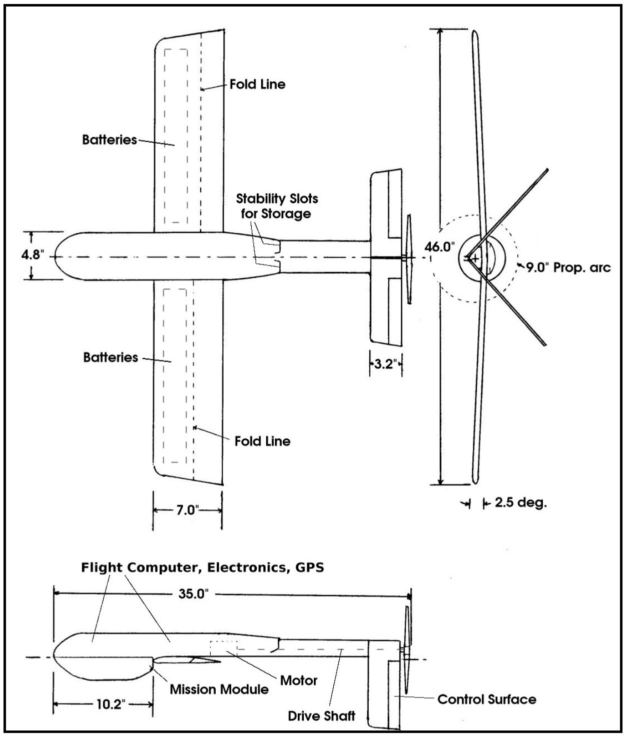
Sonobouy Tube Launched Small Unmanned Air Vehicle (SUAV)



Section I - Identification & Significance of the Problem

1.1 Introduction

There currently does not exist a small unmanned air vehicle (SUAV) that can fit into and automatically deploy from a size "A" sonobouy tube (4.875" x 36.0"). The objective of this proposal is to demonstrate such a SUAV can be developed.

1.2 Technical Problems

Some of the technical problems that must be resolved in Phase I are:

- Vehicle must fit inside of a size "A" sonobouy tube.
- Deployment speeds of 150 – 250 knots.
- Self unfolding.
- The SUAV should not use explosive fuels.
- Cruise speeds of 50+ knots, duration of 1.5 hours and have a range of 50 nautical miles.
- Interchangeable payloads are required.

Section 2 – Phase I Technical Objectives

2.1 Introduction

To clearly state the technical objectives, a design concept for the SUAV had to be selected. To help determine which design would be chosen, some preliminary work along with a proof of concept model was developed.

2.2 Preliminary Design

Various wing types were investigated: these included simple folding wings, inflating wings, and compound folding wings. Cruise speed, deployment, volumetric and structural efficiency were all considered in the selection of the wing planform. Based on initial calculations simple folding wings resulted in a wing too small to carry the SUAV weight or hold any significant number of batteries. Inflatable wings were eliminated because the airfoil would be thick, any leak in the wing would result in mission failure, and the wing and gas cartridge would have to account for a wide range of temperatures. Various types of compound folding wings were investigated. The type that had the wing chord rotate 90 degrees and then fold back (Such as the TBF - 1 Avenger) was eliminated because it did not give a high enough volumetric efficiency and it required complex mechanisms to achieve the desired movement. Compound wings still seemed to have the best potential; but keeping symmetry resulted in waisted space. To avoid waisted space, a different approach was applied. First, find the optimum placement of the wing inside the tube; then determine the best mechanism for self unfolding and iterate until the desired results are achieved. The final results of this exercise is shown in figure 2.1.

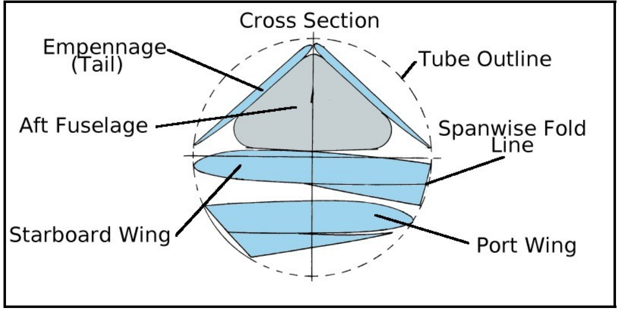


Figure 2.1

After selecting the wing, the next step was to determine how to unfold the wing. The goal was to use robust mechanisms combined together to solve this problem. Initial design concepts showed hinges, pivots and torsion springs could be used. The last remaining problem was to have the wings align themselves. A pivot mechanism that could slide on it's rotation axis solved this problem. A proof of concept model was constructed to test this theory.

