**Feasibility Study: Using Drones to Reduce GHG Emissions for Deliveries to Remote Locations**

A Master’s Capstone Project

Submitted to

The Department of Engineering and Computing

National University

In Partial Fulfillment of the Requirements

for the Degree of Master of Science in of Engineering Management

by

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**October 20, 2023**

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# Dedications

This project is dedicated to the unwavering pursuit of innovation and sustainability, a shared vision of countless pioneers who envisioned a world where technology harmonizes efficiency and environmental responsibility.

We express our admiration to the myriad of visionaries who dared to dream of a brighter future and the resolute engineers, researchers, and trailblazers who defied the limits of what is possible. We convey our gratitude to those communities, industries, and ecosystems touched by our choices. May our endeavors illuminate the path towards a greener tomorrow.

We deeply appreciate our professors and mentors who encouraged our creativity and nurtured our passion for learning. This project is a resounding testament to our collective dedication to positive change. With each new idea, every research endeavor, and a the potential of innovation, we take another step toward a world where progress and the planet flourish hand-in-hand.

Lastly, we want to thank our family members who patiently stood by during countless hours of meetings and deadlines. Their unwavering encouragement and understanding have been a source of strength throughout this academic journey.

# Acknowledgments

The entire team would like to express our sincere gratitude to all the professors, facilitators, student advisors, and support personnel at National University for their invaluable guidance and support in the field of engineering management during this research project.

We extend our deepest appreciation to Professor Ben Radhakrishnan for his unwavering dedication to equipping us, the students, with a comprehensive toolbox and preparing us for the challenges of the job market and real world.

Lastly, we are immensely grateful to Armada Defense Corporation for their invaluable partnership and to Mr. Kamiar Tehrani for his generous support, expertise, and accessibility. His contributions were pivotal in ensuring the success of this project.

# Abstract

This feasibility study explores the potential for reducing greenhouse gas (GHG) emissions in the delivery industry by evaluating Armada’s Long-Range drone solution against conventional transportation methods. The project aims to assess whether Armada’s drone technology, powered by an internal combustion engine (ICE), can positively reduce GHG emissions within a 155-mile delivery range. The comprehensive study considers environmental impacts, delivery frequency, reasons for delivery, and remote community requirements while also defining its limitations. Through a structured approach, the study begins with SMART goals linked to key objectives and a meticulous project decomposition and morphology analysis. This analysis identifies core components, current state, desired state, and gaps in employing drone technology for significant GHG emissions reduction. Finally, the project highlights the potential for regulatory changes, the continuous evolution of standards, future emission reductions, and cleaner propulsion technologies as areas of concern and opportunity.

# Student Biographies

**Omar Acuna**

Born in Tijuana, Mexico, and currently residing in San Diego, California, Oma Acuna is a quality manager with an impressive 25-year track record in electronic manufacturing. He also served with honor as a rotary wing powerplant mechanic in the United States Marine Corps. With a strong educational foundation, Omar Acuna holds engineering degrees in industrial and manufacturing engineering design, reflecting a dedication to excellence and a passion for driving innovation.

**Benjamin Nicholas**

Born and raised in the greater Seattle area, Ben Nicholas left home at the age of 18 to attend the United States Naval Academy, where he earned a bachelor’s degree in Ocean Engineering. After commissioning a second lieutenant in the U.S. Marine Corps upon graduation, he has spent the last twelve years serving in multiple key billets across the U.S. and Pacific regions. He is currently stationed in Yokosuka, Japan, with his wife and son. While on leave, they often fly home to their small log cabin in a remote region of Alaska.

**John Sievert**

A native of Valparaiso, Indiana, who dedicated two decades of his life to the United States Navy before retiring. Fueled by a fervent passion for engineering, he earned a bachelor’s degree in manufacturing engineering design and is pursuing further excellence, studying engineering management with a focus on project management. John is a devoted family man, happily married with one child, and has called Chula Vista, California, his home since 2005.

**Patrick Tonganbou**

An accomplished engineering professional who earned his Engineering degree from Cal Poly Pomona in 2016. After graduation, he embarked on a successful four-year career at Boeing in the aerospace industry. Since then, Patrick has transitioned into the semiconductor sector, where he continues to excel. He is deeply committed to his family and is currently married with one child and another on the way. Patrick and his family proudly call Murrieta, California, their home, where they enjoy the community.

**Steve Wolford**

A California native with over 40 years of industry experience and a background in Nuclear Engineering at the US Naval Nuclear Power School. Recently promoted to Quality Administrator, his primary expertise remains manufacturing engineering, product development, and numerical controlled machine programming. With an MA in Education, his experience includes teaching industrial arts at the high school level. As Engineering Project Manager, he coordinates engineering services to ensure machine capabilities align with performance expectations.

