

Aerially Monitored Aerially Deployed Surface Sensors

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Glacial movement is related to global climate change and is currently measured using human-placed sensors. Glaciers and sea ice present hazardous conditions to the scientists and an alternative method designed by the senior projects group Aerially Deployed Aerially Monitored Surface Sensors (ADAMSS) from the University of Colorado, Boulder uses a radio controlled airplane to deploy the surface sensors to the glacier surface. The ADAMSS design incorporates three sensor packages connected to the exterior of a Senior Telemaster R/C airplane. The sensors are released via a ground-based radio transmission and then deploy from a height of no less than 30 meters. After the sensor has been released from the aircraft, the drag device opens and controls the decent speed. The drag device is called the Whirlybird wing system and it models a samara wing system as a spin stabilized drag device. The sensor package wings deploy using torsion springs to slow the decent and allow for the survivability of the electronics. The sensors are designed to measure GPS, temperature, and pressure data for five days. Once five days of data has been collected, a receiver device mounted on the R/C aircraft travels above the sensor and receives the data.

Nomenclature

<i>SP</i>	=	sensor package
<i>RP</i>	=	receiver package
<i>DP</i>	=	deployment package
<i>RC</i>	=	radio controlled
<i>RECUV</i>	=	Research and Engineering Center for Unmanned Vehicles
<i>RoHS</i>	=	Restriction of Hazardous Substances
<i>GPS</i>	=	Global Positioning System
<i>BET</i>	=	blade element theory
<i>a</i>	=	fifth-order polynomial for the samara-shaped wing
α	=	angle of attack
φ	=	angle of incoming flow
θ	=	mounted angle of attack
<i>r</i>	=	distance along chord
<i>v</i>	=	terminal velocity
ω	=	spin rate
<i>c(l)</i>	=	chord distribution
<i>c_l</i>	=	sectional lift coefficient
<i>c_d</i>	=	sectional drag coefficient
<i>c_{di}</i>	=	sectional induced drag coefficient
<i>L</i>	=	lift
<i>D</i>	=	drag
<i>Z</i>	=	vertical normalized forces
τ	=	torque
<i>m</i>	=	mass
<i>I</i>	=	moment of inertia
<i>c</i>	=	chord
<i>e</i>	=	Oswald efficiency
η	=	efficiency of the lifting line curve

I. Introduction

THE need for glacial movement and environment data has prompted the creation of the Aerially Deployed Aerially Monitored Surface Sensors (ADAMSS), which is a senior projects student group from the University of Colorado, Boulder. A radio-controlled aircraft will deliver the sensor packages (SP) to the glacial surface via the deployment package (DP). The surface sensors collect GPS, temperature, and pressure data which is later retrieved by the receiver package (RP) interfaced with the aircraft. This paper will discuss the project requirements, system architecture, integration, and novelty.

II. Primary Objectives and Requirements

A. Background and Context

Researchers are typically required to trek out across the glacier to several locations and manually place the GPS equipment. Additionally, most of the equipment is unable to remotely transmit data back to a nearby research station, requiring that the scientists return at regular intervals to retrieve the data. These procedures require the researchers to travel through hostile environments, placing themselves and the expensive equipment in danger. In response to these dangers the Research and Engineering Center for Unmanned Vehicles (RECUV) has proposed a new technique that will provide a higher level of safety to the glacier researchers as well as reducing cost. RECUV is sponsoring the development of a system that will allow GPS receivers to be placed via one or more remotely controlled air vehicles (RCs), eliminating many of the hazards posed by current methods. This system will allow scientists to remotely deploy and receive data from the sensors.

B. Overall Project Requirements

The top level requirements will be briefly discussed in this section. The first being the customer set requirement that the system will be interfaced with and delivered by a fixed-wing aircraft. A Telemaster R/C plane will be used to test the overall system because fixed wing works best for delivery time and range. The system should be capable of adapting to a UAV at a later point.

Since a requirement for the specific aircraft to be used was put into place, a weight limit needed to be created in order to allow the aircraft to fly under close to normal conditions. Therefore the total mass of the sensors as well as the deployment package shall be no more than 5 kg.

