University of Colorado

Department of Aerospace Engineering Sciences

ASEN 4018

Project Definition Document (PDD)

AMADEUS

1. Approvals

	Name	Affiliation	Approved	Date
Customer	Prof. John Mah	CU Instructor		
Course Coordinator	Kathryn Wingate Chris Muldrow	CU/AES		

2.1 Project Customers

Professor John Mah 3775 Discovery Dr, Boulder CO 80303 (303) 735-4900 John.Mah@colorado.edu	

2.2 Team Members

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3. Problem or Need

The need for a high endurance, human-portable, and rapidly deployable unmanned aerial system (UAS) spans a variety of applications. These applications include emergency management, search and rescue in austere environments, observation, and survey, as well as combat overwatch. For each of these applications there exists a problem that has yet to be addressed or a solution that does not completely resolve the challenge.

In emergency scenarios (specifically natural disasters), critical communication infrastructure becomes damaged or limited, impacting the effectiveness of crisis management and control.

Austere environments, such as deserts, large bodies of water and mountainous terrain, provide a similar logistical challenge to that of emergency scenarios. In such areas communication is a challenge due to limited infrastructure and challenging terrain that can make certain areas inaccessible. These complications severely inhibit the effectiveness of search and rescue efforts.

Atmospheric observations are restricted by current platform capabilities that only survey limited areas for short periods of time. Combat UASs are most often employed in remote environments where support and infrastructure are lacking.

The challenge of these scenarios is further compounded by current UAS's short endurance and observation capabilities. All these applications share the need for a vehicle design/concept that is agile, low cost, has high persistence and broad coverage capabilities. A low-cost design, and use of Consumer off the shelf (COTS) parts, will allow for easier manufacturability and provide a readily available replacement process in the case of damage to the platform. Affordability will also be advantageous for customers who require the UAS capability but lack the funding of large organizations. As a result, the design must be something that can be built, maintained, and operated with little additional infrastructure or training.

4. Previous Work

TALON Design Synthesis:

A previous design group within the University of Colorado, Boulder Aerospace Department began the design process of a high-endurance, human-portable, rapidly deployable UAV launch and recovery system referred to as TALON. It was designed to address the same issue of limited communication and observation capabilities in a variety of emergency scenarios. Their design has a span of 10 feet, an aspect ratio of 14.25, and a mass of 7.4 kilograms. TALON also consists of an easily removable fuselage for access to internal electrical components. Due to safety concerns, TALON was not able to perform a flight test, leaving room for possible unknown issues with the design. The span of 10 feet puts the requirement of human-portability into question as it makes the design difficult to fit into the back of a vehicle or carry as a single person. This would also make hand-launching the UAV difficult, which could potentially be necessary depending on location. TALON was also given a budget of $5,000, creating a design worth $4,667.54, whereas the current project budget stands at $4,000[1].

RALPHIE Design Synthesis:

Another design group for the University of Colorado, Boulder tackled the project of creating an autonomous flight controller for the aforementioned UAV in order to increase endurance and make the system more user friendly. This project was named RALPHIE. Simplifying the operation of the UAV decreases the amount of training necessary to utilize it. This also increases endurance by maintaining an optimal trajectory throughout the UAVs flight. This system was able to sense the wind direction and modify its orbit of the desired area to fly parallel to the wind. RALPHIE also possessed the capability to sense changes in the wind direction and adjust accordingly. The RALPHIE project was also given a budget of \$5,000, creating a design worth \$4,488[2].

