Icarus

Submitted in Response to the Real World Design Challenge

Submitted by

Rancho RamJets

Name	Age	Grade	Email	Phone
Maranata Gebre (Lead)	17	12	maranatagebre25@gmail.com	(702) 497-4536
Jordan Tran	16	11	Jordan23tran@gmail.com	(702) 482-0716
Andrew Palmberg	17	12	Andrew.320801@gmail.com	(702) 764-9397
Jacob Johnson	17	12	Jacob.Johnson0826@gmail.com	(702) 913-5358
Tony Jackson	18	12	jordanthejoker05@gmail.com	(702) 290-1388
Biniam Gebre	16	10	biniamgebre17@gmail.com	(702) 493-3968
Alexander Palmberg	16	11	alexandermpalmberg@gmail.com	(702) 764-9596

Rancho High School
1900 Searles Avenue - Las Vegas, NV 89101

March 29, 2024

Coach Name	Address	Phone	Email
Kimberly Hopps	4992 Michael Jay Way Las Vegas, NV 89149	(775) 843-2056	nvhopperly@gmail.com

Participating students/team members completed Formative Surveys:

Kimberly Hopps

Table of Contents

List of Figures

List of Tables

Executive Summary

Within the last five decades, there has been a 172% increase in wildfire occurrences, causing 893 billion USD worth of damage within the US annually. Wildfires release many toxic gases that contribute to the worsening effects of climate change and burn ecosystems leaving many species vulnerable to extinction. Change needs to happen soon to preserve the environment, protect families, and lower the financial burden associated with damage caused by wildfires.

In recent years, the use of Unmanned Aerial Vehicle (UAV) technology has rapidly increased in wildfire surveillance but is often slow and inefficient due to their size, weight, and cost. For example, the FVR-10, a wildfire monitoring drone features an empty weight of 6.5 kg, maximum payload of less than 0.5 kg, and a flight endurance of only 25 minutes. Larger drones like the FVR-90 feature great endurance and data collection but have a larger airframe causing longer assembly times of up to an hour and cost billions of dollars in development. In response to this, the RamJets have created a small UAV solution called “Icarus” that eliminates many of these issues. Icarus is capable of being carried in a duffel bag to any mission location, assembled in the field, and has a mission endurance of approximately 2.5 hours. Icarus also has the capacity to carry an assortment of sensors to meet any fire surveillance mission requirement. Icarus reduces the response time of local firefighters by having a duffel-bag to airtime of only 10 minutes.

The RamJets followed a strict engineering design process to create an effective solution. Icarus needed to be small and lightweight to be quickly transported in any terrain. The RamJets would go through three design phases: conceptual, preliminary, and final detailed design, to create an effective response to the challenge. To determine the weight and size requirements of the airframe, sensors needed to be selected first. The RamJets downselected small and lightweight tail sitter designs, as they allow for vertical takeoff in unknown terrain and light tree canopies. The remaining components of Icarus’ airframe minimize weight and size while maximizing flight endurance.

In addition to this, the RamJets Safety and Concept of Operations (CONOPS) team was challenged with creating an effective safety system that followed Federal Aviation Administration (FAA) regulations for traditional aircraft monitoring wildfires and protocols for all three missions. The team needed a complete 360° view of Icarus due to smokey conditions as well as Icarus being beyond the visual line of sight (BVLOS) of the Mission Control Element (MCE). Flight checklists and procedures were established throughout the mission to ensure flight safety and streamline operations.

At this point, the RamJets had created a surveying and fire monitoring UAV that far outperforms current fire surveillance UAV’s. Fixed and operating costs were calculated to ensure that Icarus is cost-effective for firefighting groups with a cost of $77,598 total with $5.57 per flight. Icarus is in turn able to provide policymakers with a UAV that has an 11 times larger flight time, a 5.6 times greater flight speed and 257% more area coverage than that of industry-leading fire monitoring UAVs. This leads to better data collection per flight. Additionally, the RamJets Icarus can be assembled over 6 times faster than industry-leading fire monitoring UAVs. To effectively present Icarus to prospective operating agencies, the communication plan advertised Icarus as an efficient fire monitoring drone delivering firefighting groups with crucial raw data in a cost-effective manner.

An array of Chemical, Long Wave Infrared (LWIR), Multispectral, Light Detection and Ranging (LiDAR), and Red-Green-Blue (RGB) sensors onboard Icarus were designed to provide the highest quality of wildfire data on the market. Utilizing a large assortment of sensors, while maintaining an extended flight duration of over two hours, Icarus provides an extremely effective means of wildfire monitoring. Icarus provides a financially viable option for firefighting efforts and is the future of fire surveillance.

Specification Table

Criteria	Value	Met (yes/no)	Section #, page #
Aircraft			
Takeoff weight	10.612 kg		Section 2.5, pg. 40
Wingspan (fixed-wing) or max width (other)	1.1 m		Section 2.6, pg. 43
Operational/communication range. At least 5 miles.	15 km (9.321 mi)	yes	Section 2.3.2, pg. 22
Transportation size within 28 in. by 16 in. by 12 in. (71.1 cm by 40.6 cm by 30.5 cm)	71.1 cm x 40.6 cm x 30.5 cm	yes	Section 2.6, pg. 43
Pre-Fire			
Method to measure fuel type and amount. Better than current methods.	Sniffer 4D, Altum PT	yes	Section 3.1.1, pg. 45
Method to measure moisture levels. Better than current methods.	Altum PT	yes	Section 3.1.1, pg. 45
Method to measure air boundary layer. Better than current methods.	Sniffer 4D, Pixhawk 6X, SCD 30	yes	Section 3.1.1, pg. 45
Method to measure thermal information. Better than current methods.	WIRIS Pro, Altum PT	yes	Section 3.1.1, pg. 45
Time to assembly UAS at deployment location	<10 min		Section 3.1.1, pg. 45
Active Fire			
Method to measure current fire edge. Better than current methods.	WIRIS Pro	yes	Section 3.1.2, pg. 51
Method to measure thermal information. Better than current methods.	WIRIS Pro, Altum PT	yes	Section 3.1.2, pg. 51
Method to measure fuel type and amount. Better than current methods.	Sniffer 4D, Altum PT	yes	Section 3.1.2, pg. 51
Method to measure moisture levels. Better than current methods.	Altum PT, Micro-SWIR 640CSX	yes	Section 3.1.2, pg. 51
Method to measure air boundary layer. Better than current methods.	Sniffer 4D, Pixhawk 6X, SCD 30	yes	Section 3.1.2, pg. 51
Measure in presence of dense smoke.		yes	Section 3.1.2, pg. 51
Time to assembly UAS at deployment location	<10 mins		Section 3.1.2, pg. 51
Post-Fire			
Method to measure vegetation. Better than current methods.	Altum PT, Livox AVIA	yes	Section 3.1.3, pg. 53
Method to measure moisture levels. Better than current methods.	Altum PT	yes	Section 3.1.3, pg. 53
Method to measure air boundary layer. Better than current methods.	Sniffer 4D, Pixhawk 6X, SCD 30	yes	Section 3.1.3, pg. 53
Method to measure thermal information. Better than current methods.	WIRIS Pro, Altum PT	yes	Section 3.1.3, pg. 53
Time to assembly UAS at deployment location	<10 mins		Section 3.1.3, pg. 53
UAS Command, Control, and Communication			
Provide real time and accurate location information		yes	Section 2.3.2, pg. 22
Detect and Avoid (DAA)			
Aircraft must detect static and dynamic obstacles		yes	Section 3.1.1, pg. 45
Aircraft must avoid conflicts		yes	Section 3.1.1, pg. 45
DAA system architecture must fit with C3 capabilities		yes	Section 3.1.1, pg. 45
Lost Link Protocol			
Aircraft must have protocols in case of partial loss of communications		yes	Section 3.3.2, pg. 59
Aircraft must have protocols in case of total loss of communications		yes	Section 3.3.2, pg. 59

1. Team Engagement

1.1 Team Formation and Project Operation

Rancho High School's Real World Design Challenge (RWDC) team is an extracurricular school club. Recruitment of new team members began at the beginning of the school year to allow time for members to learn necessary information such as reviewing previous year's submissions and developing the skills for Computer-Aided Design (CAD) modeling on SolidWorks.

The team implemented a leadership structure by which members were assigned to sections where their knowledge would best fit. Team members were generally given work in which they could contribute their best work as per their knowledge base, while also having input over the overall design process to ensure successful alignment of sections. Below is a description of each member, their role, and what they bring to the team.

Maranata Gebre (Project Lead) is a fourth-year member of the team and is enrolled in the Aerospace Engineering program. She is responsible for managing the overall project and ensuring the team's progress is on track with the timeline delineated in 2.2 Project Plan. Prior to RWDC, she had virtually no background in engineering but has developed significant skills in research, team leadership, and technical writing through her years on the team. Her interaction with mentors in the STEM field has inspired her to work harder. Her experience, work ethic, and unique perspective made her the perfect candidate for team leadership and the systems design aspect of the challenge.

Jordan Tran (Project Manager) is a third-year member of the team enrolled in the Aerospace Engineering program who is tasked with ensuring the team is meeting established goals and deadlines. Last year, he was the Command, Control, and Communications (C3) and Concept of Operations (CONOPS) lead, integrating communication systems for the UAS to be semi-autonomous. During the summer of his sophomore year, he attended the Four-Star Leadership Academy, adding to his RWDC knowledge the necessary skills to manage a team. RWDC allows him to learn from professionals in that field and have a better understanding of his passion.

Tony Jackson (CONOPS Lead) is a third-year member of the RamJets and a senior in the Aviation Technology program. Despite being hard of hearing, he never let that stop his interest in engineering. He is now in Aerospace Engineering Advanced Studies and plays sports such as tennis, bowling, and volleyball. His prior experience and work in the C3 and CONOPs sections last year makes him a prime leadership candidate.

Andrew Palmberg (Co-Engineering Lead) is a third-year member of the team and a fourth-year member of Rancho High School's Aerospace Engineering program. He has significant experience in leadership roles and working with others from being an Eagle Scout. He completed Calculus III and Differential Equations his senior year. His knowledge gained through working on the engineering section of previous year's challenges gave him the skills required to lead the RamJets' engineering team.

Jacob Johnson (Co-Engineering Lead) is a second-year member of the team and is a part of Rancho's Aerospace Engineering program. Jacob's love for engineering comes with his vast interest in space and exploring the universe. His knowledge of design skills with SolidWorks from the previous year's challenge added to his knowledge of math and physics makes him a great candidate to lead the engineering team. He is enrolled in classes through Embry Riddle to better his output for the team.

Biniam Gebre (Lead Business Development Engineer) is a second-year member of the team and is in the Aerospace Engineering program at Rancho High School. He is a hard-working individual who brings his skills and talents gleaned from other clubs, such as robotics, UNLV Research Enterprise Program (REP), and Stanford's iGEM program to RWDC. RWDC advances his ability to work effectively with a team in a STEM-oriented challenge. His leadership skills last year from the business case made him a prime leadership candidate to lead the Business Case team.

Alexander Palmberg (Business Case Engineer) is a third-year member of the team enrolled in the Aviation Technology program. He joined the team with existing leadership experience, having leadership roles in other clubs and being an Eagle Scout. His time in the aviation technology program motivated him to join the RWDC team.

1.2 Acquiring and Engaging Mentors

Before the end of the previous school year, the team reached out to mentors from the previous five years to secure their assistance for this challenge. Las Vegas, Nevada is the primary home for all United States Air Force (USAF) and Great Britain's Royal Air Force (RAF) Medium Altitude Long Endurance (MALE), Unmanned Aerial Systems (UAS) global activities. As such, the military mentors were critical assets for the aviation and mission elements of this project. From previous experience, the team identified that strong mentors would be needed in engineering and design, CONOPS, and business to ensure the team received guidance for all parts of the challenge. The Team Lead made sure to incorporate mentorship from individuals, both familiar with the RWDC as well as technical business concepts. The team met either online or in person with mentors weekly throughout the challenge, even during school breaks.

Kimberly Hopps, Director of Financial Planning and Analysis at NV Energy with 20 years of experience, primarily focused on business performance management and the financial aspects of electric generating stations. She supported the team with the business case and CONOPs components and took the role of the team's coach due to her extensive experience with the team.

Master Air Crew (MAcr) Eric McCabe, the UAV Sensor Operator and Mission Analysis Mentor, helped the team understand how engineering, CONOPS, and business case were dependent on one another.

Robert Balmer, Field Engineer IV for a government contract, provided mechanical and electrical engineering support, specializing in aviation structures and instrumentation. He gave vital information to the team regarding the selection of sensors, power sourcing, and UAV airframe selection for the mission scenario.

Derek Finnigan, a recent graduate of Embry Riddle Aeronautical University (ERAU) with a master's degree in Uncrewed and Autonomous Systems Engineering, is a military veteran who served in the UK RAF as a communications engineer and engineering manager for 30 years. The latter part of his military career was spent at Creech AFB, Nevada working as an engineering manager for the USAF and RAF on their respective MQ-9 Reaper UAV programs. Upon retirement, he spent 3-years working for General Atomics, Aeronautical System, Inc. (GA-ASI) in San Diego supporting the current MQ-9 Reaper program and helping to develop the next generation of ground control station (GCS) and supporting command, control, communications, and computers (C4) systems for GA-ASI's future MALE systems. He is currently working for the USAF in Europe (USAFE) regenerating the entire C4 ground environment of a dormant USAF air base to support new manned and unmanned aviation missions.

MAcr McCabe and business mentor Kimberly Hopps consulted with the team as they developed their CONOPSs. Mrs. Hopps worked with the team to help them understand the business case, and together with MAcr McCabe and Mr. Balmer helped the team understand how the CONOPS and the business case were dependent on each other. Additionally, Derek Finnigan provided crucial guidance for the C3 and engineering design process.

1.3 State the Project Goal

The RamJets were tasked to design a UAS to collect data that will assist emergency services in all phases of wildfire prevention, fighting, and post-fire damage assessment. The

UAS must have an operational and communication range of at least 5 miles and be small enough in size and weight for an operator to be able to hike it to the deployment location. The UAV must have at least 30 minutes of flight time and endurance to carry out the Pre-Fire, Active-Fire, and Post-Fire monitoring missions. The UAV must fit in a duffel bag with a maximum storage dimension of 71.1 cm by 40.6 cm by 30.5 cm, and if necessary, be assembled at a deployment location.

During all missions, the UAS must be capable of gathering information such as the fuel types for the fire, the moisture levels within the ground and air, the air boundary layer, and thermal information. During the active fire, in addition to the information collected in other missions, the UAV must be able to collect information about the current fire edge even with the presence of dense smoke.

The UAS also must comply with aviation safety standards from the FAA and include proper communications devices to ensure safe operations in national airspace and integration with manned aircraft. All components associated with the operation and control of the UAV must be included in the written discussion of the notebook.

The team must also create a business proposal that accounts for the operational costs, such as fuel; fixed costs, such as aircraft and support equipment; and elements of the communications plan. The communications plan and product must appeal to an audience of relevant policy makers providing a compelling argument regarding the significance of wildfires and providing reasoning on why the RamJets design should be used.

1.4 Tool Setup/Learning/Validation

The team expanded on learning from previous challenges and included more in-person meetings than in previous years. The team utilized the knowledge and experience from returning team members, but valued the new perspectives brought by new members to select the use of these tools.

Airfoil Tools were used to find accurate information about airfoils the RamJets would be utilizing. Its easy accessibility allowed the team to create the airfoils in SolidWorks as well as get data regarding them which significantly contributed to the airfoil downselection process. Airfoil Tools eliminated the complexity when designing the airframe of the UAS as seen in previous years.

Google Drive was used for organizing files effectively to benefit the success of the team. It allows all who are in the shared drive to view and edit documents at the same time. This also allowed the mentors to view the files so that they could review the information. Due to a cybersecurity event, Clark County School District (CCSD) restricted school accounts, costing the team two weeks' worth of time. After retrieving access, the team included personal accounts to ensure no further disruptions.

Google Docs allowed the team to create drafts for the engineering notebook. Its online sharing functionality allowed the team to collaborate simultaneously and create edits in real-time, while performing research on subjects assigned.

Google Spreadsheets were used for the CONOPS and business case. This application allowed the team to visualize and calculate necessary components compared to struggles experienced in normal, Google Docs tables. Team members have developed significant skills with formulas and formatting options as well as spreadsheet organization.

Microsoft Word was used for the final version of the RamJets notebook. There were formatting difficulties when transferring Google Docs to Microsoft Word, but this was solved by allocating more time to creating the word document and editing the submission.

SolidWorks is the CAD program the team used to model the UAV. After many hours of studying the application, the engineering team was able to become familiar with the program and successfully created a 3D rendition of Icarus. However, the team would need to overcome greater challenges in converting the files to the older versions applicable on school computers. In turn, one member worked on the bulk of modeling at home and saved the files on an older version to allow the other member to perform needed calculations.

Communication tools such as iMessage and Google Meet were used to plan meetings and to discuss the project. Because of the limited access for in-person meetings, due to after-school club rules requiring a teacher to be present, the team needed to find a way to gather and complete assignments online. Google Meet was the primary way of contacting mentors and for virtual work-meetings. After the CCSD cybersecurity event, the team needed to find a new way to communicate with mentors.

1.5 Impact on STEM

Prior to participating in RWDC, each of the RamJets had a minimal idea of what a Science, Technology, Engineering, and Mathematics (STEM) career would entail. Most of the team is enrolled in Rancho High School's Aerospace Engineering or Aviation Technology program, a 4-year course that teaches students the fundamental concepts of aerospace engineering as well as basic skills with engineering software such as SolidWorks. Team members are also enrolled in many honors, advanced placement, and advanced study courses.

Due to its focus on real-world design, the RamJets were provided with a unique opportunity to explore a practical application of some of the skills and knowledge that was studied in their engineering program. RWDC has developed the team’s problem-solving abilities, critical thinking, teamwork, and other skills essential to future STEM endeavors.

The mentors offered real-world professional and technical experience from their fields ensuring that the RamJets’ design, operations and business plan were as realistic as possible. Not only did the mentorship inspire the RamJets to further investigate STEM fields for themselves, but it also allowed the team to understand how their own classes would apply to the different STEM fields. Students in other classes with the team members were greatly interested in the undertaking of a large-scale engineering project. In addition, teachers were curious and fascinated about the challenge and wanted to help in any way.

Overall, the team greatly improved in teamwork and engineering fundamentals. Working with each other and mentors increased cooperation amongst the team. The overall engineering notebook created a great impact on engineering fundamentals, mathematical equations, and scientific studies within aviation.

2. System Design

2.1 Engineering Design Process

One of the team's first considerations was how to approach and complete each step of the challenge. After deliberation and help from mentors, the team created a process that allowed the UAS to be designed efficiently and be relevant to the challenge statement. The RamJets mentors stressed the iterative nature of the engineering process because it demonstrated that the team was constantly reevaluating the design to ensure the best possible UAS. This process was employed in large decisions that are most essential to the design, such as evaluating the airframe and selecting equipment for fire monitoring, flight time and area covered to ensure all possible solutions were considered. All design phases utilize AND Gate Boolean logic, where designs are eliminated that cannot meet criteria/requirements. The following are chronological stages to the engineering design process.

Stage 1: Conceptual Design Phase

To understand the challenge, the team thoroughly read and highlighted goals in the challenge statement. With these goals in mind, the team created a list of ideas that were compared to the challenge's requirements using spreadsheets. If the idea(s) could meet the challenge criteria, it would move on to the preliminary design phase.

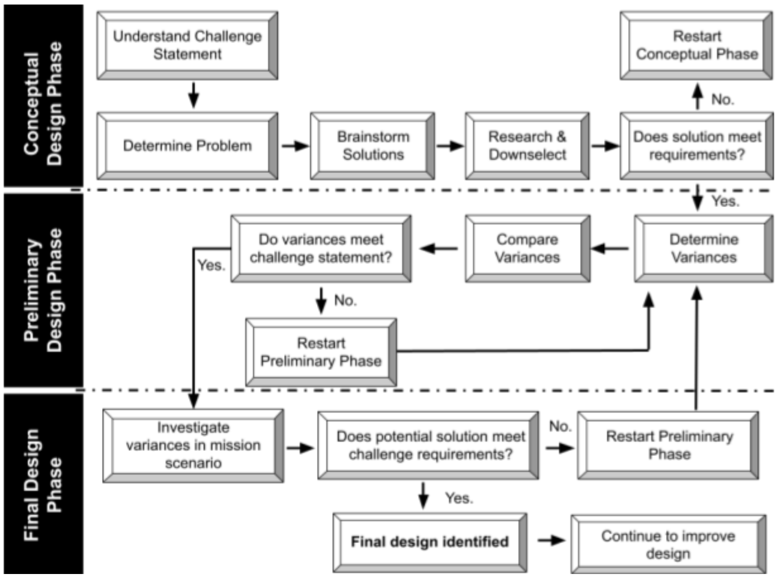
Stage 2: Preliminary Design Phase

During the preliminary phase, the team visualized and compared potential variants from the solutions determined in the conceptual design phase to identify the most optimal design. The team then visualized these concepts through sketches to compare them even further.

Stage 3: Final Detailed Design Phase

During the last stage, the final design was compared to the national challenge statement. The team then searched for potential improvements. If discovered, the engineering design process was restarted to polish the final design. Refer to Figure 1: Engineering Design Process for an illustration of the design process.

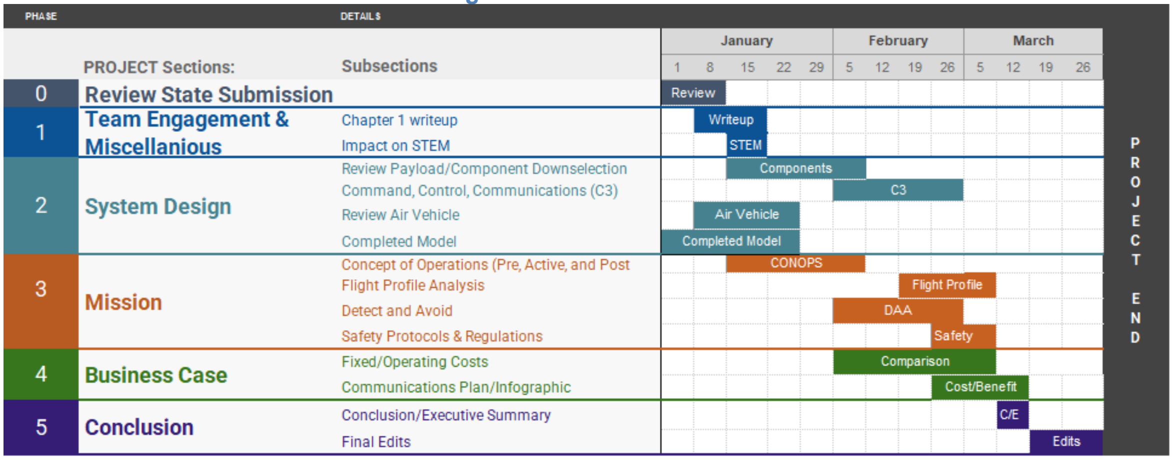
Figure 1: Engineering Design Process



2.2 Project Plan

The team decided to have a clear schedule for assignments to ensure productivity. At the beginning of the challenge, milestone dates were set based on prior experience, and the challenge's point allotment per section. For example, chapter two was worked on first because the information found in that section was instrumental in completing other sections. Returning team members met with all the mentors prior to the challenge release to create a plan of action for assignments. Figure 2: Gantt Chart demonstrates the iterative process used in all aspects of design which meant that despite working on one specific aspect of the notebook all other parts were also being considered. For example, when deciding on the sensors and materials used on Icarus; quality, price, mission applicability and compatibility with the CONOPS section were considered.

Figure 2: Gantt Chart



2.3 Subsystems

2.3.1 Air Vehicle

Conceptual Design Phase

The RamJets followed the downselection process detailed in 2.1 Engineering Design Process to efficiently select the airframe of the UAV. For the conceptual design, the team used the following constraints derived from the challenge statement.

One Engine Out - The team would judge airframes based on the design's ability to sustain flight and land safely with the loss of one engine which increases the redundancy of Icarus, a paramount safety objective.

Flight Time - The challenge statement requires at least a 30-minute flight time. Additionally, the team would look to maximize flight time and area coverage as per the requirements in 3.1 Concept of Operations.

Cruising Speed - A cruising speed of 17 m/s was chosen as it maximizes data quality from sensors and fuel efficiency (Qi Pan, 2018). If the selected airframe is not fuel efficient at 17 m/s, overall efficiency would be impacted.

Weight - The challenge states the design must be a small unmanned aerial system (sUAS), which according to FAA Part 107.3, cannot weigh more than 25 kg (FAA, 2023). Additionally, the military allows soldiers to carry up to 25.4 kg (Modern War Institute, 2017). Thus, all support equipment the hiker may need, any tools for assembly, and the entire gross weight of the aircraft before launch needs to be less than 25 kg. Icarus has a net payload (including all sensors and C3 devices) of 6.466 kg as mentioned in 2.3.3 Payload and 3.3.1 Detect and Avoid. The team selected sensors before any airframe down selection to prioritize an airframe built to carry the needed sensor weight. The team would look to minimize weight, allowing the airframe to weigh approximately 4.5 kg creating ample room for support equipment.