Proof of Concept Model

To prove the compound folding wing and how the other components of the SUAV would integrate together, a half scale proof of concept model was built. Image 2.2 shows the model in the folded state next to the half size sonobouy "A" tube. Image 2.3 shows the model unfolded in the flight position.

Image 2.2 Folded position

Image 2.3 Deployed position

Unfolding Proof Tests

Tests were conducted on the proof of concept model to verify the compound folding wing. Below is a series of images showing the unfolding sequence.

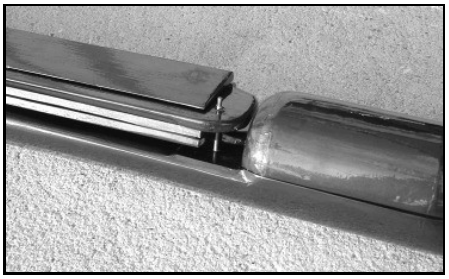


Image 2.4 – Folded Position

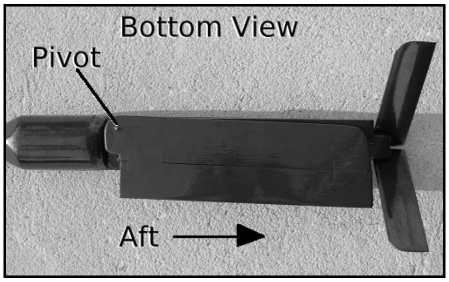


Image 2.5 - Port wing unfolds spanwise.

Image 2.4 shows that one wing rest upon the other in stored position. You can observe that a pin is protruding from the fuselage through the port wing (upper relative to the picture). This pin represents both the pivoting axis of the wing and the axis which the wing will transverse on to the fuselage. The first part of the unfolding process involves the port wing unfolding spanwise.

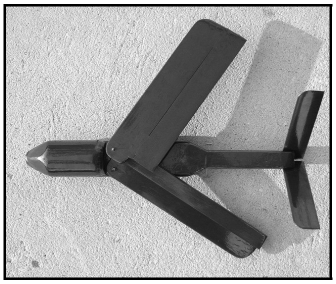


Image 2.6 - Wings pivot forward.

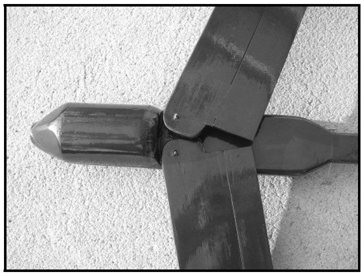


Image 2.7 – Starboard unfolds spanwise

Next, both wings begin to pivot forward. It should be noted that the starboard wing has not unfolded spanwise. After both wings have pivoted forward enough, the starboard side is free to unfold spanwise (images 2.6 & 2.7).

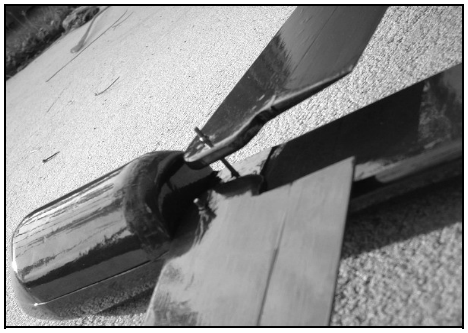


Image 2.8 – Transverse movement.


Image 2.9 Final pivot and lock.

With both wings near final position, the port wing mechanism allows for transverse movement to the proper z axis location. With both wings in the same z axis (vertical) location, the wings finish pivoting and lock into place (images 2.8 & 2.9).

Empennage Selection (Tail)

Considerations for the selection of the empennage included proper size with respect to the wing (tail volume), storage inside the tube (see figure 2.1), self unfolding, minimum interference in electronic communications, and allowance for a potential drive shaft (pusher propeller design). After several iterations, the inverted V-tail was selected.

Fuselage & Mission Module

Initial calculations show the fuselage is able to have adequate volume for flight electronics (receiver, servos, GPS, flight computer) and the motor within the upper semi-circle of the fuselage. This left the lower half of the fuselage front section available for mission electronics. From the proof of concept model it was discovered that lower front half of the fuselage could also have interchangeable mission modules (images 2.10 & 2.11).

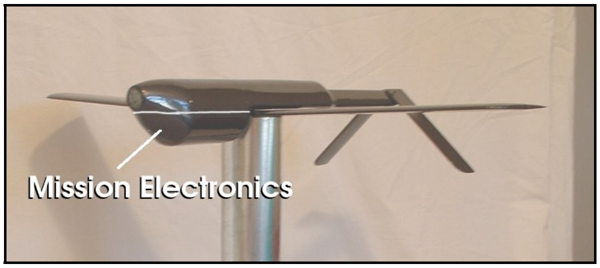


Image 2.10 – Fuselage front.