Low Speed Aerodynamics:

Designing a low speed (incompressible regime) aircraft with an emphasis on mission endurance will require the aircraft to fly with the most efficient aerodynamic design possible during all flight scenarios. This is generally measured by the lift to drag ratio and can be improved in all cases by maximizing lifting effects and minimizing accumulated drag. The majority of drag for low-speed airframe applications is the result of lift induced drag associated with three-dimensional lifting effects. This increases with the square of the lift coefficient, making this detrimental to climb and cruise performance. In a paper with aerodynamic researcher Musavir Bashar [3], vortex lattice methods were used to iteratively minimize induced drag using winglets. The resulting ‘adaptive winglet’ design increased efficiency by 7% through reducing induced drag. The next largest source of drag inefficiency at low speeds arises from pressure distributions over the wings and body and can be significantly worsened by flow separations. In Mohd Nizam Sudin’s research of drag reduction in automotive vehicles through active and passive flow control techniques [4], it was found that the effects of pressure drag can be significantly reduced, boosting fuel efficiency. For example, the use of a simple vortex generator, a passive technique using raised spikes on the body to create sections of vorticity, the total drag on an automobile vehicle can be reduced by up to 10%. Investigating the commonly used Prandtl Lifting Line Theory for downwash effects on finite wings, it is notable that wings with higher aspect ratios not only produce more lift, but they also increase the wing efficiency rating. By using a longer wingspan, lift can be generated with a smaller tradeoff in drag which can further improve high endurance operations.

Electronics and Power Systems:

Adapting a power system to efficiently power the subsystems is crucial in this design. The propulsion system must be interchangeable and rechargeable so it can be adapted to each mission. The battery used in this payload is to be readily available in the market for customers to replace them without a long hold over time. The most efficient battery system consists of lithium ion, dry cell and wet cell batteries which are widely used in the UAV sector. Such systems are already readily available but the specific system that we will use, has yet to be chosen. The power management system will be considered on safety standards, energy output to weight ratio, long cycle life, energy density and reliability to perform at all mission scenarios.

Hybrid piston engines are driven by a battery and gasoline engine to power the propeller. This may be considered for takeoff as that will be the highest energy consumption stage of the missions. The gasoline can give a considerable amount of edge in getting the UAV to the desired altitude and the battery can switch over for the cruising mission face as it is much less energy dependent. The gasoline engine can also power the propeller for extra boost in need of speed for swift approach to an emergency mission. This will obviously add mass to the UAV and safety concerns which will be studied and discussed with the customer during our analysis of the design.

The lithium-ion battery has been widely used in many UAV projects, the Trinity F90+ has a battery of 12000 mAh which is used for a duration of 60-90 min depending on the mission. This battery unit weighs about 1.5 kg. This battery unit is a rechargeable battery, with interchangeable options[5].

Structural Mechanics and Dynamics:

Our team will be required to conduct advanced research upon the mechanics of aircraft structures, including Basic Structural Elements as Pertaining to Aircraft, such as axial members, shear panels, torsional members, and members bending members. The inherent requirement to maintain a low structural weight in any aircraft, coupled with the extreme aerodynamic and propulsive forces and moments applied to its body in flight will require high strength, low density materials such as aluminum and titanium alloys or composites materials. Wing and Fuselage considerations, such as Load transfer between these two components, which can cause high and very unpredictable stresses on joints and fasteners. Elastic Buckling considerations, this can include, Eccentrically Loaded Beams, Axially Loaded Straight Bars, Torsional or Torsional-Flexural Buckling, and Buckling of Thin-walled Pressure Vessels [6, pp. 1–14].

Many of the engineering problems that will arise with the structural requirements of this aircraft can and likely will be solved using a Finite Element Method (FEM) analysis; these are costly affairs, in time, computational power, and staffing. Fortunately, scientific literature is readily available in which first and second order analytical analysis has been proven for the above topics. These can be utilized primarily during preliminary design. But they can also be utilized as a sanity check as final design is approached and computational sciences must be deployed.