Cruising Altitude - During any wildfire scenario, a Fire Traffic Area (FTA) is erected 5 nmi radially around the fire and extends at least 762 meters above ground level (AGL) (NWCG, PMS 505). Sensors found in 2.3.3 Payload operate best 50m above the tree canopy with a maximum ideal sensing range of 120 m. For the sake of fulfilling both criteria in all environments, the cruising altitude will be a function of the tree canopy height:

Cruising Altitude Above Tree Canopy = Tree Height (m) + 50m

If Tree Canopy Height > 70m, Cruising Altitude = 120m

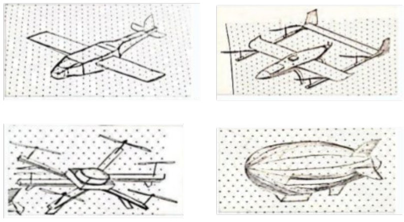
Table 1: Airframe Conceptual Downselection shows the downselection of plausible airframe types. Every requirement that an airframe meets is marked with a green ‘Y’. Requirements that are not met are marked with a light red ‘N’ and eliminated from further consideration using AND Gate Boolean logic. If one requirement is not met, the design is eliminated from further evaluation. Requirements that are marked with a gray ‘X’ represent conditions that are no longer under consideration as prior requirements are not met.

Table 1: Airframe Conceptual Downselection

Airframe	One Engine Out	Minimum 30-minute flight time	Operate at 17m/s Cruising Speed	<4.5 kg Empty Weight	Carry 6.466 kg Payload	Operate at 120 m altitude
Fixed Wing	Y	Y	Y	Y	Y	Y
Hybrid Fixed Wing	Y	Y	Y	Y	Y	Y
Multicopter	Y	Y	Y	Y	Y	Y
Lighter Than Air	Y	Y	Y	Y	Y	Y
Helicopter	N	X	X	X	X	X
Tandem Rotor Helicopter	Y	Y	Y	N	X	X

Following the conceptual design downselection, the fixed wing, hybrid fixed wing, multicopter, and lighter-than-air airframes were all viable options for this mission and would advance to the preliminary design phase. Refer to Figure 3: Airframe Conceptual Downselection for the airframe conceptual sketches.

Figure 3: Airframe Conceptual Downselection



Preliminary Design Phase

In the preliminary design phase, the team further researched the requirements for the UAV and selected an airframe for the final design phase. Table 2: Airframe Preliminary Downselection shows the downselection of the remaining airframes using the following requirements:

Cost: Airframes in the preliminary stage would be downselected based on their cost. The team wanted to ensure fixed costs fell under $100,000. This estimate ensures Icarus remains reasonably cost-effective.

Breakdown: The challenge statement requires a UAV and all supporting equipment to fit within the required small duffle (detailed later in 2.6 Final Design Drawings) **711 mm x 406 mm x 305 mm** in size. Because of this, designs must be able to break down or fold into smaller parts to conserve space and be easily assembled on the field.

Graceful Landing: Having a graceful landing is important to preserve the health of the environment and the structural integrity of Icarus in variable terrain so that it may be used for multiple missions. If Icarus needed to crash into a net or be caught to land, that could cause damage to the airframe or Launch Recovery Element (LRE) that would harm Icarus for future flights.

Passive Lift: An important factor emphasized in the challenge statement is the high flight duration during an active fire scenario and the ability to cover large areas during pre- and post-fire missions. Passive lift is an additional lift gained simply by moving. This makes any airframe that benefits from passive lift intrinsically more viable as it would be able to fly longer and cover more area due to the decreased fuel consumption by the motors.

Table 2: Airframe Preliminary Downselection

Airframe	Under $100,000	Breakdown	Graceful Landing	Passive Lift
Fixed Wing	Y.	Y	N	X
Hybrid Fixed Wing	Y	Y	Y	Y
Multicopter	Y	Y	Y	N
Lighter Than Air	N	X	X	X

As the hybrid fixed wing was the only design to meet all criteria, it was selected and fixed wing, multicopter, and lighter than air were all eliminated as determined in Table 2: Airframe Preliminary Downselection. The team then had to investigate the three specific types: Tail sitter, convertiplane, and dual system. The team then established additional requirements for this downselection shown in Table 3: Hybrid Fixed Wing Preliminary Downselection.

Multi-Use Propeller: As hybrid fixed wing aircraft always have Vertical Takeoff and Landing (VTOL) capabilities, the team would look for airframe types that used the same propeller for VTOL and horizontal flight. This is essential as having idle propellers used only during certain portions of flight adds unnecessary weight. Decreasing the amount of unnecessary weight increases the fuel economy immensely because the motors must exert less energy to propel Icarus.

Design Simplicity: The team would use this design philosophy to designs that would work; but had features that created great complexity, added too many parts, or overall increased the weight too much. This requirement follows the principle of Occam's razor later defined in 2.4 Lessons Learned.

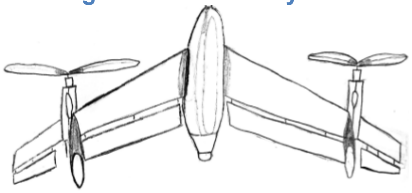
Table 3: Hybrid Fixed Wing Preliminary Downselection

Airframe	Multi Use Propeller	Design Simplicity
Tail Sitter	Y	Y
Convertiplane	Y	N
Dual System	N	X

Overall, a tail sitter design would be the best fit for the challenge due to its reduced weight while maintaining a simple design. Refer to Figure 4: Preliminary Sketch.

Final Detailed Design: The national challenge included more specific design requirements for the size and weight of the UAV. For the state challenge, the team had a UAV with a wingspan greater than three meters that had great difficulties breaking down to fit size constraints. With the addition of specific size dimensions, the team had to restart the conceptual phase, as per the engineering design process. The team made many engineering decisions based on the size and weight of the UAV. For example, the team redesigned the UAV interior to allow all payload and C3 equipment to fit within the main body. This reduced size and allowed the UAV to break down more easily.

Figure 4: Preliminary Sketch



Another major change made from the teams' state submission was the elimination of a sensor gimbal. The addition of the gimbal significantly decreased flight time and area covered because of its poor aerodynamic qualities and its weight. This decision was made using the RamJets' custom engineering design process and the principle of Occam's Razor.

Fuselage: The four main options for a fuselage are truss, geodetic, monocoque, and semi-monocoque. The truss fuselage is typically used in small-engine aircraft and is made out of steel or aluminum tubing (Paramount Business Jets, 2022). Geodetic fuselages use cross weaving that creates a strong airframe with sufficient space for payload in the center (Barnes Wallace Foundation, 2023). However, geodetic framing is very complex for a UAV of Icarus' size. Monocoque construction uses stressed skin to support loads from every direction. While it does allow large areas of the fuselage to be covered with minimal support, they are not very durable because the sides can become easily deformed (Flightstudy, 2023). Semi-monocoque provides aspects of truss and monocoque to create great strength. However, semi-monocoque is primarily used in larger aluminum-based aircraft (Aerospace News, 2021). Icarus utilizes a **truss fuselage** due to the lightweight yet strong features.

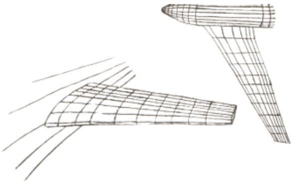
Wing Design: The team compared the different wing shapes: Rectangular, elliptical, tapered, delta, trapezoidal, ogive, swept-back, forward-swept, and variable swept. The RamJets took great inspiration from the pictured UAV in Figure 5: Project Valkyrie.

Figure 5: Project Valkyrie

Delta, trapezoidal, and ogive wings often fail to produce sufficient lift for slow-moving drones, leading them to be removed from further consideration. Forward-swept wings create great maneuverability but are very unstable in flight and create a significant amount of stress on the wing root. Variable-swept wings change the angle between the wing and the fuselage at different flight speeds to maximize flight performance. Variable-swept wings can be eliminated using Occam's Razor, detailed in 2.4 Lessons Learned, as their design is far too complex for the design of Icarus as well as great amounts of moving parts. This leaves the team swept back, rectangular, elliptical, and tapered.

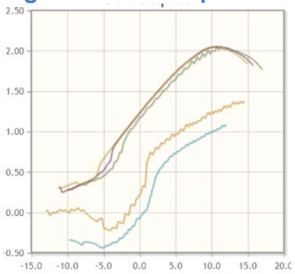
Rectangular wings are not efficient because of their high induced drag when compared to the remaining wing types and were eliminated from consideration. Elliptical wings are aerodynamically efficient but have poor stall tendencies due to the equal amount of lift being applied at every portion of the wing. Tapered wings require a larger wingspan due to the wing area tapering off over a distance. This would make it very difficult for Icarus to fit within the given dimensions. Many tail sitter UAVs use a swept-back wing design as it allows the UAV to balance on the wings for takeoff and landing. Swept-back wings are great at reducing induced drag and are less prone to violent, sudden wind gusts during an active fire. Thus, **swept-back wings** – seen in Figure 6: Swept-Back Wings Sketch - would be great for Icarus as they allow a platform for takeoff and landing while greatly reducing drag and performing well in wind. (Aerocorner, 2023).

Figure 6: Swept-Back Wings Sketch



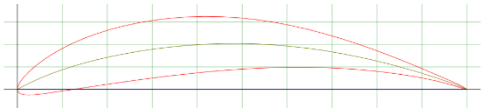
Airfoil: When researching airfoils, the team looked for airfoils with high lift to reduce the required wing size. Using the Illinois Airfoil Database, the team found the Chuch Hollinger CH 10-48-13 airfoil. This airfoil offers a larger chamber for a greater amount of lift. This airfoil still offers a relatively high thickness creating strength on the wing (UIUC Airfoil Data Site, 2023). Figure

Figure 7: CL v. Alpha



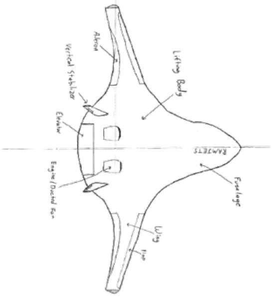
7: CL v. Alpha and Figure 8: Airfoil Plot show the CL at varying AoAs and the shape of the airfoil respectively.

Figure 8: Airfoil Plot



The RamJets researched blended-wing aircraft bodies to further reduce the size and weight of Icarus, a method of designing aircraft bodies such that the fuselage portion also creates lift. This was done primarily to ensure Icarus fits within the given size requirement. Aircraft with blended-wing bodies are less stable because they lack a distinct empennage (Wikipedia, 2023). To avoid the instability of a flying wing, the RamJets selected a **hybrid blended wing** design, as pictured in Figure 9: Hybrid Blended Wing Sketch. This wing design adds great aerodynamic efficiency without sacrificing stability. It is a newer design used by entities like NASA and Boeing to reduce aerodynamic drag by around 30%, fuel consumption by 50%, and increase flight time by around 50% (Airforce Technology, 2023).

Figure 9: Hybrid Blended Wing Sketch



Integration with payload and C3 was the paramount objective when determining the exact dimensions of the airframe. When modeling the airframe, the RamJets started by finding the most space-efficient layout for the sensors chosen in 2.3.3 Payload, then creating an airfoil-like shape around them. The RamJets then utilized the 3D sketch feature to create guidelines for a loft between the payload airfoil and the Chuch Hollinger CH 10-48-13 airfoil selected above. By using a hybrid blended wing aircraft, wingspan was reduced, easing Icarus' ability to fit in the required duffle bag size. See Figure 10: Airframe Payload Sketches for a visual representation. To show the RamJets' effective utilization of the hybrid blended wing airframe type, the team ran a flow simulation on the SolidWorks model. This allowed the analysis of the effect of Bernoulli's Principle; an increase in the speed of a fluid occurs simultaneously with a decrease in pressure on the airframe body. The results of this simulation can be seen in Figure 11: Flow Simulation. The top image is the top view and the bottom is the bottom view. Darker colors indicate lower air pressure, thus there is lower pressure on the top which generates lift.

Figure 10: Airframe Payload Sketches

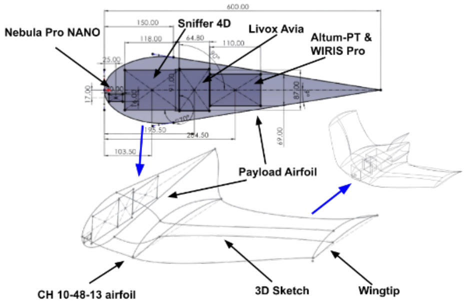
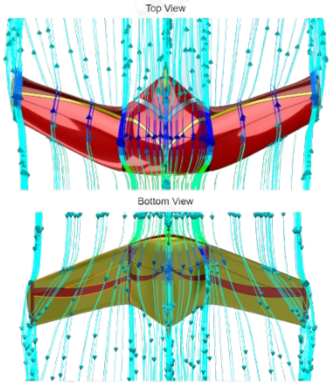


Figure 11: Flow Simulation



The aspect ratio greatly affects fuel and aerodynamic efficiency as well as wing size. Since the challenge places a great concern on size, a low aspect ratio is critical to reduce the wingspan and overall size. The RamJets chose an aspect ratio of **five**, which is low but does not create extreme amounts of drag (Nassise, 2023). Additionally, greater maneuverability would allow Icarus to effectively take off and land in small areas of dense foliage.

Wing Area: The modern lift equation was used shown in Figure 12: Modern Lift Equation.

Figure 12: Modern Lift Equation

$$Lift = \frac{Coefficient\ of\ Lift \times Density \times Wing\ Area \times Velocity^2}{2}$$

First, the team looked to estimate the weight of the UAV before construction. All components create a weight of 6.466 kg. Assuming the UAV could be created under an empty weight of 4.5 kg, the entire UAV with sensors weighed 10.966 kg.

Lift force, or just lift, was found by subtracting the applied thrust force from the engine from the force of gravity using a mass of 10.966 kg. The vertical thrust force was found using the equation seen in Figure 13: Vertical Thrust.

Figure 13: Vertical Thrust

$$Power\ =\ Force\ \times\ Velocity$$

To conserve power and increase flight time, the motors would not be using full throttle for the whole flight as cruising speed does not require full throttle. A lower throttle still provides about 4 kg worth of total thrust between both motors, a motor power of 384 W produces a velocity of 17 m/s, as mentioned earlier.

The team would need to maximize lift to minimize total weight which would require a large standard AoA of 7°. The CL was approximated to be 1.75 at a 7° AoA from *airfoiltools.com*. Density on a standard day at 120 m, the approximated maximum altitude, is about 1.225 kg/m^3. Manipulating this equation to solve for wing area gives a value of about 0.338 m^2**.**

Figure 14: Wingspan Calculations

$$P = Fv$$

$$F_T = \frac{P}{v} = \frac{384}{17}\sin(7^{\circ}) = 2.753$$

$$L = F_G - F_T = 10.966 \cdot 9.81 - 2.753 = 104.823$$

$$A = \frac{2L}{C \cdot \rho \cdot v^2} = \frac{2 \cdot 104.823}{1.75 \cdot 1.225 \cdot 17^2} = 0.338$$

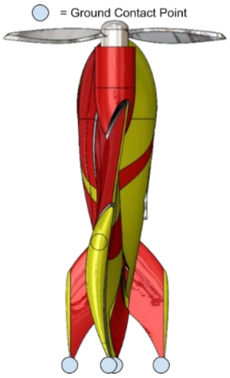
$$s = \sqrt{AR} = \sqrt{0.338 \cdot 5} = 1.301$$

The team would use wing geometry definitions from NASA (Tom Benson, 2023) to calculate the wingspan, which was 1.301 m. While this is larger than the minimum dimensions, the downselection process also includes methods of breaking down Icarus into components to fit within the required size. Figure 14: Wingspan Calculations are shown. Using basic parallelogram (wing shape) calculations gives a chord length of 0.260 m. Due to the continuous nature of the chord length from the fuselage to the wings of a hybrid blended body, these would act as general estimates for creating the model where the wing area would be found afterward to ensure flight.

Empennage: As the aircraft sits on the tail, there was a special consideration of how the empennage interacts with the ground. Swept back wings were selected as they create two contact points with the ground. The empennage fins would need to act as two additional contact points in a perpendicular axis. The fin took a swept-back shape like the wings near the center of the rear of the UAV, ensuring all contact points were coplanar. A single empennage is 20% more effective aerodynamically than a twin empennage while also decreasing weight (IRNet, 2022). Only **one empennage** is needed to provide stability about the vertical axis, which also adds two extra ground contact points, allowing Icarus to properly sit on its tail. This design is very common amongst tail sitters, an example can be seen in Figure 16: Empennage. Also see Figure 15: Ground Contact Point for a visual aid to how Icarus sits vertically while ready for takeoff.

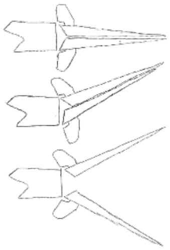
Figure 16: Empennage

Figure 15: Ground Contact Point



Flight Control Surfaces: Icarus does not include flaps, slats, or air brakes as they are too complex for Icarus' scale. However, typical flight controls like elevators, rudders, and ailerons are still needed. The first challenge the team investigated was retaining flight control during a vertical hover, where less airflow over the flight control surfaces undergoing yaw and roll would become more challenging. To combat this, the team spoke with mentor Robert Balmer regarding a split rudder design seen in Figure 17: Split Rudder Sketch. Split rudders placed behind the propeller would create the possibility for both yaw and roll during vertical hover, as it creates airflow that the split rudder would deflect. This creates the possibility of yaw, pitch, and roll during vertical flight as well as acting as a rudder and elevator in horizontal flight. Any corrections that may need to happen in vertical flight due to wind or takeoff and landing errors could now be accounted for with the use of the split rudder. During the horizontal flight, the **split rudder** paired with an aileron would allow for all three needed flight controls. All flight controls would be controlled using small servos. Since their use would only be turning the plane, their power output could be considered negligible.

Figure 17: Split Rudder Sketch



Powerplant: The team decided that Icarus' thrust would be controlled by a propeller (prop) as other types of motors are far too large, heavy, and power consuming for a small UAV. **Twin motor props** were selected as they generate greater thrust, enabling the UAV to carry heavier payloads and a larger battery, increasing flight time. Additionally, twin motors create redundancy in case of motor failure and take weight off the UAV nose (VikingAir, 2023).

Tail-sitters can be vectored or non-vectored. Vectored tail sitters can tilt their rotors independently to provide vectored thrust. However, this provides great complexity within the propellers (ArduPilot, 2023). **Non-vectored thrust** tail sitters were selected as they can land using a stall method, are less complex, and are lighter.

Two prop blades were selected as they allow for greater room in the UAV duffle bag and have more examples of their use in the industry of small UAVs. For instance, Project Valkyrie, as previously pictured in Figure 5: Project Valkyrie, uses two prop blades. Furthermore, Icarus will feature a smaller motor due to its size and more propeller blades would create inefficiencies in the motor.

A curved propeller, or a scimitar propeller, creates greater aerodynamic efficiency due to the reduction of drag (Hartzell, 2020). The faster the propellers rotate, the greater the chance of wave formation at the tip of the blades. **Scimitar propellers** were added as they reduce this formation and create a more aerodynamic UAV.

Motor: Electric motors are more efficient than gas-powered engines and require fewer moving parts (ALD, 2023) prompting the team to investigate electric motors. The team decided to use the MAD M6 IPE motor for the UAV as it features a high thrust ratio with low power consumption. The MAD M6 IPE has a diameter of 72 mm and weighs 250 g. With two **MAD M6 IPE** motors and scimitar propellers, Icarus has a lifting capability greater than the maximum weight, proven in motor flight tests (UnmannedRC, 2024). To ensure the motors can be placed in the UAV in an aerodynamic fashion, the team utilized nacelles on the front of each wing. This motor works best with a prop sized 0.406 m in diameter.

Battery: The batteries Icarus utilizes are one of the most important factors in determining flight time. The three primary types of batteries are Alkaline, Nickel Metal Hydride (NiMH), and Lithium-Ion Polymer (LIPO). Alkaline batteries are not rechargeable and provide too low voltage for the motors. NiMH batteries are rechargeable, but their total mAh capacity is much lower than LIPO per charge. Therefore, **LIPO** batteries were further considered. The **16000 mAh Lumenier LIPO** Battery can provide 16 Ah, weighs 1.190 kg, and is 182 mm x 74 mm x 40 mm which could easily fit in the main body of Icarus (GetFPV, 2023). Due to the small size, two batteries were positioned in the main body, doubling Icarus’ energy storage, hence greatly increasing flight time. Additionally, batteries added greater weight to the center fuselage creating a center of gravity (CG) more centered to the airframe and consistent across fire phases.

Exact Flight Speed: Now with all the specifications of Icarus' motor and power supply, a more accurate, ideal flight speed could be calculated. This was done utilizing an equation based on a fixed pitch propeller; the equation is seen in Figure 19: Flight Speed Equation (F. Settele, M. Bittner, 2020). An advanced ratio (J_{Prop}) of 0.7 is typically seen in motors and was used for simplicity (Franklin Harris, 2008). Icarus' motor is made for a propeller which has a diameter of 0.406 m (D_{Prop}). Rotations Per Minute (RPM) (N) is given as 1,862 at the throttle used for cruising flight as mentioned later in 3.2 Flight Profile Analysis. With all of this, flight speed can be calculated based on the propeller and motor in Figure 18: Flight Speed. It is seen that at the ideal RPM, Icarus has a flight speed of 17 m/s. This speed will not affect sensor data quality as the Altum-PT, which has the lowest optimal speed, is 17m/s. The throttle will be controlled by an electronic speed controller (ESC), an electronic circuit that controls and regulates the speed of an electric motor that will be placed between the Flight Management Unit (FMU) and the motor. This component has negligible power usage.

Figure 19: Flight Speed Equation

$$J_{\text{Prop}} = \frac{V \cdot 60}{D_{\text{Prop}} \cdot N}$$

Figure 18: Flight Speed

$$V = \frac{J \cdot D \cdot N}{60}$$

$$V = \frac{0.7 \cdot 0.406 \cdot (1862 \cdot 2)}{60} = 17.639$$

Materials: The airframe material must be strong and light to support the weight of the sensors and create a longer flight duration. Commonly used metals such as aluminum and titanium are heavy and not ideal for a smaller UAV. Carbon fiber has a high ultimate tensile strength at a lower density which would make it the best option for Icarus.

Normal carbon fiber still has too large of a density that would create an overweight UAV. A popular kind of carbon fiber is honeycomb core carbon fiber; used by SpaceX, a leading astronautical engineering company. The **DragonPlate Honeycomb core carbon fiber** has a density of 376 kg/m^3 with an estimated cost of $245 per kilogram (DragonPlate, 2023). Despite being more expensive than regular carbon fiber, honeycomb core carbon fiber is vital due to its significantly lower weight while maintaining ultimate tensile strength. To protect sensors and Icarus in the case of a crash landing, Icarus' expected contact points during landing features additional carbon fiber plating to create a reinforced section.

Detaching Body: Because of the wing area and wingspan required (See math above), Icarus must be able to break down into different components to fit in a **711 mm x 406 mm x 305 mm** duffle bag size, as per the challenge requirements. Strong connections between the wings, fuselage, and body sections are required to ensure that the wings and fuselage do not detach during flight. This connection method should also be reusable; methods like glue or welding will not be considered.

Connection methods include bolted connections, latches, bayonet connections, and snap-fit connections. While bolted connections are considered the strongest, they greatly increase assembly time while adding more weight to the UAV. Latches quicken the assembly time process but create a risk in their strength when holding together the UAV. Bayonet connections would be very difficult to properly operate due to their need to rotate. Snap-fit connections are slightly weaker than bolted connections but create great simplicity when assembling the UAV. Moreover, multiple snap-fit connection points would create plenty of strength to hold the body together if all points were held still in three dimensions. These connection methods are seen in modern-day UAVs like the Lynx VTOL Drone, a small agricultural monitoring UAV (Lynx VTOL, 2024).

Therefore, **snap-fit** connections will be selected. There will be two snap-fit connections. Having multiple connections for each wing is important as it significantly increases the amount of force the snap-fit connections can handle throughout the flight. To assist in attaching the wings are two rods that disallow movement along the vertical and lateral axis to ensure structural integrity. A complete view of the rods and clamps is seen in Figure 21: Wing Attachment. In addition, the empennage follows a similar connection method with two guide rails and a clamp seen in Figure 20: Empennage Attachment. Inside the rods, electrical connections can be found to allow for operating flight controls and motors. To ensure that these connections will remain stable in flight and that they do not add any unnecessary stress to the airframe, the RamJets performed a stress analysis of a simplified version of the airframe. The RamJets first used information on the DragonPlate Honeycomb core carbon fiber website to create a custom material, then ran a Von Mises stress analysis to see if the airframe could withstand up to 150% of the limit load of the aircraft, as is the standard for Boeing's destructive tests (Gunter, 2024). Results are shown in Figure 22: Stress Analysis. Red indicates instability, thus while the connections between the wings and body are under some strain, the lack of any bright red portions means that Icarus has an infinite life cycle.