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# List of Acronyms

ARCUS (Arctic Research Consortium of the United States)

CO2 (Carbon dioxide)

FMEA (Failure Mode and Effect Analysis)

GHG (Greenhouse Gas)

kg (Kilograms)

km (Kilometers)

lbs (Pounds)

LP (Linear Programming)

POD (Point of Destination)

POO (Point of Origin)

UAS (Unmanned Aerial System)

UPS (United Parcel Service)

CPS (Canada Postal Services)

# Chapter 1

## Project and Sponsor Background

**Project Background**

In 2021, Transport Canada identified 182 remote Canadian communities throughout Canada (Transport Canada, 2021). The same year, the Arctic Research Consortium of the United States identified over 60,000 people inhabiting 240 remote communities in the state of Alaska (Fried, 2022). Access to these remote communities is usually by plane or helicopter, such as delivery of groceries, toiletries, everyday-use items, building materials, mail, medical, medications, and more.

The frequency and payloads delivered to these remote communities vary greatly. However, one thing is certain: resulting greenhouse gas (GHG) emissions, specifically CO2, are extremely high, especially when the package is something small, light, and can easily be delivered by a more environmentally friendly drone.

**Sponsor Background**

Armada Defense Corps was founded by a small group of aerospace engineers and tech enthusiasts passionate about augmented and artificial intelligence. Over the years, they have developed a range of advanced aerial systems used by the Canadian military, law enforcement, and other government agencies for various applications. They believe advanced aerial systems have the potential to transform the way we live and work and are fully committed to being at the forefront of this revolution.

Our project sponsor representative, Kamyar Tehrani, has an extensive background in augmented and artificial intelligence, tech, entrepreneurship, and innovations and advancements in the aerospace and military industries. He has been instrumental in developing cutting-edge unmanned aerial system (UAS) technologies for the Canadian military and aviation security industry. Mr. Tehrani is highly motivated and continually pushes the boundaries of what is possible, putting him in pivotal leadership roles driving forward aerospace technology’s capabilities and safety standards.

## 1.2 Problem Statement

The airplanes and helicopters used to deliver parcels to remote Canadian and Alaskan communities are often old, rarely loaded to full capacity, and release hundreds of thousands of pounds of CO2 into the atmosphere with every trip. Armada’s internal combustion engine (ICE) drone can transport payloads of 44 lbs at a distance of 155 miles, giving it access to about 70% of these remote communities. This study will investigate how Armada’s drone can reduce CO2 emissions for air-delivered parcels to these communities by 70% when compared to traditional methods.

## 1.3 Key Objective

This study aims to assess the effectiveness of Armada’s Long-Range solution in mitigating greenhouse gas emissions by up to 70% in comparison to conventional air transport methods for deliveries within a 155-mile radius.

## 1.4 Project Scope

  The scope of this project is the use of simulation models to execute GHG emissions comparison specific to carbon dioxide (CO2) emissions between traditional last-mile air parcel transport. The study is limited to remote Alaskan and Canadian Arctic communities and has a maximum single parcel payload of 44 lbs, as illustrated in Figure 1.

A diagram of a project

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Figure Project scope is specific to CO2 emissions resulting from air parcels.

The Following is considered out of scope:

* Technical design
* Engineering
* Copyright for sales, manuals, etc.
* Product testing and experimentation
* In-depth market research and projections
* Legal and regulatory lobbying
* Financial assessments and costings
* Anything not specifically listed in the scope of this project

## 1.5 Limitations

Reasonable assumptions were made to construct simulation models, such as averaging the fuel efficiency of aircraft. The following factors are not considered as part of environmental factors such as headwind and tailwind, aircraft’s carbon footprint of manufacture, and maintenance.

## 1.6 Chapter Summary

In this opening chapter, we delve into the background of the project. The problem is introduced succinctly with the promise of a novel solution involving drones. The project’s key objective is outlined, focusing on evaluating the potential reduction in greenhouse gas emissions using Armada’s Long-Range delivery solution within a 155-mile range, compared to conventional transportation methods.

The chapter also defines the project’s scope, which encompasses various aspects such as environmental impacts, delivery frequency, reasons for delivery, and the requirements of remote communities. It explicitly outlines its limitations, excluding technical design, engineering, copywriting, product testing, market research, regulatory matters, and anything beyond the predefined project scope.

# Chapter 2

## 2.1 SMART Goals

The feasibility study adheres to the **SMART+ framework** to ensure our research’s effectiveness and ethical conduct.

