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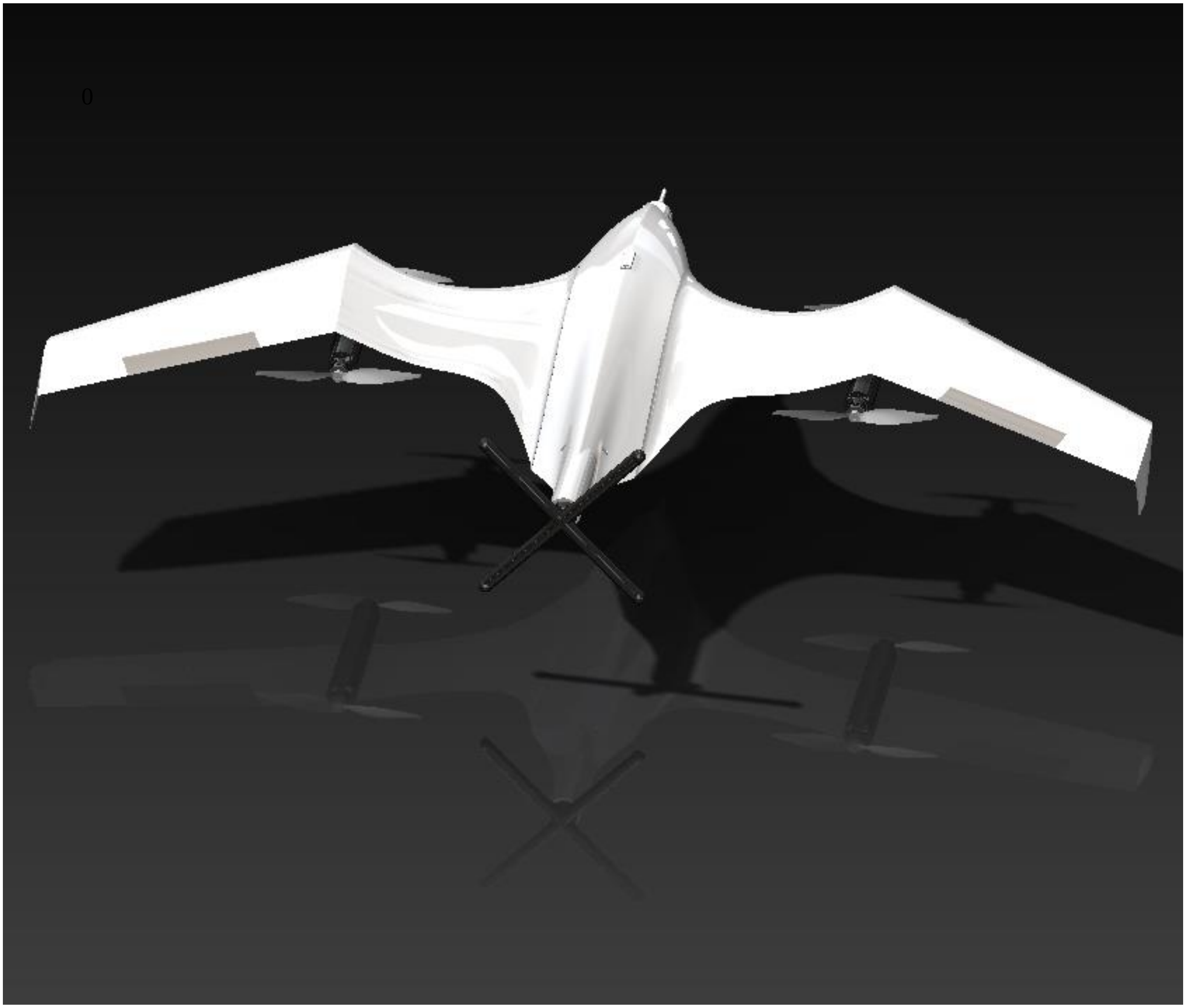

StratoAvis S-713 'Ranger'

Agile Aerial Unit for Wildfire Response

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RWDC FY-24

S-713 Wildfire Response Aerial Unit

Submitted in Response to the Real World Design Challenge

Submitted by

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Executive Summary

Despite advancements in mitigation technologies and efforts made, wildfires remain highly destructive events across multiple regions. For example, more than 362 thousand acres are burnt due to wildfires during 2022 in California [1]. As a fast-growing industry, UAVs have been taking up significant roles in firefighting, with 900 government agencies adopting UAVs in their firefighting operations in the U.S. [2]. Wildfire fighting agencies have also increased their fleets of UAVs, 2389 tasked flights were completed in 2019 [3].

While drones are taking up an increasingly significant role, it must be acknowledged that current usage of UAVs in fire mitigation is limited. Current wildfire missions commonly use multirotor UAVs [4] with their capability of thermal and optical imaging [5]. These professional multirotor UAVs are also able to carry payloads of approximately 3 kg. However, they lack the ability to effectively scan large areas and provide more complicated sets of data. Most such UAVs are also incapable of taking direct actions, while more expensive and heavier units are able to launch rockets to put out smaller fires. These current limitations restrain the performance of UAVs in wildfire mitigation.

In response to current shortcomings and mission requirements, the StratoAvis System proposes a VTOL system solution, S-713. The S-713 utilizes a blended-wing-body bionic wing design to optimize its structural dynamics and aerodynamic efficiency. While providing a wide variety of data collection methods and dependable carrying ability, the S-713 solution shows a decrease in cost and increase in flight performance compared to its counterparts.

With a fixed-wing layout, the 30-minute endurance and 5-mile communication range can be easily satisfied. The design sector is hence focused on, using the Occam's razor, the optimization of airframe to minimize the requirements for construction and materials. An M-shaped innovative bionic wing form is eventually chosen, affiliated with a pair of fixed inverted stabilizers to provide optimal structural and aerodynamic performance while maintaining a small wingspan. CFD and wind tunnel experiments have been conducted to ensure the validity of the process, and a 1:2.7 functional model of the airframe has been produced for demonstration.

The entire UAV and dependent systems can be dissembled into eight segments when transporting, easily contained in a backpack carried by a pair of hiking operators. The design of the UAV incorporates rapid installation and high survivability, making it competent for extended operations in the harsh conditions. Meanwhile, the safety and controls team have developed extensive control and command strategies for the

UAV in order to best function in the case of wildfire mitigation, allowing the S-713 to be competent in both performance and other means.

For business extension, not only is the design a cost-efficient alternative for existing solutions, it is also applicable to other scenarios, including communications restoration or hydrological surveys.

Hence, the StratoAvis team provides a revolutionary high-performance wildfire mitigation UAV, which brings the utilization of UAVs in emergency response missions to a higher level.

Specification Table

Table 1. Specifications.

Criteria	Value	Met (yes/no)	Section #, page #
Aircraft			
Takeoff weight	5941 g		#2.3.2 P31
Wingspan (fixed-wing) or max width (other)	1.89 m		#2.3.1 P18
Operational/communication range. At least 5 miles.	>9.375 mi	Y	#2.3.2 P24, 25
Cruise Velocity	20-56 m/s	Y	#3.2 P42
Pre-Fire			
Method to measure fuel type and amount. Better than current methods.	AI Image Analysis, Optical data	Y	#3.1.1 P38
Method to measure moisture levels. Better than current methods.	Atmospheric Sensing, Radar	Y	#3.1.1 P37, #2.3.3 P30
Method to measure air boundary layer. Better than current methods.	Hypersonic sensor, atmospheric sensor.	Y	#3.1.1 P37, #2.3.3 P29, 30
Method to measure thermal information. Better than current methods.	Gimbal Camera	Y	#3.1.1 P37
Active Fire			
Method to measure current fire edge. Better than current methods.	Gimbal camera and AI	Y	#3.1.2 P39
Method to measure thermal information. Better than current methods.	SWIR and gimbal	Y	#3.1.2 P39, #2.3.3 P29
Method to measure fuel type and amount. Better than current methods.	AI analysis, gimbal and radar	Y	#3.1.2 P39
Method to measure moisture levels. Better than current methods.	Atmospheric Sensors, Radar	Y	#3.1.2 P39, #2.3.3 P30
Method to measure air boundary layer. Better than current methods.	Hypersonic sensor, atmospheric sensor.	Y	#3.1.2 P39, #2.3.3 P30
Measure in presence of dense smoke.		Y	#3.1.2 P39, #2.3.3 P28, 29
Post-Fire			

Method to measure vegetation. Better than current methods.	AI Image Analysis, Optical data	Y	#3.1.3 P41
Method to measure moisture levels. Better than current methods.	Optical RGB and atmospheric sensors	Y	#3.1.3 P41#2.3.3 P30
Method to measure air boundary layer. Better than current methods.	Hypersonic sensor, atmospheric sensor	Y	#3.1.3 P41, #2.3.3 P30
Method to measure thermal information. Better than current methods.	SWIR and gimbal	Y	#3.1.3 P41, #2.3.3 P29
UAS Command, Control, and Communication			
Provide real time and accurate location information		Y	#2.3.2 P27
Detect and Avoid (DAA)			
Aircraft must detect static and dynamic obstacles		Y	#3.3.1 P 42-44
Aircraft must avoid conflicts		Y	#3.3.1 P42
DAA system architecture must fit with C3 capabilities		Y	#3.3.1 P43, #2.3.2 P24
Lost Link Protocol			
Aircraft must have protocols in case of partial loss of communications		Y	#3.3.2 P45, 46
Aircraft must have protocols in case of total loss of communications		Y	#3.3.2 P46

1. Team Engagement

1.1 Team Formation and Project Operation

StratoAvis Systems is an extracurricular student start-up company consisting of aerospace enthusiasts with different strengths around the world formed in June, 2023. The StratoAvis Systems RWDC Team is formed by core engineers who are willing to participate from the start-up company and externally recruited students from Shanghai Pinghe School, who are less experienced in aerospace engineering but interested by aspects of the project. The team initiates the course of this challenge by evaluating and integrating design requirements specific to this purpose onto existing solutions that are close fit to UAVs that can satisfying the terms.

Hanyue (Henry) Shen (Leader and General Engineer): G-11 high-schooler at Shanghai Pinghe School. He holds responsible for all flight science prior research and analysis, as well as taking up most design procedures of the S-713, including the initial designs and adaptations. The initial idea of the biomimetic design derives from his research project. As a licensed UAV pilot, Survey Engineer, experienced UAV designer, interned at Shanghai Academy of Spaceflight Technology and Jet Propulsion Laboratory as satellite control engineer and research intern respectively, and award-winner of the Yau Science Awards, he is experienced with all aspects of the design procedure of UAVs, from aerodynamic evaluations, CFD, optimizations, structural and aeroelastic engineering, to control systems and field operations.

Kele (Floria) He (Material and Safety Engineer, Business Engineer): G-10 high-schooler at Guiyang No. 1 School. As one of the core design team members of StratoAvis System company, Floria has engaged in the material evaluations, manufacturing, and flight safety evaluations for previous models designed by the StratoAvis Systems, the S-701 and S-712, as well as taken part in marketing evaluations and calculations of the UAV. She has taken the same role in the RWDC challenge, while taking up more role in the business evaluations than previously did. Being a provincial representative in the Chinese Mathematics Olympiad and experienced project leader in material science, she is able to apply his professional knowledge to improve the design of our UAV.

Zhengsiyue (Kelly) Gao (Payload and Control Engineer): G-11 high-schooler at Shanghai Pinghe School. As an experienced engineer in robotics and sensing technologies, she is responsible for the development of control strategies and the selection and evaluation of onboard payloads in the challenge, which not only involves traditional sensing methods, but also, in our instance, incorporates elements of machine learning and prediction models. She is a high-level associate of the SSAYT and is experienced in engineering projects and contests.

Ningzi Chen (Environment and Control Engineer): G-10 high-schooler at Chongqing Bayu School. Previously conducting a project as a Yuanpei Project participant on wildfire prediction models, she plays the crucial role of environmental evaluation and related strategy developments in the RWDC challenge. With her extensive knowledge on wildfire mitigation, her role is to better integrate the functions of the product into the required scenario.

YuCen Ying (Assistant Mechanical Engineer): G-9 student at Shanghai Pinghe School. As a student with former experience on smaller engineering projects, he is responsible for the modeling and production of some mechanical parts and payloads required by the system engineering sector.

Ruqing Xu (Data Engineer): G-9 student from Shanghai Pinghe School. As an experienced computer programmer, he is in charge of affiliating the work of data collection and strategy formation as required by the system and control engineering sectors.

1.2 Acquiring and Engaging Mentors

While the core of the team is situated in Shanghai, we have best utilized the advantages brought by our location. Being one of the centers of China’s newborn eVTOL industries, Shanghai is the home of a large number of civil companies as well as the COMAC headquarters, SAST (rocketry and sensing technologies), and a number of universities involved in the aerospace industry, including Tongji University, Jiaotong University, and Fudan University. It is also in close vicinity to Jiangsu Province, home to Nanjing University of Aeronautics and Astronautics and a few other institutions specialized in flight sciences. These institutions and firms are able to provide our team with advisors both in technological terms and in applications.

Professor Daqing Huang is our main mentor for this stage of the project. As the vice president of the Unmanned Aerial Vehicles Research Institute of NUAA and the CEO of his own company, he is an ideal choice of mentor who is proficient both in system engineering and in commercialization and applications. While the team members are equipped with the basic professional knowledge, he provides the team with insights that guides the general direction of the design and plausibility of proposals.

Dr. Qiang L. is a control engineer specialized in rocketry at SAST. He has provided the team with knowledge on flight controls and related mechanical designs.

Other professionals have also given the team valuable suggestions for which we are grateful of, and will not be extended here.

Here we also acknowledge other important mentors who have generously given support for the development of S-701, the predecessor of S-713. These stages are completed individually by the general engineer.

Dr. Jonathan Jiang of Caltech – JPL has mentored the development of the project during June to August 2023, providing valuable insights into research methodology and applications. He is a crucial mentor in the development stage of the predecessor of S-713, which determines the wing form and its improvements compared to common solutions.

Mr. L. Fang, Ms. Duan W., and the SAWTC CWT engineering crew have assisted the wind tunnel experiment of the full-scale half model of the S-712 wing, the results of which have validated the theoretical assertions of the preliminary research. We are honored to have their assistance.