The next requirements put into place were environmental requirements stating that the system must be able to work in temperatures as low as -10°C (14°F). These are Arctic & Antarctic temperatures in summer/spring, which is when the customer is interested in collecting data. Other requirements were set to establish the surface of the glaciers that can be expected as well as maximum wind speeds for deployment.

Once these sensors are deployed, it is not anticipated at the present time that these sensors will be recovered. Therefore the next requirement put into place is that all electronic deployables shall comply with environmental standards for electronics (RoHS), with the exception of the batteries. This would require lead free components.

Because the data would not be retrieved by on-site human interaction, a requirement was set forth in order for the data on the sensors to be acquired. The data acquired by the ground-based sensor system shall be transmitted via radio at 2.4GHz frequency to an airborne fixed wing aerial platform.

III. System Architecture

A. Overview of Systems

The ADAMSS project been divided into three systems: Deployment, Sensor, and Receiver Packages.

The Sensor Package (SP) is the system that is dropped onto the glacier and records GPS, pressure, and temperature data for 5 days. This package is the design driver for the project and after careful consideration, a whirlybird system was chosen for the design. A whirlybird is a spin stabilized self contained drag device (See **Error! Reference source not found.**). The whirlybird sensor packages will be deployed from the Telemaster aircraft and will remain secure to the ice because the wings angle of attack causes an anchoring action when horizontal wind is present.

The Deployment Package (DP) includes all components necessary for the interface of the SP to the plane and the deployment of the SP. It is designed to allow for proper sensor package deployment and protection during transit with minimal drag and center of gravity effects on the aircraft. The sensor package wings are bent and folded to fit into the deployment package canisters. These canisters are attached to the aircraft with a linear bearing release system activated by a pin servo.

The Receiver Package (RP) is interfaced with the plane and aerially collects the data from the sensor after the 5 days of data collection. The receiver package has minimal structural components and is designed to fit in the bay of the aircraft with simple attachment/detachment capabilities.

During deployment phase preflight, the sensors packages will be powered on and loaded onto the Telemaster aircraft. The aircraft will then fly to a specified location, within 10km of the takeoff location and the sensor packages will be deployed from the aircraft (one at a time) to three locations on a given glacier. The aircraft will return to the takeoff location and the sensors will be left on the glacier to record pressure, temperature, and GPS data for 5 days. After the five days of data collection is complete, the receiver package will be loaded into the bay initiating the data retrieval preflight phase. The aircraft will fly over the 3 sensor packages and the data will be aerially uploaded by the receiver package. Finally, the Telemaster will land at the takeoff location with the data onboard for analysis. This concept of operations is shown below in Figure 1.

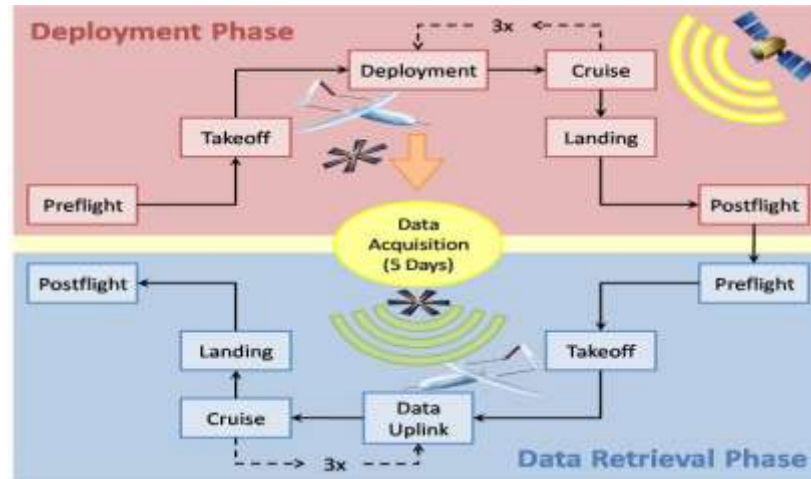


Figure 1: Concept of Operations

B. System Structure Model

The deployment package interface with the aircraft is shown in Figure 1: . The figure clearly shows the locations of the deployment tubes and loaded sensor packages on the Telemaster aircraft. The deployment packages are all attached to the fuselage with two under the wings at 60° angles and one underneath the fuselage.