Other computational work to be considered includes Heat Transfer analysis. Which will have massive implications on the structural success of the system. Heat transfer analysis can be modeled brilliantly in Solid Works, however Solid Works will not be used in any final deliverables to customers as it is not an open source software. Fortunately, many computational methods of varying accuracy can be considered, such as the Dufort-Frankel Method, an Explicit Three-time-Level Scheme for one-dimensional heat flux. More complex implicit methods for two-dimensional heat flux problems, such as the ADE methods or the Hopscotch method could also be used in these scenarios. These advanced numerical techniques can be programmed by open-source software easily on a high-level interpreter language like PYTHON. Alternatively, if run time is a consideration, they could just as easily be programmed in a compiler language such as C++ [6, pp. 126–144].

Additive Manufacturing:

Due to the combination of the power system and electronics on board, the UAV will rely on a lighter material for manufacturing. A common chosen material is a composite of carbon fiber due to the lower density, allowing for a higher lift to weight ratio, and a higher specific strength and stiffness. This is typically desired since the material will maintain shape under high loads that may be experienced when in flight. Carbon fiber composites are known for reliability since it is widely used in aerospace applications and electromagnetic properties for shielding against interference with antennas. Depending on the specific type of prepared carbon fiber composite used, such as prepegs or thermoplastic, the cost can range from affordable to more expensive. [7] Carbon fiber is more brittle, introducing the possibility to crack and split, which will be taken into consideration when deciding on the material. Composites generally have other drawbacks such as damage to the non-visible impact damage, requiring more inspections to be done and overall increasing the cost. [8] The benefit of a carbon fiber composite being lightweight is desired for CU Herd and so will be further studied.

5. Specific Objectives

Category	Level 1	Level 2
Endurance	UAS shall provide 4 hours of continuous flight time.	UAS shall provide 6 hours of continuous flight time.
FAA compliance	Refer to Level 2.	UAS shall adhere to FAA 14 CFR Part 107, SMALL UNMANNED AIRCRAFT SYSTEMS, contingent on waivers.
Ease of manufacture	Aircraft shall be 90% additively manufactured, with remaining parts commercially available, or able to be fabricated in-house.	Aircraft shall be 90% additively manufactured, with remaining parts commercially available, with minimal in-house fabrication required.
Cost	Total budget of our project will not exceed $4000.	Total budget of our project will not exceed $3500.
Payload	Aircraft shall support a 1.5-3kg payload.	Aircraft shall support a payload exceeding that outlined in Level 1, TBD.
Power	Aircraft shall provide continuous 12V power supply with up to 10 W power output.	Aircraft shall provide continuous 12V power supply with up to (TBD) W power output.
Portability	System shall be transported and set up via a team of one user. System shall weigh less than 50 lbs.	System shall be transported and set up via a team of one user. System shall weigh less than 20 lbs.
Structural	UAS structure shall be capable of withstanding 30 ft/s discrete wind gust loads from sharp-edged vertical gusts and 30 mph winds while at cruise.	UAS structure shall be capable of withstanding TBD ft/s discrete wind gust loads from sharp-edged vertical gusts and TBD mph winds while at cruise.
Reusability	UAS structure shall be capable of 1000-hour service life under normal operating conditions.	UAS structure shall be capable of 1500-hour service life under normal operating conditions.
Launch Requirements	Aircraft shall have the ability to launch in a (TBD) ft clearing with no dedicated infrastructure with 20 mph wind speeds and clear a 5ft obstacle.	Aircraft shall have the ability to launch in a (TBD) ft clearing with no dedicated infrastructure with 30 mph wind speeds and clear a 15ft obstacle.

Flight Conditions	UAS shall be capable of operating in IMC conditions (day/night/rain/snow) and a temperature range of -20°F to 120°F.	UAS shall be capable of operating in IMC conditions (day/night/rain/snow) and a temperature range of -30°F to 130°F.
Flight Altitude	UAS shall operate within an altitude band of 5,000-10,000 ft while carrying payload level 1.	UAS shall operate within an altitude band of 5,000-10,000 ft while carrying payload level 2.
Stability	UAS shall exhibit both static and dynamic longitudinal and lateral-directional stability naturally.	UAS shall exhibit both static and dynamic longitudinal and lateral-directional stability naturally.