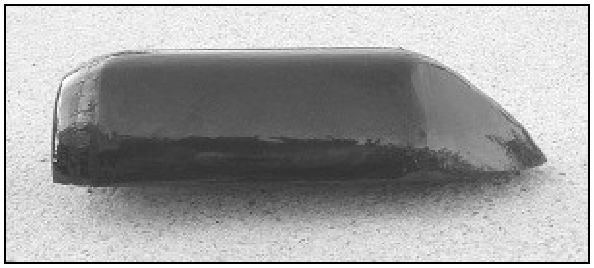


Image 2.11 – Interchangeable Module.

2.3 Preliminary Calculations

Some initial calculations were done to determine the approximate energy and power requirements for the SUAV to perform a mission. Power requirements determine the motor size. Energy requirements determine the amount of fuel needed. Solicitation data plus supplemental data from one of the authors (Mr. Larry Branthoover) was used to attain these values. Both optimistic and pessimistic calculations were performed and an average of these two was determined.

Solicitation Data

Container Size	4.875” dia. X 36” (123.8mm x 914mm)
Cruise Speed	50+ knots (25.75+ m/s)
Duration	1.5+ hours

Additional Data

To help define a mission better, expected SUAV launch altitude was requested.

Launch Altitude	16000+ ft	4877+ m

SUAV Data

By using the solicitation data, proof of concept model and performing a parametric study, the following SUAV was derived.

Weight Range	4.5 – 6.0 lbs (2.04 – 2.72 kg)
Lift to Drag Ratio (L/D) Range	7:1 – 10:1
Propulsive Efficiency	0.85
Motor Efficiency	0.8
Battery Efficiency	0.95
Cruise Speed	50 – 60 knots (25.75 - 30.90 m/s)

Flight Profile

Two types of missions were selected. One is based on a Sea Level launch requiring immediate motor power (mission 1). The other launched at 16,000 ft (4877 m) gliding down to Sea Level before requiring motor power (mission 2).
Mission 1: Power time = **1.5 hr**
Mission 2: Power time = 1.5 hr – glide time (16,000 ft to SL)

$$\boxed{\text{Glide Time} \approx \frac{\text{Height x (L/D)}}{V_{\text{glide}}}}$$

Glide	Time
Optimistic (15,000 ft loss; L/D = 10; V = 50 kt)	29.6 min
Pessimistic (15,000 ft loss; L/D = 7; V = 60 kt)	27.3 min
Average Glide Time	23.5 min (.4 hr)

Mission 2: Power time = 1.5 hr – 0.4 hr = **1.1 hr**

Estimated Power Requirements

For steady state flight (cruise) the following equations apply.

1. Thrust = Drag
2. Lift = Weight
3. Power = Thrust x Velocity

Using the above equation and account for efficiencies, the following equation for power required is derived.

$$\boxed{\text{Power} = \frac{\text{Weight x Velocity}}{(L/D)} \times \frac{1}{\eta_{\text{prop.}} \eta_{\text{motor}}}}$$

Power Cruise	Hp	Watts
Optimistic (4.5 lb; V = 50 kt; L/D = 10; η_{motor} = 0.8; η_{prop} = 0.85)	0.1	75.76
Pessimistic (6.0 lb; V = 60 kt; L/D = 7; η_{motor} = 0.8; η_{prop} = 0.85)	0.23	173.25
Average Power	**0.17**	**124.51**

Estimated Total Energy Requirements
For initial calculations a power of **10** watts will be assumed for flight controls and computer.

Energy	Watt Hr
Pessimistic (173.25 + 10)W x 1.5hr	275 W-hr
Optimistic (75.76 + 10)W x 1.1hr	94.34 W-hr
Average Energy	**184.7 W-hr**

Due to non explosive fuel requirements, Li/MnO2 batteries were selected to power the SUAV because of their high energy to weight ratio. Below is a summary of the number of required batteries.

Battery	Dimension (mm)	Watt Hr	Battery Weight	No. Req.	Total Weight
Ultralife Li (U10004) non-rechargeable	5 X 44.5 X 54.61	3Vx1.5aH = 4.5	15g	42 (184.7/4.5)	630g 1.3lb
Ultralife Li U6VF-K-T2 non-rechargeable	5.3 X 48.6 X 75.4	6Vx1aH = 6	16.4g	31 (184.7/6)	508g 1.12lb

2.4 Objectives

This SUAV must be aerodynamically efficient, have the required volume for the mission payload and unfold in a robust and reliable manner. To insure these objectives are met, the following will be done in Phase I.

1) Determine the optimum wing, empennage, fuselage, and propulsion system that will maximize the mission capability of the SUAV. This includes:

- Wing planform optimization - A combination of energy storage, minimum drag, minimum weight, and high packing efficiency.
- Empennage optimization - Correct size to provide stability, control surfaces large enough to provide both pitch and roll authority.
- Fuselage optimization - Maximum mission module size, volume to hold flight electronics and have a minimum drag.
- Propulsion system optimization - Minimum size and weight, plus maximum propulsion

efficiency.