1.3 State the Project Goal

The StratoAvis team has been invited to produce a proposal on fire mitigation UAV capable of, minimally, situation sensing in pre, mid, and post stages of fire, including thermal, environmental, and weather data collections. It is also required to be capable of a minimal control distance of 5 miles, and can be carried by hiking operators. The minimal cruise duration is 30 minutes. The system is also required to provide real time location updates to other aerial systems operating in the same region. Meanwhile, costs and communication plans must be generated by the team in terms of business.

Through the general technological requirements, the StratoAvis team interprets these implications:

- Operational weight is heavily limited, hence multirotor and helicopter solutions are not advantageous.

The system requires flexible transportation by a hiking operator. According to existing conclusions, a hiker must not carry more than 20% of their body weight [6], and substituting with average data of Americans [7], we give a maximum carriage of 10.5 kg (at 15% of the bodyweight, considering that other utilities needed aside from the UAV system is needed). Under this constraint, it is meaningless in payload terms to adopt multirotor or helicopter solutions which are typically extremely payload-efficient but not range efficient. Therefore, VTOLs and tiltrotor solutions are also justifiable competitive layouts considering this requirement.

- Cruising efficiency is not a priority.

The cruising requirement of 30 minutes, although fitting with commercial level multirotor solutions, is a low requirement for mixed-wing or industrial helicopter solutions. Hence, cruising efficiency, despite being a required consideration, is not a prioritized consideration as the term can be easily satisfied.

- Prefer stable layout and aeroelastic-improved structure.

Wildfire frontlines are turbulent in many aspects. The takeoff conditions are harsh, while the heat from the fire and wind conditions cause turbulence in flight. For this reason, the UAV must adopt a stable design which is able to resist the harsh airflow conditions. Such conditions could cause severe effects such as aerodynamic fluttering. Meanwhile, to prevent loss of control due to bad flight attitude, a stable layout is preferred, which implies advantages of winged solutions. These stable layouts will be able to resume flight attitude even if the propulsion is insufficient to counter the airflow.

- Must have large cabin space.

The minimal sensing requirements will result in the usage of multiple types of sensors corresponding to their separate situations. To install these sensors and their related dependencies, such as data protocol transitions and battery, there must be a larger cabin space that satisfy the installation of these parts as well as the common control and command utilities.

- Must provide fast assemble/dissemble structure.

It is illogical for the hiker to carry a fully expanded UAV, which causes hazard both to the hiker and to the UAV. Hence, the UAV must be able to be dissembled in a way suitable for individual transportation. Meanwhile, due to the emergency of the scenario, the UAV must be able to allow quick restoration from the dissembled state to the mission-ready state without the usage of complicated tools and time-consuming procedures.

- Must implement DAA system.

As there are other aerial systems (such as manned helicopters) and possible avian creatures present in the region, the lightweight UAVs are obligated to avoid these potential sources of collision. Hence, a system must be present to warn the operator of possible collisions to take corresponding actions.

The design by the StratoAvis System follow these interpreted guidelines as well as the original guidelines.

1.4 Tool Setup/Learning/Validation

Despite participating in the RWDC for the first time, the team consisted of a strong and experienced engineering crew with varied knowledge of tools required to plan unmanned aerial systems, along with previous knowledge of USV/UAV designing, forest fire prediction, AI algorithms, etc.

Profili 2: an airfoil analysis tool with a rich database, capable of performing preliminary analysis on foils with **Xfoil** core. It is used for airfoil comparison, selection, and modification.

Flow 5 and XFLR 5: aircraft design tools that use VLM/Panel methods to give preliminary predictions to the aerodynamic properties of the wing design. Using this tool, balancing and aerodynamic optimization can be done with fast iterations. Flow 5 is also capable of particle swarm optimization, which aids in adjusting complex wing twisting.

AutoCAD: a planar CAD tool used to draw initial plans for airfoils and some internal structures, which can be imported to SolidWorks as sketches for further development.

SolidWorks Flow Simulation and Simulation: a professional CAD tool used to develop and virtually assemble the full system, as well as provide insights into full-UAV aerodynamic analysis, structural analysis, and aeroelastic analysis to more accurately validate parameters and make adjustments accordingly.

Symula: an online wind tunnel platform the team used in preliminary stages to run aerodynamic diagnostics of the full design.

MATLAB: a professional mathematics tool utilized to analyze collected data and generate plots to aid optimization process and demonstration.

Microsoft Word: a text writing and formatting software used for the final version of the engineering notebook.

WeChat: one of the prevalent communication tools in China, where the team conducts virtual meetings and update results in the group.

1.5 Impact on STEM

Through this project, the StratoAvis team have obtained more first-hand experience in the process of system engineering and design, especially in terms of designing the system in a specific context. We have exercised knowledge on the different aspects the system design requires, aside from flight sciences and electronics, and have practiced in blending them in an operable way, modifying the systems to make way for one another in order to form a well-integrated product.

Our design has also interested Aviation club and enthusiasts in our school. As the head of the school Aviation club, the team leader also pass on experiences and holds demonstrations with other interested students to encourage engagement in aeronautics. Physics and engineering teachers at school are also interested by the development of the large-scale project in response to RWDC.

2. System Design

2.1 Engineering Design Process

The development of the product follows a standard iteration procedure of interpretation, optimization, and finalization.

The workflow moves from segments from left to right, and completes the subdivided sections in order, unless a certain term is not satisfactory and reverting to previous stage is required. To ensure that the layout is an efficient one, when analysis of layout indicates a low efficiency even after optimization trials are made, the design phase will revert to the start of the Evaluation phase and re-consider for another layout.

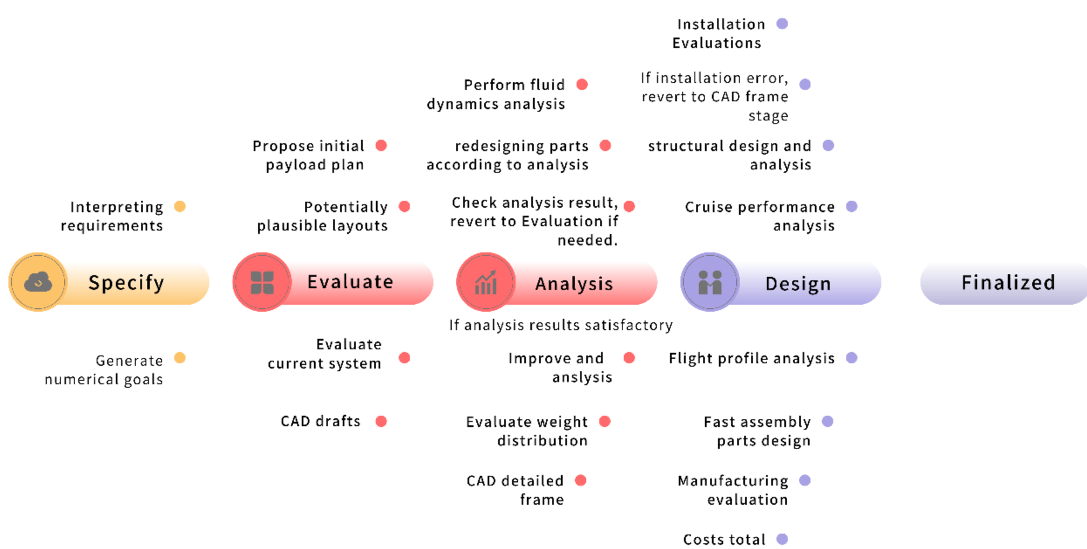

Figure 1 Working Process

Specification Phase

In this phase, the team turns the design requirements into specific numbers, which helps setting optimization goals in the design process.

Evaluation Phase

In this phase, the control and payload team generate a rough draft for the payload planning on the UAV, while the design team brainstorms possible layouts. The original S-712 plan is evaluated and improvement requirements are specified. Quick CAD drafts for the different layouts are generated once the design team believes that it should be considered.

Analysis

At this stage, airframe and flight-related designing is carried out, which helps improving the design of different parts of the UAV as well as confirming which layout should the final design adopt. In this stage, once a layout is believed to be unsatisfactory, the design is zeroed out and starts back again from the evaluation phase.

Design

The system design phase focuses on further design details of the UAV, including arranging the internal and external devices needing to be installed, the internal structure of the UAV, and the conclusive calculation of numbers of the UAV such as the flight range, flight duration, etc.

2.2 Project Pelan

The team devised the following planning that outlines the basic progress of the project, ensuring sufficient time for thorough investigation on each phase.

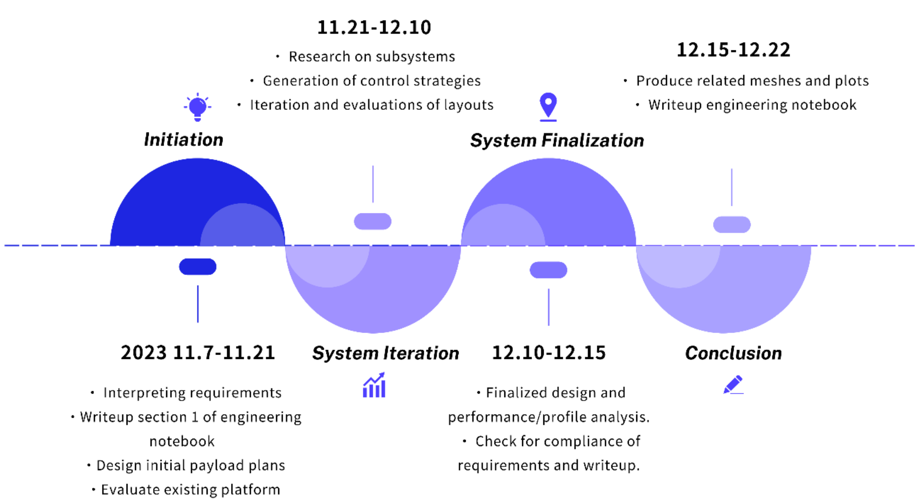

Figure 2. Project timeline

The distribution of time is based on previous experience of the team in designing, with special considerations to the relatively tight schedule and the curricular events that might reduce the time devotion to the project temporarily. This table does not reflect iteration and minor corrections, which are dynamically planned within the course of the project.

2.3 Subsystems

2.3.1 Air Vehicle

With reference to section 1.3, the StratoAvis team carries out the design process with these targets. These requirements that are crucial to the selection of the layout as well as optimizations.

- Cruise Time: at least 90 mins;
- Effective Payload: at least 20% of takeoff weight (propulsion system excluded)
- Takeoff weight between 5000 g to 6000 g;
- Flexible takeoff and landing;
- Maximum flight velocity over 30 m/s;

While these metrics are required, there are several other metrics that are important, including reliability and stability. The different layouts and their respective evaluations are listed below.

Table 2. Layout evaluation.

Layout/Requirement	*Endurance*	*MTOW*	*Speed*	*VTOL*	*Reliability*	*Stability*	*Consider?*
Multirotor	N	Y	N	Y	High	N	N
Fixed Wing	Y	Y	Y	N	High	Y	Y
Helicopter	Y	Y	N	Y	Low	N	N
Fixed QP	Y	Y	Y	Y	High	Y	Y
Tiltrotor	Y	Y	Y	Y	High	Y	Y
Transitional	Y	Y	Y	Y	High	Y	Y

While all types of VTOLs can satisfy all design requirements, the fix-winged design can also satisfy the mission requirements if a pneumatic catapult launch combined with parachute recovery is implemented, allowing it close-to-VTOL takeoff mobility. Hence, there are, in total, four layouts considered in our design.

The design of the control system is separated from the design of the airframe, as the C3 modules selected can operate with all types of layouts considered. However, they still influence the design in terms of requirements for cabin dimensions. The design of the aerodynamic layout and the specific airframe are also separated in response to the adaptability method of design the team exercises. The team gives an aerodynamic layout design with capability to be integrated with different propulsion setups.

The initial drawings of three of the considered layouts are given – the FW, QP, and TR designs.

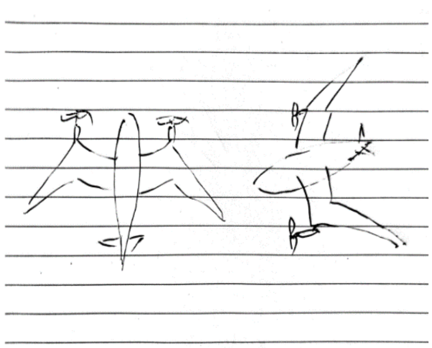

Figure 3. FW Sketch

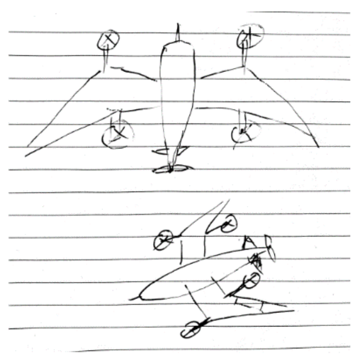

Figure 4 QP Sketch

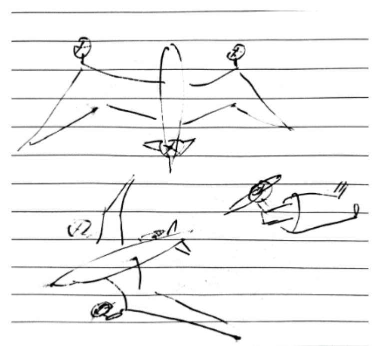

Figure 5. TR Sketch

These are the first designs analyzed, and a later design is produced for transitional layout. Notice that all these designs are based on the BWB layout and the hanging points on which different nacelles can be applied.

Preliminary Design

Between the initially sketched layouts, the tiltrotor design is selected for its efficiency in aerodynamic properties as well as reduction in deadweight carried by the UAV. It is able to satisfy the VTOL requirement without having a large deadweight as the QP layout would. It is also safer and less complex than the FW model. Despite the FW model having no deadweight except the parachute, it requires operators to carry a rail for pneumatic launch. This is a more complex installation and hence out of consideration.

Finalized Layout

The finalized layout is a transitional VTOL. The VTOL does not have any vector propulsion. Rather, it takes off with its propellers facing upwards and alter its attitude to cruising state with the elevons when reaching transition height.

While using four rotors in total, adding to the safety standards of the UAV as any partial failure on any or both sides will not cause crash, while a crash is very possible if any of the multirotor propulsion fails in the 4+1 or Y3 tiltrotor designs.