6. High Level Functional Requirements

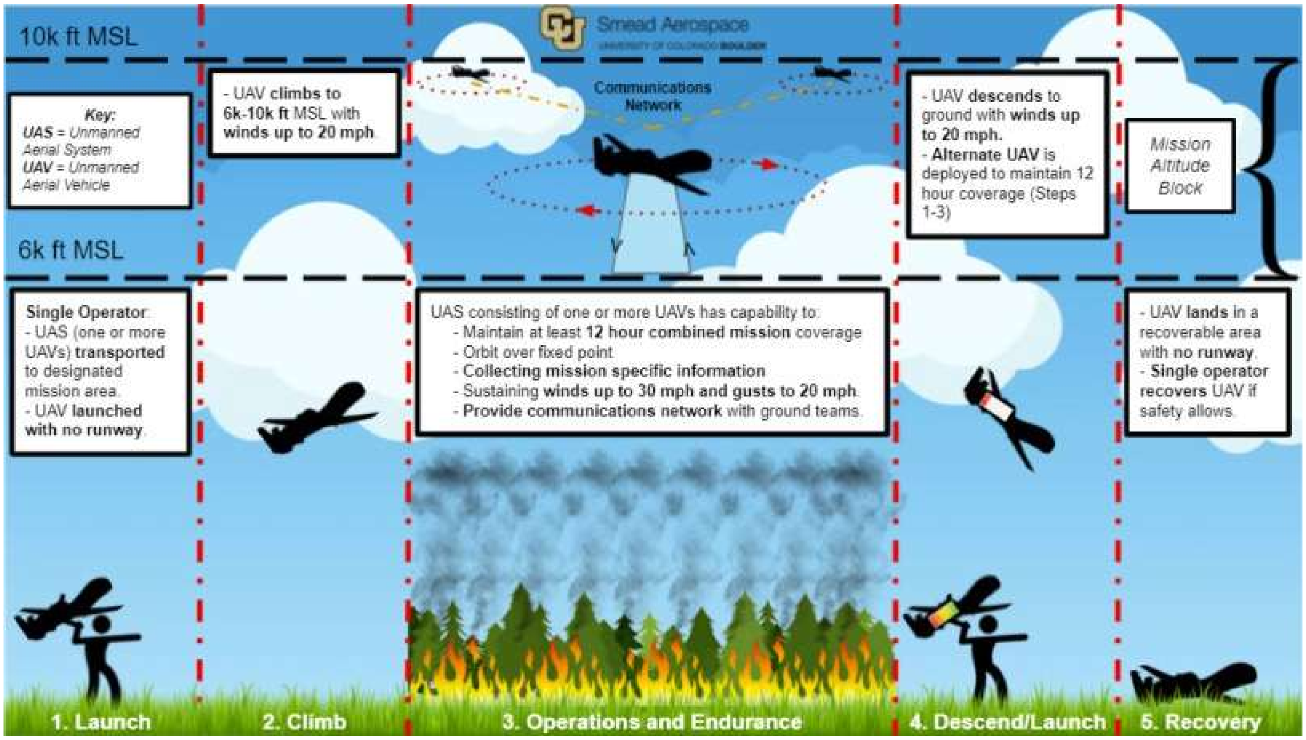
- System shall be human-portable
    - Rational: Remote locations in challenging environments can be inaccessible to transportation equipment, such as cars or other emergency vehicles. A system that can be carried relatively easily on foot provides the most adaptable solution to our user's needs.
- System shall operate solely with the ground support of the primary user
    - Rational: Additional support is not a reliable resource in an emergency, and this would divert emergency resources away from other needs.
- The system shall be able to provide 12-hour mission coverage with [TBD] or less orbit swaps
    - Rational: The 12-hour duration is desired by BES. Additional orbit swaps increase strain and risk of failure for the user
- The airframe design should be capable of a 4-hour flight time without the use of any optimized autonomous control at 6,000 ft MSL altitude
    - Rational: flight time with no optimized controls at an easy to reach altitude above Boulder (~570 ft AGL) is a reasonable way to measure performance without relying on any systems, like the controls, that are outside the scope of this project. 4 hours is a good goal because it would only require the BES user to swap out airframes and batteries 3 times to reach our 12-hour mission duration - minimizing risk and effort that comes with these swaps.
- System should operate within an altitude band of 5000-10000 feet MSL
    - Rational: UAS shall be able to operate at varying altitudes within the given band as operations and conditions may influence desired flight altitude. Above the maximum altitude of this band requires more strict FAA regulations that we shall avoid, to make the UAS less complex.
- System shall maintain 100% standby posture
    - Rational: UAS will be ready for take-off instantly as it shall arrive quickly to the destination and optimize time spent in air. Shall maintain at least 80% of operations to be fully capable during Instrument Meteorological Conditions (IMC). The users at BES