2) Design and development of robust mechanisms and supporting structure or system that will insure proper deployment of the SUAV. This includes:
- Unfolding of the wing.
- Pivoting and translating wing movement.
- Pivoting of the empennage.
- Unfolding of the propeller.
- Maintaining proper unfolding sequence.

3) Loads and structural analysis. This includes:
- Deployment loads.
- Flight envelope.
- Critical loads conditions.
- Initial Wing and fuselage skin thickness.
- Margin of Safety calculations.

4) Verify with a CAD (Computer Aided Design) model that it can fit within the sonobouy tube, has no interference when it unfolds, and has enough storage for all of the required equipment (GPS, flight computer & electronics, motor, and batteries).

Section 3 - Phase I Work Plan

The proposed SUAV is shown on the next page (figure 3.1). This model features refined geometry to help reduce drag and have more volume in the fuselage. The aft fairing of the fuselage have slots in them to help stabilize the empennage in the folded position from vibration and deployment loads.

Mission Module

Based on the proof of concept model, the mission module will be approximately 10.2 inches (25.9 cm) long and a 2.4 inch (6.1 cm) radius half circular arc. This provides a volume of approximately 70 cubic inches (1060 cubic cm). The volume calculation was reduced by 30 percent to account for the taper in the module.

Wing Planform

The wing chord (distance between the leading and trailing edge) is held constant. The Selig 2050 airfoil was chosen because of the Reynolds number range of the SUAV and its shape allows storage of batteries inside the wing. Initial calculations indicate that 85 to 100 percent of the mission's energy requirements could come from the batteries inside the wing.

Controls

Control of the SUAV will come from the empennage surface providing both pitch and roll. This concept has been successfully demonstrated in other UAV projects. In addition to pitch and roll control, the electric motor power will be controlled from 0 to 100 percent power.

Propulsion System

Initially a tractor propeller mounted directly to the motor on the nose was considered. However the propeller may have interfered with the forward looking electro-optical-infrared (EO-IR) equipment. To avoid this problem a pusher propeller mounted to a drive shaft will be located on the aft fuselage boom. The motor will be located inside the fuselage near or just aft of the wings. The propeller will fold aft when it is not revolving to help streamline the SUAV when gliding. When stored in the tube, the propeller will be folded forward.

