University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018

Project Definition Document (PDD)

VORTEX: Vertically Optimized Research, Testing, & EXploration

Approvals

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3. Problem or Need

The Integrated Remote and In-Situ Sensing (IRISS) group at the University of Colorado Boulder is working with Project TORUS (Targeted Observation by Radars and UAS of Supercells) to design, develop, and deploy new sensing systems that utilize the expanding mobility of aerospace vehicles. The University of Colorado Boulder is working to expose how small-scale structures within the storm contribute to tornado formation.

Specifically, this undergraduate team will be working to develop an unmanned aerial system (UAS) with innovative functionality. This design will be similar to the Robust Autonomous Airborne Vehicle - Endurant and Nimble (RAAVEN) which uses a fixed wing aircraft design to measure atmospheric conditions. Currently, the RAAVEN launches via a rail bungee system or via an automobile mounted Rapid Aircraft Pnuematic Catapult (RAPCat). In many applications, however, an aircraft capable of Vertical Take Off and Landing (VTOL) would be a more practical system. Without being restricted to the RAPCat, the choice of launch and landing sites for each mission becomes more diversified such as heavily wooded areas or coastal launch sites.

The aircraft must maintain design characteristics of long endurance flight of one or more hours, be capable of two autonomous take-offs and landings per mission, and have a production cost ideally below $1000 per unit. The successful completion of this project will allow IRISS to be increasingly agile and robust when taking atmospheric in-situ measurements by expanding launch and landing capability. Accomplishing these requirements will enhance severe weather data collection and improve detection of potentially lethal storms.

4. Previous Work

As previously mentioned, the purpose of this project is to modify the current Drak aircraft wingset utilized by IRISS in the TORUS project, which aims to investigate and measure the meteorological phenomena of severe storms. In the context of this document, "wingset" refers to the foam fuselage and wings provided by RiteWing. The goal of the project is to collect atmospheric data including temperature, pressure, humidity, and wind speed in order to improve the conceptual model of supercell thunderstorms - the parent storms of most destructive tornadoes - to help with future forecasting. The team based at the University of Colorado Boulder, led by faculty through the IRISS initiative, is trying to understand how small-scale structures within the storm contribute to tornado formation with the goal of reducing false alarm tornado warnings and improving detection of potentially lethal storms.

The current Drak wingset has a wingspan of 60”, a weight of approximately seven pounds, and provides a total flight time of 15 to 20 minutes using a Ritewing 5s 8000mAh 25c battery pack. The current fleet of UAS utilized by the IRISS storm chasing program is launched into the air from the aforementioned RAPCat mounted to the roof of an SUV. After completing its in-situ sensing mission, the aircraft lands on its belly and slides to a stop, as it features no landing gear. While the current launch system allows for some elevation from the ground, improvements are desired to allow for takeoff and landing in areas where the launch support vehicle cannot access or where the distance needed for the UAVs to gently set down is unavailable.

Current modifications to the Drak kit that have been integrated into the IRISS fleet have proven to expand the endurance capabilities of the kit to 2 hours for both the RAAVEN aircraft and the Super RAAVEN. The two craft differ notably in wing size, weight, payload mass, and battery size. RAAVEN’s goals and characteristics are closely related to the project at hand, as its fuselage is from the Drak kit, the same nose probe is included on the tip, and the endurance is closer to this project's goals. VTOL configurations utilizing the Drak wing kit will be researched with efficiency and simplicity as primary objectives. Minimal modifications to the Drak kit are desired to allow for an easily replicable aircraft, as opposed to the complexity required in producing both RAAVEN aircraft.

IRISS currently utilizes the Pixhawk Cube flight controller, which includes its own computer hardware and connections for propulsion, controls and data collection. The Pixhawk has the ability to autonomously control the aircraft, for which IRISS currently uses the open source ArduPilot software. Ardupilot is used extensively by hobbyists and professionals for many types of UAS, including quadcopters, fixed wing aircraft, rovers and even boats.

5. Specific Objectives

The objectives for this project are outlined in the leveled requirements in Table 1.