    requested a maximum of 5-minute setup/assembly time with little technical knowledge required.

- System shall support a modular payload with generic parameters requested by user
    - Rational: Users may require mission specific equipment not already present on the system. BES also prefers equipment that can adapt to evolving needs and new technology.
    - Note: they requested capabilities for
        - 1.5-3kg payload
        - 12V power supply with up to 10W power consumption
            - Rational: User payload may require a power source. 10W power consumption allows for a wide range of payloads.
        - External attachment points
        - Payloads should be swappable in the field
- System structure shall have a minimum service life of 1000 hours under normal operation
    - Rational: Shorter structure lifespan would require additional manufacturing and assembling for replacing the structure which costs the user time and money.
- Total cost shall not exceed $4000 dollars
    - Rational: This is the maximum budget for senior projects this year
- The system shall be 90% manufacturable via commercially available 3D printers, and any remaining components or materials shall be consumer-grade COTS components
    - Rationale: The purpose of this project is to create a design that is both affordable and easy for emergency services to manufacture in-house. This will also help drive the constraint of minimizing the complexity and time required for manufacturing and repair of the airframe.
- Aircraft shall be durable and reliable
    - Emergencies often occur because of extreme conditions like fire or storms, so it is important for the airframe to be able to withstand rain, snow, or sharp-edged vertical wind gusts (up to 30 ft/s that are sometimes caused by fire) and to also be able to fly reliably in the day or night. Additionally, it must be able to maintain stable flight in operational winds of up to 30 mph while at cruise.
- Non-Augmented flying qualities shall meet MIL-F-8785C Class I Light Utility Aircraft Requirements to a level 1 standard for all flight phases
    - Rationale: This keeps the aircraft within the operational flight envelope and sets a basis of what the airplane normal states shall be to determine when the aircraft is operating in abnormal conditions. [9]
- UAS shall adhere to 14 CFR Part 107, SMALL UNMANNED AIRCRAFT SYSTEMS [10]
    - Rationale: UAS shall stay within follow these FAA regulations to operate legally and for safety purposes
- The user shall be able to operate the system using only open-source or team-developed software.
    - Rational: this keeps operational costs low because they do not have to pay for software licenses, and it could also help reduce special training because open-source software is often a more general skill that people have or at least has plenty of publicly available help documentation

6.1 High and Low Level CONOPS

High level CONOPS



Key:
UAS = Unmanned Aerial System
UAV = Unmanned Aerial Vehicle

Single Operator:
- UAS (one or more UAVs) **transported** to designated mission area.
- UAV **launched with no runway**.