Figure 21: Wing Attachment

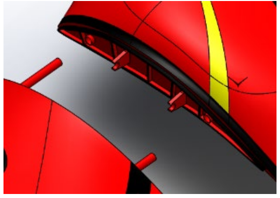


Figure 20: Empennage Attachment

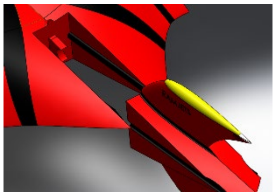
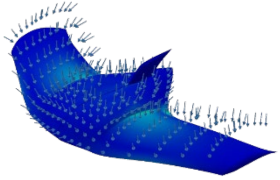


Figure 22: Stress Analysis



To have access to the fuselage to change sensors and batteries, a detachable cover plate allows access to the center fuselage, secured with an elastic-plastic latch. Since the plate is not encountering any airflow, it can stay attached with simple connection methods without the risk of detaching during flight. This will easily allow all sensors to be interchanged during pre-departure at the Mission Component Element Ground Control Station (MCE GCS).

Color Scheme: Red and yellow are commonly used in emergency settings to display emergency conditions. If Icarus were to ever crash land, a red-yellow color scheme would make the UAV easily visible for recovery. Finally, Icarus' top side is red compared to the bottom side being yellow for quick distinction between the top and bottom of parts when assembling the UAV. This difference in color scheme, along with the decal placed on the top and bottom of Icarus, allows the LRE to easily determine orientation from the ground.

VTOL Platform: In 3.1 Concept of Operations, a landing and takeoff platform is described to maintain takeoff and landing in the rough terrain that could be present at the wildfire location. This platform would need to be lightweight and small to conserve weight and space in the duffle bag of the UAV while being large enough to hold Icarus' four contact points. The platform would need to level in some way to create an even surface for takeoff up to a certain degree of terrain.

To manually level the platform, there would need to be threaded rods joined through the platform that can freely move at the bottom to ensure the cross-section of the rods fit through the platform. Threaded rods are inserted through the side of the platform to ensure Icarus never collides with them upon landing. Stakes can be drilled into the ground to allow proper strength with threaded rods attached to ball joints secured on the stakes. Utilizing the same Carbon Fiber used in the airframe, the team created a rectangular landing platform utilizing the distance between Icarus' contact points creating room for 20% error, which can be seen in Figure 23: Final Platform. Using known weight and cost, the platform itself would weigh 0.945 kg and would cost $274.38. The platform can then fold at the middle to easily fit in the required duffle bag. Using four 0.61 m rods with a 109 kg load capacity (EngineersEdge, 2024), the landing platform can allow for great clearance while holding Icarus.

Figure 24: Final Platform

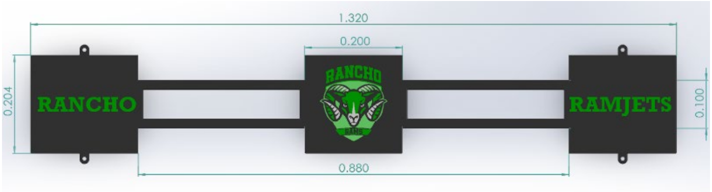
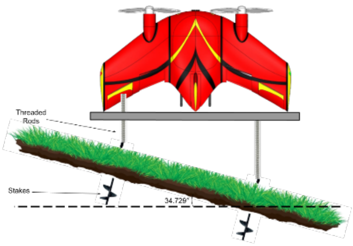


Figure 23: Final Platform Design



With the dimensions of the platform, the angle can remain level at 34.729°.

A demonstration of this platform can be seen in Figure 24: Final Platform Design. The total weight of the platform and components is 2.293 kg.

Table 4: Air Vehicle Components shows a completed list of components used in the air vehicle.

Table 4: Air Vehicle Components

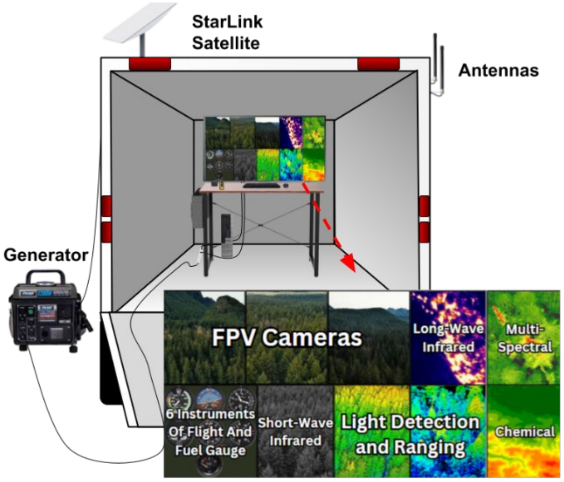
Air Vehicle	Dimensions (mm)	Unit Weight (kg)	Quantity	Total Weight (kg)	Total Cost ($)
Air Frame	See 2.3.1	4.146	1	4.146	1,016
Lumenier Lipo Battery	182 x 74 x 40	1.190	2	2.380	340
MAD M6 IPE	72 (Diameter) x 25.5	0.250	2	0.500	230
Prop	Diameter: 406	0.050	2	0.100	190
Electronic Speed Controller	-	0.011	2	0.022	20
Servo	23 x 12.2 x 29	0.009	6	0.054	12
Navigation Lights	-	0.014	4	0.057	6
Total				**7.259**	**$1,814**

2.3.2 Command, Control, and Communications (C3) Selection

To ensure regulations with FAA Part 107 are met, along with creating a safer mission with multiple redundancies for commanding the UAV, a semi-autonomous approach for Icarus was developed. Autonomous flight allows for greater operational efficiency and improved flight control. However, the risk of failure in the UAV's autopilot software and hardware systems, which could lead to losing the UAV entirely, made it necessary to have a control element monitor the UAV's position and take over command of the aircraft when needed. This is also known as a Human-In-The-Loop (HITL) system. The **MCE GCS** is the trailer-mounted system where the **MCE** communicates with **Airspace Management (ASM)** and actively monitors the UAV while it autonomously flies in a predetermined flight path (UAV Ground Control Station, 2023). ASM monitors, regulates, and controls the airspace in which Icarus flies. Thus, the MCE must maintain communication with the ASM throughout the flight. During the fire monitoring phase of a wildfire, the MCE GCS must be at a location near the fire coordinating efforts, to ensure current data on the area monitored is given and should also have access to complete Line of Sight (LOS) with the UAV through the entire mission. A direct hardwire connection can be established between the MCE GCS into the fire response coordination and control center to allow sensor data from Icarus to be directly presented to the fire response. Additionally, the MCE GCS could serve as the landing site for the UAV after it completes its mission, decreasing overall turnaround time for the next mission.

MCE GCS Layout: The layout of the control room where the MCE resides and actively monitors the UAV is detailed in Figure 25: Control Room Layout. The mobility of a trailer allows for the MCE GCS to travel to different mission locations. The total GCS components are: Keyboard (1), Mouse (1), Joystick (1), Monitor (1), Fuel Tank (1), Starlink Satellite System (1), Generator (1) and Antenna (2). A fuel tank will be needed to fuel the gas generator, providing power to antennas, a monitor, and Starlink Satellite.

Figure 25: Control Room Layout



Monitor Display: The monitor in the MCE GCS allows the MCE to see the data from the UAVs sensor's and respond accordingly. On the left side of the display, the six instruments of flight, which provide airspeed, altitude, heading, vertical speed, and turn direction, will be shown to the MCE through information from Inertial Measurement Units (IMUs) on the Pixhawk 6X, an included system component mentioned later in this section. Fuel status will be displayed as well, and a warning will automatically appear on the monitor when the UAV has less than 20% of fuel. In the middle, DAA sensors will be displayed, providing the MCE 360° real-time awareness of the UAVs surroundings, described in detail in 3.3.1 Detect and Avoid and enabling the MCE to control the UAV when necessary. On the right, information from payload sensors is presented. The MCE will check this section of the display to ensure mission data is being collected throughout the entire flight.

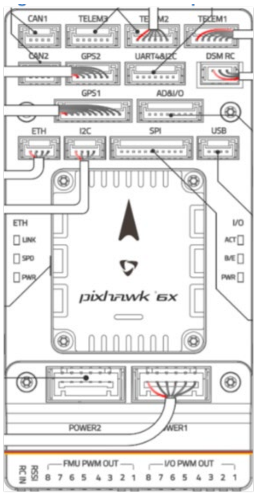
The **LRE** will travel to the predesignated takeoff location equipped with a **LRE GCS** to control Icarus during takeoff and ascent. This is due to changes in aircraft orientation when ascending for takeoff, as noted in 2.3.1 Air Vehicle. Furthermore, performing takeoff and landing is simpler when within Visual Line of Sight (VLOS). The LRE GCS must be lightweight and meet the 5-mile communication range requirement while being able to display flight telemetry information and first-person view (FPV) imagery with minimal communication latency. The **SIYI MK15,** pictured in Figure 26: LRE GCS, was selected due to its range of 9.3 miles with only 180 ms of latency and 850 g weight (SIYI MK1, 2023). Therefore, there are two separate ground control stations in the Icarus C3 system; the MCE GCS which is the larger trailer-based station where the MCE monitors Icarus during the mission and the LRE GCS which is the smaller handheld GCS that allows the LRE to control the UAV during takeoff.

Figure 26: LRE GCS

UAV Components for Navigation and Data Collection: The Flight Controller Unit (FCU) enables autonomous operations by utilizing a compatible flight path software to dictate Icarus's direction of flight. Computations for following the flight path occur in the FMU, a unit inside of the FCU. IMUs in the flight controller collect precise positional data from the UAV to accurately monitor Icarus's position in its flight path. Doing so allows the UAV to orient autonomously in conditions that may threaten its stability, ensuring fire monitoring equipment is capturing desired areas (Flight Controller Explained, 2023). Thus, the team recognized the flight controller's ability to support the UAV.

After further research, the **Holybro Pixhawk 6X** (Pixhawk 6X, 2023) was selected as Icarus' FCU. Integration with the open-ended **PX4** autopilot software system allows the MCE to have command over the UAV when necessary (What is PX4?, 2023). Three IMUs and two barometers on separate electrical buses provide multiple redundancies for identifying the aircraft's flight characteristics. These are components that come included on the Pixhawk 6X, but the flight controller also has inputs for sensors, global positioning systems, and telemetry shown in Figure 27: Pixhawk Inputs. Furthermore, the Pixhawk 6X has an integrated multiplexer (Mux) where inputs from various sensors are collected and multiplexed together, where the information is relayed to a radio transceiver, described later in the section.

Figure 27: Pixhawk Inputs

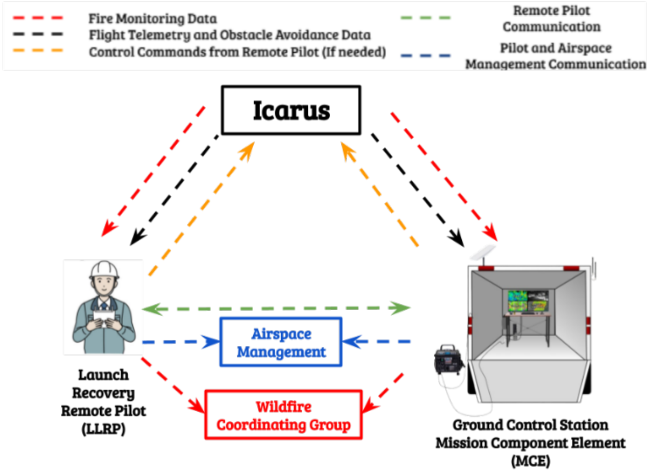


To avoid non-cooperative obstacles in the flight path, which is later detailed in 3.3.1 Detect and Avoid, the PX4 autopilot system requires a companion computer to make appropriate changes to the flight path. The RamJets selected the **Raspberry Pi Zero 2** for its companion computer as it is compatible with the PixHawk system and has a quad-core 64-bit ARM Cortex-A53 processor (Raspberry Pi Zero 2 W, 2023). Furthermore, for there to be communication between the companion computer, FMU, and both GCSs the RamJets selected **Micro Air Vehicle (MAV) Link software** as it is also compatible with the FMU and sends messages with low latency (Vision-Based Obstacle Avoidance for Small Drone using Monocular Camera, 2023) ((Path Planning Protocol (Trajectory Interface), 2023)). MAVLink is used in communication between both GCSs and Icarus in addition to intercommunication between sensors and subsystems in the UAV. MAVLink is also used to transfer data regarding aircraft position and orientation (MAVLink Developer Guide, 2023).

In combination, these three components enable a HITL system, where the MCE actively monitors Icarus while the autopilot system controls Icarus.

Communications with MCE: The mission-phase of the flight requires communication to occur at a range of at least five miles in real time to ensure that data collection displays are live and Icarus is responsive to control data from the MCE. Satellite Communications (SATCOM), would be ineffective in this operational scenario because of high latency and additional heavy equipment required for its operation (Why is Satellite Latency High?, 2023). Thus, the team found it beneficial to have complete Radio Line-Of-Sight (RLOS) communications where there will be direct point-to-point communication between the control elements and the UAV to ensure latency remains low during all phases of the flight. This can be seen in Figure 28: Communications System. Transceivers can be designed to operate different frequencies, such as Very High Frequency (VHF), which broadcasts in a frequency band of 30-300 MHz and Ultra High Frequency (UHF), which transmits at a frequency of 300 MHz-3 GHz (Understanding Transceivers: What is Transceiver and How Do They Work?, 2019). The largest consideration in determining which frequency was needed for the C3 system was bandwidth size, as all sensors on the UAV need to be transmitted at once and in real-time.

Figure 28: Communications System



Icarus and MCE GCS: The communications transmitted between Icarus and the control elements will be separated into low data rate and high data rate communication pathways. Low data rate components transmit command and control (C2) information and DAA sensor data needed for the control elements to pilot the UAV. This data link will be known as the **Aviate Communications Link.** High data rate components are additional payload sensors for wildfire monitoring and/or data collection, which will be called the **Payload Data Communications Link.** Thus, the RamJets created two separate radio communications systems pathways to decrease overall bandwidth required for a single transceiver, ensuring commercial transceivers are available, and add redundancy in communications between control elements and aircraft.

To select an appropriate radio transceiver, a frequency band was found that could support the sensors on Icarus. The bandwidth and total data rate required by onboard sensors was determined through the Nyquist formula, which provides the maximum data rate based on the frequency bandwidth. In the formula shown below, the value C represents the total data rate of the sensors in megabits per second (Mbps), the value M represents the total number of signal levels, and B is the frequency bandwidth in MHz needed to transmit the given data rate. The team incorporated typical binary signaling, where binary signals only have two possible values (0 and 1) which resulted in the M value equaling two (Noise, Data Rate and Frequency Bandwidth, 2023), (Binary Signal, 2023).

$$C = 2B \log2 (M)$$

When M equals two, the total data rate is double the bandwidth, as shown below.

$$C=2B$$

$$B=C2$$

Table 5: Sensor Data Budget shows the calculations done on each sensor, selections are discussed in 2.3.3 Payload and 3.3.1 Detect and Avoid.

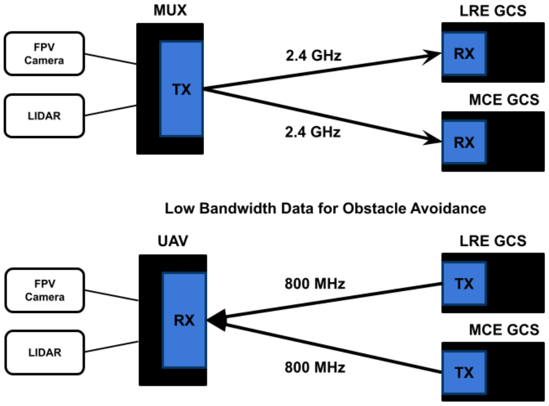
Table 5: Sensor Data Budget

Fire Monitoring	Total Data Rate (Megabits per second, C)	Frequency Bandwidth (MHz, B)
Livox Avia	7.68	3.84
WIRIS Pro	4.50	2.25
SCD30	0.10	0.05
Sniffer 4D	64.00	32.00
Total	**76.28**	**38.14**
DAA		
SF/30 D LiDAR	8.32	4.16
640CSX SWIR	0.35	0.18
Nebula Pro Nano (3)	1.04	0.52
Total	**9.71**	**4.86**

Aviate Communications Link: Telemetry data, which consists of a combination of IMUs on the Pixhawk 6X and DAA sensors found onboard the UAV, are needed to aviate and navigate the aircraft when it is being manually controlled by the control elements. These sensors form the core unit of the UAV, non-negotiable items that must be always on Icarus. A radio transceiver component needs to have a bandwidth and data rate larger than DAA sensors listed above. IMUs bandwidth was negligible and was therefore not considered in calculations. As with all other components on the UAV, this transceiver must be capable of integrating into a size, weight, and power constrained aircraft.

Component: The **FDM-6600** radio transceiver supplies a 15 km (9.32 miles) communication range with transmission and receiving bandwidths fitted for the needs of the communications system as seen in Figure 29: Radio Communications for Obstacle Avoidance. A transceiver is a combination of a Transmitter (TX) and receiver (RX). The 2.4 GHz frequency channel from the IWAVE FDM-6600 transceiver is used to transmit the high data rate telemetry, system health status, and DAA sensor data (Discussed in 3.3.1 Detect and Avoid) from the UAV to the GCSs. The 800 MHz frequency channel is utilized to transmit the low data rate C2 information from the GCSs to the UAV (IFLY: FDM-6600, 2023). This pathway will be utilized if the MCE requires manual control over the UAV. Additionally, the FDM-6600 transceivers are extremely lightweight at 50g. The FDM-6600 transceiver installed in the UAV is also in the MCE GCS.

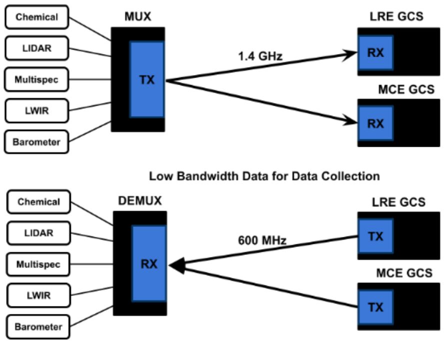
Figure 29: Radio Communications for Obstacle Avoidance



Payload Data Communications Link: Data solely from payload sensors will be transmitted through this pathway and sent to control elements. Additionally, the firefighting group will be sent the payload data information through hardwire connections from the MCE GCS and/or the cloud. Control elements that wish to control the payload sensors will also utilize this pathway. Furthermore, the challenge requires the LRE to be able to receive information pertaining to data collection.

Component: The **FDM-6680** radio transceiver has a larger data rate than the FDM-6600 at 120 Mbps (IWAVE: FDM-6680, 2023), which is suitable for the fire monitoring sensors that require a higher data rate at a combined 113.66 Mbps, as seen in Table 5: Sensor Data Budget. The 1.4 GHz frequency channel on the IWAVE FDM-6680 was used to transmit the high data rate mission sensor data from the UAV to the GCSs while the 600 MHz frequency channel was employed to transmit the low data rate C2 information on the data collection sensors from the GCSs to the UAV, as seen in Figure 30: Radio Communications for Data Collection. Weighing only 60 g and with a range of 15 km (9.32 miles), this transceiver also meets the criteria of a communication range of at least five miles. The FDM-6680 transceiver installed in the UAV is also located in the MCE GCS. Additionally, as the

Figure 30: Radio Communications for Data Collection



frequency ranges for the two transceivers differ, radio interference will not occur. A handheld transceiver, also known as a Walkie-Talkie, operating at the VHF range, is suitable for person-to-person communications as it is portable and works effectively in short-range. These frequencies will be utilized for the mission that pertains to the challenge:

ASM = 118.000 to 136.975 MHz

MCE/LRE = Unique frequency that is available

Control Elements and ASM Communication: For the control elements to communicate with ASM, the **Yaesu FTA 450L** is specifically designed to broadcast in the 118 to 136.975 MHz frequency range (Yaesu FTA-450L, 2023). While Icarus is in the fire monitoring/data collection phase of the mission, any shift in control commands or changes outside of the predetermined flight plan will be communicated by the MCE or LRE to ASM, depending on whoever is controlling the UAV. Two of these VHF transceivers are needed, one for each control element.

MCE and LRE: The **Dewalt DXFRS800** is a VHF handheld transceiver used by the MCE and the LRE to communicate with each other. A radio frequency that is available in the surrounding area will be used to ensure there is no interference. The LRE will check communications before the mission begins, as detailed in 3.1 Concept of Operations.

By having two handheld transceivers for each control element, it ensures redundancy in the case a transceiver malfunctions during the mission.

Antenna: The antenna selected must match the bandwidth from the transceivers while being lightweight enough to be put on the UAV. The Southwest 4G LTE Cellular Omni Antenna meets the frequency bands required for the transceivers and only weighs 0.31kg. (4G LTE Cellular Omni Antenna, 2024) Two onboard the UAV and two at the MCE GCS, one for the FDM-6600 and the other for the FDM-6680, are needed. In terms of placement on the UAV they are underside near the trailing edge of the main body facing backwards. This helps with CG, flight stability, and aerodynamics.

Starlink: To broadcast Icarus' fire monitoring data to all firefighting groups in the region, a Starlink satellite dish will be on the MCE GCS to connect the payload data to a cloud service.

Payload data not being sent in real-time will be stored on a two terabyte **Secure Digital Card (SD Card)**. Data on an SD Card can be read by any device via physical insertion of the SD Card. The UAV will have one SD Card as two terabytes of storage is sufficient for each mission. This also adds redundancy in the case of communication loss where fire monitoring/data collection sensors are no longer able to transmit to the MCE GCS as seen in 3.3.2 Lost Link Protocol, as information can still be recovered after mission completion.

Data Compression: As there are a multitude of sensors collecting data and gathering information of the UAVs surroundings, it is imperative to include components for compressing data from the UAV to the MCE to lessen the bandwidth required for sending the information through the UAV to GCS radio link, detailed earlier in the section.

Encoders: Greatly compresses video data by converting it into formats that require less storage. H.264 and H.265 video compression is most used, with compression ratios of 2000:1 and 4000:1 for H.264 and H.265 respectively (H.254 Profiles, 2023). The **Z3 Technology Full 4K Encoder** was selected**,** which allows for this compression to take place anywhere and without the need for a computer on Icarus. The encoder will be used to compress video from the three FPV cameras and two short-wave infrared (SWIR) sensors. The encoder can only compress two video streams, therefore three are needed. Being 60 g, this would not severely impact the weight constraint of the design. As the encoder compresses the video data to where it cannot be displayed, a decoder was necessary at the MCE GCS. The **Z3 Technology Full 4K Decoder** was added at the MCE GCS, which is manufactured by the same company.

Multiplexing: Combines multiple streams of data into a single output (What Does a Multiplexer Do?, 2023). **Demultiplexing** is a method of separating a single data signal into multiple outputs (Demultiplexer: What is it?, 2023). This kind of data transmission simplifies communication between the MCE GCS and UAV as it is transferred as a single signal. The Mux that will be used is integrated into the previously mentioned Pixhawk 6X and the demultiplexer (deMux) is the **Intersil DG406DYZ** which also functions as a Mux (IC Components, DG406DYZ, 2023). The DG406DYZ is a 1:16 deMux and 16:1 Mux that will exist on the UAV and in the MCE GCS in combination with the Mux present in the Pixhawk 6X. The LRE GCS includes the built-in feature of multiplexing and demultiplexing.

Table 6: Air Vehicle C3 Components (below) describes all C3 components physically on Icarus. Remaining GCS components are listed in Table 7: MCE GCS Components (below).

