air traffic control (ATC) tower. There is an increased risk of collisions during the night and in poor visibility conditions. Examples of dispatch towing incidents are listed in Table 3.9 and are reported for general towing, rather than sustainable towing operations.

Table 3.9: Incidents Reported During Aircraft Towing (SKYBrary, n.d.a)

Aircraft	Airport	Date Reported	Incident	Probable Cause
A320	Dublin, Ireland	2017	Collision of the tug with the engine	Wet Surface
A343	Copenhagen, Denmark	2016	Collision with aircraft	Tug driver negligence
B773	Lisbon, Portugal	2016	Collision with obstruction	Icy Surface

Aircraft	Airport	Date Reported	Incident	Probable Cause
B744	London, UK	2004	Collision with A321 aircraft	Collision happened during the tow was in progress
JS41	Birmingham, UK	2007	Collapsed nose landing gear due to unsuccessful pushback	Tow bar could not be disconnected

On-board AGPS

Much like external systems, On-board AGPS provide a solution for eliminating airplane engine use during taxi-in and taxi-out phases. The distinguishing factor is that these systems use electric traction derived from additional electric motors fitted to the landing or main gear wheels (Guo et al., 2014). These systems present a promising opportunity to decrease emissions, reduce fuel consumption, and reduce the risk of FOD. Examples of these types of systems are presented in Table 3.10 and include the Wheeltug and the Electric Green Taxiing System (EGTS). Both systems utilize the aircraft’s onboard APU to power motors in the plane’s wheels without utilizing the main engines.

Table 3.10: Internal Alternative Ground Propulsion Systems

Internal AGPS	Application
EGTS	Additional motor at main wheels powered by onboard APU
Wheeltug	Additional motor at nose landing gear powered by onboard APU

Re (2012) highlighted challenges associated with these systems, including the motor’s thermal response, the thermal influence of nearby brakes, and challenges during the LTO phases. Guo (2014) noted that while the use of On-board AGPS could lead to fuel savings during the LTO phase, the extra weight might increase weight during cruise mode. However, Dzikus et al. (2011) demonstrated fuel savings between 1.1% and 3.9% based on U.S. domestic flights in 2007 with a 1000 kg on-board AGPS. As stated by Vaishnav (2012), providing sufficient energy to propel aircraft at the required speeds, and run other electrical systems, might require larger and heavier APUs, or other technologies to provide sufficient power to the On-board AGPS. Additionally, upfront costs of installing On-Board AGPS could, potentially, exceed savings realized compared to conventional taxiing.

3.4.2 Airfield Design and utilities

An effective airfield layout can reduce fuel consumption for aircraft and GSE (ICAO, 2014). By strategically positioning taxiways in relation to terminals, it is possible to cut down on delays and taxiing time, leading to a reduction in fuel consumption. This includes the layout of the buildings, service stations, runways, taxiways, rapid exit taxiways, pavement, and other related facilities (Hassan et al., 2021; ICAO, 2014).

3.4.3 Reducing APU Use

Auxiliary Power Units (APUs) are generators powered by the aircraft's engine, supplying the aircraft with power while it is parked at the gate (Postorino & Mantecchini, 2014). The APU can be started using only the aircraft battery, providing electrical power to aircraft systems and for engine start (SKYbrary, n.d.b). Consequently, aircraft may continue to produce GHG emissions even when stationary (Postorino & Mantecchini, 2014). The fuel consumed by APUs constitutes a minor fraction of the total aircraft usage, estimated to be approximately 0.8% to 3.5% of total fuel consumption.

A major challenge to reducing APU use lies in establishing control and accountability over which individuals operate the APU and its duration of usage (Benito & Alonso, 2018). This is primarily because APU usage is not monitored at the individual user level. In most cases, multiple users utilize the APU without defined procedures for transferring control, resulting in a lack of accountability. Alternatively, further expanded in the subsequent section, this energy can be sourced from Ground Power Units (GPUs) at the airport.

Ground Power Units

GPUs serve as auxiliary power sources for aircraft, particularly when the APU or main engines are not in operation (ICAO, 2014). In situations where aircraft require power and cooling, flight crews may opt to use GPUs in lieu of the APU (USAF EATF, 2018). Given a choice between utilizing a GPU or an APU, airlines typically use GPUs because they consume less power and cost less to operate (ICAO, 2014).

The two basic types of GPUs include mobile GPUs and fixed electrical ground power (FEGP) systems. The mobile GPU is powered by a diesel or gasoline generator that generates electricity for the aircraft. This leads to exhaust emissions but has the benefit of being available at all stands (Padhra, 2018). The FEGP system allows a lead to be connected to the aircraft and draw power from the main electricity supply to the airport terminal (ICAO, 2014). Leveraging local electrical grids for pre-conditioned air allows personnel to initiate APUs closer to takeoff, thereby reducing GHG emissions (ATAG, 2021).

3.4.4 Ground Support Equipment

GSE encompasses a wide range of vehicles and tools used in servicing aircraft (ICAO, 2014). This includes equipment for towing, maintenance, loading and unloading of passengers, handling cargo, and supplying fuel, electricity, and other necessary services to aircraft (see Table 3.11).

Table 3.11: Common Types of GSE (ICAO, 2014)

Type	Description
Aircraft tractors	Tows or tugs used during pushback service, operational towing, and maintenance towing.
Air conditioning units	Provides preconditioned air to aircraft at the terminal and during servicing.
Air start units	Trailers of trucks equipped with compressors to supply compressed air to initiate the main engines of an aircraft. Air starts are used when an aircraft lacks an APU, or the APU isn't working.
Baggage tractors	Facilitates transport of luggage or cargo between terminals and aircraft .
Belt loaders and container loaders	Conveyor belt to transport luggage or cargo with short travel distances between terminals and aircraft.
Bobtail tractors	Provides transports of luggage or cargo over longer distances.

Type	Description
De-icer	Transports and sprays de-icing and anti-icing fluid on aircraft.
Lavatory service	Vehicles or carts equipped with stainless steel tanks, a pump, and a hose to service aircraft lavatories.
Lifts	Forklifts, scissor lifts, and loaders to provide aircraft access for servicing both at the terminal and maintenance bay.
Ground Power Unit (GPU)	Provide electrical power to the aircraft when the aircraft's APU and engines are not operating.
Passenger Transport	Passenger buses, steps, and vehicles to facilitate transport of passengers between the terminal and aircraft.

Airport GSE like baggage tractors, belt loaders, and lifts have conventionally relied on fossil fuels for power, but there is potential for them to transition to grid electricity or alternative low-carbon and emissions-free fuels in the future (Canada, 2022a). The ICAO (2014) notes that while using all-electric GSE can achieve up to 100 percent reduction in ramp emissions, electric GSE may not be available or able to meet duty requirements for cargo tractors, aircraft tractors, cargo loaders, air starts, mobile GPU, service trucks, and lifts.

3.4.5 Surface Traffic Management

Time spent taxiing on the ground is a significant factor in overall flight duration, with aircraft estimated to spend 10-30% of their total flight time taxiing in Europe (Deonandan & Balakrishnan, 2010). Prolonged taxi times not only result in increased fuel consumption and emissions, negatively impacting the financial performance of airlines but also release emissions into the local environment, raising concerns about public health (Guo et al., 2014). In the United States, the excess fuel burn associated with elongated taxi time is estimated to be 75kg per flight. Airport bottlenecks lead to extended taxi durations, which in turn increase fuel usage and GHG release (Eklund & Osvalder, 2021).

Optimizing aircraft taxiing routes is necessary for optimizing energy consumption and reducing emissions (Li et al., 2019). Aside from this, there are some constraints to the improved ATM which includes the air traffic controller (ATC) (Singh & Sharma, 2015). ATCs may prevent the ideal trajectory of the aircraft from being flown due to many reasons such as safe separation, congested airspace, restricted airspace, delay management and weather avoidance. For ATCs, safety is the top priority, followed by performance.

3.4.6 De-icing and Anti-icing

De-icing and anti-icing are standard protocols at airports located in colder climates (Johnson, 2012). These procedures involve applying de-icing and anti-icing fluids (ADAFs) to airplanes and runways to keep them ice-free, ensuring safe takeoffs and landings. De-icing involves the removal of frozen contaminants such as frost, ice, snow, or slush from an aircraft surface using heated de-icing fluid, ensuring frozen-contaminant-free surfaces (Transport Canada, 2004). Anti-icing consists of applying an anti-icing fluid to a contaminant-free surface, to prevent the build-up of frozen contaminants.

Specifications for aircraft de-icing fluids (ADFs) and aircraft anti-icing fluids (AAFs) are governed by the Society of Automotive Engineers (SAE) and the International Standards Organization (ISO) (Transport Canada, 2004). Aircraft de-icing and anti-icing fluids (ADAFs) consist of four types: type I, II, III, and IV and are characterized by their holdover time (HOT). Holdover time refers to the approximate duration during which an application of AAF prevents the accumulation of frozen contaminants in the treated areas. De-icing fluids typically contain ethylene glycol, diethylene glycol, or propylene glycol, with additional components such as water, corrosion inhibitors, surfactants, and dyes. Anti-icing fluids share a similar composition but also include polymeric thickeners that enable them to inhibit the accumulation of frozen contaminants for an extended period compared to de-icing fluids. Colours serve as visual indicators during the application of ADAFs to the surface of the aircraft. SAE ADAF guidelines specify the correct colour for each type of fluid. ADAF types and characteristics are summarized in Table 3.3.

Table 3.12: ADAF Types and Characteristics (Transport Canada, 2004)

ADAF Type	Colour	Characteristics
SAE Type I	Orange	In their concentrated state, these fluids contain at least 80% glycol and are considered unthickened, due to their relative low viscosity. They are used for both de-icing and anti-icing but offer minimal protection for anti-icing.
SAE Type II	Clear or Pale Straw	These fluids are considered thickened due to the inclusion of thickening agents, allowing for a dense film to be applied and maintained on the aircraft's surface until takeoff. They are used for both de-icing

ADAF Type	Colour	Characteristics
		and anti-icing but offer an increased HOT compared to Type II fluids.
SAE Type III	Not Specified	These fluids have properties that fall between those of Type I and type II. As a result, they offer an extended HOT compared to Type I but less than Type II.
SAE Type IV	Emerald Green	These fluids meet the specifications of Type II but have a significantly longer HOT.

Preventative Measures

Reducing the amount of ADAF used can yield positive impacts for both cost and the environment (Transport Canada, 2004). The best preventative measure for reducing the quantity of ADAF required is by preventing the collection of frozen contaminants in the first place. This can be accomplished by parking the aircraft in a hangar. Availability of space, particularly for larger aircraft, presented the greatest challenge when it comes to regularly using hangars. For smaller aircraft, wing covers can be used to prevent the contamination of aircraft wings with frozen matter. Notably, care must be taken during the installation and removal of wing covers to prevent damage to the aircraft. Another measure that can be used to reduce the amount of ADAF required is to manually remove frozen contaminants using devices such as brooms, brushes, ropes, and scrapers. Care must be taken when using manual methods to prevent damage to sensitive and fragile components such as sensors and navigation antennas.

3.4.7 Weight Reduction

Aircraft weight reduction is a proven measure to save fuel and is consists of minimizing the aircrafts dry operating weight (DOW) and decreasing the quantity of on-board fuel (Airbus, 2004; ICAO, 2014). The specific range of an aircraft, when flying at a particular altitude, temperature, and speed, is contingent on its weight (Airbus, 2004). Carrying additional weight increases the quantity of fuel burned in flight, thus, reducing unnecessary weight is an effective measure for reducing fuel consumption (ICAO, 2014).

The cost-to-carry is defined as the incremental fuel cost associated with carrying a unit of weight over a unit of distance and will vary based on the characteristics of each aircraft (ICAO, 2014; Mouton et al., 2015). This measure can be employed when assessing the advantages of removing excess weight from an aircraft. The increase fuel consumption resulting from additional weight on board an aircraft typically ranges from 2.5 to 4.5 percent of the additional weight per hour of flight (ICAO, 2014). The United States Air Force (USAF) estimate that their cost to carry is approximately 3% across most of their transport airframes (USAF EATF, 2018).

General Weight Reduction

To enhance fuel efficiency, aircraft manufacturers have been innovating to reduce the overall weight of the aircraft by employing lighter materials and simplifying complex assemblies. A notable example is the Airbus A350, which has achieved a significant reduction in weight and fuel consumption by incorporating up to 54% composite materials in its design (Airbus, 2021). The shift towards composite materials in aircraft construction has been growing in recent years, offering the benefit for weight reduction and increased structural strength (ATAG, 2010). On average, replacing conventional aluminum allows with composite materials in new aircraft designs can lead to weight savings up approximately 20%. In upcoming years, it is expected that new aircraft paints that weigh 10-20% lighter than existing paints will be available. In addition to being lighter, the new paints will also be more resistant to chipping and cracking.

Although newer aircraft benefit from lighter materials and increase fuel efficiency, general weight reduction extends beyond only new aircraft. Many weight savings modifications are also possible when a major overhaul is needed, particularly for parts of major aircraft subsystems such as fuel, electrical, and lighting systems (ATAG, 2010). Overhauls present an opportunity to replace older components with more advanced and lighter components, leading to better fuel efficiency. An aircraft’s fuel consumption can also be reduced by 0.5% through routine inspections of its exterior surfaces to identify and repair defects, such as chipped paint, scratches, and damaged seals.

Beyond major overhauls, periodically reviewing and removing non-essential items from the aircraft also presents an opportunity to improve fuel efficiency (ATAG, 2010). Measures such as updating or removing obsolete equipment and optimizing catering loads and water loads based on passenger numbers can yield significant savings. In addition, replacing paper manuals with digital versions can also result in weight savings, especially in the cockpit where extensive documentation is required.

Excess Fuel Reduction

In addition to the fuel required to reach the destination, airlines are required to carry contingency fuel. Contingency fuel serves as a precaution against unforeseen circumstances, aiding in mitigating the risks and costs associated with potential diversions to alternate airports due to fuel shortages or emergencies (Honeywell, 2019). Drawing from their experience, pilots may opt for even more fuel than the standard contingency requirement. Airlines have historically taken a conservative approach when loading fuel, often carrying more than the minimum fuel mandated for the trip. A 2015 study involving an American airlines revealed that on average, 4.48% of a flight's fuel consumption was attributed to carrying unused fuel, of which 1.04% was for fuel that exceeded a reasonable safety margin.

Leverage statistical flight data is an effective strategy for minimizing excessive fuel carriage. Conventional methods do not consider the characteristics of each flight, leading airline to carry 2 to 3 times more discretionary fuel than what statistical analyses suggest is needed (Benito & Alonso, 2018). More recently, new technologies that employ sophisticated data analytics allow for a more precise determination of fuel requirements for each flight (Honeywell, 2019). These solutions utilize Statistical Contingency Fuel (SCF), a method that calculates the needed contingency fuel based on a percentage of the planned mission fuel. SCF leverages an airline's historical data to determine the appropriate contingency fuel percentage, which can vary according to the type of aircraft and airports involved in the flight.

3.5 Sustainable Aviation Fuels

The primary contributor to GHG emissions in the aviation sector is the consumption of fossil fuels (Canada, 2022a). Although advancements in technology and operational practices have improved the efficiency of air transportation and reduced overall fuel consumption, there is a limit to how much emissions can be reduced while still relying on conventional jet fuel. Therefore, to continue to make substantial reductions in aviation emissions, it is necessary to transition to a lower-carbon energy source for aviation. In contrast to ground transportation, where viable alternatives to conventional fuels are available, aviation currently has no practical substitute for conventional jet fuel except for SAFs.

SAFs are fuels produced from sustainable sources and emit fewer carbon emissions compared to conventional fossil-based jet fuels (ATAG, 2021). It is expected that SAFs will play a pivotal role in the decarbonisation of the aviation sector. Currently, there are a myriad of SAFs under testing and development. This includes biofuels derived from plants, waste, algae, and synthetic fuels generally from renewal sources (IATA, 2023).

SAFs are designed to be compatible with existing aircraft, negating the need for any modifications (IATA, 2023). Their integration can substantially reduce GHG emissions, potentially by up to 80%. However, in accordance with the Canadian General Standards Board (CGSB), synthetic fuels are currently subject to a blending limit of 50% by volume (Canada, 2022c). They can be blended with standard jet fuel, leveraging existing infrastructure and negating the need for modifications to aircraft or their engines (IATA, 2023). Benito and Alonso (2018) have identified the subsequent alternatives as potentials for fuels for aircraft operations:

Table 3.13: Classification of Alternative Fuels for Sustainable Aviation (Benito & Alonso, 2018)

Group	Fuel Type
Fossil Fuel	Fischer-Tropsch fuels
Renewable Fuels	Ethanol
	Biokerosene
	Bio to liquid
	Hydrogen
Non-liquid Fuels	Fuel Cells
	Solar Energy

The trajectory of the aviation industry indicates an expanded adoption of SAFs globally in an effort to curtail GHG emissions (IATA, 2023). Increased demand for low carbon alternatives to jet fuel and technological advancements are driving the expanded adoption. Nations worldwide and the aviation sector are supporting the expansion and integration of SAFs (Deloitte, 2022; IATA, 2023). Many airlines have already incorporated SAFs into their fuel strategies in parallel.

Nevertheless, the widespread adoption of SAFs faces several challenges moving forward. Establishing a resilient, sustainable supply chain and the requisite infrastructure for SAF production and distribution remains as one of the primary challenges (IATA, 2023). Production of SAFs would need to double from 2021 production levels to reach merely 2% of global aviation fuel consumption. Ensuring that SAFs are economically competitive with fossil fuels is an equally important challenge, as conventional jet fuel remains the most economical option for air travel. According to the European Union Aviation Safety Agency (EASA), current SAF prices can range from 1.5 to 6 times higher than conventional jet fuels (EASA, 2023).

In order to utilize SAFs to their full potential, it is imperative to address the issues of production and cost. Deloitte (2022) delineates the steps, investments, and partnerships that will be required to accelerate capabilities and SAF adoption in Canada. A shared perspective, as underscored by the DoD (2015) and the US Government (2015), emphasizes that immense efforts are mandated for SAFs to emerge as the primary aviation fuel. Furthermore, the RCAF (2022) recognizes that the demand for SAFs will surpass their availability for the foreseeable future, making immediate adoption unfeasible.

4. Methodology

4.1 RMC Green Team Methodology

The methodology employed for this research in the framework was modelled after a methodology developed by the RMC Green Team. The RMC Green Team is a team of internal (to DND) subject matter experts that provides technical advice and conducts nation-wide studies related to sustainable infrastructure and the environment that is relevant for DND and the CAF.

As illustrated in Table 4.1 and elaborated upon in the subsequent sub-sections, the questionnaire development, interviews, and site visits (i.e. qualitative components and not just quantitative data collection), and analysis is a cyclical process that is repeated until sufficient data has been amassed to produce accurate outcomes and recommendations. Prior to finalization of this research undertaking, the outcomes and recommendations were validated using feedback from operators and support staff at 8 Wing Trenton.

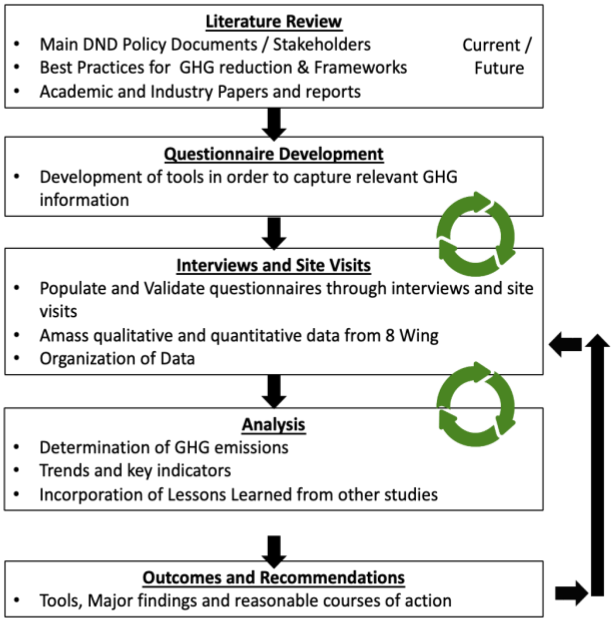


Figure 4.1: An example of the research methodology (modified after RMC Green Team, 2020)

4.1.1 Literature Review

The objective of the literature review component is to provide a comprehensive overview and critical analysis of existing research, synthesize existing knowledge, identify patterns, gaps, and trends, evaluate strengths and weaknesses of existing research, and provide context for future research.

Contributors in this domain have laid out the foundation to achieving net zero and identified measures to decrease emissions through measures outlined on a macro level in Chapter 2 and targeted measures outlined in Chapter 3. Specific to operations and infrastructure, opportunities to reduce emissions are well established in the literature (ATAG, 2021; IATA, 2022). The key areas of interest that have been identified as requiring further investigation are outlined in Table 4.1.

Table 4.1: Operations/Infrastructure measures identified for further analysis to reduce environmental impact of air operations at 8 Wing Trenton

Measure	Tasks	Outcomes
Building Layout	Identify all buildings supporting the airfield	Optimize building layout Quantify GHG savings
Airfield Layout	Identify aircraft movement trends Analyze layout efficiency	Optimize airfield layout Quantify GHG savings
Ground Traffic Management	Identify current ground traffic practices Analyze impacts of traffic congestion	Optimize ATM if deemed ineffective
Ground Power	Identify existing ground power type Measure time idling and using APU	Quantify GHG savings Recommend infrastructure modifications
Taxi Method	Analyze policy for approved taxi methods Measure time and distance travelled during taxi	Quantify GHG savings Provide alternative taxi methods
Ground Support Equipment (GSE)	Inventory of all GSE and emissions Conduct life cycle analysis for modernizing GSE	Quantify GHG savings Provide alternative GSE
Weight Reduction	Define excess weight and range Identify minimum reserve fuel in policy	Quantify GHG savings Recommend changes to policies or procedures
Training	Identify existing training for fuel efficiency Determine attitudes/beliefs of staff	Recommend changes to training Discuss trends

Measure	Tasks	Outcomes
Fuel Tracking	Identify gaps in fuel tracking Quantify fuel diverted due to spills or disposal	Recommend fuel tracking improvements for data-driven decision making
De-icing	Identify current procedures for de-icing Identify equipment and fuel indices Identify the type of glycol used	Quantify GHG emissions Provide alternative environmentally friendly de-icing procedures

4.1.2 Questionnaire Development

Development of operational-specific questionnaires is a non-trivial undertaking. The qualitative input obtained using targeted, scientifically developed questionnaires add much value in appropriately assessing and optimizing operations during aircraft taxiing to minimize fuel consumption:

a. Current practices: Questionnaires can be used to collect qualitative data from personnel, such as pilots and ground crews, about current practices during taxiing and idling. This data can assist in identifying trends, opportunities for improvement, and inform the development of fuel-efficient procedures. Further, it provides insight beyond the quantitative data that has been collected. It also compliments the numerical data that has been collected by giving the conditions in which the data were collected.

b. Evaluating attitudes and beliefs: Questionnaires can also be used to evaluate attitudes and beliefs towards fuel efficiency. This information can assist in identifying trends, areas for improvement, and help determine the organizational culture and potential resistance to change.

c. Monitoring progress: Questionnaires can be used to monitor progress over time and track the effectiveness of efforts to reduce fuel consumption.

The objective of exploratory research is to formulate problems, clarify concepts, and form hypotheses (Sue & Ritter, 2007). This form of research is typically undertaken when the researcher has minimal prior knowledge about the topic or when the subject is relatively new, intricate, or lacks a well-defined scope. During the literature review and initial interviews, it was evident that the research topic was not an area that had been previously explored in depth within the context of the RCAF. Through a more in-depth analysis, it became clear that there were gaps in the existing literature regarding sustainable operations within a military / air force context. This led to the need for an iterative process in terms of developing RCAF-specific questionnaires, where assumptions about the applicability of sustainable measures from the airline industry to the military could be validated and either confirmed or refuted.

Given the exploratory nature of the research, the questionnaires were developed using proper theoretical underpinnings (Skordaki, 2016) with the intention to determine the current practices at 8 Wing Trenton as well as the attitudes and beliefs of participants regarding the sustainable practices. In future research, questionnaires could also be used to monitor progress over time and track the effectiveness of sustainable practices to reduce fuel consumption. This ongoing assessment would contribute to a more comprehensive understanding of the evolving dynamics and outcomes associated with the implementation of recommendations derived from this research.

The structure of the questionnaire was organized with a mix of closed and open-ended questions that were organized into specific aspects of ground operations identified in the literature review such as chiller carts, GPUs, shut down and start-up procedures, and APUs. This format closely mirrored Patton's (2010) general interview guide for collective qualitative data, as further amplified in the subsequent section. The questionnaire format was structured yet flexible with specific information being sought through closed-ended questions and detailed insights encouraged through open ended questions. The questions were also detailed and specific, aiming to gather precise information about procedures, decision-making, responsibilities, and equipment specifications. Where applicable, questions requested information related to specification manuals, model numbers, types of fuel used, and fuel consumption to further validate the information provided by participants. The development of the questionnaire was an iterative process, involving continuous revisions based on data collected and analyzed from interviews and site visits. The final version of the questionnaire developed and utilized in seen below in Figure 4.2. It should be noted that the questions that were included in the questionnaires were used to guide the interviewees and open the discussions to gain their insights.

Participant Profile

Participant #:
Location:
Name:
Rank:
Position:

Interview Guide

1. Can you run me through the general sequence of events for a typical flight before takeoff and after landing?
2. One known method of reducing overall fuel consumption is using heating and chiller carts, as they are typically more fuel-efficient than the aircraft's onboard systems. Under which circumstances are heater and/or chiller carts used?
3. Another known method to reduce fuel consumption is to minimize Auxiliary Power Unit (APU) use as much as possible. This can be accomplished by delaying APU start-up as much as possible before departure.
    a. When are APUs turned on and shut down during departure and arrival?
    b. Are pilots encouraged at all to delay APU start before departure?
    c. Do you feel that there are any opportunities to minimize APU use?
4. It is well known that Ground Power Units typically consume less power than APUs. One method to reduce fuel consumption is by using ground power in lieu of the APU.
    a. Under what circumstances would GPUs be used?
    b. Are there any instances where the use of GPUs is unavailable?
    c. How often do you encounter depowering of the aircraft due to load shedding?
    d. How would you describe the reliability of the GPUs?
    e. When are GPUs and APUs used simultaneously?
    f. When would GPUs be used without the APU running?
5. Start-up procedures
    a. How long do start-up procedures take on average (safety checks)?
    b. Do you think that there is any opportunity to streamline the existing checklists?
    c. Are all start-up procedures completed prior to taxi?
    d. Is there any pilot discretion on start-up procedures?
6. De-icing and other winter-related procedures can extend the time an aircraft spends on the ground before departure, thereby increasing fuel consumption as systems are running.
    a. What impact does cold weather have on engine warm-up time?
    b. What impact does cold weather have on APU use?
    c. How long do de-icing and anti-icing typically take during the winter?
    d. Best practices state that hangars should be utilized during cold weather to reduce the required de-icing and anti-icing. In practice, how much are hangars utilized to park aircraft overnight?
    e. How often do you encounter delays due to de-icing operations?
7. Reduced engine taxi is a fuel-conserving technique, where half the engines are shut down to reduce the amount of fuel consumed during the taxi.

    a. Is there any procedure for your airframe to use a single-engine taxi during taxi out or int?
    b. Are there any considerations that would prevent the use of reduced-engine taxi?
    c. Do you think that this procedure could be easily implemented and standardized?
8. Additional weight such as cargo or fuel has a cost to carry of between 2.5-5% per hour.
    a. Do you feel that there are opportunities to minimize discretionary fuel through better mission planning?
    b. How much discretion do pilots have in exceeding their mission planning factors for fuel loads?
    c. How much discretion do pilots have in exceeding their discretionary fuel?
9. Under what circumstances would fuel tankering be used?
10. Flight simulators
    a. Under what situations would simulators be used?
    b. Do you feel that flight simulators could be used more to reduce fuel consumption?
11. How would you describe the culture around fuel efficiency?
12. Are you aware of any sustainable procedures to reduce fuel consumption?
    a. Do you employ any sustainable procedures in your day-to-day operations?
13. Are there any measures that you feel could be implemented to reduce fuel consumption?

Figure 4.2. Questionnaire developed and utilized for this research project.

4.1.3 Interviews and Site Visits

Site visits allow the researcher to observe processes and operating conditions firsthand, while also facilitating discourse with the operators executing the actual operational tasks on the ground. Observations can validate information gathered through secondary data by providing a more comprehensive picture of the organizational behaviour and the situation on the ground. During this phase, the intent was to amass site-specific information and gain a more thorough understanding of reality on the ground in terms of practices etc. and specific trends. In addition to interviews, the author was embedded within the day-to-day operations and decision-making processes at 8 Wing Trenton to create an accurate portrayal of operations.

Interview Format

According to Patton (2010), there are three main approaches for collecting qualitative data through open-ended questions. The alternatives include the informal conversational interview, the general interview guide, and the standardized open-ended interview. As each alternative has inherent strengths and weaknesses, this study employed the use of both the information conversational interview and the general interview guide approaches.

The informal conversational interview is the most open-ended approach to interviewing (Patton, 2010). This type of interview provides the highest degree of flexibility to explore information in any direction deemed suitable, depending on observations within a setting or conversations with individuals in the setting. The questions primarily emerge from the immediate context, making the conversational interview a critical tool in fieldwork. In many emergent field circumstances, where the researcher lacks prior knowledge of upcoming events, attendees, or important questions during an incident, the use of a predetermined set of questions may not be appropriate.

The interview guide lists the questions or themes that intended for exploration during the interview (Patton, 2010). It serves as a tool to ensure consistency in the main topics covered with each participant. The interview guide presents subject areas or topics that the interviewer is free to delve into, probe, and pose questions to gain a deeper understanding of the subject. Consequently, the interviewer retains the freedom to word questions spontaneously, shaping a conversation within a predetermined area. The interview guide designed for an open-ended unstructured interview is regarded as a versatile instrument, as the researcher has the flexibility to incorporate or omit questions based on the feedback, experience, and willingness of the interviewees to share their perspectives (Skordaki, 2016).

Interviewee Selection Process

In the context of this research, the author employed snowball sampling, commonly referred to as chain sampling, to establish an initial pool of participants. The approach of snowballing includes the initial identification of participants with relevant characteristics and interviewing or collecting data from them (Lune & Berg, 2017). Subsequently, the participants are requested to provide referrals of individuals who may possess the desired knowledge or experience to answer interview questions. This, in turn, creates a chain of participants, driven by participants referring another until sufficient data has been collected. Snowball sampling is at times, the most effective approach for identifying individuals with attributes or characteristics necessary for the research. Given its exploratory and ethnographic characteristics, this method was appropriate for the objectives of the research (Skordaki, 2016).

Summary of Interviews and Site Visits

Over the course of 25 days, the primary author conducted 10 site visits to 8 Wing Trenton, as summarized in Table 4.2. The site visits methodically planned, utilizing the interview guide format, informal discussions, and direct observation techniques. The interviews spanned a various ranks including civilians (Civ), Majors (Maj), Privates (Pte), Corporals (Cpl), and a Warrant Officer (WO), with a focus on pilots from 429 Squadron, 426 Squadron and 437 Squadron. The scope of the interviews expanded beyond pilots, with personnel from Base Environment, Real Property Operations (RP Ops), refueling, fuel management, aircraft maintenance technicians, and loadmasters.

A significant amount of time was spent within the Air Traffic Control (ATC) Tower, engaging with both ATC Officers and Operators (Op). This engagement allowed offered direct observations of ground and tower operations. In addition, it also provided a clear view of the entire airfield, which facilitated the collection of data on taxi times and routes.

Two tours of the airfield and supporting infrastructure were facilitated by 8 OSS. The first tour provided a general overview of the infrastructure, while the second was more targeted at examining the critical airfield infrastructure, aiding in the redesign of the airfield’s layout and infrastructure. Additionally, a detailed examination of the refueling facility was conducted. This also included direction observation of the entire scope of responsibilities of the refuelling section including testing of fuel and an aircraft refuelling operation.

Furthermore, a tour of Hangar 10 was conducted, offering a close examination of the different types of functions of GSE. This visit also included a formal interview with an aircraft maintenance technician.

Lastly, local trainers for the CC-130J, CC-150, and CC-177 were attended to gain firsthand observations of pre- and post-flight ground operations. The training flights provided practical context to validate procedural information obtained from prior interviews concerning ground operations.

Table 4.2: Summary of Site Visits and Interviews

Date	Location	Personnel Interviewed	Remarks
9 Nov 2022	Trenton	1x Base Environment (Civ) 1x 8 OSS Infrastructure (Capt)	Conducted a tour of the Airfield and Infrastructure
15-19 May 23	Trenton	1 x RP Ops (Capt) 1 x 8 OSS Infrastructure (Capt) 2 x 8 OSS Ops (Capt)	Conducted a tour of the Airfield and Infrastructure
15-17 Aug 23	Trenton	4 x ATC Officer (1 Lt, 3 Capt) 8 x ATC Op (4 Cpl, 1 Pte)	Site visit was spent in the ATC Tower
6 Sep 23	Trenton	2 x ATC Officer (1 Lt, 1 Capt) 4 x ATC Op (3 Cpl, 1 Pte)	Site visit was spent in the ATC Tower
12-14 Sep 2023	Trenton	2 x Bulk Fuel Management (Civ) 3 x Refuelling Section (1 Cpl, 2 Civ) 2 x 8 OSS Ops (Capt)	Tour of refuelling facility Observed a refueling operation
19-21 Sep 23	Trenton	2 x CC-150 Pilot (Capt) 1 x CC-177 Pilot (Capt) 1 x CC-130J Pilot (Capt)	
3-5 Oct 23	Trenton	1 x CC-177 Pilot (Capt) 1 x CC-150 Pilot (Capt) 1 x RP Ops (Capt)	
10-12 Oct 23	Trenton	1 x CC-150 Pilot (Capt) 1 x CC-177 Pilot (Capt) 1 x CC-130J Pilot (Capt)	
17 Oct 23	Trenton	1 x 8 OSS Ops (Capt)	
24-26 Oct 23	Trenton	1 x Maintenance Tech (WO) 1 x CC-130J Pilot (Capt)	Tour of hangar 10 and overview of Ground Support Equipment
7 Dec 2023	Trenton	2 x CC-177 Pilot (Maj) 1 x Loadmaster (MCpl)	Attended CC-177 Local Training Flight
15 Dec 2023	Trenton	1 x CC-150 Pilot (Capt) 2 x CC-150 Student Pilots (Capt) 1 x Aircraft Technician (Civ)	Attended CC-150 Local Training Flight
30 Jan 2024	Trenton	1 x CC-130J Pilot (Capt) 2 x CC-130J Student Pilots (Capt) 1 x Loadmaster (Sgt)	Attended CC-130J Local Training Flight

In addition to the interviews conducted during site visits, a series of virtual interviews were conducted virtually over the phone. This approach added flexibility to the data collection process, allowing for a broader range of participants and the accommodations of their schedules with the constraints of physical site visits. The virtual interviews conducted as part of this research are summarized in Table 4.3.

Table 4.3: Summary of Virtual Interviews

Date	Personnel Interviewed
12 Oct 23	CC-177 Pilot (Maj)
7 Sept 23	CC-177 Pilot (Maj)
26 Oct 23	CC-130J Pilot (Capt)
1 Nov 23	CC-150 Pilot (Capt)
25 Jan 24	CC-177 Pilot (Capt)
27 Mar 24	CC-177 Pilot (Capt)
27 Mar 24	CC-150 Pilot (Capt)

4.1.4 Outcomes and Recommendations

Outcomes were presented in the form of recommendations outlining opportunities for operational efficiencies (to include infrastructure layout), and potential activities that will produce reductions in GHG emissions. These are summarized in Chapter 7 of this thesis document. Before finalising these recommendations, the findings, and recommendations were validated in consultation with the staff at 8 Wing Trenton. These recommendations will also be provided to the Directorate of Operational Sustainability (DEOS) of the RCAF for consideration and potential implementation.

4.2 Data Collection and Analysis

4.2.1 Airfield Redesign

The airfield redesign process for 8 Wing Trenton was a non-trivial undertaking to ensure safety and operational efficiency in compliance with the TP 312. The process involved several stages, beginning with data collection and analysis to assess existing conditions and identify deficiencies with the existing airfield. Tours of the airfield and interviews with operational personnel, such as those from RP Ops Trenton, were crucial for gaining firsthand insights into operational challenges and future needs of the airfield.

Additionally, the data collection phase included studying relevant course materials such as those from the RCAF Airfield Surface and Reconnaissance (ASAR) course and attending specialized workshops like the Transportation Systems Centre Airfield Design Workshop. These courses facilitated the understanding of the technical and safety specification required in airfield design. The design also adhered to established safety and operational specifications outlined in TP 312, ensuring all safety measures were met. Consultation with strategic plans such as Trenton’s

MRPDP (Master Real Property Development Plan) was also part of the process, ensuring that the design aligned with both current and future requirements.

While designing the airfield, considerations for reducing GHG emissions were integrated into the strategic layout. This was achieved by incorporating sustainable design best practices like optimizing runway and taxiway layouts to minimize on-ground travel distances, which directly reduce fuel consumption as suggested by Norton (2014). These best practices also included strategic relocation of hangars, construction of new facilities, demolition of existing facilities, and the addition of rapid exit taxiways, all which contributed to more efficient and sustainable aircraft operations.

4.2.2 Ground Fuel Consumption

The data collection process for ground fuel consumption at 8 Wing Trenton was initiated to address a gap in existing RCAF data, which reports total fuel consumption per fleet primarily for GHG emissions reporting without differentiation between ground and cruise fuel or a breakdown by individual sorties. Recognizing the importance of this data for targeted fuel reduction initiatives, efforts were focused on understanding fuel usage specifics such as APU operation, taxi-in, and taxi-out phases.

Since flight data recorder data was not available, alternative methods were employed. Pilots provided start and taxi out fuel allocations based on values used in ForeFlight, which does not account for extended APU usage or taxi-in phase. To estimate ground fuel consumption more accurately, these values were adjusted to include the additional fuel used during these activities.

Monthly fuel logs were aggregated to quantify annual fuel consumption for each fleet. Further insights into average APU usage were gained through interviews with staff and validated by direct observations during local training flights. Since the Flight Crew Operating Manuals (FCOMs) do not detail APU or aircraft taxi fuel burn, various external studies were consulted to estimate these specific fuel burns.