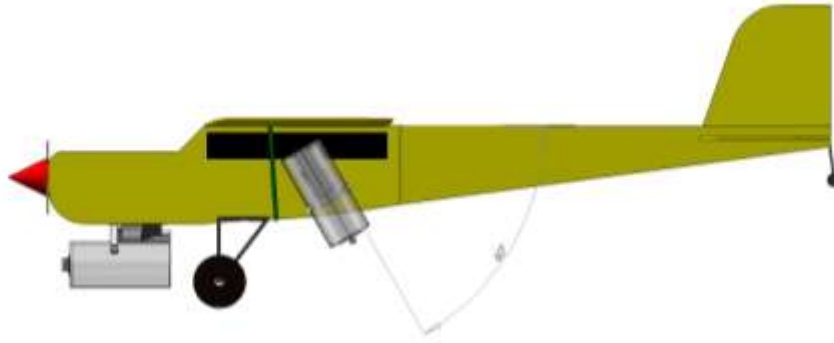


Figure 1: Telemaster with the 3 SP's Loaded
 (Note the third SP is directly behind the under-wing mounted SP)

The sensor packages are dropped from either side first, and then from under the fuselage. This is done in order to minimize changes of the center of gravity location so the flight can be as stable as possible. Once the deployment canister has fully separated from the ball bearing track the whirlybird wings separate the canister sides with the help of a spring hinge on the canister. The sensor package then deploys the wings and spins to the terminal velocity where it continues descent to the glacier.

The sensor and deployment tube materials have been designed to meet RoHS requirements since they will be left on the glaciers and eventually will end up in the ocean.

C. Sensor Package

The sensor package with wings deployed can be seen in **Error! Reference source not found..** The relative size of the central component canister to the wings, as well as the GPS antenna and Zigbee Pro radio antenna locations are shown. The wings are composed of aluminum wing spars and polycarbonate wing area.

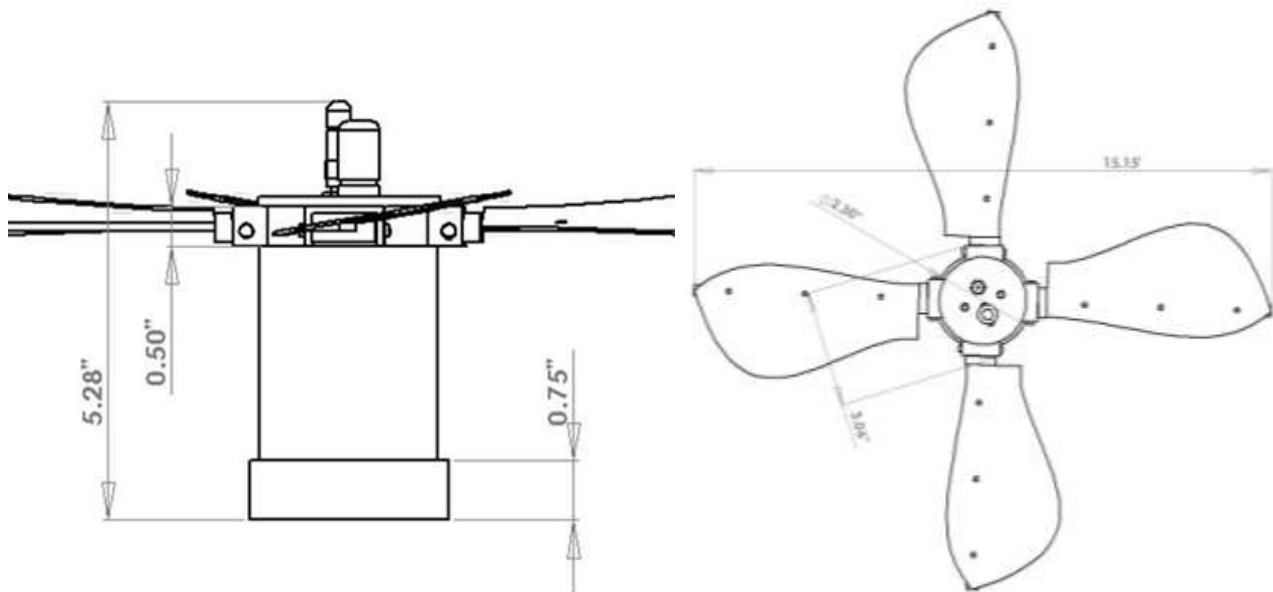


Figure 3: SP with Wings Deployed (left:side view, right:aerial view)