Table 6: Air Vehicle C3 Components

Air Vehicle C3 Components	Cost ($)	Unit Weight (kg)	Quantity	Total Weight (kg)	Total Cost ($)
PixHawk 6X	384	0.074	1	0.074	384
FDM-6680 Transceiver	1,750	0.03	1	0.03	1,750
FDM-6600 Transceiver	750	0.01	1	0.01	750
Z3 Technology Encoder	1,100	0.06	3	0.18	3,300
Intersil DG406DYZ	18	0.06	2	0.12	35
Southwest Antennas	140	0.342	2	0.684	280
Micro SD Card	22	0.018	1	0.018	22
Totals				**1.116**	**$6,522**

Table 7: MCE GCS Components

GCS Components	Unit cost ($)	Quantity	Total Cost ($)	UAS Components	Unit cost	Quantity	Total Cost ($)
FDM-6680	1,750	2	3,500	Keyboard	11	1	11
FDM-6600	750	2	1,500	Mouse	5	1	5
SIYI MK15	429	1	429	Joystick	23	1	23
Z3 Decoder	1,000	3	3,000	Monitor	80	1	80
Intersil Encoder	18	1	18	Battery Charger	150	1	150
Trailer	5,000	1	5,000	FourTrax Recon	4,800	1	4,800
Southwest Antennas	140	2	280	Generator	180	1	180
Yaesu Radio	235	1	235	Starlink Satellite System	600	1	600
Desktop	878	1	878	Pix4D Capture	0	1	0
Dewalt Radio	75	1	75	PX4 Autopilot	0	1	0
Gas Tank	671	1	671	SLAM	0	1	0
Total							**$21,435**

DAA Sensors: The two control elements must be prepared to take command of the aircraft and avoid the obstacle safely ahead of time. This requires situational awareness of the UAV's surrounding environment, which is achieved using sensors. A minimum range requirement was established at 170 meters, allowing the MCE enough time to adjust the flight by 10 seconds for a non-moving obstacle, based on the UAV cruising speed of 17 meters per second. The team researched a broad spectrum of these sensors as many exist. The following obstacle detection sensors were researched:

Radio Detection and Ranging (RADAR) dispatches electromagnetic radio waves which get reflected from an object to the sensor for detection. The sensor then receives the camera object's characteristics such as its location, shape, and its overall velocity. (How Do Radars Work?, 2023). Though the range of Radar is substantial the weight of this sensor is too great. Thus, the team eliminated RADAR from DAA sensor selection.

Infrared (IR) motion sensors use heat signatures to detect an object's location and its temperature (Understanding Infrared Sensor: Role in Safety & Security, 2023). Like RADAR, they emit rays to an object and reflect to the sensor, measuring the temperature of the object and displaying its position. However, there is little information on the market concerning the range of IR sensors. They are compatible with Simultaneous Localization and Mapping (SLAM), an important machine learning algorithm that is detailed in 3.3.1 Detect and Avoid, but does not measure at high accuracy in remote locations (Investigation of Widely Used SLAM Sensors

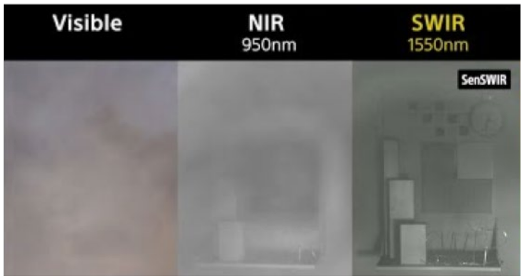
Using Analytical Hierarchy Process, 2023). Therefore, the IR sensors were eliminated from the team's consideration.

LiDAR sensors emit a pulse of light into the environment and gathers the depth of surrounding objects by measuring the time it takes for each individual light point to reflect to it, with an extremely high degree of accuracy and speed (Synopsis, 2023). As a result, SLAM works best with LiDAR. (What is UAV LiDAR?, 2022). Multiple LiDAR sensors were found to be suitable in weight for the design. Thus, LiDAR was selected to be a detection sensor on Icarus.

FPV video-transmitting camera greatly increases the pilot's awareness of the UAVs surroundings (What is FPV?, 2023). With a near-instantaneous radio communications link established, this provides the control elements with views and monitoring capabilities similar to that of a manned aircraft.

SWIR cameras are specific cameras in the thermal range capable of clearer display in smoky conditions (NASA, 2023). Figure 31: Camera Comparison in Smoke (SWIR Imaging Enhances Fire Zone Visibility: Visible Spectrum, NIR & LWIR Comparison, 2023) compares the difference in video quality between an FPV camera in the visible spectrum and a camera in the SWIR range. Their utility during an active fire allows SWIR cameras to proceed to the final selection process.

Figure 31: Camera Comparison in Smoke



2.3.3 Payload

Before selecting sensors, the team researched current methods of fire surveying before, during, and after fires and how sensor data can be used to create and improve dynamic fire modeling methods. To remotely monitor wildfires, there are various imaging and chemical sensor arrays that are commonly used either individually or in unison (Aqil & Na, 2023). The team consulted Justin Baxter, a drone specialist with the United States Forest Service, to determine criteria for sensor selection. According to Mr. Baxter, to create a system that helps firefighting groups more effectively than current ones, several different types of sensors should be added to gather a large quantity of data points. This allows firefighting groups to compile the data into a model with the use of algorithms. This model can then be used to accurately predict the movement of wildfires and possible locations of spot fires. In line with Mr. Baxter's advice, the goal of sensor selection was to choose sensors that gather all the required information with exceptional quality. Sensors were selected using the downselection process detailed in 2.1 Engineering Design Process.

Conceptual Design Phase

The following were considerations made throughout the sensor downselection.

Weight - As payload weight significantly affects UAV design, it was essential to keep the weight of sensors low for a small UAV.

Applicability - Sensors must be able to collect at least one, but preferably more, of the following pieces of data directed by the challenge: fuel type/amount, moisture levels, air boundary layer, vegetation health, and thermal information. During the active fire stage, fire edge information is also required. Furthermore, the overarching sensor data collection system must be of higher quality than other current fire monitoring systems. A list of fire-monitoring systems was used to compare against and ensure the sensors selected met or exceeded current methods for fire monitoring. This will be discussed in 3.1 Concept of Operations.

Power, size, and range - The listed factors were considered to determine the viability of the sensor. If a specific sensor was too large, used excessive power, or had too small of a range relative to other options it was eliminated.

The Field of View (FOV) was another factor, as incorporating sensors with narrow FOVs would result in a need for a greater number of sensors, increasing Icarus' weight. Only the horizontal FOV needs to be considered as the sensors will be placed facing downwards as discussed in 2.3.1 Air Vehicle.

LiDAR was previously described in 2.3.2 Command, Control, and Communications (C3) Selection. LiDAR creates highly detailed maps of the environment using hundreds of thousands of point scans per second. (Synopsis, 2024) LiDAR allows for direct measurement of forest structure, such as tree height, canopy density, and distribution of branches (Kane et al, 2022). LiDAR is also capable of creating a detailed image of the canopy and underlying brush, identifying what type of fuel is burning, and measuring the air boundary layer (Patrick Jantz, et. al., 2019) It also allows for the mapping of topography accurately which can be used in conjunction with wind speed to estimate the direction and speed of a fire. This information is invaluable to surveying lands in the pre-fire and post-fire missions to evaluate how fires change landscapes. While the challenge does not directly require this data, the addition of LiDAR would make Icarus better than current UAS systems. Furthermore, as there are no specific sub models, LiDAR advances directly to the final design phase.

Thermal cameras measure the infrared energy off objects at varying frequencies, converting that data into a digital image (How Do Thermal Cameras Work?, 2024). The varying sub models of infrared sensors depend on the frequency at which they measure. This is extremely useful in detecting objects that a typical RGB camera cannot capture, such as through dense smoke or at night, and to monitor different vegetation characteristics such as plant health that could be employed to predict the likelihood of a fire occurring. Furthermore, the varying thermal signature of objects could be used to distinguish hot spots where a fire is developing during pre-fire and post-fire or the fire edge during an active fire. (Teledyne FLIR Thermal Security Cameras Help Firefighters Monitor Wildfires in California, 2024) Therefore, thermal cameras proceed to the preliminary design phase.

RADAR sensors are capable of penetrating through tree canopy to measure the shapes and structures of the forest floor, similarly to LiDAR. (Review of Applications of Radar Remote Sensing in Agriculture, 2024) There are many specific types of RADAR, with Synthetic Aperture Radar (SAR) found to be most useful in relation to the challenge because of its ability to generate three-dimensional high-resolution images of the terrain, although it is relatively heavy compared to the other sensors. (Understanding the Different Types of Radar Systems and Their Use of Electromagnetic Waves, 2024). Despite this, RADAR proceeds to the preliminary design phase of the payload sensor selection in the form of SAR.

RGB cameras capture light in the visible spectrum, like what a human would see. RGB cameras generally weigh less than a kilogram with a relatively high FOV. RGB cameras can serve multiple purposes using algorithms that distinguish specific details. For example, RGB cameras could determine the fire edge if used in conjunction with an algorithm that looks for orange pixels in the media produced. They could also be used to determine what kind of fuel is burning if programmed to identify flora species. As there are no sub models of RGB cameras, they advance to the final design phase.

Chemical sensors collect data by allowing gases to diffuse through holes to react with an anode. The strength of the electrical signals created by this reaction is then analyzed to determine the specific gasses present (A Ivask, J. Bobacka*,* 2005). Concerning wildfires, chemical sensors are often used to identify carbon dioxide and Volatile Organic Compounds (VOC), which are released in significant amounts (Ciccioli et al, 2014). The ability to gather data about atmospheric conditions could be useful in several different ways, thus allowing chemical sensors to move onto the preliminary design phase.

Hygrometers detect humidity in the atmosphere by varying methods, discussed in the preliminary design phase (Woodford, 2023). Their inclusion would fulfill a part of the “Air boundary layer” data collection requisite. Thus, hygrometers move onto the preliminary design phase.

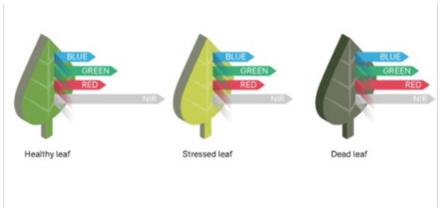
Altimeters measure altitude relative to sea level and are essential for the control elements to ensure Icarus is at the correct cruising altitude. The onboard Pixhawk 6X contains two barometers that measure the atmospheric pressure, which can be deduced to measuring altitude (“Altimeter,” n.d.-b). Therefore, another altimeter was not needed.

Preliminary Design Phase

Upon further research, the team learned that IR sensors are split between many categories based on the wavelength used, such as LWIR, Mid-Wave Infrared (MWIR), and SWIR. The team analyzed these individually.

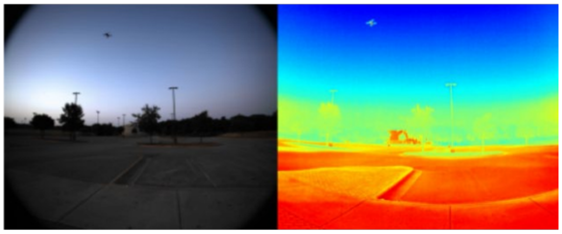
Multispectral sensors gather data by detecting up to 15 different wavelengths of IR light and are widely used in wildfire monitoring to detect plant health and vegetation. They use 5 different bands: red, green, blue, near-infrared (NIR) and red-edge bands. Depending on the health of the vegetation, the level of reflection of said bands varies. The variations of reflection in vegetation are shown in Figure 32: Bands and Vegetation Health. As multispectral sensors combine the benefits of multiple IR ranges and can determine the moisture content of plants from a distance, multispectral sensors are extremely useful for vegetation analysis and move on to the final design phase.

Figure 32: Bands and Vegetation Health



LWIR sensors capture light in the 8 to 14 micrometer (μm) spectral range and are commonly called thermal cameras for their colored contrasts, as seen in Figure 33: Visible Vs. LWIR Camera. LWIR’s sharp contrasts in heat signatures make it highly beneficial for detecting fires. LWIR sensors have a range of up to 10 km and do not typically weigh more than 900 g (Infiniti, 2016). LWIR can measure the temperature of fuel and create a map of the fire edge. Thus, the LWIR sensor proceeds to the final design phase.

Figure 33: Visible Vs. LWIR Camera



MWIR sensors measure a 3.0 – 5.0 μm wavelength range. Like LWIR, MWIR sensors detect heat waves emitted. Unlike LWIR, however, MWIR lacks clarity through smoke, fog, or any other fire-like conditions and is significantly more efficient indoors where there is a lack of solar radiation (Axiom, 2023). Therefore, MWIR sensors were eliminated.

SWIR sensors were previously mentioned in 2.3.2 Command, Control, and Communications (C3) Selection. In terms of fire monitoring, they detect light waves which can monitor vegetation health and moisture levels by detecting biomass, nitrogen levels, and stress factors (NASA: Reflected NIR Waves, 2010). However, bands in the multispectral range already account for the wavelength these sensors measure, so SWIR was eliminated.

SAR produces imagery by recording how long it takes for radio waves produced by the sensor to travel back. High-resolution images developed by the SAR device can penetrate through smoke and clouds (What is Synthetic Aperture Radar, n.d.). UAVSAR are SAR systems that are deployed on UAVs. However, very few were light enough to be considered on the UAV and were extremely expensive. The team decided that the benefits of SAR, such as seeing through smoke, were found in other sensors that were lighter in weight. Therefore, SAR was eliminated from selection.

Chemical sensors are primarily designed to assess the chemical composition of either open-air or closed-air systems. As Icarus will be operating in an open-air system, closed-air system sensors are not viable and will be removed for further consideration. Open-air chemical sensors can measure the impact wildfires have on the environment by comparing the amount of carbon dioxide in the air before and after fires. They also can help determine what type of fuel is burning based on what VOCs are released (Sever, 2020). Furthermore, because VOCs are released when plants burn, they can be used to detect spot fires during the post-fire stage. Therefore, open-air chemical sensors proceeded to the final design phase.

Psychrometers are a form of hygrometer that are designed for measuring outdoor humidity. (Different Types Hygrometers Uses, 2024) Many were found to be lightweight and small. Furthermore, they are typically more accurate than electrical hygrometers and are utilized in medical and industrial industries. As a psychrometer would be the most accurate method to measure humidity, they proceeded to the final design phase.

Final Design Phase

LiDAR will be used for its capability to create a detailed map of forest structure, topography, and underlying brush (Patrick Jantz, et. al., 2019). LiDAR will only be used during the pre- and post-fire missions as smoke will distort the laser scans sent by the sensor and affect image quality during active fire. The **Livox Avia** was selected because it has a weight of 498g and a 450 m range, while transmitting 240,000 points per second with triple-return support, meaning the same area is measured three times to create extremely accurate detail and depth measurement. This data is critical to creating an extremely detailed map of the surveyed area (Livox, 2023). The Livox Avia will be used during the pre and post-fire stages.

LWIR sensors are manufactured by many different companies, such as WIRIS and Livox. The **WIRIS Pro** has a maximum thermal reading temperature of 1500° C, suitable for spotting fires, and only weighs 480 g. In terms of pre-fire, the WIRIS Pro can detect and monitor areas that are smoldering, which are more prone to wildfires. During an active fire mission, thermal imagery would clearly outline the fire edge and is crucial for post-fire to identify hot spots. As a result, the WIRIS Pro was selected to be used for all three mission phases.

RGB cameras provide another viewpoint on the surrounding environment, capable of detecting dead vegetation before and after the fire as well as the fire edge during the active fire phase. The WIRIS Pro includes an RGB camera paired with the existing LWIR sensor to provide a detailed understanding of the fire. Thus, a standalone RGB camera was not required.

Multispectral sensors would be critical in vegetation analysis. The **Altum-PT** weighs 460 g and can measure 120 m away from the fire while being compact at 110 mm x 80 mm x 69 mm. The employment of multispectral and its different bands, mentioned in the conceptual phase, creates an understanding of plant health, type, and amount. This is important in determining whether an area is more prone to burn. In terms of pre-fire, this information can help predict where a fire is more likely to occur and/or spread. For post-fire, it can monitor the extent of vegetation damage. Therefore, the Altum-PT was selected.

Chemical sensors were important in determining fuel types, levels of combustible particulates, and levels of VOCs. The Sniffer 4D, SPS30, and SCD30 were of particular interest. The Sniffer 4D measures combustible particles, VOCs, humidity, wind velocity, and direction (Soarability, Sniffer 4D - drone-based Gas Detection System 2023). The Sniffer 4D can create a digital map of combustible particulate concentrations, as well as monitor levels of specific VOCs to estimate fuel types consumed. The SCD30 measures CO2, humidity, and ambient air pressure which makes it valuable for all fire stages. The SPS30 measures combustible particles, VOCs, and humidity. These abilities are already present in the Sniffer 4D and SCD30. Thus, the team decided to use the **SCD 30** and the **Sniffer 4D**.

Hygrometers were eliminated as the SCD 30, a chemical sensor, already measures humidity.

Optimal Altitude Range: During the active-fire mission stage, operating at an altitude that is accommodating to the operating temperature range of applicable payload and DAA sensors is crucial to ensuring sensor health. Of the sensors used during the active fire mission, the Altum PT and Livox Avia have the lowest maximum operating temperature of 50°C. Consequently, Icarus must operate at an adequate distance from the fire to ensure the safety of the sensors during the active-fire mission stage. FAA Part § 107.51 FRA CFR Section 107.51 states that Icarus remains less than 400 feet (121.92 meters) above structures, and the aircraft must operate between 50 and 121.92 meters above the treeline to receive an accurate output from payload sensors (FAA § 107.51, 2023). Unpredictable updrafts must be accounted for to maintain compliance with the FAA. Therefore, to accommodate for the operating temperature ranges of these sensors, the team determined that Icarus must operate at least 50 meters above the tree line during the active-fire mission stage (Gas Temp&Smoke Height, 2023).

Table 8: Payload Sensor Specifications is displayed below. All sensors will be used for every mission stage, except for the Livox Avia during the active fire stage.

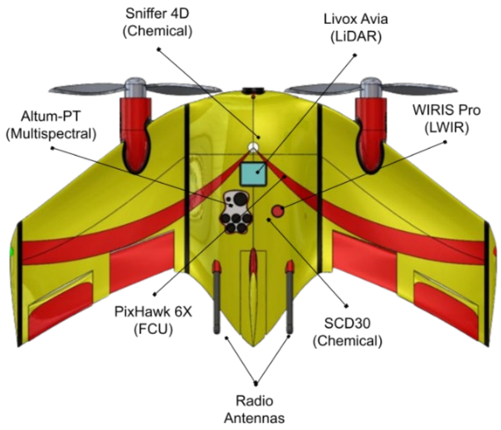
Table 8: Payload Sensor Specifications

Payload Sensors	Dimensions (mm)	Unit Weight (kg)	Quantity	Total Weight (kg)	Total Cost ($)
Sniffer 4D	157 x 103 x 87	0.5	1	0.5	8,920
SCD30	35 x 23 x 7	0.0034	1	0.0034	70
Altum-PT	110 x 80 x 69	0.577	1	0.577	15,995
WIRIS Pro	83 x 85 x 68	0.43	1	0.43	14,950
PixHawk 6X Barometer	52.4 x 103.4 x 16.7	*	1	*	*
Livox AVIA*	91 x 61.2 x 64.8	0.498	1	0.498	1,600
Total				**2.0084**	**$41,535**

*Only used during pre/post-fire missions

Integration with C3: As mentioned in 2.3.2 Command, Control, and Communications (C3) Selection, there is the Aviate Communication Link for onboard DAA sensor data and C2 information from the GCSs and the Payload Data Communications Link where mission data collection is transmitted and received. The bandwidth and data rate required by these sensors were calculated in 2.3.2 Command, Control, and Communications (C3) Selection to ensure the transceivers utilized accommodated both pathways. Figure 34: Payload Sensor Location displays the payload sensors on the underside of the UAV. The Altum-PT multispectral, Livox AVIA LiDAR, and WIRIS Pro LWIR. The Sniffer 4D is only required to have an air intake, thus there is a hole in the front of Icarus. Additionally, the Pixhawk 6X is fully encapsulated and SCD30 shares an air input with the Sniffer 4D, thus the arrows in the diagram only point to their location. The antenna is also seen, transmitting the information from Icarus to the control elements.

Figure 34: Payload Sensor Location



While it is beyond the scope of this challenge, the RamJets wanted to emphasize the versatility of how data given to firefighting groups can be used. With photogrammetry and machine learning, firefighting groups could use data provided by Icarus to create 3D maps, accurate to the centimeter, that display the exact conditions of a fire. These maps would be a vital tool to strategizing how to fight a fire and when making decisions that are based on the current state of the fire front.

2.4 Lessons Learned

SMARTER goals: The RamJets set SMARTER goals to increase efficiency and reduce time. “S” in SMARTER goals stands for specific short-term goals. “M” stands for measurable goals that can be quantified in the notebook’s context. “A” stands for achievable tasks where large assignments are broken into small tasks. “R” stands for relevant, realistic, and resourced tasks meant to impress more weight on certain goals. And “T” stands for time sensitivity when completing tasks. In many scenarios, the team found the importance of time management and that satisfying deadlines was a must. This became more important towards the end of the challenge when the business case was unable to be completed because the final flight characteristics were not finalized. Finally, the “E” and “R” are for evaluating and reviewing what has been accomplished and making any necessary improvements The team reassessed the state notebook submission and outlined improvements that needed to be made based on comments by the judges and team mentors. These goals were established due to flexible timeline standards set in previous years, where the team waited until there was a very short amount of time before the national notebook deadline to finish most of the revisions. The team would learn the effectiveness of SMARTER goals and how better time management and efficiency allows a more complete notebook and challenge solution.

Meetings: In previous years, the team would meet in a trusted teacher’s room at Rancho High School to accomplish work. With the retirement of the teacher this year, the RamJets had no room to meet in. To continue normal meetings, the team had to find a new teacher to organize meetings and, in some cases, meet at outside locations. The RamJets hosted many meetings throughout the course of this project and saw the significance of organization and proper accountability in completing assigned goals. When the team needed additional time to meet goals, they were able to organize meetings outside of regular in-person meetings at Rancho High School, such as libraries. Along with normal club meetings, the team also held mentor meetings where the RamJets realized the importance of preparing questions and planning to properly utilize the mentor’s time. The challenges faced this year taught a greater sense of planning ahead. Not only would the RamJets need to check with mentors for their availability, but they would also need to check with teachers who provided meeting times.

Engineering Design Process: In previous years, the team would typically change the design following the State submission. This created difficulties in communication between sections due to the lack of time. The team created a unique and custom Engineering Design Process in 2.1 Engineering Design Process as a basis for selection of UAS components. Instead of using an Engineering Design Process from another party that roughly outlines what the challenge calls for, the RamJets created a process that was tailored to their own needs and goals to guide them through system design. This allowed the efficient creation of Icarus without the need to go back and change components.

Occam's Razor: Occam's Razor is a concept where the simplest solution is often the best solution (Duignan, 2023). Many times, throughout the challenge, the RamJets looked for every possible and innovative solution. However, these often cause incredible struggles, consume large amounts of time, and increase the difficulty of the challenge. It was learned that the best solution to the challenge was not necessarily the most complex design, increasing the team's work efficiency. A notable use of Occam's Razor is seen in the selection of wing design, where variable-swept back wings were eliminated from selection because of the large number of moving parts needed, therefore, additional research was not needed on the product and team members could move on to other aspects of the wing design.

2.5 Component and Complete Flight Vehicle Weight and Balance

Weight Breakdown: The airframe weight was first calculated using *Volume x Density.* Icarus' Dragon Plate carbon fiber offers a thickness of 6 mm and a density of 0.000376 grams per cubic millimeter with the overall airframe volume being 11,027,255.3 mm^3 as provided by SolidWorks. This gives a formula of 11,027,255.3 mm^3 x 0.000376 g/mm^3 = 4,146 g or **4.146 kg**. Refer to Table 9: Weight Breakdown for additional component weight. The total weight for Payload sensors during each phase of the fire was calculated in 3.1 Concept of Operations. DAA and C3 sensors were found in 3.3.1 Detect and Avoid and 2.3.2 Command, Control, and Communications (C3) Selection, respectively. The SWIR sensors were added to the active fire payload sensors.

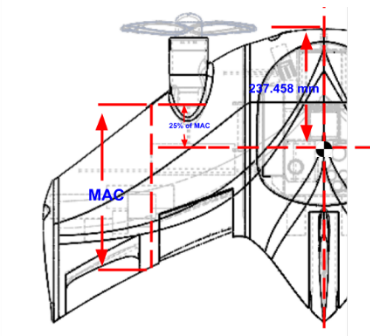
Table 9: Weight Breakdown

Section:	Pre/Post Fire Weight:	Active Fire Weight:
Airframe	7.259	7.259
C3	1.116	1.116
Payload	2.0084	1.5104
DAA	0.229	0.319
Total	**10.612**	**10.204**

Adding the weight given in the table with each fire phase gives the final weights of pre and post fire being **10.612 kg** and active fire being **10.204 kg**.

CG Analysis: Now that a weight breakdown was performed, CG could be calculated. According to one of the RamJets' mentors, Robert Balmer, the CG should be located at 25% of the Mean Aerodynamic Chord (MAC) to maximize aerodynamic performance. In Icarus' case, the MAC is in the middle of the wing since the chord length remains constant (RC Airplanes Simplified, 2023). Because Icarus has a constant chord length and sweep angle, the actual CG should resemble the CG represented below in Figure 35: Icarus MAC. This CG is the most aerodynamically stable point for Icarus, making Icarus naturally level in flight. Sensor removal will provide very little change to the CG between each phase. Originally, Icarus' batteries would have been on a track allowing them to move between 3 predetermined locations to ensure the same CG location every flight regardless of changes in what sensors Icarus would be equipped with during each flight phase. However, this was not done due to size constraints within the main payload body, and because of how little variance there was in the CG between flight phases.