The number of sorties was determined by manually tabulating daily flight logs from the hangar cloud system, which lacks export functionality, complicating data aggregation especially as certain squadrons did not have readily available information. Using the number of sorties and the amount of fuel dispensed from fuel logs, average fuel consumption per fleet per flight was calculated. From this, the estimated ground fuel consumption was subtracted from the average total fuel consumption to determine the cruise fuel consumption.

4.2.3 Fuel Management

A comprehensive approach was taken to assess the airfield fuel management at 8 Wing Trenton. The process began with interviews with the bulk fuel management and refuelling teams to gather insights into their roles, responsibilities, and operational workflows. Access to historical fuel logs was granted during this phase, enabling an analysis of fuel consumption for both aircraft and GSE on site.

A focus was placed on quantifying the amount of fuel diverted to waste following fuel testing, a crucial factor since this waste fuel was not reported for GHG emissions. The author personally observed the fuel testing process for refuellers to gain a firsthand understanding of the process. Additionally, the maintenance and testing procedures for quality control of aviation fuels, ground fuels, and lubricants were analyzed to determine when and how these tests were conducted.

Tours of the refuelling facilities provided further insight into the types of equipment and infrastructure present at the site. Observing a real-time refuelling operation helped to delineate the process more clearly. Moreover, a comparison between the fuel tanker system and the fuel hydrant system was conducted, outlining the advantages and disadvantages of each system.

4.2.4 Ground Traffic Management

The data collection for ground traffic management at 8 Wing Trenton aimed to fill a significant gap in research, as ground traffic has been extensively studied in civilian airports but not within the RCAF. The primary focus was to assess congestion, route selection, and taxi times to identify potential opportunities for optimization and thereby reduce aircraft GHG emissions.

To accurately collect this data, the author spent a week embedded in the ATC tower. This placement allowed for direct observation of air traffic control operations and ground movements. It also facilitated interviews with ATC staff, which provided valuable insights into their processes for selecting routes, their perceptions of congestion, and taxi durations. Additionally, the author manually collected data on taxi times and routes using a stopwatch, carefully noting the routes, and overseeing the ground traffic control procedures in real time. This hands-on approach was crucial as it addressed an area that had not been previously analyzed by the RCAF, offering new perspectives and data on ground traffic management at the site.

4.2.5 Reduced Engine Taxi

Although RET has been extensively studied as a fuel-saving measure in civil aviation, its application in the military context had received minimal attention. To address this gap, author used the FCOM to verify the existence of any procedures related to RET. This information was further validated through interviews with pilots, which also explored how RET was integrated into their operational practices. Alongside these interviews, an extensive literature review was conducted to delineate considerations for employing Reduced Engine Taxi-Out (RET-out) and Reduced Engine Taxi-In (RET-in).

Quotes from pilot interviews were codified into themes such as Ease of Operation and Habitual Practices, and Risk Aversion and Safety Concerns, highlighting resistance to adopting new operational procedures. Given the lack of existing literature on operational considerations in the military context, insights were primarily derived from these interviews. The discussions were grouped into themes such as Fuel Savings vs. Safety, Fuel Savings vs. Operational Risks, Support Staff and Equipment Availability, and Engine Running Onload/Offloads (EROs).

The author utilized both primary and secondary data to formulate informed recommendations on the feasibility of implementing RET-in and RET-out for each fleet. By using estimated engine fuel flows, taxi-in durations, and annual sorties, they were able to project potential fuel and GHG savings for RET-in across different fleets.

4.2.6 Mission Fuel Planning

The analysis of mission fuel planning involved an assessment of the cost-to-carry, which quantifies the additional fuel expense incurred when the aircraft carries more fuel than necessary. The data collection was designed to outline the fuel allocation process and benchmark it against industry best practices. To gain a better understanding of the practical aspects of fuel planning, interviews with pilots were conducted. These discussions sought to clarify the process used for fuel planning, particularly examining the rigidity of protocols regarding fuel above the required minimum amount. Additionally, the interviews explored how frequently pilots chose to exceed minimum fuel amounts and the factors influencing such decisions.

The mission fuel planning was categorized into force employment flights and force generation flights. This distinction helped in tailoring fuel planning strategies to the specific needs and objectives of each flight type. Another area of the investigation was tracking and reporting back to pilots about the extent of excess fuel loading, assessing whether this practice was monitored effectively. To validate the information gathered from the interviews, the author attended local training flights, observing firsthand the fuel allocation practices. This approach provided practical insights regarding fuel allocations for force generation flights.

4.2.7 De-icing

The data collection process for de-icing at 8 Wing Trenton involved a comprehensive review of procedures and environmental impacts, beginning with a consultation of 8 Wing Flying Orders. These orders provided a clear outline of the standard operating procedures for de-icing, including de-snowing and anti-icing processes. To validate and elaborate on these procedures, interviews were conducted with pilots who regularly engage in these operations. Additionally, a training flight was attended during the winter, offering a first-hand observation of the de-icing process.

Management and disposal practices for Aircraft De-icing and Anti-icing Fluids (ADAFs) were analyzed, with a particular focus on exploring environmentally friendly alternatives such as on-site recycling. Historical data on the usage of ADAFs was obtained from 8 OSS, enabling a detailed analysis of past consumption patterns and disposal methods.

Further discussions during interviews with personnel revealed the preventative measures currently in place for dealing with icy conditions. These interviews also highlighted operational limitations, such as the availability of hangar space and other logistical challenges that impact de-icing operations.

Lastly, the lifecycle GHG emissions for Type 1 and Type 4 ADAFs were quantified. This analysis was based on historical average consumption data, offering insights into the environmental impact of ADAFs and informing potential improvements in the de-icing process at 8 Wing Trenton.

4.2.8 Reducing APU Use

Data on APU usage at 8 Wing Trenton was primarily collected through interviews with pilots, focusing on when the APU is utilized during pre- and post-flight operations. Factors influencing APU usage, including conditions unique to military operations, were examined, along with the extent to which APU usage was tracked and reported. Run times for each fleet were documented, highlighting differences across fleets.

Recommendations for APU reduction strategies, based on industry best practices such as delaying APU start-up and utilizing GPUs, were provided. The types and usage of GPUs available for each fleet were assessed, along with suggestions for sustainable alternatives to APUs, such as fixed electric ground power and electric ground power systems.

Insights into the considerations affecting the use of GPUs and APUs at 8 Wing Trenton were presented, including nuisance and noise, operational and technical considerations, and the reliability of GSE. The potential for GHG reduction by delaying APU start-up was quantified, taking into account the duration of the engine start sequence for each fleet.

To validate the information from interviews, training flights for each fleet were attended to observe firsthand the usage of GPU and APU, ensuring a thorough understanding of current practices and potential improvements.

4.2.9 Ground Support Equipment

Data collection on GSE at 8 Wing Trenton involved a comprehensive approach to understand and catalog the various types available. A tour of 10 Hangar was conducted to observe and photograph the different types of GSE in use. This visual documentation helped in accurately categorizing the equipment based on their purpose.

Further insights were gained through an interview with personnel responsible for managing the GSE. The discussion focused on the types of GSE available, their fuel types, and operational roles. Fuel consumption data for each type of GSE was quantified using historical fuel logs, expressed as GHG emissions, and presented as a percentage of the total ground fuel consumption at the base. This analysis highlighted the significant contributors to emissions and areas where improvements could be made.

Based on the findings, sustainable alternatives were recommended. These suggestions included the adoption of more environmentally friendly fuel options and the implementation of charging infrastructure for electric-powered GSE.

4.2.10 Culture of Fuel Efficiency

Data on the culture of fuel efficiency at 8 Wing Trenton was primarily collected through interviews with various staff members, with their responses codified into themes to assess the current state of fuel efficiency culture. These themes helped identify areas of concern and opportunities for improvement. Common themes extracted from the interviews included issues related to data reporting, building confidence, awareness and training, and the balance between operational priorities and fuel efficiency.

Based on the findings, recommendations were presented on how to foster a culture of fuel efficiency at 8 Wing. These recommendations emphasized making fuel efficiency a strategic priority and enhancing stakeholder engagement, data-driven decision-making, adopting operational best practices, improving training and awareness programs, leveraging technology and innovation, and implementing benchmarking and continuous improvement processes. These strategies are aimed at integrating fuel efficiency more deeply into the daily operations and long-term planning at 8 Wing Trenton.

5. Site Overview and Redesign

As illustrated in Figure 5.1 and Figure 5.2, CFB Trenton is situated in the town of Trenton in the Quinte West region of Ontario, along the shores of the Bay of Quinte (DND, 2022). CFB Trenton serves as Canada's main operating base (MOB) for deployable expeditionary forces, search and rescue operations, and air mobility. The CC-130, CC-150, and CC-177 transport aircraft fleets are primarily supported by CFB Trenton, which serves as the RCAF's primary transportation hub. The CAF receive supplies and assistance from CFB Trenton for both domestic and international missions. CFB Trenton is a DOB that supports Canadian Forces Station (CFS) Alert and tactical fighter operations for the RCAF and North American Aerospace Defence (NORAD) missions.

Figure 5.1: Location of 8 Wing Trenton

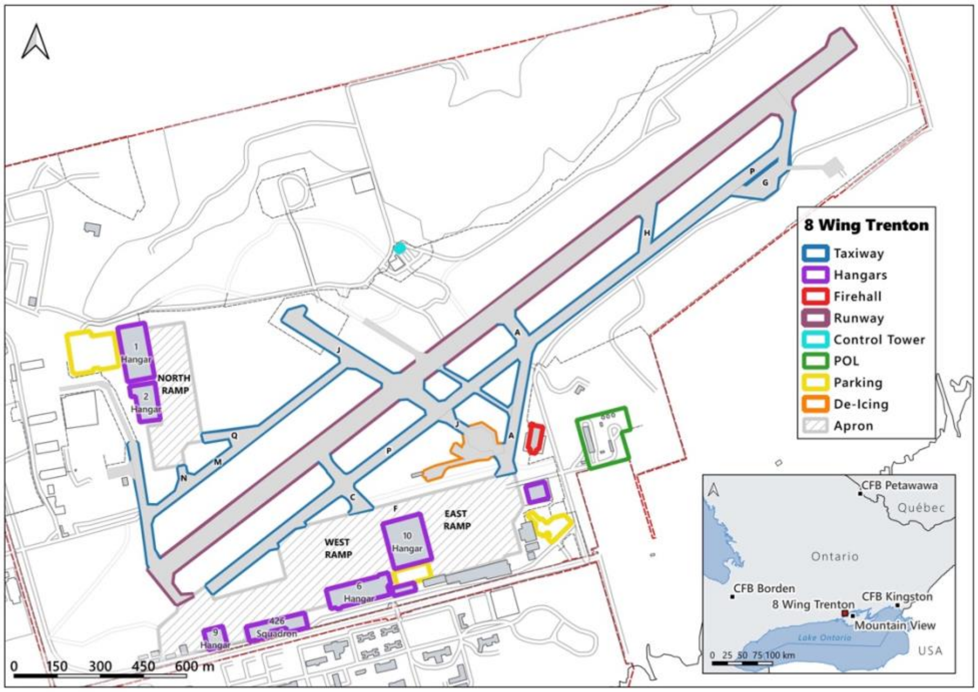


Figure 5.2: 8 Wing Trenton Airfield Site Map

5.1 Organizational Layout

The primary units and squadrons at 8 Wing Trenton include 424 Transport and Rescue Squadron [424 (T&R) Sqn], 426 Transport and Training Squadron[426 (T) Trg Sqn], 429 Transport Squadron[429 (T) Sqn], 436 Transport Squadron [436 (T) Sqn], 437 Transport Squadron [437 (T) Sqn] , 2 Air Movements Squadron [2 Air Mov Sqn], 8 Air Maintenance Squadron (8 AMS), 8 Operations Support Squadron [8 OSS] , and 8 Missions Support Squadron (8 MSS). In addition, selected lodger units operating out of 8 Wing Trenton include Real Property Operations Detachment Trenton (RP Ops Det Trenton), and the Transport Standardization and Evaluations Team (TRSET). Each unit/squadron has a distinct function as summarized in Table 5.1.

Table 5.1: Main Squadrons/Units at 8 Wing Trenton

Squadron/Unit	**Main Function**
424 (T&R) Sqn	Operates the CH-146 Griffon helicopter and the CC-130H Hercules, and the Provides search and rescue spanning from Quebec to the British Columbia/Alberta border and from the Canada/US border to the North Pole.
426 (T) Trg Sqn	Responsible for training aircrew, technicians, and aeromedical evacuation personnel to meet the needs of Air Mobility forces.
429 (T) Sqn	Operates the CC-177 Globemaster III and is responsible for providing domestic and global strategic airlift for the CAF.
436 (T) Sqn	Operates the CC-130J Hercules and is responsible for providing tactical airlift for the Canadian Armed Forces. The squadron operations the CC-130J Hercules.
437 (T) Sqn	Serves a dual role with its fleet of CC-150 Polaris aircraft, performing long-range strategic airlift and air-to-air refueling missions.
2 Air Mov Sqn	Provides processing of passengers, baggage, freight and mail originating, staging through or terminating at 8 Wing Trenton and provides Mobile Air Movements Sections (MAMS) in support of operations and exercises.
8 AMS	Responsible for providing support to 424 Transport and Rescue Squadron, 436 Transport Squadron, 437 Transport Squadron, and 429 Transport Squadron in their operational duties by carrying out second line support and training on systems and components of the CC-130H, CC-130J, CC-150, and CC-177 aircraft.
8 OSS	Provides operational support and training for 8 Wing Trenton including air traffic control. The Multi-Engine Utility Flight is part of 8 Operations Support Squadron. Operating the King Air, it provides the RCAF with a cost-effective means of maintaining and enhancing pilot proficiency, while providing the Canadian Armed Forces with a platform capable of light transport and other non-combat roles.
8 MSS	Provides logistics and engineering services to 8 Wing Trenton.
RP Ops Det Trenton	Provides Real Property support including planning, delivery, sustainment, management, and reporting of real property services to 8 Wing Trenton
TRSET	As a lodger unit based out of 8 Wing Trenton, responsible for aircrew standards for the various 8 aircrew trades at transport stations across Canada and reports directly to the 1 Canadian Air Division HQ in Winnipeg

5.2 Airfield Layout

A significant portion of the land at CFB Trenton is taken up by the operational zone that includes both the airfield and hangar line. The main hangar line is densely developed and situated to the southwest of the runway, while the hangar line on the north ramp includes hangars 1 and 2. Infrastructure adjacent to the airfield primarily support squadron operations with administration, maintenance, and materiel movement. A summary of the supporting infrastructure is presented in Table 5.2.

Table 5.2: Summary of Supporting Infrastructure

Supporting Infrastructure	**Unit/Squadron**	**Aircraft**	**Number of Bays**	**Description**
Hangar 9 (B112)	424 (T&R) Sqn	CH-146 CC-130H CH-149	2	1st Line Maintenance and Admin
Hangar 7&8 (B65)	Canadian Army Advanced Warfare Centre (CAAWC)	N/A	0	Functional Centre of Excellence for the Canadian Army's environmental domains
Hangar 6 (B606)	429 (T) Sqn 436 (T) Sqn	CC-177 CC-130J	2	1st Line Maintenance and Admin
B34	426 (T) Trg Sqn	N/A	N/A	Training for the CC-130H, CC-177
Hangar 4 (B50)	Wing Ops	N/A	N/A	Operations
Hangar 3 (B51)	8 AMS		N/A	Propulsion Shops
Hangar 10 (B52)	8 OSS (MEUF) 436 (T) Sqn	BE350 CC-130J	6	1st Line Maintenance and Admin
B66	2 Air Mov Sqn	N/A	N/A	Freight Reception
Hangar 7 (B522)	429 Sqn	CC-177	1	Interim holding area for CC-177.
B611	Fire Hall	N/A	N/A	Fire Hall
Hangar 1(B575)	8 AMS	CC-130H CC-130J CC-177	2	2nd Line Maintenance
Hangar 2 (B607)	8 AMS	CC-130H CC-130J	2	2nd Line maintenance

Supporting Infrastructure	Unit/Squadron	Aircraft	Number of Bays	Description
		CC-177		
B579	8 AMS	N/A	N/A	Workshops and storage
B478	8 OSS - ATC	N/A	N/A	Control Tower

5.2.1 Airfield Deficiencies

Existing infrastructure deficiencies were key considerations leveraged in the airfield redesign process. These deficiencies include operational constraints posed by reliance on a single runway, the limitations of taxiway Papa, the poor conditions of runways and taxiways, and the impact of the Strategic Tanker Transport Capability (SSTC), and summarized are as follows:

a. Single Runway Operational Limitation: CFB Trenton operates with only one runway, Runway 06-24. This presents an operational burden due to the lack of infrastructure redundancy, meaning that significant maintenance or recapitalization work requires extensive planning due to the impact on operations. The lack of runway redundancy creates an added strain on operations considering that CFB Trenton cannot operate without constant access to the airfield. Furthermore, a total shutdown of 06-24 often necessitates the relocation of 8 Wing squadrons to Mirabel or Mountainview. The south side of the taxiway Papa, which is parallel to runway 06-24, also functions as a runway for the CC-130 and CC-177 during training and emergency scenarios. Even as an austere runway, taxiway Papa does not meet the criteria for runway classification, thus it operates under a waiver. The CC-150, CF-18, and CC-144 are not permitted to use taxiway papa as a runway and rely solely on 06-24 for take-off and landing.

b. Taxiway Papa Limitations: Taxiway Papa, running parallel to Runway 06-24 on its south side and serving as a runway during training and emergency situations for specific aircraft, does not meet the required standards for runway classification, even for an austere runway. It operates under a waiver, and there are risks associated with its use as a runway. Certain aircraft types are not permitted to use Taxiway Papa for take-off and landing, relying solely on Runway 06-24.

c. Inadequate Runway and Taxiway Infrastructure: The resurfacing of Runway and Taxiway Papa in 2021 addressed issues related to Foreign Object Debris but did not rectify underlying major issues such as the old/failing underground drainage system, structural deficiencies, pavement and site grading issues, and the absence of taxiway shoulders to meet TP312 code requirements. A comprehensive runway/taxiway reconstruction project is required to address these deficiencies.

d. Impact of Strategic Tanker Transport Capability (STTC): The introduction Airbus CC-330 Husky, a higher category of aircraft than currently operated by the DND, necessitates reinforced airfield surfaces due to increased rates of deterioration. This includes considerations for runway strength, taxiway width, fueling capabilities, and a new hangar.

5.2.2 Planned Infrastructure Projects

Planned infrastructure projects derived from the MRPDP were considered during the development of the new airfield layout as they provide insight into future requirements. These planned activities include:

a. Construction of New Hangar 5 (Accommodate 436 Squadron): This project aims to construct a new hangar to accommodate 436 Squadron, providing first-line maintenance capabilities for CC130J-30 aircraft. The new hangar will feature four aircraft service bays, technical service staff workspace, office space, and supply storage.

b. Construction of New Strategic Tanker Transport Capability (STTC) Hangar: At the time that the MRPDP was published, it was uncertain whether CFB Trenton would be selected as the MOB for the CC-330, however, it has since been announced that a 2 bay hangar will be required to support the arrival of the nine CC-330s.

c. Demolition of Hangar 10: Part of the Accommodate 436 Squadron project, the demolition of Hangar 10 will greatly improve maneuverability and provide available parking on the southern flight line, especially for larger airframes like STTC. The removal of Hangar 10 is crucial for freeing up space and improving the overall layout of the airfield.

d. Demolition of Building 65: The construction of the new Hangar 5 necessitates the demolition of Building 65. This action is part of the broader effort to modernize and improve the infrastructure at CFB Trenton, ensuring it meets the current and future needs of the RCAF.

e. Consolidation of Hangar 6: While not a consolidation of physical structures, this project represents a functional consolidation of operations. 437 and 429 Squadrons, currently and temporarily housed in Building 20, will be accommodated via an internal fit-up project of new Hangar 6. This project is aimed at meeting their requirements and improving operational effectiveness due to its location on the airfield.

5.3 Overview of Aircraft

Fixed-wing transport aircraft at 8 Wing Trenton include the CC-130, CC-150, CC-177, CC-144, and CC-145. For this study, the focus was on the CC-130, CC-150, and CC-177, however, finding can be applied to other fleets. Across the RCAF, the CC-130, CC-150, and CC-177 consume approximately 50.3% of all AvPOL consumed, whereas the CC-144 and CC-145 consume approximately 2.4% (RCAF, 2023). The types and quantity of fixed wing transport aircraft at 8 Wing Trenton delineated by squadron/unit are presented in Table 5.3.

Table 5.3: Fixed Wing Transport Aircraft at 8 Wing Trenton

Squadron/Unit	Aircraft	Quantity
412 (T) Sqn	CC-144 (Challenger)	6
424 T&R Sqn	CC-130H (Hercules) CC-130J (Hercules)	2 3
426 (T) Trg Sqn	CC-130H (Hercules) CC-150 (Polaris)	1 2
429 (T) Sqn	CC-177 (Globemaster)	6
436 (T) Sqn	CC-130J (Hercules)	14
437 (T) Sqn	CC-150 (Polaris)	3
8 OSS MEUF	CC-145 (King Air)	4

5.4 Design of New Airfield

The exercise of designing a new airfield layout for 8 Wing Trenton is motivated by the requirement to accommodate the evolving operational requirements and address the deficiencies of the current layout while anticipating the needs of 8 Wing over the next 25 to 30 years. This initiative is a forward-looking endeavor that seeks to enhance the operational effectiveness and sustainability of the Wing, drawing insights from existing challenges and successes, and aligning with CFB Trenton's MRPDP for long term development. MRPDPs serve as key strategic guides, outlining a 30-year vision and developmental direction for Real Property (RP) needs within DND and the CAF(DND, 2022). They are crucial for any RP related decision-making processes within these organizations. The primary goal of MRPDPs is to ensure that the physical infrastructure of an establishment is in sync with the operational needs of its DND occupants. Superimposed on this plan is the need to incorporate sustainable practices as they apply to the reduction of GHG's due to ground operations of the aircraft at the Wing.

5.4.1 Design Best Practices

In the realm of sustainable ground operations, the design of airfields plays a key role in mitigating environmental impact while enhancing efficiency and safety. The implementation of strategic airfield designs is a crucial step in reducing aircraft fuel consumption on the ground. Best practices such as the integration of Rapid Exit Taxiways, FEGP, placement of buildings and infrastructure, consolidation of hangar spaces, and centralized de-icing pads, streamline ground operations while also reducing fuel consumption. These best practices, as outlined in subsequent bullet points, were considered by the author in the redesign of the airfield at 8 Wing Trenton.

a. Rapid exit taxiways: A rapid exit taxiway, serves a critical function in airport operations by enabling aircraft to vacate the runway at higher speeds compared to conventional taxiways. As a secondary effect, rapid exit taxiways reduce the movement distance between the runway and taxiway for aircraft (Korth & Momberger, 2021). Thus, airports can lower the fuel and time expended during the taxi in after landing.

b. Fixed Electric Ground Power: FEGP systems are installed at fixed locations on the airfield, such as at parking stands or hangars. These systems provide a stable and reliable power source for aircraft on the ground, allowing them to operate onboard systems, perform maintenance tasks, and prepare for flights without running their engines or APUs.

c. Placement of buildings: Designing runways and taxiways to reduce on-ground distances will reduce the associated fuel usage (Norton, 2014).

d. Consolidation of Hangars: Consolidating hangar space, by moving multiple locations into a single centralized facility can both enhance the operational effectiveness of the unit and reduce GHG emissions. Centralizing activities into a single hangar can improve operational effectiveness as all parts, tools, and personnel can be managed more effectively when all resources are in a single facility.

e. Location of De-icing pad(s): Centralized de-icing points streamline the de-icing process, leading to improved efficiency and reduced flight delays (Kazda & Caves, 2015). A significant benefit of this approach is the ability to de-ice aircraft just prior to takeoff, often eliminating the need for subsequent application of anti-icing fluids.

5.4.2 Overview of Projects

During the development of the new airfield layout, planned infrastructure projects derived from Trenton’s MRPDP were considered to ensure alignment with anticipated future needs. The emphasis was more on the layout and functionality of buildings rather than the specifics of interior fittings, which meant that detailed internal configurations were not a primary concern. Consequently, the planning was primarily concentrated on aspects of new construction and the demolition of outdated structures to pave the way for an optimized layout that supports operational efficiency and future growth. Projects from Trenton’s most recent MRPDP are illustrated in Appendix A are as follows:

Being Built:

a. New Hangar 5 (Accommodate 436 Squadron): This project aims to construct a new hangar to accommodate 436 Squadron, providing first-line maintenance capabilities for CC130J-30 aircraft. The new hangar will feature four aircraft service bays, technical service staff workspace, office space, and supply storage.

b. New Hangar (CC-330): At the time that the MRPDP was published, it was uncertain what aircraft would be replacing the CC-150 and whether CFB Trenton would be chosen as the MOB. It has since been announced that nine CC-330s will operate out of Trenton and will require an additional 2 Bay Hangar to support the aircraft (Manuel, 2024).

Being Demolished:

a. Hangar 10: Part of the Accommodate 436 Squadron project, the demolition of Hangar 10 will greatly improve maneuverability and provide available parking on the southern flight line, especially for larger airframes like the CC-330. The removal of Hangar 10 is crucial for freeing up space and improving the overall layout of the airfield.

b. Building 65: The construction of the new Hangar 5 necessitates the demolition of Building 65. This action is part of the broader effort to modernize and improve the infrastructure at CFB Trenton, ensuring it meets the current and future needs of the RCAF.

5.4.3 Airfield Re-design Changes

The new airfield layout, presented in Figure 5.3 and Appendix C, was designed with the specifications outlined in the TP 312 (Transport Canada, 2015). The supporting structures, except for the Air Traffic Control (ATC) tower, have been repositioned to be adjacent to a single primary apron situated to the south of the main runway. This reorganization aims to reduce the distances aircraft must taxi compared to the previous layout. The hangar buildings have been shifted to the outer edges of the apron, optimizing the space for aircraft parking. This adjustment, coinciding with the introduction of nine CC-330 aircraft, improves the movement around and the availability of parking space on the primary apron. The buildings have been arranged into clusters based on their operational functions, which include first line maintenance, second line maintenance, and materiel movement.

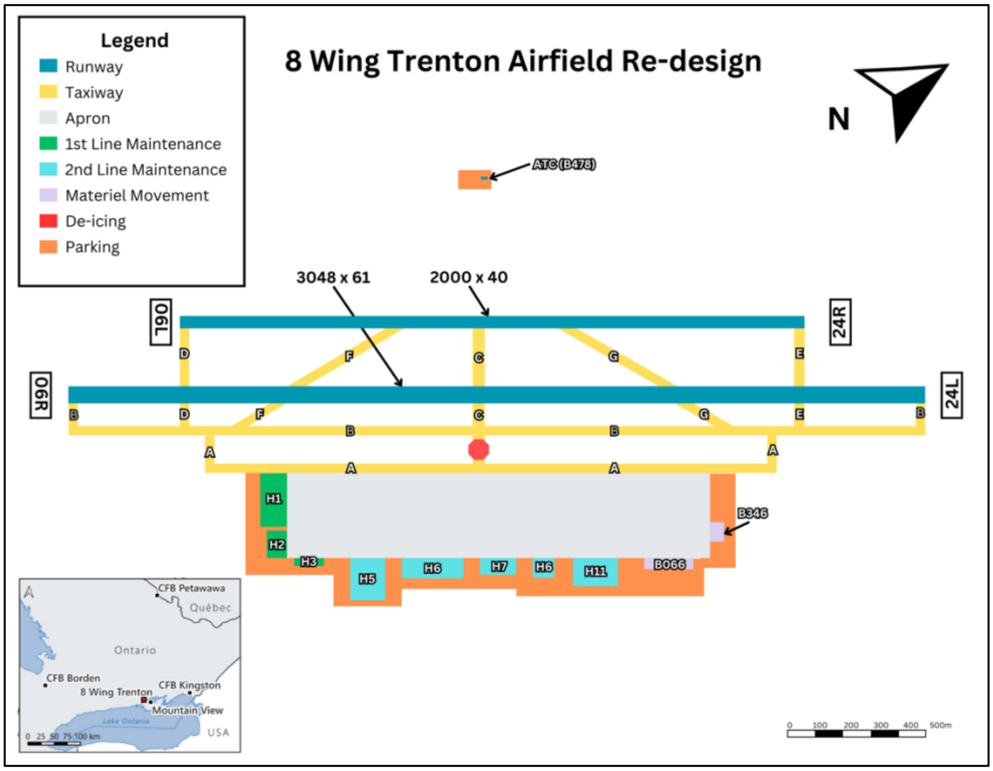


Figure 5.3: 8 Wing Trenton Airfield Redesign

Directly to the west of the apron, the second line maintenance facilities, are arranged consecutively as Hangar 1, Hangar 2, and Hangar 3. The hangars currently satisfy user requirements; thus, no modifications were made to the structures or their footprints. Nearby, each squadron's corresponding hangars for administrative purposes and first line maintenance are located, comprising the newly constructed Hangar 5, along with Hangars 6, 7, 9, and 11. Hangar 5, a newly built four-bay structure, is designated to replace Hangar 10 for 436 (T) Sqn. Furthermore, Hangar 7 has undergone a transformation from a single bay to a dual bay to enhance its capacity for storing CC-177s and to provide extra workshop space for second line maintenance. A new two-bay Hangar 11 has also been erected to accommodate the fleet of nine CC-330s. On the logistical side, the materials movement area, including the freight reception (B066) and the passenger terminal (B346), has been situated on the western side of the ramp. The ATC tower retains its position to the north of the runway to maintain an unobstructed view of the entire airfield. The relocation of infrastructure shortens the distance between the hangars and the aircraft parking stands. These changes make the incorporation of FEGP at parking stands feasible and reduces the taxiway length needed in the new configuration. This strategic centralization of facilities is detailed in Table 5.4.

Table 5.4: Summary of New Building Layout

Building	Footprint	Number of Bays	Changes	Description
Hangar 1	95m x 190m	2	Relocated to main apron	8 AMS 2nd Line Maintenance
Hangar 2 (B607)	72m x 98m	2	Relocated to main Apron	8 AMS 2nd Line Maintenance
Hangar 3 (051)	28m x 106m	NA	NA	8 AMS - Propulsion Shop
NEW Hangar 5	125m x 150m	4	New Construction	436 (T) Sqn
Hangar 6 (B606)	70m x 220m	2	NA	429 (T) Sqn and 437 (T) Sqn
Hangar 7 (B522)	60m x130m	2	Increased to 2 Bay Hangar	Overflow
Hangar 9 (B112)	78m x 70m	2	NA	424 Sqn
NEW Hangar 11	160m x 100m	2	NA	New Hangar for CC-330
B066	40m x 175m	NA	NA	2 Air Mov Sqn – Freight reception
B346	50m X 70m	NA	NA	Pax Terminal
B478	25m x 10m	NA	NA	ATC Tower

Provided that the current dimensions of the main runway adequately support the operations of the CC-330, there have been no alterations to its original design. In addition to the main runway, a secondary parallel runway has been constructed to ensure that the CC-177 and CC-130J can still operate when the primary runway is busy or under maintenance. To improve efficiency, rapid exit taxiways have been installed connecting the two runways. These allow for quicker clearing of the runway and reduce taxi times, thereby minimizing fuel consumption. Additionally, the new airfield taxiway and runway dimensions are presented in Table 5.5.

Table 5.5: Airfield Taxiway and Runway Dimensions

Component	Length	Width (m)
Taxiway A	2000	33
Taxiway B	3208	33
Taxiway C	485	33
Taxiway D	482	33
Taxiway E	482	33
Taxiway F	746	33
Taxiway G	746	33
Runway 06L/24R	3048	61
Runway 06R/24L	2000	40

Considering the traffic of the aircraft and the configuration of the airfield, a central de-icing pad was strategically placed to the south of the secondary runway. This location helps prevent de-icing fluid from contaminating the apron areas and reduces the distance that aircraft need to travel to reach the runway threshold. Moreover, the installation of multiple de-icing bays was deemed unnecessary, as simultaneous de-icing of multiple aircraft is an infrequent occurrence in Trenton.

To illustrate potential fuel savings resulting from the new airfield layout, average taxi distances were calculated for the existing airfield layout and the new airfield layout. As presented in Table 5.6 and Table 5.7, taxi distances were measured and multiplied by their frequency to created weighted averages for both layouts. Due to prevailing winds on site, it was estimated that 60% of departures and arrival occur at Runway 06, whereas the remainder occur at Runway 24. Staff also indicated that approximately 10% of aircraft taxiing occurs from the North Apron, with the remainder occurring from the South (East and West) Apron. With these consideration in mind, the average taxi distance for the existing airfield layout was 1894 m and the average taxi distance for the new airfield layout was 1630 m. Thus, the new airfield layout effectively reduces the average taxi distance by 14%.

Table 5.6: Existing Airfield Layout Average Taxi Distance

Taxi In/Out	**Start**	**End**	**Distance (m)**	**Weight**	**Weighted Distance (m)**
Taxi Out	South Apron	RWY 06	1000	27%	270
Taxi Out	South Apron	RWY 24	2200	18%	396
Taxi Out	North Apron	RWY 06	750	3%	22.5
Taxi Out	North Apron	RWY 24	3600	2%	72
Taxi In	RWY 06	South Apron	3640	18%	655.2
Taxi In	RWY 24	South Apron	1330	27%	359.1
Taxi In	RWY 06	North Apron	2720	2%	54.4
Taxi In	RWY 24	North Apron	2160	3%	64.8
			Total	**100%**	**1894**

Table 5.7: New Airfield Layout Average Taxi Distance

Taxi In/Out	**Start**	**End**	**Distance (m)**	**Weight**	**Weighted Distance (m)**
Taxi Out	Apron	RWY 06L	1600	35%	560
Taxi Out	Apron	RWY 24L	1600	15%	240
Taxi In	RWY 06R	Apron	1660	15%	249
Taxi In	RWY 24L	Apron	1660	35%	581
			Total	100%	1630

6. Quantitative and Qualitative Analysis

This chapter presents a comprehensive quantitative and qualitative analysis of the ground fuel consumption, fuel management practices, Ground Traffic Management, Reduce Engine Taxiing, mission fuel planning, reducing APU use, and the culture of fuel efficiency at 8 Wing Trenton with a focus on the CC-130J, CC-150, and CC-177. It quantitatively estimates the fuel consumed during ground operations, to identify opportunities for enhancing fuel efficiency in ground operations. The analysis evaluates the operational feasibility and benefits of reduced engine taxi, including pilots' attitudes towards it, and the operational and environmental impacts. It evaluates mission fuel planning for force generation and force employment flights with insights into best practices in the aviation industry. Furthermore, the chapter explores the use of APUs including current practices and methods to reduce APU use by delaying start and sourcing power from GPUs. Additionally, the chapter explores current practices for de-icing and targeted measures for reducing the use of ADAFs through preventative measures and recycling. Lastly, the chapter evaluates the current culture surrounding fuel efficiency at 8 Wing, drawing from themes derived through the interview process. By addressing both quantitative and qualitative aspects of fuel consumption and management at 8 Wing Trenton, the chapter aims to provide a holistic view of current practices and identify opportunities to reduce fuel consumption and GHG emissions.

6.1 Ground Fuel Consumption

Provided that this research investigates sustainable ground operations with a focus on primarily transport aircraft, it was important to first quantify the estimated fuel consumption for ground operations of the studied fleets. Ground fuel consumption is an important metric for several reasons. While the existing fuel tracking mechanisms capture the total fuel consumed, they do not delineate between the fuel consumed during the cruise and the fuel consumed during ground operations. As this research aims to optimize ground operations of aircraft, the fuel consumed during ground operations serves as an upper limit for how much of an improvement can be made in fuel efficiency without impacting the flight operations. By isolating the ground fuel consumption, the study highlights potential areas for sustainable ground operations such as RET, optimized APU usage, and ground traffic management.

The ground fuel consumption per sortie was estimated by first identifying the amount of fuel allocated during the planning process for the engine start and taxi out. This is a fixed planning number for each airframe regardless of the operating condition, except for EROs). An average taxi-in time of 10 minutes was utilized for each airframe as it is a typical taxi-in time at most airports. Lastly, the APU burn time was based on the average run time as reported by users that were interviewed by the author.

The number of flights, delineated as force generation and force employment, were obtained for the calendar year 2022 using the hangar cloud app. The hangar cloud app is an online cloud-based software developed by the RCAF to digitally enable RCAF personnel through amplification, automation, and data driven processes (RCAF 2019). Its core features include mission planning and execution, communications, and claims processing. Within the mission planning and execution suites, is the daily flying schedule, containing current, future, and past flight arrivals, and departures at 8 Wing. As such, the numbers are representative of the calendar year studied, however, the ratio of fuel consumed to number of flights is expected to be the same or very similar year to year due to the standing annual operational commitments.

6.1.1 Ground Fuel Consumption Methodology

The estimate of the total ground fuel consumption began by determining the amount of fuel allocated to the engine start and taxi out for each airframe. The values used in mission planning for the CC-130J, CC-150, and CC-177 were 800lbs, 850lbs, and 2300lbs respectively. Notably, the planning figure do not include APU fuel consumption or fuel consumed during the taxi-in. Thus APU fuel consumption was calculated by multiplying the average APU run time by the APU fuel consumption. Lastly, the taxi-in fuel consumption was calculated using an average taxi-in time of 10 minutes multiplied by the average APU run time for each fleet. Ground fuel consumption for the CC-130J, CC-150, and CC-177 are presented in Table 6.1, Table 6.4, Table 6.7.

Estimating the average fuel consumption per flight, required the total amount of fuel consumed for the fleet and the total number of flights for that year. As several squadrons did not have historical flight data, this necessitated leveraging the hangar cloud daily flying schedule to calculate the total number of departures for 2022. As the hangar cloud does not have an export functionally, this required the cumbersome activity manually recording and tallying daily flights from the app. The total number of flights for the CC-130J, CC-150, and CC-177 are presented in Table 6.2, Table 6.5, and Table 6.8. Lastly, the total fuel consumed for each fleet was calculated using 2022 fuel logs from the bulk fuel manager. As the fuel logs were not consolidated in a master document, this involved manually tabulating all the historical data. The average fuel consumption per fleet was calculated by dividing the total number of flights for the year by the total volume of fuel dispensed for the squadron. Lastly, the total cruise fuel consumption per fleet was calculated by subtracting the average ground fuel from the average total fuel. The fuel breakdown by flight phase are presented for the CC-130J, CC-150, and CC-177 in Table 6.3, Table 6.6, and Table 6.9.