**Specific:** our project evaluates the impact of Armada’s Long-Range drone compared to traditional aircraft delivery methods to remote Arctic communities.

* **Measurable:** assesses if the Armada drone can reduce GHG emissions, specifically CO2, by at least 70% when compared to traditional air transport.
* **Attainable:** by employing a multifaceted research approach encompassing data collection, emissions modeling, and comparative assessments against traditional delivery systems.
* **Relevant:** Armada is aligned with the urgent global concern of reducing GHG, which directly relates to environmental awareness.
* **Time Bound:** The project completion is geared to satisfy the project’s sponsor requirements.

Figure 2 illustratesthe **SMART** objectives summary as the key considerations to evaluate and characterize the feasibility study goals.

A diagram of a smart objectives

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Figure The feasibility study adheres to the SMART+ framework to ensure our research’s effectiveness and ethical conduct.

## 2.2. Project Decomposition and Morphology

The following section clarifies this project’s decomposition and morphology, providing a structured framework for assessing the viability of employing drone technologies to reduce GHG emissions in the delivery industry significantly. By methodically analyzing these environmental impact assessments, we aim to illuminate the path toward a more sustainable and environmentally responsible long-range drone delivery system.

## 2.2.1 Project Decomposition

Assessing a long-range drone system’s feasibility with the primary focus on mitigating GHG emissions presents an intellectually stimulating and environmentally conscientious endeavor. Figure 3 illustrates the deconstruction of the project into its core components, allowing for a systematic evaluation of each facet’s current state, future aspirations, and the gaps between them.

A diagram of a project

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Figure The Project structure is based on seven core steps designed for systematic evaluation of the problem

1. During project initiation, the scope and objectives focus on assessing the feasibility of reducing GHG emissions through a drone system. Similarly, scope exclusions were defined, stakeholders and robust communication plans and channels, ensuring a well-structured and effective academic approach to the project’s commencement.
2. Within the framework of the Environmental Impact Assessment (EIA), an in-depth examination was conducted. The GHG emissions linked to conventional delivery methods were assessed. Subsequently, a comprehensive analysis was carried out to gauge the potential emission reductions achievable through the long-range delivery drone system. Followed by calculating the anticipated GHG reductions across a spectrum of competition-based
3. In the context of Drone Technology Evaluation, a comprehensive examination was undertaken. Initially, the technological prerequisites for the delivery drone were assessed, encompassing factors such as range, payload capacity, and delivery frequency.
4. In the Risk Assessment phase, the team pinpointed technology and stakeholder-related risks and then devised strategies to mitigate them effectively.
5. Under the Data Collection and Analysis phase, extensive data gathering took place. The team collected data on various traditional delivery methods, spanning performance, energy usage, and GHG emissions. Simultaneously, data on drone performance, energy consumption, and emissions were also acquired.
6. For Communication and Reporting, concise reports and presentations were prepared to share the feasibility study findings with the project’s stakeholder sponsor, with a focus on emphasizing the environmental benefits of the proposed drone system.
7. In the ongoing academic research, the Project Conclusion and Recommendations segment succinctly summarizes the key findings of the feasibility study. It currently provides recommendations on whether to proceed with the development of the drone system and outlines the next steps for implementation if the project is deemed feasible.

## 2.2.2 Project Morphology

The swimlane flowchart illustrated in Figure 4 provides a comprehensive understanding of the project’s anatomy and execution by defining the key components and processes involved in assessing the feasibility of reducing GHG emissions through a long-range delivery drone system from initiation to conclusion.

A diagram of a flow chart

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Figure The swimlane flowchart provides a comprehensive view of the project’s key stages.

## 2.3 Analytical Process

The primary focus of this study is on CO2 when calculating greenhouse gases. While we are aware that the other greenhouse gases produced, such as methane (CH4) and nitrous oxide (N2O), are also important contributors to global warming, CO2 tends to receive the most attention due to its sheer abundance, long-term effects, and direct connection to human activities, particularly the burning of fossil fuels.

Regarding the GHGs produced per unit volume of energy, the combustion of jet fuel and gasoline produces a similar amount of CO2 for a given energy output. Jet fuel (Jet-2) commonly has a specific density of approximately 6.80 pounds per gallon (lb/gal) at 60 degrees Fahrenheit.

At the same time, gasoline, such as that commonly used in automotive vehicles and the drones in this study, often exhibits specific densities that vary slightly depending on precise formulations and seasonal blends. For this study, we use the common specific density for gasoline of 6.25 lb./gal at a temperature of 60 degrees Fahrenheit. (Fuels - Densities and Specific Volumes, 2003).