The whirlybird wings are opened due to the torsion springs after the deployment tube has fully separated from the aircraft. The wings create drag which allows the package to reach the ground with a terminal velocity of 5m/s and have an angle of attack of 15° which increases the spin stabilization of the

falling system. The wing spar material was chosen to maximize tensile strength and the modulus of elasticity while the wing material was chosen for the high strain at breaking point, high strength, and performance at low temperatures. The high strain at breaking point is necessary for bending of the wings in the deployment package with minimal creep effects.

D. Receiver Package

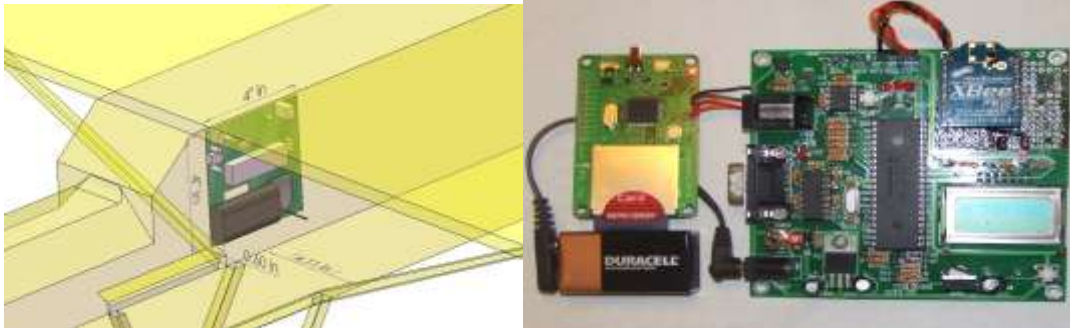


Figure 4: left) RP on Telemaster right) RP Electronics

Since the receiver package is primarily made of electronic components, the only structural consideration addresses how to interface the package with the aircraft. **Error! Reference source not found.** shows how the receiver package will fit into the aircraft bay for the data retrieval stage. The Qwik-Flash board is 4"x4" and the batteries are 0.6" thick, which define the dimensions of the receiver package. This package can easily fit into the 4.11" wide aircraft bay and the board has screw holes to allow for simple attachment.

E. Deployment Package

The deployment package with the sensor package loaded inside can be seen below in Figure 5. The orientation of the deployment system in this figure shows the servo, acrylic canister, track, stability wheels, and sensor package. This figure also shows the orientation of the folded and bent whirlybird wings.

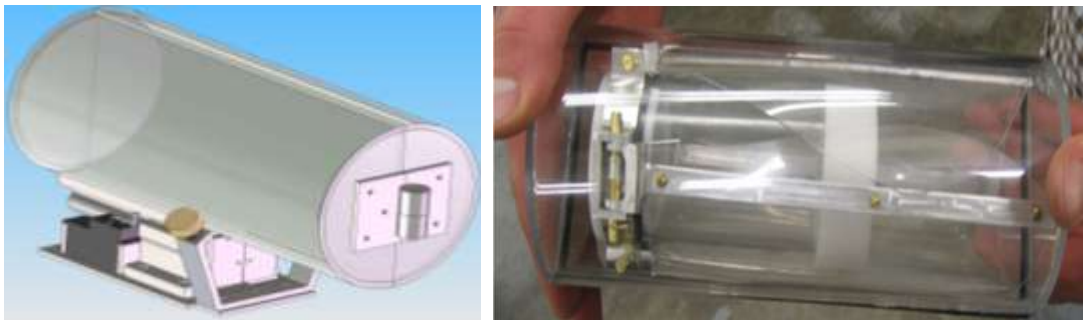


Figure 5: left) DP Mounted on Track right) Fabricated DP with the SP Folded Inside