6.1.2 Ground Fuel Consumption for the CC-130J aircraft

Table 6.1: CC-130J Estimated Ground Fuel Consumption Per Sortie

Phase	Fuel Burn	Time	Extended Fuel Consumption (lbs)
Start, Taxi Out	800 lbs		800
Taxi In	35 lbs/min	10 min	350
APU	317 lbs/hr	0.5 hr	159
Total			1309

Table 6.2: CC-130J Flights Departing from 8 Wing Trenton (2022)

Flight Type	Number of Flights	Percentage
Force Generation	452	57%
Force Employment	340	43%
Total	792	

Table 6.3: CC-130J Average Fuel Consumption Per Flight

Phase of Flight	Fuel Consumption	Percentage
Cruise Fuel	15, 056 lbs	92%
Ground Fuel	1,309 lbs	8%
Total Fuel	16,365 lbs	

6.1.3 Ground Fuel Consumption for the CC-150 aircraft

Table 6.4: CC-150 Estimated Ground Fuel Consumption Per Sortie

Phase	Fuel Burn	Time	Extended Fuel Consumption (lbs)
Start, Taxi Out	750 lbs		750
Taxi In	50 lbs/min	10 min	500
APU	386 lbs/hr	3 hr	1158
Total			2408

Table 6.5: CC-150 Flights Departing from 8 Wing Trenton (2022)

Flight Type	Number of Flights	Percentage
Force Generation	218	54%
Force Employment	185	46%
Total	403	

Table 6.6: CC-150 Average Fuel Consumption Per Flight

Phase of Flight	Fuel Consumption	Percentage
Cruise Fuel	35,912	94%
Ground Fuel	2,408	6%
Total Fuel	38,320	

6.1.4 Ground Fuel Consumption for the CC-177 aircraft

Table 6.7: CC-177 Estimated Ground Fuel Consumption Per Sortie

Phase	Fuel Burn	Time	Extended Fuel Consumption (lbs)
Start, Taxi Out	2500 lbs		2500
Taxi In	100 lbs/min	10 min	1000
APU	408 lbs/hr	1.5 hr	612
Total			4112

Table 6.8: CC-177 Flights Departing from 8 Wing Trenton (2022)

Flight Type	Number of Flights	Percentage
Force Generation	85	37%
Force Employment	144	63%
Total	229	

Table 6.9: CC-177 Average Fuel Consumption Per Flight

Phase of Flight	Fuel Consumption (lbs)	Percentage
Cruise Fuel	79,461	95%
Ground Fuel	4,112	5%
Total Fuel	83,573	

6.1.5 Summary of Aircraft Ground Fuel Consumption

Aircraft ground fuel consumption for the transport fleet were aggregated to illustrate the components of fuel consumption and the breakdown of average fuel consumption based on the phase of flight. As illustrated in Figure 6.1, the estimated fuel consumption for the CC-130J, CC-150, and CC-177 yielded values of 1309 lbs, 2408 lbs, and 4112 lbs respectively. Furthermore, a summary of estimated breakdown of ground and cruise fuel consumption by airframe is presented in Figure 6.2. This data presents an opportunity for relevant managers to identify specific phases of ground operations that are more fuel intensive, thus hold greater potential for fuel savings. This detailed understanding of ground fuel consumption patterns can facilitate in developing targeted fuel reduction initiatives. By leveraging this data, informed decisions can be made to implement effective sustainable measures targeting ground operations.

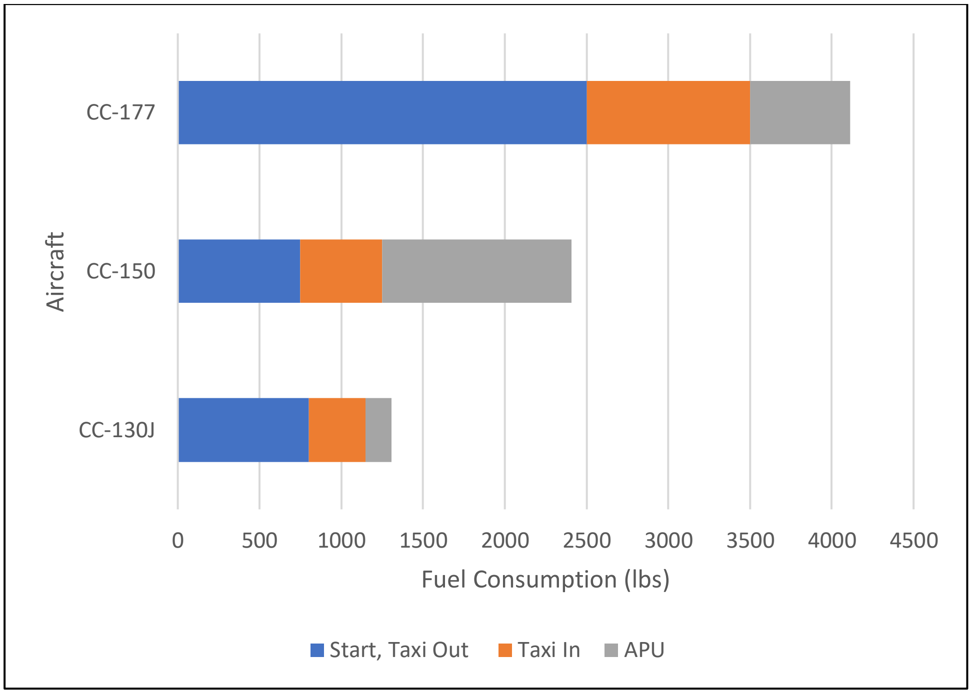


Figure 6.1 Summary of Estimated Ground Fuel Consumption

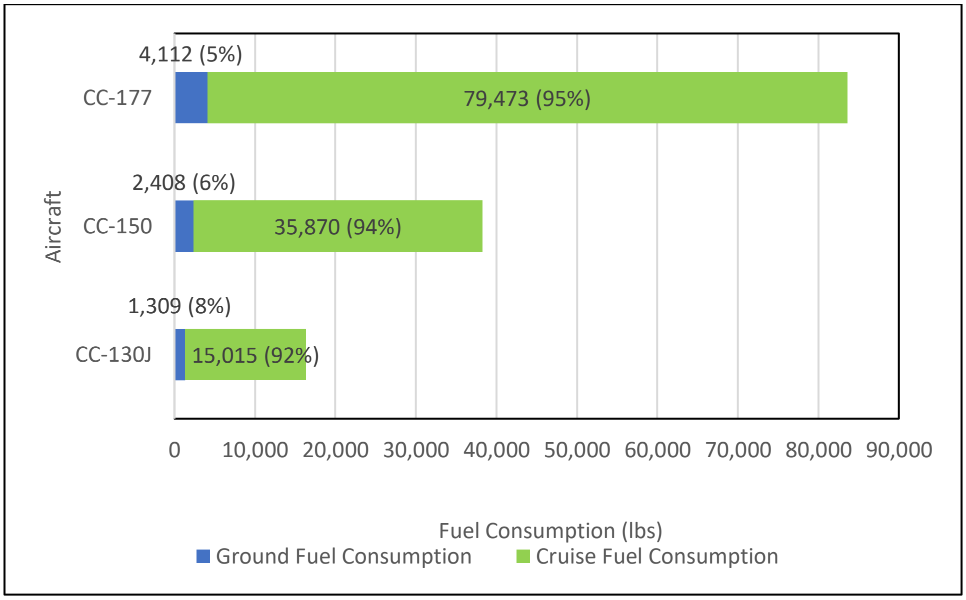


Figure 6.2: Summary of Estimated Breakdown of Ground and Cruise Fuel Consumption

6.2 Fuel Management

Fuel management at 8 Wing Trenton represents a critical component of its operational efficiency and environmental impact. Over the course of two days, an evaluation was conducted through interviews and site visits at the CFB Trenton fuel farm. This assessment aimed to investigate the existing fuel management practices, discern the roles and responsibilities of the stakeholders involved, and assess their impact on fuel consumption across the squadrons. The first day was dedicated to interviewing supervisors to understand the decision-making process, while the second day involved a tour of the refueling facility and oversight of a refuelling process. This tour offered insights into the equipment used, the types of fuel available for aircraft and ground support equipment, and the procedures for fuel testing and handling.

The assessment sought to identify the fuels used on the airfield and to compare the refueling infrastructure at 8 Wing Trenton with other airports. Understanding the protocols for fuel testing, including the measures taken when fuel fails to meet minimum quality requirements was a central part of this investigation. Additionally, the investigation aimed to uncover any potential gaps in the tracking mechanisms that could impact the accuracy of fuel consumption records or efficiency of fuel use. The assessment offers insights into improving operational and fuel efficiency.

6.2.1 Roles and Responsibilities

The fuel facility at 8 Wing Trenton plays in critical role in the operations of the wings, with its activities divided into two distinct but complementary sections: bulk fuel management and refuelling. These sections, despite being house in the same building, serve unique functions within the fuel management system. The bulk fuel manager is primarily concerned with the upstream operations in the fuel supply chain. Upstream operations include activities in the initial stages of the fuel supply chain, focusing on procurement, storage, and initial handling of fuel before it is ready to be used by the end user. This includes initiating fuel orders, handling invoicing, generating reports, and ensuring the compliance and maintenance of fuel tanks. Their role is vital in the testing and verification of fuel upon delivery, managing the storage facilities, and maintaining a minimum fuel reserve.

The refuelling section is primarily concerned with the downstream operations, which are essential for the direct support of flight operations. Downstream operations refer to the activities involved in distributing and supplying the fuel to end users. The section oversees managing refueling trucks, ensuring that they are filled and dispatched to aircraft across the airfield. Their responsibilities extend to coordinating with aircraft technicians for aircraft refuelling and defueling, managing the documentation of fuel dispensed into refueling trucks, vehicles, and aircraft, and maintaining records of these transactions.

6.2.2 POL Types

As summarized in Table 6.10, the types of petroleum, fuel, and lubricants (POL) available for ground support equipment and aircraft at 8 Wing Trenton include F-34, F-37, and Diesel (F-54). F-34 is stored in bulk fuel storage tanks and dispensed into refuelling trucks. NATO S-1749 is a thermal stability improver additive that is stored in separate storage tanks that is dispensed into separate storage tanks on the refuelling trucks. When aircraft require F-37, the F-34 is mixed with the additive on site using the refuelling trucks and dispensed to the aircraft.

Table 6.10: Summary of POL Types (NATO, 1997; United States DoD, 2011)

NATO Code	Type	Description
F-34	Jet Fuel	Kerosene type turbine fuel which will contain a static dissipater additive, corrosion inhibitor/lubricity improver, and fuel system icing inhibitor, and may contain antioxidant and metal deactivator.
F-37	Jet Fuel	JP-8 type kerosene turbine fuel which contains thermal stability improver additive (NATO S-1749)
F-54	Diesel	Diesel-based military fuel used in used in compression ignition engines

Interviews with refueling staff disclosed that the specific type of fuel dispensed for each aircraft is determined by the requesting unit or user. In the majority of instances, aircraft receive F-34 fuel. However, it has been observed that certain Search and Rescue (SAR) operations, specifically those involving rotary wing aircraft, utilize F-37 fuel.

6.2.3 Refuelling Infrastructure

The two main types of refuelling infrastructures at airports include: refuel trucking systems and fuel hydrant systems (Aviation Learnings Team, 2020). A refueling truck, essentially a fuel tanker, carries several thousand litres of fuel in its tank and is equipped with pumping systems, essential for connecting to an aircraft to replenish its fuel (see Figure 6.3). The airfield maintains a fleet of refueling trucks, which operate throughout the day, refuelling aircraft and returning to the fuel farm for replenishment once their tanks are empty. On the other hand, the fuel hydrant system involves an underground network of fuel supply lines that reach from the fuel farm to the aircraft stands (see Figure 6.4). A hydrant fuel dispenser, a specialized piece of equipment, connects to the underground supply line on one end and the aircraft on the other end.

Figure 6.3 Depiction of Refuel Trucking System (Aviation Learnings Team, 2020)

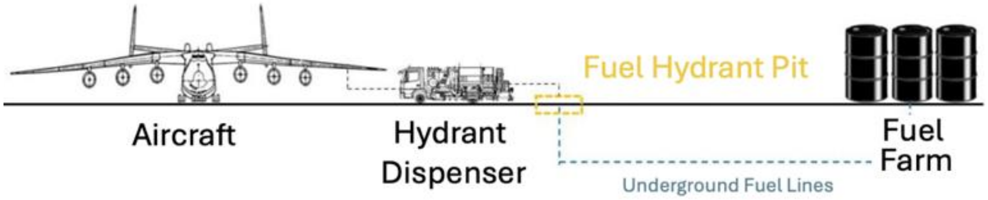


Figure 6.4: Depiction Fuel Hydrant Dispenser System (Aviation Learnings Team, 2020)

At 8 Wing Trenton, aircraft fueling operations are carried out using a refuel trucking system. As outlined Table 6.11 and pictured in Figure 6.5, refuelling and de-fuelling trucks at 8 Wing Trenton consist of the ALMAC, R-11, and Sterling Models. Both the ALMAC and R-11 are equipped with F-34 jet fuel and NATO S-1749 additive, allowing them to dispense both F-34 and F-37 AvPOLs. While both models serve the same purpose, the selection of the number and type of refuelling trucks is contingent on the required volume of fuel. The two de-fuelling trucks are both Sterling models, with each CFR specifically designated to de-fuel either F-34 or F37, to prevent any cross contamination. Additionally, there is a single diesel truck responsible for dispending diesel exclusively for ground support equipment on the airfield.

Table 6.11: Summary of refuelling and refuelling trucks

Model	Purpose	Quantity	Capacity (L)	Fuel Type
ALMAC	Refuelling	4	34,500	F-34, F-37
R-11	Refuelling	4	21,500	F-34, F-37
Sterling	Defueling	2	18,000	F-34, F-37
Diesel Truck	Refuelling	1	6,500	F-54

Figure 6.5: Overview of Refuelling Trucks A) R-11 Refueller, B) ALMAC Refueller, C) Sterling Defueller, and D) Diesel Refueller

Comparison of Aircraft Refuelling Trucks and Fuel Hydrant Systems

Both types of aircraft refuelling systems have their own set of advantages and disadvantages. The primary advantage of the aircraft refuelling trucks is their upfront costs compared to fuel hydrant systems, since the latter involves additional expenses for constructing underground fuel supply networks (Aviation Learnings Team, 2020). Refuelling trucks need to continuously travel between the airside and the fuel farm to refill from the airport's fuel farm after servicing aircraft. In contrast, the hydrant dispenser system reduces the number of trips required, as the dispenser only moves from its parking station to the designated aircraft stand with an existing fuel hydrant pit for refueling. A fully loaded refuelling truck incurs higher fuel consumption, whereas a hydrant dispenser, which neither carries fuel nor covers as much distance as a refuel truck, lowers transportation costs. Refuelling trucks pose a higher safety risk due to potential accidents with other vehicles and ground support equipment, leading to fuel spillage. Hydrant dispensers, that do not carry fuel, mitigate this risk. The choice between fuel hydrant dispensers and refuel trucks ultimately depend on a thorough cost-benefit analysis. If the added expenses of developing an underground fuel supply network do not outweigh the benefits of the simpler trucking system, it should not be chosen. However, the majority of modern airports opt for the fuel hydrant dispenser system, prioritizing cost benefits, logistical ease, and a safer operational mode over the potential cost savings associated with the fuel trucking system.

6.2.4 Refueling Testing and Sampling

Sampling is a technique of drawing a limited quantity of POL or associated product from a batch or lot for on-site verification or testing in a certified laboratory. Since a sample is used for determining the physical and chemical characteristics of a particular fuel product, the sample must be truly representative of the total product. As outlined in Part 2 Section 4 of C-82-010-007/TP-000, POL products are sampled under the following circumstances:

a. when requested by NDHQ/QETE 5;
b. on receipt or after pickup from a supplier;
c. during daily tender inspections and water checks;
d. when suspected that the product is contaminated, or does not conform to specification;
e. following a change of grade or type of fuel in bulk storage;
f. when requested during an investigation;
g. following a change of grade or type of fuel in refuelling tenders;
h. prior to commissioning a new tank or tank farm or following a tank or tank farm upgrade; and,
i. following the cleaning and/or repairs to refuelling tenders.

Amount of Waste Fuel Diverted

Fuel samples that have been tested are poured into a fuel recovery system and then stored in waste fuel tanks, as illustrated in Figure 6.6. As there is no means to store or use the fuel long-term, a contractor is paid to remove the waste fuel once the tanks are almost full. The contaminated fuel redirected to waste tanks and disposed through a contractor does not factor into the calculations when reporting the base’s

AvPOL consumption. This prompted the primary author to investigate the volume of contaminated fuel redirected to waste tanks in the overall context of GHG emissions.

Figure 6.6: Overview of Waste Fuel Storage System A) Waste fuel collector, and B) Waste Fuel Storage Tank

Fuel tracking spreadsheets provided by the bulk fuel manager were compiled in order to calculate the total volume of fuel dispensed and waste fuel diverted to disposal. As summarized in Table 6.12, in the calendar year 2022 a total of 103, 502L of AvPOL were diverted to waste, accounting for 0.38% of all AvPOL consumed in 2022 and this amounts to an equivalent of 274 tonnes of CO_{2E}. Moreover, the assessment fuel diversions from other years were not considered for practical reasons. The historical data for these years was not easily accessible, and given the operational norms, it was anticipated that these figures would be within the same range as the year assessed. It is important to note that the aim of this analysis was not to pinpoint an exact figure for each year but rather to offer an order of magnitude and approximate percentages.

Table 6.12: Amount of Fuel Diverted to Waste in 2022

Parameter	**Volume (L)**	**GHG Emissions (t CO_{2E})**
Fuel Dispensed	27, 633, 691	71, 294.9
Waste Fuel Diverted	105, 202	274.0
Percent of Total	0.38%	

6.2.5 Refuelling Procedures

The refuelling process as outlined below, demonstrates a reactive operational process, initiated by squadron fuel requests submitted through Wing Operations (Ops).

1. Squadron submit their fuel request through Wing Ops;
2. The refuelling section receives a call from Wing Ops;
3. The refuelling section creates a ticket and dispatches the type and appropriate number of trucks;
4. The refuelling member(s) drive the truck(s) to the ramp adjacent to the aircraft;
5. The fuel pump is handed off to one of the squadron's techs;
6. The squadron tech refuels or defuels the aircraft;
7. The refuelling section generates a fuel ticket and provides a copy to the tech;
8. The refuelling section returns to the fuel farm and documents the transaction in its logbook; and,
9. The transaction is added to the fuel transaction tracker master spreadsheet.

6.3 Ground Traffic Management

Prolonged taxiing not only results in increased fuel consumption and emissions, negatively impacting the financial performance of airlines but also releases emissions into the local environment, raising concerns about public health (Guo et al., 2014). Airport bottlenecks lead to extended taxi durations, which in turn increase fuel usage and GHG release (Eklund & Osvalder, 2021). While increased demand for consumer air travel has resulted in an increased volume of flights and airport congestion, it was hypothesized that this trend was unlikely to be observed within the context of the RCAF. This is because air travel in the military is driven by operational requirements rather than consumer demand.

The investigation into ground traffic management of aircraft on the airfield at 8 Wing sought to answer questions regarding the efficiency of ground operations, particularly in the context of taxi times, which have direct implications on fuel consumption, emissions, and operational effectiveness. Firstly, it aimed to determine the range of taxi times experienced, acknowledging that extended taxi times lead to excessive fuel consumption. Secondly, the study investigated how congestion at the site impacted taxi times due to bottle necks and excessive idling. Lastly, it aimed to assess whether ground controllers are selecting the most direct paths available to minimize unnecessary delays and fuel consumption.

6.3.1 Data Collection

For analysis and statistical purposes, flight data is typically extracted from the aircraft's flight data recorders. This allows researchers to examine taxi trends on mass and produce statistically significant results. For this research, secondary data regarding taxi times could not be obtained as it is not current being collected or tracked by the RCAF. Several staff indicated that the aircraft manufacturers were collecting and maintaining flight data through proprietary systems but that they were mainly for maintenance and troubleshooting purposes. The general sentiment was that without a formal contract in place, it would be difficult to gain access to the data. 8 OSS indicated that flight data could only be made available but that the request would need to be due to a safety incident or national security. Given these barriers and time constraints, gaining access to historical flight data was not further pursued for practical purposes. Due to the broad nature of this research and time constraints, it would have not been feasible to amass enough data to produce statistically significant results. Nevertheless, the quantitative data was validated through interviews with 8 Wing Staff.

Instead of analyzing secondary data, primary data was obtained from site visits. During this time, the author was embedded in the air traffic control tower for approximately one week. This allowed observations of taxi trends on the ground and to conduct informal discussions with the staff. Notably, the weather conditions during the data collection period were optimal with high visibility and temperate weather conditions. Thus, it should be noted that the sample is likely not truly representative of all scenarios. Interviews and discussions with staff were conducted to validate how representative the small sample size was of the spectrum of scenarios.

6.3.2 Assessment of Ground Traffic

Increased demand for air travel has historically led to increased taxi times. At civilian airports, it is common to see several aircraft queuing with their engines running and waiting for clearance to taxi out to the runway. Airport bottlenecks lead to increased taxi times and idling, thus increasing fuel consumption and GHG release. Similarly, minimizing taxi out time before takeoff, has been established as an effective method for reducing fuel consumption (USAF EATF, 2018). Opting for shorter taxi routes towards nearby runways can minimize ground time and decrease fuel consumption. By choosing the most efficient route to the runway and considering the opposite direction takeoff when safe and feasible, air crews can maximize fuel efficiency.

Selection of Routes

Upon completion of the start engine procedure, the aircraft commander requests clearance from the ATC to taxi to the designated runway. The ATC or ground controller will select the most efficient route, aiming to minimize taxi time to the runway threshold. This practice ensures timely departures but also reduces fuel consumption during the taxi out phase by minimizing the taxi distance. The active direction of the runway refers to the direction in which aircraft are currently taking off and landing based on prevailing winds. Operating under the principle that aircraft take off and land into the wind whenever possible, the active runway direction is selected to align with the current wind patterns. This practice improves safety as it provides better lift during takeoff and aids in deceleration during landing, but also improves fuel efficiency and reduces GHG emissions. The alignment of the active runway direction with the dominant wind conditions is considered a best practice, ensuring that aircraft are taking off and landing under optimal conditions. The ATC actively monitors and evaluates wind conditions to make an informed decision on the optimal takeoff direction. Additionally, if the aircraft commander requests a specific takeoff direction aligned with their destination and wind conditions permit, the ATC will adapt the active runway accordingly.

The selection of taxiing routes at 8 Wing Trenton was assessed as effective. When conditions permit, ATCs will always select the most direct routes to minimize taxiing time from the tarmac to the runway threshold. Safety is the number one priority during ground operations, followed by selecting the most direct route. The ATC's flexible approach also permits switching of the active runway direction, allowing aircraft to take off and land towards their respective destinations.

Congestion

The desire to understand the impact of congestion on ground operations at 8 Wing Trenton stems from the recognition that congestion and bottlenecks are causes of concern at major civilian airports. This is primarily because they lead extended taxi and idling times and contribute to delays on the taxiways and runways. The goal of this investigation was to assess the extent to which congestion may be affecting operations at the site. Recognizing the implications of congestion, the focus was on determining whether it posed a challenge to efficient ground operations, potentially leading to delays and unnecessary fuel consumption. If congestion was identified as an issue, the subsequent step would involve an analysis of the current operational practices to identify areas for optimization.

The level of congestion was assessed qualitatively by observing the taxiing of aircraft from the control tower and through interviews with pilots and ATC staff. At 8 Wing Trenton, flights are planned, whenever possible to occur during regular working hours. As indicated in the Wing Flying Orders, this is primarily due to minimize disruption to the local population due to noise generated by the aircraft. Time spent in the ATC tower was selected based on the first planned flight of the day and terminated once the last plane had taken off or at around 1800.

During the week spent in the control tower, there were several hours where no aircraft were taking off or landing. Generally, there were few flights per day, and they were scheduled with enough time in between then, so simultaneous takeoffs and landings were a rare occurrence. The exception to this was primarily due to preplanned training flights. If there were multiple flights from different squadrons that were set to depart at the roughly the same time, priority to start engines and taxi out would be given to the first aircraft to request clearance from the ATC tower. Ensuing aircraft typically waited until the taxiing aircraft was close to the threshold before starting their engines and beginning their taxi. This both avoided unnecessary congestion on the taxiway and reduced the total time that the engines were running prior to taxiing. In some instances, there were planes scheduled to take off at the same time, but these were generally C-130Js, intending to fly in formation as part of their training. In the rare instances that there were different aircraft taking off at the same time, they were initially scheduled to take off at different times but were ready to taxi out at the same time due to delays.

Given the temporal limitations of the site visits, staff were solicited to determine whether the congestion levels observed during the site visits were truly representative of all operational scenarios. ATC staff were asked to provide input on potential fluctuations in traffic volume, seasonal variations, and specific operational circumstances that might not have been fully captured during the observational period. This engagement with staff was critical to obtain a more comprehensive understanding of the broader operational context at 8 Wing. Conversations with staff revealed that, although the total number of flights exhibited fluctuations between months, the impact on instantaneous traffic levels was minimal. Across the combined years of experience working in the ATC tower, they had not observed any situations where congestion led to unnecessary prolonged taxi times or queuing on the taxiways. Furthermore, given the relatively low traffic levels compared to major airports, there was a consensus that the current ATC ground traffic management was effective. Thus, any sort of ground traffic optimization would likely not improve the already efficient operations substantially.

Taxi Times

Measuring taxi times serves as a quantitative metric that complements the qualitative data collected regarding the congestion at 8 Wing Trenton. While qualitative observations derived from interviews have the advantage of providing insights beyond the observation period, measuring taxi time provides an objective and measurable indicator of the efficiency of the ground operations on site. This data is particularly useful as it can be used to compare to major civilian airports, where idling and taxi times have historically trended upwards. This comparison provides insights into how efficiently ground operations are handled at 8 Wing Trenton relative to larger and more complex civilian airports. For this portion, data for taxi in and out times were collected while imbedded in the ATC tower. Being situated in the ATC afforded the opportunity to hear the ATC staff providing taxi and engine start clearance while also providing a vantage point to visually track the movement of the aircraft from the tarmac to the runway threshold.

Interestingly, it was observed that the taxi times were more a function of the aircraft operator's habits and the total distance travelled rather than a function of congestion. Upon explaining to the ATC staff that taxi times would be collected to analyze trends, the ATC staff expressed concerns regarding the potential difficulty in identifying conclusive trends. This apprehension stemmed from the variability in taxi durations, driven by the distinctive behaviours of each individual pilot.

The insights provided by the ATC staff were consistent with the observations on site. The observations validated the assumption that certain aircraft taxied at notably faster rates, while others taxied more slowly. Variations in the behaviours of different pilots were evident, with some executing several stop-and-go movements, while others maintained a more consistent speed throughout the taxi process. Based on these observations and minimal congestion observed, it can be deduced that taxi times at this site were primarily a function of taxi distance and pilot behaviours rather than congestion.

The primary goal of this undertaking was to capture the range in taxi times rather than achieve statistical precision. The use of stopwatch allowed for a straightforward practical approach to gather real-time data during aircraft movements. For taxi out measurements, the timer commenced upon the aircraft's breakaway from its parked position and concluded when the aircraft came to a complete stop at the runway threshold. For taxi in measurements, the timer was initiated as soon as all the aircrafts wheels contacted the ground and stopped once the aircraft had reached its designated parking location and come to a complete stop. Tombstone data, encompassing details such as date, time, weather conditions, runway, flight type, arrival or departure, call sign, squadron, and tail number along with the legs taken and taxi durations were noted on a tracking sheet. The tombstone data ensured that the recorded taxi times could be analyzed with considerations for the various factors influencing ground operations.

Given the low frequency of arrivals and departures per day at 8 Wing, the decision was made to aggregate the data into arrivals and departures. It was recognized that producing statistically significant results would be challenging due to the limited number of daily movements, thus the emphasis remained on capturing the range of taxi times. The taxi times recorded throughout this exercised are presented in Table

6.13, the taxi out time ranged from 2:51 minutes to 6:38 minutes whereas the taxi in times ranged from 1:32 minutes to 3:40 minutes.

Table 6.13: Taxi Times Observed at 8 Wing Trenton

Parameter	**Taxi Out Time (M:SS)**	**Taxi In Time (M:SS)**
Min	2:51	1:32
Max	6:38	3:40
Average	4:55	2:36
Number of Samples	8	3

Figure 6.7 provides a visual representation of the average taxi times documented at 8 Wing Trenton in contrast to the average taxi times reported for major Canadian airports during the summer of 2022, as published by Eurocontrol (2022). Notably, the observed taxi durations were consistently and significantly shorter when compared to the data from the airports presented in comparison. The marked difference indicates that the taxiing and ground traffic management at 8 Wing Trenton are already remarkably efficient, stemming from the low volume of flights.

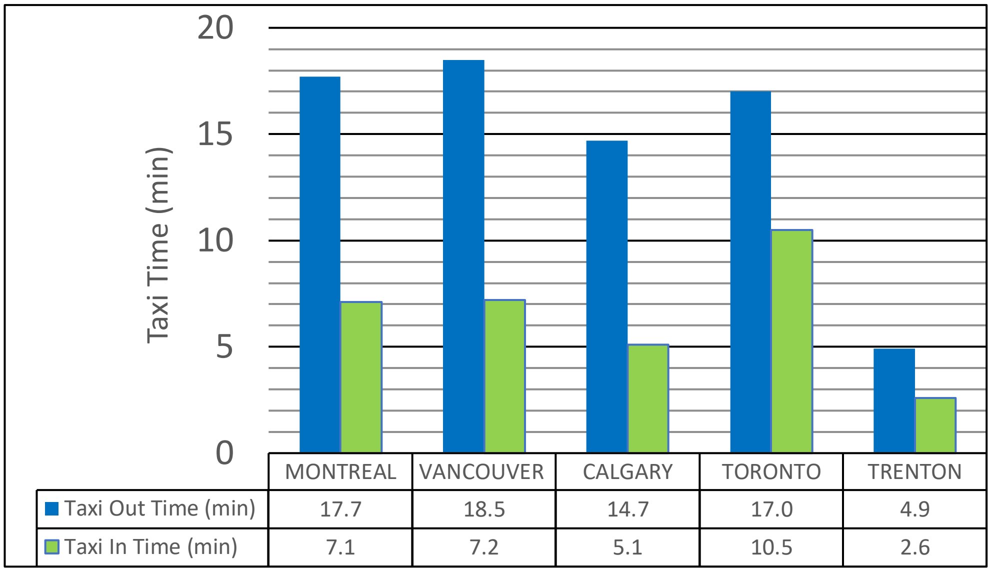


Figure 6.7: Taxi Times Compared to Major Airports in Canada

6.4 Reduced Engine Taxi

In the commercial aviation sector, Reduced Engine Taxi (RET) is widely used to reduce fuel consumption. Despite having proven to be an effective fuel reduction measure, RET has yet to be adopted in military aviation at the same scale. This section focuses on 8 Wing Trenton, aims to understand to what extent RET is used, the attitudes and beliefs of staff towards RET, operational factors influencing its use, how feasible it is to implement, and the projected fuel savings. This section also includes lessons learned from the existing literature, to support decision makers in standardizing RET across the studied fleets.

6.4.1 Use of RET at 8 Wing

In the early phases of this research, a key priority was to determine the approval status of reduced-engine taxi procedures within each fleet at 8 Wing and to gauge the extent of their utilization by pilots. This investigative process began with a review of each fleet's individual Flight Crew Operating Manual (FCOM) to determine the existence of any procedures related to reduced-engine taxi (RET). Once this groundwork was laid for each fleet, interviews were conducted with staff members to investigate the specifics of how extensively RET is integrated into their operational practices. Pilot insights, derived from their feedback and firsthand operational experiences, played a key role in revealing the considerations and potential advantages or challenges associated with the incorporation of RET procedures.

Across all fleets under consideration, there were no established procedures delineating the use of reduced-engine taxi-out (RET-out) within their respective FCOMs (See Table 6.14). This absence of formal guidance was reaffirmed through discussions with pilots, none of whom had ever executed RET-out in any circumstances. This aligned with the prevailing trend observed in the airline industry, where the utilization of RET-out remains infrequent. Notably, many airlines refrain from approving RET-out procedures due to the heightened workload associated with the engine start procedure (Pillirone, 2020). Should RET-out be adopted, manufacturers would need to update FCOMs with revised engine start procedure checklists, as the current protocols mandate all engines to be operational as part of the engine start procedures.

Conversely, reduced-engine taxi-in (RET-in) is an approved procedure for the CC-177 and the CC-150 (see Table 6.14). However, despite its sanctioned status, a few pilots mentioned having employed RET-in in the past, but they collectively conveyed that it is not commonly practiced. Furthermore, those who had experimented with RET-out had done so on rare occasions, emphasizing that their motivation was curiosity rather than a deliberate pursuit of fuel savings. Regarding the CC-130J, there was no amended engine shutdown checklist within the FCOM specifically tailored for reduced-engine taxi-in (RET-in), and the interviewed pilots expressed a lack of awareness regarding any such procedure. One CC-177 pilot expressed that they had taxied out in on two engines while deployed abroad but that it was not something that they did regularly.

Table 6.14: Approval Status of RET by Aircraft

Aircraft	RET-In	RET-Out
CC-177	Yes	No
CC-150	Yes	No
CC-130J	No	No

In summary, through examination of the FCOMs and interviews with staff members, including pilots, it is evident that there is an absence of standardized procedures for RET-out across all fleets. This finding aligns with the aviation industry trend, where RET-out remains infrequent primarily due to concerns about the increased workload during the engine start procedure. Conversely, although RET-in is permitted for certain aircraft, interviews with staff indicate that it is not commonly utilized. Pilots expressed limited awareness, and occasional usage was driven more by curiosity than a deliberate pursuit of fuel savings.

6.4.2 Attitudes and Beliefs of Pilots

The adoption of Reduced Engine Taxi (RET) procedures has the potential to reducing fuel consumption and has garnered attention in commercial aviation for its environmental and commercial benefits. In the realm of military aviation, under the Mission Execution Excellence Program (MEEP), the United States Air Force (USAF) selected Reduced Engine Taxiing as one of the six efficiency techniques to lower energy demand across their fleets (Air Force Operational Energy, 2022). However, the integration of RET into RCAF operations, presents unique challenges that warrant consideration. Pilots, as the end-users of such procedures, are in a key position to provide insights into the practical implications of RET.

Table 6.15 outlines pilots' perspectives on Reduced Engine Taxi (RET) and categorizes their responses into two main themes: Ease of Operation and Habitual Practices, and Risk Aversion and Safety Concerns.

Table 6.15: RET Interview Themes

Ease of Operation and Habitual Practices	3 RET “*We normally taxi in on four engines, as it is easier and requires less steps. I taxied in on two engines once but haven’t done it since*.” (CC-177 Pilot) 4 RET: “*The fuel savings [for RET] wouldn’t be worth it. By following the same procedures every time, you don’t have to worry about extra steps. If you do the same procedure every time, you are less likely to make a mistake”.* (CC-150 Pilot)
Risk Aversion and Safety Concerns	4 RET: “*The fuel savings [for RET] wouldn’t be worth it. By following the same procedures every time, you don’t have to worry about extra steps. If you do the same procedure every time, you are less likely to make a mistake*”. (CC-150 Pilot) 5 RET: “*The risk of engine malfunction and control of the plane are factors that could prevent the use of RET*” (CC-150 Pilot) 6 RET: “*With RET, there is more throttle on the two engines that remain on. With the higher throttle setting, there is a greater potential to damage to anything behind you*.” (CC-177 Pilot) 7 RET: “*If your landing weight is heavy to due cargo, it requires a higher throttle setting which can lead to jet blast*.” (CC-177 Pilot)

Pilots expressed a preference for maintaining uniform procedures that minimize the number of steps and decisions required during taxi operations. This preference was rooted in the desire for ease of operation and habitual practices, which can reduce the likelihood of errors. The quotes suggest that pilots find it easier and safer to taxi with all engines running, as this avoids the need for adjustments specific to using fewer engines. The mention of not repeating a two-engine taxi after a single attempt and the assertion that the fuel savings would not justify the deviation from standard procedures underscore a general inclination towards maintain the status quo through familiar routines.

Risk aversion and safety concerns represents pilots' concerns about the potential risks associated with RET, including engine malfunctions, difficulty in controlling the aircraft, and the dangers posed by increased throttle settings on the operational engines. These concerns highlight a fundamental emphasis on safety and risk management in ground operations. The pilots' comments reflect an evaluation of RET's risks versus its benefits, with a particular focus on the physical safety of the aircraft, its occupants, and ground personnel. Concerns about engine malfunction and the control of the plane, along with the risk of causing damage through jet blast due to higher throttle settings, illustrate the complex considerations pilots must balance when evaluating new operational practices like RET.

Synthesizing insights from pilots at 8 Wing Trenton reveal a recurrent theme. A cultural shift may be necessary to foster greater acceptance and integration of green procedures such as RET. The absence of standardized procedures, coupled with pilots expressing reservations or limited awareness, reflects a prevailing mindset leaning towards the status quo. Despite potential fuel savings highlighted by RET proponents, there seems to be resistance rooted in comfort with established procedures and concerns about operational feasibility. To facilitate a culture shift, ongoing dialogue with pilots and operational staff is crucial, addressing concerns and emphasizing the potential benefits of embracing fuel-efficient practices.

6.4.3 Operational Considerations

One of the key differences between reduced engine taxiing and total engine taxiing (TET) is that RET requires a greater level of discretion by the pilot. For TET, pilots have the advantage of performing the same set of procedures after every landing and before every takeoff. In contrast, RET requires to continuously assess their environment to make an informed decision on whether to taxi on reduced engines or total engines. The process adds a layer of complexity to the taxiing phase, requiring pilots to strike a balance between reducing emissions and prioritizing safety. Reduce engine taxiing places a greater emphasis on the pilot’s judgement and situational awareness, making it a measure that requires a more adaptive approach compared to the more straight forward total engine taxiing.

With these considerations in mind, RET in a military context requires an additional layer of judgement on behalf of the pilots. The implementation of RET in military operations involves several additional operational considerations, particularly in austere environments or in environments with an increased threat assessment. Although the operational considerations for employing RET in military operations have not been studied extensively, broad considerations can be deduced from conversations with pilots and aircrew. In all cases, the opportunity for potential fuel savings should be weighed against the potential operational risks associated with RET.