To calculate the amount of CO2 produced from burning 1 gallon of C8H18 hydrocarbon fuel, we utilize the stoichiometric ratio for the theoretical combustion reaction to occur. The stoichiometric air-fuel ratio is simply the ideal theoretical air-fuel ratio for complete combustion. (x-engineer.org, 2023). This process is summarized in Figures 5 & 6.

The explanation is given by the following equation showing that for every mole of C8H18 hydrocarbon fuel that is burned, we produce 8 moles of CO2.

**C8H18 + 12.5 O2 → 8 CO2 + 9 H2O**

Calculating the number of moles of hydrocarbon fuel in 1 gallon:

We use the molar mass of C8H18 = 114.26 g/mol

Converting this to pounds per mole @ 1 lb. = 453.592 g

Molar mass of C8H18 = 114.26 g/mol / 453.592 g/lb. = .252 lb./mol

A diagram of several blue squares

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Figure The use of the stoichiometric ratio for the theoretical combustion reaction to occur was used to estimate CO2 emissions.

A diagram of a diagram

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Figure According to these calculations, burning 1 gallon of C8H18 hydrocarbon fuel will produce approximately 19.26 pounds of CO2.

**Calculating the moles of C8H18 in 1 gallon:**

Given our calculated molar mass of C8H18 = .252 lb./mol

Given our above common specific density for gasoline = 6.3 lb./gal

Moles of C8H18 in 1 gallon = Mass of C8H18 / Molar mass of C8H18 =

6.25 lb. / 0.252 lb./mol = 24.8 mol

**We then use the stoichiometry to calculate moles of CO2 produced:**

Moles of CO2 produced =

Moles of C8H18 \* (8 moles CO2 / 1 mole C8H18) =

24.8 mol \* 8 = **calculate moles of CO2 produced**

**We then calculate the mass of CO2 produced:**

Molar mass of CO2 = 44.02 g/mol

Convert this to pounds per mole:

44.02 g/mol / 453.592 g/lb. = 0.097 lb./mol

**The resulting mass of CO2 produced is equal to:**

Moles of CO2 produced \* Molar mass of CO2 =

198.4 mol \* 0.097 lb./mol = **19.26 lb.**

**Technological Conclusion:**

According to these calculations, burning 1 gallon of C8H18 hydrocarbon fuel will produce approximately **19.26 pounds of CO2**.

## 2.4 Secondary Data Collection

Information concerning remote community delivery services is generally scarce. Flight records are typically held by charter or delivery companies and are not accessible to the public. Until specific aircraft are identified, and comprehensive data and measurements are gathered, assumptions and averages must be utilized on similar feasibility studies. These data sets, as seen in Appendix A, were collected from industry authorities and based on the aircraft used by UPS and CPS. The selection of these sources was strategic, ensuring access to comprehensive information on prevalent aircraft models, fuel consumption rates, and cargo capacities.

## 2.5 Analytical Model

The simulation models created for this study were developed to create a comprehensive assessment. The independent variables influencing the resulting emission of last-mile air parcel transport are identified on the cause-and-effect diagram seen in Figure 7.

A diagram of a cause and effect diagram

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Figure The independent variables influencing the resulting emission of last-mile air parcel transport are identified on the cause-and-effect diagram.

The diagram highlights the difference between Armada’s drone and traditional air transport payload. Delivery range and frequency of delivery have a direct impact on the dependent variable defined as the CO2 emissions in pounds as a result of air-parcel transport.

## 2.6 Simulation Process Architecture

Once the independent and dependent variables were defined, a transportation network model, seen in Figure 8, was created. The transportation network model provides a comprehensive visualization of the total CO2 emissions in pounds emitted by each type of aircraft and its corresponding destination.

The model’s **decision variables** are defined as the CO2 emissions in pounds emitted are represented by the numbers on each of the arcs that connect to each of the respective nodes that represent the different types of aircraft and their corresponding miles to their destination. To transcribe the problem into a formal linear program, let

Xij= Number of CO2 lbs. emissions to each destination

The **objective function** of the Linear Programming model is to reduce the number of emissions of CO2 as the result of last-mile air-parcel transport, and it is defined as follows:

**Minimize**

Y= 300X1A+600X1B+900X1C+1200X1D+1500X1E+ 350X2A+700X2B+

1050X2C +1400X2D+1750X2E+2X3A+4X3B+6X3C+8X3D+10X3E

A diagram of a network

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Figure The transportation network model provides a comprehensive visualization of the total CO2 emissions in pounds emitted by each type of aircraft and its corresponding destination.