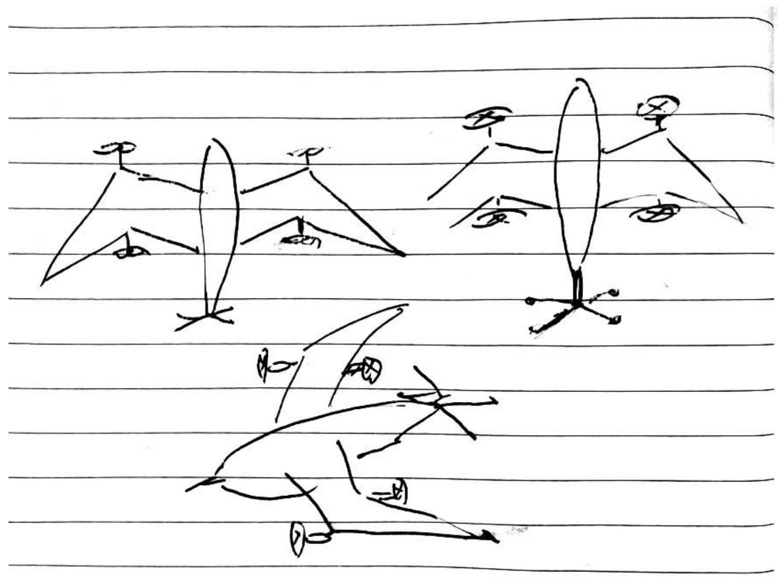

Figure 6. Finalized Layout

An additional X-shaped tail is added to the UAV. While it does not provide aerodynamic balancing, it is beneficial for the stabilization of the aircraft when it lands vertically on its tail.

Fuselage Design

To maintain aerodynamic efficiency as well as a small size, a blended-wing-body layout (BWB) is utilized, featuring smooth transition between the body and the main wings. Meanwhile, to maintain the cabin dimensions, the fuselage is designed to be larger than a totally smother BWB as in cases such as the B-2 bomber.

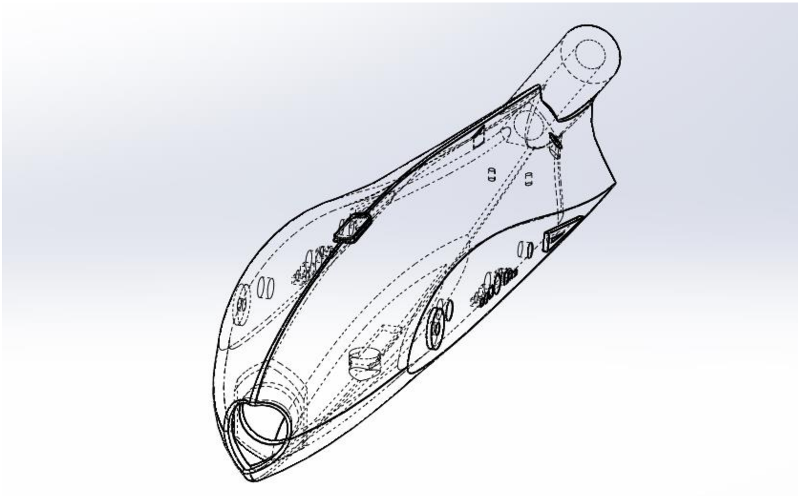

Figure 7. The BWB Fuselage initial sketch.

With consideration to installing avionics, the fuselage is further modified with a removable cap cut out from the main structure, and can be fixed onto the main frame by ten M3 screws.

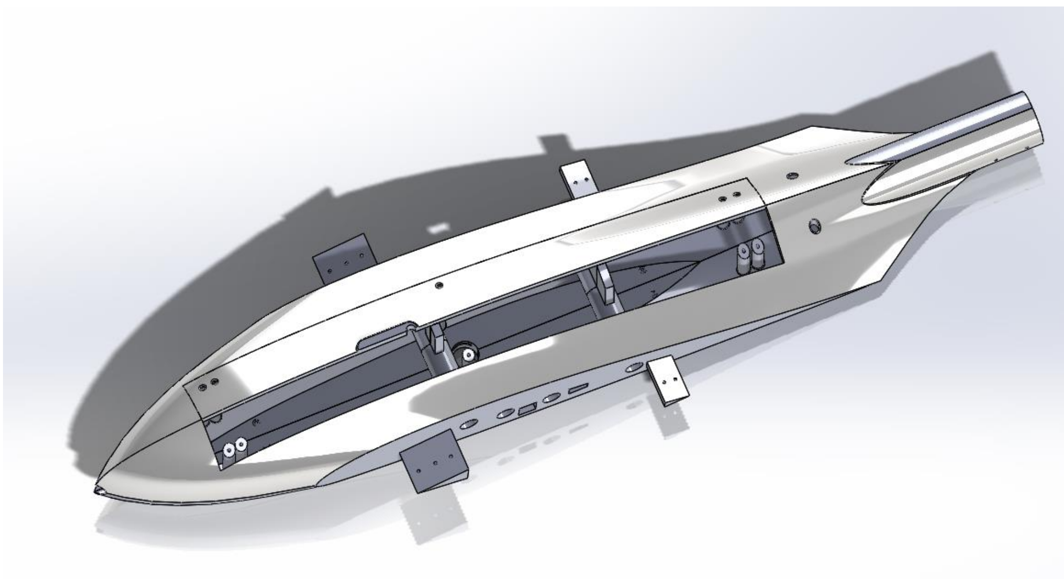

Figure 8. Final CAD of the fuselage. It shows the fuselage with half of the cap removed.

Airfoil Selection

For stability, the StratoAvis team has decided on selections of high-efficiency low-moment airfoils. Using Profili 2, at 30 m/s, we calculate that the Reynold's number of the UAV is approximately 610,000.

Table 3. Airfoil comparison [11].

Type/Factor	*Max L/D*	*Max Thickness*
StratoAvis Z-20	105 @ 8 deg	11.90%
HS-510 12.3%	101 @7.5 deg	12.3%
MH-78	82 @ 8 deg	10.84%

Prior StratoAvis products use the Z-20 airfoil, which is a combination of the MH series and highly curved airfoils to aim for high lift and good stalling properties. However, for a BWB design, it will pose stability issue as its pitching moment is large.

While the MH-78 and HS-510 are low-moment airfoils that allows the wing to be easily adjusted to balance position even without a stabilizer, the Z-20 airfoil developed by the StratoAvis team has an excessively large pitching moment despite its highest aerodynamic efficiency. Hence, the HS-510 modified version is chosen for it maintains aerodynamic efficiency as well as the low-moment quality. The thickness of the wing also reduces production difficulties.

Wing Form Design

The team uses the high-speed wing form uniquely developed by previous researches by the team leader and utilized previously by the StratoAvis core team. The following table lists comparisons of the performance of the wing form and more commonly used types.

Table 4. Wing form evaluations.

Wing form	*Low-Speed Eff*	*Aspect Ratio*	*Loading capability*	*CTRL Eff*	*L/D Ratio*
High Speed	Optimal	Medium	High	High	High
Backward	Medium	High	Low	Medium	High
Forward	Low	Medium	Low	High	Medium
Elliptic	High	Medium	Low	High	High

In the case of wildfire, as there is not a strict requirement for endurance and range, the aerodynamic efficiency does not pose a primary design issue. Rather, a wing which is able maneuver in highly turbulent areas and dash at higher speeds is preferred. The aspect ratio of the wing is also an important matter. Due to the requirement for agile deployment, a long, thin wing is not a preferred solution as it will require more complicated packaging. Hence, the high-speed wing of the StratoAvis team is a preferable selection for this matter.

Figure 9. The S-701-C Prototype on the left of a larger VTOL in the StratoAvis team lab. The high-speed wing adopts a unique M-shape compared to conventional wing forms.

The wing of the S-701 has an aspect ratio of approximately 7.8, which is slightly less than that of the Boeing-737, but has a maximum lift-drag ratio of over 19 at 19 m/s, which is higher than the cruising efficiency of the 737 [8][9].

The wing of the StratoAvis is tested in the Tongji University's SAWTC conditions wing tunnel installation, which is able to indicated that simulated results ran by the team is within industrially acceptable level of deviation (less than 8% in pressure and less than 4% in displacements). The high-speed wing shows an over 5% decrease in aeroelastic bending, over 20% decrease in highly loaded area, and over 8.8% decrease in loading stress compared to an efficient-optimal tapered wing under equivalent lifting conditions [10], indicating its value in improving loading ability and structural optimization of the wing.

Figure 10 Installing the S-701-C high-speed wing inside the Conditions Wind Tunnel

The wing is slightly modified to cater to manufacturing requirements for the later models, by giving slightly more positive twists to some inner chords, while the changes caused to aerodynamic and aeroelastic properties are trivial.

With experience, let the minimal cruising speed to be approximately 21 m/s. The lift coefficient required can hence be calculated with the lift force formula:

$$F_{lift} = \frac{1}{2} C_L \rho S \cdot 21^2$$

Given the approximate value for the effective lifting area S, the required cruising lift coefficient can be solved for substituting the force to be able to counter the gravitation applied to 7 kg.

The data concerning the High-Speed wing is given below. Specific optimization processes will not be elaborated further here.

Table 5. SA high-speed wing configs.

Factor	Quantity	Unit
Aspect Ratio	7.788	/
Effective Lifting Area	0.498	m^2
Surface Area	0.514	m^2
Wing Span	1890	mm
Wing Length	2000	mm
Tip Twist	-0.8	deg
M.A.C.	283	/
MTOW	7180 @ 22 m/s	N
Stall AOA	11	deg
Max Efficiency	23.6 @ 22m/s	/
Static Stability Margin	2%	/

Propulsion Selection

The propulsion system of the UAV is consisted of four nacelles, powered by AT-2814 KV1200 rotors with the recommended 10*5.5 APC Propellers. At maximum, each rotor can output over 2.6 kg, which is sufficient for lifting a 7 kg (maximum) UAV. At 40% throttle, the output can reach over 900 g [12]. The propulsion factors are capable of commencing the design requirements of the UAV. Meanwhile, it must also be acknowledged that because of the propulsion selection, and that is generally undesired by UAV pilots to takeoff at over 70% throttle, structural weight must also be reduced maximally.

The AT-2814 rotor requires 4S battery for the power source and weight 108 g each. This allows sufficient propulsion to be provided without a heavy rotor or heavy power modules. The implementation of the four rotors also demonstrates a high-voltage low-current strategy. The distributed force allows all rotors to be able to operate at very low current during cruise, and hence less battery units need to be used.

Nacelle Design

The propulsion segment is consisted by removable nacelles on each side of the UAV. The nacelle is situated under the inner forward swept section of the wing so that it would not demand excessive extra structural enhancement.

In order to hold the propellers on a straight, horizontal line, the nacelle adopts a cylindrical shape, with a 40 mm * 20mm * 196 mm cabin space allocated to cables and two Skywalker 60A OPTO ESCs. The propellers are held on to the nacelle with four M3 screws and the speed controllers are fixed with tape.

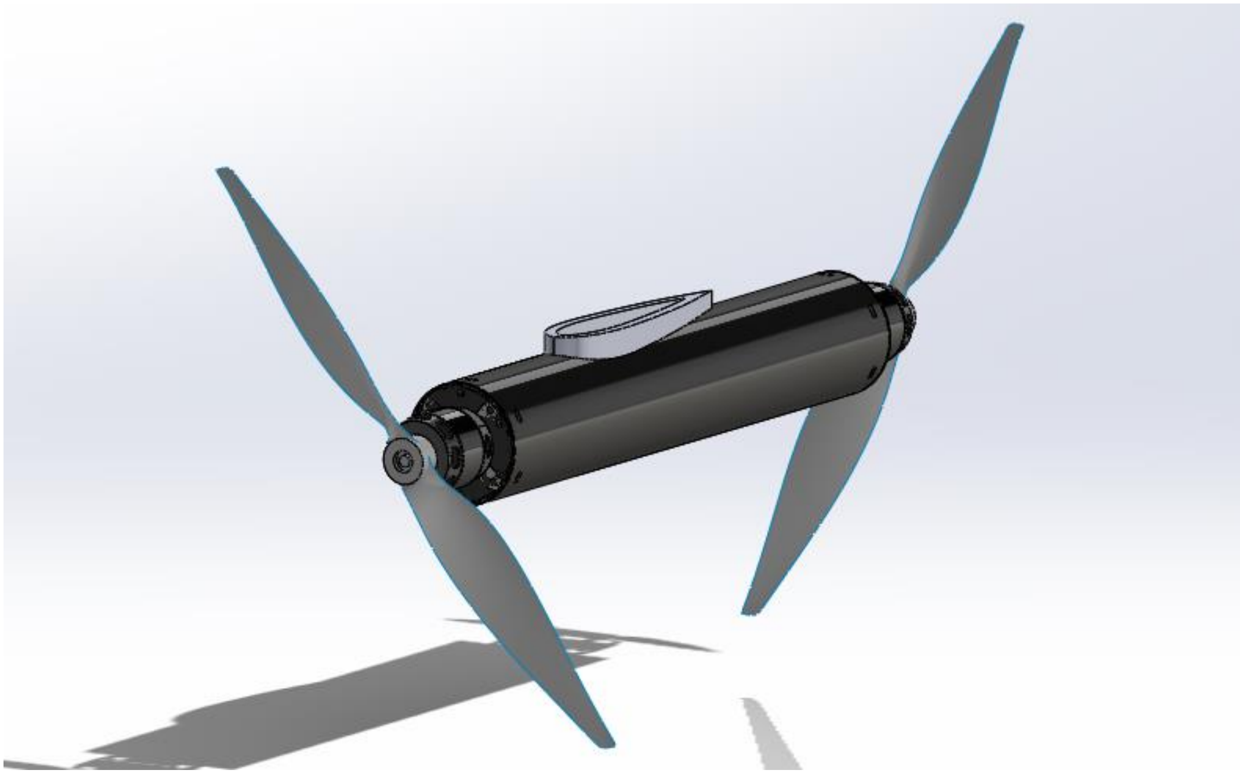

Figure 11. Nacelle design.

The nacelle is easily carried concerning its regular shape, while maintaining acceptable aerodynamic efficiency and internal space allowance, making it suitable for the designated mission.

Landing Gear Design

The VTOL will land on its tail. While some VTOLs adopt landing strategies such as the one utilized by PteroDynamics [36], they typically adopt long nacelles with their tips as the landing device. However, considering the geometry of the fuselage that aims for large cabin space, such a fuselage will become excessively long when used on our design. Hence, an alternative of placing an additional structure connected to the rear of the fuselage is chosen.

The landing structure is turned 45 degrees, providing stability for the UAV to stand upright in its landing position. Four spheres are integrated onto the X-shaped structure in order to provide small elevation for the structure to prevent landing failures as a result of minor unevenness on the ground.