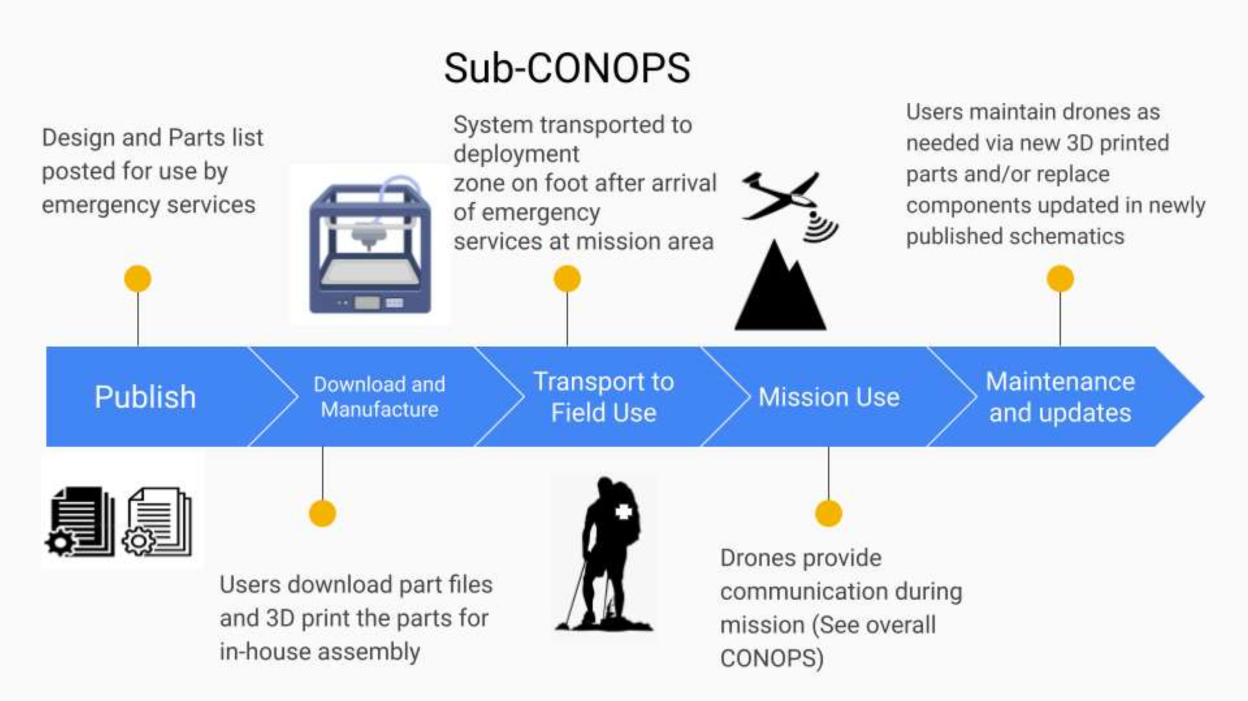
- UAV **climbs to 6k-10k ft** MSL with **winds up to 20 mph**.

UAS consisting of one or more UAVs has capability to:
- Maintain at least **12 hour combined mission** coverage
- Orbit over fixed point
- **Collecting mission specific information**
- Sustaining **winds up to 30 mph and gusts to 20 mph**.
- **Provide communications network** with ground teams.

- UAV **descends** to ground with **winds up to 20 mph.**
- **Alternate UAV** is deployed to maintain 12 hour coverage (Steps 1-3)

- UAV **lands** in a recoverable area with no **runway**.
- **Single operator recovers** UAV if safety allows.