Figure 35: Icarus MAC

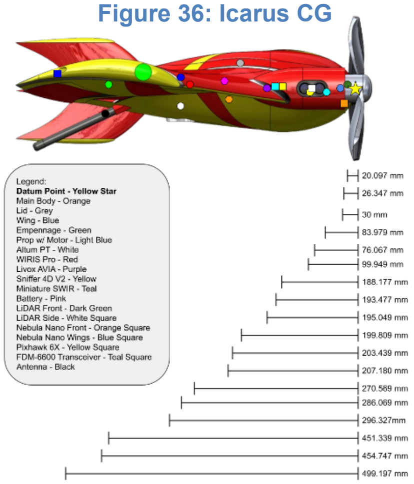


The datum point is considered the 0, 0, 0 coordinate when calculating CG. It is used as a reference to find how far away every component is using a set point. In Icarus' case, the datum point is the nose of the UAV.

The 25% MAC line is **237.458 mm** below the datum point, marked by the CG symbol in Figure 35: Icarus MAC. The desired CG lies at X=237.485 mm.

In terms of flight variability, CG remains constant during the whole flight; no components can move in flight. Unlike if liquid fuel was used, Icarus' batteries will not change the CG during flight as they are depleted and all of Icarus's payload sensors, DAA sensors, and C3 equipment have dedicated, fitted compartments.

Figure 36: Icarus CG



Using the datum point, weight and moment calculations were performed to find the CG of Icarus along the X and Y-axis; the Z-axis would be arranged so components are arranged symmetrically, creating a central CG. Moment is a weighted measurement of mass that increases as the distance from the datum point increases or mass increases. It is found by multiplying the weight of a certain component by its distance from the datum point on an axis. All of these moments are added together and then divided by the net weight, giving the distance of the CG from the datum point on that axis. Table 10: Pre/Post Fire CG **do not completely match previous weight breakdowns**. The datum point is marked by the yellow star in Figure 36: Icarus CG. Positive values are to the left and up of the datum point and negative values represent down from the datum point.

The CG for each phase of the fire could now be calculated, removing sensors between fire phases as needed. Refer to Table 10: Pre/Post Fire CG for these calculations. A diagram displaying the distance of each component from the datum point can be seen in Figure 36: Icarus CG. Note the ‘Y’ axis lengths are not shown due to their small size and difficulty presenting them on such a small scale. Pre and post fire share the same components and CG analysis.

Table 10: Pre/Post Fire CG

Item	Weight (Kg)	Length X (mm)	Length Y (mm)	Moment X (Kg*mm)	Moment Y (Kg*mm)
Main Body	1.549	203.439	-9.012	315.127	-13.960
Lid	0.214	199.809	47.788	42.759	10.227
Wings	2.192	296.327	15.928	649.549	34.914
Empennage	0.192	451.339	-0.622	86.657	-0.119
Prop w/ Motor	0.600	30.000	3.998	18.000	2.399
Wiris PRO	0.430	270.569	4.658	116.345	2.003
Livox Avia	0.468	195.049	0.038	91.283	0.018
Battery	2.380	207.180	13.000	493.088	30.940
Altum PT	0.577	286.069	-24.932	165.062	-14.386
Sniffer 4D	0.450	99.949	-2.512	44.977	-1.130
Nebula Nano Pro Front	0.0035	26.347	-32.739	0.092	-0.115
Nebula Nano Pro Wings	0.007	499.197	40.041	3.494	0.280
LiDAR Front	0.0315	20.097	9.489	0.633	0.299
LiDAR Sides	0.063	76.067	6.511	4.792	0.410
Pixhawk 6X	0.074	188.117	5.801	13.921	0.429
FDM-6600 Transceiver	0.050	193.447	5.131	9.672	0.257
FDM-6680 Transceiver	0.06	157.637	9.000	9.458	0.540
Antenna	0.684	454.747	-45.639	311.047	-31.217
Total	10.025			2375.957	21.789

$$CG_x = 2{,}375.957 / 10.025 = 237.003 \text{ mm}$$

$$CG_y = 21.789 / 10.025 = 2.173 \text{ mm}$$

Active fire shares similar components to pre and post fire. The only difference is in Active fire which includes the removal of the Livox AVIA as well as the addition of two Micro-SWIR 640CSX cameras. These sensors combined weigh 0.09 kg and have an 'X' and 'Y' distance of 83.979 mm and -7.492 mm respectively. This creates a new calculation weight of 9.647 kg, an 'X' moment of 2,292.232 kg*mm, and a 'Y' moment of 21.097 kg*mm. This gives the calculations below.

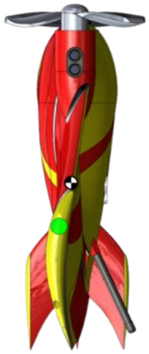
$$CG_x = 2{,}292.232 / 9.647 = 237.611 \text{ mm}$$

$$CG_y = 21.097 / 9.647 = 2.187 \text{ mm}$$

Following these calculations, the CG of Icarus during each flight phase was determined, which is shown in Figure 38: Final CG according to dimensions given by SolidWorks. From the diagram, the change in CG between the three fire phases is very minimal. These values are very similar to the calculated MAC CG. Figure 37: Vertical CG shows that Icarus' CG maintains stable flight characteristics through vertical flight.

Figure 38: Final CG

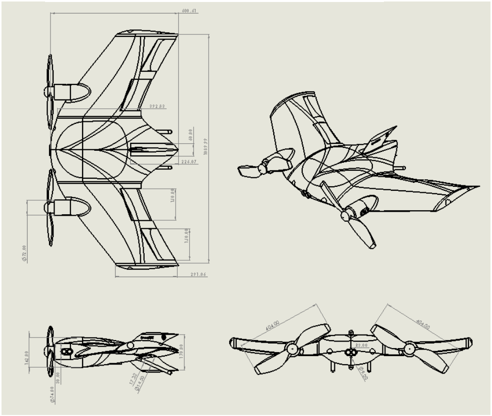
Figure 37: Vertical CG



2.6 Final Design Drawings

Refer to Figure 39: Icarus Dimensions for the completed dimensions of Icarus. Wingspan and wing chord dimensions are not the same as what was calculated in 2.3.1 Air Vehicle. However, the wing area is confirmed to be larger than needed in 3.2 Flight Profile Analysis. This means, Icarus' aspect ratio is slightly smaller than what was calculated, allowing greater UAV maneuverability. Figure 40: Body Dimensions are shown as proof that every sensor and the batteries can fit in their required slot.

Figure 39: Icarus Dimensions



It was additionally required to show that all needed features fit within the duffle bag dimensions of 711 mm x 406 mm x 305 mm. The duffle bag must include all components the LRE is responsible for carrying, aside from radios to communicate with ASM and the MCE. A complete list of said components can be seen in

Table 11: LRE Components. Note that the total air vehicle weight includes the SWIR sensor weight, which is only used in the active fire phase.

Figure 40: Body Dimensions

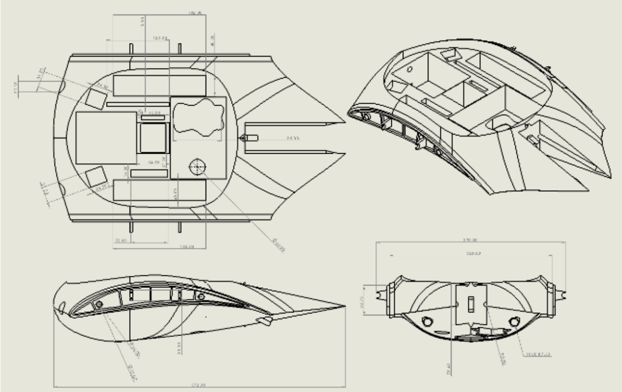


Table 11: LRE Components

LRE Components	Unit cost	Unit Weight	Quantity	Total Weight	Total Cost ($)
Air Vehicle			1	10.702	
Platform	274	0.95	1	0.95	274
Threaded Rod	2	0.10	4	0.21	8
Stakes	25	0.29	4	1.14	100
Assembly Drill	29	0.75	1	0.75	29
Extra Battery	170	1.190	1	1.190	170
Extra Prop	95	0.050	1	0.050	95
Protective Foam	20	1.00	4.402	4.402	88
Level	13	0.08	1	0.08	13
LRE GCS	449	0.85	1	0.85	449
Duffle Bag	90	2.63	1	2.63	90
Dewalt DXFRS800 Hand-Held Radio	75	0.42	1	0.42	75
Yaesu FTA-450L	235	0.41	1	0.41	235
Total				**23.640**	**$1,626**

All of Icarus' equipment, spare parts, and protective foam/shell inserts will be placed in a modified Ripstop Turnout Gear Bag. This bag is a heavy-duty duffle bag specifically made for firefighting groups. This custom bag will be modified to fit the exact size requirement given by the challenge. See Figure 41: Duffle Bag. With its protective exterior, Icarus should suffer no damage while being transported. This duffle bag has an empty weight of 2.63 kg. Using the remaining empty volume, the duffle bag would need 4.402 kg worth of protective foam.

Figure 41: Duffle Bag

Figure 42: Inside Duffel Bag shows all required components fitting in the required dimensions. Additionally, as per Table 11: LRE Components, the total weight of the components the LRE will carry is 23.640 kg, which is less than the 25 kg requirement set in 2.3.1 Air Vehicle. Components are separated by foam layers that can be removed to access parts while stopping components from colliding while implemented. In addition, the duffle bag contains an extra battery and extra propeller to increase redundancy in the case of damage. Foam layers are made to fit every component while being removed to allow access to all parts. Sensors, motors, and in-use batteries are arranged inside Icarus in their compartments to not take up any additional space. Finally, Figure 43: Exploded View shows Icarus' exploded view with all the components.

Figure 42: Inside Duffel Bag

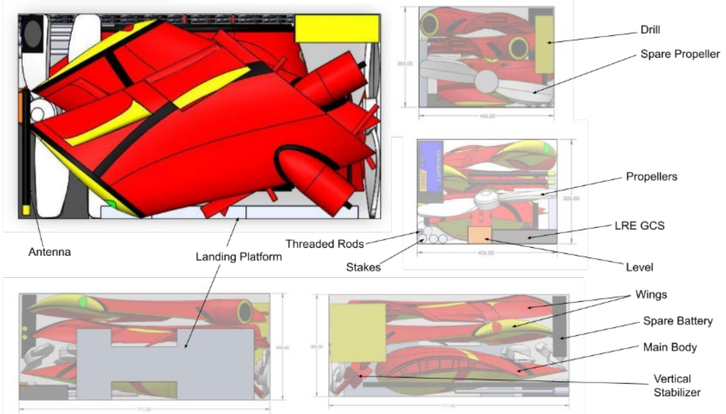


Figure 43: Exploded View

3. Missions

3.1 Concept of Operations

3.1.1 Pre-Fire

Pre-Mission Preparation

The MCE will establish a standing agreement with the ASM so that the enterprise can operate on a schedule as well as maintaining the ability to complete reactive tasking. A day before the mission, the power generator located on the MCE GCS will be loaded with gasoline. Upon arriving at the location, the MCE will request the ASM to activate airspace as mission requires on the day given weather conditions (wind direction and speed that will influence manned air traffic). The MCE will provide vertical limits based on the terrain and lateral constraints through flight planning.

Flight planning conducted by the MCE includes a 4 m by 4 m launch site that is as flat as possible and must include a 4 m by 4 m opening in the tree canopy. To ensure the LRE can monitor the data collection, per requirement by the challenge, the launch site must also support

RLOS with the LRE and UAV throughout the entire duration of the flight by being in elevated terrain, or there must be another location close to the launch site that can achieve RLOS. If even terrain is not possible, the LRE will be provided with a launch platform to provide stability to the UAV, as mentioned in 2.3.1 Air Vehicle. A power drill will be provided on-site for the landing platform to decrease assembly time. Optionally, a landing location near the MCE GCS with the same criteria as the launch site will achieve a quicker turnaround time. If a location cannot be found, the UAV will land at the same location where it launched, with the LRE controlling descent.

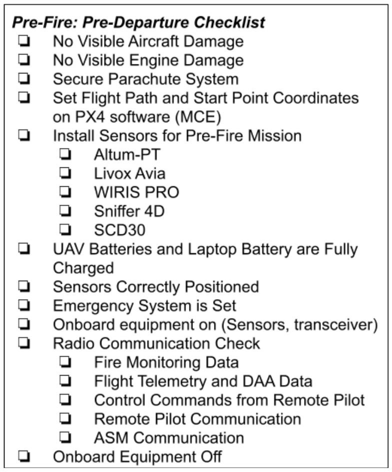
The MCE will translate the area desired by the firefighting group into a flight path through the **Pix4D CapturePro,** a flight planning software system that integrates with the PX4 autopilot software system Icarus uses.

Additionally, the cruising altitude is calculated utilizing the provided height of the treeline. The cruising altitude is set to 50 m. If obstacles require Icarus to fly higher than 70 meters, it will fly at an altitude of 120 m.

Mission Day

Upon approval, at 0600 hours on mission day, the LRE conducts the Pre-Departure Checklist as shown in Figure 44: Pre-Fire: Pre-Departure Checklist at the MCE GCS. The LRE secures the Pre-Fire assortment of data collection sensors into the UAV's fuselage and detaches the wings of the UAV. All UAV components, one spare propeller and a charged battery will be put into the duffle bag.

Figure 44: Pre-Fire: Pre-Departure Checklist



Pre-Fire: Pre-Departure Checklist

- ☐ No Visible Aircraft Damage
- ☐ No Visible Engine Damage
- ☐ Secure Parachute System
- ☐ Set Flight Path and Start Point Coordinates on PX4 software (MCE)
- ☐ Install Sensors for Pre-Fire Mission
  - ☐ Altum-PT
  - ☐ Livox Avia
  - ☐ WIRIS PRO
  - ☐ Sniffer 4D
  - ☐ SCD30
- ☐ UAV Batteries and Laptop Battery are Fully Charged
- ☐ Sensors Correctly Positioned
- ☐ Emergency System is Set
- ☐ Onboard equipment on (Sensors, transceiver)
- ☐ Radio Communication Check
  - ☐ Fire Monitoring Data
  - ☐ Flight Telemetry and DAA Data
  - ☐ Control Commands from Remote Pilot
  - ☐ Remote Pilot Communication
  - ☐ ASM Communication
- ☐ Onboard Equipment Off

Mobile Vehicle

To reach the launch site from the MCE GCS as quickly as possible, the LRE needs another vehicle that is smaller and can maneuver in tight areas. This brought the team to four-wheelers, specifically the **FourTrax Recon**, which can be carried with the UAV's duffle bag and the spare part on the back of the vehicle. The LRE will use the four-wheelers up to the point where the LRE cannot reach the launch site with the vehicle. From there, the LRE will walk to the launch site. If terrain is too difficult for the FourTrax Recon, the LRE will walk with the duffle bag the entire way. The gross weight of everything being carried by the LRE is 23.640 kg, which is less than the 25 kg max established in 2.3.1 Air Vehicle.

Arrival at Launch Site: Upon arrival, the LRE will assemble the launch pad and Icarus's airframe.

Step 1: (Necessary only when launching from rough terrain): LRE drills four stakes with a provided power drill to secure the landing platform to the ground and inserts threaded rods through the platform. The landing platform is installed with knowledge of cross-sectional winds to ensure Icarus has a safe takeoff and landing. The LRE will utilize a level to ensure the platform is even as they are adjusting. (3 minutes)

Step 2: Slide wings into respective slots, clamp them in, and ensure secureness (See Figure 20: Wing Attachment) use rails on the back of Icarus to slide the empennage on, clamp the empennage in, then ensure secureness (See Figure 21: Empennage Attachment). (3 Minutes)

Step 3: Communicate to MCE to confirm Icarus is ready, then deploy Icarus on the launch pad and follow the rest of the Pre-Flight Checklist shown in Figure 45: Pre-Fire: Pre-Flight (LRE). (4 minutes)

The design of the UAV enables a duffel bag to air in a time of only ten minutes. Sensors have already been pre-arranged inside the UAV prior to departure, and modularity allows for simple and tool-less attachments.

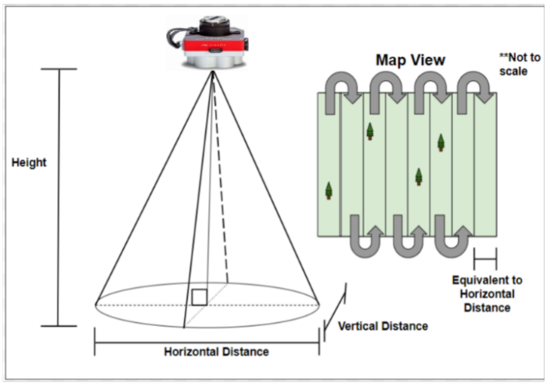
Figure 45: Pre-Fire: Pre-Flight (LRE)

Pre-Fire: Pre-Flight Checklist (LRE)
- ☐ Establish Crash Point Location in PX4 Autopilot
- ☐ Turn on Onboard Equipment (Sensors, Transceiver)
- ☐ Radio Communication Check
  - ☐ Fire Monitoring Data
  - ☐ Flight Telemetry and DAA Data
  - ☐ Control Commands from Remote Pilot
  - ☐ Remote Pilot Communication
  - ☐ ASM Communication
- ☐ Receive Takeoff Confirmation From ASM
- ☐ Propellers and Flight Controls Running
- ☐ Account for Wind Direction and Speed

Launch and Handover: When the desired cruising altitude is reached, the LRE orients the aircraft into conventional flight. The UAV then begins a loiter, where the MCE checks for radio communications and if control commands are responsive. The loiter should take no longer than one minute. Once the MCE confirms systems are optimal, the PX4 autopilot system is engaged, while the LRE remains for another five minutes in case an emergency landing is needed while the UAV is near the launch site. As mentioned above, the LRE then either remains at the launch site if they achieve RLOS or to another location specified by the flight planning.

To ensure consistent data from sensors is collected across the entire region, the flight path needs to be constructed using the sensor with the smallest FOV. Of the sensors Icarus is equipped with during the pre-fire mission, the Altum PT has the smallest horizontal FOV of 50°. A diagram showing the view given by the Altum PT along with an approximate flight path as an example can be seen below in Figure 46: Flight Path.

Figure 46: Flight Path



In its most basic definition, a flight path is a set of points overlaid onto a map or an environment that Icarus will follow in a certain order. There have been several proposed algorithms for how to generate these points and apps that can create a flight path given a region. Icarus will fly across the region parallel to one axis, move a certain distance as directed by the firefighting group to best accomplish mission goals. Because fixed-wing aircraft cannot make 90° instantaneous turns, Icarus will instead best approximate the path by following a semi-circle-like contour to turn 180° where the length of the turn is a derivative of the altitude and the smallest horizontal FOV. The process is repeated until the entire region is covered.

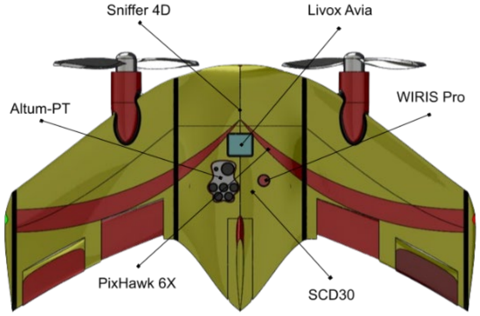
Data Gathering: Icarus's data-gathering sensors efficiently capture accurate data for the entire flight duration. There are multiple sensors gathering information for each required type of data (i.e. fuel type, fire edge, etc.), providing redundancy and ensuring the mission is still efficiently capturing data even if a sensor(s) becomes inoperable. Below, in Table 12: Pre-Fire Sensor Usage, there is an outline of everything being measured and how. For a full technical description of how each sensor accomplishes its respective task, see 2.3.3 Payload.

Table 12: Pre-Fire Sensor Usage

Sensor	Fuel Type/Amount	Moisture Levels	Air Boundary Layer	Thermal Information
Altum PT	Y	Y	N	Y
Livox Avia	Y	Y	N	N
WIRIS Pro	Y	N	N	Y
SCD30	N	N	Y	Y
PixHawk 6X Barometer	N	N	Y	N
Sniffer4D	Y	Y	Y	N

How Data is Measured: Sensors are secured in the fuselage of the UAV, as seen in Figure 47: Data Collection Sensor Measurement. The LiDAR, multispectral, and LWIR sensors will be focused directly on the ground as the UAV goes along the flight path, which is optimized to account for the FOV of these sensors. The Sniffer 4D and SCD 30 chemical sensor's probe will be facing out in front of the UAV where the air particles will be passing through.

Figure 47: Data Collection Sensor Measurement



Maximize Area Measured: Maximizing area measured was included as a criterion for the UAV airframe. Because of this, it was a significant factor throughout the entire design process. An example of a choice made exclusively for this reason was the elimination of the gimbal selected during the

State Challenge, as described in 2.3.1 Air Vehicle. Additionally, by utilizing the smallest horizontal FOV and previously established airspeed, analysis for the maximum area able to be covered was performed in 3.2 Flight Profile Analysis.

Comparison to Other Systems

The **Leica BLK2FLY** is a quadcopter with autonomous UAV scanning capabilities and a 5-camera obstacle avoidance system. Its current use cases include agricultural mapping and search and rescue using a single 360° LiDAR sensor with a maximum range of 25 m (BLK2FLY, 2023). Furthermore, the LiDAR payload sensor on Icarus has a triple return point rate of 240,000 points per second (pt/s) which results in a total of 720,000 pt/s compared to the LiDAR on BLK2FLY which is only 420,000 pt/s. Therefore, the imaging resolution is of higher quality in Icarus than BLK2FLY in terms of LiDAR. The BLK2FLY has a maximum flight time of 13 minutes, approximately 1/10 that of Icarus. Even accounting for the difference in energy capacity between the BLK2FLY and Icarus of 6Ah vs 32Ah, respectively, Icarus is still twice as efficient in terms of energy used for flight time, while carrying not only a LiDAR sensor but also a thermal, multispectral, two chemical sensors, and a comparable obstacle avoidance system. Lastly, the BLK2FLY can survey a maximum area of 0.004 km^2, considerably less than the 16.648 km^2 Icarus can survey, as discussed in 3.2 Flight Profile Analysis. The BLK2FLY costs $60,055 for the air vehicle with only LiDAR which does not include any ground support equipment.

The **Lynx VTOL** drone is a fixed wing agricultural drone capable of covering 4.5 km^2 in its two-hour flight time. Icarus again features greater flight time and greater area covered. The Lynx's agricultural monitoring utilizes the RedEdge-MX. This multispectral camera features a resolution of 1280 x 960 while Icarus has a better resolution of 2064 x 1544 offered by the Altum-PT (Srp Aero, 2024). Icarus is considerably better at agricultural monitoring than similar sized agricultural drones. The Lynx VTOL does not include LiDAR, thermal, or chemical sensors.

The **FVR-90** is a gas-powered airframe currently being used by the National Forest Service for wildfire monitoring. The FVR-90 can hold up to a 10 kg payload, has an 8-hour flight endurance, and utilizes the WESCAM MX gimbal to hold an electro-optical, IR, laser range finder, and/or an LP gas detector sensor. While comparable in sensor array and better in terms of flight time, the FVR-90 has an assembly time of over one hour compared to Icarus' rapid assembly of less than 10 minutes. The FVR 90 also has a 54 kg gross weight, which notably does not include the case, extra gas, or any GCS equipment required for operation which greatly limits the terrain in which the FVR can be launched from. Further limiting its versatility, the FVR-90 has a wingspan of 4.27 meters and a launch area of 50 m^2. Icarus has a total weight including the duffle bag and all accessories listed in 2.6 Final Design Drawings of 23.640 kg and a wingspan of 1.1 meters, ensuring ease of transport. Two people are required for the setup and operation of the FVR 90. After launch by a single LRE, Icarus is semi-autonomous, only requiring human interaction to ensure safe flight. While this UAV is in operations, the per unit price is not available, but the development of the FVR 90 cost over $1 billion (Maritime Executive, 2020), compared to Icarus' cost of $77,598 (see 4.1.2 Fixed Costs). Icarus is a more rugged system that is launched by one person and this ability to be deployed rapidly in an emergency makes it more suited for use by firefighting groups than the FVR 90.

In summary, Icarus fills the niche of rapid wildfire monitoring better than three of the most prominent, market available UAVs. Icarus' flight time of 2 hours and 18 minutes makes it able to survey more terrain than smaller UAVs like the BLK2FLY, whilst also maintaining the large payload and data-gathering potential of larger systems like the FVR 90. Once in flight, Icarus uses its advanced DAA sensors and flight path programming to sustain semi-autonomous flight, only requiring human intervention as a safety precaution during emergencies. Icarus is lightweight and rugged, allowing for deployment within a matter of moments in nearly any terrain by one person, with only a 16m^2 region required for launch, much smaller than the 50m^2 the FVR 90 requires. Icarus is the best wildfire management solution for firefighting groups.