Figure 12. X-shaped holding structure.

Structure and Docking Design

Considering the mobility of the UAV, unlike commonly used assembly methods, the S-713 design splits the wing into a total of four segments to reduce the difficulty of carrying the device for a hiker. Between the segments, there are two fixture measure taken. A pair of docking structures, either connected to one of the wing segments or as a separate component, is applied to the leading and trailing edges of each connection between the segments to dock them into place. Meanwhile, M3 standardized screws and locknuts are applied in the vertical direction (or a near-vertical direction) are used to lock the docking structure tightly so it is completely fixed. Through these two measures, the four segments will be installed easily when arriving at position and fixed rigidly. The docking measure is also used for connecting the main wing and the fuselage, as well as connecting the nacelles to the wing.

The S-713 does not have any conventional supporting structures. Rather, it is totally filled except for carbon fiber supporting structures. This greatly reduces the manufacturing difficulty and simplifies the repairment process when required.

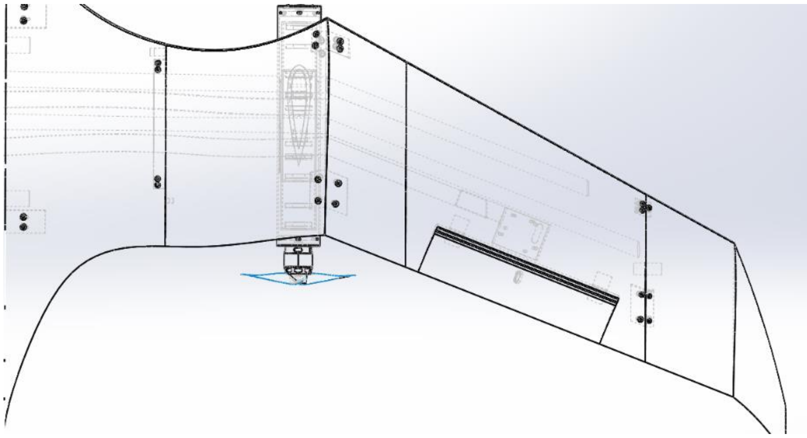

Figure 13. Internal structure of the wing, including carbon fiber, small connection parts, as well as cavities for cables.

The structural enhancement weight approximately 50 grams (overestimate) referencing the weight for carbon fiber tubes and industrial plastic [19]. The weight is almost trivial in moment calculations.

Quick Assembly

The operation requirements indicate that the UAV must be carried easily without large containers and can be assembled on spot with speed. Hence, each wing is transported with five segments (elevons included) and five small parts, while the fuselage is carried as a whole, with a covering removable cap if circuit repairment and checks are required. All 21 components except the fuselage have a length of under 500mm, making the assembly reasonable to carry on back.

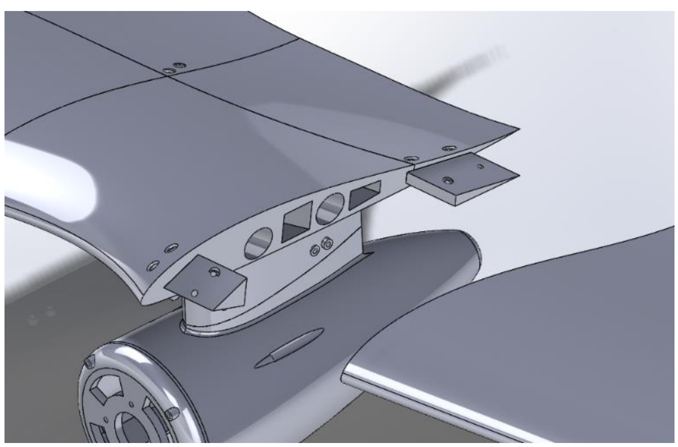

Figure 14. Detailed demonstration of quick-assembly docking design.

With electronic screw driver, each screw can be fixed within 5 seconds. With 54 screws needing to be fixed before flight, the assembly will be ready within 3 minutes after been taken out for installation with the effort of both operators. Considering all setup and pre-flight checks, under conditions where no anomalies occur, the VTOL will be ready within 8 minutes.

Structure Materials

The customary materials for small UAVs include foam, compound materials, and 3D printed materials. The approximate parameters of three common types of materials are given below.

Table 6. Evaluation of materials.

Material/Factor	*Density* g/cm^3	*Inflammable?*	*Strength*	*Production*	*Reparable?*
Composite	1.9 [13]	Y	Strong	Molding	No
eSUN PLA	0.54 [16]	Y	Strong	3D Print	Yes
Light Wood	0.32 [14]	Y	Medium	Assemble	Yes
Foam	0.96 [15]	N	Weak	Molding	Yes

With this comparation, it can be shown that while foam is the most ideal material based on its inflammability, it is relatively heavy and with weak strength, hence requiring complex additional supporting structures. Wood, although extremely light, is extremely flammable, and hence out of the question. Carbon fiber (and other compound materials) is commonly used for UAVs, but its density is high and the cost is expensive. With these considerations, the eSUN PLA material is selected (will be sprayed with fire-resistant paint) Despite it does not have the lightest density, 3D printing only requires filling the printed volume to 20%, hence only 20% [32] of the actual volume need to be calculated for the density.

The fire-resistant paint shall be calculated with thickness of 0.8 mm and density of 0.03 g/cm^3.

The structural volume of the S-713 is 15221.80 cm^3, the surface volume is 32617.87 cm^2. Hence, the PLA material gives the weight

$$M_{struct} = 0.2 \cdot 0.45 \frac{g}{cm^3} \cdot 15.82141\, m^3 \approx 1.424\, kg;$$

$$M_{paint} = 0.8\, cm \cdot \frac{0.03g}{cm^3} \cdot 14329.08\, cm^2 \approx 0.344\, kg;$$

Hence, the total airframe weight is 1.768 kg as estimated (nacelle structural included).

To maintain structural strength, some minor connection segments that will undertake high loadings are 3D printed with industrial plastic to ensure their strength. With a density of 1.3 [37], considering these parts are extremely minor in size, they will be simplified from the mass estimation.

This completes the statement on the airframe design, with the aerodynamic, aeroelastic, structural factors concerned discussed. Now, the avionics aspects will be discussed.

2.3.2 Command, Control, and Communications (C3) Selection

FMU and Air Units

There are two types of mainstream air unit FMUs – open source and closed source, respectively represented by PixHawk and the latter by large manufacturers such as AheadX. Although closed-source FMUs are generally industrially reliable and come with easily operated ground units, many of them are not capable of integrating with unconventional control requirements and anti-collision measures.

The team first considered Taurus II FMU – a closed-source industry solution by AheadX. However, after reviewing its capabilities, the team believes that it is incapable of satisfying the mission requirements, as it is not capable of integrating with the complex avionic system and payloads, as well as not flexible enough to cater to control demands. More importantly, it is not able to integrate with a collision-avoidance sensor.

With internet search, the team found that FMU units with PX4 as their cores will be capable of anti-collision mode given sensor data. Hence, a **CUAV 5+** autopilot module [39] is chosen as the FMU.

The CUAV 5+ FMU, based on PixHawk 4 FMU [20], has redundant sensing modules and is capable of receiving from 400MHz telemetry units, which are chosen instead of more commonly used 900 MHz ones in order to allow the UAV to be capable of operating with less interference in communications link, while the unit is also capable of performing anti-collision maneuvers when the mode is activated given target inputs.

The radio control reception unit is the **FR** receiver [24] by SIYI Tech. It is capable of long-range (15km) Bluetooth and radio transmission and will allow ground operator interference whenever required.

There are two sets of telemetry systems on the UAV, one directly connected to the FMU, the other transmitting payload information.

Since there is a relatively large variety of payloads carried, two **SIYI MK-15 Enterprise** [22] 15km range air units are used as the mission and payload telemetry. Condensing capabilities of the radio control and the telemetry as well as capability of connecting to a wide range of SIYI's products, it is a powerful mobile unit fitting the scenario.

Active DAA

The sensor input for the DAA system, in this case, comes from the **ARS** millimeter wave radar, which will be discussed more thoroughly in the payload section. It provides 80 degrees FoV for objects within 70 meters and 18 degrees for objects within 250 meters [31], allowing the system to be capable of detecting incoming threats operating at similar speeds (i.e. around and below 30 m/s) in time to conduct related maneuvers.

Under maximum velocities assumed, the DAA gives **1.17 seconds** for proximity reaction and **4.17 seconds** for long range reaction. These maneuvers are automated and the UAS will assume its pre-designed course once the threat is out of range.

The DAA system is mainly functional to avoid objects including: birds, other S-713 units, and other small or micro-sized UAVs. It is NOT capable of avoiding very fast systems.

Ground Unit

The ground units are consisted of two sections: the operator end and the payload control end.
The operator of the UAV carries the ground unit of **SIYI MK-15** [22] radio control. It corresponds to one of the MK-15 air units to give radio control as well as gimbal camera attitude controls. Note that accurate control can also be sent by commands via the ground station software.

The MK-15 control is also connected to an **ASUS TX-4** [25] computer, which is a high-performance lightweight windows system laptop which can be easily carried with the operational team. Moreover, its rigid screen betters glass screens in harsh conditions as it will be less vulnerable during transportation. The operators will connect with the UAV with the **Mission Planner** ground station software. This software is highly adaptable and will cater to the unconventional control sequences required for the takeoff. For automated flying sequences, Mission Planner will be in charge of controlling the aircraft, while MK-15 will only control the gimbal.

The operators will also carry a **F9N** [30] RTK unit tuned to the base station mode to provide accurate locating for the F9N RTK air unit. It will be situated near the liftoff location on a separate holder.

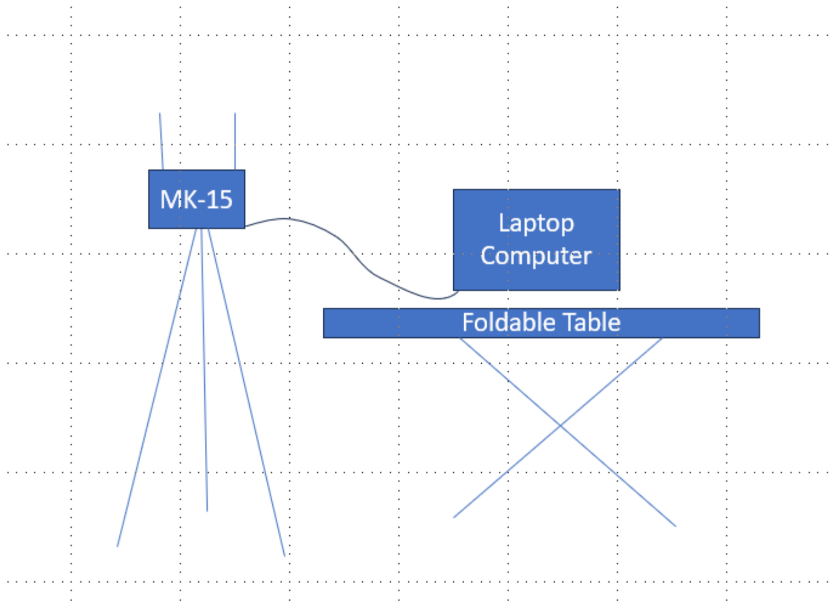

Figure 15. Demonstration of operators' unit setup.

On the other hand, the payload receiving sector uses a **HM-30** [26] ground unit affiliated with AAT (Automatic Antenna Tuning) directed antennae. This unit is used instead of the original MK-15 as the payload end does not require the mobility stressed by the MK-15, hence a longer-ranged antenna is preferred. The HM-30 is plugged into a computer for data transmission and display. This sector is based on a separate location, not with the operator.

The payload station is operated by two data scientists on a mobile vehicle at safe range from the fire. They will receive operational data collected by the operators, or multiple groups of operators if applicable, and update commands to the operators if necessary as well as producing analyses that act as guidance for further actions of all units involved. These people are located on a mobile truck at safe distance close to the HQ of the entire wildfire mitigation mission.

The truck provided is able to support two crews operating together. While both might operator S-713, it is possible that the other functions differently – for example, command for the mitigation mission. The layout demonstration of the commanding truck is given below. A space of 1.1 meters wide, 2.9 meters long, and 2.1 meters tall is allocated to the two data scientists, with the AI data scientist on the right and the environmental data engineer on the left.

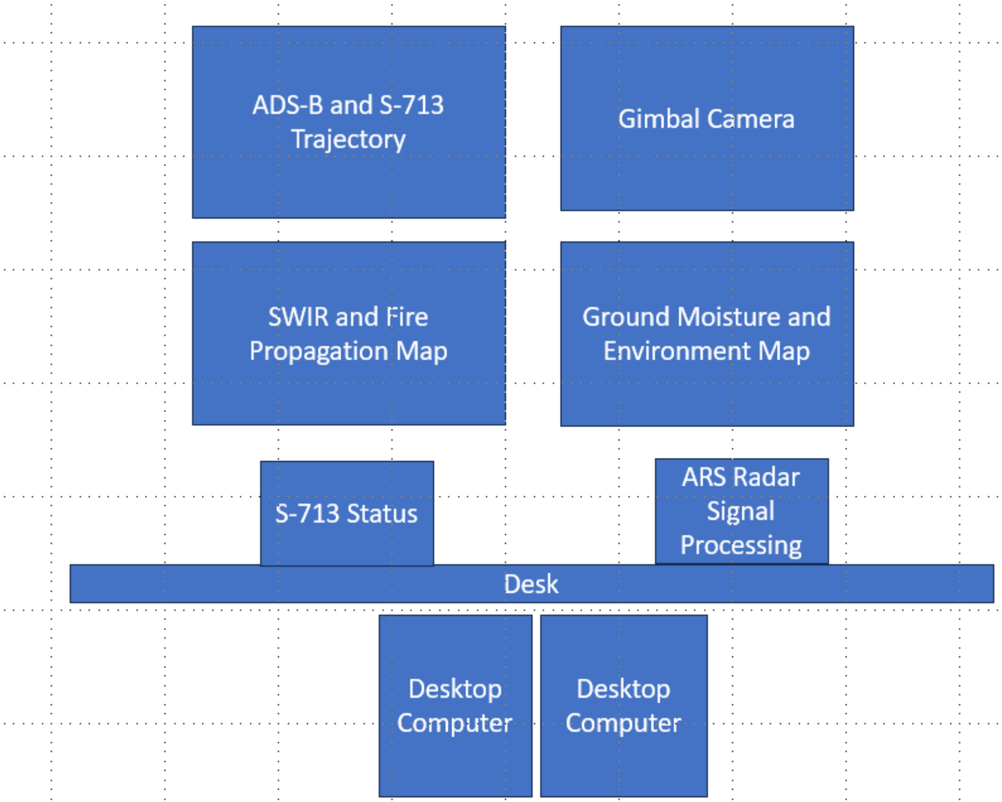

Figure 16. Demonstration of ground base command setup.