Table 1: Objectives Table for Levels of Success

	Level 1	Level 2	Level 3
Flight	Aircraft must cruise in wind conditions up to 5 m/s, and takeoff with wind speeds up to 2 m/s in any direction.	Aircraft must cruise in wind conditions up to 10 m/s, and takeoff with wind speeds up to 7 m/s in any direction	Aircraft can cruise, take-off, and land with wind speeds up to 12 m/s in any direction
Budget	The aircraft shall cost no more than $1250, not including IRISS avionics package.	The aircraft shall cost no more than $1000, not including IRISS avionics package.	The aircraft shall cost no more than $900, not including IRISS avionics package.
Endurance	The aircraft shall perform 2 vertical takeoffs and 2 vertical landings with the capability to cruise for 1 hour with >15% battery charge remaining in moderate flight conditions (<10 m/s wind speed)	The aircraft shall perform 2 vertical takeoffs and 2 vertical landings with the capability to cruise for 1.5 hour with >20% battery charge in moderate flight conditions	The aircraft shall perform 3 vertical takeoffs and 3 vertical landings with the capability to cruise for 2 hours with >20% battery charge in moderate flight conditions
Airframe	The Drak kit shall be modified for VTOL capability with the IRISS Avionics Package; Current launching system (RAP-Cat) capability shall be maintained	-	-

	Level 1	Level 2	Level 3
Structural Integrity	All components stay operational and firmly mounted during RAP-Cat launch acceleration of TBD; as well as be capable of protecting sensor payload during potential uncontrolled landing impacts	-	Components maintain operation in wind speeds up to 12 m/s, can withstand landing impact of TBD m/s
Ground Support Equipment (GSE)	The GSE shall be capable of utilizing the provided avionics and telemetry package from IRISS.	-	-
Payload	The 0.5 kg, TBD cm^3 payload and nose probe shall remain protected and attached for the entire nominal flight operation	The 0.5 kg, TBD cm^3 payload and nose probe shall remain protected and attached for the entire nominal flight operation	-
Autonomy	The aircraft shall be able to perform autonomous takeoffs and landings within a 3 meter radius of a target beacon, with manual pilot control available in case of emergency	The aircraft shall be able to perform autonomous takeoffs and landings within a 1.5 meter radius of a target beacon	The aircraft shall be able to perform autonomous takeoffs and landings within a 1 meter radius of a target beacon
Safety	The aircraft shall have an autonomous return to loiter function if telemetry is lost for an extended period (90 seconds) as well as capability to terminate the flight immediately upon command from the GSE	The aircraft shall have a kill switch that engages an emergency autonomous landing procedure and a return to loiter function if telemetry is lost for an extended period	-

6. High Level Functional Requirements

In order for this project to succeed, a series of requirements have been set and ranked by importance. Firstly, the primary focus of this project is the successful implementation of a Vertical Takeoff and Landing (VTOL) system on the Drak wing set. It shall also be capable of transition from VTOL to a fixed-wing configuration to maintain the original purpose of the UAS. The aircraft shall also have a navigation system capable of taking off and landing within a specified accuracy relative to a landing beacon. Interfacing with the RAPCat take-off system is required. Finally, the aircraft shall maintain cruise flight for at least one hour not including two takeoffs and landings. If these requirements were to not be met, then the project cannot be labeled a success. The following sections propose a basic functionality of the solution and concept of operations.

6.1 Functionality/FBD

A basic functional block diagram has been created, noting that it is a high level preliminary design. There are two main divisions, the ground station and aircraft body. The ground station is where all preparations and commands will be executed. In this station, the operator will configure the mission profile for the flight controller, transmit and receive vehicle state data, and set the RC manual control setting for pilot input in case of emergencies. On the aircraft body, there are two main subsystems, the avionics package and mechanisms. The avionics package provided by IRISS centers around the PixHawk Cube, which includes IMU sensors, a barometer sensor, a power module, ARDUPilot flight control software, a receiver, and an SD card for data backup. The mechanisms on board, which include propulsion, avionic actuators, and supplementary motors, are controlled by the power module shared with the avionics package. The method by which the vehicle transitions from VTOL to fixed-wing mode is yet to be determined. The battery on board the aircraft supplies power to the power module and supplementary sensors directly. Everything works on this feedback loop and will be autonomous with ARDUPilot as the main processing unit.