3.1 Proposed SUAV

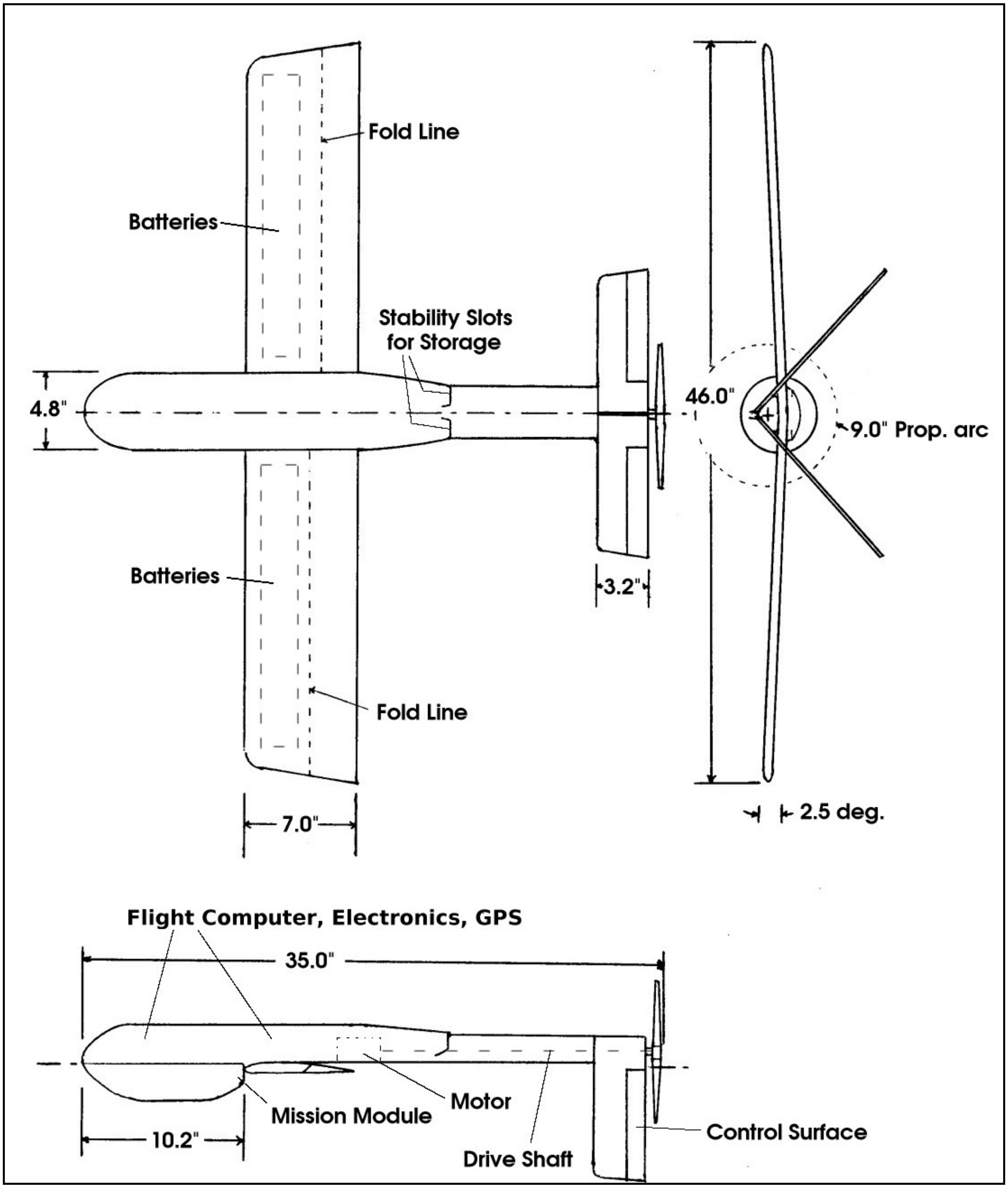
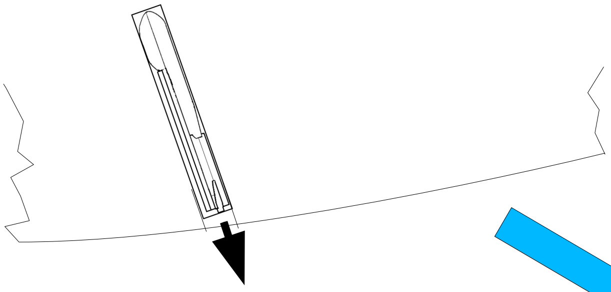


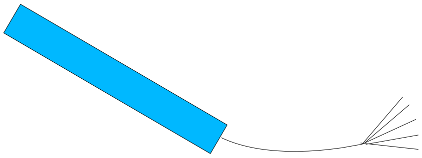
Figure 3.1 - Proposed SUAV

3.2 Deployment

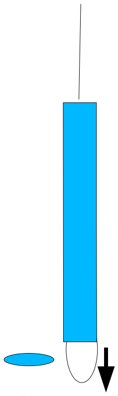
Deployment of the SUAV consist of seven steps. First the SUAV & tube is ejected from the aircraft with a cartridge charge (step 1). The strength of the charge will be determined in the analysis. Second, a parachute will finish the deceleration and start the SUAV & tube into a vertical descent (step 2). Once a steady state descent is reached, the tube will open from the bottom and eject the SUAV (step 3). As the SUAV leaves the tube, one or more release pins will be removed from the SUAV that will start the unfolding process (steps 4 & 5). Step six completes the unfolding process by having all structure locked. Finally, the SUAV having gained speed during the unfolding sequence implements a pitch maneuver to level flight.



1. Ejection from aircraft



2. Deceleration using a parachute.



3. Ejection from tube

4. Empannage unfolds

5. Wings unfold

6. Structure locked

7. Level flight

3.3 High Level Tasks

The goal of the Phase I project is to prove the feasibility of this SUAV. To prove feasibility, the SUAV will go through a design iteration. Phase I optional is a second second design iteration. The second iteration does not take as long since all the analysis processes and programs already exist from the first iteration. Below are the high level tasks (Work Breakdown Structure level 1) for Phase I and the Phase I optional tasks. All time estimates are actual hours worked.

WBS Level One Tasks for Phase I

Task	Name	Description	Time
1.0	CAD Model & Flight Electronics Selection	CAD (Computer Aided Design) model of the SUAV and unfolding mechanisms. Insure the SUAV will fit inside the tube, unfold properly, and hold the flight electronics (receiver, GPS, servos, computer, etc.).	160 hr
2.0	Weight Estimation	Airframe, flight controls, computer, batteries, motor, and payload will be included. CG location determined.	32 hr
3.0	Aerodynamic Analysis	Aerodynamic properties of the SUAV will be calculated. This includes L/D and lift distribution on the wing.	120 hr
4.0	Propulsion System Selection	Based on results of aerodynamic analysis determine the propeller and motor size. Determine actual power requirements.	104 hr
5.0	Deployment Analysis	Deployment analysis determines the parachute size and deceleration forces.	104 hr
6.0	Loads Analysis	Determine loads on SUAV from deployment and create initial load envelope.	92 hr
7.0	Structural Analysis	Structural analysis of key components such as wing's pivot and folding mechanism. Wing and fuselage analysis using maximum bending moments.	112 hr
8.0	Mission Segments	Determine the power requirements of the SUAV for various mission segments.	38 hr
9.0	Design Refinements	Design refinements selection and recommendations. Based on results of the previous tasks.	40 hr
10.0	Reports	Produce the Final Report and Summary Report	44 hr