The decision variables are limited to a supply of 1,000 lbs. of parcel, which is based on the minimum quantity of parcel in weight required by the US Postal Service to issue deliveries to remote communities in Alaska. Similarly, the demand is limited to 44 pounds of parcel, which is the maximum payload the Armada’s drone can carry.

The LP programming model is represented in the tableau seen in Table 1 (Appendix B), in which two scenarios are contemplated to evaluate the difference between the current state of the traditional air parcel and the desired future state incorporating Armada’s drone as a solution to reduce CO2 emissions. Figure 9 illustrates the assumptions and limitations of the simulation models.

A screenshot of a computer

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Table The coefficients represent the CO2 emissions in pounds as defined in the Linear Transport Network Diagram.

A diagram of a flight model

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Figure List of limitations and assumptions considered in the simulation model’s architecture.

The causal diagram seen in Figure 10 assesses the effects of range, payload, number of deliveries, and the inherent CO2 emissions. The observations made in this model provided valuable insights. For instance, a greater payload capacity may necessitate larger, less fuel-efficient aircraft, potentially increasing emissions. Conversely, a longer range might enable more efficient routing, reducing emissions. The period between deliveries influences the frequency of flights, which, in turn, impacts emissions.

A diagram of a carbon dioxide emission

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Figure The diagram illustrates the factors affecting fuel efficiency that contribute to Aircraft emissions.

 The simulation process architecture was conducted using a matrix generated through an Excel-based interactive table (Appendix C). The values in this simulation table are determined in Pounds of CO2 emissions per mile, per pound of cargo transported.

## 2.7 Chapter Summary

In summary, our feasibility study adheres to the SMART+ framework, ensuring both the effectiveness and ethical conduct of our research. Furthermore, we recognize that data pertaining to remote community delivery services is limited. During this section, the independent variables responsible for CO2 emissions are recognized in the cause-and-effect diagram. With this information, the basis for an LP programming model was developed. Lastly, the limitations of the assumptions and limitations of the LP and simulation models are identified prior to the execution of the model’s predictions.

# Chapter 3

## 3.1 Results of the I/O Process when Exercised

## 

Two LP models were developed using Excel’s Solver to optimize transportation strategies, see Table 2 (Appendix B). The initial model, employing traditional aircraft, yielded an objective function value of 231,000 lbs. of CO2 emitted. In contrast, the second model, featuring Armada’s Drone technology, significantly reduced emissions, resulting in an objective function value of 1,320 lbs. of CO2 emitted. This substantial reduction highlights the environmental benefits of adopting Armada’s drones, which replaced all other aircraft types within the limits and characterization of these specific scenarios.

A screenshot of a computer

Description automatically generated

Table The use of Armada Drone technology significantly reduced emissions.

However, these models have inherent limitations, failing to consider non-linear flight characteristics, including factors such as take-off and landing dynamics, wind influences, temperature fluctuations, cargo weight variations, flight frequency, and other logistical intricacies like specific flight patterns.

## 3.2 Results of the Simulation Process when Exercised

In order to account for variations in cargo weight and delivery distances, an interactive heat map table was introduced (Appendix C). The heat maps seen in Tables 3 and 5 are excerpts of an Excel interactive slide bar matrix in which the weight required can be adjusted to different transport scenarios.

As the weight increases, the number of Armada drones required also increases. Modifying the total delivery weight of 1,805 lbs requires 42 Armada drones. This weight serves as a tipping point. Beyond this threshold, using a single Robinson R44 Helicopter proves more efficient than employing 42 of Armada’s drones, provided all packages are destined for the same location.

**Percent CO2 Reduction Simulation Tables Transporting 44 lbs.**

A screenshot of a computer

Description automatically generated

Table Heat table simulation model showing CO2 emissions per mile transporting 44 lbs of cargo. Armada’s drone emits significantly less CO2 in this loading scenario compared to all other traditional air transport methods listed.

At the same time, Tables 4 and 6 (appendix B) represent the percentage of CO2 reduction efficiency of the Armada drone in comparison to the aircraft listed in the tables. This nuanced approach enhances the accuracy of our evaluation and refines our strategic decision-making process.