A key differentiator between military operations and their civilian counterparts is the availability of support staff and equipment. This is particularly true in remote locations, where both support maintenance staff and equipment may be limited. An engine failure in a remote location could prove to be detrimental to the success of a mission, as the resources required to troubleshoot and remedy the failure may not be sufficient or present. These types of situations often necessitate engine running onload/offloads (EROs). EROs, involving the loading or unloading of personnel or cargo, are an important strategy in remove settings, allowing the mission to proceed despite the challenges posed by limited resources. In these types of situations, the trade-off between fuel consumption and expediency becomes a careful choice. While EROs may not align with fuel saving objectives, they align with the broader goal of maintaining operational effectiveness. The additional fuel expended during EROs is considered an acceptable cost in exchange for the agility and reduced downtime.

Ultimately, the decision to prioritize operational considerations over fuel efficiency underscore the dynamic nature of military operations. Similarly, one of the risks introduced by RET is the risk of engine malfunction. When employing this procedure, pilots are required to shut down and restart engines, introducing a risk of engine malfunction. The risk of engine malfunction necessitates a careful balancing act, such that pilots will need to use their best judgement to determine, on a case-by-case basis, under which circumstances RET would be appropriate. The choice to adopt RET, requires a risk assessment that weighs the potential fuel savings against the risk of engine malfunction. A summary of the operational considerations for employing RET are presented in Table 6.16.

Table 6.16: Operational Considerations of RET

Consideration	Expansion
Fuel savings vs. safety	Pilots must strike a balance between reducing emissions and prioritizing safety, adding complexity to the taxiing phase.
Fuel Savings vs. Operational Risks	Potential fuel savings with RET must be weighed against operational risks in military operations.
Support Staff and Equipment Availability	In remote locations, limited availability of support staff and equipment affects the decision to employ RET.
Engine Running Onload/Offloads (EROs)	EROs are critical in remote settings for maintaining mission progress despite resource challenges.

6.4.4 Feasibility

Regarding the feasibility of standardizing reduced-engine taxis for a RCAF fleets, several factors need to be considered. The most critical consideration for RET operation lies in the aircraft's design, as the aircraft must have sufficient residual thrust with half of the engine's operative. If the manufacturer's documentation lacks a modified engine start or shutdown checklist, it may suggest that RET has not been validated for the aircraft. Furthermore, if certain checks require all engines to be running, RET may not be feasible for the fleet. It also crucial to ensure that the aircraft is operating within established parameters, such as engine pressure ratio, during RET procedures. The absence of manufacturer approved procedures and need for all engines operational for certain checks may limit the feasibility of RET, requiring careful consideration and potentially additional guidance or modifications to existing procedures.

Feasibility of RET-out

RET-out, is a procedure during the taxi out phase where half of the engines of an aircraft are started at the tarmac and the aircraft taxis to the runway using half of the engines. Once there is about 3-5 minutes of taxi time remaining, the pilot will start the remaining engines and continue to taxi with all engines operational. In theory, the practice of RET-out appears to be straight forward, but as the nuances are investigated, RET-out is not as straight forward as it appears to be. In the commercial aviation industry, RET-out is sometimes viewed as untapped potential. This is because, unlike RET-in, the majority of airlines have not adopted RET-out as a standard practice (Pillirone, 2020). Considering that taxi out times are significantly longer than taxi in times, RET-out can be seen as an underdeveloped capacity to reduce fuel consumption on the ground. Thus, a key consideration in determining the feasibility of RET-out for RCAF fleets was to determine the factors preventing its widespread adoption in the commercial aviation industry.

The largest barrier to the widespread adoption of RET-out is that the workload is significantly higher than RET-in due to the engine start procedure (IFALPA, 2016). Pilots undertaking RET-out procedure are the pilots required to execute the engine start sequence not once but twice; initially at the stand and subsequently during the taxi-out to start the remaining engines. This process necessitates careful planning by the aircrew to incorporate the time needed for both engine starts and the engine warm-up period, which is heavily influenced by atmospheric conditions, as well as the remaining taxi out duration. In addition to these tasks, pilots must simultaneously maintain a high level of situational awareness, ensuring that safety is not compromised throughout the operation. Thus, the potential fuel savings of RET-out must carefully be weighed against safety considerations. RET-out appears to be a daunting task for even the most seasoned pilots and, in the case of airlines, it appears that the majority have decided that the safety implications are not worth the fuel savings.

Further to the barriers to adoption identified in previous studies was another consideration specific to the RCAF fleet uncovered during the interview process. To better understand what sort of the impact the engine start process would have on RET-out procedures, candidates were asked to estimate the range of durations for the engine start procedures for their respective aircraft. Interestingly, the engine start process ranges from 3 minutes for the CC-130J all the way up to 20 minutes for the CC-177. The values, presented in Table 6.17, were validated by attending local trainers, where the engine start procedures observed fell within the ranges described in interviews.

Table 6.17: Engine Start Procedure Average Times

Aircraft	Engine Start
CC-130J	3-5 min
CC-150	5-10 min
CC-177	15-20 min

Most interestingly, were the nuances observed and described across the different airframes. As described a CC-130J pilot, "*Our checklists are developed with flows, allowing us to go through them more quickly. Other airframes slowly go through the checklist, whereas we can run through it in 30 seconds*." The time to get a CC-130J running and ready to taxi was notably more streamlined compared to the other fleets. In contrast, the engine start procedure for the CC-177 was significantly longer and required more steps compared to the other two airframes. As described a CC-177 pilot, "*Our engine start process is significantly longer than other aircraft because we need to do everything manually. Comparatively, for some other aircraft, all they need to do is flip a switch and the checks will be done automatically. We need to go through each item individually and it can take quite some time*."

Based on the differences in engine start procedures, it is evident that different airframes have varying complexities and durations for engine start-up. For example, the C-130J has a streamlined engine start process, with checklists designed to be completed rapidly. For such an airframe, implementing RET-out may be less burdensome because the engine start and system checks can be accomplished quicky. On the other hand, the CC-177 requires a more elaborate and manual start-up procedure. If the engine start process is lengthy, it would add an additional layer of complexity, particularly if the is insufficient taxi time left for the engines to be started and warmed up before takeoff.

In addition to the considerations, implementing RET-out for these fleets would also require a modified engine start-up checklist. Modified would be necessary to ensure the safe and consistent implementation of the procedure for each respective fleet. An effective RET-out checklist would need to address the unique requirements and considerations for each airframe associated with starting and taxiing on reduced engines during the taxi out phase. Gaining approval and input from the aircraft manufacturers and relevant stakeholders is critical to validate the technical aspects and safety implications of the modified checklist. According to a CC-177 pilot and standards staff member, there have been discussions between allies and Boeing regarding changes to checklist but none of them have led to any tangible changes to the checklists. This begs the question whether aircraft manufacturers would be willing to change engine start checklists to accommodate RET-out, as this type of change would be unprecedented.

In summary, RET-out is used to some extent within the aviation industry, most airlines do not employ it as a standard practice. The main deterrence to employing RET-out as a fuel saving mechanisms is associated with the increased workload due to the engine start procedure. Currently, none of the airframes examined in this study have amended checklists to facilitate the use of RET-out, therefore, collaboration with manufacturers would be required to release new amended and standardized checklists. An additional consideration for adopting RET-out are the engine start-up times, as they may impede the use of RET-out during shorter taxi durations.

CC-177 Feasibility (RET-in)

The modified engine shutdown checklist in the FCOM for the CC-177 specifically outlines the steps required to execute Reduced RET-in procedures. The inclusion of the amended checklist is indicative that the manufacturer acknowledges the potential advantages and feasibility of RET-in. The successful implementation of RET-in would require the training of flight crews to ensure proper adherence to the revised checklist and familiarity with the specific procedures involved.

Compared to the other airframes studied, RET-in for the CC-177 has been studied relatively extensively within a military context. In 2018, the Energy Analysis Task Force (EATF), identified RET-in as a feasible and proven fuel conversation measure (USAF EATF, 2018). Interestingly, USAF C-17 pilots interviewed cited reasons for not using RET-In like RCAF pilots interviewed in this study. Overlap areas included insufficient training in the procedures and shorter taxi distances. More recently, the USAF launched a pilot Mission Execution Excellence Program (MEEP) at two air forces, aiming to incentivize efficient flying with a focus on the C-17 fleets (Air Force Operational Energy, 2022).

CC-150 Feasibility (RET-in)

The modified engine shutdown checklist in the FCOM for the CC-150 specifically outlines the steps required to execute RET-in procedures. The inclusion of the amended checklist is indicative that the manufacturer acknowledges the potential advantages and feasibility of RET-in. The successful implementation of RET-in would require the training of flight crews to ensure proper adherence to the revised checklist and familiarity with the specific procedures involved.

Unlike the other fleets, the CC-150 fleet, which are converted civilian Airbus A-310-300 aircraft, have not been explicitly studied for the feasibility of Reduced Engine Taxi-In (RET-in). However, given their design and operational similarities to their civilian counterparts, it is reasonable to deduce that RET-in could be applied to the CC-150 with comparable efficiency. Airbus notes that using reduced engine taxi can yield fuel savings, provided that that factors such as gross weight, reduced redundancy, and engine cooldown times are considered carefully (Airbus, 2004).

CC-130J Feasibility (RET-in)

Provided that the FCOM for the CC-130J, the feasibility of RET-in for this fleet would need to be explored further. Beyond the FCOM, collaboration with the aircraft manufacturer, standards and evaluations teams, and flight crew would be required to gain insights into the technical, operational, and safety considerations associated with RET-in for the CC-130J.

Moreover, given that there were no reported instances of pilots using RET-In for the CC-130J, its feasibility remains uncertain without more data. As outlined by a CC-130J Pilot, "*Two-engine taxi doesn't work in practice for the CC-130J because several checks need to be done with all engine's operatives. In addition, two engines are generally insufficient to taxi the aircraft at a representative operational weight*." In contrast a different CC-130J pilot stated "*I've taxied on two engines at nearly the maximum takeoff weight*" noting that it was done to comply with the airport's regulations rather than to conserve fuel. Provided that RET is not a standard procedure, the sample did not extend beyond these two candidates as others interviewed had not used RET or even heard of it. This suggests that any consideration for RET-in must address these technical challenges to ensure that the aircraft's performance and safety are not compromised.

Projected Fuel Savings

Accurately estimating projected fuel savings due to RET can be challenging, particularly without access to real-time or historical flight data. Aircraft fuel burn is a function of several dynamic variables such as aircraft configuration, weight, weather conditions, air traffic control instructions, and ground conditions. Even within the same fleet, under similar conditions, these variables will directly impact the fuel flow of the aircraft and the total taxi time. The absence of historical data can make it difficult to account for these variables with a high degree of confidence. Another challenge with projecting fuel savings is that assumptions are deduced without empirical evidence from actual data. It is challenging to validate whether these assumptions align with real-world scenarios.

Within the literature, fuel savings due to RET can be broadly classified into two methods. The first method involves the analysis of historical flight data, to examine aircraft fuel flows, taxi durations, and empirical savings realized using reduced engine taxiing. Researchers use this data to construct highly accurate models to project fuel savings through different scenarios. The second method is a much more simplified approach, utilizes average engine fuel burn with half the engines operational. Provided that historical flight data was not available, this research will employ the simplified approach to project fuel savings that could be achieved through Reduced Engine Taxi-In for each fleet.

Engine Run Time Saved Per Sortie

The fuel savings because of reduced engine taxi-in procedures can be estimated by calculating the amount of fuel saved by taxiing with half of the engines operational. As illustrated in Figure 6.8, the initial RET-in process begins immediately after landing, when the wheels of the aircraft touch the ground after landing. After wheels down, the aircraft continues to taxi on all engines until the engine cooldown period has elapsed. Cooldown periods vary based on the airframe and operating conditions but are generally between 2-5 minutes. Once the cooldown period has elapsed, half of the engines are shut down and the aircraft will reduce engine taxi to the aircraft stand. As shown in Figure 6.8 and Equation 1, the engine runtime saved is the total duration that the aircraft taxis on reduced engines.

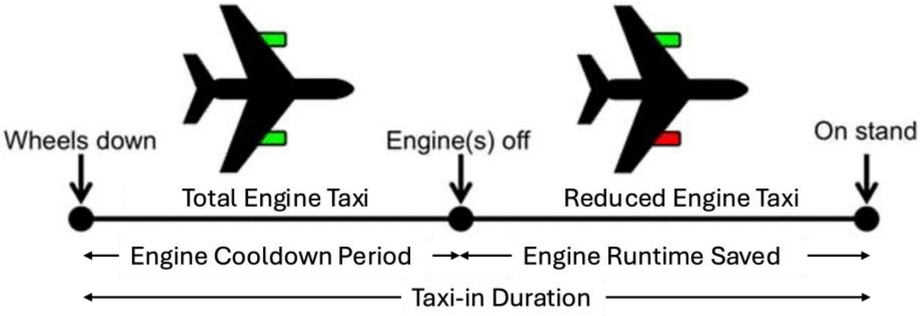


Figure 6.8: Reduced Engine Taxi-In Process. modified (Stettler et al., 2018)

Equation 1: $$\textbf{Engine Runtime Saved} = \textbf{Taxi in duration} - \textbf{Engine Cooldown Period}$$

For this projection, it was assumed that the typical taxi-in time from landing until parking spot block-in was 10 minutes. Time between landing time and block-in were not measured as part of this research, however, the 10 minutes estimate is conservative as the average taxi-in time observed was 2.6 minutes. This estimate allows for 7.4 minutes after parking the aircraft at its stand for the block-in to occur. It was also assumed that that each aircraft requires a cooldown period of 3 minutes. This estimate was based on the 3 minute estimate provided for the C-17 by the EATF (2018) and falls within the 2-5 minute range specific by Airbus (2004). The FCOMs for each airframe were also consulted but did not contain specific information on engine cooldown periods.

Engine Fuel Burn

Estimating the engine fuel burn for each fleet proved to be a challenging task as not all the fleets published their fuel specific fuel consumption during ground operations. When asked about average fuel burn on the ground a CC-130J pilot explained, *"[Fuel Burn] figures are largely meaningless because that plane can weigh anywhere from 100-175k lbs and the operating environment could be at sea level at -45C or 6000ft at +35C. Each scenario will place different bleed air, electrical and power demands on the aircraft*."

One method to estimate fuel consumption during ground operations, as suggestion by Moulton (2015), express the ground fuel consumption as a percentage of the cruise fuel consumption. Their analysis suggests that the ground operations fuel consumption is approximately 30 percent of the cruise fuel consumption. This estimate was also consistent with Moulton’s experience operating a Boeing 747 simulator.

Provided that none of the fleets, apart from the CC-177, publish their ground fuel consumption rates in their respective FCOM, the method suggested by Moulton (2015) was used to estimate the specific ground fuel consumption of each fleet. The cruise fuel consumption for each fleet were the values provided by pilots and are the widely accepted fuel cruise consumption used in the RCAF. For simplicity sakes, the fuel consumption is expressed in pounds per hour (pph) and pounds per minute (ppm) as operators continue to use pounds for the purpose of measuring aviation fuels. The estimated fuel consumption by fleet is presented in Table 6.18. Notably, the estimated ground fuel consumption of 100ppm for the CC-177 was the same as the figure provided in the FCOM.

Table 6.18: Estimated Fleet Fuel Consumption

Aircraft	**Cruise Fuel Consumption (pph)**	**Ground Fuel Consumption (ppm)**	**Number of engines operational**
CC-130J	7000	35	4
CC-150	10000	50	2
CC-177	20000	100	4

Percent of Annual Sorties

The process of collecting data on annual sortie rates for each squadron presented significant difficulties. For Squadron 429, there was a clear record of annual sorties categorized by fiscal year. In contrast, 436 and 437 Squadron did not have immediate access to such data. To ensure a consistent approach across all units, the sortie data for the calendar year 2022 were compiled by individually logging every departure and local training exercise from the Hangar Cloud's daily flight records for each squadron. Due to the absence of an export feature in the Hangar Cloud application, this required a manual review and recording of activities for each day of the year into a separate document. Due to the labor-intensive nature of this method, sortie data compilation was limited to the year 2022. Despite the limited sample size, it is expected that the projected savings calculated would remain constant across other years, as the projected fuel savings are expressed as a percentage.

As presented in the literature review, one of differentiators between TET and RET is that RET cannot be safely executed after every landing. Thus, estimating fuel savings resulting from RET-in requires an estimate of the percentage of sorties that have landing weights where all required taxiing can be safely executed with half of the engines operational. For RET-in, the EATF (2018) estimated that 90% of their flights met the conditions to perform RET-in. In contrast, Pilirone (2020) estimated that RET-in is used in approximately 50% of arrivals. Although the data on the percent of flights suitable for RET-in is limited, the estimate provided by the EATF is likely the most suitable, as it describes military transport aircraft. Thus, for the purpose of these projections, it will be assumed that 90% of RCAF flights meet the requirement for RET-in. As data becomes more available, it is recommended that the projections be updated with new figures.

Equation 2: $$\textbf{Fuel Savings per Sortie} = \textbf{Engine Run Time Saved Per Sortie} \times \textbf{Engine Fuel Burn}$$

Results

As presented in Table 6.19, the projected savings resulting from the use of RET-in on 90% of sorties were 0.68%, 0.41%, and 0.24% respectively for the CC-130J, CC-150, and CC-177. Provided that these projections were computed using several assumptions such as engine run time per sortie, engine fuel burn, and the percent of annual sorties, the assumptions should be validated using empirical data to assess the full potential of these savings accurately. Real-world data on engine run times, fuel burn rates, and the actual percent of sorties utilizing RET-in would provide a more comprehensive understanding of the fuel consumption reduction benefits.

Table 6.19: Reduced Engine Taxi-In Projected Fuel Savings

Aircraft	**CC-130J**	**CC-150**	**CC-177**
Engine Run Time Saved Per Sortie (Min)	7	7	7
Engine Fuel Burn (Lbs/Min), Half Engines Operational	17.5	25	50
Fuel Savings Per Sortie (Lbs)	105	87.5	350
Annual Sorties	792	403	229
90% Annual Sorties	396	201.5	114.5
Annual Fuel Savings (lbs)	83, 160	60, 450	68, 700
Annual Fuel Consumption (lbs)	12, 896, 444	15, 366, 219	29, 470, 863
Percent Savings	0.68%	0.41%	0.24%

When examining the potential fuel savings on a per sortie basis in relations to ground fuel consumption, it is evident that considerable efficiencies can be achieved, particularly when considering that most fuel consumption occurs during the cruise portion. As summarized in Table 6.20, the resulting percent savings of aircraft ground fuel consumption through RET-in were 8.02% for the CC-130J, 3.63% for the CC-150, and 8.51% for the CC-177, demonstrating the impact of such fuel-saving in relation to ground fuel consumption.

Table 6.20: Reduced Engine Taxi-In Projected Fuel Savings in Relation to Ground Fuel Consumption

Aircraft	**CC-130J**	**CC-150**	**CC-177**
Fuel Savings Per Sortie (Lbs)	105	87.5	350
Ground Fuel Consumption	1,309	2,408	4,112
Percent Savings	8.02%	3.63%	8.51%

Projected fuel savings were aggregated using the data from Table 6.19 to calculate the determine the GHG reduction potential because of RET-in. As presented in Table 6.21, RET-in, when standardized for the transport fleet, has the potential to reduce GHG emissions by 455.4 Tonnes CO_{2E}.

Table 6.21: Reduced Engine Taxi-In GHG Reduction

Aircraft	**Fuel Saved (L)**	**Emission Factor (g CO2e/L)**	**Emissions (Tonnes CO2e)**
CC-130J	83,160	2,569	213.6
CC-150	60,450	2,569	155.3
CC-177	68,700	2,569	176.5
Total	213, 310		545.4

The comprehensive analysis for RET for the RCAF transport fleet, as presented in this section, highlights both the potential fuel savings and challenges associated with its adoption. While commercial aviation has adopted RET to a certain degree, the military has unique operational requirements and considerations that must be considered. The inherent challenges presented by the engine start workload and absence of an amended engine start checklist, indicate that adopting RET-out is likely unfeasible at the current time. To implement RET-out for transport fleets, further analysis would be required to determine if aircraft manufacturers would create new checklists and how the change would impact safety on the ground. The feasibility of RET-in, while approved for certain fleets, remains underutilized due to a combination of a lack of awareness, training, and operational habits. Despite these challenges, the projected fuel savings, suggest that the adoption of RET-in could contributed to the RCAF’s broader environmental goals of achieving net zero emissions.

6.5 Mission Fuel Planning

Accurate mission fuel planning allows for a precise determination of the necessary fuel required for a mission by considering variables such as distance, aircraft fuel consumption, atmospheric conditions, and contingency fuel for potential diversions or unforeseen circumstances (Honeywell, 2019). This accuracy is critical for minimizing unnecessary fuel burn as the additional weight is directly correlated to the fuel consumption of the aircraft. By loading the minimum amount of fuel for a mission, the cost-to-carry is reduced, and the fuel efficiency of the aircraft is optimized.

When additional fuel beyond the require amount for the safe and efficient completion of the mission is carried, it is essentially dead weight (Honeywell, 2019). This extra weight requires more thrust from the aircraft to maintain flight, leading to increase fuel consumption. In aviation, this is referred to as the cost-to-carry, which is additional fuel burned due to carrying fuel that is not utilized during flight. This additional weight creates a cycle where fuel is being burnt to carry that fuel that is not needed, thereby decreasing the fuel efficiency for that mission.

The cost-to-carry is defined as the incremental fuel cost associated with carrying a unit of weight over a unit of distance and will vary based on the characteristics of each aircraft (ICAO, 2014; Mouton et al., 2015). This measure can be employed when assessing the advantages of removing excess weight from an aircraft. The increased fuel consumption resulting from additional weight on board an aircraft typically ranges from 2.5 to 4.5 percent of the additional weight per hour of flight (ICAO, 2014). The United States Air Force estimate that their cost to carry is approximately 3% across most of their transport airframes (USAF EATF, 2018). In this case, for every 100lbs of unburnt fuel carried the aircraft will burn an additional 3lbs of fuel per hours.

6.5.1 Force Employment

In contrast to fuel loading for force generation flights, the mission fuel planning for force employment flights is a more deliberate process, as mission fuel loads are tailored according to each flight. During mission planning, pilots utilize Foreflight to guide their fuel load calculations. Foreflight is an electronic flight bag (EFB) that can improve fuel efficiency through precise planning tools that account for aircraft performance, weather conditions, and route optimization. The program is loaded with a performance profile from the original equipment manufacturers (OEMs) specific to each airframe. Additionally, a performance correction factor is applied to each individual aircraft, ensuring that the fuel consumption is accurately estimated and customized for the unique characteristics of each aircraft. Features like weight and balance calculations, performance profiles for specific aircraft, real time weather updates, and route suggestions help pilots select the most fuel-efficient flight paths and improve the precision of fuel loading.

The use of EFBs has several advantages over manual methods including cost savings, increased efficiency, and improved safety (Glinka, 2023). When utilized properly, EFBs can yield cost savings by eliminating paper-based materials such as chart, manuals, and flight plans. Weight reduction is another advantage, as EFBs are significantly lighter than paper materials, leading to lower fuel consumption. EFBs also enhance efficiency during pre-flight preparations as they allow pilots to access and process information quickly, reducing preparation time compared to conventional measures. The provision of real time information, including weather reports and notice to airmen (NOTAMs) improve flight safety by enabling pilots to make data informed decisions. Lastly, EFBs automate and streamline various processes such as calculations for weight and balance, fuel planning, and performance data, which saves time while also reducing the risk of human error and increasing operational efficiency.

Pilots are ultimately in charge of determining how much fuel to put in their aircraft, and are allowed to add discretionary fuel on top of all other reserves (OpenAirlines, 2020). Pilots often carry additional fuel beyond what is necessary out of precaution or access to statistical data. Once the aircraft commander has input all the pertinent information into foreflight, they can manually adjust the contingency fuel to exceed the minimum fuel requirements for the specific flight. Based on interviews with pilots, a recurrent theme was that pilots felt more comfortable exceeding the minimum fuel reserves prescribed in the Flight Operations Manual (FOM).

6.5.2 Force Generation

A key difference between the use of military aircraft and commercial aircraft is the use of local trainers. Local trainers are force generation flights conducted in the local area with the primary purpose of training personnel and maintaining proficiency. Local trainers allow both new and experienced pilots to participate in a variety of training exercises to build and maintain proficiency. Examples include practicing different phases of flights, emergency procedures, and mission-specific manoeuvres. Pilots frequently perform circuits or pattern work in the vicinity of the airfield. This involves flying a standard rectangular pattern around the airfield, incorporating takeoffs, landings, and touch-and-go manoeuvres to practice fundamental flight procedures. The duration of local training flights varies based on operational requirements and will generally last between one to four hours.

In contrast to mission flights, local trainers are fueled with predetermined amount of fuel for each aircraft. The CC-177 and CC-150 are fueled with 60k and 100k pounds of fuel, equivalent to approximately 6 and 5 hours of cruise fuel consumption. For the CC-130J, local trainers are fueled to 32k pounds of fuel, equivalent to 4.57 hours of fuel. For search and rescue operations and EROs, the quantity of fuel is increased to 36k fuel, equivalent to 5.14 hours of fuel. The standard fuel loads for local trainers are summarized in Table 6.22.

Table 6.22: Local Trainer Standard Fuel Loads

Aircraft	Max Fuel (lbs)	Fuel Loaded (lbs)	Cruise Fuel Consumption (pph)	Hours of Fuel
CC-130J	42, 000	32000	7000	4.57
		36000 (ERO/SAR)		5.14
CC-150	80, 000	60000	10000	6
CC-177	245, 000	100000	20000	5

Notably, the quantity of CC-130Js and frequently of local trainers is significantly higher than the other two aircraft. Thus, when a subsequent training flight on the same aircraft is scheduled within 3 hours of the first training flight, the crews may opt to keep the engines running and perform an ERO. In these circumstances, the engines are kept running instead of shutting the aircraft down between sorties. It was noted by staff that EROs are not done out of laziness or convenience. They believed that EROs allowed the plane to be turned around quicker and reduced how much fuel was being consumed.

6.6 De-icing

De-icing activities at 8 Wing are done in accordance with the guidance in this section, the CF Flying Orders, applicable aircraft AOI's or FCOM's, and work instructions (WI) (8 Wing Trenton, 2023). All aircraft de-icing is performed on the de-icing pad located on taxiway Juliette, between taxiways Alpha and Papa. Under the direction of the ATC, aircraft start engines and taxi from their parking locations via taxiways Papa or Alpha to the de-icing pad.

The de-icing season starts on 1 October and ends on 30 April. To minimize the transfer of de-icing fluids during the de-icing season, only aircraft requiring de-icing services are permitted to taxi on taxiway Juliette between Alpha and Papa. At the end of the de-icing season, the ATC will not let aircraft or vehicle traffic on Juliette taxiway, between Alpha and Papa, until advised by 8 OSS that the de-icing pad is free of residual glycol.

6.6.1 Engine State during De-icing

According to the guidelines set out in the 8 Wing Flying Orders, the procedure for shutting down or leaving aircraft engines running during de-icing operations is determined by the specific Aircraft Operating Instructions (AOIs), Flight Crew Operating Manual (FCOM), or Standard Operating Procedures (SOPs) relevant to each type of aircraft. These guidelines stipulate the following:

1. CC-177 de-icing will be with engines OFF and the APU running;
2. CC-130 de-icing will be with engines OFF and the APU running; and
3. Normal de-icing for civilian patterns will be with the engines OFF unless otherwise directed by the aircraft commander.

The overarching guidance from Transport Canada, emphasizes the importance of shutting down engines during de-icing operations to prevent the ingestion of ADAF's, which can lead to engine damage or malfunction (Transport Canada, 2004). Nevertheless, it is recognized that proactive measures to limit ADAF intake can significantly reduce the risk of occurrence of such incidents.

Despite guidelines stipulating that de-icing should be conducted with engines off, discussions with staff revealed that this was seldom the case. Feedback from pilots indicated a preference for conducting de-icing operations with the engines running. Furthermore, it was noted that de-icing with engines running is common practice at most airports, as it allows aircraft to get to the runway more quickly after de-icing. When the ground crews allow it, pilots will opt to de-ice with the engines running rather than shutting them down. The primary motivation for pilots preferring to de-ice with the engines running stemmed from several practical and safety considerations.

Firstly, was the concern of engine malfunction, as starting an aircraft engine in cold weather conditions can sometimes result in engine malfunctions. Secondly, the workload associated with the engine start procedure is another significant factor. Starting engines can be complex, time-consuming process, requiring careful monitoring of engine parameters. In comparison, maintaining the engines in a running state simplifies the preparation for departure, allow the pilots and crew to focus on other pre-flight checks and procedures.

6.6.2 Management of ADAFs

The environmental criteria for ADAFs at 8 Wing are governed by the Order in Council (O.I.C) for Glycol at federal airports (Canada, 2010). Depending on air temperatures and the lowest operational use temperature (LOUT), either ethylene or propylene glycol ADAFs may be used. Currently, there are various holding/storage tanks for capturing ADAFs, however, glycol is not currently being re-used. There are three waste streams for disposal of ADAFs as follows:

a. If compliant with O.I.C. and Wing Standing Orders (WSO) (at or below 100ppm): controlled discharge into the local environment.
b. If above 100ppm: Dilution into the RP Ops Sewage Treatment Plan via sanitary line for sewage treatment; and,

c. Contracted hazmat disposal for destruction.

The recycling of ADAFs presents a potential opportunity to mitigate the environmental impact associated with their disposal or discharging into the local environment. Establishing a recycling program would require investment into equipment capable of processing and purifying the used glycol to meet the required standards for reuse. When the Pierre Elliot Trudeau International Airport, invested in an ADAF and glycol recovery and recycling system, it reduced their glycol costs by 30% (Nordstrom, 2017). Similarly, it was found that recycling ADAF cuts the carbon footprint of de-icing by 40-50% (Johnson, 2012). Given the scale of de-icing operations at larger airports, economies of scale would likely play a role compared to a smaller airport like Trenton. Thus, while technically feasible, the viability of recycling ADAFs at this site would require a thorough cost benefit analysis, considering factors such as the volume of fluid used, frequency of de-icing, and environmental benefits.

6.6.3 Preventative Measures

Reducing the amount of ADAF used can yield positive impacts for both cost and the environment (Transport Canada, 2004). The best preventative measure for reducing the quantity of ADAF required is by preventing the collection of frozen contaminants in the first place by storing the aircraft in a hangar. In principle, 8 Wing has implemented measures to prevent the accumulation of frozen contaminants on aircraft. The 8 Wing Flying Orders outlines the proactive use of hangar space to protect aircraft from adverse weather conditions, thus, reducing the need for ADAF. The Duty Watch Officer (DWO) plays a crucial role in this process, ensuring optimal utilization of hangar space with a prioritization system that reflects the environmental and cost implications of de-icing larger aircraft. By giving priority to the CC-150 and CC-177 due to their size and associated higher de-icing costs, 8 Wing's SOPs align with best practices that lead to cost savings and reduced carbon footprint.

In practice, the availability of hangar space stands as the limiting factor preventing most aircraft from being stored in hangars the night prior departure. Staff members recounted in many instances being unable to hangar their aircraft overnight due to the hangars being monopolized by unserviceable aircraft. Another challenge is the logistical aspect of storing the aircraft in a hangar and having it moved to the tarmac prior to departure. One CC-130J pilot recounted challenges they faced while storing their aircraft in the hangar overnight. In one instance, the hangar door failed to open, causing delays in moving the aircraft to its parking spot. In another instance, a snow plow had recently passed and left a significant amount of snow blocking the hangar door, further complicating the task of moving the aircraft out for its scheduled departure. These logistical challenges highlight the complexities involved in managing hangar space and aircraft movements, especially in adverse weather conditions. The hangar space issue is not just about the availability but also about ensuring that operational needs are met efficiently without compromising the readiness and punctuality of flight schedules. Such experiences underscore the importance of developing more effective strategies for hangar utilization, ensuring that serviceable aircraft have priority for overnight storage, and improving the coordination of ground services to mitigate delays and ensure smooth operations.

6.6.4 De-snowing process

De-snowing an aircraft is a process aimed at removing snow accumulation on the aircraft's surface. This process is key for ensuring the effectiveness and efficiency of the subsequent de-icing operations. Snow can absorb significant quantities of ADAFs, reducing their efficacy and requiring the use of larger quantities of the fluid (D'Avirro & Chaput, 2011). Furthermore, the removal of snow before applying ADAFs allows for a more direct contact between the ADAFs and the aircraft's surface, ensuring that formations of frozen materials are adequately addressed. Thus, de-snowing both optimizes the quantity of ADAFs required during de-icing and enhances the effectiveness of its anti-icing properties.

In accordance with the 8 Wing Flying Orders, it is mandated that all aircraft undergo de-snowing before de-icing. De-snowing operations are initiated on aircraft as soon as possible after precipitation has ceased, minimizing the necessity for extensive de-icing and de-snowing operations. Notably, the de-snowing process is conducted on the Apron, allowing for the concurrent utilization of the de-icing pad, and streamlining the de-icing process. As illustrated in Figure 6.9, prior do de-icing the de-snowing vehicle moves to the aircraft's parking position on the apron to de-snow the aircraft. The vehicle used compressed air to dislodge snow a frozen material of the surface from the aircraft, thus there is no risk of contaminating the apron with ADAFs.

Figure 6.9: De-snowing of a CC-177

By waiting until precipitation has stopped before initiating de-snowing operations, the amount of snow and ice accumulation is limited to what has fallen during the precipitation period. If de-snowing were to occur while precipitation is ongoing, efforts would be counteracted by precipitation, necessitating repeated de-snowing and de-icing procedures. Delaying de-snowing until the end of precipitation ensures that the operation is only conducted once per precipitation event, effectively reducing the need for additional de-snowing and de-icing procedures.

6.6.5 De-icing process

At 8 Wing Trenton, de-icing operations are centralized at a designated de-icing pad, situated adjacent to glycol storage facilities. The dedicated area for de-icing is beneficial primarily as it prevents the contamination of the larger apron and local environment by ensuring that runoff is contained and can be managed (Freeman et al., 2015). A centralized de-icing pad also allows for the implementation of treatment and containment strategies to manager or treat ADAFs before they enter the environment, thereby mitigating the impact on the surrounding environment. Lastly, centralized de-icing operations can result in more efficient scheduling and use of de-icing vehicles, minimizing delays caused by reducing the travel distance for de-icing vehicles (Norin et al., 2012). Provided that aircraft are already adjacent to the runway, the centralized location also reduces the chances of holdover time (HOT) expiring, necessitating an additional round of de-icing.

The use of type 1 and type 4 ADAF's offer flexibility across a range of temperatures. Type 1 is typically used to remove ice and snow from aircraft surfaces due to its lower viscosity and Type 4 is applied to protect against ice formation during precipitation and lower temperatures. Thus Type 1 ADAF is used for de-icing and Type 4 is used for anti-icing. Notably, if conditions permit, the aircraft will be de-iced but not anti-iced. This practice of de-icing but not anti-icing under favourable circumstances is consistent with the ADAF consumption for the previous four fiscal years presented in Table 6.23. De-icing equipment primarily consists of de-icing vehicles and is illustrated in Figure 6.10.

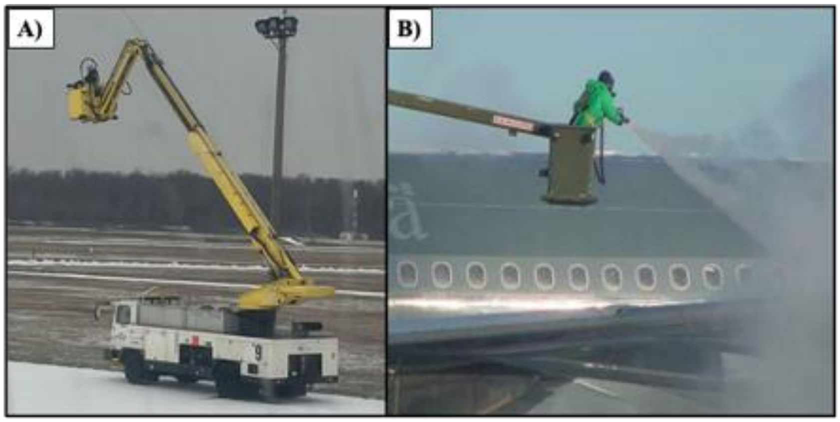


Figure 6.10: De-icing A) De-icing vehicle B) De-icing of CC-150

Table 6.23: Historical ADAF Consumption at 8 Wing Trenton

Fiscal Year	ADAF Consumed (L)
2020-2021	69305 Type 1 6342 Type 4
2021-2022	63896 Type 1 9325 Type 4
2022-2023	72771 Type 1 7964 Type 4
2023-2024	61161 Type 1 3679 Type 4
Average	66783 Type 1 6828 Type 4

6.6.6 ADAF GHG Reduction Potential

Assessing the GHG mitigation potential of ADAFs remains a challenge due to the absence of literature on the topic. For illustrative purposes, this study assumes that preventative measures reduce ADAF usage by about 5%. Analysis of four years' data yielded average annual consumptions of 66,738L for Type 1 and 6,828L for Type 4 ADAFs. Density data were sourced from Boeing (2024) and Cryotech (2019), while Johnson (2012) provided an emission factor at 65% dilution of 3,917 kg CO2e/tonne. Consequently, annual GHG emissions were estimated at 350.5 tonnes for Type 1 and 27.5 tonnes for Type 4, totaling 378 tonnes CO2e (see Table 6.23). Based on a 5% reduction potential, it was estimated that preventative measures could reduce GHG emissions by 18.9 tonnes CO_{2E}.

Table 6.24: GHG Emissions of ADAF Consumption at 8 Wing Trenton

Average ADAF Consumed (L)	**Density (kg/L)**	**Emission Factor (kg CO_{2E}/ tonne)**	**GHG Emissions (tonne CO_{2E})**
66783 Type 1	1.34	3,917	350.5
6828 Type 4	1.03	3,917	27.5

6.7 Reducing APU Use

Reducing APU usage involves strategies aimed at minimizing the reliance on the APU for power, air conditioning and bleed air when the aircraft is on the ground. The APU, although necessary for operations when the main engines are off, consumes fuel and contributes to GHG emissions. It provides electrical power and pneumatic pressure for starting the aircraft’s main engines and electrical power, air conditioning, and heating when the main engines are not running.