WBS Level One Tasks for Phase I Option

Task	Name	Description	Time
11.0	Implement Improvements	Update the CAD model with the improvements from the phase I (Task 9.0).	88 hr
12.0	Cycle Through Analysis	Run improved model through the above tasks (3, 4, 5, 6, 7, 8 and 9).	216 hr
13.0	Report	Phase I Option Report	48 hr

3.4 Detailed Tasks

The following section describes the high level tasks (Level One) in more detail (Level Two). Organization of the task is based on a numbering system where the first number is the parent task (Level One) and the number after the decimal is a subtask. For example in task '1.2', '1' is for CAD Model (Level One); the decimal, '.' notes the next lower level (level two); and '2' represents the second subtask under CAD Model which is 'Starboard Wing'.

Task 1.0 - CAD Model & Flight Electronics

The creation of the CAD model of proposed SUAV serves as the foundation of this project. The data collected from this task will be used in the weight estimation, aerodynamic analysis, and stress analysis. The CAD model will:

- verify that the SUAV can fit inside the sonobouy tube.
- the SUAV can unfold without interference.
- precisely locate wing's and empennage's pivot axis.
- locate flight equipment (servos, receiver, computer, GPS, etc.).
- determine the mission module size.
- locate the motor and drive shaft.
- provide detailed design of the wing's pivoting and folding mechanisms.
- provide detailed design of the empennage pivoting mechanism.

WBS Level Two Tasks for CAD Model & Flight Electronics

Task	Name	Description	Time
1.1	Port Wing	Create port wing with spanwise fold axis, airfoil, battery cavity and pivot axis location.	24 hr
1.2	Starboard Wing	Create starboard wing with spanwise fold axis, airfoil, battery cavity and pivot axis location.	24 hr
1.3	Wing in Stored Position	Cross section of the wing in stored position, check clearances, determine geometric clearance planes required for unfolding.	8 hr
1.4	Empennage	Empennage with control surfaces, airfoil, pivot axis	24 hr
1.5	Wing & Emp. in Stored Position.	Cross section of the wing and empennage in the stored position, determine, unfolding sequence that avoids interference.	8 hr
1.6	Fuselage Boom	Create fuselage boom that will fit between the wing and empennage in the stored position.	16 hr
1.7	Fuselage Mid Section	Create the fuselage mid section that will fit above the folded wings.	20 hr
1.8	Fuselage Fwd Section	Create the fuselage forward section that will include the mission module.	20 hr
1.9	Flight Electronics	Select receiver, GPS, servos, flight computer, and other equipment to control and communicate with the SUAV. Insure fit inside the SUAV.	16 hr

Task 2.0 – Weight Estimation

The SUAV geometry and initial component selection will allow the weight to be estimated. The estimation will be based on summing up the weight of individual components. In addition to the weight estimation, the center of gravity (CG) will also be calculated.

WBS Level Two Tasks for Weight Estimation

Task	Name	Description	Time
2.1	Airframe	Weight of the empty airframe weight, including the mechanisms required for unfolding.	8 hr
2.2	Flight Electronics	Weight of all equipment necessary for the SUAV to be controlled and communicate.	6 hr

Task	Name	Description	Time
2.3	Propulsion System	Weight of the motor, drive shaft, propeller and supporting structure of the propulsion system.	6 hr
2.4	Batteries	Weight of all batteries used in the SUAV.	4 hr
2.5	Mission Module	Investigate and estimate typical mission module weight, if it is not provided.	6 hr
2.6	CG	Calculate the center of gravity (CG).	2 hr

Task 3.0 – Aerodynamic Analysis
Using the geometry, weight and inertia properties, aerodynamic properties and performance values will be computed. ***These tasks will be performed at the University.***

WBS Level Two Tasks for Aerodynamic Analysis

Task	Name	Description	Time
3.1	Basic Properties	Calculate the various aerodynamic properties of the SUAV such as, C_L, C_D, control surface C_p distribution, etc.	32 hr
3.2	Performance Curves	Calculate the various performance curves including, L/D vs speed, Power vs velocity, etc.	24 hr
3.3	Stability & Control	Perform a static and dynamic analysis on the SUAV model, determine it's characteristics, and the CG range	32 hr
3.4	Power Requirement	Power required for level flight, reserved power requirements for climbing (determine rate of climb)	16 hr
3.5	Drag Reduction	List areas of high drag. List possible means of reducing this drag.	16 hr