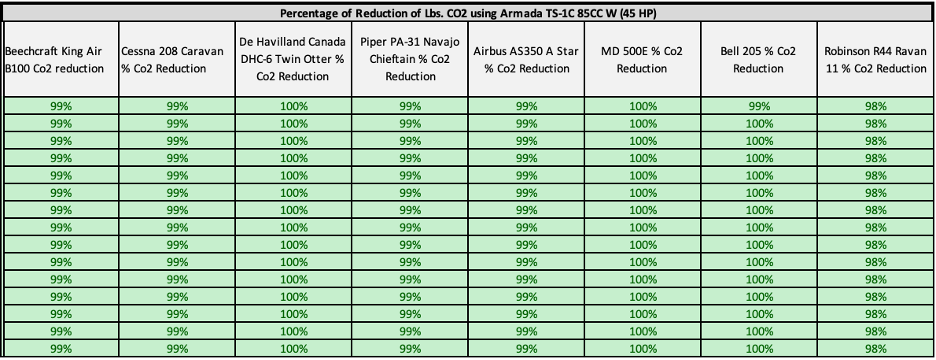


Table CO2 reduction table, by percentage compared to the Armada drone. 1 Armada drone transporting 44 lbs of cargo is 98%-100% more efficient than traditional air transport methods listed in this table.

**Percent CO2 Reduction Simulation Tables Transporting 1,805 lbs**

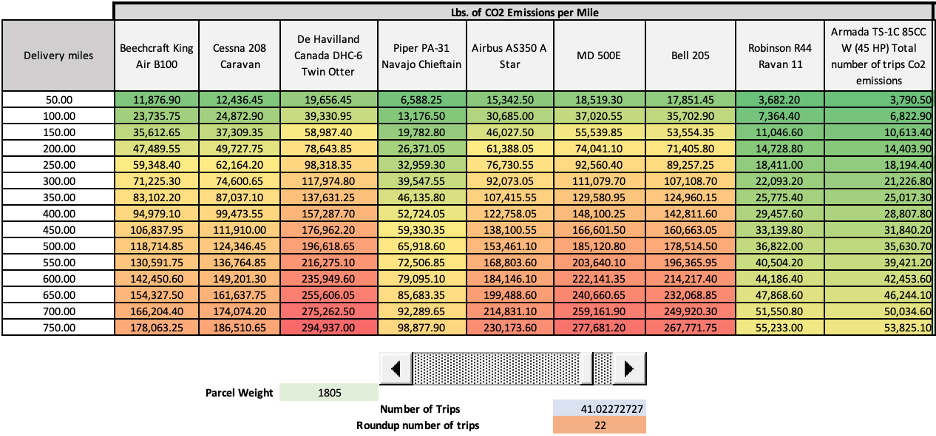


Table The heat table shows the tipping point where the Robinson R44 helicopter emits less CO2 per mile, transporting 1,805 lbs of cargo compared to 22 Armada drones.

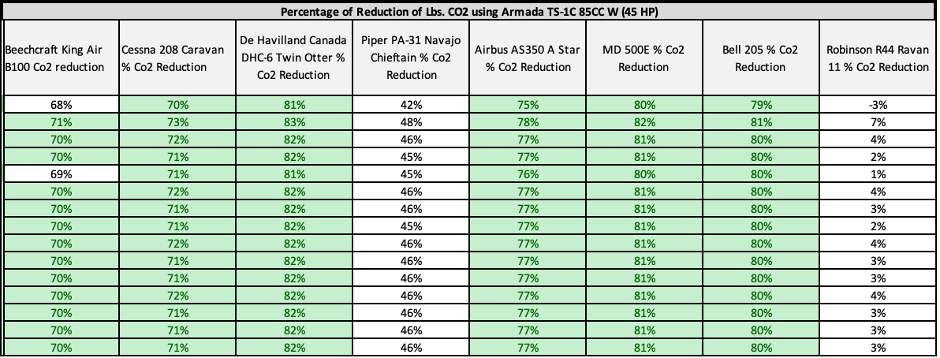


Table CO2 reduction table, by percentage compared to the Armada drone. The Robinson R44 helicopter percentage is negative in some cases, meaning it is more efficient than the 22 Armada drones required to lift 1,805 pounds of combined cargo.

## 3.3 Analytical Model – Input / Output Model

Reducing GHG emissions from 231,000 lbs of CO2 to 1,230 lbs of CO2 emitted far exceeds Armada’s desire to reduce GHG emissions in this sector by 70%. Nonetheless, the simulation models are not entirely realistic. For context, not every package will weigh under 44 lbs, and some may be too bulky for a drone to carry.