6.7.1 APU Usage

Examining the timing and conditions under which the APU is turned on and shut off can assist in identifying strategies for reducing reliance on it. As outlined in Table 6.26, the APU is utilized for several different tasks during pre-flight, and post flight procedures.

Table 6.25: Overview of APU Usage

APU Operation Pre-Flight	
Maintenance crews:	In certain cases, such as during more extreme temperatures, the maintenance crews will start the APUs before the aircraft commander arrives on scene. This is primarily to bring the aircraft to temperature for crew comfort.
Pre-flight procedures:	The APU is often started as part of the pre-flight checks, which occur before the main engines are started. It's used to power up the aircraft's systems, conduct necessary checks, and prepare for engine start without relying on external power sources.
Engine Start	The APU provides the necessary pneumatic power to start the main engines, a process typically initiated after all pre-flight preparations are complete.
APU Operation Post Flight	
After Landing	Post-landing, the APU is usually be started again once the aircraft is taxiing or has come to a stop at the parking area, to provide power and air conditioning once the engines are shut down.
Post-Flight Operations	The APU remains operational to power down systems properly and for maintenance crews to perform their tasks. It's also used for cabin cooling/heating as needed while the aircraft is parked.
Final Shutdown	The APU is one of the last systems to be shut down after all post-flight activities are completed, ensuring that the aircraft is fully powered down in an orderly manner.

6.7.2 Factors Influencing APU Usage

Environmental Conditions

Extreme weather conditions (hot or cold) can lead to increased APU usage to maintain acceptable cabin temperatures for crew and passenger comfort or to ensure proper temperatures for equipment. During extreme weather conditions, the maintenance crews or pilot may turn on the APU up to several hours before departure to bring the aircraft to a comfortable temperature. Crews reported using heaters and chiller carts to supplement heating and cooling in more extreme climates such as the arctic and the desert. However, noted that neither heater nor chiller carts were utilized in Trenton or at commercial airports.

Availability of Ground Power Units

The availability of GPUs has a direct impact on APU usage as ground power units can be used to supplement or replace electrical power provided by the APU. Despite some of the literature indicating that ground power units can also provide heating and cooling, crews confirmed that the GPUs used by the RCAF are only capable of providing electrical power. At 8 Wing, mobile GPUs were widely available to the squadrons should they choose to use them. On the other hand, GPUs were said to not be widely available for the RCAF at commercial airports. Crews explained that typically ground power was available at gates and primarily for commercial airlines. As an SOP, crews request for ground power but will often end up running off APU as airlines get priority.

Delays

Departure delays can significantly increase APU usage due to various operational necessities and constraints. These delays, often unforeseen, require the aircraft to remain powered for powering systems, environmental control, and for troubleshooting and maintenance activities. When a departure is delayed, maintenance teams often prefer to keep the APU running until ground power units are available and connected. During this waiting period, the APU continues to remain operational and consume fuel. Maintenance crews sometimes find it more reliable or convenient to use the APU for power, especially if the aircraft needs to be moved or there's uncertainly about how long the maintenance work will take. When fault codes or operational issues arise, the APU may need to be run to ensure that electrical power is consistently available for the diagnostic equipment and the aircraft's systems.

During troubleshooting, maintenance crews will often instruct the aircraft commander to keep the APU running. The process of switching from the APU to the GPU can sometimes cause fluctuations or interruptions in the electrical power supplied to the aircraft systems. These fluctuations can disrupt onboard systems leading to resets, faults, or malfunctions. Thus, rather than risking introducing more issues and creating further delays, the APU may continue to operate for an extended period.

6.7.3 APU Use Tracking

Originally the intent was to gather data on average APU usage times. However, discussions 8 Wing personnel highlighted the difficulties in obtaining this information without historical data. Squadrons do not currently track APU run times, meaning data collection would need to be done manually for each flight. In lieu, pilots were asked to provide ranges of the best case, typical, and worst-case APU run times for their respective fleets.

For the CC-130J, the aircraft will typically be connected to ground power until the pilot turns on the APU as part of the engine start process. In contrast, when pilots arrived at the CC-150, the aircraft technicians will usually have the APU already running. At Trenton, the APU is typically turned at the aircraft’s scheduled ramp time, 3 hours before the scheduled departure. Outside of Trenton, the standard turnaround time is 90 minutes, therefore the pilot will turn on the APU at that time. For the CC-177, the APU may or may not be running when the pilot arrives, depending on whether one of the aircraft technicians turns it on before their arrival. In the worst-case scenario, the APU will be started by a technician at the aircraft’s scheduled ramp time, 5 hours before departure. In the best-case scenario, the pilot will turn on the APU 1 hour before departure, allowing them the minimum time to complete their pre-flight checks and engine start procedure. Based on the aforementioned factors, the estimated APU run times by fleet are presented in Table 6.26.

Table 6.26: Estimated APU Run Times

APU Run Time	CC-130J	CC-150	CC-177
Best Case (min)	15	90	60
Typical (min)	30	180	90
Worst Case (min)	60	180	300

6.7.4 APU Use Reduction Strategies

Use of GSE

By providing essential services to the aircraft on the ground, GSE such as air carts, GPUs, and air conditioning units can drastically lessen an aircraft's need on its APU. At commercial airports, these are typically available at the gate and hardwired into the infrastructure, thus do not consume any fuel. In these cases, the GSE is usually powered by the electrical grid and emits nearly no emissions. Alternatively, there also exists mobile air carts, GPU's and air conditioning units that are typically powered by gasoline or diesel. In the case of RCAF airfields, these pieces of equipment tend to be mobile diesel-powered models.

While each piece of GSE serves a distinct purpose, they all replace certain capabilities provided by the APU. If the APU is neither operational nor available, air start carts can be used to supply the pneumatic power required to start the aircraft's engines. Aircraft can start their engines without using the APU by employing air start carts, which lowers fuel consumption and APU wear and tear. An aircraft's GPUs supply electricity while its engines and APU are off. The electricity powers the aircraft's electrical systems, which include the avionics, lighting, and certain passenger amenities. By using a GPU, the aircraft can maintain all necessary electrical functions without using the APU, reducing emissions and noise. Air conditioning units supply conditioned air directly to the aircraft, maintaining comfortable temperatures and air quality without using the APU for air conditioning. This is advantageous in extreme weather conditions, where cabin temperature is necessary for crew comfort. By using an air cart, the aircraft can avoid the significant fuel consumption associated with running the APU for air conditioning purposes.
Even when air start carts, GPUs, and air conditioning units are used simultaneously, they typically consume less power than the APU and are more cost effective. GSE typically runs on electricity or diesel, which is consumes less fuel and releases less GHG emissions compared to running an APU. As illustrated in Table 6.27, the use of all three pieces of equipment consumes less fuel than the most efficient APU. In addition, operating the APU incurs wear and tear, leading to maintenance and operational costs. In contrast, GSE maintenance is often less expensive and does not directly impact the aircraft's maintenance schedule.

Table 6.27: Fuel Consumption of APU's and Alternatives. Adapted from (Mouton et al., 2015)

Equipment	Fuel Consumption (lbs/hr)
CC-130J APU	317
CC-150 APU	386
CC-177 APU	408
Air Start Cart	111
Ground Power Unit	42
Air Conditioning Unit	51

Delaying APU Startup

Delaying the start-up of the APU is a straightforward yet effective strategy for reducing APU usage. Like the previous strategy, this offers several benefits such as reductions in fuel consumption, GHG emissions, and operational costs. This strategy is particularly viable under certain conditions, such as moderate temperatures, where the immediate use of the APU for cabin comfort and aircraft systems is not necessary. On the other hand, if the APU is required during more extreme temperatures to bring the cabin to a comfortable temperature, ground crews can postpone starting it until just before boarding commences, ensuring the cabin reaches a comfortable temperature by the time passengers enter while still avoiding unnecessary APU run time on the ground. This approach balances passenger comfort with environmental considerations.

6.7.5 Use of Ground Power Units at 8 Wing

The GPUs at 8 Wing Trenton, as illustrated in Figure 6.11, are mobile diesel-powered GPUs allocated to each respective squadron. Crews felt that the GPUs allocated to them were reliable in providing power to their aircrafts. In contrast, crews had less favourable opinions of mobile GPUs outside of Trenton, particularly in austere and foreign locations. Pilots regularly spoke about situations they encountered where non-CAF owned GPUs were unreliable. In many cases those GPUs would break down and run out of fuel, causing the aircraft to depower itself. In cases where the provided GPUs were thought to be unreliable, pilots preferred to either supplement the GPUs by running their APUs or run strictly off APUs and avoiding the GPUs all together.

Figure 6.11: Mobile GPU

Interviews with squadron personnel revealed that the use of ground power units was not consistent across the studied fleets. It was noted that the frequency and manner that GPUs were used for different aircraft in the transport fleet differs greatly. Notably, for the CC-130J and CC-177, crews recurringly expressed their preference in running off GPUs rather than APUs. This was simply because they preferred that the GPUs were much quieter than running the APUs. If there were crew working onboard the aircraft, they would generally opt to using the GPUs to provide power to the aircraft.

For the CC-130J, ground power is used until the engine start sequence necessitates the APU's activation. Furthermore, there were no reports of the GPU and APU being used simultaneously. For most of the ramp time, the CC-130J utilizes ground power only to power the aircraft (see Figure 6.12).

Figure 6.12: CC-130J with GPU

For the CC-177, ground power is the preferred option when available as illustrated in Figure 6.13. The APU is generally avoided due to noise, fuel consumption, and potential wear and tear. In contrast to the CC-130J, the CC-177 often uses the GPU in conjunction with the APU before engine start-up, after which it disconnects from ground power. Extreme temperatures necessitate this approach since the APU, although capable of delivering 90kVa, has limited capacity for providing both air and electricity and defaults to supplying electrical power. This can compromise air availability when electrical demand is high. Pre-flight procedures require activating all four auxiliary hydraulic systems, demanding ample electrical power. While the APU supplies sufficient electricity, it may not provide enough air when electrical loads are heavy. Here, the GPU assists by taking on the electrical load, allowing the APU to focus on air supply. Furthermore, should the APU become overloaded, it risks depowering the aircraft, potentially delaying departure by an hour as all pre-flight checks must be redone. The APU also serves as a dependable backup if the GPU's fuel supply is depleted, which is particularly relevant for the power-intensive CC-177.

Figure 6.13: CC-177 with GPU

In contrast to other aircraft, the CC-150 typically operates on APU power, as seen in Figure 6.14. Despite having GPUs available, pilots at 8 Wing reported that they rarely used them with the CC-150. They speculated that the negligible use of GPUs might be due to the APU's higher, less intrusive exhaust placement compared to other planes. Maintenance staff, on the other hand, suggested the preference for the APU was because GPUs failed to adequately regulate cabin temperature. They noted that heater carts could potentially be used with GPUs to avoid running the APU for extended periods. Maintenance also expressed concerns about GPU reliability, noting frequent breakdowns. While initially it was claimed that no GPUs were operational, further discussion with their colleagues called this into question.


Figure 6.14: CC-150 running off of APU

6.7.6 Interview Themes

Table 6.28 presents insights into the considerations affecting the use of GPUs and APUs at 8 Wing Trenton, highlighting themes of nuisance and noise, operational considerations, technical considerations, and the reliability of GSE.

Table 6.28: Interview Themes - Reducing APU Use

Nuisance and noise concerns	3A “*If we have crews on board, we will try to opt to use ground power as the APU’s are very loud*” (CC-177 Pilot) 5A “*We have GPUs available but don’t use them. The APU is in the tail 30-40 feet up in the air and the APU exhaust is near the landing gear. Due to their location, noise is not as much of an issue*” (CC-150 Pilot) 18A: “*An advantage of using a GPU is that it’s quieter than the APU.*” (CC-130J Pilot)
Operational Considerations	2A “*In most cases, we will run the APU and GPU simultaneously. If we run only off the GPU and it kicks off or runs out of fuel, it will depower the plane and delay departure by up to an hour*” (CC-177 Pilot) 8A “*Some airports will force you to run off the APU*” (CC-150 Pilot) 9A “*Certain airports will force airlines to run off ground power to reduce emissions. As the CAF, we will usually be exempt from these restrictions and run off our APUs*” (CC-150 Pilot)

	12A: “*The APU’s been running all morning [due to maintenance related delays*]” (CC-177 Pilot) 13A: “*In many circumstances, civilian aircraft will get priority and we will run off the APU.*” (CC-177 Pilot) 16A: “*If GPUs are used, it will necessitate redoing checks and increasing the workload. For subsequent flights, the aircraft will remain on APU to streamline operations*.” (CC-130J Pilot)
Technical Considerations	14A: “*We will run off the APU 70% of the time and 100% of the time its cold*” (CC-177 Pilot) 15A: “*The APU provides the aircraft with air and electricity. Since it prioritizes electricity over the air a big draw on electricity takes away the air. The GPU is used at the same time to supplement power so that the APU can provide air.*” (CC-177 Pilot) 17A: “*The GPUs don’t provide air so we will run the APUs when it’s cold or hot for crew comfort.*” (CC-150 Technician)
Reliability and dependability of GSE	10A “*GPUs at other airports are not always reliable. Sometimes they will run out of fuel or depower because they are older pieces of equipment.*” (CC-177 Pilot) 11A: “*In the event the APU should not be available an external pneumatic cart can be used but from practical experience I know these to be commonly unreliable, if available at all*.” (CC-177 Tech Crewman)

Nuisance and Noise Concerns

Pilots and technicians expressed the concern that APUs are loud and can be a nuisance, especially when crew members are on board the aircraft, which leads to a preference for using GPUs due to their quieter operation when feasible. This recurring observation was particularly true for the CC-130J and CC-177. For the CC-150, one pilot noted that due to the location of the APU, noise is less of an issue. Thus, the CC-150 regularly runs off the APU for electrical power rather than a GPU.

Operational Considerations

Several quotes highlight the complexity of using GPUs and APUs. Crews for the CC-177 may run both systems simultaneously as the GPUs alone can fail and depower the aircraft due to running out of fuel or excessive loads. GPUs at certain airports are seen as unreliable, thus the simultaneous use of the APU provides redundancy. The landing location also plays a role in APU and GPU usage as certain airports restrict the use of APUs whereas other mandate it. Civilian planes are typically prioritized over military aircraft; therefore, ground power will not always be available at every location. Furthermore, crews may opt to forego the use of ground power for short turnaround times, to streamline operations and reduce workload.

Technical Considerations

Technical considerations also influence the use of APUs and GPUs, particularly during intemperate conditions. Provided that the GPUs lack the capability to provide air, the APU must be utilized in hot or cold conditions to bring the cabin to a comfortable temperature for the crew. For the CC-130J and the CC-150, the APU has the adequate capacity to provide both heating and cooling without requiring a GPU to provide electrical power. In contrast, the CC-177 APU, which prioritizes electrical power over air, often requires both the APU and GPU to provide adequate air and electricity. Otherwise, there is a risk that the APU or GPU become overloaded and depowers the aircraft.

Reliability and Dependability of GSE

The reliability of GPUs is questioned with some reporting that they are not always dependable, which can lead to operational delays or increased workload due to additional checks if GPUs fail. While most personnel viewed the GPUs at 8 Wing Trenton as reliable and dependable, the reliability of equipment at other airports were reported as being unreliable at times. In these cases, crews would generally opt to remain on APU power rather than risk using unreliable ground power units.

6.7.7 Sustainable Ground Power Solutions

As previously indicated, at 8 Wing Trenton, squadrons rely on mobile diesel-powered units for their ground power. Although mobile GPU’s have a higher environmental impact that alternatives such as FEGP, it should be noted that the fuel consumption is still comparatively lower than relying on the APU to provide ground power. Table 6.33 summarized APU fuel consumption of the transport fleet compared to mobile ground power units, air carts, and air conditioning units.

Notably, even for the CC-130J, the fuel consumption of all three pieces of GSE is still remarkably lower than using the APU. Furthermore, under most conditions, air carts and air conditioning units would not be required, further increasing fuel savings compared to using an APU.

Table 6.29: Comparison of APU and GPU Fuel Consumption.
Adapted from: (Mouton et al., 2015)

Equipment	**Fuel Consumption (lbs/hr)**
CC-130J APU	317
CC-150 APU	386
CC-177 APU	408
Air Cart	111
Ground Power Unit	42
Air Conditioning Unit	51

Conversely, a Fixed Electrical Ground Power (FEGP) system, which is installed permanently at a stand, allows for a cable to be attached to the aircraft, enabling it to draw power directly from the airport terminal's main electricity supply (Padhra, 2018). While FEGP systems offer the advantage of producing no emissions on the apron, their installation can be costly, especially at stands that are situated far from the terminal building.

Unlike most major airports, where aircraft park in front of terminals, airport stands at 8 Wing Trenton are spread across the apron. Thus, the fixed nature of FEGP systems may not be the most appropriate solution for a military installation like this. In such contexts, the flexibility of mobile GPUs becomes invaluable. Mobile GPUs can be moved to wherever they are needed across the apron, providing power to aircraft regardless of their parking location. This mobility ensures that all aircraft, whether parked close to or far from the terminal, have access to the necessary electrical power without the need for extensive and costly infrastructure. Furthermore, mobile GPUs can be quickly repositioned to support operational changes or emergency requirements, offering a level of adaptability that fixed systems cannot match. This makes mobile GPUs a versatile and efficient power solution for military operations, where flexibility and rapid response are paramount.

Another alternative that the RCAF could consider adopting is an electric ground power system like those tested by the USAF in collaboration with GM Defense, as illustrated in Figure 6.15. These systems, which powered a KC-135 tanker aircraft using GM Defense's Electric GPU at Edwards Air Force Base, utilize commercial battery electric technology (Air Force Research Laboratory Public Affairs, 2023). This approach offers zero emissions during operation and provides nearly silent operations. This solution combines the flexibility of mobile GPUs with the zero-emission benefits of a FEGP systems, offering both environmental and operational advantages.

Figure 6.15: GM Defense's Electric GPU at Edwards Air Force Base (Air Force Research Laboratory Public Affairs, 2023)

6.7.8 Delaying APU Start: GHG Reduction Potential

To calculate the GHG reduction potential resulting from delaying the APU start, the first step was to determine the duration of the engine start sequence, as it is the minimum time that the APU must be running to prior to the engine start. For the CC-130J, the engine start sequence ranges from 10 minutes for mild to warm temperatures to 20 minutes. Interviews and validation through direct observations, confirmed that the process is already streamlined, with minimal APU usage. Thus, there is limited opportunity to reduce APU fuel consumption. For the CC-150, the engine start sequence takes 5 minutes, therefore 60 minutes should be sufficient to run the APU before pre-engine start checks. For the CC-177, the engine start process takes approximately 30 minutes, thus 60 minutes was proposed for the APU run time. The comparison of APU run time and the engine start sequence duration are summarized in Table 6.30.

Table 6.30: Comparison of APU Run Time and Engine Start Sequence

Aircraft	Average APU Run Time (min)	Engine Start (min)	Proposed APU Run Time (min)
CC-130J	30	10-20	30
CC-150	180	5	60
CC-177	90	30	60

The difference between the proposed APU run time and the current average, were used to determine the average APU run time savings. This yielded APU run time savings of 0, 2, and 0.5 hours for the CC-130J, CC-150, and CC-177 respectively. Using the APU fuel consumption for each aircraft, fuel saved per sortie in pounds and converted to litres, yielded 435.5L and 115.1L for the CC-150 and CC-177. These values are presented in Table 6.31.

Table 6.31: APU Fuel Saved per Sortie

Aircraft	APU Fuel Consumption (pph)	Average APU Run Time Savings (h)	Fuel Saved (Lbs)	Fuel Saved (L)
CC-130J	317	0	0	0
CC-150	386	2	772	435.5
CC-177	408	0.5	204	115.1

As presented in Table 6.32, to determine the APU GHG reduction potential, the fuel saved per sortie converted to yearly fuel savings and an emission factor was applied. This calculation yielded an estimated yearly GHG savings of 450.9t CO_{2E} for the CC-150 and 67.7t CO_{2E} for the CC-177, for a total savings of 518.6t CO_{2E}.

Table 6.32: APU GHG Reduction Potential

Aircraft	Fuel Saved (L)	Annual Sorties	Emission Factor (g CO2e/L)	Yearly GHG Savings (t CO2E)
CC-130J	0	792	2569	0.0
CC-150	435.5	403	2569	450.9
CC-177	115.1	229	2569	67.7

6.8 Ground Support Equipment

6.8.1 Overview of GSE

GSE encompasses a wide range of machinery and tools designed to support the operations of aircraft on the ground and in preparation for flight. GSE plays an important role in ensuring the smooth and efficient handling on the ground, providing services that range from mobilizing aircraft to maintaining aircraft systems. As summarized in Table 6.33, GSE at 8 Wing Trenton can be broadly categorized as aircraft mobility equipment, aircraft servicing equipment, ground power units, aircraft maintenance support, cargo and personnel loading equipment, aircraft de-icing equipment, aircraft de-icing equipment and airfield support equipment. Furthermore, examples of equipment in selected categories are illustrated in Figure 6.16, Figure 6.17, Figure 6.18, Figure 6.19, and Figure 6.20. Provided that ground power units and de-icing were analyzed in their own respective sections, this section will not explore them in detail.

Table 6.33: Categories of Ground Support Equipment at 8 Wing Trenton

Category	Description
Aircraft Mobility Equipment	Used to move aircraft between hangars and around the airfield, and includes tow tractors and aircraft tugs
Aircraft Servicing Equipment	Used for fueling, defueling, servicing aircraft hydraulic and pneumatic systems and includes fuel trucks, combined services unit, and nitrogen servicing carts.
Ground Power Units	Ground Power Units provide electrical power to aircraft systems while the aircraft engines are not running, supporting system checks, and maintenances.
Aircraft Maintenance Support	Includes a wide range of tools and platforms such as maintenance stands, work platforms, and engine hoists. These are vital for allowing personnel to safely access and work on various parts of the aircraft.

Category	Description
Cargo and Personnel Loading Equipment	Includes cargo loaders for handling cargo and baggage, and passenger stairs
Aircraft De-icing Equipment	For operating in cold weather environments, de-icing trucks and equipment are necessary to remove ice and snow from aircraft surfaces to ensure safe flight operations.
Snow and Ice Removal Equipment	For maintaining clear runways and taxiways in winter conditions, airports deploy specialized snow removal vehicles such as snow melters and plows, which are essential for safe and efficient airport operations.
Fire and Rescue Equipment	Aircraft Rescue and Fire Fighting (AARF) fire trucks and rescue equipment are maintained adjacent to the airfield, providing firefighting capabilities.
Airfield Support Equipment	Includes a broad range of equipment supporting airfield operations including lighting systems, airfield markers, communications tools, and weather monitoring systems.

Figure 6.16: Aircraft Mobility Equipment A) Aircraft Tug, and B) Tow Tractor

Figure 6.17: Aircraft Servicing Equipment A) Combined Services Unit, B) Aircraft Wash, C) Nitrogen Servicing Cart, and D) Heater Cart

Figure 6.18: Aircraft Maintenance Support Equipment

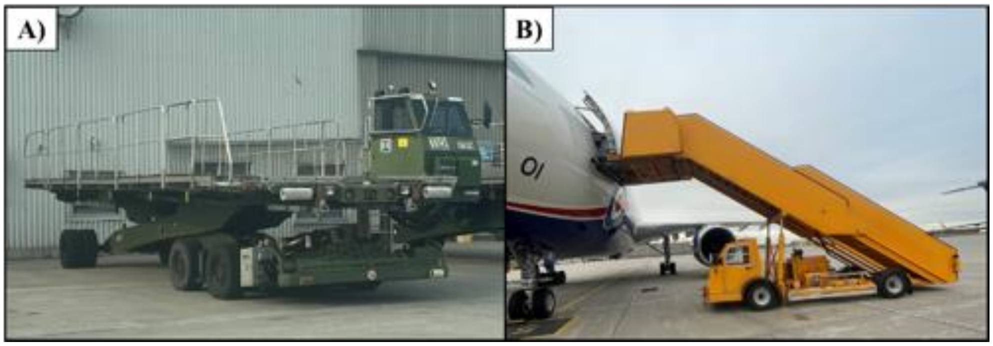


Figure 6.19: Cargo and Personnel Loading Equipment A) Cargo Loader, and B) Passenger Stairs

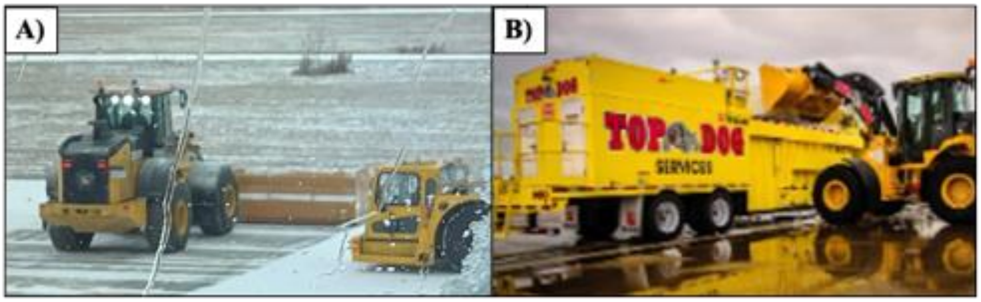


Figure 6.20: Snow and Ice Removal Equipment A) Snow plow, and B) Snowmelter (Trecan, 2024)

Snowmelter

As depicted in Figure 6.20B, 8 Wing Trenton currently utilizes a Trecan 135PD snowmelter for the melting of snow on the airfield. Snowmelters offer several advantages over trucking of snow off site. The Trecan 135PD snowmelter can melt 135 tons of snow per hour which is ideal for settings such as airports where accumulated snow can disrupt operations and safety (Trecan, 2024). According to Trecan, snowmelting can yield savings of up to 50% and reduce GHG emissions. Additionally, melting snow on site can mitigate the spread of contaminants such as ADAFs by diverting the melted snow into the wastewater treatment plant. Additionally, this model of snowmelter has a thermal efficiency of 98%, meaning that most of the heat generated is used to melt snow, with minimal energy wasted.

As illustrated Figure 6.21, snowmelters operate on the principle of direct heat transfer to efficiently melt snow (Trecan, 2024). In this process, snow is loaded into a melting chamber equipped with a burner system that is submerged in water. The burner directs flames downwards through a tube that is immersed in the water, allowing the hot combustion gases to mix with the water as they ascend through a weir tube. At the chamber's top, the cooled gases are vented into the atmosphere, while the warmed water is sprayed over the snow to enhance the melting process. This method ensures optimal mixing and agitation, resulting in an impressive thermal efficiency of approximately 98%.

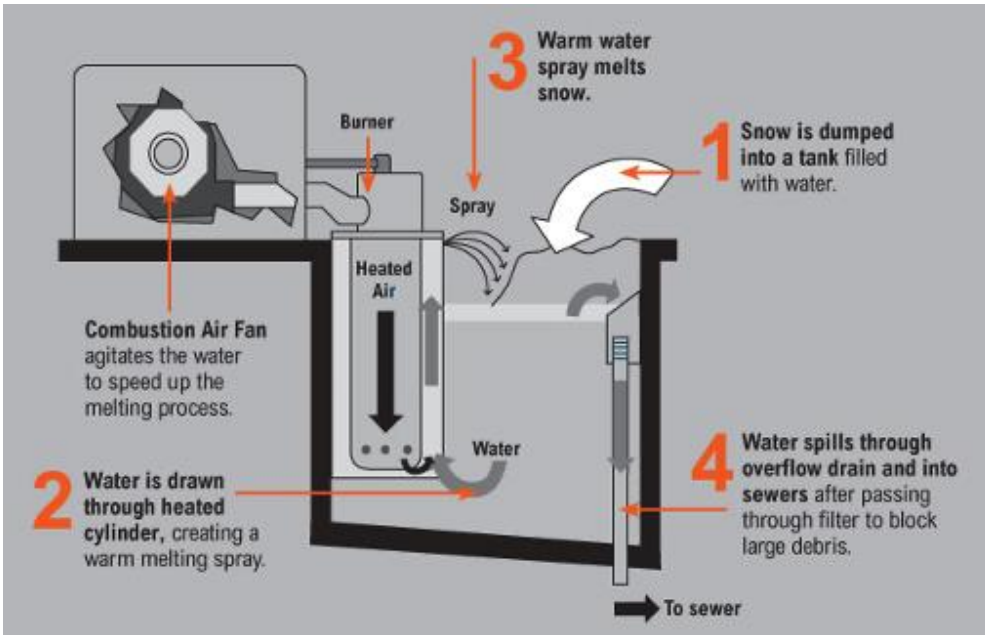


Figure 6.21: Snowmelter Principles of Operation (Trecan, 2024)

According to the manufacturer’s specifications, the current model of snowmelter can run on either diesel or AvPOL. Conversations with staff revealed that while diesel was used in the past, AvPOL has been used for the snowmelter in recent years. From the perspective of the base transport, it was noted that AvPOL has been the preferred choice for several years. One of the key reasons for this preference is that jet fuel burns cleaner and hotter than diesel. Conversations with refuelling staff at the base revealed that the existing diesel refueller could not support the switch to diesel for the snowmelter. It was said that the refueling equipment at the base, which includes a 7,000-liter diesel fuel bowser, is insufficient to meet the demands of the snowmelter, especially considering that a single snowmelter consumed 13,500 liters of fuel during a 24-hour snow event last winter. Of note, this assessment was the member’s best educated postulation as to why the switch to AvPOL happened, thus it could not be determined with certainty when and why the decision happened.

On the contrary, it was unclear based on the manufacturer’s whether the use of diesel or AvPOL is preferred for snowmelters. Furthermore, existing literature on the advantages and disadvantages of each type of fuel was sparse therefore it is unconclusive which fuel type is better both operationally and environmentally. Furthermore, it is unclear why the snowmelter could not be refuelled using the diesel refueller, provided that the manufacturer’s specifications show the fuel capacity of this model as 5, 678L. As shown in Table 6.35, the emission factor for diesel is greater than AvPOL, however, if the AvPOL burns hotter is it uncertain which option would have a lower carbon footprint.

6.8.2 GSE Fuel Types

To assist with assessing greener alternatives, it was first important to determine the types and quantity of fuel or energy source used to power the GSE at 8 Wing. As shown in Table 6.34, the vast majority of the GSE at 8 Wing Trenton runs on diesel. Within the category of aircraft servicing equipment, the combined services unit (see Figure 6.17A), is the only piece of equipment that uses AvPOL. As described by an aircraft technician, the combined services unit is essentially an external APU used while servicing the aircraft. The aircraft maintenance support equipment includes mainly lifts and are electrically powered. Lastly, the snowmelter, although capable of using diesel or AvPOL, has been using AvPOL in recent years.

Table 6.34: GSE Fuel Types

Category	Type of Fuel
Aircraft Mobility Equipment	Diesel
Aircraft Servicing Equipment	Diesel AvPOL (Combined Services Unit)
Ground Power Units	Diesel
Aircraft Maintenance Support	Electric
Cargo and Personnel Loading Equipment	Diesel
Aircraft De-icing Equipment	Diesel
Snow and Ice Removal Equipment	Diesel and AvPOL (Snowmelter)
Fire and Rescue Equipment	Diesel
Airfield Support Equipment	Diesel

The ground fuel consumption at Trenton shown in Table 6.35 was created by compiling fuel consumption records for 2022 provided by the bulk fuel manager. Provided that this breakdown only considers the fuel consumption for ground operations, a factor of 6 percent was applied to the total AvPOL dispensed to aircraft for the calendar year. This was based on the estimated ground fuel consumption for the transport fleet, which ranged from 5 to 8 percent. An emission factor was applied to the fuel consumption for each section to produce the total emissions in tonnes CO_{2E}.

Table 6.35: Ground Fuel Consumption Breakdown

Type	Fuel Consumption (L)	Fuel Type	Emission Factor (g CO2e/L)	Emissions (Tonnes CO_{2e})
Aircraft (Ground)	1,802,473	AvPOL	2,569	4630.6
GSE (Diesel)	189,448	Diesel	2,800	530.5
GSE (AvPOL)	149,714	AvPOL	2,569	384.6
Water Checks	29,262	AvPOL	2,569	75.2
Testing and Maint	19,214	AvPOL	2,569	49.4

As illustrated in Figure 6.22, aircraft ground emissions contributed to 81.7% of GHG emissions on the ground. The remaining emissions for GSE (Diesel), GSE (AvPOL), water checks, and testing and maintenance were 9.4%, 6.8%, 1.3%, and 0.9%

respectively. Within the category of GSE that run on AvPOL, the snowmelter contributed to 94% of fuel consumption whereas the combined services unit consumed 6% of total fuel consumption (see Figure 6.23).

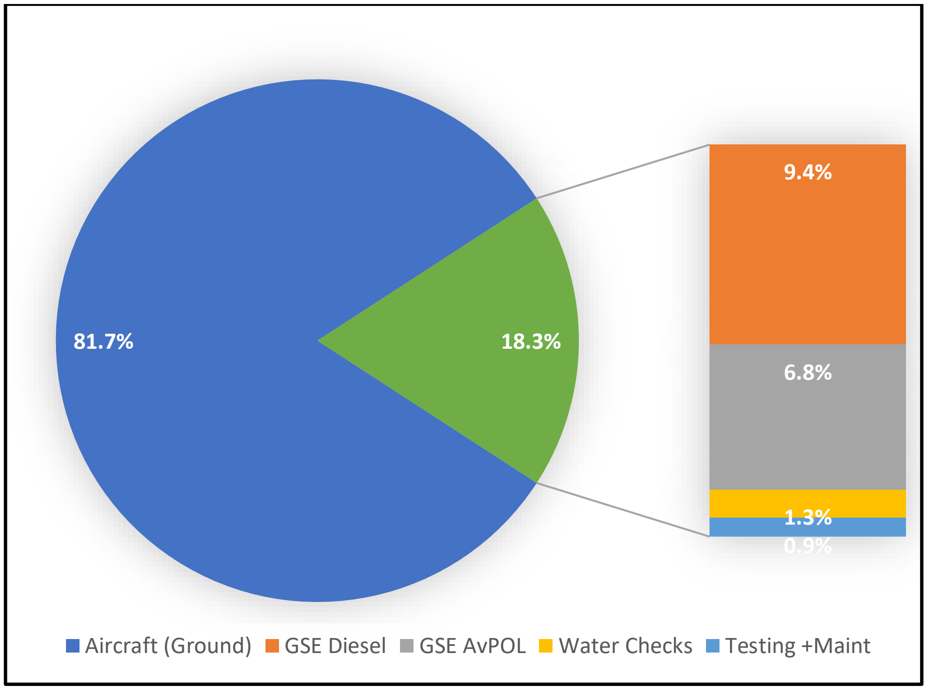


Figure 6.22: Ground Fuel Consumption Emissions Breakdown

Table 6.36: AvPOL GSE Fuel Consumption Breakdown

Type	**Fuel Consumption (L)**	**Emission Factor (g CO2e/L)**	**Emissions (Tonnes CO_{2e})**
CSU	5962	2569	15.3
Snowmelter	143752	2569	369.3

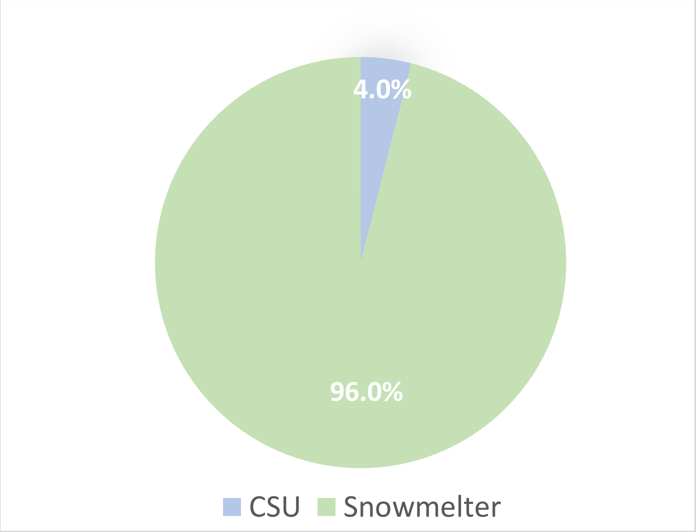


Figure 6.23: GSE AvPOL Fuel Consumption Breakdown

6.8.3 GSE Sustainable Alternatives

Electric GSE (eGSE) is becoming more popular due to its ability to help reduce carbon emissions, which aligns with the RCAF's goal or achieving net zero emissions. Several airports have already started converting their fleets to electric options, utilizing technologies such as lithium-ion batteries for improved efficiency and longer run times compared to traditional lead-acid batteries (Ortega, 2020). These batteries offer the added benefit of being more energy-efficient and not having the risk of lead contamination or acid spills. The operational costs of running eGSE are also typically lower than those for gas or diesel-powered vehicles, as they do not produce carbon emissions, especially during idling, which leads to reduced overall emissions for the airport. Some ground handling operators have seen savings of up to $3000 in operational costs per vehicle annually by transitioning to eGSE.

Notably, the capital investment for transitioning to eGSE can be significant and includes several components. Firstly, is the cost associated with purchasing the eGSE itself, which might be offset over time by lower operating costs. The second major category involves the charging infrastructure, including the chargers themselves and any related hardware. The price for chargers can vary significantly based on capacity, features, and technology.

Increasing the electrical capacity of facilities to accommodate eGSE is another area of investment. Given the age of the existing buildings, this would likely involve upgrading existing electrical systems or installing new substations or distribution systems (Vigilante & Reynolds, 2021). These upgrades are necessary to handle the increased electrical demands of eGSE charging stations, especially in older buildings that were not originally designed with such electrical loads in mind. Each of these components comes with its own set of considerations and costs, and careful planning and life cycle assessments are required to ensure that the transition to eGSE is economically viable and operationally feasible.

Over time, provided that the proper studies support the decision, diesel powered GSE could likely be replaced with eGSE as the existing equipment reaches the end of its lifespan. Provided that these pieces of equipment are generic in nature, not specific to any one aircraft, there are likely suitable commercial off the shelf solutions available. This transition to eGSE could offset up to 530.5 tonnes of CO_{2E} per year based on 2022 diesel consumption.

With respect to the GSE that are currently consuming AvPOL, namely the snowmelter and combined services unit, it does not appear that there are currently any electric alternatives. One option would be to use a lower carbon fuel such as a sustainable aviation fuel (SAF). However, it should be noted that these fuels are typically more expensive than conventional fuels and not yet widely available.