The DP downfall angle from the UAV is 60° in order to minimize excess drag and ensure that the whirlybird wings do not interfere with the aircraft upon deployment. The release is initiated using a pin servo that allows the canister to slide through the ball bearing track due to the weight and drag forces. A zoomed image of the ball bearing track can be seen in **Error! Reference source not found.**

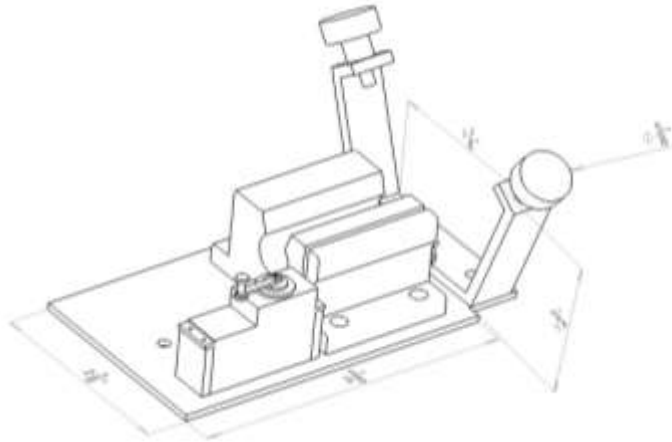


Figure 6: DP Aircraft Interface

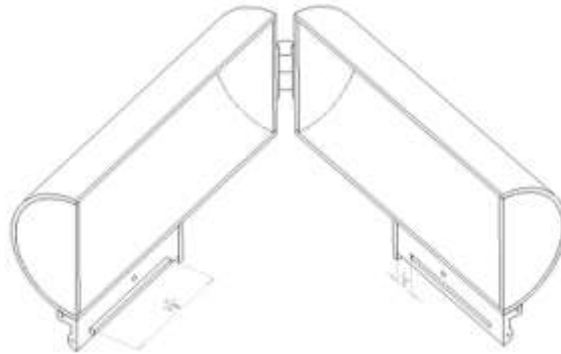


Figure 7: DP Canister after Deployment

Figure 7 shows what the deployment package looks like after the canister has separated from the Telemaster aircraft. The linear bearings are connected to the aircraft and the deployment package is being opened by the force of the sensor package torsion springs as well as the spring loaded hinge on the canister. Along with the sensor package, the acrylic canister and aluminum track will fall to the glacier surface and will not be retrieved.