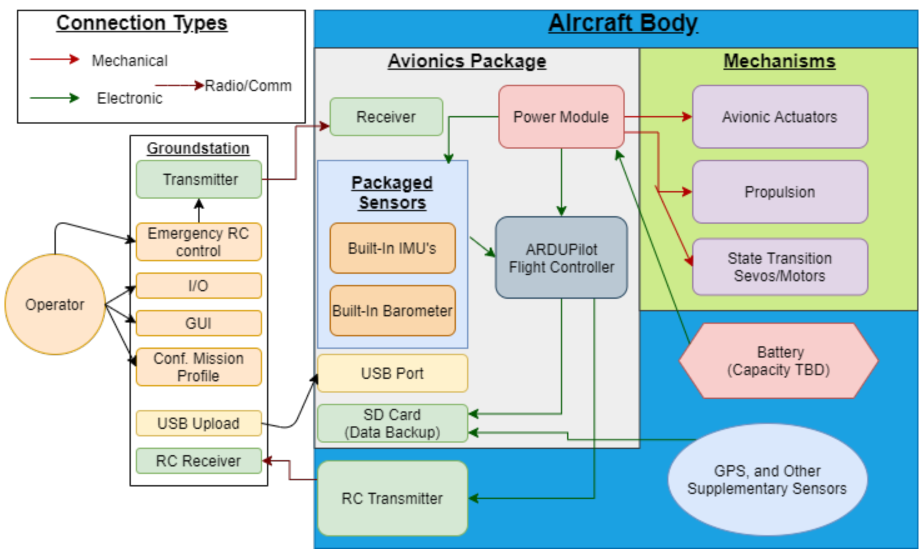

Figure 1: Functional Block Diagram

6.2 Concept of Operations (CONOPS)

The primary focus of this project is the successful implementation of a Vertical Takeoff and Landing (VTOL) system on the Drak wing set. As this vehicle will share the same Drak base of the RAAVEN platform, no additional transportation or launch infrastructure will be required to accommodate the VTOL version. Once the system is transported to its operational location, it will be configured for flight by connecting the on-board computer to a ground station (e.g. a laptop computer) and uploading the desired mission profile. After the computer is configured, the vehicle is set up for deployment with any necessary launch hardware before executing a vertical takeoff. Once airborne, the vehicle will transition to a horizontal flight mode and engage in standard mission operations. Once mission operations are complete, the vehicle will perform a vertical landing at a specified beacon location, with [TBD] meters of accuracy. Two key components of a successful mission will be the ability to cruise for at least 1 hour as well as performing a minimum of two takeoff and landing procedures.