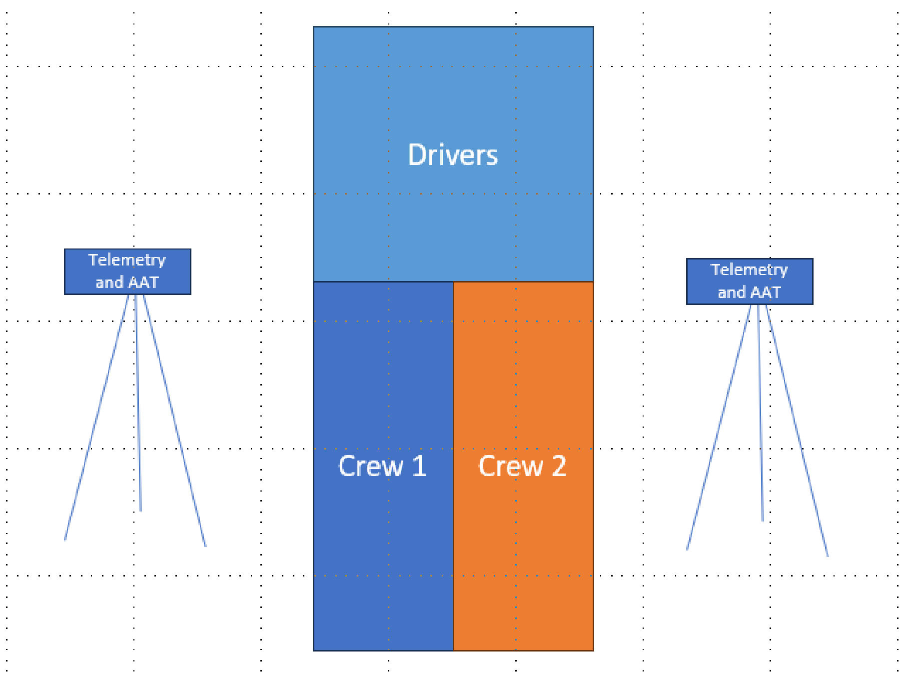

Figure 17. Demonstration of ground base layout. The vehicle dimensions [50] are to scale while telemetries are not.

Pilots and Analysts

The operational crew consists of two pilots, one carrying a CAAC/FAA license (or as mandatory by local laws) and the other a visual observer assisting the pilot in carrying and assembling the UAS as well as providing additional situation awareness to the pilot [27]. While the operating pilot must carry a **BVLOS license for type III (small) VTOL**, the visual observer should carry a **line-of-sight operational license** for the same class. In cases where the pilot is non-functional, the observer will take over and land the UAS if manual operations must be done. In ordinary cases, the entire process of flight will be completely automatic.

Two data analysts are required in the base sector, as the data from the UAS needs professional processing. One of the analysts must be one dealing with environmental modeling, mapping thermal data to existing maps and generate evaluations of the fire propagation; the other is the AI data engineer, using artificial intelligence to identify important targets as well as interpret ground moisture results based on millimeter-wave radar results. While both play important roles in all stages, the role of the AI engineer is most intensive in the pre and post stages, since these stages require analytics from radar results that will not directly show interpretable data.

Operational Sensing

The operational sensing includes the airspeed and locational modules. A **MS-4525** [29] digital airspeed sensors by SIYI Tech is installed for the measurement of airspeed. It is a high-accuracy product which is essential to the operation of the system. The location and heading are provided by a **F9P** [30] RTK unit. The S-713 requires this accurate sensing unit as its transition and landing must be precise. The UAV must return accurately to its launch position, else it would be in hazard of landing onto unfitting terrain and causing damage to the system.

ADS-B Location Reporting

The design requirements indicate that the UAV must be capable of reporting its real-time locations to other systems nearby. Manned UAS or larger UAS that operate at high velocities are required to take anti-collision measures should their course intersect with that of S-713, as the DAA system of the S-713 is only capable of avoiding objects with similar or slower operating configurations than itself, and hence they will require the real-time location broadcasts of S-713.

Aside from internet communications carried out by the ground units with the other systems, which might be delayed due to systematic or human factors, an ADS-B transceiver **TR-1A** [28] is placed on the UAV, allowing it to broadcast its own time, location, and registry while receiving information from a maximum of 100 other ADS-B targets.

2.3.3 Payload

Gimbal Camera

While accurate scientific data must be gathered according to design requirements, the pilot must also obtain environment sensing capability to best operate the UAS. Hence, a gimbal camera controlled by the operating pilot is installed.

The UAV carries a **ZT-6** [23] gimbal camera controlled with the MK-15 during cruise. It is a powerful camera with wide-angle and ordinary optical camera as well as laser distancing and thermal imaging integrated. The information is not sufficient data collection for the purpose, yet it is enough for the operators to make on-site decisions, while detailed information is processed by the data scientists.

Millimeter Wave Radars

Remote sensing technology is used to gain ground information as well as anti-collision alerts. Since the fire mitigation process involves alerting at long distances, SONARs are out of consideration as they are not strong enough to penetrate long distances. Meanwhile, since smoke is likely during a fire, optical sensing, including LIDARs, will be out of operation. This leaves the only choice to be electromagnetic sensing technology.

Millimeter waveband is commonly used for obstacle detection and scanning both in civil and military cases with the quality of high penetration capability and long ranges, hence the team believes it is also suitable for the purpose here. It is capable of penetrating long distances without as large a power requirement as LIDAR poses.

The UAS carries a Continental **ARS-408-21** [31] 77GHz millimeter wave for obstacle recognition and collision avoiding. The module is capable of sensing over 200 obstacles at up to 1200 away at a time, providing redundant sensing capability for possible collision and sufficient time for the FMU or the human pilot to maneuver.

As a result of the landing requirements, a **V-7 Pro** [32] terrain radar is installed on the tail of the UAV. In cases where the original landing location is no longer suitable, the terrain radar will alert the operator and help evaluating new landing sites.

Other than obstacle detection, the millimeter wave radar has another purpose. The CIR signal collected by the ARS-408 radar will be relayed back to the data analysts. Scientists have discovered that the millimeter wave reflection patterns can indicate the percentage of water soil contains [34][35], which is in fact an important metric in fire mitigation and alert process aside from its original application in agriculture. When extremely dry areas are detected, analysts will mark them as potentially hazardous using AI technology that help interpret the reflective patterns.

To utilize the ARS radar for both anti-collision and ground scanning, the radar is installed with an 8-degree angle tilted towards the ground. Using trigonometry, the maximum height at which this radar will be capable of scanning the ground at would be

$$h_{Rmax} = 1200m \cdot \sin(8\,deg) \approx 167m$$

Hence, when the UAV is conducting a scan on the ground to gain data on the current moisture, typically in the pre and post stages of the fire, the cruising height must be below this value so that long range scanning from the radar will return meaningful results.

SWIR Sensing

Considering the thermal imaging data that is crucial to the survey of the fire scene, and that smoke can be heavy in the air, utilizing SWIR sensing is a good choice that is competent in accuracy as well as adaptability.

Since a thermal imaging unit is already present on the gimbal camera, the separate sensor acts as a payload directly sending to the data center, providing accurate air-to-ground data collection. The imaging probe is pointed vertically downwards from the fuselage.

An **SA-D2580AR** industrial probe is utilized, with a conventional focal length, placing the focus at 1400m and the optical resolution at focus be 70:1 (that is, the resolution will be 20 meters at 1400m distance) [44]. The optical sensor is 20mm * 20mm and can read temperatures from -25 degrees to 800 degrees Celsius, will into the range of temperature of red fires [45]. The data will be transmitted by this sensor to the data analysts with location data to provide pointel temperature confirmation, outlining a temperature contour especially useful when the fire is in progress and temperature of the burning locations can only be acquired through aerial means.

Weather Sensing

The weather sensing modules carried by the S-713 offers real-time location environmental reporting capability, allowing an accurate assessment of the prediction to fire propagation.

Two SCD-40 atmospheric sensor chips are placed on the outer hull of the S-713. They are medium-level accuracy atmospheric sensors with negligible weight and power usage that can provide usable data concerning temperature, air moisture, and CO2 concentration, which are important figures that affect the decision-making in fire mitigation.

Four hypersonic probes are utilized for the determination of wind strength and direction. They are placed at the vertices of a square. The data from the hypersonic probes are processed with the MOGEER-CI-IMPORT01 control board in order to produce the measurement result. The measurement subtracts the velocity vector of the UAS provided by the FMU to obtain the real windspeed data.

These two sensors satisfy the mission requirement to gain data on the aerial environment on site.

The air boundary layer is a region where turbulence is heavy, which can be determined by the rapid change in airspeed. Using the continuous wind speed and direction data from the hypersonic probes, the UAS will be able of outlining air boundaries that it comes across in real-time.

Final Design

The final design concludes costs of all onboard and ground assets split into the three sectors. Their weight, cost, and quantities are included in the table below. The final design concludes related costs for both the system and effective payloads.

Table 7. Onboard Assets.

Onboard Assets	*Weight (kg)*	*Cost ($)*	*Quantity*
Main Hull Structures	1.768	300	1
Minor Docking Parts	0.100	160	1

AT-2814 KV-1200 Long Shaft Props	0.432	194	4
Skywalker 60A OPTO ESC	0.240	79	4
Falcon 10-Inch Carbon Fiber Blades	0.060	105	4
PTK-8525MG-D Digital Servo	0.057	29	2
CUAV 5+ FMU	0.091	889	1
MS-4525 Airspeed Sensor	0.020	65	1
F9P RTK Air Unit	0.031	272	1
ZT-6 Gimbal Camera	0.197	2815	1
MK-15E Telemetry	0.232	222	2
Continental ARS-408-21 Radar	0.320	400	1
V7-Pro Terrain Radar	0.050	172	1
SA-D2580AR SWIR Probe	0.390	530	1
SCD-40 Air Quality Sensor	0	14	2
DYA-200-01A-K	0.027	13	4
MOGEER-CI-IMPORT01	0.020	388	1
TR-1A Transceiver + Antenna	0.034	950	1
FR Receiver	0.020	0	1
4S 22Ah Li-Po Battery	1.385	150	1
6S 3.3Ah Li-Po Battery	0.467	96	1
TOTAL	5.941	7843	1

The effective payload takes up approximately 29.24% of the total takeoff weight.

Table 8. Operators.

Operators and Assets	*Weight (kg)*	*Cost ($)*	*Quantity*
UAV Pilots	NA	140 / hr	2
Stand for RTK Base	0.031	5	1
Foldable Table	2.3	27	1
Foldable Chairs	2	9	2

Safety Vests	NA	17	2
Speakers (50km+)	NA	41	2
Mobile WiFi Source	NA	71	1
Bottled Water	2.2	8	4
66W 20Ah Battery	NA	34	4
TX-4 Desktop Computer	2.9	1157	1
MK-15E Radio Control and Telem	0.050	80	1
F9P RTK Base	0.031	272	1
4S 22Ah Li-Po Battery	1.385	150	1
6S 0.33Ah Li-Po Battery	0.467	96	1
Repair toolbox and glue	1	NA	1
TOTAL	12.364	1967+980	1

The variable cost is given after the fixed cost, and is calculated in days, assuming 7 working hours.

Table 9. Base

Base Assets	*Cost ($)*	*Quantity*
Generic Data Scientist 1	25 / hr	1
AI Data Scientist	55 / hr	1
Renault Sherpa 2 Tactical Truck	150 / day	1
Erazer X-315 Desktop Computer	1600	2
TX-4 Laptop	2314	2
Speakers (50km+)	41	2
Mobile WiFi Source	71	1
Bottled Water	8	4
66W 20Ah Battery	34	4
HM-30 Long Range Telemetry	542	2
Stand for HM-30	10	2

TOTAL	4620+710	1

This completes the design of the UAS system as well as all related components. The assets considered are not only the ones required for flight, but also includes those required for the safety of the mission.

2.4 Lessons Learned

During the design process, the team has encountered difficulties that involve the integration of the required sensors onto the UAS, as well as the combination of sensors utilized. We have realized that reduction of complexity to accomplish the most tasks with the least energy and weight are crucial to UAV designing. We have also gained increased understanding that the design of the UAS is a cooperation of the payload, the layout, and the structure. Each sector not only has to be optimized by itself, but also cater to the requirements of other sectors to fit specific mission requirements.

2.5 Component and Complete Flight Vehicle Weight and Balance

The weight and balancing is based on stability considerations and mesh calculations. The establishment of axes directions are shown below.

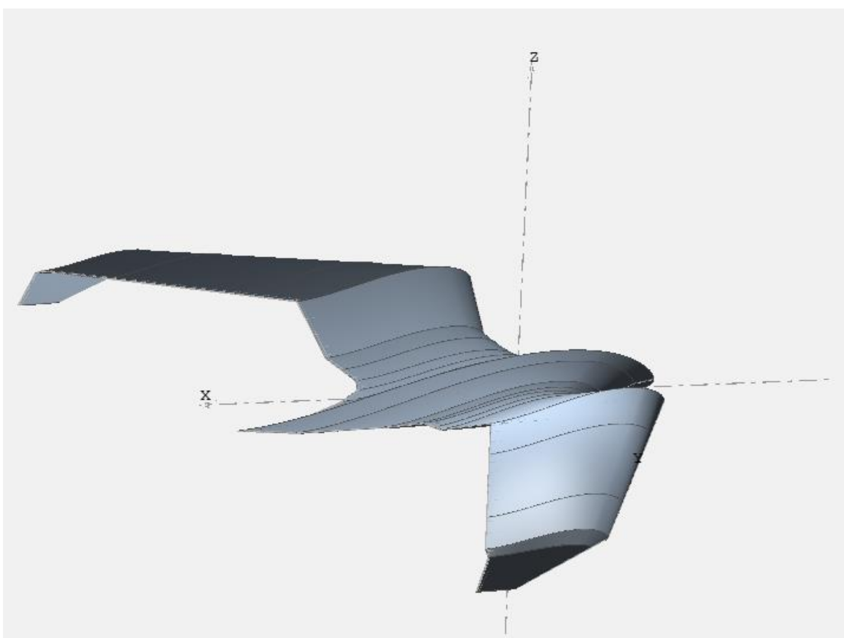

Figure 18. Orientation definitions. Front is negative X, starboard is positive Y, and upwards is positive Z.