Low level CONOPS



Design and Parts list posted for use by emergency services

Users download part files and 3D print the parts for in-house assembly

System transported to deployment zone on foot after arrival of emergency services at mission area

Drones provide communication during mission (See overall CONOPS)

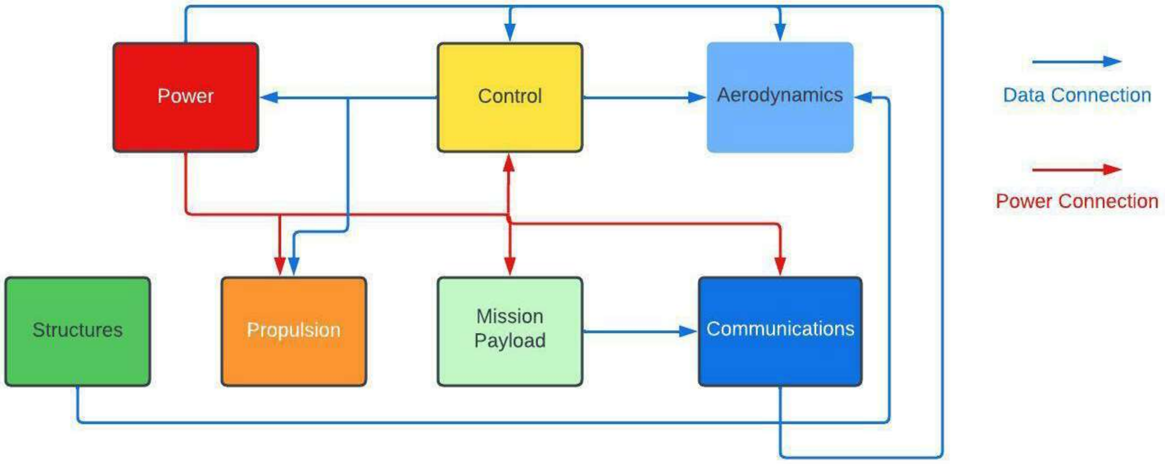
Users maintain drones as needed via new 3D printed parts and/or replace components updated in newly published schematics

7. Critical Project Elements

Element	Name	Description
#1	Software, Simulations and Testing	Utilizing simulation technology, such as structural finite element methods, CFD modeling, circuit analysis software, and MATLAB/Python coding will prove necessary to the success of the project. The results of these analyses will be used in the preliminary design of the vehicle and then validated through cross-checking and testing. Testing could include models used in wind tunnel testing, structural vibration analysis, and structural loading tests. The validation results can then be used to improve simulation fidelity and iterate past early design phases.
#2	Structures and Mechanical	The UAS structure must support its own weight and that of the payload to meet mission requirements. The structures must be strong enough to accommodate the aerodynamic loading and any other environmental loadings that occur during flight without significant yielding or deformations. The structural design will factor in additive manufacturing with consumer grade materials while maintaining the lightest possible empty airframe to satisfy the endurance requirements.
#3	Payload	The payload consists of radio transmitters, power source, and communication instruments used by the customer during their operations. The payload for this system will be in the range of 1.5-3 kg. The Payload design must be able to be substituted as necessary by the customer for the specific mission of the aircraft. The UAS will also be capable of carrying payload on external attachments that can be used as needed for the operation. In addition to this, the UAS must be able to work with variations in loading and center of gravity due to the changing payload.
#4	Avionics and Control	The vehicle will require a fully integrated control system and flight controller. While the flight controller will be taken care of by the other team, manual controls will be developed for testing needs. The vehicle airframe must accommodate a full suite of flight control surfaces, to provide lateral and longitudinal stability in a wide range of conditions, in addition to guidance, navigation and control (GNC) within the mission area. This system will also include a full layout of sensors so that the feedback controllers can ensure proper course.
#5	Propulsion and Power	The UAS requires a fully operational propulsion and power delivery system to climb/descend, maintain mission altitude, and operate onboard electronics such as control