Furthermore, some remote communities are not accessible by the drone’s operational range, and the drone cannot operate in high winds like their larger, more capable traditional aircraft counterparts. Therefore, traditional aircraft and transportation methods cannot be completely eliminated. Several additional assumptions had to be made to explore a more reasonable combined solution,

Assumptions:

* 70% of remote communities are accessible by the Armada drone
* 422 total communities x 70% = 296 accessible communities
* POO to POD distance is 75 miles (150-mile round trip)
* Traditional aircraft are utilized equally for deliveries
* 296 accessible communities / 8 aircraft types = 37 deliveries for each aircraft
* Traditional aircraft fly to each community one time each week
* Armada drones fly to each community six times each week

Using the Excel solver function, we optimized the number of flights required by traditional aircraft types to achieve a 70% and an 80% reduction in GHG emission solution. These calculations also considered the resulting GHG emissions from the Armada drones that would be making six weekly trips, while traditional aircraft made only one weekly trip to each community.

As a result, we determined that traditional aircraft usage would have to be reduced from 37 trips per aircraft type every week to about ten trips per week to achieve an 80% reduction in GHG emissions. This number would only have to be reduced to about ten weekly trips to achieve a 70% reduction in GHG emissions. In both cases, the Armada drone could make deliveries to the delta number of communities six times per week. We recommend using the traditional aircraft transport method for specific deliveries outside the Armada drone’s capabilities.

A screenshot of a computer

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Table Excel solver calculations showing required reduction in traditional air transport flights to achieve 70% and 80% reduction in CO2 emissions. Methods must be reduced from 27 trips to 10.608 trips to achieve a 70% reduction and 6.908 trips to achieve an 80% reduction.

## 3.4 Synthesis of Findings

Our linear programming model demonstrated how the Armada drone could be used to reduce GHG emissions from 231,000 pounds of CO2 per trip to 1,320 pounds of CO2 per trip for deliveries up to 155 miles round trip.

Our simulation table showed how the efficiency of the Armada drone compares to traditional transportation methods under different load capacities and distances out to 750 miles. Specifically, the simulation table shows how the Robinson R44 helicopter became more efficient than 42 Armada drones transporting 1,805 lbs of cargo.

After making additional assumptions and combining the results from these two models, we determined that the Armada delivery drone system can reduce GHG emissions by 70% in the remote community parcel delivery industry.

## 3.5 Risk to Analysis

There are three factors identified as potential risks hampering the deployment of Armada’s drone for last-mile deliveries. Figure 11 illustrates the likelihood and impact of each of the risk factors. Future environmental concerns could lead to future legislation with stricter regulations. Similarly, civilian aviation regulatory changes are considered a moderate risk since they could affect the efficiency of drone operations due to restrictions in flight patterns. Lastly, Supply chain disruptions pose a moderate to high impact risk because they could hinder the timely production of drones to satisfy the optimum number of drone deployments.

A diagram of a risk assessment

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*Figure 11 Risk assessment of factors impacting the implementation of Armada’s Drone as a solution to reduce CO2 emissions on last-mile air parcel transport.*

The Failure and Analysis Mode and Effect Analysis (FMEA), seen in Table 8, identifies three possible failure modes affecting the operational stage of the Armada Drone. These failure mode mitigation statuses remain open for Armada to review and implement the necessary actions.A screenshot of a computer

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Table The FMEA lists three open potential failure modes that could affect drone deployment during its operational stage

## 3.6 Chapter Summary

Our LP model rendered two objective function values: one showing the current state of CO2 emissions from traditional air transport methods and one showing how much the Armada drone could reduce CO2 emissions under perfect circumstances. Our simulation model expanded our research to investigate how changing cargo capacity would impact CO2 emission for the Armada drone. Finally, by combining these findings, we were able to offer a more comprehensive and realistic solution to reducing CO2 emissions in this industry by 70%, utilizing a fair combination of airplanes, helicopters, and Armada drone systems.

# Chapter 4

## 4.1 Feasibility Key Question Objectives Answered

To reduce GHG emissions resulting from air deliveries to remote Canadian and Alaskan communities by 70%, each traditional aircraft type needs to reduce its round-trip deliveries from 37 trips per week to 10 trips per week. The delta of 27 delivery trips can be fulfilled with 216 armada drones to service all accessible communities.

As an added benefit and to partially compete with traditional aircraft’s higher payload capacity, Armada drones will make deliveries six days per week, meaning some remote communities could receive mail on a near-daily basis. Assuming Armada can produce 300 drones per year, the critical number of drones required to fulfill delivery requirements adequately can be achieved in 260 days.

Instituting a safety factor of 2 would allow Armada to rapidly package and ship new drones to existing and future customers for all reasons (maintenance, new orders, replacement orders, to name a few). This number can be achieved in about 520 days, assuming there are no issues or breaks in production.