Task 4.0 – Propulsion System Selection
Various combinations of motors and propellers will be able to provide thrust for the SUAV. Many of these combinations will have low efficiencies that will result in unnecessarily large power consumption. Some of these motor and driveshaft combinations may not fit in the fuselage, or the folded propeller may not fit in the tube with the SUAV. ***These tasks will be performed at the University and make use of their wind tunnel equipment.***

WBS Level Two Tasks for Propulsion System Selection

Task	Name	Description	Time
4.1	Motor	Select a motor that will meet all power requirements and provide peek efficiency at cruise.	16 hr
4.2	Propeller	Select a propeller that will be matched with the motor and provide peek efficiency at cruise.	32 hr
4.3	Drive shaft	Select drive shaft and supporting components that will handle the required power and be light weight.	8 hr
4.4	Power Usage Verification	Determine the actual power usage at cruise speed through the use of wind tunnel testing.	32 hr
4.5	Fit	Verify selected propulsion system fits.	16 hr

Task 5.0 - Deployment Analysis

The SUAV will need to withstand high accelerations during deployment from the aircraft. These values need to be determined. Additional work on selecting the correct parachute is also needed to allow the tube to descend at a slow enough rate, when the SUAV is released. Finally the deployment time and altitude loss will be calculated. ***These tasks will be performed at the University.***

WBS Level Two Tasks for Deployment Analysis

Task	Name	Description	Time
5.1	Aerodynamics of the Tube	Determine the aerodynamic drag on the tube and type of deceleration load it will have, at various airspeeds.	24 hr
5.2	Cartridge Size	Determine the accelerations experienced by the SUAV/tube for various cartridge charge size.	24 hr
5.3	Parachute Sizing	Determine the parachute to use that will allow the tube to descent at a rate to properly eject the SUAV.	24 hr
5.4	Maximum acceleration	Determine the maximum acceleration/deceleration during deployment.	16 hr
5.5	Time & Alt.	Determine the time and altitude loss for deployment.	16 hr

Task 6.0 - Loads Analysis

Perform basic load analysis on the SUAV.

WBS Level Two Tasks for Loads Analysis

Task	Name	Description	Time
6.1	Deployment	Calculate ejection, parachute deceleration and aerodynamic loads during unfolding.	8 hr
6.2	Envelope	Create an initial envelope.	16 hr
6.3	Wing	Determine max loads for shear, moment, and torsion.	24 hr
6.4	Fuselage	Determine max loads for shear, moment, and torsion.	24 hr
6.5	Empennage	Determine max loads for shear, moment, and torsion.	20 hr
6.6	Control Surfaces	Determine the max loads on the control surfaces. Insure servos have adequate torque.	16 hr

Task 7.0 - Structural Analysis

A structural analysis based on critical load conditions will determine the sizing and margin of safety (MS) of the SUAV components.

WBS Level Two Tasks for Structural Analysis

Task	Name	Description	Time
7.1	Wing Pivot Mechanism	Determine the margin of safety for the wing pivots and the surrounding fuselage and wing structure.	24 hr
7.2	Wing	Determine initial skin thickness.	32 hr
7.3	Fuselage	Determine initial skin thickness.	32 hr

Task	Name	Description	Time
7.4	Empennage	Determine the margin of safety for the pivots and the surrounding fuselage and empennage structure.	24 hr

Task 8.0- Mission Segment Analysis

Power requirement are calculated for each mission segment. Knowing the power requirement of each segment will give mission planners the ability to calculate the total energy for a specific mission.

WBS Level Two Tasks for Mission Segment Analysis

Task	Name	Description	Time
8.1	Descent	Determine the power required for various descent speeds.	4 hr
8.2	Cruise	Determine the power required for various cruise speeds.	4 hr
8.3	Climb	Power required for various climb speeds/ rates.	6 hr
8.4	Maneuver	Determine the power required for maneuvers to be performed (turns, S turns, figure 8's).	8 hr
8.5	Flt. Electronics	Determine the power required by the flight electronics.	16 hr

Task 9.0 - Design Refinements

After performing the analysis and reviewing the results of the prior tasks, the current design may need some refining. These design refinements should be captured and organized.