The reference point for the X axis is the 'tip' of the M-shaped wing (the front-most point of the aerodynamic chord at that location), the reference for the Z axis is the front-most point of the root aerodynamic chord, and the Y axis is the axis of symmetry.

According to SolidWorks mesh CoG calculation, the CoG coordinates for the hull (nacelles included) is (-144.55, 0, 2.37). The chart gives balancing data for the specific structural components and their percentage weight with respect to the entire structural weight.

Table 10. Struture weights.

Name	*Weight %*	*X*	*Y*	*Z*
RW	30.5%	136.08	448.31	12.01
LW	30.5%	136.08	-448.31	12.01
RW Nac	2.5%	108.00	461.23	-17.09
LW Nac	2.5%	108.00	-461.23	-17.09
Gear	2.6%	-724.47	0	-19.93
Fuselage	31.4%	118.94	0	-11.38

The actual weights and the CoG locations of all components are concluded as below.

Table 11. Component weights.

Name	*Weight kg*	*X*	*Y*	*Z*
Struct	1.868	-144.55	0	2.37
Thrust RW	0.366	108.00	461.23	-17.09
Thrust LW	0.366	108.00	-461.23	-17.09
All Pld	1.038	83.16	0	-44.23
All Avionics	0.451	224.36	0	0.47
Pld Batt	0.467	83.16	0	0.47
Prop Batt	1.385	-149	0	0.47

The eventual rigid properties of the UAV are hence estimated as below. The CoG is adjusted with consideration to the stabilization of the aircraft, so that the UAV maintains a statically stable (6%) layout when the aerodynamic loading is added.

Table 12. Full-body weight and torque.

X	Y	Z
-28 mm	0 mm	-8.9 mm
Tau X	**Tau Y**	**Tau Z**
-1.63 N*m	0 N*m	0 N*m

While the UAV remains statically stable, the CoG is slightly below the reference plane, and hence it provides additional stability due to the pendulum effect.

2.6 Final Design Drawings

Below shows the final drawing of the S-713 transitional VTOL solution. Note that an additional radar box is placed at the front of the fuselage, for the containment of the millimeter-wave radar. The airspeed sensor is placed on the nose slightly above the radar to prevent interference. All important dimensions are marked in millimeters.

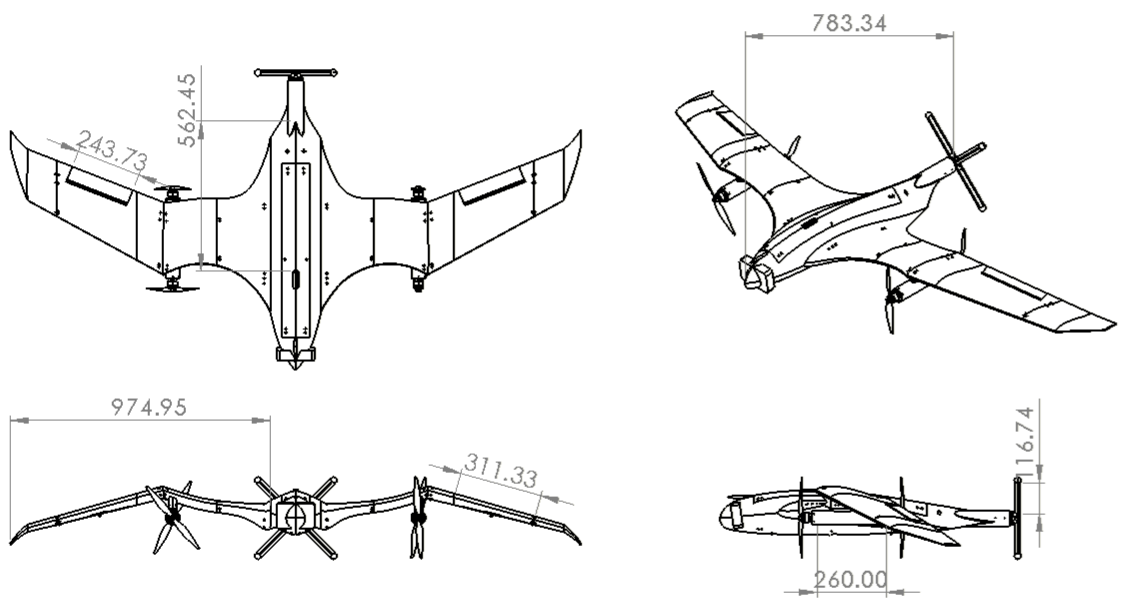

Figure 19. Four views of the S-713 engineering drawing.

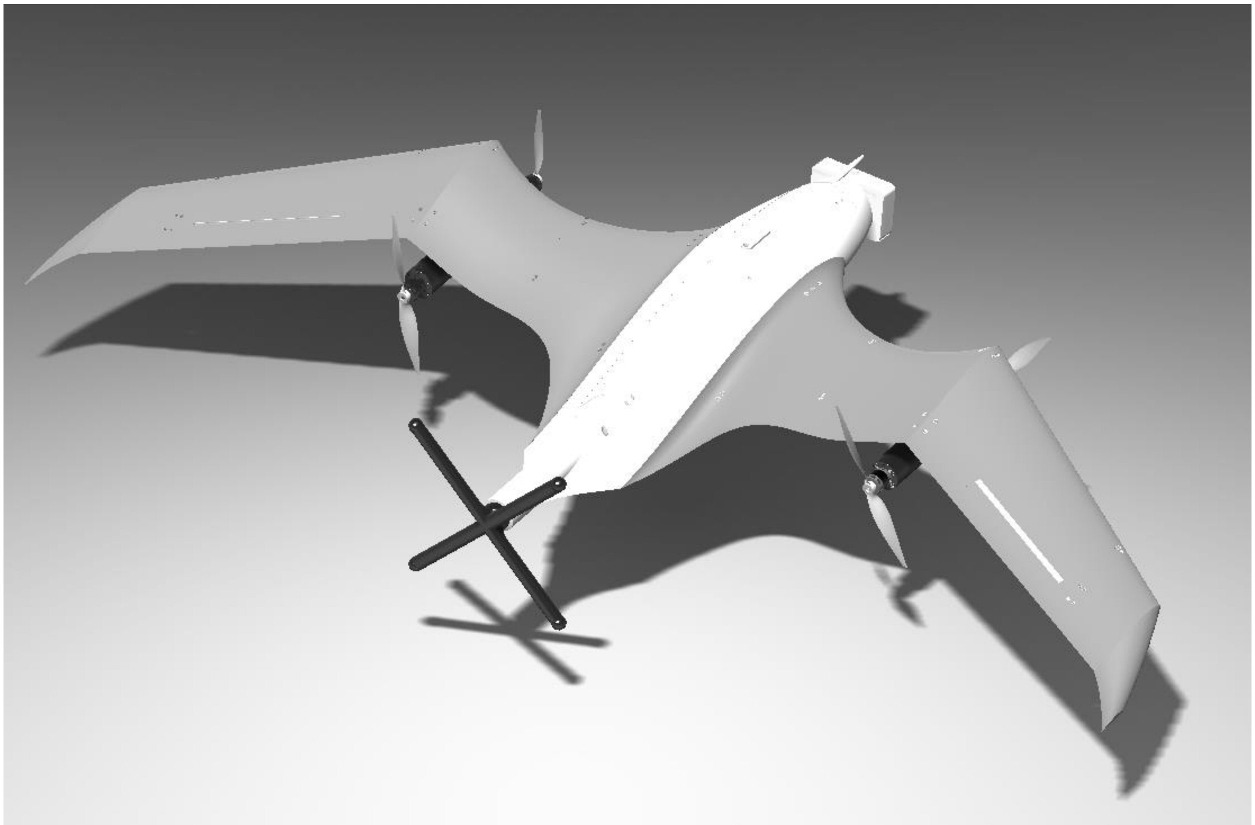

Figure 20. S-713 Mesh 1.

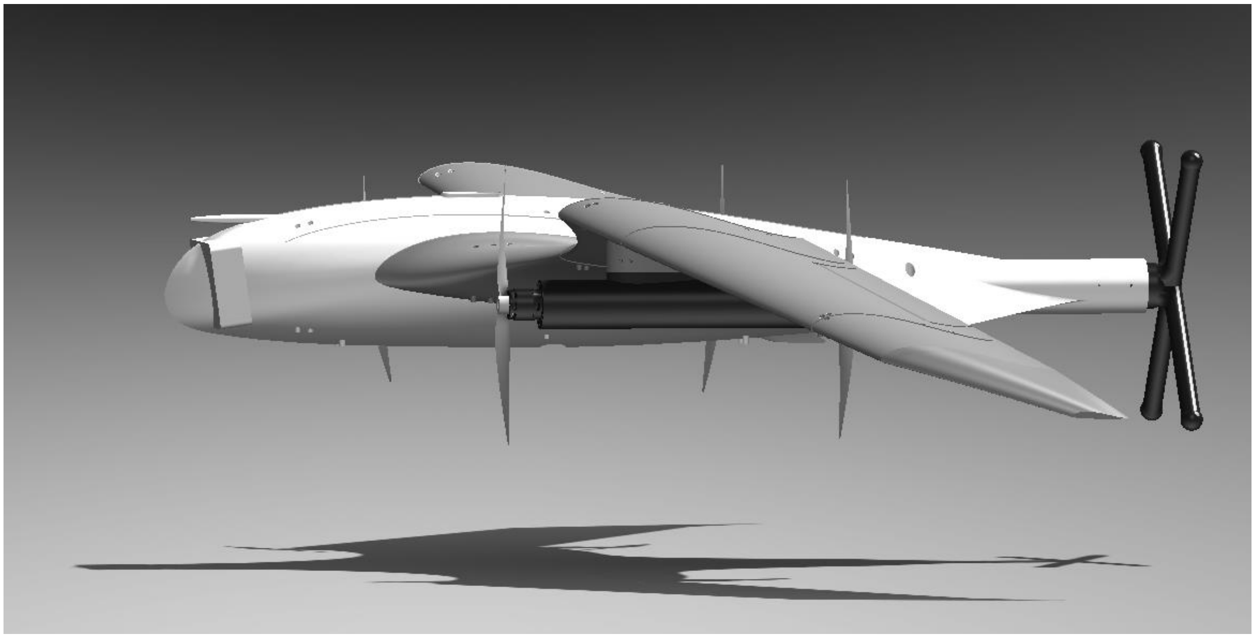

Figure 21. S-713 Mesh 2.

3. Missions

3.1 Concept of Operations

In the fire control mission, there are three scenarios: pre, active, and post fire stages. In these stages, the S-713 is expected to take on the role of aerial survey, environmental sensing, and real-time status reports. In the first stage, the system, is operated automatically by data scientists without needing a pilot, since it is only routine patrolling, whereas in the latter two scenarios, the UAV is controlled by a separate group of pilots. The core of the S-713 is lightweight and high performance, as will be more thoroughly discussed in the expanded explanation.

3.1.1 Pre-Fire

A pre-fire mission involves patrolling a designated area for potential hazards. In this stage, the UAV must be able to promptly report and existing fire or ignition possibilities in the designated area.

The flight in this stage is fully automated. The UAV will take off from a base five times a day – in 0500, 0900, 1300, and 1800, and 2300 hours. A special operator who hikes is not required, as the drone will be set on routine patrol trajectories at a relative height of 150 meters – remaining in range for the millimeter wave radar scan.

After confirming a takeoff, the UAV cruises to collect optical, thermal imaging, atmospheric data (including wind velocity from the hypersonic windspeed sensors, the CO2 concentration, the temperature, and the air quality with the two SCD-40 sensors), and millimeter wave data using its sensors and the gimbal camera (which now follows a set of commands given instead of actively controlled by the operator). While optical imaging and thermal imaging will give the AI data engineer a direct warning if a fire is identified, as well as providing a scanning of the local vegetation in order to determine the fuel type and amount, millimeter wave radar helps identify regions that a dry by analyzing the properties of reflecting waves, the mechanism described in section 2.3.3. These data are transmitted through the MK-15E backed to the base, while the video is also stored in the SD card in the ZT-6 gimbal camera as a full-resolution copy. The air-boundary layer is plotted by the system automatically onto the screens of the base operators when discovered, marked by sudden changes in the wind velocity measurement.

The cruising strategy of the S-713 is different from a conventional, fixed scanning trajectory. Rather, it is actively adjusted based on measurements from the previous flight. The two data analysts will produce a mapping of the high-risk areas of the region surveyed using a RSOM algorithm [47]. This enables the UAV to gain higher efficiency as its survey will be focused on areas with the largest likelihood of a fire according to analysis. Constantly surveying moist areas near a river, for example, according to conventional scanning trajectories, would be a waste of energy, because certain areas are almost impossible of supporting the formation of a fire.

The data collected provides a more prospective patrolling result than conventional optical and thermal imaging, because not only does it identify existing threats, it also gives environmental data that will allow prediction of risk of fire and spread of fire, enabling more accurate precautions.

With a focal length of 13mm, the ZT-6 gimbal is able to provide a horizontal scanning width of approximately 180 meters according to the calculated field of view [46]. The UAS cruises at 40% throttle with two propellers engaged, giving

$$F_{thrust} = 0.981 \cdot 9.8 \cdot 2 = 19.2776N$$

The force-power ratio of AT-2814 peaks at this point, giving a ratio of 5.27. This places the cruising speed at 34.3 m/s according to the VLM method analyses. From analysis, this speed is also a preferred velocity with high cruising lift-drag ratio of 25.3. The cruise time will be hence given by:

$$22000mA \cdot \frac{0.75\%}{12.35A \cdot 2} \approx 0.668\, hrs$$

This puts the range at 82.5 kilometers and the coverage area at over 3459 acres per flight with the standard setup, reaching the standard of a short-range UAV, surpassing the 50 km threshold. According to data tolled, the average coverage of wildfires in U.S. up to 2020 has a maximum value of 172 acres per fire. This indicates that the range of S-713 under the above given cruising condition is sufficient for the mission. Moreover, for larger areas, the range of the S-713 can be enhanced by adding an additional 6S 18Ah battery (weighing around 1300g) if needed, which is well within its payload capability and more than doubles the coverage.