A diagram of a question

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Figure To reduce CO2 emissions by 70%, it will take replacing 37 airplane deliveries for a combination of ten airplane deliveries combined with 162 drone deliveries per week.

## 4.2 Gap Analysis

GHG emissions resulting from aircraft, internal combustion engines, and parcel delivery services is an extremely complex science. Figure 13 illustrates the gaps detected in this feasibility study. Although our models serve as adequate representations of the real world for the scope of this project, six gaps are identified.

1. **Aircraft Types:** Through extensive research, our team identified eight of the most common types of airplanes and helicopters used in this industry. Nonetheless, diverse configurations of types of aircraft and other transportation methods are not considered in this study.
2. **Engine efficiency:** Internal combustion engine efficiency varies significantly depending on age, maintenance, quality of fuel, air temperature, elevation, wind direction, weather conditions, and more. For our simulations and calculations, we assumed constant efficiencies for each type of aircraft based on research.
3. **Loading Scenarios:** Data on real-world deliveries to remote communities is not readily available. The true number of deliveries, type of aircraft, and the actual amount of cargo on board the aircraft for each community varies widely.
4. **Modeling:** The models assume linear fuel consumption and do not consider weather conditions and specific flight patterns that could affect the CO2 output per mile.
5. **Armada Drone:** A prototype delivery drone has not yet been constructed and tested. Once this is done, simulations and models can be conducted using the drone’s real flight characteristics and capacities.
6. **Implementation:** Open-source delivery data to remote communities in Canada and Alaska is not readily available. Thus, limited data combined with logical assumptions were used as variables in our simulation models; this includes Armada’s ability to establish a network of delivery drones able to support deliveries in remote areas.

A diagram of a gap

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Figure Replacing assumptions with field research and the inclusion of additional variables such as weather and flight patterns are essential to close the gaps inherent to this theoretical assessment.

## 4.3 Summary of Lessons Learned

Through a linear programming model, the superior efficiency in terms of CO2 emissions of Armada’s long-range delivery drone compared to commonly used airplanes and helicopters was made apparent through two LP models and simulation tables. The simulation models showcased different loading scenarios and the percent CO2 reduction the Armada drone could achieve for these diverse situations compared to traditional aircraft.

Last, by combining the results of the linear programming model and interactive simulation model with additional assumptions on delivery frequency to remote communities, a solution combining traditional aircraft and the Armada drone was proposed. This solution reduces CO2 emissions by 70%, increases the number of deliveries received by remote communities, and still incorporates traditional aircraft transportation methods for transporting parcels and equipment outside the drone’s capabilities.

**Lessons Learned**

1. **Data collection.** Data pertaining to remote community delivery services is not plentiful available. Flight records are generally maintained by the charter or delivery company and are not available to the public. Additionally, flight characteristics and efficiency vary, even between similar aircraft. Factors like maintenance, oil and fuel quality, time of year, age of aircraft, and age of engine factor into the efficiency and environmental effects of each aircraft. Assumptions and averages need to be made until specific aircraft are identified and data and measurements are collected.
2. **Delivery frequency.** Every community receives parcels and deliveries differently. Some receive deliveries once every week regardless of the number and weight of parcels, while other communities receive deliveries after the number of parcels surpasses a set weight. To account for this, we made reasonable assumptions accounting for delivery frequency in our models.
3. **Assumptions and community-specific models.** To account for delivery weights, delivery frequency, type of aircraft used for deliveries, and more, we made reasonable assumptions that were required to continue progress with simulation models and solution derivation. As Armada receives contracts to use their drone in specific communities, change the variables in the models to match those more realistic in that specific community; this will yield more accurate CO2 emission reduction results.
4. **Loading scenarios.** Chartering an entire Cessna 208 or Robinson R44 aircraft to deliver life-saving medication, a drive belt for heavy machinery, or oil filters for a remote cannery operation is neither cost-efficient nor environmentally friendly. Scenarios like this are ideal for the Armada delivery drone.

## 4.4 Recommended Next Steps

Moving forward, we recommend that Armada Defense Corps runs official tests on their drone’s capabilities and efficiency once a prototype is constructed. This will allow accurate data necessary for the design of future 4D simulation models, yielding more refined results. As a fielding plan is developed, pull information and delivery data for geographical areas and communities Armada is specifically targeting. This refined and more accurate data can be used to run the region and community-specific simulation models and accurately determine if the Armada delivery drone system is suitable for those real-world parameters.

# Appendices

### Appendix A: Aircraft Fuel Efficiency and Range Data Table



### Appendix B: Linear Programming Tables with Excel Solver results and sensitivity Analysis



### Appendix C: CO2 Simulation Tables and Graphs



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