IV. Requirements Flow Down of the Three System Packages

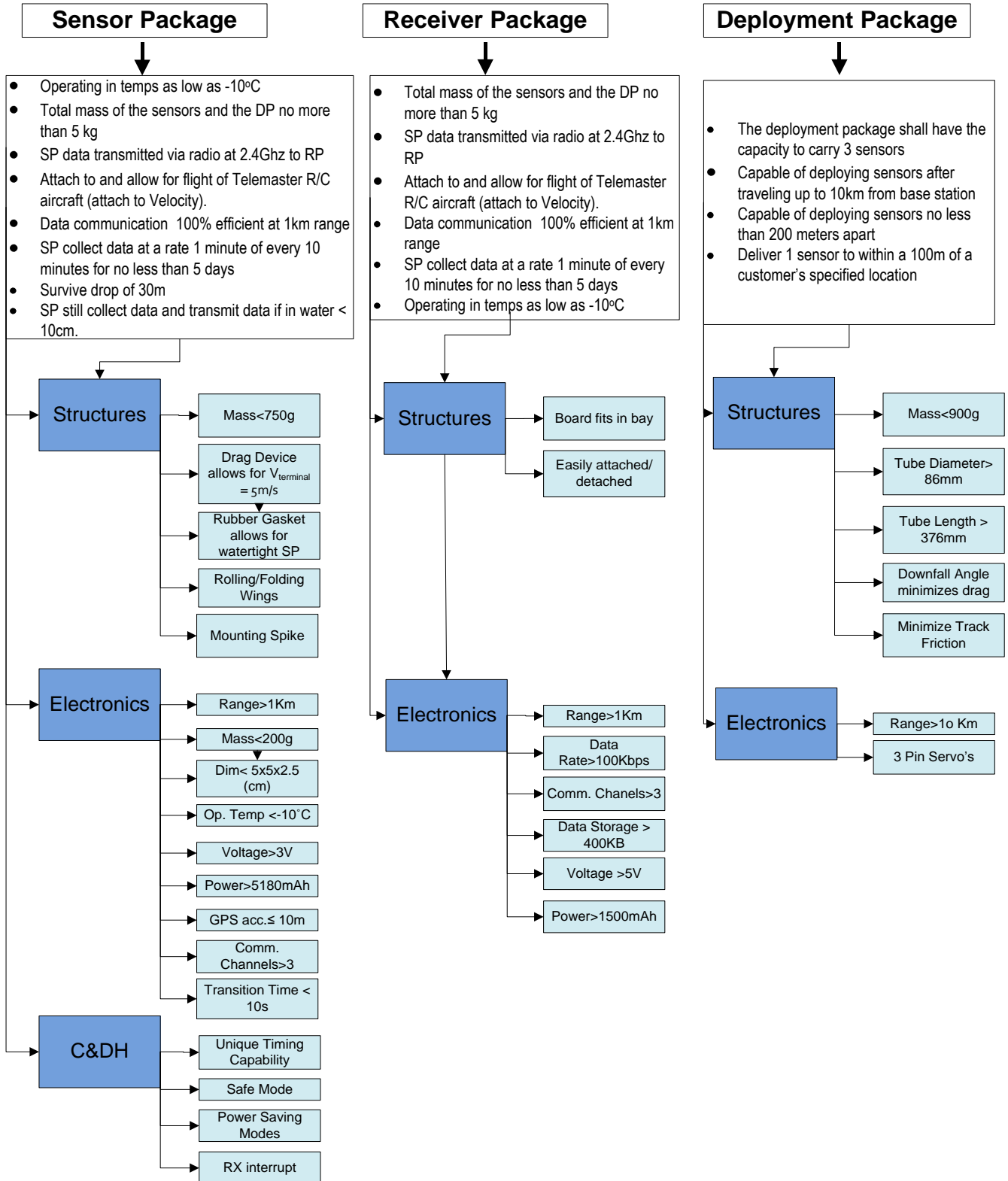


Figure 8: System to Subsystem Requirements Flow Down

V. System Novelty

A. Whirlybird Aerodynamic Modeling

The foundation of the modeling for the whirlybird is derived from Blade Element Theory (BET) which has been traditionally used to model propellers. This system differs from the conventional propeller because the angular velocity of the system is driven by the aerodynamic forces and is unknown. The sectional lift and drag coefficients for flat plate theory are integrated along the length of the samara-shaped blades to determine the overall lift and drag.

The blade shape was modeled after a samara seed. To do this, a fifth-order polynomial was fit to a scaled picture of samara. The coefficients of the polynomial that best fit this planform are shown in Figure 9 and Equation 1.

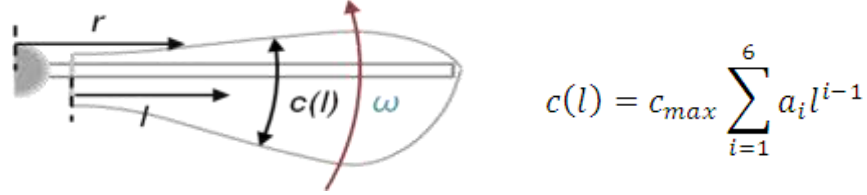


Figure 9: Visualization of the whirlybird wing

$$a = [.482 \quad -.325 \quad 5.992 \quad -10.887 \quad 10.203 \quad -5.466]^T \quad (1)$$

The angle of attack (α) is a function of both the decent velocity and angular velocity and is shown in Figure 10 and Equation 2.