		surfaces, cameras and any powered payload. To meet mission standards, the integration of the propulsion and power systems should be simple. Furthermore, the power system must be reusable and rechargeable while in the field. Meeting the high endurance standards, the vehicle should meet trim stability with as little power usage as possible and operate at the highest possible efficiency.
#6	Aerodynamics	The UAS must have a high aerodynamic efficiency that ensures natural stability, long endurance for minimal orbit swaps, and little energy losses at operation altitudes. It also must withstand highly varying in-air environments including fluctuations in temperature, humidity, and wind shear. The aerodynamics of the system will be modeled with MATLAB, ANSYS Fluent CFD, AAA and XFLR5 and verified through testing as defined above in element 1. Aerodynamic efficiency will be closely related to the lift to drag ratio. Analyses will also be conducted on control surface effects, stall angles/speeds and control stiffness.
#7	System Integration	The systems integration will link all the specified design areas into a single comprehensive product. The power system will provide adequate propulsion as well as electronic actuation of control surfaces and sensor operations. The avionics will use the aerodynamic effects of the control surfaces to stay on a determined flight path and maintain balance of the aircraft with payload changes. The structural mechanics will support the structure during its whole operation and ensure no breakage during extreme conditions and maneuvers. The testing and simulation of the completed product will verify that the final product can achieve mission success.
#8	System Survivability	The UAS must be designed to operate and survive in harsh rescue conditions. This will include temperature extremes from -20 to 120 degrees Fahrenheit, adverse weather such as rain, snow, and fog, as well as other hazardous conditions. The rescue environment will heavily affect the UASs operation through aerodynamic loading conditions, structural strength, and controlled stabilization.

8. Sub- System Breakdown and Interdependencies



9. Team Skills and Interests

Critical Project Element	**Team Member(s) and associated skills/interests**
Aerodynamics	*Linus Schmitz, Devon Paris, Aziz Alwatban, Jake Ramsey, Amanda Marlow, Ella Mumolo*
Airframe & Structural Design	*Linus Schmitz, Alex Fitzgerald, Aziz Alwatban, Ben Gattis, Jake Ramsey, Mikaela Felix, Amanda Marlow, Ella Mumolo,*
Avionics	*Devon Paris, Ben Gattis, Jake Ramsey*
Payload	*Alex Fitzgerald, Brady Hogoboom, Ben Gattis, Mikaela Felix, Godwin Gladison*
Propulsion & Power system	*Alex Fitzgerald, Brady Hogoboom, Jake Ramsey, Ben Gattis, Ella Mumolo, Godwin Gladison*
Launch & recovery	*Linus Schmitz, Brady Hogoboom, Adam Pillari, Amanda Marlow, Godwin Gladison*
Software & simulation	*Devon Paris, Aziz Alwatban, Adam Pillari, Ben Gattis, Jake Ramsey, Amanda Marlow*
Manufacturing	*Alex Fitzgerald, Jake Ramsey, Adam Pillari, Mikaela Felix, Amanda Marlow, Godwin Gladison*

Technical Documentation	*Linus Schmitz, Brady Hogoboom, Aziz Alwatban, Amanda Marlow, Ella Mumolo*
Safety & Testing	*Jake Ramsey, Adam Pillari, Mikaela Felix, Amanda Marlow, Ella Mumolo, Godwin Gladison*

10. Resources

Critical Project Element	Resource/Source
Electronics	Smead Electronics Lab Trudy Schwartz Bobby Hodgkinson
Hardware development	Smead Machine Shop Matt Rhode KatieRae Williamson
Aerodynamics	John Evans John Mah Donna Gerren John Farnsworth
CFD Software	John Evans (ANSYS Fluent)
Solidworks/CAD	CU Boulder
AAA Software	CU Boulder
3D Printers	ITLL Smead Machine/Fabrication Shop KatieRay Williamson Matt Rhode
Machine Shop	Matt Rhode Mark Eaton
Wind Tunnel Access	Trudy Schwartz Josh Mellin
Customer Communications	Hunter Ray John Mah
Software Integration	Team 7 (TEAM SEVEN)
Flight Testing & Demonstrations	Academy of Model Aeronautics
Admin help	KatieRae Williamson (room access) Emerson Earthman (conference room) Jacqui Stang (finance lead) Kayla Vandegrift (front desk/basic help)

11. References

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