WBS Level Two Tasks for Design Improvements

Task	Name	Description	Time
9.1	Min Power	List potential modifications or improvements that would reduce the power required for cruise speed	8 hr
9.2	Max Payload	List potential modifications or improvements that would maximize the payload size and weight	8 hr
9.3	Mechanisms	List potential improvements to the mechanisms (pivots, hinges).	8 hr
9.4	SUAV Airframe	List potential improvements to the SUAV airframe.	8 hr
9.5	Priority of Improvements	Organize and list all modifications and improvements in order of priority.	8 hr

Task 10.0 - Reports

WBS Level Two Tasks for Reports

Task	Name	Description	Time
10.1	Final	Develop a final report according to paragraph 5.3 of the STTR Program Solicitation. Include a simulated mission.	40 hr
10.2	Summary	Develop a summary report according to Navy Proposal Submission.	4 hr

Phase I Optional Tasks (11 – 13)

Task 11.0 - Implement Improvements

Modify the SUAV with the improvements.

WBS Level Two Tasks for Implement Improvements

Task	Name	Description	Time
11.1	Revise CAD Model	Update the CAD model with the improvements.	56 hr
11.2	Revise Weight	Update the weight and CG, as necessary.	32 hr
11.3	Components	Revise the component selection (servos, etc.)	16 hr

Task 12.0 - Cycle Through Analysis

Modify the input to the various tasks with the revised data and re-run the analysis (3-9).

WBS Level Two Tasks for Analysis

Task	Name	Description	Time
12.1	Aerodynamic	Perform aerodynamic analysis.	40 hr
12.2	Propulsion	Perform propulsion analysis.	40 hr
12.3	Deployment	Perform deployment analysis.	32 hr
12.4	Loads	Perform loads analysis.	32 hr
12.5	Structural	Perform structural analysis.	48 hr
12.6	Mission Seg.	Perform mission analysis.	24 hr

Task 13.0 - Improvement Results Report

Create a report showing the performance gained by implementing the various improvements.

WBS Level Two Tasks for Improvement Results Report

Task	Name	Description	Time
13.1	Gains	List performance gains from the improvements.	32 hr
13.2	Improvements	List additional improvements that could be implemented.	16 hr

Section 4 - Related Work

4.1 Principle Investigator

The principle investigator (PI) has over 13 years of experience designing, building, and flying radio controlled aircraft, 15 plus years of experience working as an aeronautical and structural analysis engineer for the Boeing Company and Sky Mountain Engineering.

The PI developed several computer applications to help size and construct the wing and empennage of radio controlled aircraft. These applications also contained a library of airfoils to choose from and had the ability to plot the wing ribs with the appropriate skin thickness. The PI investigated various methods for producing small composite propellers. This investigation included making several molds and developing different types of layup procedures. The PI became proficient at flying complex radio controlled aircraft. They had throttle, elevator, rudder, ailerons, flaps, landing gear controls and flew at speeds in excess of 80 knots.

The PI performed external loads analysis (aerodynamic & inertia) for the wing, fuselage, and nacelle on Boeing commercial airplanes. This included selection of the critical load cases and maintaining and enhancing computer applications. The PI performed stress analysis of various Boeing airplane components. Analysis were based on ultimate, limit, and fatigue loads. The PI helped develop and improve computer applications used in the design of airplane components. At Boeing, the PI was able to attend several aircraft design classes. The PI has been managing multiple simultaneous projects and leading a group of twenty people. These PM roles taught the PI to manage time, develop schedules, delegate tasks, and deal with risk mitigation. All of these skills will be necessary in managing a phase I and/or phase 1 option project.

Section 5 – Future Research and Development

Successful completion of phase I will affirm that a SUAV could be developed and mass produced within 4 to 5 years. The following tasks to occur in Phase II are:
- selection & development of mission electronics
- mission planning
- mission simulations
- manufacturing method selection
- manufacturing requirements
- cost estimation

Section 6 – Commercialization Strategy

Completion of Phase I and II will prove that a SUAV can fold into a compact space, deploy from a moving aircraft, and have interchangeable mission modules. With modifications and development of a new container to replace the sonobouy tube, the SUAV could be launched from a stationary or moving land or sea vehicle. The SUAV could be mounted on such vehicles as a Hum-V, tank or armored personnel carrier. The compact size allows the SUAV to be carried on small water crafts in addition to larger ones. For Search & Rescue, multiple SUAVs could be simultaneously deployed to cover a large area. In a hostile environment the SUAVs locate the party to be rescued before the actual recovery aircraft moves in. Large UAVs could carry several of these SUAV to help expand it's effectiveness. With all these potential uses, our strategy would to be market these ideas to other DOD agencies and Homeland Security.

These SUAVs could be marketed to forest fire fighting agencies, police and other law enforcement agencies to help them reduce costs, while maintaining or enhancing their capabilities and increasing safety.

Modifying the SUAV to be reusable could also lead to markets in the commercial fishing industry as the next generation of spotting vehicles. Finally, the SUAV and its supporting systems could be marketed to friendly countries in similar roles.

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