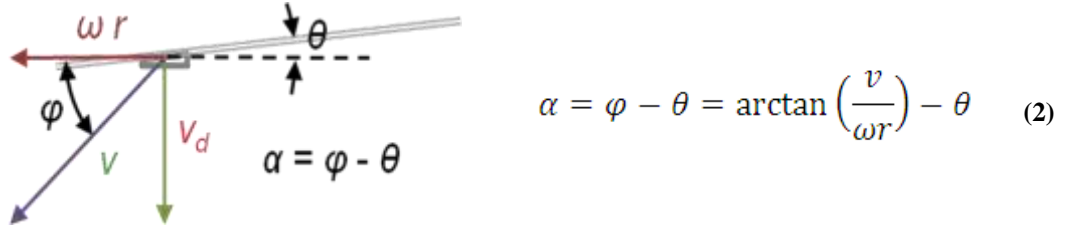


Figure 10: Breakdown of the angle of attack and incoming flow velocity

The angle of attack is substituted into the sectional coefficients of lift (c_l), drag (c_d), and induced drag (c_{d_i}). The sectional coefficients are then substituted into the sectional lift and drag force equations shown in Equation 4. There are two aerodynamic efficiency factors introduced in Equation 3. η is the deviation of the sectional lift curve from the theoretical 2π . e is the Oswald efficiency which determines the effective induced drag due to lift. These sectional forces are integrated along the full length of the wing to determine the overall lift and drag. Z is the net aerodynamic force in the vertical direction and τ is the net aerodynamic torque.

$$c_l = \eta\pi \sin(2\alpha), \quad c_d = 2\eta\pi \sin^2(\alpha), \quad c_{d_i} = \frac{c_l^2}{\pi e AR} = \frac{c_l^2}{\pi e \frac{L^2}{A_w}} \quad (3)$$

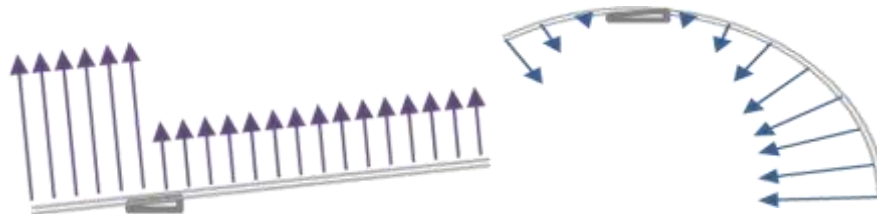
$$L' = \frac{1}{2}\rho V^2 c_l c, \quad D' = \frac{1}{2}\rho V^2 (c_d + c_{d_i}) c \quad (4)$$

The aerodynamic forces are used in Newton's equations of motion to form two second-order coupled differential equations. The first describes the linear momentum and the second equation describes the angular momentum of the whirlybird. The final resulting equations, the Runge-Kutta equations of motion are shown below in Equation 5.

$$\frac{dv}{dt} = g - \frac{NZ}{m}, \quad \frac{d\omega}{dt} = \frac{N\tau}{I} \quad (5)$$