6.9 Culture of Fuel Efficiency

6.9.1 Interview Themes

At 8 Wing Trenton, the culture surrounding fuel efficiency is multifaceted, influenced by operational practices, pilot experiences, and the broader institutional framework within which these activities occur. This section draws on interview themes to bring light to the current state of fuel efficiency culture, highlighting areas of concern and opportunities for improvement. As summarized in Table 6.37, common themes extracted from the interview process include data reporting, building confidence, awareness and training and operational priorities versus fuel efficiency.

Table 6.37: Culture - Interview Themes

Data Reporting	1F "*After each aircraft is refuelled, we do not have any oversight of how the fuel is being used*." (Refueller) 4F "*We record how much fuel we have on landing in a logbook in the plane, but I don't think that anybody is actively looking at the numbers*" (Pilot) 6A "*I don't think that you would be able to quantify APU usage. It's not something that we are actively tracking, and it would be different for each flight*" (CC-150 Pilot)
Building Confidence	1F: "[When] *I was asked to fly and land with minimum fuel, I didn't comfortable flying over the ocean without extra fuel so when I got to the destination, I flew in circles until most of the fuel was burnt*" (CC-150 Pilot) 2F: "*We are liberal with our fuel planning. The standard is to load the aircraft with the minimum fuel plus an additional 2000lbs. Most pilots will increase that number to 5000lbs*" (CC-150 Pilot) 3G "*Green procedures may be something to consider if you have senior pilots. Pilots in the RCAF are generally newer and less experienced than airline pilots. We feel more comfortable doing the same procedure every time*." (CC-150 Pilot) 4 RET: "*The fuel savings [for RET] wouldn't be worth it. By following the same procedures every time, you don't have to worry about extra steps. If you do the same procedure every time, you are less likely to make a mistake*." (CC-150 Pilot) 3RET: "*We normally taxi in on four engines, as it is easier and requires less steps. I taxied in on two engines once but haven't done it since*." (CC-177 Pilot)
Awareness and Training	1A "*Aircraft are constantly running their APUs and there is not much regard for minimizing fuel use*." (Refueller) 4A "We aren't encouraged to delay APU start before departure" (CC-150 Pilot) 7A "*I'd imagine if we used GPU's, it would cut down consumption*" (Aircraft Technician) 1G "*I'm not aware of any fuel saving mechanisms*" (CC-150 Pilot) 4G: "*Green procedures aren't something that is taught to us in training or something that we actively do*" (CC-150 Pilot) 1C: "*We need to change the culture on fuel efficiency. When I plan my flights, I try to use a little fuel as possible. Most don't have this mentality*" (CC-130J Pilot)
Operational Priorities Versus Fuel Efficiency	2F "*We are liberal with our fuel planning. The standard is to load the aircraft with the minimum fuel plus an additional 2000lbs. Most pilots will increase that number to 5000lbs*." (CC-150 Pilot) 4 RET: "*The fuel savings [for RET] wouldn't be worth it. By following the same procedures every time, you don't have to worry about extra steps. If you do the same procedure every time, you are less likely to make a mistake*. 2C: "*We are driven by operations, not by fuel efficiency*" (CC-150 Pilot)

Data Reporting

At core of fuel efficiency issue is the gap in data utilization. Despite mechanisms for recording fuel data, there seems to be a disconnect in leveraging this information for efficiency improvements. As noted by a refueller, "*After each aircraft is refuelled, we do not have any oversight of how the fuel is being used*" (1F). This sentiment is echoed by pilots, with one stating, "*We record how much fuel we have on landing in a logbook in the plane, but I don't think that anybody is actively looking at the numbers*" (4F). The challenge of quantifying APU usage further complicates the scenario, as a CC-150 pilot remarks, "*I don't think that you would be able to quantify APU usage. It's not something that we are actively tracking, and it would be different for each flight*" (6A).

Building Confidence

A conservative approach to fuel management is deeply ingrained within the pilot community at 8 Wing Trenton, manifesting in practices that prioritize carrying excess fuel. This cautious approach, while strengthening the pilots' sense of safety, particularly during long overwater flights, may inadvertently undercut efforts towards achieving greater fuel efficiency. One CC-150 pilot's admission, "*I didn't feel comfortable flying over the ocean without extra fuel, so when I got to the destination, I flew in circles until most of the fuel was burnt*" (1F), exemplifies this mindset. This behaviour reflects a broader trend where pilots, erring on the side of caution, routinely load their aircraft with up to 5000lbs more fuel than the 2000lbs buffer (2F), significantly beyond what is deemed necessary.

This cautious approach is influenced by the relative inexperience of RCAF pilots compared to their counterparts in the commercial aviation sector. The tendency to adhere to familiar, standardized procedures regardless of their fuel efficiency stems from a desire for operational predictability and risk aversion. As one pilot puts it, "*Green procedures may be something to consider if you have senior pilots. Pilots in the RCAF are generally newer and less experienced than airline pilots. We feel more comfortable doing the same procedure every time*" (3G). This sentiment is further echoed in the reluctance to adopt RET procedures, which, despite their potential for fuel savings, are often overlooked in favour of standard practices. A CC-150 pilot elaborated, "*The fuel savings [for RET] wouldn't be worth it. By following the same* *procedures every time, you don’t have to worry about extra steps. If you do the same procedure every time, you are less likely to make a mistake*" (4 RET).

The resistance to adopting more fuel-efficient taxiing methods is also observed among CC-177 pilots, who typically opt to taxi in on four engines for ease and simplicity. One pilot shared, "*We normally taxi in on four engines, as it is easier and requires less steps. I taxied in on two engines once but haven’t done it since*" (3RET), highlighting a broader apprehension towards integrating new, albeit more efficient, procedures into routine operations. This collective cautiousness, while understandable from a safety perspective, underscores a significant barrier to enhancing fuel efficiency across flight operations at 8 Wing Trenton. The prevailing culture, marked by a preference for preparation and procedural uniformity, suggests a need for targeted initiatives to foster greater openness to fuel-saving practices without compromising safety or operational integrity.

Awareness and Training

The operational culture at 8 Wing Trenton reveals a significant disconnect between existing protocols and the potential for enhanced fuel efficiency, underscored by a notable deficiency in awareness and formal training amongst both aviation and ground personnel. This gap manifests across several domains, notably in the management and operation of APUs and implementation of alternative, more efficient power sources.

Observations from refuelling personnel and pilots highlight a pervasive lack of emphasis on optimizing APU usage, a substantial source of fuel consumption during ground operations. For instance, one refueller noted, "*Aircraft are constantly running their APUs with little regard for minimizing fuel use*" (1A), a sentiment echoed by a pilot's statement indicating a lack of incentivization for delaying APU initiation prior to departure (4A). This absence of encouragement for adopting fuel-efficient practices points towards a resistance to cultural change within the organization.

Additionally, the potential for reducing fuel consumption through the utilization of GPUs has been recognized by technical staff. An aircraft technician suggested that GPU usage could significantly decrease fuel consumption (7A), highlighting an underexploited avenue for enhancing operational efficiency for the CC-150.

A shortfall in formal education and emphasis on fuel efficiency practices is evident, as indicated by crew members' acknowledgments. The admission by a pilot of being unaware of any fuel-saving mechanisms (1G) illustrates the lack of structured information dissemination and education on fuel efficiency within the organization. This issue is compounded by another pilot's acknowledgment that green procedures are neither incorporated into training nor routinely practiced (4G), further illustrating the systemic nature of this oversight.

Within these observations, there's a clear call for significant changes in the organization's culture and operations. A CC-130J pilot articulated a personal commitment to minimizing fuel usage, contrasting this stance with the prevailing norm (1C). This perspective highlights the necessity for broader organizational changes that integrate fuel efficiency as a core operational metric.

These insights collectively reveal an organization facing challenges, as the integration of fuel-efficient practices into daily operations is impeded by significant cultural and educational barriers. To bridge this gap, a concerted effort is required to elevate the importance of fuel efficiency through targeted training initiatives, enhanced awareness campaigns, and a strategic evaluation of existing protocols to prioritize sustainability alongside safety and operational efficiency.

Operational Priorities Versus Fuel Efficiency

Operational imperatives often overshadow efforts to improve fuel efficiency. The focus on mission completion and adherence to standard operating procedures frequently takes precedence over exploring fuel-saving opportunities. This operational mindset, while crucial for mission success, may limit the exploration and adoption of more efficient practices (2C, 4 RET). Compounding this issue is the explicit acknowledgment of operational priorities superseding efficiency concerns, with one pilot stating, "*We are driven by operations, not by fuel efficiency*" (2C). This explicit prioritization of operational objectives over efficiency captures the prevailing sentiment among the personnel at 8 Wing Trenton, indicating a significant cultural and procedural barrier to the adoption of fuel-efficient practices.

6.9.2 Creating a Culture of Fuel Efficiency

Within the operational environment of the RCAF, the emphasis has long been on mission effectiveness, operational readiness, and flight safety. However, an area that has received less attention is the culture of fuel efficiency within the organization. This oversight is evident in several aspects of operations. Mission planning often proceeds with minimal consideration for fuel consumption, indicating a broader organizational trend where fuel efficiency is not prioritized. Leadership efforts and messaging to promote fuel saving practices are minimal, leading to a lack of awareness among personnel to adopt more fuel-efficient behaviours.

Furthermore, there is a widespread lack of awareness about fuel efficient procedures among personnel. This issue is amplified by insufficient data collection on fuel usage for individual flights. This hinders the ability to analyze and improve fuel consumption patterns. Without detailed tracking, opportunities to optimize fuel savings are missed, and the potential for environmental benefits remain unrealized. The absence of a feedback loop means that crews do not receive information on the fuel efficiency of their flights, missing a critical opportunity for continuous learning and improvement. This gap in the RCAF’s operational culture highlights a significant area for improvement, where integrating fuel efficiency into the culture of operations can facilitate the RCAF’s aspirational goals of curtailing emissions from air operations.

The Green Airline Book published by OpenAirlines (2020) offers a comprehensive guide on implementing and spreading a fuel efficiency culture across all facets of operations. This approach is highly relevant to the RCAF, aiming to enhance operational efficiency and decrease fuel consumption. Key takeaways, as expanded subsequent sections, include fuel efficiency as a strategic priority, stakeholder engagement, data-driven decision making, operational best practices. training and awareness, technology and innovation, and benchmarking and continuous improvement. These are expanded upon below.

<u>Fuel Efficiency as a Strategic Priority</u>: Leadership at all levels must endorse fuel efficiency as a strategic objective, integrating it into mission planning, execution, and review processes. This includes setting clear fuel efficiency goals, measuring progress, and recognizing achievements.

Stakeholder Engagement: A culture of fuel efficiency requires engagement across all levels. From flight operations, maintenance, to ground operations, every unit plays a role in achieving fuel efficiency goals. Encouraging cross-functional teams to collaborate on fuel-saving initiatives can lead to innovative solutions.

Data-driven decision making: Leverage modern digital tools and data analytics to monitor fuel consumption, identify trends, and pinpoint areas for improvement. This encompasses the use of Aircraft Performance Monitoring (APM) to track and enhance aircraft efficiency and the integration of fuel efficiency metrics into flight planning and operational decision-making processes.

Operational Best Practices: Best industry practices should be implemented across flight operations to minimize unnecessary fuel consumption. Sustainable practices such as reducing taxi times, minimizing APU usage, ensuring accurate fuel loading, optimizing de-icing procedures, and efficiently using Ground Support Equipment (GSE) are essential.

Training and Awareness: Comprehensive training programs and awareness campaigns must be developed to embed fuel efficiency principles into daily operations. Educating pilots, maintenance crews, and ground personnel on how their actions impact fuel consumption and teaching strategies to optimize fuel use are critical steps.

Benchmarking and Continuous Improvement: Regularly benchmarking fuel efficiency performance against industry standards and best practices is necessary. Insights gained from these benchmarks must be used to drive continuous improvement initiatives and adapt to emerging trends and technologies in fuel efficiency.

6.10 Summary of GHG Savings

The annual GHG savings derived from the initiatives discussed in the preceding sections have been aggregated and are detailed in Table 6.38. The strategies contributing to these savings encompass a spectrum of measures targeting key areas of ground operations at 8 Wing Trenton. These areas include the optimization of Ground Traffic Management, the adoption of RET-in practices, enhancements in De-icing procedures, efforts to reduce APU usage, and the transition towards the electrification of diesel-powered GSE. Of note, the ground traffic management was assessed at already being highly effective, thus, there were no GHG savings that could be achieved.

This comprehensive approach combines both qualitative assessments and quantitative data analysis to evaluate the potential environmental impact of the proposed sustainability measures. The quantitative aspect involved calculating the specific GHG emission reductions associated with each strategy, while the qualitative assessment provided insights into the feasibility, operational impact, and potential barriers to implementation. The synthesis of these analyses led to the estimation that by adopting the outlined sustainable practices, 8 Wing Trenton could achieve a significant reduction in its carbon footprint, quantified as approximately 1613 tonnes of CO2 equivalent ($CO2_E$) annually. This figure represents a tangible contribution towards the RCAF's broader environmental goals, underscoring the potential of targeted sustainability measures to yield meaningful reductions in GHG emissions within military aviation ground operations.

Table 6.38: Sustainable Measures Annual GHG Savings

Sustainable Measure	**Annual GHG Savings (t CO_{2E})**
Ground Traffic Management	0
Reduced Engine Taxi-In	545.4
De-icing	18.9
Reducing APU Use	518.2
Ground Support Equipment	530.5
Total:	1613.0

7. Recommendations and Conclusion

The recommendations proposed for enhancing the sustainability of ground operations in the RCAF were derived from a thorough analysis, incorporating a variety of factors, measures, and metrics. Factors included safety, ensuring that measures did not compromise safety at the expense of fuel savings; the potential environmental impact, focusing on the reduction of GHG emissions; operational feasibility, assessing the practical implementation in the RCAF environment; technical limitations in relation to aircraft and GSE capabilities; the need for adapted or expanded personnel training programs; and cultural acceptance within the RCAF, necessitating in culture shift regarding fuel efficiency.

The measures identified include the implementation and standardization of RET procedures, necessitating a comprehensive risk assessment and amending of SOPs. Another key measure included the reduction of APU usage, in favour of more efficient GPUs and by delaying APU start. Mission fuel planning was also re-evaluated, proposing adjustments to standard fuel loads based on historical data and optimizing fuel efficiency through fuel efficiency briefings. Additionally, strategies for reducing emissions associated with de-icing and GSE have also been proposed, including lifecycle assessment and exploration of green alternatives.

Metrics employed in the formulation of these recommendations include projected fuel savings, quantified through analysis of current consumption patterns and potential efficiency gains; GHG emission reductions, calculated by assessing the impact of proposed measures on the RCAF's carbon footprint; and operational impact assessments, evaluating how changes might affect mission readiness and effectiveness. These recommendations were developed based on a thorough understanding of current operations, stakeholder input, and best practices within both civilian and military aviation sectors, aiming to achieve a balance between operational efficiency, safety, and environmental sustainability.

7.1 Reduced Engine Taxi

Conduct a Risk Assessment: Perform a comprehensive risk assessment for implementing RET-in, identifying potential safety and operational risks. Develop clear strategies for mitigating these risks. This assessment should thoroughly examine all facets of RET-in implementation, from pilot training to aircraft technical limitations. Leveraging existing studies such as those conducted by the USAF, can provide valuable insights and proven methodologies for risk mitigation. This proactive approach aims to uphold the standards of safety and operational integrity, while also opening an avenue for reducing GHG emissions.

Standardize RET-in: Create detailed guidelines RET-in procedures for each airframe where there is an existing engine shutdown checklist for RET-in. This should include the CC-177 and CC-150, as identified in the analysis. The guideline should include engine cooldown periods, the specific steps for conducting RET-in, and criteria for when RET-in should and should not be used. Establish operational parameters for RET-in use that account for factors such as aircraft weight, runway conditions, and weather, ensuring a balance between safety and fuel efficiency. The implementation of RET-in, guided by comprehensive and airframe-specific protocols, can lead to a significant reduction in GHG emissions. This reduction is achieved by minimizing unnecessary fuel consumption during the taxi phase of flight operations, thereby decreasing the overall GHG emissions during ground operations.

Conduct Training Sessions: Conduct dedicated training sessions for aircrews on RET-in procedures. Training should focus on the operational benefits, safety considerations, and how to effectively conduct RET-in under various scenarios. This training will equip pilots with the knowledge and confidence needed to make informed decisions about when and how to implement RET-in, aligning with safety protocols and operational guidelines. By understanding the benefits and mechanics of RET-in, pilots are more likely to embrace and apply these practices, resulting in a reduction of GHG emissions.

Update RET Projections: As data becomes more available, it is recommended that the projected fuel savings be updated with new figures. By regularly updating these projections with new and more accurate figures, the RCAF can ensure that their estimations of fuel savings and corresponding reductions in GHG emissions are as close to reality as possible. Regularly updated projections can help identify trends and insights that were not previously apparent, guiding further optimizations in fuel efficiency strategies.

7.2 Mission Fuel Planning

Re-evaluate Force Generation Fuel Allocation: Re-evaluate and standardize standard fuel loads based on historical data and mission profiles to ensure that fuel is not over allocated. Consider optimizing fuel loads for local trainers based on anticipated durations like what is being done for mission flights. By ensuring that fuel is allocated more precisely, unnecessary fuel carriage and the associated "cost-to-carry" are minimized, leading to a reduction in GHG emissions.

Mission Fuel Brief and Debrief: Incorporate discussions on fuel efficiency into the briefing sessions before and after missions, allowing crews to review fuel efficiency outcomes and strategies. During missions and decision-making processes, the consideration of fuel efficiency should be balanced with other operational factors. Incorporating fuel efficiency into mission briefings ensures that all crew members are aligned on the importance of fuel conservation. By balancing fuel efficiency with other operational factors, crews can achieve a more sustainable approach to missions, contributing to reductions in GHG emissions.

7.3 Reducing APU Use

Standardize GPU Use: Develop and enforce SOPs that prioritize the use of GPUs over APUs when aircraft are parked, and ground power is available. These SOPs should clearly outline guidelines for the optimal timing of APU start and shutdown, aiming to minimize APU run time while maintaining operational effectiveness and ensuring the comfort of crew and passengers. The implementation of SOPs for APU use ensures that APUs are only operated when necessary, such as in situations where GPU availability is limited, or specific operational requirements dictate their use. By standardizing the use of GPU’s, the RCAF can reduce APU fuel consumption and GHG emissions.

Monitor and Review APU Usage: Regularly monitoring, reviewing, and analyzing APU run times is critical for the RCAF to identify and capitalize on opportunities to enhance fuel efficiency. By employing data logging and analysis to observe APU usage trends, the RCAF can develop and implement targeted strategies aimed at minimizing unnecessary APU usage. This approach can be used to develop benchmarks for optimal APU operation, establish best practices, and set clear guidelines for APU use under various operational scenarios. Through this strategy, the RCAF can achieve significant reductions in fuel consumption.

Conduct Training Sessions: Implement training programs for air crew and ground crews on the environmental impacts of unnecessary APU use and the best practices for using GPU's. The best practices should include measures such as delaying APU start prior to departure and utilizing GPU's. By educating members of the environmental impacts of unnecessary APU use and the adoption of best practices, they can decrease fuel consumption and lower GHG emissions.

7.4 Ground Support Equipment

GSE Lifecycle Assessment: Conduct a lifecycle assessment of existing diesel powered GSE to determine the optimal timing for phasing out and replacing them with electric or fuel cell alternatives. This should consider the operational lifespan, maintenance costs, fuel efficiency, and environmental impact of existing equipment compared to green alternatives. This transition to greener alternatives will enhance fuel efficiency and reduce GHG emissions.

Investigate Snowmelter: Assess the feasibility, efficiency, and environmental implications of using AvPOL in lieu of diesel for snowmelter operations. Initially, this should include surveying RCAF wings to determine if this is common practice. In addition, snowmelter manufacturers should be consulted to provide guidance on the pros and cons of each type of fuel for snow melting operations. Such a switch has the potential to enhance fuel utilization efficiency and could lead to a reduction in GHG emissions, depending on the comparative environmental footprint of AvPOL versus diesel in snowmelter applications.

Engineering Study: Initiating an engineering study to assess the electrical infrastructure needed for GSE charging stations will aid the RCAF in understanding the power requirements, grid capacity, and strategic placement for chargers. A study would provide a roadmap for installing efficient and accessible charging stations, a change that could lead to increased use of electric GSE, thereby reducing the RCAF's reliance on fossil fuels and contributing to a decrease in GHG emissions.

7.5 Culture of Fuel Efficiency

Leadership Messaging: Regular communication from leadership at all levels emphasizing the importance of fuel efficiency can significantly influence the RCAF's environmental impact. By sharing success stories, establishing clear targets, and providing updates on advancements towards these goals, leaders can inspire and motivate personnel. This engagement can lead to increased collective effort in fuel-saving measures, ultimately contributing to a reduction in GHG emissions and fostering a culture of sustainability within the RCAF.

Establish a Quality Assurance/Quality Control (QA/QC) Program: The RCAF should implement a robust QA/QC program to monitor the implementation and progress of fuel saving initiatives. This program would measure the effectiveness of practices designed to reduce fuel consumption. Utilizing questionnaires as part of this program could offer ongoing insights into the success and perceptions of these measures over time. Such a program would assist in developing a better understanding of fuel efficiency initiatives and aid in guiding ongoing enhancement of operational sustainability.

Collaboration and Knowledge Sharing: Engaging in collaboration and knowledge sharing with other military organizations can streamline the RCAF’s efforts towards fuel efficiency, minimizing duplicated efforts. The sharing of knowledge would facilitate the identification of new measures and technologies for saving fuel. Importantly, this collaborative approach could lead to the implementation of effective strategies that contribute to a tangible reduction in GHG emissions.

7.6 De-icing

Maximize use of hangar space: Although hangar space is already being utilized to a certain extent, it is recommended that hangar space always be utilized when available to reduce the need for de-snowing and use of ADAFs. Larger aircraft should be prioritized as they are the costliest to de-snow and de-ice. By reducing reliance on energy-intensive de-icing methods, the RCAF can achieve considerable reductions in GHG emissions.

Investigate recycling of ADAFs: Evaluate the feasibility and cost-effectiveness of recycling ADAFs. Considering the low volume of aircraft compared to larger airports, an analysis should assess the viability of ADAF recycling by considering the initial capital and ongoing operational costs against the potential cost savings and GHG emission reductions. Recycling ADAFs could both lower the carbon footprint, by minimizing the amount of ADAFs requires and produce cost savings over time.

7.7 Airfield Infrastructure

Reconstruct Runway and Taxiway Papa: The resurfacing of Runway and Taxiway Papa in 2021 addressed issues related to Foreign Object Debris but did not rectify underlying major issues such as the old/failing underground drainage system, structural deficiencies, pavement and site grading issues, and the absence of taxiway shoulders to meet TP312 code requirements. A comprehensive runway/taxiway reconstruction project is required to address these deficiencies.

7.8 Summary of Recommendations

A summary of the recommendations is presented in Table 7.1, highlighting key recommendations across various measures. Upon review and endorsement from the project sponsor, these measures will be integral to reducing the environmental impact of ground operations in the RCAF.

Table 7.1: Summary of Recommendations

Measure	Recommendation
Reduced Engine Taxi	Conduct Risk Assessment Standardize RET-in Conduct Training Sessions Update RET Projections
Mission Fuel Planning	Re-evaluate Force Generation Fuel Allocation Mission Fuel Brief and Debrief
Reduce APU Usage	Standardize GPU Use: Monitor and Review APU Usage Conduct Training Sessions
Ground Support Equipment	GSE Lifecycle Assessment Engineering Study Investigate Snowmelter
De-icing	Maximize use of hangar space

Measure	Recommendation
	Investigate recycling of ADAFs
Culture of Fuel Efficiency	Leadership Messaging Engineering Study Establish a QA/QC Program
Airfield Infrastructure	Reconstruct Runway and Taxiway Papa

7.9 Conclusion

In summary, this research investigated how the RCAF can implement more sustainable practices during airfield ground operations. This research recognizes the department's commitment to achieve net zero emissions and how ground operations fit within this context. By analyzing current practices at 8 Wing Trenton and comparing them to best practices from the civil and military organizations, the study aimed to find practical measures to reduce GHG emissions from RCAF operations without compromising operational effectiveness.

The study identified several areas for optimization, such as placement of the infrastructure, airfield layout, ground support equipment, use of reduced engine taxiing, reducing APU usage, and de-icing. These measures have to potential to lower GHG emissions and improve operational efficiency. Insights derived from 8 Wing staff were key in understanding the realities on the ground, the practical aspects of implementing sustainable measures, and confirming the feasibility of sustainable measures. As part of this research, nine objectives were identified and addressed as expanded in subsequent sections.

Objective 1: Establish a Baseline of Fuel Consumption for Ground operations.

Objective 1 sought to enhance the understanding of fuel consumption during ground operations for aircraft in the transport fleet through during engine idling, taxiing, and APU usage, and GSE such as GPUs. Using qualitative and quantitative data derived from site visits, interviews, and fuel logs, fuel consumption during different phases of ground operations were quantified for each aircraft and GSE. These insights present an opportunity for relevant managers to identify specific phases of ground operations that are more fuel intensive, thus hold greater potential for fuel savings. This detailed understanding of ground fuel consumption patterns will facilitate in developing targeted fuel reduction initiatives. By leveraging this data, informed decisions can be made to implement effective sustainable measures targeting ground operations.

Objective 2: Provide a re-design option for the airfield and infrastructure.

Objective 2 aimed to provide a redesign option for the airfield and infrastructure that would enhance sustainability while meeting the future needs of 8 Wing Trenton. For this exercise, Trenton's MRPDP was consulted to obtain data on the future requirements of the 8 Wing projects 25 to 30 years into the future. The redesign addressed deficiencies with the current layout while adhering to airfield best practices to reduce aircraft and infrastructure GHG emissions.

Objective 3: Assess Feasibility and Projected Fuels Savings of Reduced Engine Taxi

The aim of this objective was to evaluate the operational feasibility and projected fuel savings of RET for airframes in the transport fleet at 8 Wing Trenton. Firstly, FCOMs for each aircraft were analyzed, to determine which fleets had the necessary engine start and shutdown checklists and were permitted to perform RET. Additionally, surveys or interviews were undertaken to understand the attitudes and beliefs of pilots regarding RET and its frequency of use. Technical and operational considerations were explored to understand potential limitations and benefits of RET. Furthermore, the feasibility of RET for each airframe was assessed. Lastly, the projected fuel savings for each airframe were calculated, factoring in variables such as taxi distance and fuel consumption rates. By addressing these key areas, valuable insights were gained, providing stakeholders with the necessary information to make informed decisions about the adoption of RET and its potential benefits in terms of operational efficiency and fuel savings within the transport fleet at 8 Wing Trenton. It was estimated that the implementation of RET-in would yield savings of 545.4 tonnes of CO2 equivalent.

Objective 4: Assess Strategies to Reduce APU Fuel Consumption

This objective aimed to evaluate strategies for reducing APU fuel consumption. To achieve this, several key steps were taken. Firstly, APU usage for each aircraft was thoroughly examined, considering factors such as environmental conditions, the availability of GPUs, and departure delays. The extent to which APU usage is tracked at 8 Wing Trenton was also investigated, providing a comprehensive range of APU run times, including best-case, typical, and worst-case scenarios. Additionally, various APU use reduction strategies were proposed, such as employing GPUs and delaying APU startup. The investigation further explored the utilization of GPUs for each respective aircraft, highlighting themes from interviews regarding the use of GPUs and APUs, including concerns about nuisance and noise, technical considerations, and the reliability and dependability of GSE. Sustainable ground power solutions, such as GPUs and FEGP were also presented as viable options. Furthermore, the GHG reduction potential by delaying APU start was calculated, resulting in a significant savings of 518.6 tonnes of CO2 equivalent.

Objective 5: Optimize Aircraft De-icing

This objective aimed to enhance understanding and optimize the de-icing process 8 Wing Trenton. The research explored the procedures involved in de-snowing, de-icing, and anti-icing at the site. Furthermore, it investigated measures, such as hangaring the aircraft overnight and recycling, to reduce the consumption of ADAFs. Utilizing historical data, the study presented the GHG emissions associated with ADAFs, thereby offering insights into their environmental impact. Additionally, it provided an estimate of the potential reduction in ADAF usage through preventative measures, highlighting that this aspect had not been previously investigated, and emissions reductions had not been quantified.

Objective 6: Identify Types of GSE, Fuel Consumption, and Provide Sustainable Alternatives

This objective focused on identifying the types of GSE used at 8 Wing Trenton, analyzing their fuel consumption, and suggesting sustainable alternatives. A comprehensive tour of Hangar 10 facilitated insights into the types of GSE employed at the site and the specific types of fuel they utilized. Categorization efforts classified GSE into distinct categories such as aircraft mobility equipment, servicing apparatus, ground power units, maintenance support gear, loading equipment, de-icing apparatus, and airfield support tools. Special scrutiny was placed on the snowmelter, which had been using AvPOL as an alternative to diesel fuel in recent years. Fuel logs were aggregated and analyzed to calculate the GHG emissions associated with GSE, offering valuable insights into their environmental impacts. Recommendations for sustainable alternatives, notably eGSE, were proposed as viable replacements for diesel-powered counterparts during equipment life cycle management. Lastly, it was estimated that transitioning to eGSE could potentially mitigate up to 530.5 tonnes of CO2 equivalent emissions annually.

Objective 7: Assess Mission Fuel Planning

Objective 7 focused on evaluating the mission fuel planning process at 8 Wing. It aimed to understand the methodology behind fuel allocation for aircraft, distinguishing between planning for missions and local training exercises. Interviews with staff delineated the difference between fuel allocations for missions and local trainers. In the case of missions, pilots employed the use of an electronic flight bag to calculate their minimum fuel allocations. It was noted that pilots tend to take a conservative approach, often exceeding the minimum fuel quantities stipulated in the FOM. For local trainers, aircraft were fueled to a predetermined amount in most cases. Recommendations were provided to reassess the local training fuel loads and utilize statistical fuel contingency for missions.

Objective 8: Assess Ground Traffic Management

Objective 8 focused on analyzing ground traffic management at 8 Wing Trenton, with an emphasis on determining whether congestion, a prevalent issue at major civilian airports, also affected military installations characterized by a lower volume of flights. The evaluation of ground traffic management at 8 Wing Trenton focused on analyzing the selection of routes, taxi times, and the impact of congestion gathered through interviews with staff and firsthand observations of real time aircraft ground movements. Taxi times at 8 Wing Trenton were compared to major airports in Canada, noting that taxi times were significantly faster at 8 Wing Trenton compared to major airports in Canada, highlighting the efficiency and effectiveness of ground traffic management on site.

Objective 9: Assess the Culture of Fuel Efficiency

Objective 9 aimed to assess the culture of fuel efficiency within 8 Wing Trenton by exploring how deeply fuel efficiency principles are ingrained in the staff practices and attitudes, and the overall leadership messaging. Assessing the culture of fuel efficiency involved exploring how principles of fuel efficiency were integrated into staff practices, attitudes, and leadership messaging at 8 Wing Trenton. Common themes extracted from the interview process included data reporting, building confidence, awareness and training and operational priorities versus fuel efficiency. Targeted measures for enhancing the culture of fuel efficiency were presented including fuel efficiency as a strategic priority, stakeholder engagement, data-driven decision making, operational best practices. training and awareness, technology and innovation, and benchmarking and continuous improvement.

The insights gathered through this study underscore the critical role of accurate and comprehensive data in guiding engineering decisions and informing the development of engineering solutions tailored to GHG emissions. Without high-quality data, the capacity to design and implement strategies aligned with GHG reduction targets remains highly constrained. The engineering re-design outlined in Appendix C demonstrates the utility of such data, offering a concrete example of how informed engineering can lead to substantial improvements in sustainability. By leveraging detailed analyses and precise data, the recommendations for engineering modifications present an opportunity for achieving GHG reduction goals while enhancing overall operational efficiency.

7.10 Potential Future Work

Long-term Studies: It is recommended to conduct studies over a longer period using flight data recorder data to see how effective the recommended sustainable practices are in reducing fuel consumption and carbon emissions of ground operations.

Air operations: As the focus of this research was on ground operations, future work could focus on in-air operations to identify strategies for reducing emissions while airborne. This could involve exploring more fuel-efficient flight routes and optimizing altitudes and speeds for better fuel economy.

Expand scope to other airframes: Expanding this research to include other fleets, such as rotary-wing, fighter aircraft, maritime patrol, and SAR operations, could offer a broader understanding of sustainability opportunities across the RCAF. Each fleet has unique operational characteristics, suggesting different strategies for fuel efficiency and emission reduction.

7. References

ACI. (2009). *Guidance Manual: Airport Greenhouse Gas Emissions Management*.

ACRP. (2009). *Airport Cooperative Research Program (ACRP) Report 11 Guidebook on Preparing Greenhouse Gas Emissions Inventories*. https://crp.trb.org/acrpwebresource4/acrp-report-11-guidebook-on-preparing-airport-ghg-inventories/

AEON. (n.d.). *Engine-off Taxiing Operations*. AEON. Retrieved November 15, 2023, from https://www.aeon-project.eu/engine-off-taxiing-operations/

Air Force Operational Energy. (2022, February 1). *Department of the Air Force launches pilot program to incentivize optimized flying*. Retrieved 5 December, 2023, from https://www.af.mil/News/Article-Display/Article/2919058/department-of-the-air-force-launches-pilot-program-to-incentivize-optimized-fly/

Air Force Research Laboratory Public Affairs. (2023, October 5). *USAF partners with GM Defense to successfully power aircraft with Electric Ground Power Unit.* Edwards Air Force Base. Retrieved 1 March, 2024, from https://www.edwards.af.mil/News/Article-View/Article/3549525/

Airbus. (2004). *Getting to grips with Fuel Economy*. Retrieved November 15, 2023, from https://ansperformance.eu/library/airbus-fuel-economy.pdf

Airbus. (2021, June 24). *A350 Less Weight. Less Fuel. More Sustainable.* | A350 | Aircraft | Airbus Aircraft. https://aircraft.airbus.com/en/aircraft/a350-clean-sheet-clean-start/a350-less-weight-less-fuel-more-sustainable

Alonso, G., Benito, A., Lonza, L., & Kousoulidou, M. (2014). Investigations on the distribution of air transport traffic and CO2 emissions within the European Union. *Journal of Air Transport Management*, 36, 85–93. https://doi.org/10.1016/j.jairtraman.2013.12.019

ATAG. (2010). *Beginner's Guide to Aviation Efficiency*. http://large.stanford.edu/courses/2016/ph240/ginsberg2/docs/atag-beginner.pdf

ATAG. (2021). *Waypoint 2050: An Air Transport Action Group Project*. https://aviationbenefits.org/media/167417/w2050_v2021_27sept_full.pdf

Aviation Learnings Team. (2020, May 31). *How Aircraft Refueling Works | Role of Fuel Hydrant Dispensers & Aircraft Refueling Truck*. https://aviationlearnings.com/how-airplane-refueling-works/#The_Two_Main_Types_of_Refueling_Infrastructures_at_Airports

Benito, A., & Alonso, G. (2018). Operational procedures. In *Energy Efficiency in Air Transportation* (pp. 95–108). Elsevier. https://doi.org/10.1016/B978-0-12-812581-6.00006-5

Boeing. (2024). *Aircraft Deicing Ice-Off^{TM} TYPE I De-Icing Fluid Clear Orange, 5 gal pail*. Boeing . Retrieved April 8, 2024, from https://shop.boeing.com/aviation-supply/p/F1-5GL=33

Canada. (2022a). *CANADA'S AVIATION CLIMATE ACTION PLAN 2022-2030*. https://tc.canada.ca/sites/default/files/2022-11/canada-aviation-climate-action-plan-2022-2030.pdf

Canada. (2022b). *Government of Canada's Greenhouse Gas Emissions Inventory*. https://www.canada.ca/en/treasury-board-secretariat/services/innovation/greening-government/government-canada-greenhouse-gas-emissions-inventory.html

Canada. (2022c). *Aviation Turbine Fuel (Military Grades F-34, F-37 and F-44)*. Canadian General Standards Board. https://publications.gc.ca/collections/collection_2021/ongc-cgsb/P29-4-3-24-2020-1-eng.pdf

Canada, E. and C. C. (2010, February 15). *Order in council: Glycol guidelines [Guidance]*. https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/guidelines-objectives-codes-practice/order-council-glycol.html

Cokorilo, O. (2016). Environmental Issues for Aircraft Operations at Airports. *Transportation Research Procedia*, 14, 3713–3720. https://doi.org/10.1016/j.trpro.2016.05.491

Collins, B. P. (1982). Estimation of aircraft fuel consumption. *Journal of Aircraft*, 19(11), 969–975. https://doi.org/10.2514/3.44799

Cryotech. (2019, August 1). *Polar Guard® Advance Type IV Aircraft Deicing / Anti-icing Fluid*. Retrieved April 8, 2024, from https://www.cryotech.com/images/docs/products/aircraft/MKT1602-Polar-Guard-Advance-SDS-2019.pdf

D'Avirro, J., & Chaput, M. D. (2011). Optimizing the use of aircraft deicing and anti-icing fluids. *Transportation Research Board*.

Deloitte. (2022). *Reaching cruising altitude: A plan for scaling sustainable aviation fuel* (p. 36). https://www2.deloitte.com/content/dam/Deloitte/ca/Documents/strategy/ca-en-strategy-sustainable-aviation-pov-aoda.pdf

Deonandan, I., & Balakrishnan, H. (2010, September 13). Evaluation of Strategies for Reducing Taxi-out Emissions at Airports. 10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, Fort Worth, Texas. https://doi.org/10.2514/6.2010-9370

Di Mascio, P., Corazza, M. V., Rosa, N. R., & Moretti, L. (2022). Optimization of Aircraft Taxiing Strategies to Reduce the Impacts of Landing and Take-Off Cycle at Airports. *Sustainability*, 14(15), 9692. https://doi.org/10.3390/su14159692

DoD. (2015). *Department of Defense 2016 Operational Energy Strategy*. DoD.

DND. (2022). *CFB Trenton Master Real Property Development Plan (MRPDP)*.