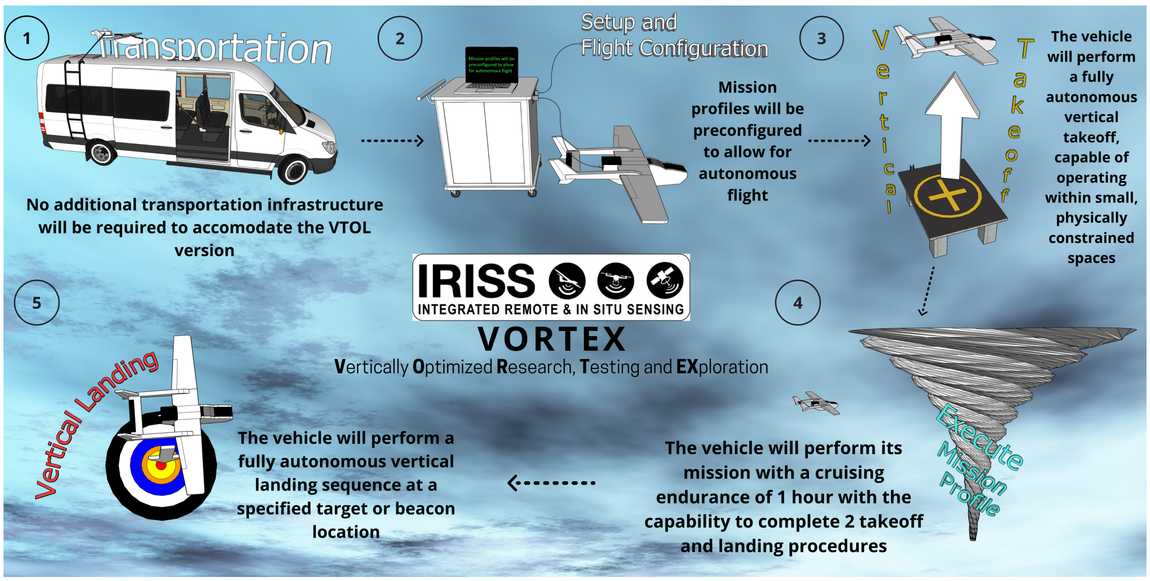

Figure 2: Concept of Operations

7. Critical Project Elements

7.1 VTOL Capability

The central goal of this project is to convert an existing fixed-wing platform into a VTOL capable aircraft. The aircraft must be be able to take off and land in constricted areas such as forests or the deck of a ship. The aircraft must be able to transition from vertical to horizontal flight after takeoff. Choosing the optimal VTOL system will require modeling of multiple configurations of motor and mounting systems.

7.2 Endurance

The aircraft must have a cruising endurance of at least one hour and be able to complete at least two takeoffs and landings. The introduction of VTOL systems could have a profound impact on the aerodynamic performance of the aircraft and efficiency of the propulsion system. Therefore, a proper balance between the aerodynamics of the aircraft and the efficiency and capacity of the propulsion system must be found to maximize endurance while not compromising other performance aspects or mission requirements.

7.3 Automation/GNC

The aircraft must be able to execute fully autonomous flight profiles during the mission, with capability for manual pilot control if necessary during a flight. It must be able to land at a target beacon with an accuracy of 3 meters. In addition, the aircraft needs to be able to maintain stability during transitional phases and cruise phases using some measure of vehicle state (body rates, altitude, etc).

7.4 Airframe

The vehicle must be based on the commercially available Ritewing Drak wing kit. The mounting of all components to the Drak wing kit (including any payloads and sensors) must be able to maintain structural integrity during all phases of flight. If secure mounting cannot be guaranteed, loss of components or functionality due to structural failure will result in an inability to complete mission requirements.

7.5 Operations and Testing

A full scale transition flight test as well as a high wind test must be conducted. Validation of the project will require testing of the aircraft in tether tests as well as full flight tests in both nominal and high wind situations. A proof of operation for the transition from vertical to horizontal flight will require a careful testing approach to avoid loss or damage to the aircraft.

8. Team Skills and Interests

Table 2: Team Skills and Interests

Critical Project Elements	Team Member(s)	Associated Skills/Interests
VTOL Capability	Mohamed Aichiouene	Strong Dynamics Understanding, Dynamic Modeling and Controls
	Cameron Kratt	Control system understanding, Aircraft dynamics modeling
	Stephen Albert	Aircraft dynamics understanding and controls
	Delaney Jones	Dynamics and control systems
	Roland Ilyes	Dynamics modeling and Controls implementation, Kalman Filters, Ardupilot firmware
	Joe Buescher	Control and Sensor Electronics, Aircraft Dynamics stability modeling, Optimizing control surfaces and systems
	Michael Patterson	Aircraft dynamics modeling and testing
	Justin Troche	Interest in further understanding of dynamics and controls, Aircraft Dynamic Modeling
Endurance	Bill Chabot	RC Batteries, Propulsion system design, Propeller analysis, Aerodynamic modeling
	Delaney Jones	Aerodynamic modeling, Fluent
	Roland Ilyes	XFLR5, Aerodynamic Modelling
	Joseph Rooney	Fluent
	Brandon Cummings	Aerodynamic modeling and dynamics
	Michael Patterson	Propulsion system design and analysis, Aerodynamic modeling
	Colton Cline	Strong interest in integrated electronics, propulsion system design and analysis
	Joseph Buescher	Aerodynamic modification modeling and analysis
	Justin Troche	Aerodynamic Modeling, XFLR5
Automation/GNC	Mohamed Aichiouene	Aircraft Dynamics, Matlab, Experience with Accelerometers
	Cameron Kratt	Control system understanding, Aircraft dynamics modeling
	Delaney Jones	Control systems, Matlab, statistics and machine learning
	Roland Ilyes	Aircraft Dynamics Modelling and Controls Implementation, Ardupilot Quadplane Configurations
	Joe Buescher	Statistical Estimation for Dynamic Systems, Ardupilot, Avionic Controls System Design, Python, and C++
	Justin Troche	Interest in control systems, learning Ardupilot and more about avionics