After the mission, the operators will remove the battery and perform system check. The battery is recharged and will be re-installed ten minutes prior to next mission. The system check must be carried out fully before and after every flight to ensure that all operational and payload components are functioning correctly.

3.1.2 Active Fire

The active fire mission involves real-time data acquisition as well as time-varying mission area requirements.

During the active fire mission, the UAV is taken to the release position by the two pilots by hiking. The location chosen should be away from the threat of fire for a reasonable amount of time. Alternatively, the landing location can be chosen at another location, but the operators must ensure that such a landing is safe and the UAV can be secured by their colleagues.

The pilots must plot a course based on the mission requirements given by the commanding personnel of the action before takeoff, and the UAV will follow the trajectory while the pilot controls the gimbal to observe ground targets through both optical and thermal imaging, reporting through the intercom when necessary. This allows detection of fire edges based on thermal and visual data, as well as returning fuel conditions with thermal data as optical measurement is likely to be hindered by smoke. The operators control the UAV through the MK-15E RC control interface and the Mission Planner on TX-4 Laptop computer. Meanwhile, the payload data are transmitted back to the base with the other MK-15E telemetry, reporting data as well as trajectory information. The onboard SD cards store the uncompressed files of the gimbal camera and the SWIR probe for record.

In the active fire stage, all components active in the pre-fire stage will be utilized, while the high-accuracy SWIR probe is activated at designated locations of fire. This collects environmental data on fire location, fire development tendency, environmental factors – specially wind, temperature, and moisture, as well as specific data for fire prediction. The SWIR and thermal imaging will be capable of measuring in the presence of smoke, unaffected.

Unlike conventional solutions carrying only the gimbal camera, the S-713 is able to offer very specific environmental data, including moisture, temperature, and wind of any precise location, which will act in continuing to report the air boundary layers when encountered. This allows decision makers to better understand and predict the development of the fire, without the risk of being misled by global environment measurements, which might be inaccurate considering the complex turbulence in the region of fire. Moreover, the high-accuracy SWIR probe is able to measure at a larger temperature range than the gimbal cameras, allowing a more accurate modelling of ignition points. Knowing this specific data allows data analysts to model the fire progression and evaluate the fire better with existing mathematics models, providing a more accurate evaluation that help produce better mitigation solutions as well as guaranteeing the safety of rescue personnel on site.

The continental radar and the onboard atmospheric sensors will continue to give moisture level information, and since the radar is on an electro-magnetic band rather than lase, it will also keep functioning under heavy smoke.

During cruise, since the cruise time is aimed for maximization, the lowest cruising speed of 20 m/s will be adopted, and in this situation, merely 3.25N of thrust is needed, which indicates less than 170g of thrust provided from each nacelle as all propellers are engaged. This eventually gives a current of 4.28A for the propulsion, hence the cruise time being:

$$22 \cdot \frac{0.75}{4.28} \approx 3.855\ hrs$$

Note that for the propulsion calculation, a 25% of the power is always reserved for landing and takeoff, as well as possible emergency cases. The UAV cruises at a height of 150m still unless otherwise required due to specific cases. The lowered velocity and height are also beneficial to reduce the potential collision hazard that to other larger systems operating in the area such as helicopters.

The flight duration given exceeds the design requirements significantly, as well as surpasses the flight durations of most competitors of the same size and purpose. This allows S-713 to gain a high advantage in its missions, capable of lingering in the air longer to collect more information and survey further areas.

After the return of the UAV, as the operators are required to carry another unit of battery, the operator will communicate the command of the mission to inquire whether to launch again, to return, or to launch at another position.

Directly prior to and after a flight, the operators must perform system outlook and functionality check, ensuring all rotors and control surfaces are operational, while datalink confirmation must be confirmed with the base, ensuring that both MK-15Es are connected to their respective ground units.

3.1.3 Post-Fire

The post fire mission is less intense than the active fire stage, and under this scenario, S-713 will primarily help evaluating the loss caused by the fire.

The trajectory will be planned by the base and sent to the operators. The RSOM algorithm is used, substituting the fire hazard locations for ignition points and severely burnt areas. This course will guide the

S-713 to devote most of its time scanning severed areas instead of covering unaffected areas extensively, hence increasing its efficiency.

Since at this stage, ground units will be concentrated, the millimeter wave radar scanning will no longer be required extensively. Hence to comply with the optimization of coverage, the UAS will rise to a height of 300 meters, increasing the width of each optical and thermal imaging scan to almost 360 meters. Added with the range-maximizing 34.3 m/s speed, the UAS will cover 7339 acres during its flight, while reserving 25% of its propulsion battery, while much of the commercial fixed-wing and multirotor UAVs limit their coverage at 'hundreds of acres' [49].

The data transmission at this stage is the same as that of the active stage, except that the high-accuracy SWIR probe now closed as its performances are no longer necessary for the purpose. The ARS radar will stay opened for collision detection. The data engineers will work mostly on marking damages on the area as well as possible casualties if any.

During this stage, the advantageous speed of the S-713 makes it a perfect candidate to gain full control of the surveyed region, dismissing all possibilities of re-ignition and report any casualties with the shortest delay. The optical and thermal imaging from the gimbal camera will identify the vegetation type and changes with the assistance of AI, as well as using the RGB data combined with thermal imaging integrated with AI algorithms to estimate area moisture, while the SWIR probe will be launched at important locations if accurate measurement of temperature of certain points are still required. The atmospheric sensing will carry on measuring air boundaries, as well as temperature and air quality data for evaluation. The air boundary data as well as moisture data will be acquired with the same methodology as the previous stages.

The takeoff and landing procedures are constant – check, flight, and contact for further instructions.

3.2 Flight Profile Analysis

The S-712 is capable of satisfying any speed and range related requirements posed by the challenge, as indicated below:

Table 13. Flight profile.

Term	*Quantity*	*Unit*
Stall velocity	12.3	m/s

Minimum Cruise Velocity	20	m/s
Efficient Cruise Velocity	34.3	m/s
Never-Exceeding Velocity	56	m/s
Stall AOA	11	deg
Cruise AOA	0	deg
Zero Lift AOA	-6.4	deg
Wind Resistance	9	Level

This indicates that the propulsion and the maneuverability of the UAV is sufficient to comply with all sorts of situations that might be encountered during the process of wildfire mitigation.

The energy of the payload is separated from the propulsion. The payload provides 3300 mAh at 6S, which is sufficient for the relatively low energy consuming payloads considering that no LiDARs are carried. The 22000 mAh 4S battery. While the cruising requirement is less than 4N – which is approximately 102g of output force for each rotor, the AT-2814 is capable of outputting 981N at 12.35A current under 40% throttle. Hence, for minimal balanced cruising, when engaging two props, the system will be capable of leaving 25% of the propulsion energy, cruising for 0.67 hours. Even if all four props are engaged, the system can still cruise for 0.33 hours with the same amount of energy left. Hence, the propulsion energy is ample for the mission requirements.

The datalink of MK-15 is 15 kilometers (over 9 miles), exceeding the 5-mile requirement, and can be further enhanced to 30 km through using more powerful antennae.

3.3. Safety Requirements

The S-713 implements an extensive list of safety procedures that includes active evasive maneuvers and protocols to deal with unexpected emergencies as a result of external and internal causes. These allow the S-713 to operate safely in the complex and stressed mission environment the wildfire poses.

3.3.1 Detect and Avoid

The S-713 is capable of detecting and actively avoiding incoming threat. As mentioned in section 2.3.2, a millimeter wave radar manufactured by Continental Engineering is installed on the nose of the UAV, pointing slightly downwards to cater to both DAA and scanning needs. Only a forward radar signal aside from the ADS-B is given to the FMU as a fix-winged UAS typically are not required to avoid obstacles incoming from its sides.

The DAA decision is made by the operator and automated sequences in FMU. Due to the complexity of the situation, the command station will not reach the decision in time, so the operators will be allowed decisions within warning time and automated decisions will be made if impact is imminent. The interference of the operator is essential for the inclusion of considerations such as safe systems and cooperative ones, which might not require maneuvers.

Radar and ADS-B Sensing Range and Actions

While the radar is capable of a maximum detection range at 1200m with the augmentation of specific algorithms, such implementation is not available for the FMU. Hence, the radar gives an alert at 1.17 seconds for objects within 70m and at 4.17 seconds for between 70m to 250m, assuming a relative incoming velocity of 60 m/s. According to FAA regulation Part 107 [40], the speed limit for commercial drones is 87 knots, which is approximately 28 m/s. Hence, a relative velocity of 60 m/s is already slightly beyond the maximum possible incoming speeds if two units are both under the limit set by Part 107. The reaction time for humans is 0.284 seconds [41] on average. According to a study on UAV pilot reaction time, among the samples studied, 60% are capable of reacting within 1 second, and all react within 2 seconds [43]. Hence, the long-range collision detection provides ample time for the human pilot to react, while the proximity warning allows a possible human intervention, whereas if a human intervention is not available, the anti-collision mode of the FMU will automatically decide the actions taken.

The ADS-B sensing allows detection of aerial objects broadcasting their positions. Although it is not capable of sensing unexpected objects, it is useful when integrating with manned systems in the network, especially when the radar is not capable of sensing at a long enough range to avoid these fast-moving objects.

The first warning is given by ADS-B transceiver. The FMU calculates objects within 3000m range picked up by the ADS-B for their projected trajectories and test whether intersection occurs. The 3000m is determined by the average speed of small manned aircrafts at 117 m/s [42] and the S-713's 30 m/s movement, giving 20 seconds for reaction. FMU computer calculates the projected trajectory of the incoming object every 0.5 seconds, with linear fitting

$$P(x, y, z, t) = v(\Delta x, \Delta y, \Delta z) \cdot (t - t_0) + P_0(x_0, y_0, z_0, t_0)$$

If a collision trajectory is projected, the ADS-B system will return a warning with three repetitions of ‘Collision Possibility’ with an interval of 3 seconds. The pilot can, in this time, determine whether an anti-collision maneuver is to be taken, or if the target is safe and cancel the warning. When the range closes to 900m, a collision warning at 523.2Hz is given at an interval of 0.5 seconds.

If an ADS-B collision trajectory is detected within 300m range (slightly more than 2 seconds’ reaction time according to previous calculations), a starboard roll at 30 degrees is automatically taken to make a 25-degree turn. The turn is made so that the trajectory is altered to prevent collision while the target will remain on the millimeter wave radar (which has a 30 degrees FoV in proximity range) if incoming action continues.

Upon detecting an object with the long-range sensing at 250m, the ground station will alert the operator with a 440Hz ‘beep’ with an interval of 1000 milliseconds as the approach notice, regardless whether the incoming object is a threat. This is to warn the operator of existence of possible threat so that precaution measures can be taken. Meanwhile, the projected trajectory of the object is calculated by the FMU every 0.5 second as done above.

The approach warning is first engaged under one of two conditions: if the projected trajectory of an object intersects the planned course of the UAS, or if a non-cooperative system is within 120 meters away from the UAS (the 120 meters is set to give the operator 2 seconds to respond, under which UAV pilots will be capable of making a turning decision if required). The warning alerts the pilot with a 523.2Hz beep recurring every 500 milliseconds.

Between 70m to 120m, the operator is capable of actively deciding if an anti-collision measure is required. For cooperative systems, such as a formation when conducting joint missions, avoidance is sometimes unnecessary. Under this case, the operator can turn off anti-collision for the target via sending a command to the FMU, indicating that a certain tracked object is not a threat.

Under 70m range, the operator will receive a 523.2Hz 100 millisecond beep as the proximity warning. In this range, due to the possible high relative speed (as assumed, 60 m/s) because of the highly stressed mission, possible impact can be considered imminent. This is the last change an operator can manually take an anti-collision measure.

If an unassigned object reaches within 48m of the UAS, the FMU will automatically take evasive action by rolling 50 degrees starboard***. Note that all UAS systems operated will be instructed to, both automatically***

and manually, evade by rolling to starboard. The range is set as study on the reaction time indicates that the pilot has a less than 20% [43] chance of reacting successfully at this distance, making automated intervention necessary.

Obstacle Identification

Obstacles detected by the radar can be either non-cooperative, such as unidentified UAS or birds, or cooperate, such as manned aircrafts and UAS operated under the same organization or even under a formation with the UAV. Hence, obstacle identification measures are required to determine whether the DAA measure should be activated. The ADS-B will act as the primary means of detection, and all radar objects that fit with an ADS-B coordinate will be assigned to the ADS-B tracking list and removed from the radar tracking, so that the millimeter wave radar only tracks objects with no ADS-B transceiver.

Step 1: Cooperative System

Since all S-713 and large UAS and manned systems are required to carry ADS-B transceivers, the operator can set certain registry as safe. This will refrain, under the full mission duration unless cancelled, the UAV from carrying out any DAA-related actions for the object. Note that the operator should remove the registry from the 'safe' object list if the mission has been terminated and formation is broken by sending a command to the FMU. Before flights, the list of safe systems must be cleared to prevent accidental mistaken warning cancellation.

Step 2: Temporary Alert Cancellation

If an approach can be asserted as safe in its ADS-B collision possibility phase or radar approach notice phase, the operator can manually turn off the warning. However, ADS-B evasive maneuver or radar evasive action will still be taken without further notice under this case, unless an additional cancellation is set, dismissing all proximity warning and actions. The temporary alert cancellation and the additional cancellation will be removed once an ADS-B objects is out of the 3000m range or the unidentified object out of tracking range.

3.3.2 Lost Link and System Protocols

The lost link protocol is a set of automated steps the UAS will carry out in cases where communication with the operator is lost. This section is consisted of A protocols (lost link), B protocols (emergency actions), and G protocols (global protocols). The other two types of protocols will be discussed in 3.3.4.

A series protocols copes with different cases of partial or complete linkage lost. It will, when the system determines a critical situation or if the pilots demand so upon receiving alert, direct the UAS into homing and landing sequences.

Protocol A1: Base Link Lost

When the connection between the *ground base* is lost, the UAS will alert the operator and automatically circles the current position to await further commands. Under this scenario, the operator and the mobile ground station is still available. The operator and the command center must *communicate* to determine whether the UAS should be retrieved or should it carry on even without data for the analysts.

Protocol A2: GCS Link Lost

When the operator's ground control station – the Mission Planner – loses connection with the UAS, protocol A2 is activated. There is a buffer time of 90 seconds in which the UAS will automatically circle the current position to await link restoration. If the communications are restored during this time, the UAS will carry on the plotted course upon confirmation; else, the UAS automatically enters homing and landing sequence.