DND. (2023). *Defence Climate and Sustainability Strategy 2023-2027*. https://www.canada.ca/content/dam/dnd-mdn/documents/corporate/reports-publications/dcss/dcss-e-signed.pdf

Dzikus, N., Fuchte, J., Lau, A., & Gollnick, V. (2011, September 20). Potential for Fuel Reduction through Electric Taxiing. 11th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, Virginia Beach, VA. https://doi.org/10.2514/6.2011-6931

EASA. (2023). *Current landscape and future of SAF industry*. EASA Eco. https://www.easa.europa.eu/eco/eaer/topics/sustainable-aviation-fuels/current-landscape-future-saf-industry

ECCC. (2021). *Federal Sustainable Development Strategy: 2021 Progress Report*. https://publications.gc.ca/collections/collection_2021/eccc/En1-46-2021-eng.pdf

Eklund, R., & Osvalder, A.-L. (2021). Optimising aircraft taxi speed: Design and evaluation of new means to present information on a head-up display. *Journal of Navigation*, 74(6), 1305–1335. https://doi.org/10.1017/S0373463321000606

Ellerbeck, S. (2022). The aviation sector wants to reach net zero by 2050. How will it do it? *World Economic Forum*. https://www.weforum.org/agenda/2022/12/aviation-net-zero-emissions/

Eurocontrol. (2022). *Taxi times—Summer 2022*. https://www.eurocontrol.int/publication/taxi-times-summer-2022

Freeman, A. I., Surridge, B. W. J., Matthews, M., Stewart, M., & Haygarth, P. M. (2015). Understanding and managing de-icer contamination of airport surface waters: A synthesis and future perspectives. *Environmental Technology & Innovation*, 3, 46–62. https://doi.org/10.1016/j.eti.2015.01.001

Glinka, M. (2023, February 5). 7 benefits of using an Electronic Flight Bag (EFB). *EFBOne - A Cross-Platform Electronic Flight Bag Powered by IFS*. https://ifs.aero/efb-benefits/

Guo, R., Zhang, Y., & Wang, Q. (2014). Comparison of emerging ground propulsion systems for electrified aircraft taxi operations. *Transportation Research Part C: Emerging Technologies*, 44, 98–109. https://doi.org/10.1016/j.trc.2014.03.006

Hassan, T. H., Sobaih, A. E. E., & Salem, A. E. (2021). Factors Affecting the Rate of Fuel Consumption in Aircrafts. *Sustainability*, 13(14), 8066. https://doi.org/10.3390/su13148066

Heathrow Airport. (2012). Reducing the Environmental Impacts of Ground Operations and Departing Aircraft An Industry Code of Practice. https://www.sustainableaviation.co.uk/wp-content/uploads/2018/06/Departures-Code-of-Practice-June-2012-1.pdf

Honeywell. (2019). *Managing Contingency Fuel*. https://aerospace.honeywell.com/content/dam/aerobt/en/documents/landing-pages/brochures/N61-126-000-001 _Honeywell_Forge_Managing_Fuel-wp.pdf?download=true

IATA. (2022). *IATA Carbon Offset Program*. https://www.iata.org/contentassets/922ebc4cbcd24c4d9fd55933e7070947/icop_faq_general-for-airline-participants.pdf

IATA. (2023). *Developing Sustainable Aviation Fuel (SAF)*. International Air Transport Association. https://www.iata.org/en/programs/environment/sustainable-aviation-fuels/

ICAO. (2014). *Operational Opportunities to Reduce Fuel Burn and Emissions (Doc 10013)*. http://www.icscc.org.cn/upload/file/20190102/Doc.10013-EN%20Operational%20Opportunities%20to%20Reduce%20Fuel%20Burn%20and%20Emissions.pdf

ICAO. (2020). *ICAO Doc 9889: Airport Quality Manual*. https://www.icao.int/publications/documents/9889_cons_en.pdf

ICAO. (2021, July). *ICAO Aircraft Engine Emissions Databank*. EASA. https://www.easa.europa.eu/en/domains/environment/icao-aircraft-engine-emissions-databank

ICAO. (2022). *ICAO Standards and Recommended Practices: Annex 16, Volume II*. https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2022/ENVReport2022_Art17.pdf

IFALPA. (2016). *Engine Out Taxi*. https://www.ifalpa.org/media/2093/16pos03-engine-out-taxi.pdf

Johnson, E. P. (2012). Aircraft de-icer: Recycling can cut carbon emissions in half. *Environmental Impact Assessment Review*, 32(1), 156–164. https://doi.org/10.1016/j.eiar.2011.08.001

Kameníková, I., Kameník, M., Capoušek, L., & Cejnar, Ing. J. (2022). Application of the single-engine taxi-out procedure for commercial transport, focusing on the Airbus A320 fleet. *Transportation Research Procedia*, 65, 126–132. https://doi.org/10.1016/j.trpro.2022.11.015

Kazda, A., & Caves, R. E. (2015). *Airport design and operation* (Third edition.). Emerald Group Publishing Limited. Retrieved from https://app.knovel.com/hotlink/toc/id:kpADOE0013/airport-design-operation/airport-design-operation

Korth, J., & Momberger, N. (2021, September 16). *Riga Airport starts operating the second rapi exit taxiway*. Airport Information. https://airport-information.com/data/news/riga-airport-starts-operating-the-second-rapid-exit-taxiway-65647.html

Khadilkar, H., & Balakrishnan, H. (2012). Estimation of aircraft taxi fuel burn using flight data recorder archives. *Transportation Research Part D: Transport and Environment*, 17(7), 532–537. https://doi.org/10.1016/j.trd.2012.06.005

Khammash, L., Mantecchini, L., & Reis, V. (2017). Micro-simulation of airport taxiing procedures to improve operation sustainability: Application of semi-robotic towing tractor. 2017 5th IEEE International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS), 616–621. https://doi.org/10.1109/MTITS.2017.8005587

Li, N., Sun, Y., Yu, J., Li, J.-C., Zhang, H., & Tsai, S.-B. (2019). An Empirical Study on Low Emission Taxiing Path Optimization of Aircrafts on Airport Surfaces from the Perspective of Reducing Carbon Emissions. *Energies*, 12, 1649. https://doi.org/10.3390/en12091649

Macintosh, A., & Wallace, L. (2009). International aviation emissions to 2025: Can emissions be stabilised without restricting demand? *Energy Policy*, 37(1), 264–273.

Mouton, C. A., Powers, J. D., Romano, D. M., Guo, C., Bednarz, S., & O'Connell, C. (2015). *Fuel reduction for the mobility air forces*. RAND Corporation.

NATO. (1997). *NATO Logistics Handbook: Chapter 15: Fuels, Oils, Lubricants and Petroleum Handling Equipment*. https://www.nato.int/docu/logi-en/1997/lo-15a.htm

Nordstrom, R. (2017, April). *Trudeau Int'l Invests in Deicing Services and Glycol Recycling Facilities*. https://airportimprovement.com/article/trudeau-intl-invests-deicing-services-and-glycol-recycling-facilities

Norin, A., Yuan, D., Granberg, T. A., & Värbrand, P. (2012). *Scheduling de-icing vehicles within airport logistics: A heuristic algorithm and performance evaluation*. Journal of the Operational Research Society, 63(8), 1116–1125. https://doi.org/10.1057/jors.2011.100

Norton, T. M. (2014). *Aircraft Greenhouse Gas Emissions during the Landing and Takeoff Cycle at Bay Area Airports.* Retrieved February 6, 2023, from https://repository.usfca.edu/cgi/viewcontent.cgi?article=1013&context=capstone

IATA. (2022). *IATA Carbon Offset Program*. https://www.iata.org/contentassets/922ebc4cbcd24c4d9fd55933e7070947/icop_faq_general-for-airline-participants.pdf

IATA. (2023). *Developing Sustainable Aviation Fuel (SAF)*. International Air Transport Association. https://www.iata.org/en/programs/environment/sustainable-aviation-fuels/

ICAO. (2014). *Operational Opportunities to Reduce Fuel Burn and Emissions (Doc 10013)*. http://www.icscc.org.cn/upload/file/20190102/Doc.10013-EN%20Operational%20Opportunities%20to%20Reduce%20Fuel%20Burn%20and%20Emissions.pdf

ICAO. (2020). *ICAO Doc 9889: Airport Quality Manual*. https://www.icao.int/publications/documents/9889_cons_en.pdf

ICAO. (2021, July). *ICAO Aircraft Engine Emissions Databank*. EASA. https://www.easa.europa.eu/en/domains/environment/icao-aircraft-engine-emissions-databank

ICAO. (2022). *ICAO Standards and Recommended Practices: Annex 16, Volume II*. https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2022/ENVReport2022_Art17.pdf

IFALPA. (2016). *Engine Out Taxi*. https://www.ifalpa.org/media/2093/16pos03-engine-out-taxi.pdf

Johnson, E. P. (2012). Aircraft de-icer: Recycling can cut carbon emissions in half. *Environmental Impact Assessment Review*, 32(1), 156–164. https://doi.org/10.1016/j.eiar.2011.08.001

Kameníková, I., Kameník, M., Capoušek, L., & Cejnar, Ing. J. (2022). Application of the single-engine taxi-out procedure for commercial transport, focusing on the Airbus A320

fleet. *Transportation Research Procedia*, 65, 126–132.
https://doi.org/10.1016/j.trpro.2022.11.015

Khadilkar, H., & Balakrishnan, H. (2012). Estimation of aircraft taxi fuel burn using flight data recorder archives. *Transportation Research Part D: Transport and Environment*, 17(7), 532–537. https://doi.org/10.1016/j.trd.2012.06.005

Khammash, L., Mantecchini, L., & Reis, V. (2017). Micro-simulation of airport taxiing procedures to improve operation sustainability: Application of semi-robotic towing tractor. 2017 5th IEEE International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS), 616–621. https://doi.org/10.1109/MTITS.2017.8005587

Li, N., Sun, Y., Yu, J., Li, J.-C., Zhang, H., & Tsai, S.-B. (2019). An Empirical Study on Low Emission Taxiing Path
Optimization of Aircrafts on Airport Surfaces from the Perspective of Reducing

Lune, H., & Berg, B. L. (2017). *Qualitative research methods for the social sciences*. Pearson.

Carbon Emissions. *Energies*, 12, 1649. https://doi.org/10.3390/en12091649

Macintosh, A., & Wallace, L. (2009). International aviation emissions to 2025: Can emissions be stabilised without restricting demand? *Energy Policy*, 37(1), 264–273.

Mouton, C. A., Powers, J. D., Romano, D. M., Guo, C., Bednarz, S., & O'Connell, C. (2015). *Fuel reduction for the mobility air forces*. RAND Corporation.

NATO. (1997). *NATO Logistics Handbook: Chapter 15: Fuels, Oils, Lubricants and Petroleum Handling Equipment*. https://www.nato.int/docu/logi-en/1997/lo-15a.htm

Nordstrom, R. (2017, April). *Trudeau Int'l Invests in Deicing Services and Glycol Recycling Facilities*. https://airportimprovement.com/article/trudeau-intl-invests-deicing-services-and-glycol-recycling-facilities
Norin, A., Yuan, D., Granberg, T. A., &
Värbrand, P. (2012). Scheduling de-icing vehicles within airport logistics: A heuristic algorithm and performance evaluation. *Journal of the Operational Research Society*, 63(8), 1116–1125. https://doi.org/10.1057/jors.2011.100

OpenAirlines. (2020). *The Green Airlines Fuel Book*. https://blog.openairlines.com/the-green-airlines-fuel-book

Ortega, J. (2020). *Electrification of Ground Handling Operations: Benefits of Current & Future Innovations*. https://avconww.com/electrification-of-ground-handling-operations-benefits-of-current-future-innovations/

Padhra, A. (2018). Emissions from auxiliary power units and ground power units during intraday aircraft turnarounds at European airports. *Transportation Research Part D: Transport and Environment*, 63, 433–444. https://doi.org/10.1016/j.trd.2018.06.015

Patterson, J., Noel, G. J., Senzig, D. A., Roof, C. J., & Fleming, G. G. (2009). Analysis of Departure and Arrival Profiles Using Real-Time Aircraft Data. *Journal of Aircraft*, 46(4), 1094–1103. https://doi.org/10.2514/1.42432

Patton, M. Q. (2002). *Qualitative research & evaluation methods*. sage.

Pillirone, G. (2020). *Greener Aircraft Taxiing: Single-Engine Taxi-out Evaluations*. SESAR digital academy. https://www.sesarju.eu/sites/default/files/documents/webinars/Guiseppe.pdf

Postorino, M. N., & Mantecchini, L. (2014). A transport carbon footprint methodology to assess airport carbon emissions. *Journal of Air Transport Management*, 37, 76–86. https://doi.org/10.1016/j.jairtraman.2014.03.001

RCAF. (2017, June 26). We need your help planning Canada’s birthday party. Facebook. Retrieved, May 14 2023, from https://www.facebook.com/RCAF.ARC/photos/a.10150142814416237/10154490368026237/

RCAF (2019). Hangar. Retrieved November 21, 2022, from https://hangar.cloud.forces.gc.ca/

RCAF. (2022). *Royal Canadian Airforce Path to Net Zero Strategy*.

RCAF. (2023). *AvPOL Fuel Consumption Data GHG Emissions*.

Re, F. (2012). Viability and state of the art of environmentally friendly aircraft taxiing systems. 2012 Electrical Systems for Aircraft, Railway and Ship Propulsion, 1–6. https://doi.org/10.1109/ESARS.2012.6387462

RMC Green Team. (2020). *Decision Making Considerations for Urban Planners within ADM(IE) with a view to Reducing Greenhouse Gas Emissions*.

Singh, V., & Sharma, S. K. (2015). Fuel consumption optimization in air transport: A review, classification, critique, simple meta-analysis, and future research implications. *European Transport Research Review*, 7(2), 12. https://doi.org/10.1007/s12544-015-0160-x

Skordaki, E.M., (2106). Blended Training for Scientific Software Users. EdD Dissertation, Athabasca University, 2016. https://dt.athabascau.ca/jspui/handle/10791/213

SKYBrary. (n.d.a). *Aircraft Towing | SKYbrary Aviation Safety*. Retrieved November 21, 2022, from https://www.skybrary.aero/articles/aircraft-towing

SKYbrary. (n.d.b). *Auxiliary Power Unit (APU) | SKYbrary Aviation Safety*. Retrieved August 18, 2023, from https://skybrary.aero/articles/auxiliary-power-unit-apu

Stettler, M. E. J., Koudis, G. S., Hu, S. J., Majumdar, A., & Ochieng, W. Y. (2018). The impact of single engine taxiing on aircraft fuel consumption and pollutant emissions. *The Aeronautical Journal*, 122(1258), 1967–1984. https://doi.org/10.1017/aer.2018.117

Strong, D. A. (2019, September 24). *RCAF Environmental & Operational Sustainability Program: Concept & Policy Discussion*.
St-Jean, K. (2023, May 25). *Fuel Efficiency Monitoring: Military Transport Aircraft Within the Canadian Armed Forces*.

St-Jean, K., Moore, K., Skordaki, E. M., & Vlachopoulos, N. (2023). *Fuel Efficiency Monitoring of Military Transport Aircraft Within the Canadian Armed Forces*. CSCE.

Sue, V. M., & Ritter, L. A. (2007). Introduction to using online surveys. *New Directions for Evaluation, 2007*(115), 5-14.

TBS. (2020). *Greening Government Strategy: A Government of Canada Directive*. https://www.canada.ca/en/treasury-board-secretariat/services/innovation/greening-government/strategy.html

Transport Canada. (2004). *When in Doubt... Small and Large Aircraft. Aircraft Critical Surface Contamination Training For Aircrew and Groundcrew*. https://tc.canada.ca/sites/default/files/migrated/tp10643e.pdf

Transport Canada. (2015). *TP 312: Aerodrome Standards and Recommended Practices* (5th ed.)

Trecan. (2024). *About Snowmelters*. https://www.trecan.com/snowmelters

United States DoD. (2011). *DETAIL SPECIFICATION - TURBINE FUEL, AVIATION, KEROSENE TYPE, JP-8 (NATO F-34), NATO F-35, and JP-8+100 (NATO F-37)*. https://quicksearch.dla.mil/Transient/9824378890B34F7ABB5CE27788A31563.pdf

USAF EATF. (2018). *C-17 Operations Efficiency Analysis*. Secretary of the Air Force for Installations, Environment, and Energy.

Vaishnav, P. (2012). Costs and Benefits of Reducing Fuel Burn and Emissions from Taxiing Aircraft: Low-Hanging Fruit? In *Transportation Research Record: Journal of the Transportation Research Board* (Vol. 2400). https://doi.org/10.2514/6.2012-5510

Van Oosterom, S., Mitici, M., & Hoekstra, J. (2023). Dispatching a fleet of electric towing vehicles for aircraft taxiing with conflict avoidance and efficient battery charging.

Transportation Research Part C: Emerging Technologies, 147, 103995. https://doi.org/10.1016/j.trc.2022.103995

Vigilante, J., & Reynolds, M. (2021, June 29). *Airports Take the Lead Electrifying Transport*. Burns. https://www.burns-group.com/airports-take-the-lead-electrifying-transport/

Waitz, I. A., Lukachko, S. P., & Lee, J. J. (2005). Military aviation and the environment: Historical trends and comparison to civil aviation. *Journal of Aircraft*, 42(2), 329–339.
8 Wing Trenton. (2023). *8 Wing Flying Orders*.

Appendix A: 8 Wing Trenton Planned Infrastructure Projects

Serial	Project Type	Project Description
1	New Construction	New Hangar 5 (Accommodate 436 Squadron)
2	New Construction	New SSTC Hangar
3	Demolition	Demolish Hangar 10
4	Demolition	Demolish Building 65
5	Interior Recapitalization	Consolidation of Hangar 6

Figure A.1: Overview of Spatial Location of Planned Infrastructure Projects at 8 Wing Trenton

Appendix B: Airfield Infrastructure and Hangars

Appendix B provides a detailed overview of the primary infrastructure and hangars at 8 Wing Trenton, that directly support ground operations on site. The Appendix begins with Figure B.1, a map delineating the spatial organization of key facilities. Subsequent Figure, B.2 to B.15, consist of photographs detailing the external features of each infrastructure component referenced in the initial map. This section is presented to provide a comprehensive visual understanding of the infrastructure integral to ground operations at 8 Wing Trenton.

Serial	Building	Building Description
1	Hangar 7 (B522)	CC-177 Interim Maintenance
2	Hangar 1 (B575)	8 AMS - 2nd Line Maintenance
3	Hangar 2 (B607)	8 AMS - 2nd Line Maintenance
4	Hangar 6 (B606)	429 (T) Sqn 437 (T) Sqn
5	Firehall (B611)	Firehall
6	Hangar 4 (B050)	Wing Operations
7	B051	8 AMS - Propulsion Shop
8	Hangar 10 (B052)	8 OSS - MEUF 436 (T) Sqn
9	B065	Canadian Forces Land Air Warfare Centre
10	B066	2 Air Mov Sqn - Freight Reception
11	Hangar 9 (B112)	424 (T&R) Sqn
12	B346	Passenger Terminal
13	B354	Refueling Depot
14	B478	Control Tower

Figure B.1: Summary and Layout of 8 Wing Airfield Infrastructure

Figure B.2: Hangar 7, CC-177 Interim Maintenance Hangar (B522)

Figure B.3: Hangar 1 (B575)

Figure B.4: Hangar 2 (B607)

Figure B.5: Hangar 6 (B606)

Figure B.6: Firehall (B611)

Figure B.7: Wing Operations, Hangar 4 (B050)

Figure B.8: 8 AMS Propulsion Shop (B051)

[redacted]

Figure B.9: Hangar 10 (B052)

[redacted]

Figure B.10: CFLAWC (B065)

Figure B.11: 2 Air Mov Sqn Freight Reception Centre (B066)

[redacted]

[redacted]

Figure B.12: Hangar 9, 424 (T&R) Squadron (B112)

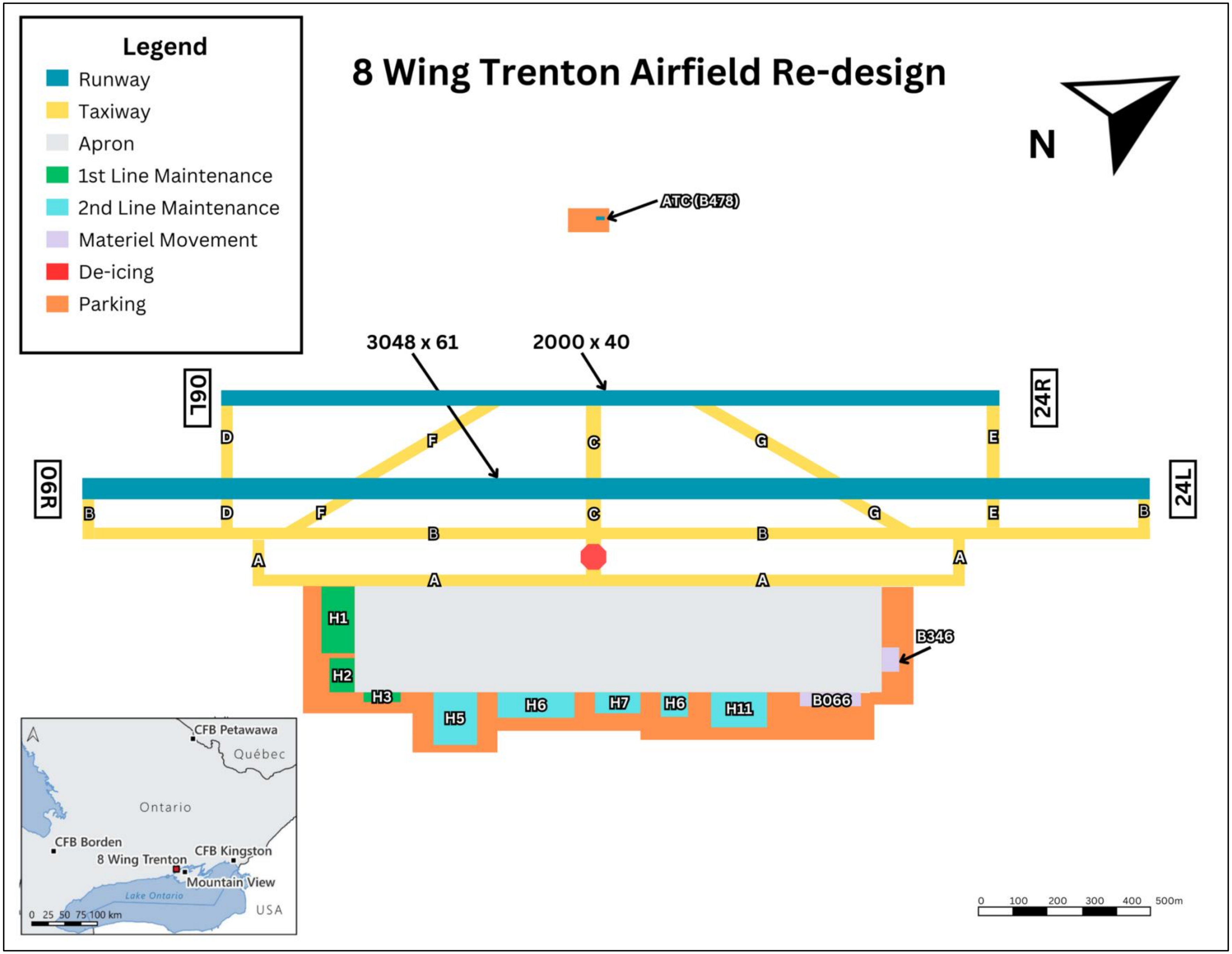
Figure A.13: Passenger Terminal (B346)

Figure B.14: Refuelling Depot (B354)

Figure B.15: 8 OSS, Control Tower (B478)

Appendix C: Airfield Redesign Layout

Appendix C presents the airfield layout redesign, conducted by the author, showcasing a strategic redesign aimed at enhancing operational efficiency and sustainability for 8 Wing. This strategic overhaul centralizes support structures around a primary apron and optimizes the placement of hangars and maintenance facilities, markedly reducing aircraft taxi distances while also addressing key deficiencies outlined in the MRPDP. Incorporating a rapid exit taxiway, the design improves overall flow and reduces fuel consumption, aligning with best practices in airfield layout. This comprehensive approach demonstrates a deliberate effort to balance operational requirements with sustainability best practices.



8 Wing Trenton Airfield Re-design

Annex 1: Conference Paper (CSCE 2023)

Fuel Efficiency Monitoring of Military Transport Aircraft Within the Canadian Armed Forces

St-Jean, Kevin[1], Moore, Kieran[1], Skordaki, Efrosyni- Maria[13], and Vlachopoulos, Nicholas[123]

[1] Department of Civil Engineering, Royal Military College, Canada
[2] Department of Geological Sciences and Geological Engineering, Queen's University, Canada
[3] School of Environmental Studies, Queen's University, Canada

Abstract. The aviation fuel used by the Canadian Armed Forces is the single largest emitter of greenhouse gas (GHG) emissions in the federal family, contributing to approximately one-fifth of the government's total emissions. In 2017, as part of the Greening Government Strategy, the federal government mandated the Department of National Defence (DND) to develop strategies to decarbonize their fleets. Historically, the CAF's GHG emissions tracking has been focused on primarily financial tracking and recording total general fuel consumption. Due to this methodology, there are certainly areas whereby more strategic operations and fuel-related data can be targeted with a view to improving the robustness of the current database in this regard. Further, such data collection can be used to improve upon and optimize current ground operations of aircraft with the CAF by providing sound data to support management decisions. Information such as engine type, operating conditions, and other significant variables have direct effects on GHG emissions or aircraft but are not currently systematically collected. Using an initial case study as the backdrop, aircraft performance monitoring has commenced with a view to determining the current uses of fuel (in all phases of ground operations by aircraft) in order to establish a baseline of relevant fuel consumption. This paper highlights the methodology that was developed for this purpose as well as selected initial findings. Resulting trends will be used to populate a database, establish a baseline, analyze the data, optimize ground operations to achieve fuel efficiency, provide re-design options for the airfield and provide input to DND fuel policy. In this way, DND and the Royal Canadian Air Force (RCAF) in particular, is being proactive in addressing climate change as it is influenced by the production of GHGs.

Keywords: Monitoring, Sustainability, Aviation, Royal Canadian Air Force, Canadian Armed Forces, Military.

1 Introduction

1.1 Governing Policy

In 2017, the Canadian government released the Greening Government Strategy, which set targets to reduce greenhouse gas (GHG) emissions from operations by 40% from 2005 levels by 2030, and subsequently 80% by 2050 (Treasury Board of Canada Secretariat, 2020). As part of the aforementioned targets, certain government GHG emissions were excluded from the government's reduction targets for safety and security reasons (Environment and Climate Change Canada, 2021). The National Safety and Security (NSS) exemption applies to operational missions within the

Department of National Defence (DND) and consequently, emissions from Royal Canadian Air Force (RCAF) aircraft are not included in the federal GHG reduction targets (Environment and Climate Change Canada, 2021). Despite the NSS exemption of aviation fuel, the RCAF is taking a proactive approach and exploring various avenues to decarbonize their fleets. Aviation fuel is the largest single emission source within the federal government, contributing to approximately one-fifth of the government's total emissions (Strong, 2019).

1.2 Problem Statement

Aviation is both the largest contributor to greenhouse gas (GHG) emissions in DND and is often considered the most difficult area to implement sustainability (McManners, 2016; Payán-Sánchez et al., 2018; Strong, 2019). This is because air travel is highly carbon-intensive and lacks viable alternatives. The military context adds an additional layer of complexity because operational requirements have a significant impact on the use and policy of aviation activities conducted by the RCAF.

Several factors warrant a scientific investigation of aircraft fuel efficiency monitoring. DND's GHG emissions tracking is currently focused primally on financial tracking and obtains total general fuel consumption. Due to this practice, there is a lack of fidelity in the data which is being collected that limits the ability to conduct specific analyses in support of operational and management decisions. Information such as engine type, operating conditions, and other relevant variables have direct effects on GHG emissions but are not currently collected with such fidelity. A transition to a data driven approach, whereby fuel consumption under different operating conditions is quantified (as well as qualified), as resulting trends can be used to perform statistical analysis, optimize fuel efficiency, and define fuel policy. As a first step, a detailed investigation of ground operations will be conducted to create a baseline of energy usage.

1.3 Site Overview

8 Wing Trenton is Canada's largest active air base and was built in the early 1930s. It is situated on the shores of Lake Ontario, about halfway between Kingston and Toronto (**Fig. 1**). 8 Wing is the hub of the RCAF's air mobility operations, strategic, and tactical airlift fleets in Canada, with a sizable fleet of tactical and strategic aircraft. The site also features a 3048 m asphalt runway with a 6/24 orientation. Given its broad mandate, 8 Wing is home to a sizeable fleet of transport aircraft including the CC-130 Hercules, CC-150 Polaris, and C-177 Globemaster III (**Fig. 2**). Notably, the total fuel consumption for the transport fleet accounts for 52% of total fuel consumption across the entire RCAF fleet (Strong, 2019).

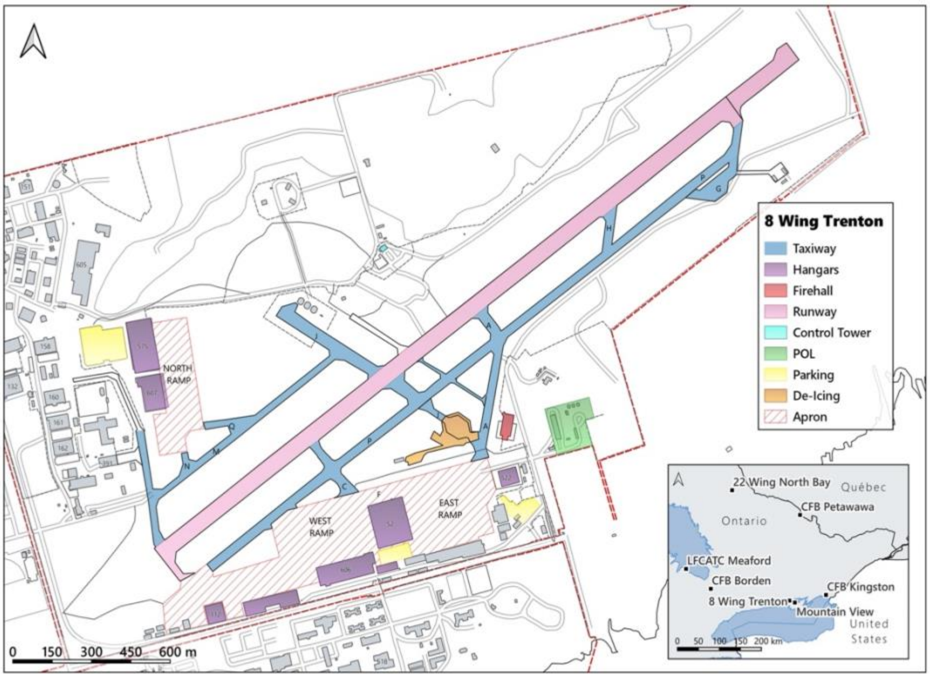


Fig. 1. 8 Wing Trenton Airfield Site Map (modified DND, 2022).

Fig. 2. 8 Wing Trenton Transport Fleet (modified RCAF, 2017).

The use of fossil fuels at 8 Wing Trenton is by far the biggest contributor to GHG emissions. As shown in **Fig. 3,** a study undertaken by the RMC Green Team at 8 Wing revealed that jet fuel (JP-8) produces the highest level emissions, accounting for approximately 80% of the emissions on the base (RMC Green Team, 2020). In effect, a reduction in aviation related emissions at this site has the potential to yield significant reductions in total GHG emissions.

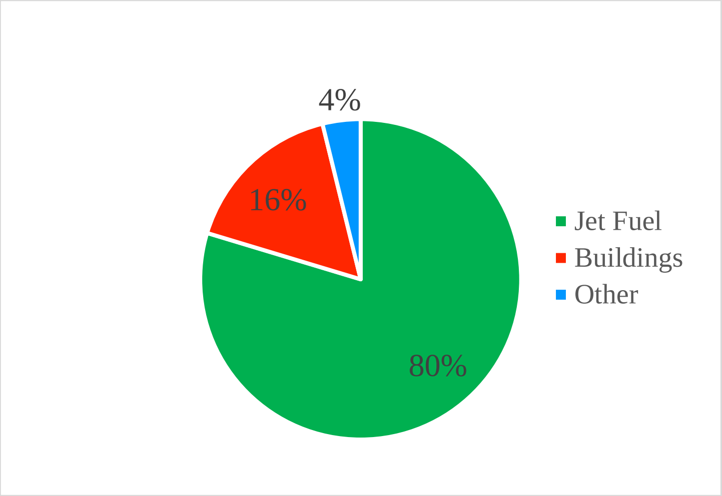


Fig. 3. 8 Wing Trenton GHG emissions. modified from (RMC Green Team, 2020)

2 Previous Research

2.1 The Path to Net Zero

The aviation industry has been concerned about fuel efficiency for many years, but the industry saw a significant increase in the focus on fuel efficiency within the last decade. This can be partially attributed to the rising costs of fuel, increased public concern over GHG emissions, and increased regulatory pressure to reduce emissions. Federal government emissions, including NSS exempt fleets, are reported annually to increase transparency and hold departments accountable for achieving reduction targets (Canada, 2022).

The aviation industry has continuously improved fuel efficiency through investments in technology and operational improvements. Since 1990, these investments have reduced fuel consumption per passenger-km by 55%. Nevertheless, these gains in efficiency have been largely negated by a growing demand for air travel (ATAG, 2021). Both the aviation industry and the RCAF are working towards attaining net zero emissions by 2050. Among experts, the consensus is that net zero will be achieved through a combination of measures categorized as sustainable aviation fuels (SAFs), offsetting and carbon capture, new technology, and infrastructure and operations. Nonetheless, the exact proportions of each of the measures will depend on how investments are allocated (IATA, 2022). **Fig. 4** illustrates a situation where technology advancements are prioritized.

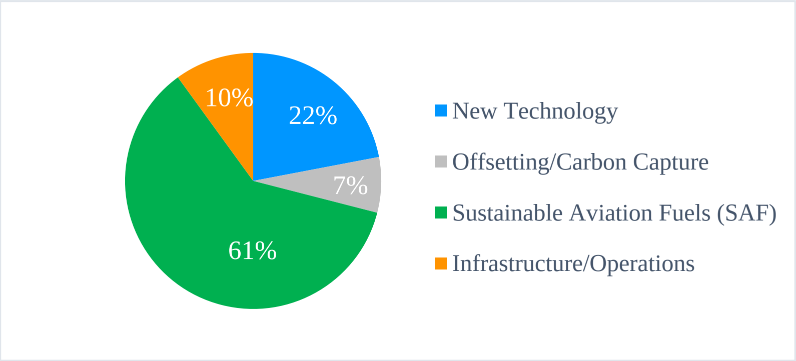


Fig. 4. Contributions to net zero emissions where technology advancements are prioritized. Modified from (ATAG, 2021)

2.1.2 Sustainable Aviation Fuels

SAFs are alternative fuels used for aviation that have lower emissions and environmental impacts than traditional petroleum-based fuels. SAFs are derived from sustainable sources such as biomass, waste, and other renewable sources, and some SAFs can reduce greenhouse gas emissions by up to 80% (IATA, 2023). In the Path to Net Zero Strategy, the RCAF acknowledges that demand for SAFs will exceed supply for the foreseeable future, thus, cannot be implemented in the short term. Production of SAFs would need to double globally to achieve 2% of all aviation fuels by 2025 (RCAF, 2022).

2.1.3 New Technology

Modern aircrafts already operate with high efficiency considering the conditions and speed in which they function. Each new generation of aircraft has seen a reduction in fuel use of around 15-20% compared to its predecessor (ATAG, 2021). This poses a challenge for the RCAF as aircraft are procured based on operational requirements, of which fuel efficiency may not be the highest priority, and the rate of replacement with newer aircraft is much slower than what would be seen in the aviation industry.

2.1.4 Offsetting and Carbon Capture

Offsetting and Carbon Capture are two measures that may be needed in order to address any residual emissions not displaced using the other measures. Offsetting refers to the process of balancing out the emissions by supporting projects that reduce or remove an equivalent amount of carbon dioxide from the atmosphere. Carbon capture refers to the process of capturing CO_2 from the air and storing it underground or using it for other purposes (ATAG, 2021).

2.1.3 Infrastructure and Operations

Although emission reductions due to operations and infrastructure are not sufficient on their own to achieve net zero, they can be implemented at a faster pace than emerging aircraft technologies that are constrained by the rate of entry of aircraft into the fleet, thus, resulting in significant fuel savings in the near term. Infrastructure improvements include measures such as use of ground power, airport layout, and building layout. Operational measures include measures such as taxi method, weight reduction, modernizing ground support equipment (GSE), weight reduction, training, fuel tracking, de-icing procedures, and air traffic management (ATM) (IATA, 2022). It is prudent, however, to first assess current operational practices to first establish a benchmark. Once the benchmark is defined, an analysis can be conducted to assess and quantify potential emission reductions and changes required to policy, operating procedures, and training.

2.2 Estimating Fuel Burn

Estimation of fuel burn plays an important role in calculating the environmental impact of air traffic operations and has been a topic of interest for several years (Collins, 1982). Taxi fuel consumption is most often determined using the fuel burn indices listed in the International Civil Aviation Organization (ICAO) engine emissions databank. The fuel burn indices provide fuel burn rates for four engine power settings corresponding to 7% or taxi/idle, 30% or approach, 85% or climb-out, and 100% or takeoff, and are based on estimates provided by engine manufacturers. The use of ICAO for taxi fuel burn estimation has inherent weaknesses as it requires the assumption that all ground operations occur entirely at 7% thrust (ICAO, 2021). Studies have shown that ICAO fuel burn indices can differ from the Flight Data Recorder (FDR) derived values and for several aircraft types, the ICAO method produces an overestimate of fuel burn (Khadilkar & Balakrishnan, 2012; Patterson et al., 2009). Fuel indices can provide a general estimation of fuel consumption, but their reliability depends on several factors including the accuracy of the data used to create the indices, the similarity of the aircraft and operational conditions being compared. It is always recommended to use actual fuel consumption data, when available, for more accurate results but fuel indices are useful as a rough guide, particularly if flight data is not readily available. Given that

RCAF does not track FDR fuel consumption data, this study will employ the use of ICAO fuel burn indices as shown in **Table 1**.