Critical Project Elements	**Team Member(s)**	**Associated Skills/Interests**
Airframe	Stephen Albert	Strong structures understanding and interest in CAD modeling
	Mohamed Aichiouene	SolidWorks, Structure design, Testing Material Failure Characteristics
	Bill Chabot	Structural Design, Material Testing and selection, CAD/CAM
	Cameron Kratt	SolidWorks, Structural analysis
	Roland Ilyes	Structural Dynamics
	Joseph Rooney	Solidworks, 3D Printing, Laser Cutting
	Brandon Cummings	All manufacturing and aerodynamic design
	Michael Patterson	CAD, FEM analysis, Topology Optimization, Material Testing, Composite Design and Layup, 3d printing
	Colton Cline	Strong interest in CAD design and manufacturing, Laser cutting, Material Testing, Mechanics
	Justin Troche	Strong interest in CAD modeling, Material testing and Structural Design
Operations and Testing	Bill Chabot	Project Management, Test procedure design and analysis, RC Piloting
	Stephen Albert	Testing and analysis
	Roland Ilyes	Test Flights, Vibration Testing
	Joseph Rooney	MATLAB, Testing
	Brandon Cummings	Testing, manufacturing, and maintenance
	Michael Patterson	Project Management, Testing and analysis
	Colton Cline	Testing and Analysis

9. Resources

Table 3: Resources

Critical Project Elements	Resource/Source	Reasoning/Explanation
7.1, 7.4	Aerospace Machine Shop	The machine shop will play a big role in manufacturing. Furthermore, the experience of the employees there allows the team to utilize feasible manufacturing processes.
7.1, 7.2, 7.3, 7.4, 7.5	IRISS Team	The IRISS team have multiple years with UAS. Their experience and knowledge will help guide the team around the more complex tasks, such as automation and testing.
7.2, 7.5	Engine Test Room	The engine test room is a crucial resource when it comes to testing the aircraft's endurance, as well as other engine operations.
7.1, 7.2, 7.3, 7.4, 7.5	Faculty	The experience and knowledge of the faculty at Smead Aerospace is fantastic for guiding the team in all portions of project design, manufacturing, and testing.
7.1, 7.2, 7.3, 7.5	UAS Testing Ground	UAS testing grounds, both on and off campus, allows for testing of the aircraft's automation capabilities, structural integrity, and aerodynamics.
7.3	Ardupilot Website	The Ardupilot website has a wealth of documentation on implementing automation for different flight configurations, as well as information about the avionics hardware package aboard the aircraft.
7.4	Team Member Manufacturing Resources	A 3D printer and other manufacturing tools are fantastic for crafting small custom parts that could assist in avionics mounting and structural support.
7.1, 7.4	IRISS Manufacturing Tools	Utilizing the IRISS manufacturing resources could allow for a more streamlined manufacturing process centered around UAS. Furthermore, the knowledge of the team there might provide solutions to project-specific manufacturing hurdles the team might encounter.
7.1, 7.3	MATLAB	MATLAB is a powerful simulation tool that will assist the team during the design and VTOL configuration trade studies. Namely, simulation of the aerodynamics and dynamics of different VTOL configurations will help in choosing a viable design.
7.2, 7.5	Aerospace Wind Tunnel	Wind tunnel testing allows for a more precise study of the aerodynamics of the aircraft.

References

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