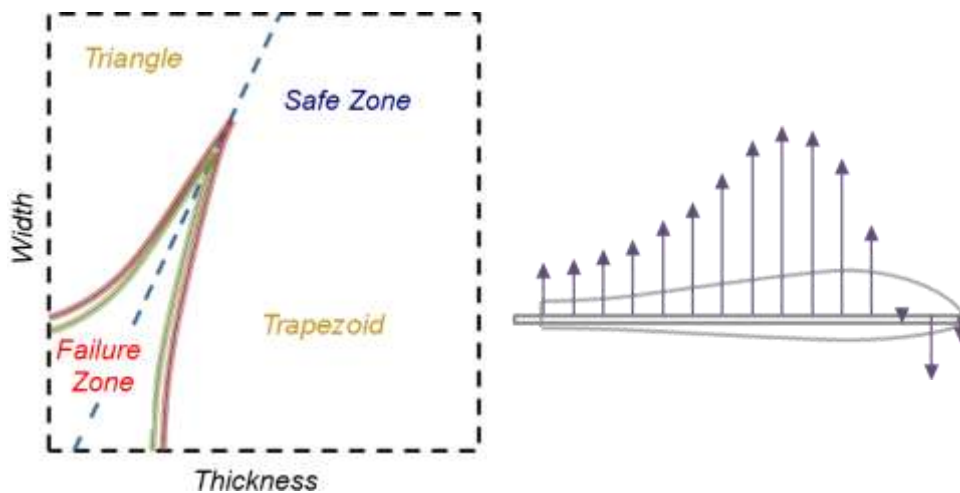
B. Wing and Spar Bending Model

Once the wing loading is known, the wing bending can be calculated. The wings and spars were assumed to be a decoupled, simply-supported beam. The forces during flight were assumed to be constant along the chord while the moments were assumed to be balanced about the quarter-chord, as shown below in Figure 11. The bending stress while stored in the DP was modeled as a linearly increasing force along the chord. The thickness of the wings was chosen to minimize wing deflection during flight and to avoid plastic deformation during storage.



**Figure 11: left) The forces experience during decent along the chord
right) The forces experienced while in storage in the DP**

The spar was designed to minimize cross-sectional area and reduce the tip deflection during decent. An upper and lower bound were calculated for the spar thickness, and the shape was chosen for fabrication and reduced mass. Figure 12 demonstrates the design criteria for the spar shape and the loads experienced during decent.



**Figure 12: left) A summary of the wing sizing criteria
right) A visualization of the aerodynamic loading**

A schematic for the completed whirlybird wing system was shown in Figure 3 of this document. The corresponding graphs (Figure 13) demonstrate the effectiveness of the angle of attack and with terminal velocity. Several proportionality coefficients were determined through experimental data collection and were used to update the Runge-Kutta differential equation. The results from prototype

testing were used to determine the non-dimensional coefficients used when modeling the flow around the whirlybird wings.

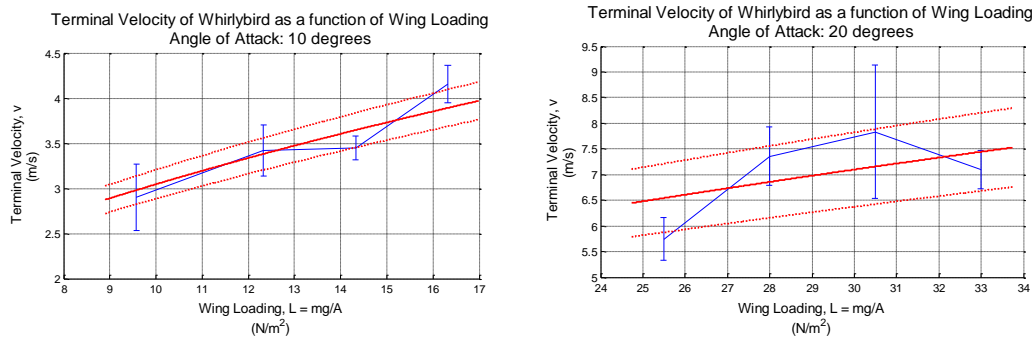


Figure 13: Experimental results from a prototype whirlybird test

VI. Conclusion

The goal of ADAMSS was to design an array of sensors to measure glacier movement using GPS, temperature and pressure data. The sensors are released from a radio-controlled aircraft to eliminate the necessity for human placement of the sensors. ADAMSS chose a whirlybird wing system as a drag device to ensure the survivability of the sensors. The project novelty is the integration of the whirlybird wing system into the sensor package. An optimization code was written to step up and down the gradients of the chord length, wing length, spar thickness, wing thickness, and angle of attack to obtain the optimized wing design for both decent and storage.

The full system includes the SP, DP, and RP. Each system is necessary for data collection. The pilot initiates the release of the DP from the radio-controller. A servo releases the DP and it falls. The spring-loaded hinge on the DP along with the torsion springs of the wings of the SP opens the tube and release the SP. The SP slows to a controlled decent (terminal velocity) due to the whirlybird drag device. Data is collected from the initial start-up and is conducted for five days. Once the board receives an interrupt from the RP the data is relayed to the RP via radio. The data is stored on the RP.

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