Protocol A3: RC Lost

This protocol will activate when the manual remote held by the operator is unable to gain control of the UAS. This will deny the pilot of the ability to deal with unplanned emergencies should they occur. The UAS will wait for 90s by circling current position and await the operator to confirm retrieval or continuation via the GCS. Technically, the UAS will be capable of carrying out radar and optical surveys with effective scientific payload under this protocol, hence it is not mandatory, in this case, for the operator to cancel operation.

Protocol A4: Complete Link Lost

This protocol is triggered when the pilot has neither GCS control nor RC control. Under this situation, the UAS will assume homing sequence automatically and carry out landing procedures, as no commands from the operator can be expected.

3.3.3 Integration with Manned Aircraft and Other Aircraft

The S-713 system integrates with other aerial systems in the region with safety and agility.

S-713 units operating on the scene will continuously broadcast their beacon information to manned systems. Moreover, the material used for the hulls, PLA covered with fireproof coating, is not an EM-wave absorber like carbon fiber. Hence, S-713's location can be accurately reported both by integrating a transponder/antenna set to the beacons' frequency passively, or by the active radar units carried by the aircraft. Hence, manned aircrafts will have sufficient time and preparation to avoid collisions with S-713. In proximity, the navigation lights from S-713 will be easily visible, providing visual attitude and heading for the observer on the aircraft.

Furthermore, if desired, an aerial unit can take over control of the S-713. This can be accomplished by using long range telemetry units to connect with the operator's end, while setting the operator's telemetry to relay mode. In this case, operators on manned aircrafts can gain direct control of the S-713 if such action is required to affiliate their missions.

With these functions, the S-713 is able to integrate with other aircrafts with safety and agile performance.

3.3.4 Regulations and Additional Safety

The section describes additional safety protocols and actions the UAS will carry out should any emergency occur.

B protocols are emergency actions that might be required if retrieval sequence encounters unexpected failures, such as landing location no longer supports landing, or battery is insufficient to reach home position. These actions have default automations and can be manually interrupted if the operator is still in control of the UAS.

Global protocols are actions taken when system failure occur on the UAV. These protocols have the highest level of importance and directly relates to the flight safety of the system.

Protocol B1 Unable to Assume Pre-Set Homing Trajectory

While a protocol requires the UAS to assume homing trajectory, the FMU will estimate the current battery of the UAS. If the power of the system is insufficient for the return, protocol B1 will be assumed to determine if alternative positions from a set of alternative homing locations are available. A failure of carrying out protocol B1 will result in a mandatory procedure of B3 or B4. The protocol can be interrupted and terminated if protocol A4 is not triggered.

Protocol B2 Landing Area Unavailable

This protocol is assumed when an RTK-guided landing is denied by the FMU. This can be a result of the optical payload's data or the millimeter wave radar data. For example, if the pre-set landing point is on fire, or if the ground below is excessively uneven. This is a weak warning. The operator can choose forced landing, takeover manually, or assume other landing positions via commanding with GCS.

Protocol B3 Self-Destruct Sequence

Protocol B3 is triggered when at least one of protocols A2, A3, or A4 is triggered and at least one of B1, B2 protocols have failed. Under this scenario, the UAS will assume trajectory to crash area designated on the GCS before flight. The UAS will assume a maximum-range velocity and altitude combination and crash at a safe distance.

Protocol B4: Emergency Landing

This protocol is triggered with the same conditions as B4, but only when the pilot has either GCS or RC control. This is because under fire, the lithium batteries carried by the UAV can cause significant hazards, so an emergency landing is only allowed when ground safety can be confirmed.

Protocol G1: Low Voltage Alert

The voltage is below 40% of the full level. The alert reminds the operator to adopt return trajectory.

Protocol G2: Critical Voltage Alert

The voltage is below 10% of the full level, the propulsion will become critically low and measures will be taken mandatorily.

Protocol G3: Non-Fatal Propulsion / Control Failure

The protocol will be triggered if any or each nacelle loses one of its propellers and/or one elevon control is lost. As each propulsion unit S-713 is able to output a maximum of 2.616N, loosing at most one propeller on each nacelle will still allow the UAS to land in a relatively safe state, despite normal landing is impossible. Meanwhile, one elevon is also capable of allowing the UAS to control its attitude, combining with the double-sided propulsion. Hence, under this situation, the UAV will still carry out a landing procedure as normally would, if possible, while operator attention is needed on final approach.

Protocol G3: Fatal Propulsion / Control Failure

Loosing at least one side of propulsion completely and/or all control surfaces will trigger the fatal propulsion failure protocol. Under this situation, unless otherwise controlled by the operator, the UAS will carry out a self-destruct sequence to crash in a designated area.

Protocol G4: Satellite Navigation Failure

If the number of satellites connected fall below 4, the navigation failure protocol is engaged. Without GPS navigation, it is dangerous for the system to linger in the area, hence return operations will be taken unless the link is restored.

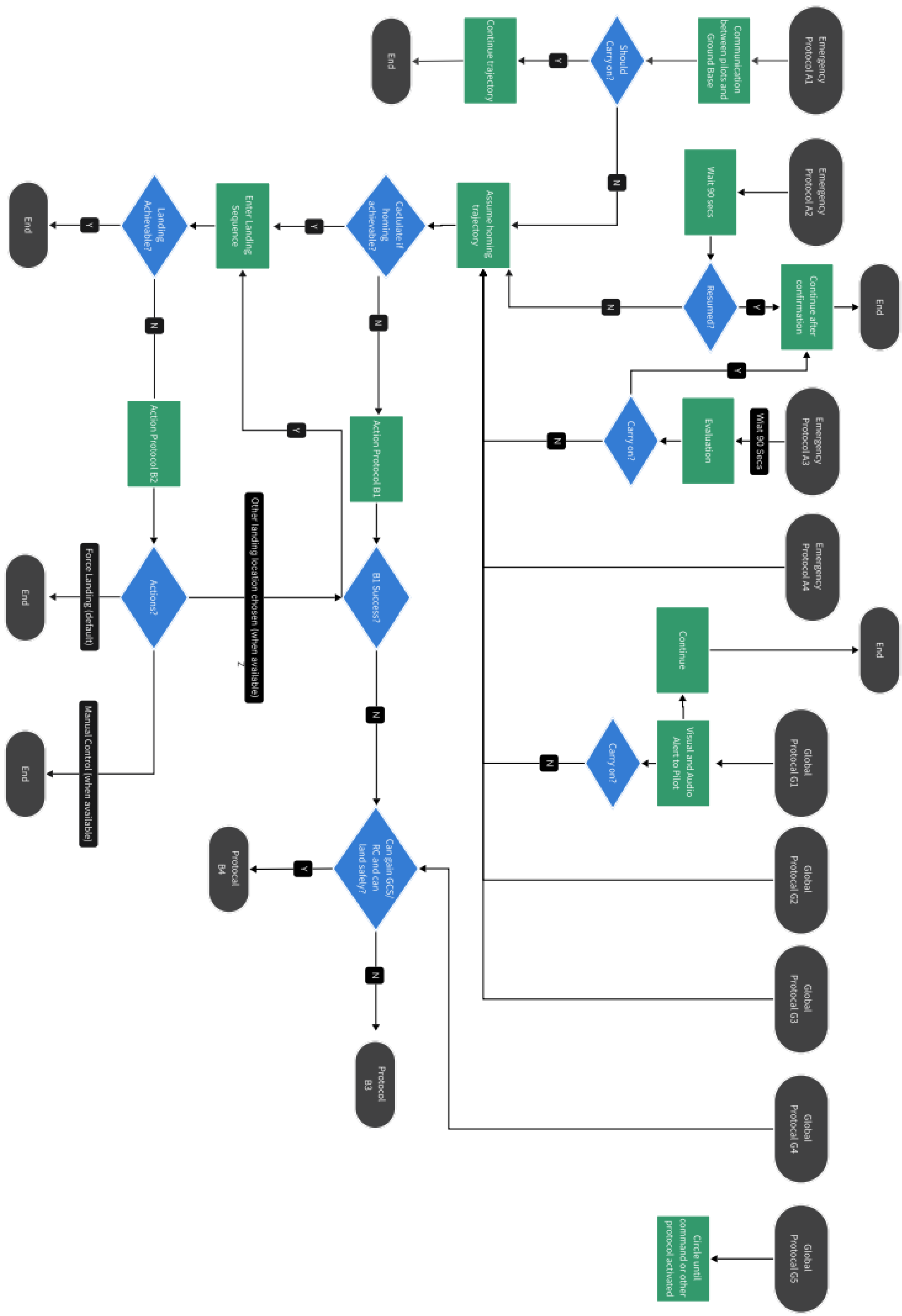

Figure 22. Internal emergency protocols action logic.

4. Business Case

4.1 Cost Analysis

This section will discuss the fixed and variable costs operating the S-713 system will take. While in a wildfire mitigation mission, the UAS operators will likely to follow the deployment of a professional firefighter crew, specialized operators are still needed both on site and at ground base.

4.1.1 Operating Costs

A typical wildfire burns for 37 days [51], meaning a brief estimation of 900 hours of intensive flights under a burning fire. Each flight takes up a 4S 22Ah battery and a 6S 3.3 Ah battery for the system propulsion and the payload power, consuming a total amount of energy of 110.46W per flight (CONOPS gives that cruising during fire takes 3.855 hours, assuming all batteries are used up).

The power each battery holds is calculated by the average voltage (3.95V per cell) multiplied by the nominal discharge current (22A and 3.3A). The total amount of flights needed can hence be given by the total duration of wildfire divided by 3.855 hours – over 233 flights.

Given that the electricity is approximately $0.23 per kWh on average [52], the total price of electricity consumed by the UAS under fire conditions hence is estimated to be around $5.93 – an almost negligible price. This indicates that the highly efficient electricity-propelled solution yields almost no variable cost concerning fuel.

For conventional cruising missions, the cost can also be given – for five cruises each day, less than $0.13 is required for the UAV energy.

Each crew carries two sets of batteries with a standard package, the cost of which are given in the Final Design section. They are considered to be fixed costs as they come with the system. The four 66W batteries will cost an additional 6.1 cents per two missions (each hike corresponds with two missions carrying the standard items). This gives the total operational energy cost to be approximately $13.01 for each wildfire.

4.1.2 Fixed Costs

The total fixed cost that includes fixed cost for the UAS the payload systems - $7843, the operators' (pilots') assets - $1976, and a more variable $4620 for ground base assets.

The first two sets contain necessary components for the mission. The basic C3 components include a $889 open-source industry autopilot controller and a compatible $111 telemetry. This is a minimal cost that ensures the flexibility, compatibility, and reliability of the UAS required for the mission, as complex sensor sets and maneuver conditions are demanded.

The hull and the basic propulsion set cost $867 in total, which is more expensive the foam materials but significantly less than the price for composite material hulls. This combination of the basic framework minimizes the construction price per unit while using reliable means of manufacturing, both reducing the price, and increasing the effective payload the UAS can carry.

The payload takes up most of the rest of the UAS' cost, while the gimbal camera is the most expensive payload – reaching over $2800, followed by the ADS-B transceiver – costing almost $1000. While taking up multiple times as much as other payloads, they are respective the most important payload in the sensing and DAA sections. While the gimbal camera allows a multi-band real-time flexible situation awareness critical for flight as well as air-to-ground situation estimation, the transceiver is the most important method the UAS will use to avoid other registered aerial systems.

The operator's system includes the remote control and the ground control station software the pilot needs to control the UAS with. The ground base consists of receiving and analytical components, and is more flexible as fire departments typically have similar command units that can be easily modified to act as the base unit by simply connecting the receiving telemetry to designated computers and monitors.

4.2 Communications Plan

To advocate our solution to policy makers and demonstrate it to related personnel, the team has devised a communication plan with illustrated infographics to convey the message condense and accurately.

4.2.1 Strategic Communications Plan

The communication plan directly gives the cruising-related performance capabilities and the payload functions, which makes it evident to non-technical audience that the UAV will satisfy the design requirements. Outstanding technology of the UAS is also briefly mentioned in order to demonstrate special advantages of S-713 over other alternatives. The data and technology presentation will allow the audience to have a direct grasp of all the technological advancements implemented on the S-713 to make a premium level solution for the fire mitigation scenario. Moreover, all data come with a brief explanation, which helps people who are not familiar to related data understand what the data means and what the S-713 can do that other systems cannot. We have also concisely stated why are UAVs in general better for fire mitigation than conventional methods, providing basic information on the topic with concise phrases and data. Hence, the infographic, using the minimal space, conveys all important information that advocates the advancements the StratoAvis team made to optimize the fire-mitigation UAV design.

4.2.2 Infographic

Figure 23. Infographic image of S-713 fire mitigation unit.

4.2.3 Sample Communication

The infographic gives a brief outlook demonstration of the S-713, as well as illustration-style explanations for the most important functions of the UAV and some of its most outstanding statistics. The demonstration clearly states the important performance requirements the UAV is capable of meeting, as well as points out the specialties the UAS is capable of, such as RSOM dynamic trajectory planning, which further improves its performance compared to other systems, giving the audience a premium impression of the S-713 system.

5. Conclusion

Through the engineering notebook, the StratoAvis team have offered a complete insight to our design, optimization, and finalization process of the S-713 unit designed for fire mitigation.

Implementing advanced concepts including bionic designs, BWB layout, transitional VTOL control, quick-assembly structure cutting and design, RSOM trajectory planning, AI-enhanced sensing technologies in the aerodynamic, structural, control, and payload design phases, the S-713 is consisted of a set of the most advanced UAS technologies aim to provide utmost performance at a low cost. These technologies not only enable utmost performance in flight and data collection, but also stays consistent with lightweight and flexible operation requirements posed by the wildfire scenario, where mobility is greatly valued.

While the aerodynamic and structural layout follows the Occam's razor and the design requirements of concise, high performance, long range, and long duration, the payload and ground station are capable of integrating well together to form a powerful sensing combination, returning real-time data on ground and atmosphere alike. It is an omniscient data collecting unit that allows the operator to gain any data the fire mitigation will need from air, in any harsh and dangerous conditions where humans fail.

With its highly automated flight and safety protocols, it can be easily controlled by its operators, and will fly automatically in all situations not involving emergencies. It is a safe unit that is highly developed in integration, cooperation, and avoidance with other units in the air.

In the stressed situation of the fire-mitigation process, S-713 stands as a reliable companion collecting essential data and provide real-time monitoring, assisting other units to the best ability of a UAS.

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