Landing/Post-Mission: Upon completion of the flight path and data collection, the MCE will pilot Icarus to the landing site by the MCE GCS or an alternate landing location such as the launch site. The MCE or LRE will perform a stall maneuver for a vertical landing depending on the landing location. Once the MCE completes Icarus's landing, they will confirm landing to the ASM.

Upon the completion of the Pre-Fire Mission, the LRE will examine Icarus by following the checklist in Figure 48: Pre-Fire, Post-Mission Checklist (LRE). The batteries will then be charged up to 50% before moving to storage, damaged components will be replaced, and Icarus will be stored in preparation for the next mission.

Figure 48: Pre-Fire, Post-Mission Checklist (LRE)

Pre-Fire, Post Mission Checklist (LRE)

- ☐ No Visible Aircraft Damage
- ☐ No Visible Engine Damage
- ☐ All Parts/Sensors are Present
    - ☐ Altum-PT
    - ☐ Livox Avia (Pre and Post-Fire)
    - ☐ WIRIS PRO
    - ☐ Sniffer 4D
    - ☐ SCD30
- ☐ Check Battery Status

At MCE GCS:

- ☐ Charge Batteries
- ☐ Replace Damaged Components

Mission Debrief: When the LRE completes the Pre-Fire, Post-Mission Checklist, a mission debrief will be held between both control elements to discuss improvements on flight efficiency and safety. For instance, they will determine any changes in the risk matrix, delineated in 3.3.4 Regulations and

Additional Safety, where there may be increased likelihood or severity of an event, such as a one engine out condition, because of the mission. They will also write general information of the flight utilizing the flight log described in Figure 49: Flight Log. Anomalies would be defined as anytime when the UAVs autopilot system had to be disengaged and manual control took place except for avoiding an obstacle, which the MCE must always do. Comparisons will be made with previous flight logs to determine if there is a noticeable difference in any category, where the control elements must form a conclusion. Furthermore, any anomalies that occurred during the flight must be addressed. The MCE GCS will be equipped with a JEGS 85325 toolbox set for more extensive repairs to the UAV. Additional propellers, batteries, landing platform, and other necessary equipment will be stored in the trailer to ensure future missions may continue.

Figure 49: Flight Log

Flight Log (MCE)

Flight Time: ____________ mins

Power Consumption: ___________ kWh

Anomalies: __

Avg. Cruising Altitude: ____ m

Avg. Cruising Speed: ______ m/s

Distance Covered: ________ km

Fuel Remaining Post-Flight: _________ w

3.1.2 Active Fire

Pre-Mission - Preparation: As most of the protocols for aircraft operations during active wildfires have been dictated by the National Wildfire Coordinating Group (NWCG), the active-fire mission adheres to the NWCG standards for operation.

Figure 50: Active Fire, Pre-Departure Checklist

Active Fire, Pre-Departure Checklist (MCE)

- ☐ No Visible Aircraft Damage
- ☐ No Visible Engine Damage
- ☐ Autopilot Software Up to Date
- ☐ Install Sensors for Active Fire Mission
    - ☐ RedEdge-P
    - ☐ WIRIS PRO
    - ☐ Sniffer 4D
    - ☐ SCD30
- ☐ Fully Charged Battery
- ☐ Sensors Correctly Positioned
- ☐ Emergency System is Set
- ☐ Onboard Equipment on (Sensors, Transceiver)
- ☐ Radio Communication Check
    - ☐ Fire Monitoring Data
    - ☐ Flight Telemetry and DAA Data
    - ☐ Control Commands from Remote Pilot
    - ☐ Remote Pilot Communication
    - ☐ ASM Communication
- ☐ Onboard Equipment Off

The firefighting group will send the map of the region to be monitored by the UAV. Since the challenge specifies that there will be firefighting efforts in the region, the FAA will have issued a Temporary Flight Restriction (TFR), meaning all aircraft must receive prior approval to fly in the region. To ensure Icarus can fly within the TFR, the firefighting group will provide a Special Government Interest (SGI) for wildfire area monitoring (Temporary Flight Restrictions (TFRs), 2024). The flight plan formulated by the MCE will include both a launch site and landing site that follows the criteria listed in 3.1.1 Pre-Fire. The LRE will conduct the Pre-Departure Checklist as shown in Figure 50: Active Fire, Pre-Departure Checklist at the MCE GCS. The LRE will then travel to the launch location following procedures listed in 3.1.1 Pre-Fire. Upon arrival, they will complete the Pre-Flight checklist shown in Figure 45: Pre-Fire: Pre-Flight (LRE) and assemble the UAV in accordance with protocols in 3.1.1 Pre-Fire. After the Pre-Flight Checklist has been completed and communication between Icarus, the MCE GCS, and LRE has been confirmed, the mission continues.

It should be noted that during an active fire mission, standard day conditions are not guaranteed; there is a high likelihood of smoke due to the nature of the mission. Furthermore, because Icarus is an emergency response UAV, it may be deployed at any time of day including night. See 3.3.1 Detect and Avoid for how this affected the design of Icarus and 3.3.4 Regulations and Additional Safety to see compliance with national regulations.

Mission: For the active fire mission, Icarus must gather the same data as is required in the pre- and post-fire missions and monitor the current fire edge. Thus, the method from pre-fire and post-fire had to be modified as the environment monitored changes frequently. To further understand the problem, the team researched fire maps from several sources [National Oceanic and Atmospheric Administration (NOAA), United States Forest Service (USFS), National Interagency Fire Center (NIFC), etc.], existing algorithms, and proposed algorithm solutions (Moulay et al., 2021). Typical wildland fires have a defined edge and points of intensity, or “hot spots” spread sporadically around the edge of the fire, both inside and out. Excluding the hot spots, the area inside the fire contours is largely burnt, therefore it is redundant to scan the entire inner part of the fire continually (Oregon, 2017).

Icarus will utilize an algorithm like the PHOENIX Rapidfire (Sultan & Gökhan, 2022), that creates a flight path to initially cover the entire region given by the firefighting group but then alternates between two phases. During the first phase, Icarus uses a modified traveling salesman problem (TSP) algorithm, which takes a set of points as its input and outputs the shortest path to travel between all of them. This allows the UAV to find the shortest path between all the hot spots mapped in the initial scan, and then follow said path in its entirety. Once completed, a transition occurs to the second phase where Icarus traces the fire edge, while using data processing methods to provide estimates for the future behavior of the fire. Once the second phase is completed, the system reverts to phase one and continues the cycle until the battery is drained to the recommended or maximum usage, underscored in 4.1.1 Operating Costs. The time it takes to complete one cycle is determined by the size of the given region. The PX4 Autopilot system will receive all updates to the flight path from this algorithm and notify the MCE. If the MCE approves the update, Icarus will follow the new flight path. Furthermore, the 15 km communication range of the onboard transceivers allows Icarus to continuously monitor the fire edge beyond the 8 km range required by the challenge.

Data Gathering: Table 13: Active Fire Sensors display the data points collected by each sensor.

Table 13: Active Fire Sensors

Sensor	Fuel Type/Amount	Moisture Levels	Air Boundary Layer	Thermal Information	Fire Edge
Altum PT	Y	Y	N	Y	Y
WIRIS Pro	Y	N	N	Y	Y
SCD30	N	N	Y	Y	Y
PixHawk 6X Barometer	N	N	Y	N	N
Sniffer4D	Y	Y	Y	N	N

Maximizing Flight Time: The airframe design and component selection in 2.3 Subsystems takes into consideration maximizing flight time as a major criterion. For example, the combination of payload sensors had to be underneath a certain weight requirement set by the engineering design, aimed at creating a UAV that has a long amount of flight time. Furthermore, the battery decision was based on a weight to power capacity ratio ensuring the battery selected further helped increase flight time. Cruising speed was set under the maximum speed; therefore, throttle is lowered throughout most of the mission decreasing overall fuel consumption. These decisions resulted in a flight time much greater than the thirty minutes required by the challenge at over two hours during active fire, detailed in 3.2 Flight Profile Analysis.

Comparison with Other Systems: Discussed in 3.1.1 Pre-Fire.

Post-Mission: Refer to 3.1.1 Pre-Fire as protocols are like that of the landing in pre-fire, Figure 48: Pre-Fire, Post-Mission Checklist (LRE), denotes the checklist used by the LRE.

Mission Debrief: Refer to 3.1.1 Pre-Fire for the mission debrief and the flight log.

3.1.3 Post-Fire

Preparation: Due to the possibilities of a landslide, hot spots (re-ignition points), or flooding during post-fire, the UAV must urgently scan the environment before these events occur, alternative methods of receiving waivers for FAA Part 107 are needed. Recall in 3.1.2 Active Fire, to get permission from the ASM in a short time, TFR is needed with other approved firefighting aircraft and filing Notice to Airmen (NOTAM) with details of the time and place of operation. Then the MCE will confirm airspace deconfliction with the TFR-controlling party and send the flight plan with a request for mission approval to ASM. Flight planning and criteria for the launch site are described in 3.1.1 Pre-Fire.

Mission: Upon approval of the ASM, the LRE conducts the Pre-Departure Checklist shown in Figure 44: Pre-Fire: Pre-Departure Checklist at the MCE GCS and follows protocols in 3.1.1 Pre-Fire.

Pre-Mission Preparation: The same pre-mission procedures are utilized from Pre-Fire, see 3.1.1 Pre-Fire. The checklist conducted by the LRE is shown in Figure 45: Pre-Fire: Pre-Flight (LRE).

Maximizing Area Covered: Reasoning is detailed in 3.1.1 Pre-Fire.

Comparison with Other Systems: Discussed in 3.1.1 Pre-Fire

Data Coverage: In-depth sensor explanations are seen previously in 2.3.3 Payload. Table 12: Pre-Fire Sensor Usage show the same sensors as well as data requirements needed during post-fire.

Post-Mission: Control elements follow the same post-mission procedures as in 3.1.1 Pre-Fire.

3.2 Flight Profile Analysis

Icarus' max net weight occurs during pre-fire and post-fire at a weight of 10.612 kg as mentioned in 2.5 Component and Complete Flight Vehicle Weight and Balance. In 2.3.1 Air Vehicle, a net weight of 10.966 kg was used to calculate the necessary wing area. Icarus' wing area is larger than the calculated amount proving that Icarus' provides the necessary lift to fly with its max weight of 10.612 kg. According to 2.3.1 Air Vehicle, a wing area of 0.338 m^2 is required to sustain flight. Using SolidWorks, the RamJets created a 2D projection of the airframe and found the wing area to be 0.415 m^2, thus Icarus can generate enough lift to sustain flight.

To determine if Icarus carried enough battery capacity for flight, first, the amperage of each component would need to be found for each flight phase; this includes flight components, payload sensors, DAA sensors, and computing devices. The amperage used during Pre-Fire, Active-Fire, and Post-Fire was calculated to be 13.885 A, 12.945 A, and 13.885 A respectively. These calculations can be seen in Table 14: Components Pre/Post. Active fire utilizes the same components minus the Livox AVIA and adding two Micro-SWIR 640CSX (total 202 mA). This creates 12945 mAh for active fire. *Safety components were not included in amperage usage because they will only be used during emergencies.*

Table 14: Components Pre/Post

Components Pre/Post	Quantity	Total (mA)
Sniffer 4D	1	857
SCD30	1	19
Altum PT	1	857
WIRIS Pro	1	857
PixHawk 6X Barometer	1	178
Ping 2020i	1	0
Nebula Nano Pro	3	345
Raspberry Pi Zero	1	80
SF 30/D	3	750
Livox AVIA	1	1142
Motor	2	8800
Total Milliamps	13885	

The amperage used by the motor is during cruising as it is the vertical thrust used in section 2.3.1 Air Vehicle to calculate wing area. The normal amperage needed is 4000 mA per motor, but an additional 10% was needed to ensure Icarus can deal with any winds that may require greater motor strength. During takeoff and landing, Icarus' motors must be able to generate a thrust force equivalent to the weight of the UAV. To provide a total of approximately 12 kg of thrust, Icarus' motors use 16 A each. However, this is only during the time required for ascending vertically to cruising altitude. Icarus' sensors operate best at 120 m, as discussed in 2.3.3 Payload. Typically, drones vertically take off at around 5 m/s (Jamie Wubben, 2022). Eliminating the short acceleration time, this would take Icarus about 24 seconds to reach a maximum cruising altitude. Assuming the landing procedure takes about double that time due to the precision required while landing, the total time spent using 16 A is 72 seconds. This would create a consumption of 0.32 Ah or 320 mAh for takeoff and landing.

Icarus' batteries can provide 32 Ah. The takeoff and landing usage was subtracted from the battery capacity as it is only accounted for once and then adding the 72 seconds to the flight time afterwards. This gives 31.68 Ah. With that, flight time can be calculated by dividing capacity by amps used. This can be seen in Table 15: Flight Time, accounting for the components amperage as well as the amps used during takeoff and landing.

Table 15: Flight Time

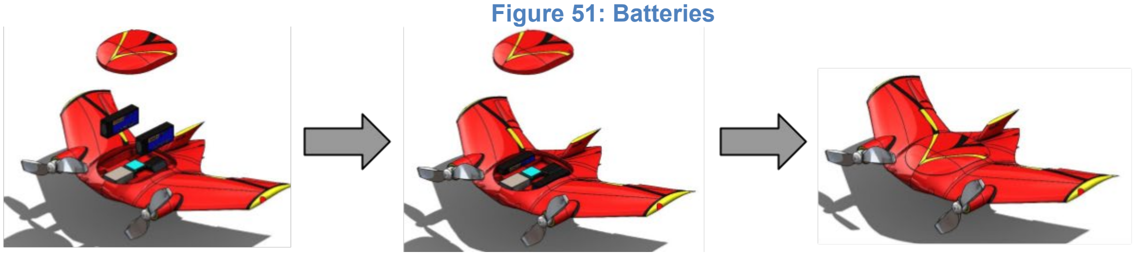
Fire Phase	Amps Used (A)	Flight Time
Pre	13.885	2 hr 18.096 min
Active	12.945	2 hr 28.037 min
Post	13.885	2 hr 18.096 min

Thus, Icarus exceeds the required 30-minute flight time in each phase, having a maximum flight time of 2 hours 18 minutes for pre-fire and post-fire and 2 hours 28 minutes for active fire, assuming Icarus flies to its maximum cruising altitude. This flight time can extend Icarus’ surveying area beyond other UAVs or allow it to fly multiple, 30-minute flights to survey different fire locations. While this is the maximum flight time, it is not recommended to fully discharge LiPo batteries past 80% (tenergy, 2024). This creates a recommended flight time of 1 hour 50 minutes for pre and post fire and 1 hour 58 minutes for active fire to avoid long term battery damage.

Icarus’ batteries can fit within the main body of the UAV, as seen in Figure 51: Batteries. The dimensions of each battery are 182 mm x 74 mm x 40 mm. Confirmation that there are holes of sufficient size for the batteries can be seen in 2.6 Final Design Drawings.

The minimum communication range given by the challenge statement is 5 miles (8.047 km). Icarus’ communication devices in 2.3.2 Command, Control, and Communications (C3) Selection create a range of **15 kilometers**. This range far exceeds the challenge requirements and ensures a secure connection within a relatively large vicinity of the GCS.

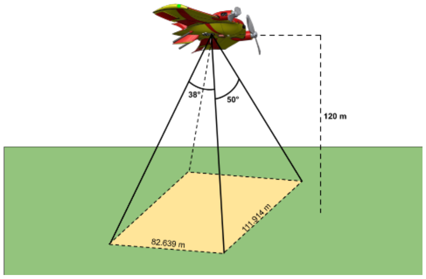
Figure 51: Batteries



It was also necessary to prove that Icarus would stay within this 15 km range during its flight time. Since the communication range goes 15 km in all directions from the MCE GCS and LRE, Icarus would have to stay in a circle with a radius of 15 km, centered at the MCE GCS, which has an area of 707 km^2.

Icarus’ flight path is limited by the sensor with the smallest FOV, that being the Altum-PT. At the maximum altitude this models the diagram seen in Figure 52: Area Covered. Using the maximum flight distance (horizontal flight time minus loiter time, times velocity) and the maximum horizontal coverage it can be found that Icarus covers a maximum area of **16.648 km^2**, far less than the **707 km^2** maximum area of the antenna. Thus, Icarus will always be inside the communication range during its flight time.

Figure 52: Area Covered



3.3. Safety Requirements

3.3.1 Detect and Avoid

Cooperative Obstacles

Cooperative obstacles are aircraft in the vicinity of the UAV that are in direct communication with ASM. As Icarus needs to establish itself in the National Airspace with manned aircraft, an Automatic Dependent Surveillance Broadcast (ADS-B) transponder was necessary. Section 14 CFR § 91.225 specifies that any aircraft that flies below 18,000 ft are required to be equipped with a Mode S transponder (Airspace ADS-B Airspace and Coverage Map, 2023).

The RamJets selected the **Ping 2020i** ADS-B IN/OUT transponder, which tracks the positions of other ADS-B equipped aircraft within 100 miles through ADS-B IN and broadcasts Icarus's position to other aircraft through ADS-B OUT. Weighing only 20 grams, it is the ideal transponder for Icarus (uAvionix:Ping 2020i, 2023).

Avoiding Cooperative Obstacles: Once an aircraft is detected, the ADS-B transponder sends a signal to the Pixhawk 6X, where it is transmitted to the control elements. Utilizing a VHF radio at the MCE GCS, the MCE will communicate with ASM. Upon receiving any needed adjustments to the flight path, the MCE will alter the course of Icarus using the PX4 autopilot software.

Avoiding Non-Cooperative Obstacles: Non-cooperative obstacles are any obstacles in the vicinity of Icarus that the ASM or the control elements of the UAV cannot communicate with. Thus, a system of sensors that detect any non-cooperative obstacles from a distance are necessary to give the control element time to execute proper avoidance. The determined safe distance between obstacles and Icarus was 170 meters. As the aircraft's cruising speed is 17 m/s, the MCE has 10 seconds to adjust the flight path, which according to the FAA is ample time (FAA, 2024).

Furthermore, DAA data must reach the control elements with negligible latency as the flight path needs to be updated in real time. Thus, the team chose radio transceivers as it transmits data at near-instantaneous speeds shown in 2.3.2 Command, Control, and Communications (C3) Selection. Additionally, 360° awareness of the UAV is necessary to detect any potential obstacles and enhance the control elements' situational awareness of the aircraft's environment. Thus, the total sensor count must have a combined FOV of 360° to provide redundancy.

As described in 2.3.2 Command, Control, and Communications (C3) Selection, the team found that LiDAR, RGB, and SWIR cameras are best equipped for detecting possible obstacles in Icarus's flight path. The following LiDAR and RGB sensors were selected to be utilized for every mission while the SWIR camera will be employed during the active-fire. These are crucial for the control elements to effectively aviate the UAV when necessary.

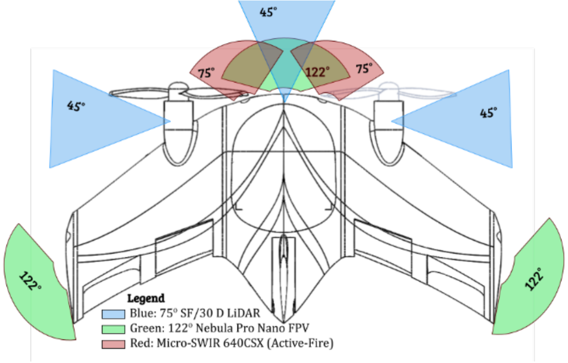
Nebula Pro Nano: This lightweight RGB camera weighs only 3.5 grams with a relatively large horizontal FOV of 122° and vertical FOV of 93°. This camera has 720p video quality which provides both control elements clear and real-time video feed of the UAVs surroundings. To provide full 360° situational awareness, three cameras were added to the UAV (Nebula Pro Nano, 2023).

SF30/D: This LiDAR sensor weighs 35 grams and has a maximum range of 200 meters (Digikey, 2023). The SF30/D's FOV is 45° horizontally and vertically. A 360° view utilizing LiDAR was no longer required since the FPV camera has 360° coverage. However, LiDAR is particularly useful in generating a map of the surrounding area in SLAM applications. Therefore, three of these sensors would be added to capture the area in front and partially to the sides of the UAV, providing full map coverage as the aircraft moves forward.

Micro-SWIR 640CSX: This SWIR camera allows the control elements to view and properly identify surroundings in low-visibility environments with a horizontal FOV of 75°. The team decided to install two SWIR cameras in the front of Icarus during active-fire missions. This allows the control elements to have a better view of Icarus's surroundings and detect incoming objects such as birds that are not visible on the RGB camera in low-visibility.

DAA Sensor Placement: The placement of sensors is carefully chosen to increase efficiency in detection. Figure 53: DAA Sensor Coverage portrays the sensor placement, and the resulting 360° FOV formed by the FPV cameras.

Figure 53: DAA Sensor Coverage



Lights: As mentioned in 3.1.2 Active Fire, it is possible that the mission occurs during the day or night, and wildfires often contain heavy smoke and low visibility. According to FAA Part 107.29, strobe lights need to be visible at a minimum distance of three miles from the UAV's surroundings. There are two different lights: navigation lights and anti-collision lights.

Navigation Lights: They are the red and green lights located on the wings of an aircraft. These lights are beneficial for the control elements, as they can determine the location of the FPV camera in relation to the aircraft based on the color light that is displayed. Two of these are needed, one red (left) and one green (right).

Anti-Collision Lights: They contain two lights, a white strobe light and a white flashing light. The white strobe light is located at the nose of the UAV and the white flashing light is located at the tail of the UAV (14 CFR 107.29, 2023). In case of an emergency where the UAV can no longer perform a controlled landing, these lights will alert any nearby bystanders of the aircraft.

Symik's Strobe Lights: This contains four different features, where the color mode can be changed to red, green, strobe, or white flashing. Therefore, four will be used, each having a different setting.

Anti-Collision Siren: This is employed in conjunction with the lights to ward off any incoming wildlife in an emergency loiter and humans in an emergency landing. The **Tundra Drone Siren** was selected as it is used to direct animals and weighs only 72 g. The Tundra Drone Siren espouses a sound of 107 dB, comparable to the sound of a power mower.

Figure 54: Audio and Light Alarm Locations

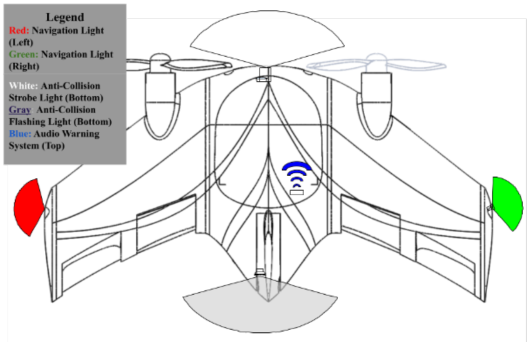


Figure 54: Audio and Light Alarm Locations illustrates the lights that are located on Icarus and their placement.

SLAM: This software installed in Icarus constructs a real-time 3D map of the UAV's surroundings while continuously locating the position of the UAV within it. The data from SLAM is displayed to the MCE GCS to ensure that they are aware of the UAV's surroundings and potential non-cooperative obstacles obstructing the flight path. SLAM utilizes data from LiDAR resulting in a map with a 200 m radius. In addition to that, any maneuvers to avoid obstacles in the flight are remembered by SLAM for future missions.

UAV Computing: As mentioned in 2.3.2 Command, Control, and Communications (C3) Selection, the computer working alongside the Pixhawk 6X is the Raspberry Pi Zero 2. During the mission phase, if an obstacle is within the flight path, the MCE or LRE will follow the procedures listed in Figure 55: UAV Solution Diagram. If an obstacle occurs during the handover procedure, then whichever control element is operating Icarus will maneuver the aircraft.

Figure 55: UAV Solution Diagram

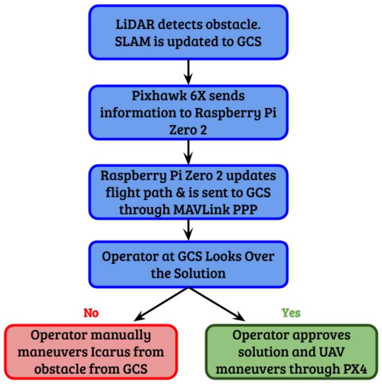


Table 16: DAA Components below shows the compiled components needed for DAA.

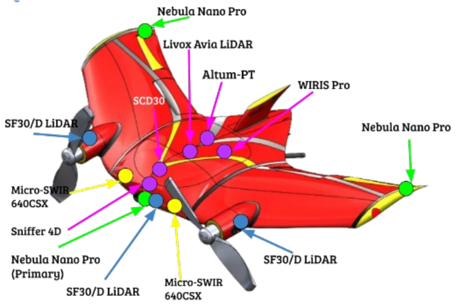
Table 16: DAA Components

DAA	Dimensions (mm)	Unit Weight (kg)	Quantity	Total Weight (kg)	Total Cost ($)
Nebula Pro Nano	16.5 x 16 x 14	0.0035	3	0.0105	201
SF30/D LiDAR	30 x 56.5 x 50	0.0315	3	0.0945	897
Ping2020i ADS-B Transponder	25 x 39 x 12	0.02	1	0.02	2,200
Rasberry Pi Zero 2	65 x 30	0.011	1	0.011	35
Siren	80 x 40 x 40	0.072	1	0.072	259
Strobe Light	36 x 112 x 136	0.021	1	0.021	50
Micro SWIR*	37.25 x 37.25 x 27.94	0.045	2	0.09	1,024
Total				**0.319**	**$4,666**

*Only used during active fire missions

All Sensors Placement: Figure 56: All Sensors Placement provides the placement of all payload sensors of Pre-Fire, Active-Fire, and Post-Fire missions, including Detect and Avoid sensors on Icarus.