Table 1. Transport Fleet Engine Specs. Created using ICAO emissions databank (ICAO, 2021)

Aircraft	CC-130J	CC-177	CC-150
Engine Manufacturer	Rolls Royce	Pratt & Whitney	General Electric
Engine	AE2100D3	PW2040	CF6-80C2A2
Idle Fuel Flow (kg/s)	0.042	0.159	0.189

2.3 Aircraft Performance Monitoring

Aircraft performance monitoring is often carried out in the frame of fuel conservation. Resulting trends can be made available to the operators' various departments, which perform corrective actions to keep a satisfactory aircraft condition and optimize fuel efficiency. Aircraft performance monitoring also allows operators to perform various statistics about fuel consumption and is a good aid to define fuel policy (Airbus, 2002). Currently, the data collected by the RCAF on aircraft performance is intended for scheduling maintenance. Other than total fuel consumption, data pertaining to fuel efficiency at the fleet or aircraft level is not collected with the existing on-board instrumentation.

For commercial airlines, the largest operating cost is fuel, accounting for up to 40% of total operating expenditures. Thus, airlines have an incentive to improve fuel efficiency in order to reduce operating expenditures. Commercially available fuel efficiency monitoring software is growing in popularity and usage in the aviation industry to increase fuel efficiency, lower costs, and reduce carbon emissions. A variety of software suites are available, but they all operate using similar frameworks. Real-time and historical flight data are used to track and monitor fuel consumption. The software analyzes the flight data, examines trends, and identifies potential fuel savings using fuel saving procedures such as single engine taxi, excess fuel reduction, and idle reverse thrust. Data and trends are aggregated, and operators are provided actionable insight and feedback into fuel and mission management to increase fuel efficiency (GE Digital, 2022; Latitude Tech, 2019; Storkjet, 2021).

3 Experimental Procedure and Methodology

3.1 Objective and Scope

The RCAF recognizes that no single measure can be relied upon to achieve net zero emissions by 2050. National level working groups comprised of subject matter experts are already in the process of laying out measures that will be required to meet future emission targets. The scope of this research is based on monitoring and analyzing ground operations and infrastructure with the objective of creating a baseline of energy usage, efficiencies that can be achieved, and resulting GHG emission reductions. This initial study will utilize a case study approach to examine the transport fleet at 8 Wing, identified in **Table 2**, and will later be expanded to other fleets. Due to the lack of historical FDR data, this study will utilize fuel indices to estimate fuel consumption and emissions.

Table 2. Specifications for the transport fleet at 8 Wing Trenton

Aircraft	CC-130J	CC-177	CC-150
Quantity in CAF	17	4	5
Cruising Speed (km/h)	660	950	535
Empty Weight (kg)	40, 823	125, 645	80, 014
Max Gross Weight (kg)	79, 380	265, 350	157, 000
Fuel Capacity (kg)	20, 519	82, 125	19, 758
Height (m)	11.81	16.79	15.8
Wingspan (m)	40.38	51.74	43.9
Aircraft Group Number	IV	IV	IV

3.2 Overview of Methodology

The methodology that will be employed for this research in the framework is the one that has been developed by the RMC Green Team. The RMC Green Team is a team of internal (to DND) subject matter experts that provides technical advice and conducts nation-wide studies related to sustainable management of infrastructure and the environment for DND and the CAF.

As shown in **Fig. 5** and elaborated upon in the subsequent sub-sections, the questionnaire development, interviews and site visits (i.e. qualitative components), and analysis is a cyclical process that will be repeated until sufficient data has been amassed to produce accurate outcomes and recommendations. Prior to finalization, the outcomes and recommendations will be validated using feedback from operators and support staff at 8 Wing Trenton.

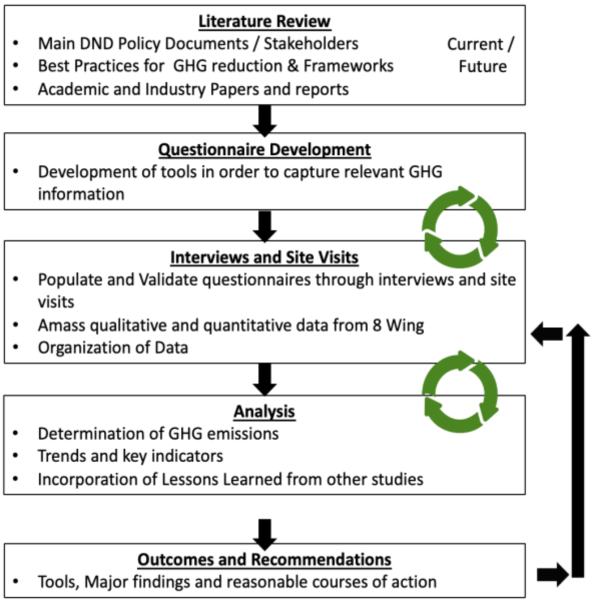


Fig. 5. An example of the research methodology (modified, RMC Green Team, 2020)

3.3.1 Literature Review

The objective of the literature review component is to provide a comprehensive overview and critical analysis of existing research, synthesize existing knowledge, identify patterns, gaps, and trends, evaluate strengths and weaknesses of existing research, and provide context for future research.

Contributors in this domain have laid out the foundation to achieving net zero and identified measures to decrease emissions through measures outlined in Section 2.1. In terms of operations and infrastructure, opportunities to reduce emissions are well established in the literature (ATAG, 2021; IATA, 2022). The key areas of interest that have been identified as requiring further investigation are outlined in **Table 3**. As site specific data is collected, this initial assessment of tasks is likely to evolve.

Table 3. Operations/Infrastructure measures identified for further analysis to reduce environmental impact of air operations at 8 Wing Trenton

Measure	Tasks	Outcomes
Building Layout	Identify all buildings supporting the airfield	Optimize building layout Quantify GHG savings
Airfield Layout	Identify aircraft movement trends Analyze layout efficiency	Optimize airfield layout Quantify GHG savings
Air Traffic Management	Identify current ATM practices Analyze impacts of traffic congestion	Optimize ATM if deemed ineffective

Ground Power	Identify existing ground power type Measure time idling and using APU	Quantify GHG savings Recommend infrastructure modifications
Taxi Method	Analyze policy for approved taxi methods Measure time and distance travelled during taxi	Quantify GHG savings Provide alternative taxi methods
Ground Support Equipment (GSE)	Inventory of all GSE and emissions Conduct life cycle analysis for modernizing GSE	Quantify GHG savings Provide alternative GSE
Weight Reduction	Define excess weight and range Identify minimum reserve fuel in policy	Quantify GHG savings Recommend changes to policies or procedures
Training	Identify existing training for fuel efficiency Determine attitudes/beliefs of staff	Recommend changes to training Discuss trends
Fuel Tracking	Identify gaps in fuel tracking Quantify fuel diverted due to spills or disposal	Recommend fuel tracking improvements for data-driven decision making
De-icing	Identify current procedures for de-icing Identify equipment and fuel indices Identify the type of glycol used	Quantify GHG emissions Provide alternative environmentally friendly de-icing procedures

3.3.2 Questionnaire Development

Development of operational-specific questionnaires is a non-trivial undertaking. The qualitative input obtained using targeted, scientifically developed questionnaires add much value in appropriately assessing and optimizing operations during aircraft taxiing to minimize fuel consumption:

Current practices: Questionnaires can be used to collect qualitative data from personnel, such as pilots and ground crews, about current practices during taxiing and idling. This data can assist in identifying trends, opportunities for improvement, and inform the development of fuel-efficient procedures. Further, it provides insight beyond the quantitative data that has been collected. It also compliments the numerical data that has been collected by giving the conditions in which the data were collected.

Evaluating attitudes and beliefs: Questionnaires can also be used to evaluate attitudes and beliefs towards fuel efficiency. This information can assist in identifying trends, areas for improvement, and help address resistance to change.

Monitoring progress: Questionnaires can be used to monitor progress over time and track the effectiveness of efforts to reduce fuel consumption.

3.3.3 Interviews and Site Visits

Site visits allow the researcher to observe processes and operating conditions firsthand, while also facilitating discourse with the operators on the ground. Observations can validate information gathered through secondary data by providing a more comprehensive picture of the organizational behaviour and the situation on the ground. During this phase, the intent is to amass site-specific information and gain a more thorough understanding of reality on the ground and specific trends. In addition to interviews, the author will be embedded within the day-to-day operations and decision-making processes at 8 Wing Trenton to create an accurate portrayal of operations.

3.3.4 Analysis

During the analysis phase, the data amassed from the literature review and site visits will be studied in order to determine actual operating conditions, identify trends, and compare the data to known best practices and regulatory frameworks. The resulting trends will be used to provide input into optimization of fuel efficiency, propose re-design of airfields and define fuel policy.

3.3.5 Outcomes and Recommendations

Outcomes will be in the form of recommendations outlining opportunities for operational efficiencies (to include infrastructure layout), and potential activities that will provide reductions in GHG emissions. Before finalising these recommendations, the findings and recommendations will be validated in consultation with the staff at 8 Wing Trenton. The recommendations will be provided to the directorate operational sustainability of the RCAF for consideration and potential implementation.

4 Conclusion

In summary, CAF aviation fuel usage is a significant contributor to the federal government's GHG emissions. Current fuel tracking and monitoring mechanisms are limited in terms of the amount and type of relevant data being collected in this regard. . As such, this research undertaking will create a baseline in terms of fuel efficiency and determine operational efficiencies that will reduce GHGs. The findings will have a direct impact on airframe ground operations and procedures, RCAF policy and guidelines as well as provide recommendations on the physical layout of the airfields at DND air bases.

References

Airbus. (2002). *Getting to Grips with Aircraft Performance Monitoring*. https://www.smartcockpit.com/docs/Getting_To_Grips_With_Perfomance_Monitoring.pdf

ATAG. (2021). *Waypoint 2050: An Air Transport Action Group Project*. https://aviationbenefits.org/media/167417/w2050_v2021_27sept_full.pdf

Canada. (2022). *Government of Canada's Greenhouse Gas Emissions Inventory* [Navigation page]. https://www.canada.ca/en/treasury-board-secretariat/services/innovation/greening-government/government-canada-greenhouse-gas-emissions-inventory.html

Collins, B. P. (1982). Estimation of aircraft fuel consumption. *Journal of Aircraft*, *19*(11), 969–975. https://doi.org/10.2514/3.44799

Environment and Climate Change Canada. (2021). *Federal Sustainment Development Strategy: 2021 Progress Report*. https://publications.gc.ca/collections/collection_2021/eccc/En1-46-2021-eng.pdf

GE Digital. (2022). *Aircraft Fuel Efficiency Monitor*. Fuel Insight. https://www.ge.com/digital/applications/flight-analytics/fuel-insight

IATA. (2022). *Net zero 2050: Operational and infrastructure improvements*. https://www.iata.org/en/iata-repository/pressroom/fact-sheets/fact-sheet-netzero-operations-infrastructure/

IATA. (2023). *Developing Sustainable Aviation Fuel (SAF)*. International Air Transport Association. https://www.iata.org/en/programs/environment/sustainable-aviation-fuels/

ICAO. (2021, July). *ICAO Aircraft Engine Emissions Databank*. EASA. https://www.easa.europa.eu/en/domains/environment/icao-aircraft-engine-emissions-databank

Khadilkar, H., & Balakrishnan, H. (2012). Estimation of aircraft taxi fuel burn using flight data recorder archives. *Transportation Research Part D: Transport and Environment*, *17*(7), 532–537. https://doi.org/10.1016/j.trd.2012.06.005

Latitude Tech. (2019). *Fuel Management Tracking & Analysis*. Fuel Management. https://www.latitudetech.com/solutions/fuel-management/

McManners, P. J. (2016). Developing policy integrating sustainability: A case study into aviation. *Environmental Science & Policy*, *57*, 86–92. https://doi.org/10.1016/j.envsci.2015.11.016

Patterson, J., Noel, G. J., Senzig, D. A., Roof, C. J., & Fleming, G. G. (2009). Analysis of Departure and Arrival Profiles Using Real-Time Aircraft Data. *Journal of Aircraft*, *46*(4), 1094–1103. https://doi.org/10.2514/1.42432

Payán-Sánchez, B., Plaza-Úbeda, J. A., Pérez-Valls, M., & Carmona-Moreno, E. (2018). Social Embeddedness for Sustainability in the Aviation Sector. *Corporate Social-Responsibility and Environmental Management*, *25*(4), 537–553. https://doi.org/10.1002/csr.1477

RCAF. (2022). *Royal Canadian Airforce Path to Net Zero Strategy*.

RMC Green Team. (2020). *Decision Making Considerations for Urban Planners within ADM(IE) with a view to Reducing Greenhouse Gas Emissions*.

Storkjet. (2021). *Aircraft performance & fuel efficiency*. Aircraft performance & fuel efficiency. https://storkjet.com/

Strong, D. A. (2019, September 24). *RCAF Environmental & Operational Sustainability Program: Concept & Policy Discussion*.

Treasury Board of Canada Secretariat. (2020). *Greening Government Strategy: A Government of Canada Directive*. https://www.canada.ca/en/treasury-board-secretariat/services/innovation/greening-government/strategy.html

USAF EATF. (2018). *C-17 Operations Efficiency Analysis*. Secretary of the Air Force for Installations, Environment, and Energy.

Wells, M., Kretser, M., Hazen, B., & Weir, J. (2020). Modified C-17 taxi procedures: A fuel cost savings exploration. *Journal of Defense Analytics and Logistics*, *4*(2), 129–145. https://doi.org/10.1108/JDAL-05-2019-0009

Annex 2: Conference Paper (CSCE 2024)

Sustainable Ground Operations in Royal Canadian Air Force: Optimization of Operations Based on Reduction of Carbon Emissions

St-Jean, Kevin[1], Moore, Kieran[1], Skordaki, Efrosyni- Maria[13], and Vlachopoulos, Nicholas[123]

[1] Department of Civil Engineering, Royal Military College, Canada
[2] Department of Geological Sciences and Geological Engineering, Queen's University, Canada
[3] School of Environmental Studies, Queen's University, Canada

Abstract. While aircraft engines are efficient at high thrust modes, they are notably less efficient at low-power settings during idling and taxiing. Recognizing the need to address environmental and economic concerns, the civil aviation industry is increasingly exploring sustainable solutions with a view to minimize fuel consumption during ground movements. As the Royal Canadian Air Force (RCAF) advances toward its federal mandate of achieving net-zero emissions in aviation, an essential requirement is to determine potential solutions by conducting a comprehensive review of best and/or relevant practices. As such, within this context, this paper examines experiences and insights derived from the global and domestic civil aviation industry and allied air force / military counterparts that could potentially be implemented and incorporated within RCAF operations. The analysis accounts for the specific requirements, constraints, and security considerations faced by military aviation, illustrating how these factors may impact the effective adoption of pertinent sustainable initiatives.

Using 8 Wing Trenton as a case study, this research study assesses the carbon emissions associated with the transport fleet and their related ground support equipment. The study also includes the feasibility and anticipated fuel savings resulting from the staging of infrastructure (i.e. organizing the location of the various task-tailored buildings that service the aircraft within the air force base) and ground operations optimizations (i.e. taxiing). This comprehensive examination offers practical insights and strategies to enhance sustainability within military aviation. The results of this research study will guide relevant managers within the RCAF and the wider military aviation sector, aiding them in making informed decisions regarding fuel efficiency, carbon emission reduction, and the integration of sustainable practices. This paper represents yet another step by the Department of National Defence (DND) and the RCAF to continue to be a leader amongst federal agencies concerning sustainability and their efforts to combat climate change while preserving national security and operational effectiveness.

Keywords: Sustainability, Carbon Emissions, Military Aviation.

1 Introduction

1.1 Objective and Scope

While aircraft engines are efficient at high thrust modes, they are notably less efficient at low-power settings during idling and taxiing. Sustainable measures targeted at aircraft ground operations have the potential to reduce aircraft GHG emissions during ground operations significantly. The primary objective of this research was to assess the feasibility and projected fuel savings of Reduced Engine Taxi (RET) for the transport fleet at 8 Wing Trenton. This objective aimed to evaluate the operational feasibility and projected fuel savings of RET for airframes in the transport fleet at 8 Wing Trenton. This was achieved through a detailed analysis of current taxi practices through site visits and interviews and comparison with best practices in civil and military aviation.

8 Wing Trenton, Trenton, Ontario, Canada, was selected as a case study location due to the type of aircraft operating there. The transport fleet at 8 Wing Trenton, illustrated in **Fig. 1**, consists of the CC-130J Hercules, CC-150 Polaris, and the CC-177 Globemaster III and collectively constitutes nearly 50% of the RCAF's aircraft GHG emissions. The choice to study the transport fleet was primarily driven by the similarity of these airframes to the extensively studied passenger aircraft in both academic research and the airline industry. Passenger aircraft have been a primary focus in sustainable aviation research, given their prevalence in commercial aviation and environmental impact. By studying the RCAF's transport fleet, which shares characteristics similar to commercial passenger planes, this study leveraged existing knowledge and sustainable practices established in academic research and within the airline industry.

Fig. 1. 8 Wing Trenton Transport Fleet [11]

1.2 Military Considerations

The goal of net zero emissions in aviation poses unique challenges when distinguishing between civil and military applications. In the civil aviation sector, the predominant goal revolves around passenger transportation. Commercial aircraft, designed primarily for the movement of passengers and cargo, has the advantage of prioritizing fuel efficiency due to its substantial contribution to operating costs. The economic viability of airlines (closely tied to their operating costs) incentivizes the civil aviation sector to invest in fuel-efficient aircraft (and associated support activities) in line with economic and environmental incentives—furthermore, the civil aviation industry benefits from well-established and maintained infrastructure. Major civilian airports have access to state-of-the-art equipment, such as pre-conditioned air and ground power units, as well as dispatch towing, all of which have been proven to reduce GHG ground emissions.

In contrast, the military adopts a different approach due to military-specific considerations. Airframes are selected based on their mission capabilities, versatility, payload capacity, interoperability, and range, often taking precedence over fuel efficiency. The requirement for military aircraft to perform diverse missions, such as combat, reconnaissance, transport, and refuelling, illustrates the need for versatile airframes that may not be optimized for fuel efficiency across all scenarios. Furthermore, military operations often occur in austere or hostile environments, where personnel, refuelling, and equipment may be limited. In such settings, aircraft may resort to less fuel-efficient measures like running off auxiliary power units (APUs) or engine running offloads to ensure operational readiness. This underscores the necessity for flexibility in fuel (and energy) consumption reduction measures.

1.3 Net Zero Policy

In 2017, the Canadian government published the Greening Government Strategy, committing to reduce GHG emissions from operations by 40% from 2005 levels by 2030 and subsequently by 80% by 2050 [1]. As part of the strategy, certain government GHG emissions were excluded from reduction targets due to safety and security concerns [2]. The National Safety and Security (NSS) exemption specifically applies to operational missions within the DND, resulting in emissions from RCAF aircraft being exempt from federal GHG reduction goals [2].

Despite exempting aviation fuel from NSS considerations, the RCAF is proactively exploring various methods to minimize its fleets' carbon footprint. In 2023, DND introduced the Defence Climate and Sustainability Strategy (DCSS), building on the strategic direction outlined in the DEES. Regarding NSS Fleets, Target 9 commits to supporting the Canadian government's pledge to achieve net-zero emissions by 2050 from the NSS fleet, considering factors such as availability, affordability, compatibility, and operational feasibility [3]. Concerning aircraft, Target 12 commits to reviewing operational procedures to identify efficiencies that effectively reduce GHG emissions for selected aircraft within the RCAF NSS fleet.

1.4 Reduced Engine Taxi

To support the RCAF in identifying operational efficiencies that would reduce fuel consumption in selected aircraft fleets, a comprehensive literature review was conducted to identify ‘green’ procedures currently employed by both allied militaries and the commercial industry. The intent was to identify potential sustainable improvements to operational procedures, assess their operational feasibility, and quantify projected fuel savings resulting from such changes. Selected procedures presented in this paper and expanded in subsequent sections include Reduced Engine Taxi (RET) Procedures. The rationale for these procedure changes is that they could be implemented relatively easily without any changes to existing equipment or additional resources, yielding immediate fuel savings.

RET is a procedure aimed at minimizing fuel consumption and emissions during aircraft taxiing by utilizing only half the number of installed engines for the majority of the taxiing duration [4]. In most cases, there is sufficient residual thrust with half of the operational engines to propel the aircraft forward during taxi. It is a proven measure that offers immediate fuel savings without needing modifications to the aircraft or infrastructure. For this reason, RET is a standard procedure for several airlines aimed at reducing fuel consumption [5]. The extent of CO_2 reductions from RET can vary between 20% and 40%, while NOx reductions vary between 10% and 30%, depending on the type of aircraft and operating conditions [6]. While the savings for each flight may appear minimal, when compounded over several flights, the savings can be significant [7].

2 Methodology

The methodology utilized for this research was adapted from the framework developed by the RMC Green Team. The RMC Green Team, consisting of internal (to DND) subject matter experts, provides technical advice and conducts national studies on the sustainable management of infrastructure and the environment for DND and the broader Canadian Armed Forces (CAF). Illustrated in **Fig. 2**, the development of questionnaires, interviews, and site visits, along with data analysis, constituted a cyclical process that was repeated until a substantial amount of data was gathered (and trends determined) to generate accurate outcomes and recommendations.

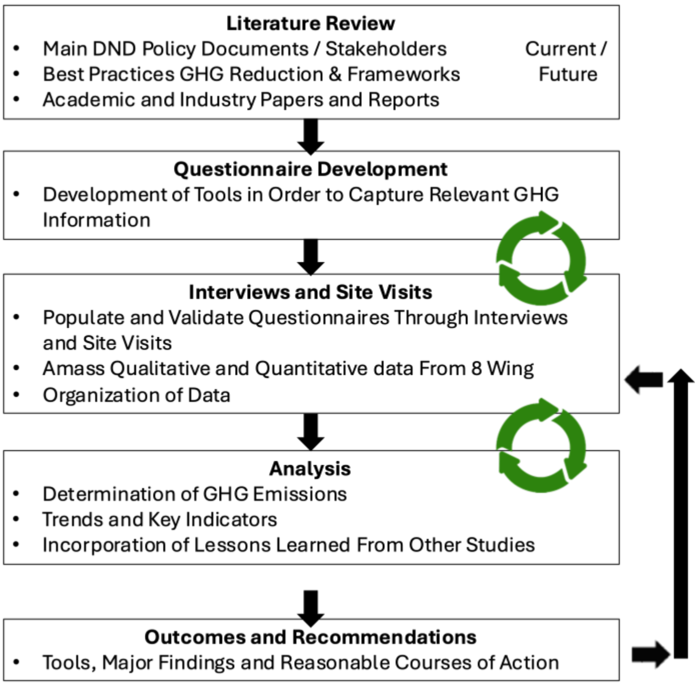


Fig. 2. Research Methodology [11]

2.1 Literature Review

The literature review explored over 150 key references, incorporating diverse sources to comprehensively understand the subject matter. The review began by leveraging a previous literature review on sustainable aviation conducted by the RMC Green Team. This review provided a foundational understanding and a preliminary source of key references for sustainable aircraft ground operations.

Initially, the focus was reviewing policy and strategic documents for the RCAF and DND. This was necessary to ensure that the sustainable measures identified aligned with the department’s overarching strategies aimed at achieving net zero emissions. These documents outline long-term goals and emissions reduction targets, serving as a baseline for subsequent searches. The review then extended to analyzing net zero strategies by major international aviation organizations such as the International Civil Aviation Organization (ICAO), the International Air Transport Association (IATA), and the Air Transport Action Group (ATAG). These documents were valuable for identifying broad, industry-wide sustainable measures relevant to military operations. Further depth was added to the review by incorporating studies from the United States Air Force (USAF) and the RAND Corporation, which often focus on the applicability of sustainability strategies within a military context. These studies provided insights into how similar measures have been conceptualized and implemented in settings resembling the RCAF, offering practical, tested solutions applicable to military aviation.

A notable gap was identified in the existing literature of RCAF-specific studies on sustainable operational procedures. Despite the literature's recommendations within a military context, there were no reports detailing the actual implementation of measures within a military setting. Further, no documented evidence illustrates the practical application and impacts of the recommendations in a military context. This gap highlighted the need for empirical evidence and real-world outcomes to validate the suggested optimizations in military operational procedures. Following the literature review, 11 measures were identified concerning the optimization of infrastructure and operations for further analysis. The identified measures are summarized in **Table 1**. This paper will outline selected findings and recommendations concerning taxi methods (Reduced Engine Taxi).

Table 1. Infrastructure and Operational Measures Identified for Further Analysis [11]

Measure	Tasks	Expected Outcome
Building Layout	Identify all buildings supporting the airfield	Optimize building layout Quantify GHG savings
Airfield Layout	Identify aircraft movement trends Analyze layout efficiency	Optimize airfield layout Quantify GHG savings
Ground Traffic Management (GTM)	Identify current ground traffic practices Analyze impacts of traffic congestion	Optimize GTM if deemed ineffective
Reducing Auxiliary Power Unit (APU) Use	Identify existing ground power type Measure time idling and using APU	Quantify GHG savings Recommend infrastructure modifications
Taxi Method	Analyze policy for approved taxi methods Measure time and distance travelled during taxi	Quantify GHG savings Provide alternative taxi methods
Ground Support Equipment (GSE)	Inventory of all GSE and emissions Conduct life cycle analysis for modernizing GSE	Quantify GHG savings Provide alternative GSE
Weight Reduction	Define excess weight and range Identify minimum reserve fuel in policy	Quantify GHG savings Recommend changes to policies or procedures
Training	Identify existing training for fuel efficiency Determine attitudes/beliefs of staff	Recommend changes to training Discuss trends
Fuel Tracking	Identify gaps in fuel tracking Quantify fuel diverted due to spills or disposal	Recommend fuel tracking improvements for data-driven decision making
De-icing	Identify current procedures for de-icing	Quantify GHG emissions

	Identify equipment and fuel indices Identify the type of glycol used	Provide alternative environmentally friendly de-icing procedures

2.2 Interviews and Site Visits

Conducting on-site visits and interviews enabled the primary author to witness processes and operational conditions on the ground directly. The design of the interviews, focusing on sustainable measures, such as RET, aimed to gather insights into current practices and the feasibility of adopting new practices to reduce fuel consumption during ground operations. The interviews and site visits aimed to understand both the familiarity and practical application of fuel-saving measures among pilots and ground crews and any barriers to their broader adoption. Example questions, as outlined in **Table 2**, began with a wide query of the general sequence of events before takeoff and after landing. The questions then explored awareness of specific procedures like RET. Further inquiry assessed whether operational checklists supported the procedure, obstacles to implementation, and perceptions on the ease of standardizing and implementing RET within the fleet.

In conjunction with the interviews, the primary author was integrated into the day-to-day operations of 8 Wing staff, aiming to capture an accurate depiction of operations. A total of 12 site visits, spanning 28 calendar days, were undertaken. This approach involved on-site and phone interviews, engaging diverse staff, including squadron personnel such as pilots, aircraft technicians, loadmasters, and support staff such as refuellers, maintainers, and operations staff. Evaluations and standards subject matter experts and representatives from aircraft manufacturers were also consulted to determine what changes would be required to standardize the use of RET for transport aircraft. The site visits extended beyond interviews to include physical attendance on training flights, enhancing the overall comprehensiveness and reliability of the data collected through firsthand observation—this hands-on experience validated information provided through the interviews with firsthand observations. The outcomes of these interviews were used to inform recommendations for operational or policy amendments to reduce GHG emissions.

Table 2. RET Sample Questions

1. Run me through the general sequence of events for a typical flight before takeoff and after landing?
2. RET is a fuel conserving technique, where half of the engines are shutdown to reduce fuel consumption during aircraft taxi.
    a. Are you aware of this procedure?
    b. Have you ever used RET under any circumstances? If so, how often are you employing RET?
    c. Is the use of RET standardized for your fleet?
    d. Does your aircraft have amended engine start or shutdown checklists to facilitate the use of RET?

e. Are there any considerations that would prevent the use of RET?
f. Do you feel that this procedure could be easily standardized and implemented for your fleet?

2.3 Analysis, Outcomes, and Recommendations

The analysis played a crucial role in synthesizing the information gathered from the literature, interviews, and site visits. It helped identify which key areas warranted further investigation due to their feasibility and projected fuel savings. Interview data was aggregated and organized into the 11 sustainable measures identified in **Table 1**.

The assessment of GHG emissions calculated emissions from fuel consumption, as aviation fuel burn is directly proportional to CO_2 emissions. For RET, the calculation involved comparing the fuel used during standard taxi procedures (all engines running) versus RET procedures (partial engine shutdown) to identify the reduction in emissions, as outlined in Equation 1.

$$\textit{Fuel Savings per Sortie} = \textit{Engine Run Time Saved Per Sortie X Engine Fuel Burn} \quad \text{[Equation 1]}$$

The key takeaways from the analysis portion of this research laid the foundation for developing outcomes and recommendations. The outcomes and recommendations will guide relevant managers within the RCAF and the wider military aviation sector, aiding them in making informed decisions regarding fuel efficiency, carbon emission reduction, and the integration of sustainable practices.

3 Results

3.1 RET Approval Status

One of the critical considerations for standardizing RET procedures is whether they have received approval from the aircraft manufacturers. The engine start and shutdown procedures are crucial phases, necessitating pilots to adhere to meticulous checklists to ensure the safety and proper functioning of the aircraft. As RET requires shutting down engines during the taxi phase, aircraft manufacturers will provide an amended checklist for such instances. The approval from manufacturers supports the reliability and safety of the RET procedures, establishing a standardized approach that aligns with industry guidelines and best practices. Thus, a critical step involved consulting the Flight Crew Operating Manuals (FCOMs) for each fleet before making any recommendations regarding integrating RET for the chosen fleets. Subsequently, this information was validated through discussion with pilots and standards officers to ensure accurate interpretation of the manuals. This process ensured a standardized procedure was in place for conducting RET within the guidelines and procedures outlined in the FCOMs.

As summarized in **Table 3**, the investigation revealed that RET-out was a standardized procedure for the CC-177 and CC-150 aircraft, yet this standardization did not extend to the CC-130J. In contrast to the CC-177 and CC-150, the CC-130J did not have RET as an approved and standardized procedure. Notably, the CC-130J is a turboprop aircraft, whereas the CC-177 and CC-150 engines are driven by turbofans, potentially explaining the absence of RET coverage in the FCOM. Furthermore, the literature needs comprehensive documentation on the use of RET for turboprop aircraft, perhaps due to insufficient residual thrust, as suggested by one of the pilots. Additionally, it was observed that RET-out was not an approved procedure for any of the aircraft fleets studied. This non-approval aligns with prevailing practices in commercial aviation, where RET-out procedures are not widely accepted across most airlines [5]. This underscores the need for careful consideration of aircraft type-specific characteristics and industry norms when evaluating the feasibility and acceptance of operational practices.

Table 3. Status of RET Procedures by Airframe

Aircraft	Amended Checklist Provided?	
	RET-In	RET-Out
CC-177	Yes	No
CC-150	Yes	No
CC-130J	No	No

3.2 Use of RET

Based on the information gathered from personnel on the ground and through firsthand observations, it was evident that RET was not standardized at 8 Wing Trenton or in the RCAF. For the fleets that had amended checklists, self-reported use of RET-in was minimal. Aircraft operators reported that, although RET was permitted under certain circumstances, its use was not covered during training nor encouraged by leadership. Pilots were unaware that the amended checklists existed in selected cases, as they were not provided with the information at any point. While some had reported having used RET in the past, it was more out of curiosity than to minimize fuel consumption. Given the additional workload associated with the amended checklists, personnel also expressed concerns with junior pilots executing the procedure, as they were less experienced than commercial pilots.

3.3 Projected Fuel Savings

Estimating projected fuel savings from RET procedures without real-world data presents several challenges. Furthermore, it is difficult to validate assumptions during the projections without this data. One challenge arises from the variability in fuel flows during taxiing. Aircraft fuel consumption is influenced by aircraft weight, thrust setting, and environmental conditions. Without specific data from executing RET procedures, accurately predicting the impact on fuel flows is challenging, as variations in these factors may not be adequately accounted for in projections. For the CC-130J, the manufacturer does not provide average fuel flows for taxiing; therefore, an estimate supplied by RAND was used as an average fuel flow [12]. Estimating taxi times also presents a challenge, as historical data on taxi times were not collected or available for this study. An estimate for taxi time of 10 minutes was made based on conversations with pilots and first-hand observation of taxi times during the study period. Using the estimated taxi in time, an engine cool down period of 3 minutes was applied, resulting in an engine run time saved per sorties of 7 minutes. As outlined in **Table 4**, fuel savings per sortie were calculated using Equation 1. The average fuel savings per sortie were then compared to each aircraft's average ground fuel consumption. It was determined that sorties that utilize RET-in would generate savings of 8.1%, 4.3%, and 8.1% for the CC-130J, CC-150, and CC-177, respectively.

Table 4. Reduced Engine Taxi Projected Fuel Savings

Parameter	CC-130J	CC-150	CC-177
Engine Run Time Saved Per Sortie (Min)	7	7	7
Engine Fuel Burn (Lbs/Min), Half Engines Operational	15	12.5	50
Fuel Savings Per Sortie (Lbs)	105	87.5	350
Ground Fuel Consumption Per Sortie (Lbs)	1300	2050	4300
Percent Savings	8.1%	4.3%	8.1%

4 Discussion

When considering RET procedures, the impact on flight safety must be weighed against the environmental benefit [13]. Mandatory RET procedures are not advised, as operational, safety, and efficiency factors must be considered case-by-case [13]. These will differ based on each aircraft, airport layout, weather, surface condition, and traffic volumes [13]. In effect, the use of RET should always be at the discretion of the aircraft commander. Given that amended engine shutdown checklists are available for the CC-150 and CC-177, it is recommended that the RCAF standardize the use of RET-in procedures for these fleets. This operational change has the potential to yield immediate savings with minimal impact on operations. Concerning junior pilots performing the procedure, data has shown that as pilots become more familiar with it, they will utilize it whenever conditions permit [5]. For the CC-130J, the lack of an amended checklist for RET presents a challenge as a non-standard procedure could introduce unnecessary risks that would outweigh the benefit of any fuel savings. Should the RCAF wish to implement RET for the CC-130J, further discussions would be required with the operators and manufacturers to assess the feasibility of implementing the procedure.

5 Conclusion and Future Work

This paper highlighted the RCAF’s proactive approach to addressing climate change and reducing GHG emissions in operational aviation. The RCAF’s commitment to achieving net zero emissions aligns with the government of Canada’s pledge to achieve zero emissions by 2050. Despite military aviation's unique challenges, the RCAF is actively exploring sustainable practices to pave the path to net zero emissions. This ongoing research study, focusing on sustainable ground operations, provides valuable insights and recommendations that can be implemented relatively easily without compromising operational effectiveness. The investigation into RET procedures demonstrates potential immediate fuel savings within specified fleets and recommends standardizing the procedure during taxi-in. Implementing RET-in is projected to generate ground fuel savings of 8.1%, 4.3%, and 8.1% for the CC-130J, CC-150, and CC-177, respectively. This research endeavour signifies the RCAF’s commitment, serving as an initial guide for relevant RCAF managers to make informed decisions regarding GHG emission reduction and the integration of sustainable aviation practices. Future work includes assessing and optimizing building layout, airfield layout, ground traffic management, GSE, weight reduction, training, fuel tracking, and de-icing.

References

[1] TBS, “Greening Government Strategy: A Government of Canada Directive.” Accessed: Nov. 16, 2022. [Online]. Available: https://www.canada.ca/en/treasury-board-secretariat/services/innovation/greening-government/strategy.html

[2] ECCC, “Federal Sustainment Development Strategy: 2021 Progress Report,” 2021. [Online]. Available: https://publications.gc.ca/collections/collection_2021/eccc/En1-46-2021-eng.pdf

[3] DND, “Defence Climate and Sustainability Strategy 2023-2027.” Dec. 2023. Accessed: Jan. 31, 2024. [Online]. Available: https://www.canada.ca/content/dam/dnd-mdn/documents/corporate/reports-publications/dcss/dcss-e-signed.pdf

[4] M. E. J. Stettler, G. S. Koudis, S. J. Hu, A. Majumdar, and W. Y. Ochieng, “The impact of single engine taxiing on aircraft fuel consumption and pollutant emissions,” *Aeronaut. J.*, vol. 122, no. 1258, pp. 1967–1984, Dec. 2018, doi: 10.1017/aer.2018.117.

[5] G. Pillirone, “Greener Aircraft Taxiing: Single-Engine Taxi-out Evaluations.” SESAR digital academy, 2020. [Online]. Available: https://www.sesarju.eu/sites/default/files/documents/webinars/Guiseppe.pdf

[6] Heathrow Airport, “Reducing the Environmental Impacts of Ground Operations and Departing Aircraft An Industry Code of Practice,” 2012. [Online]. Available: https://www.sustainableaviation.co.uk/wp-content/uploads/2018/06/Departures-Code-of- Practice-June-2012-1.pdf

[7] USAF EATF, “C-17 Operations Efficiency Analysis.” Secretary of the Air Force for Installations, Environment, and Energy, Sep. 30, 2018.

[8] M. N. Postorino and L. Mantecchini, “A transport carbon footprint methodology to assess airport carbon emissions,” *J. Air Transp. Manag.*, vol. 37, pp. 76–86, May 2014, doi: 10.1016/j.jairtraman.2014.03.001.

[9] SKYbrary, “Auxiliary Power Unit (APU) | SKYbrary Aviation Safety.” Accessed: Aug. 18, 2023. [Online]. Available: https://skybrary.aero/articles/auxiliary-power-unit-apu

[10] ICAO, “Operational Opportunities to Reduce Fuel Burn and Emissions,” Montreal, Doc 10013, 2014. [Online]. Available: http://www.icscc.org.cn/upload/file/20190102/Doc.10013-EN%20Operational%20Opportunities%20to%20Reduce%20Fuel%20Burn%20and%20Emissions.pdf

[11] K. St-Jean, “Fuel Efficiency Monitoring: Military Transport Aircraft Within the Canadian Armed Forces,” Moncton, NB, May 25, 2023.

[12] C. A. Mouton, J. D. Powers, D. M. Romano, C. Guo, S. Bednarz, and C. O’Connell, *Fuel reduction for the mobility air forces*. in Research report, no. RR-757-AF. Santa Monica, California: RAND Corporation, 2015.

[13] IFALPA, “Engine Out Taxi.” Jul. 06, 2016. [Online]. Available: https://www.ifalpa.org/media/2093/16pos03-engine-out-taxi.pdf

[14] A. Benito and G. Alonso, “Operational procedures,” in *Energy Efficiency in Air Transportation*, Elsevier, 2018, pp. 95–108. doi: 10.1016/B978-0-12-812581-6.00006-5.