Figure 56: All Sensors Placement



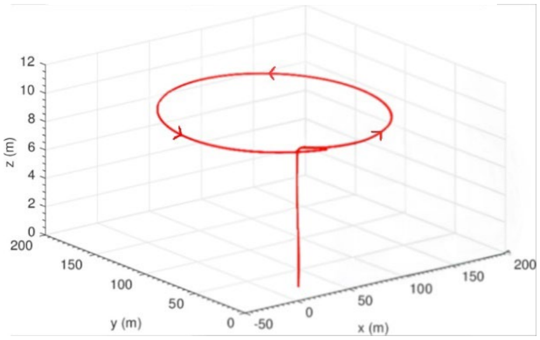
3.3.2 Lost Link Protocol

When Icarus is deployed in an unknown environment, communication between the MCE GCS, UAV, and LRE can be lost in many ways. Refer to Figure 28: Communications System for information on the different communication systems in the UAS.

To reduce potential severity, protocols were developed for different scenarios of these communication losses throughout the flight:

Takeoff: In the event the LRE loses the Aviate Communication Link with the UAV during takeoff or landing, manually controlling Icarus will no longer be possible. Therefore, Icarus will automatically switch to PX4 autopilot mode where the UAV flies in its vertical position and goes above the tree canopy to the set cruising altitude. Flight planning will have already established a launch site that is clear of tree canopy and anything obstructing the UAV during vertical takeoff. Once there, the UAV switches to conventional flight position and begins the emergency handover loiter, a specific loiter path generated by the MCE during flight planning where the UAV is unobstructed by trees. A similar version of this flight path is seen in Figure 57: Emergency Handover

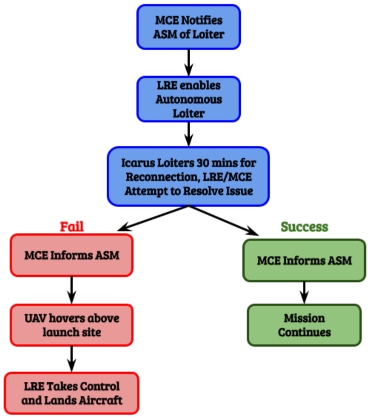
Figure 57: Emergency Handover Loiter



Loiter. The loitering is to save fuel in the case of reconnection, as hovering is extremely energy inefficient and puts the UAV in danger when there is high wind speeds. Once LOS communications are established, the MCE takes control of the UAV and commands the autopilot system to re-engage and follow the mission flight path. If the MCE cannot reconnect, the UAV follows the Crash Point Procedure described later in the section.

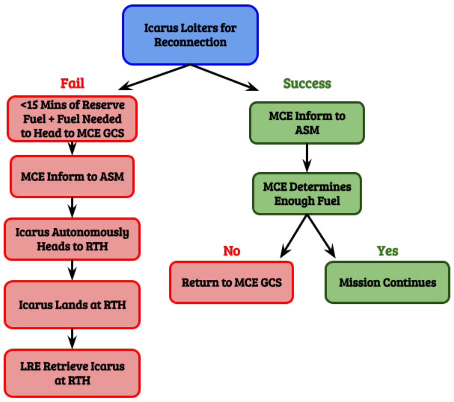
Once the UAV is above the tree canopy, LOS radio communications between the MCE and UAV should be established. If the UAV-MCE connection does not occur when Icarus reaches the set cruising altitude, the LRE will put Icarus into its conventional flight position and follows protocols in Figure 59: UAV-MCE Lost Link.

Figure 59: UAV-MCE Lost Link



Mission: The Crash Point Procedure is only used when the UAV is unable to reconnect after loitering upon a loss in communications. The loiter time for reconnection is determined by the fuel needed to cover the distance to the landing location with an additional 15 minutes of reserve fuel. Audio sirens, strobe lights, and ADS-B transponder broadcasting code 7600 will be the warning systems as the UAV travels to the crash point. The crash point is defined as a location near the MCE GCS, so it is easily recoverable. This point will be integrated into the flight path and autopilot system prior to the flight. Icarus must autonomously navigate to the designated landing location by utilizing IMUs and SLAM, which is further described in 3.3.1 Detect and Avoid. As the MCE is in direct LOS with the UAV for the entirety of the mission, the MCE may still check the status of Icarus through binoculars and relay that information to the ASM. Therefore, at any point during the flight where one of the following scenarios occurs, the UAV can autonomously divert from the flight path to the landing location. Icarus will automatically descend when approaching the landing location and conduct a precautionary landing on its reinforced belly. Upon landing, the MCE recovers the aircraft. This process is detailed in Figure 58: Crash Point Procedure.

Figure 58: Crash Point Procedure



Loss of Aviate Data Communications Link: During any time of the flight when the MCE loses telemetry and control communication with the MCE GCS, the system is no longer semi-autonomous. This prompts Icarus to autonomously enter a loiter as the UAV understands telemetry data is no longer being sent. Then, the crash point procedure is followed as displayed in Figure 59: Crash Point Procedure.

Payload Data Communications Link: Data links for fire monitoring data and telemetry data are completely independent, as detailed in 2.3.2 Command, Control, and Communications (C3) Selection. This redundancy allows for the mission to continue if the fire monitoring data link is lost as the remote pilots still have situational awareness of the UAV. The MCE will know when this link is lost if all feed from the fire monitoring sensors is lost simultaneously. The SD Card allows for fire-monitoring data to continue to be collected even in the event of disruption to the payload data communications pathway. In the post-mission phase, the MCE may take the SD Card out and insert it into the laptop where data may be sent to fire coordinating efforts.

MCE-UAV During Landing: If control communications were lost when the MCE is landing Icarus, the UAV autonomously returns to cruising altitude and follows the Emergency Handover Loiter for reconnection. When there are five minutes left of fuel, the UAV will crash land at the designated landing location near the MCE GCS, which is marked on the autopilot system. Upon landing, the MCE recovers the UAV.

3.3.3 Integration with Manned Aircraft and Other Aircraft

Icarus must comply with all FAA Part 107 regulations under § 91.203(a)(2) to qualify for integration into the National Airspace (14 CFR § 91.203, 2023). For UAS compliance to FAA Part 107 regulations and required waivers see 3.3.4 Regulations and Additional Safety.

Furthermore, ADS-B transponders are required by the FAA in section 14 CFR 91.215 for all aircraft operating in airspace, and Section 14 CFR § 91.225 specifies that any aircraft that flies below 18,000 feet are required to be equipped with a Mode S transponder-based ADS-B transmitter (14 CFR § 91, 2023). The selected Ping 2020i operates at the two major aircraft broadcasting frequencies of 978 and 1090 MHz and in Modes A, C, and S. Therefore, the Ping2020i allows communication with an aircraft with any form of ADS-B transponder. Since the Ping 2020i is an ADS-B In/Out transmitter, it can send Icarus's position while receiving the positions of other aircraft equipped with an ADS-B transponder (Ping2020 - uAvionix). Thus, Icarus and other manned aircraft will be aware of their proximity to one another and communicate with ASM as needed.

The MCE will communicate with ASM throughout the entire flight, enabling communication for situations involving avoidance. In said situations, the MCE will always give manned aircraft the right of way as established by the NWCG. However, if necessary, the MCE takes command of the UAV and adjusts the flight path on the PX4 autopilot system, communicating with ASM throughout.

Additionally, during the Active Fire mission, Icarus will be operating within TFR which involves the broadcast of NOTAMs to all aircraft.

The RamJets also considered the stressful environment that can be brought about in fire monitoring missions. To account for this, the RamJets follow all NWCG protocols and procedures as mentioned in 3.1.2 Active Fire.

3.3.4 Regulations and Additional Safety

The RamJets researched FAA Part 107 regulations to ensure that the UAS capabilities follow all regulations in wildfire missions. Furthermore, safety procedures were created to reduce possible major accidents. Finally, NWCG protocols for the Active Fire mission are further described in this section.

Table 17: Compliance with FAA Regulations lists FAA Part 107 regulations in relevance to the mission and compliances.

Table 17: Compliance with FAA Regulations

FAA Regulation	In Compliance?
§ 107.11 Applicability This subpart applies to the operation of all civil small, unmanned aircraft systems subject to this part.	In compliance. Icarus is a part of a small, unmanned aircraft system.
§ 107.15 Condition for safe operation (a) No person may operate a civil small, unmanned aircraft system unless it is in a condition for safe operation. Prior to each flight, the remote pilot in command must check the small, unmanned aircraft system to determine whether it is in a condition for safe operation.	In compliance. Prior to each flight, both remote pilots, or control elements, must complete a preflight checklist and pre-departure checklist ensuring Icarus is in condition for safe operation.
§ 107.19 Remote pilot in command (a) A remote pilot in command must be designated before or during the flight of unmanned aircraft. (b) The remote pilot in command is directly responsible for and is the final authority as to the operation of the small, unmanned aircraft system. (c) The remote pilot in command must ensure that the small, unmanned aircraft will pose no undue hazard to other people, other aircraft, or other property in the event of a loss of control of the small, unmanned aircraft for any reason.	In compliance. The MCE and LRE are predetermined for each mission. Furthermore, the MCE actively monitors the UAV during the entire flight. The MCE also follows all specific procedures under lost link protocol, emergency landing, and crash point procedure that guarantee safe flight under possibly hazardous conditions. Furthermore, the MCE is in communication with ASM via VHF radios throughout the mission to ensure no threat is posed to other aircraft.

§ 107.29 Operation at night. (b) No person may operate a small, unmanned aircraft system during periods of civil twilight unless the small, unmanned aircraft has lighted anti-collision lighting visible for at least 3 statute miles that has a flash rate sufficient to avoid a collision. The remote pilot in command may reduce the intensity of, but may not extinguish, the anti-collision lighting if he or she determines that, because of operating conditions, it would be in the interest of safety to do so.	In compliance. Icarus will be operating in standard day conditions during the Pre and Post Fire missions. For all missions, the UAV has four strobe lights for anti-collision that are visible for 3.7 miles.
§ 107.31 VLOS aircraft operation (a) With vision that is unaided by any device other than corrective lenses, the remote pilot in command, the visual observer (if one is used), and the person manipulating the flight control of the small, unmanned aircraft system must be able to see the unmanned aircraft throughout the entire flight to: (1) Know the unmanned aircraft's location (2) Determine the unmanned aircraft's altitude and direction of flight (3) Observe the airspace for other air traffic or hazards (4) Determine that the unmanned aircraft does not endanger the life or property of another.	Not in compliance. However, Icarus meets requirements for receiving a 14. CFR 91.113(b) Beyond VLOS (BVLOS) waiver. Both the LRE and MCE know the UAVs location, altitude, orientation, and direction of flight in real-time through GPS and IMU systems onboard described in Section 2.3.2. An ADS-B transponder onboard ensures Icarus is broadcasting its location to all aircraft and is aware of all aircraft in a 100-mile vicinity. FPV cameras, LiDAR sensors, and a SWIR camera ensure the UAV detects and avoids non-cooperative obstacles. Strobe light and audio systems warn people and wildlife below the UAV before it does a controlled descent and crash lands on reinforced belly and nose, which minimizes environmental damage.
§ 107.45 Operation in prohibited or restricted areas. No person may operate a small, unmanned aircraft in prohibited or restricted areas unless that person has permission from the using or controlling agency, as appropriate.	In compliance. Permission to fly in TFR will be requested and granted by the FAA before the mission provided by the firefighting group through an SGI.

Safety Assurance: Using the Pre-Mission checklists described in 3.1 Concept of Operations greatly decreases the probability of aircraft component failure during flight. Battery levels are checked twice, once before departure from the MCE GCS and another at the launch site by the LRE. Control elements hold a debrief after each mission to discuss possible improvements in efficiency and safety of the mission by employing the risk assessment table.

Risk Assessment: Table 18: Risk Assessment was based off the FAA’s risk matrix and will be utilized by the MCE to determine the severity of an issue of the aircraft.

Table 18: Risk Assessment

Incident Likeliness		Potential Severity	
Value	Definition	Value	Definition
5	Frequent	1	Negligible: Less than minor equipment damage or injury. Does not hinder the mission and repairs are not needed.
4	Likely		
3	Occasional	2	Moderate: Equipment damage where moderate minor repairs are required. Will not hinder the mission.
2	Seldom	3	Critical: Equipment damage where extensive repairs need to be done upon landing. Moderate environmental damage. Possibility to hinder the duration of flight and mission. UAV is likely to be recovered.
1	Unlikely	4	Catastrophic: UAV damage is irreversible and unlikely to be repaired into operation if recovered at all.

Risk Score Calculation: (Likeliness) * (Severity) = Risk Score

For example, the likelihood of both engines failing is unlikely, and the potential severity could be catastrophic, therefore, the risk score would be four.

The pilots would then follow Table 19: Assessing Risk Values, which demonstrates the procedures taken for a range of risk values.

Table 19: Assessing Risk Values

Risk Level	Risk Value	Procedure
High Risk	≥8	Must resolve the issue immediately. Control elements are to document the issue and discuss ways to prevent the issue from recurring. Repairs are made by the LRE. Both pilots will evaluate the risk level after repairs to determine if Icarus is safe to fly.
Medium Risk	6-7	Discussion by control elements to lower or negate risk during mission debrief. Any changes must be checked, and a re-evaluation of risk assessment must be done by control elements. If no changes are made, control elements are to document why and state areas of greater caution for future missions.
Low Risk	5	Continue Operation.

One Engine Out Condition: The aircraft will first broadcast code 7700 from the ADS-B transponder to nearby aircraft, and the MCE will immediately notify ASM. Utilizing the Pix4D Capture Pro software, Icarus's flight path will be adjusted to fly to the designated emergency landing location near the MCE GCS. The landing procedure will be adjusted as Icarus would not have the dexterity in its engines to perform a stall landing. Reinforcement on the nose and belly through thicker exterior provides enough protection where the components and airframe are not irreversibly damaged.

After the mission, all damaged components will be replaced in Post Mission procedures.

Risk Score for One Engine Out: 1 * 3 = 3

A total risk score of three is considered a **Low-Risk** score, therefore, normal operation continues. If the control elements determine the likelihood of a one engine out condition to be more likely after a mission, then risk score increases to 6 and discussion will commence to negate the risk.

Table 20: Cruising Altitude Vs. Glide Distance

Cruising Altitude (m)	Glide Distance (m)
50	1.25
100	2.5
150	3.74
200	5
250	7.5

Two Engine Out Condition: When both engines in a two-engine aircraft are lost, there will not be any applied thrust to Icarus. Although this is highly unlikely to occur since the engines were checked several times by the LRE before the mission, it is still possible during flight. This is dangerous for Icarus as airspeed corrections are no longer possible. Icarus will have to perform an emergency landing in this state in any mission. In the case of double engine failure, Icarus could glide a limited distance to find a suitable location to safely land. As mentioned in 2.3.1 Air Vehicle, Icarus features an installed AOA of 7° where Icarus' airfoil has a lift to drag ratio of around 25. This would create a glide ratio of 25:1; for each meter Icarus descends, it can glide 25 meters. Icarus' cruising altitude varies on the height of the trees. Table 20: Cruising Altitude Vs. Glide Distance shows the average distance Icarus could travel at a given altitude assuming no obstructions. At Icarus' largest cruising altitude (~121 m), it could glide about 3 km.

As losing one engine is considered unlikely during the flight, two engines is also considered unlikely. Since communication with the UAV is still working, the MCE will utilize the control surfaces to guide the UAV to a precautionary landing in a location that minimizes the damage to the UAV and ensures recoverability such as a flat and open space. A critical score, which is three, was determined for potential severity in a two engine out condition.

Risk Score for Two Engine Out: 1 * 3 = 3

One Battery Out Condition: Depending on the amount of fuel left, the MCE determines whether the mission may continue for a shortened duration or if the UAV must immediately return to the MCE GCS. As batteries and connections are checked twice before launch it is unlikely a battery fails during the mission. Furthermore, since the mission may continue, and no repairs are needed with the loss of a battery the severity is negligible. The risk assessment determines this scenario to be of low risk.

Risk Score for One Battery Out: 1 * 1 = 1

Two Battery Out Condition: With both batteries lost the UAV no longer has fuel and communication is lost with the control elements. The MCE will immediately notify ASM. The

UAV will autonomously glide and search for an open clearing. Reinforcement on the nose and belly decreases the force of impact upon forced landing. As the control elements know the UAV's flight path and are actively monitoring the UAV, they may infer the approximate location of the crashed UAV. Whichever control element is closer to the approximate location will recover Icarus. As it is unlikely for one battery to fail, two batteries failing would also be unlikely. Potential severity would be critical as the UAV would need repairs but would not be irreversibly damaged because of the reinforced nose and belly. As a result, a low-risk score is generated.

Risk Score for Two Battery Out: 1 * 3 = 3

Distress Codes: In the case of certain emergency situations, Icarus will automatically transmit distress codes according to the state of the UAV through ADS-B transponder. These codes are Code 7400: Control link lost, Code 7600: Radio communications failure, and Code 7700: Emergency.

4. Business Case

4.1 Cost Analysis

4.1.1 Operating Costs

Icarus is to be equipped with two **Lumenier LIPO** batteries, which provide enough power to exceed the minimum required flight time of 30 minutes and supply all payload sensors, DAA sensors, and C3 equipment on Icarus. As calculated in 3.2 Flight Profile Analysis, Icarus can withdraw the total battery capacity of 32 Ah. Multiplying the capacity by the voltage and cell count gives 1894.4 Wh for the battery. At full capacity of the battery, Icarus' batteries discharge all 1894.4 Wh for a maximum flight time and 1515.52 Wh at 80% max capacity for recommended flight time.

Battery Charging: Coulomb counting is a common method to estimate the State of Charge (SoC). By taking into consideration the SoC, the likelihood of overcharging and damaging a battery is reduced, thus increasing its lifespan. LIPO batteries have Coulomb efficiencies almost at 99%, which ensures that SoC estimations are accurate. (BU-808c: Coulombic and Energy Efficiency with the Battery, 2010). However, after every mission, the battery is drained over 99%, so the team determined that there was no need to consider SoC as the battery would need to be completely recharged.

The average cost of electricity in the United States, $0.23 per kWh, was used to evaluate the cost of recharging the batteries (EnergySage, 2023). Because LIPO batteries require a charge while being stored to increase their lifespan (Staff, 2016), batteries will be charged to 50% after Post Fire.

Powering MCE GCS: The team selected the PG1202SA Gas-Powered Portable Generator to supply power to all the components aboard the MCE GCS. Since power generators typically use unleaded gasoline, the RamJets used the average cost of $4.66 per gallon of gasoline in the United States to calculate the variable costs for the generator. ((Amazon, 2024), (Gas Cost, 2023)). As the maximum flight time of Icarus is no more than two and a half hours, and the generator provides power for up to 5 hours at 50% capacity, each mission will require no more than one tank of gas, or 1.1 gallons. For procedures regarding refueling/draining, see 3.1 Concept of Operations.

See Table 21: Maximum and Recommended Operating Costs for a summary of operating costs per mission.

Table 21: Maximum and Recommended Operating Costs

Variable Costs	Price	Quantity (Recommended)	Quantity (Maximum)	Total Cost (Recommended)	Total Cost (Maximum)
Battery Energy	$0.23 per kWh	1.515 kWh	1.894 kWh	$0.35	$0.44
Gas for Generator	$4.66 per gal	1.1 (gal)	1.1 (gal)	$5.13	$5.13
Total				**$5.48**	**$5.57**
Total *(Accounting Charge for Battery Storage)*				**$5.65**	**$5.79**

Thus, the cost per mission is $5.65 when operating for the recommended operating time and $5.79 cents when operating for the maximum operating time.

Personnel: The challenge does not require personnel costs to be calculated. However, for Icarus to complete the mission safely and successfully, there must be two control elements. The LRE takes the UAV out to the takeoff location, preps and performs the Pre-Flight Checklist, performs the ascent, and monitors the state of the mission through a handheld GCS. The MCE monitors Icarus consistently through its flight, recovers the aircraft after landing, conducts Risk Analysis, and performs the Pre and Post Mission Checklists.

4.1.2 Fixed Costs

Air Vehicle: The team decided to use HoneyComb Core Carbon Fiber to design Icarus' airframe due to its very low weight and its ability to withstand flight conditions during all stages of the mission. The team incorporated the Lumenier LIPO battery into Icarus' airframe due to its competitive energy-capacity-to-weight ratio and low cost. The team also chose the MAD M6 IPE Motor for its high thrust when equipped with a relatively small propeller. For more information regarding the selection of Airframe components, see 2.3.1 Air Vehicle. Table 4: Air Vehicle Components display the costs for all air vehicle components.

LRE Equipment: Due to the nature of a tail sitter aircraft the RamJets also wanted to ensure a stable and level takeoff platform, which involved the addition of threaded rods, a platform, and stakes to place into the ground. The selection of a heavy-duty bag specifically made for firefighters and foam inserts also facilitates ease of transport and equipment safety. See

Table 11: LRE Components for a complete breakdown of everything carried by the LRE.

DAA/Safety: Icarus is also equipped with the SF30/D, the Nebula Pro Nano, Micro-SWIR 640CSX, and the Raspberry Pi Zero 2 to properly avoid cooperative and noncooperative obstacles. Safety items such as the strobe light and an audio warning system ensure Icarus is safely landing in the presence of wildlife and properly integrating in the National Airspace. The cost of DAA sensors can be seen in Table 7: MCE GCS Components.

Payload Sensors: As Icarus is required to send raw data in real-time for all three missions, a system of sensors detecting the chemical composition, heat distribution, and other data points was required to properly meet mission criteria. Furthermore, the UAV must gather data better than the current methods. To do so, market analysis was conducted to find sensors fit for this challenge (See 2.3.1 Air Vehicle for details) resulting in a sensor combination that provides the firefighting group with the high-resolution data they need. For a detailed analysis of payload sensors included on Icarus and how they fulfill mission criteria, see 3.1 Concept of Operations.

Air Vehicle C3 Components/GCS Components: Icarus is semi-autonomously operated, so transponders and flight controllers are required to establish a redundant communication link with negligible latency as noted in 2.3.2 Command, Control, and Communications (C3) Selection. This also ensures that raw data is sent to the firefighting group in real-time. The MCE GCS includes a joystick, keyboard, mouse, monitor, and other systems that enable the MCE to monitor and/or operate Icarus in real-time. Encoders and decoders were added to reduce the packet size of data being transferred to optimize communications. The LRE must also be equipped with a handheld GCS to properly aviate the UAV during its takeoff and ascent. For the total costs of C3 equipment, see Table 6: Air Vehicle C3 Components.

Table 22: Total Fixed Costs

Section	Cost ($)
Air Vehicle	1,814
Payload Sensors	41,535
DAA Equipment	4,666
LRE Equipment	1,626
Air Vehicle C3 Components	6,522
GCS	21,435
Total	**$77,598**

Total Fixed Costs: The team calculated that the total fixed costs for Icarus would be $77,598, as shown in Table 22: Total Fixed Costs.

4.2 Communications Plan

4.2.1 Strategic Communications Plan

A communications plan defines what information is communicated and is strategized in a manner that addresses its audience. By developing one, the RamJets can properly address its stakeholders to receive funding for their project which aims to support firefighting efforts.

Audience: To better appeal to policymakers, the RamJets conducted research into the interests and tendencies of their audience. In general, policymakers do not have technical expertise and prefer concise content. Furthermore, they desire designs and propositions that will optimize financial return (National Co-ordinating Centre for Public Engagement, 2023). Taking this into account, the team compiled a list of objectives that both the sample communications plan and infographic should accomplish.

1. Must demonstrate the feasibility of the design.
2. Must frame the issue in a concise and easy-to-understand way.
3. Must demonstrate clarity in what the solution accomplishes, and why it is a necessity to incorporate.

Infographic: To persuade policymakers to provide funding to the RamJets initiative, the RamJets developed an infographic to provide an overview of a problem that Icarus can solve. Specifically, the increasing number of wildfires with fewer firefighting resources along with primarily manual methods of fire surveillance and data collection is insufficient to address the growing problem. This encourages the audience to consider an alternative, innovative solution to provide better fire intelligence for response planning.

The following section introduces Icarus and emphasizes the quick assembly time of the UAV. Policymakers are informed of the easy applicability and incorporation of the system into wildfire prevention and response efforts. By doing so, the UAS is demonstrated as a system that can be utilized in emergent and hectic conditions that wildfires cause.

To prove that Icarus can be a solution to the presented problem, the remaining space of the infographic is reserved for the deliverables of the system and potential applications. As Icarus is operational for any situational environment (i.e. before, during, and after a wildfire), all specific data points collected during those missions are listed concisely. Recognizing that policymakers do not have technical expertise, the graphic also includes a nominal and visual demonstration of the data directly seen in the control room, as well as the required setup for the MCE.

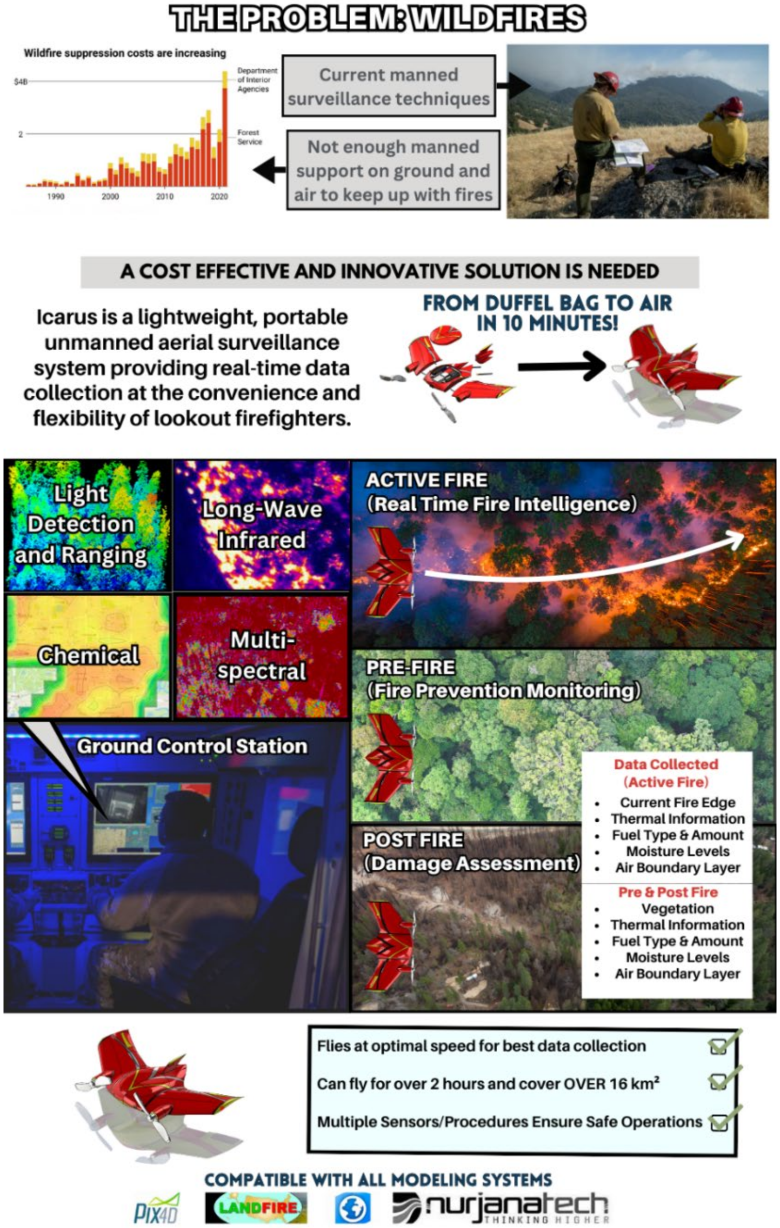
The team also wanted to emphasize UAS compatibility, thus the logos of major fire modeling and mapping companies were included. The raw data that will be sent must also be shown to be useful to the firefighting group, so showing potential applications was critical to demonstrate the usefulness of the design.

Sample Communications Plan: The primary objective of the sample communications plan was to provide an additive and concise written sample that would help policymakers who were presented with the infographic. Thus, the RamJets chose to include information that would help summarize the main takeaways that were critical to frame Icarus as a flexible and efficient solution to a rampant issue.

Following the format of the infographic, the sample communications plan paints the issue at hand whilst establishing the concern that current efforts are insufficient at resolving it and that firefighting groups are looking for a solution.

To ensure that the communications plan is not misunderstood, the team summarized what the UAS accomplishes in a sentence creating clarity and conciseness. Following that is a description of the applications of high-resolution data from Icarus, its compatibility with all software systems, and a short description of how firefighting efforts would use the data. Not only did this re-establish the usefulness of the design, but also helped resolve confusion and misunderstanding regarding the purpose of wildfire monitoring in firefighting efforts.

4.2.2 Infographic



THE PROBLEM: WILDFIRES

Current manned surveillance techniques

Not enough manned support on ground and air to keep up with fires

A COST EFFECTIVE AND INNOVATIVE SOLUTION IS NEEDED

Icarus is a lightweight, portable unmanned aerial surveillance system providing real-time data collection at the convenience and flexibility of lookout firefighters.

FROM DUFFEL BAG TO AIR IN 10 MINUTES!

ACTIVE FIRE
(Real Time Fire Intelligence)

PRE-FIRE
(Fire Prevention Monitoring)

POST FIRE
(Damage Assessment)

Data Collected
(Active Fire)
- Current Fire Edge
- Thermal Information
- Fuel Type & Amount
- Moisture Levels
- Air Boundary Layer

Pre & Post Fire
- Vegetation
- Thermal Information
- Fuel Type & Amount
- Moisture Levels
- Air Boundary Layer

Flies at optimal speed for best data collection ☑

Can fly for over 2 hours and cover OVER 16 km^2 ☑

Multiple Sensors/Procedures Ensure Safe Operations ☑

COMPATIBLE WITH ALL MODELING SYSTEMS

4.2.3 Sample Communication

The duration of wildfires has increased by 27% globally since the 1980s. (Doerr et.al, 2023). With fewer firefighting personnel spread over increasing fire areas and battling intense and fast-moving blazes, firefighting groups need better alternatives. Icarus is an unmanned aerial vehicle that gathers high-resolution fire intelligence data. It is compatible with modeling software to create real-time maps with valuable information on fire-prone areas and fire behavior to adjust response and assess damage of burned areas. This flexible solution for delivering timely and accurate fire intelligence is available for less than the cost to put out a wildfire (Bishop 2024).

5. Conclusion

The RamJets have created a UAV capable of monitoring wildfires while providing extremely detailed data to firefighting groups.

The aircraft's unique design is lightweight and capable of flying longer over greater distances than modern UAV technology through battery and motor selections. A tail sitter design creates great maneuverability and a small design perfect for unknown terrain. Compactness provides easy transportation for reducing firefighting response time and ability to take off and land in tight locations. Power-efficient motors maximize thrust capabilities to sustain Icarus at an ideal cruising speed for data collection. To ensure safety and integration within the National Airspace and NWCG, the UAS complies with FAA regulations relevant to UAVs and follows NWCG protocols during the active fire mission. The UAS also features additional safety features such as risk analysis, defined procedures, and multiple checklists that ensure safe and smooth operations.

Instantaneous radio communication allows the UAV to safely perform semi-autonomous flight, while ADS-B transponders enable communication with all other aircraft in the region. The 360° coverage of DAA sensors allows the control elements to control the UAV with similar resources as a manned aircraft. Having two separate radio communication pathways ensures the total bandwidth is large enough to accommodate DAA sensors and payload sensors, and properly transmit in real time. Designated sensors for each phase of the fire are optimized for weight and quality of data output. The payload sensors onboard Icarus collect a larger range of different data points pertaining to the fire than modern UAVs because of the capability to add additional payload from the engineering design. Area covered is maximized while ensuring sensor fidelity as Icarus' cruising altitude is determined by sensor range and image resolution.

Icarus brings change and innovation to the wildfire surveillance industry while providing maximum flexibility to firefighting groups through its ability to be launched from virtually anywhere. It is a cost-effective solution with tremendous potential for aiding in the prevention of wildfires and reducing the costs of fire response.

The RamJets' effective innovation has demonstrated the potential of UAVs in wildfire surveillance. Icarus is the UAV of the future, an exemplary model for future fire monitoring and an asset to combat the growing wildfire threat.

6. References

9 Types of Aircraft Wings in Depth. (2019, June 4). Aero Corner. https://aerocorner.com/blog/types-of-aircraft-wings/*aircraft empennage structure*. (2019). Pilotfriend.com. http://www.pilotfriend.com/training/flight_training/fxd_wing/emp.htm

Airfoil tools. (2019). *Airfoil Tools*. Airfoiltools.com. http://airfoiltools.com/

Airspace | Federal Aviation Administration. (2023). Faa.gov. https://www.faa.gov/air_traffic/technology/equipadsb/research/airspace#interactiveMap

Akash Peshin. (2018, March 14). *What Is SONAR?* Science ABC. https://www.scienceabc.com /innovation/what-is-sonar-definition-active-passive-uses-examples.html

Altimeter. (n.d.-b). Retrieved from education.nationalgeographic.org website: https://education.nationalgeographic.org/resource/altimeter/

Application of Remote Sensing in Forest Fire. (n.d.). Www.mdpi.com.https://www.mdpi.com/topics/ 06S2F7D819#:~:t ext=Drones%2C%20 unmanned%20aerial%20vehicle%20(UAV

Avia LiDAR sensor - Livox. (n.d.). Www.livoxtech.com. https://www.livoxtech.com/avia

Beacon/ADS-B Systems. (2024). Faa.gov. https://www.faa.gov/air_traffic/publications/atpubs/ atc_html/chap5_section_2.html#:~:text=Code%207400%20may%20be%20transmitted

Benson, T. (n.d.-b). *Geometry Definitions*. Www.grc.nasa.gov. https://www.grc.nasa.gov/www/k-12/VirtualAero/BottleRocket/airplane/geom.html#:~:text=Aspect%20ratio%20is%20a%20measure

Binary signal | communications | Britannica. (n.d.). Www.britannica.com. https://www.britannica.com/technology/binary-signal

Brenner, V. R. K., Liz Van Wagtendonk, Andrew. (2022, April 29). *A Lidar's-Eye View of How Forests Are Faring*. Eos. https://eos.org/features/a-lidars-eye-view-of-how-forests-are-faring

CADDXFPV Nebula Pro Nano Digital Drone Camera | Digital HD FPV System. (n.d.). CADDX FPV. https://caddxfpv.com/products/caddxfpv-nebula-pro-nano-digital-camera

Chemical Sensor - an overview | ScienceDirect Topics. (n.d.). Www.sciencedirect.com. https://www.sciencedirect.com/topics/materials-science/chemical-sensor#:~:text=A%20chemical%20sensor%20is%20composed

Clemenceau, P. (2023, January 27). *The Differences Between SWIR, MWIR, and LWIR Cameras*. Axiom Optics. https://www.axiomoptics.com/blog/the-differences-between-swir-mwir- and-lwir-cameras/#:~:text=The%20significant%20difference%20with%20short

Çoğay, S., & Seçinti, G. (2022). Phoenix: Aerial Monitoring for Fighting Wildfires. *Drones*, *7*(1), 19. https://doi.org/10.3390/drones7010019

Different Types of Hygrometers And Their Uses. (n.d.). Www.switches.co.za. https://www.switches.co.za/different-types-hygrometers-uses/

DragonPlate | Engineered Carbon Fiber Composite Sheets, Tubes and Structural Components | Made in USA. (n.d.). Dragon Plate https://dragonplate.com/carbon-fiber-nomex-honeycomb-core-05-x-24-x-36

Duignan, B. (2018). Occam's razor | Origin, Examples, & Facts. In *Encyclopædia Britannica*. https://www.britannica.com/topic/Occams-razor

Earth Science Data Systems, N. (2019). *Earthdata*. Earthdata. https://www.earthdata.nasa.gov/learn/backgrounders/what-is-sar

Edge, E. (n.d.). *Steel Threaded Rods Capacities ASTM A36 used for Pipe Support Hangers*. Www.engineersedge.com. from https://www. engineersedge.com/hardware/steel_threaded_rods_capacities_astm_a36_15714.htm

Electrical4U. (n.d.-b). *Multiplexer: What is it? (And How Does it Work) | Electrical4U*. Https://Www.electrical4u.com/. https://www.electrical4u.com/multiplexer/

EXPERTISE AND TECHNOLOGY FOR NATIONAL SECURITY. (n.d.). https://www.caci.com/sites/default/files/2021-11/F586_2110_AVT _CM142.pdf

Fagua, J. C., Jantz, P., Rodriguez-Buritica, S., Duncanson, L., & Goetz, S. J. (2019). Integrating LiDAR, Multispectral and SAR Data to Estimate and Map Canopy Height in Tropical Forests. *Remote Sensing*, *11*(22), 2697. https://doi.org/10.3390/rs11222697

Federal Aviation Administration. (2021). *Certificated Remote Pilots including Commercial Operators | Federal Aviation Administration*. Faa.gov. https://www.faa.gov/uas/commercial_operators

Federal Register :: Request Access. (n.d.-a). Unblock.federalregister.gov. https://www. ecfr.gov/current/title-14/chapter-I/subchapter-F/part-107/subpart-B/section-107.51

Fire, E. (2023, July 31). *SWIR Imaging Enhances Fire Zone Visibility: Visible Spectrum, NIR & LWIR Comparison | Sony Official*. YouTube. https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.youtube.com%2Fwatch%3Fv%3DIHkPIOVJOCM&psig=AOvVaw0fcjmM_WJzathYklZAGDLm&ust=1704145578898000&source=images&cd=vfe&opi=89978449&ved=0CBAQjRxqFwoTCMCprpHTuoMDFQAAAAAdAAAAABAD

Flynt, J. (2017, September 8). *What is FPV?* 3D Insider. https://3dinsider.com/what-is-FPV/

Flynt, J. (2019, February 6). What is the Lifespan of a LiPo Battery? How Long They Last. 3D Insider. https://3dinsider.com/lipo-lifespan/

FVR-90 Airframe Spurs Prototype for U.S. Navy Unmanned Aircraft System | L3Harris® Fast. Forward. (n.d.). Www.l3harris.com. https://www.l3harris.com/newsroom/editorial/2023/10/fvr-90-airframe-spurs-prototype-us-navy-unmanned-aircraft-system

Goud, K. A. K., & Dwivedi, Y. D. (2022). Effect of Twin Vertical Stabilizers on Lateral Directional Static Stability of an Aircraft – A Computational Study. *Graduate Research in Engineering and Technology (GRET)*, *1*(4). https://doi.org/10.47893/GRET.2022.1057

H.264 Profiles. (n.d.). RGB Spectrum. https://www.rgb.com/h264-profiles#:~:text=High%20Profile-

Harris, F. (2008). *Rotor Performance at High Advance Ratio: Theory versus Test*. https://rotorcraft.arc.nasa.gov/Publications/files/NASA%20CR%202008-215370%20Harris.pdf

How Do Radars Work? (2021, October 13). Lockheed Martin. https://www.lockheedmartin.com/en-us/news/features/2021/how-do-radars-work.html

How Do Thermal Cameras Work? (2020, June 16). Www.flir.com. https://www.flir.com/discover/rd-science/how-do-thermal-cameras-work/

How hygrometers work | Measuring humidity. (2018, July 14). Explain That Stuff. https://www.explainthatstuff.com/hygrometers.html

HYBRID QUADROTOR FVR-10. (n.d.). Retrieved March 18, 2024, from https://www.l3harris.com/sites/default/files/2021-11/as-pes-latitude-resources-fvr-10.pdf

Infrared Sensor: What is it & How does it work. (2023, June 7). https://getsafeandsound.com/blog/infrared-sensor/

Internal combustion engine vs electric motor. (n.d.). Austria. https://www.aldautomotive.at /en/useful-information/mobility-blog/articles/internal-combustion-engine-vs-electric-motor#:~:text=The%20electric%20motor%20requires%20fewer

Jason. (n.d.). *DG406DYZ Electronics Components Distributor Intersil | IC-Components.com*. Jason. https://www.ic-components.com/products/Intersil/DG406DYZ.jsp?msclkid=a8f6a1f6d5c01c8d18edc495456b9242

JetZero's Blended Wing Body Aircraft, USA. (n.d.). Airforce Technology. Retrieved March 16, 2024, from https://www.airforce-technology.com/projects/jetzeros-blended-wing-body -aircraft-usa/?cf-view

King, J. (2017, January 10). *The Overweight Infantryman*. Modern War Institute. https://mwi.westpoint.edu/the-overweight-infantryman/

LIPO Safety & Warnings. (n.d.). Power.tenergy.com. Retrieved March 22, 2024, from https://power.tenergy.com/lipo-safety-warnings/#:~:text=Avoid%20Over%2DDischarging%20LiPo%20Batteries&text=The%20damage%20caused%20by%20this

Ltd, R. P. (n.d.). *Raspberry Pi Zero 2 W*. Raspberry Pi. https://www.raspberrypi.com/products/raspberry-pi-zero-2-w/

LWIR (Long-Wave Infrared). (2016, September 14). Infiniti Electro-Optics. https://www.infinitioptics.com/glossary/lwir-long-wave-infrared

MAD M6 IPE Hexacopter Motor. (n.d.). Unmanned RC. Retrieved March 16, 2024, from https://unmannedrc.com/products/mad-m6-ipe-hexacopter-motor

MAVLink. (2009). *Introduction · MAVLink Developer Guide*. Mavlink.io. https://mavlink.io/en/

NASA. (2010). *Reflected Near-Infrared Waves | Science Mission Directorate*. Nasa.gov. https://science.nasa.gov/ems/08_nearinfraredwaves

Nassise, M. (n.d.). *ASPECT RATIO*. https://freeflight.org/Library/TechLibrary/Aspect%20Ratio%20by%20Nassise.pdf

Noise, Data Rate and Frequency Bandwidth. (n.d.). Mason.gmu.edu. https://mason.gmu.edu/~rmorika2/Noise__Data_Rate_and_Frequency_Bandwidth.htm#:~:text=C(bps)%20%3D%202B%20

Pan, Q., Wen, X., Lu, Z., Li, L., & Jing, W. (2018). Dynamic Speed Control of Unmanned Aerial Vehicles for Data Collection under Internet of Things. *Sensors*, *18*(11), 3951. https://doi.org/10.3390/s18113951

pat. (n.d.). *Wireless Transmitter Module For Ugv And Robotics With 8k Video And Control Data Transmitting*. Https://Www.iwavecomms.com/. https://www.iwavecomms.com/wirless- transmitter-module-for-ugv-and-robotics-with-8k-video-and-control-data-transmitting-product/

Path Planning (Trajectory) Protocol · MAVLink Developer Guide. (n.d.). Mavlink.io. https://mavlink.io/en/services/trajectory.html

PDHonline Course M314 (3 PDH) Fire Dynamics Series: Predicting Hot Gas Layer Temperature and Smoke Layer Height in a Room Fire with Natural and Forced Ventilation 2012. (n.d.). https://pdhonline.com/courses/m314/GasTemp&SmokeHeight.pdf

Ping2020i. (n.d.). UAvionix. https://uavionix.com/product/ping2020i/

Pixhawk 6X. (n.d.). Holybro Store. https://holybro.com/products/pixhawk-6x

PtMP Wireless MIMO(2x2) OEM Digital Data Link from China manufacturer - IFLY. (n.d.). Www.hk-Ifly.com. https://www.hk-ifly.com/PtMP-Wireless-MIMO-2x2-OEM-Digital- Data-Link-pd45467385.html

Raheem Nhair, R., & Al-Assadi, T. A. (2020). Vision-Based Obstacle Avoidance for Small Drone using Monocular Camera. *IOP Conference Series: Materials Science and Engineering*, *928*, 032048. https://doi.org/10.1088/1757-899x/928/3/032048

RC Airplanes Simplified:Plans,Design,Build and Much More. (n.d.). Https://Www.rc-Airplanes-Simplified.com/.

Remote Sensing. (n.d.). Www.mdpi.com. Retrieved March 18, 2024, from https://www.mdpi.com/journal/remotesensing/special_issues/LiDAR_wildfire#:~:text=Lidar%20is%20a%20useful%20remote

Richard. (2019, August 24). How Coulombic Efficiency in Batteries Works. News about Energy Storage, Batteries, Climate Change and the Environment. https://blog.upsbatterycenter.com/coulombic-efficiency-in-batteries/#:~:text=Lithium-ion%20batteries%20have%20one%20of%20the%20best%20coulombic

Selig, M. (2010). *UIUC Airfoil Data Site*. Illinois.edu. https://m-selig.ae.illinois.edu/ads/coord_database.html

Settele, F., & Bittner, M. (2019). Energy-optimal guidance of a battery-electrically driven airplane. *CEAS Aeronautical Journal*, *11*(1), 111–124. https://doi.org/10.1007/s13272-019-00398-x

Sever, M. (2020, January 23). *What Is Left in the Air After a Wildfire Depends on Exactly What Burned*. Eos. https://eos.org/features/what-is-left-in-the-air-after-a-wildfire-depends-on- exactly-what-burned

Simes, T., Pádua, L., & Moutinho, A. (2024). Wildfire Burnt Area Severity Classification from UAV-Based RGB and Multispectral Imagery. *Remote Sensing*, *16*(1), 30. https://doi.org/10.3390/rs16010030

SIYI MK15 Mini Handheld Remote Controller Radio Transmitter 5.5-Inch HB Screen 1080p 15KM Video transmitter. (n.d.). One-Stop Drone Parts Store. Save BIG. https://www.droneassemble.com/product/siyi-mk15-mini-handheld-remote-controller-radio-transmitter-5-5-inch-hb-screen-1080p-15km-video-transmitter/

Sniffer4D – Sniffer4D – Mobile Air Poluttant Mapping System. (n.d.). https://sniffer4d.eu/sniffer4d/

Software Overview. (n.d.). PX4 Autopilot. https://px4.io/software/software-overview/

Southwest Antennas - High Performance RF and Microwave Antennas & Custom Antenna Manufacturing. (n.d.). Southwestantennas.com. Retrieved March 17, 2024, from https://southwestantennas.com/products/omni-antennas/4g-lte-cellular-omni-antenna-690-960-mhz-1710-2170-mhz-2400-2700-mhz-215-dbi-gain

Tailsitter Planes — Plane documentation. (n.d.). Ardupilot.org. https://ardupilot.org/plane/docs/guide-tailsitter.html

Temporary Flight Restrictions (TFRs) | Federal Aviation Administration. (2022). Faa.gov. https://www.faa.gov/uas/getting_started/temporary_flight_restrictions

Tundra Drone Siren Herder. (n.d.). Tundra Drone. Retrieved March 22, 2024, from https://tundradrone.com/product/tundra-drone-siren-herder/?c=f37ec89cf952

Understanding Transceivers: What is a Transceiver and How Do They Work? (n.d.). Ampheo Electronics. https://www.ampheo.com/blog/understanding-transceivers-what-is-a-trans ceiver-and-how-do-they-work.html

Unmanned Aerial Vehicles (UAVs). (2021). Hexcel.com. https://www.hexcel.com/Resources/UAV

Viitakoski, M. (n.d.). *What is hyperspectral Imaging?: A Comprehensive Guide - Specim Spectral Imaging*. Specim. https://www.specim.com/technology/what-is-hyperspectral-imaging/

VTOL Drone - Lynx VTOL drone for mapping and survey. (n.d.). SRP. https://srp.aero/lynx-vtol/

What are the advantages of twin engine versus single engine for turbo-prop airplanes? (2015, November 18). Viking Air Ltd. https://www.vikingair.com/twin-otter-series-400/twin-otter-answers/what-are-advantages-twin-engine-versus-single-engine-turbo#:~:text=There%20are%20also%20performance%20and

What are? PARTS OF A WILDFIRE. (n.d.). https://www.nwfirescience.org/sites/default/files/publications/Parts%20of%20a%20Fire.pdf

What is UAV LiDAR? (n.d.). Routescene. https://www.routescene.com/resources/what-is-uav-lidar/#:~:text=A%20UAV%20or%20drone%20is%20an%20aircraft%20without

Why Choose a Scimitar Propeller Blade? (2020, May 6). Hartzell Propeller. https://hartzellprop.com/why-choose-a-scimitar-propeller/

Wildfires: Interesting Facts and F.A.Q. (n.d.). https://nhmu.utah.edu/sites/default/files/attachments/Wildfire%20FAQs.pdf

Wubben, J., Morales, C., Calafate, C. T., Hernández-Orallo, E., Cano, J.-C., & Manzoni, P. (2022). Improving UAV Mission Quality and Safety through Topographic Awareness. *Drones*, *6*(3), 74. https://doi.org/10.3390/drones6030074

Yaesu FTA-450L Comm-Only Aviation Transceiver. (n.d.). Marv Golden Pilot Supplies. https://marvgolden.com/yaesu-fta-450l-comm-only-aviation-transceiver/

Zhang Wangfei, Chen Erxue, Zengyuan, L., Hao, Y., & Lei, Z. (2020). Review of Applications of Radar Remote Sensing in Agriculture. *DOAJ (DOAJ: Directory of Open Access Journals)*. https://doi.org/10.12000/jr20051