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Design of a Tube-Launched UAV

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Tube-launched UAVs are a potential solution to requirements currently under consideration by the Navy. The design here was independently done by students at Cal Poly with collaboration with alumni in the business of supplying UAVs to the services. All technology specified is commercially available off the shelf and the components can be manufactured in a matter of weeks.

I. Introduction

This project was conceived in response to Navy RFP N04-T004, a sonobuoy tube launched UAV designed to be launched from the H-60 helicopter and P-3 Orion. This conceptual design shows that it is possible to meet the minimum requirements set forth in N04-T004 and carry all payloads specified except the Hyper Spectral Camera. Because N04-T004 is somewhat vague in what it requires in terms of performance and payload capability, reasonable assumptions were made in regards to what the customer will want as the program progresses. These assumptions were based on the capabilities of other UAVs in the a similar class as the Sono-scout.

Note that this design is presented in a preliminary form so that changes can be made without compromising the entire vehicle. Trade studies are presented to show what is possible with the airframe, as well as which specific payloads can be carried. This is done to a point where detailed design could refine the concept.

II. Preliminary Sizing

To start the design study, preliminary sizing was conducted to determine how large the vehicle needed to be. Because it is possible for the vehicle to fly at one speed the entire mission, all aerodynamic performance can be optimized for one flight regime. For the basic minimum performance requirements specified in N04-T004 of 1.5 hour duration and 50 knots airspeed, baseline vehicle weights can be derived using a combination of in-house developed procedures and historical data. The biggest weight driver for a vehicle to meet the requirements set forth by N04-T004 is propulsion selection. Usually a design decision must be made between internal combustion and electric systems. Since N04-T004 prohibits the use of explosive fuels, electric power becomes a working solution which is cheap and reliable.

To obtain weight estimates, all of the systems required for the mission are assembled and the weights summed. The structure weight is obtained with a structure fraction based on historical data. This reveals an initial total vehicle weight. The sizing code then iterates that weight to the final weight solution recalculating battery weight required for each iteration using an L/D of 9. The L/D was obtained from vehicle geometry analysis. The results from this initial weight estimate show an airplane that weighs between 9 and 14 pounds with a 1-1.5 pound payload.

A. Configuration

The requirement that the vehicle has to be launched from a sonobuoy tube is the highest driver for the final configuration. From the configuration studies conducted, it was determined that the cheapest and simplest way to perform the mission was to have the deployable wings that swung out from the fuselage such the wings on JASSM (Joint Air to Surface Standoff Missile). Figure 1 shows the general arrangement of JASSM.

Initial configurations had wings that deployed straight out, but this led to weight distribution problems. The wings need to be attached as far forward as possible to allow for the largest wing size to fold into the allowed space. This means the center of gravity had to be far forward to coincide with the wings, and this was hard to accomplish efficiently. A solution to this problem was sweeping the wings back 30 degrees which moves the neutral point and the CG aft. With this major design decision made, the rest of the airframe components were integrated into a workable package that would fit the requirements. This configuration can be seen in Figure 2.

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B. Propulsion

Although a COTS electric motor was chosen as the best way to power the Sono-scout, the source of the power to drive this motor is worthy of investigation. A great deal of new technology development is on going in the areas of fuel cells and higher capacity batteries, two possible power sources for the Sono-scout. Using fuel cells in UAVs is not a new idea. Using a fuel cell to power a UAV was demonstrated by Aerovironment with their Hornet MAV. Unfortunately, this system was more delicate and expensive than batteries with comparable energy output. The technology is being refined but is not ready to be implemented in an operational UAV. Because N04-T004 states that the Sono-scout wouldn't go into service for 4-5 years, the fuel cell technology needs to be monitored so that the energy system can be reevaluated as the design progresses.

This leaves batteries as a baseline power source for the preliminary design. Lithium polymer batteries were chosen because of their high energy and ability to operate at higher discharge rates than most other batteries without significant internal heating. Since exact discharge rates aren't known in preliminary design, lithium polymer batteries are an excellent selection for a first run preliminary design due their unlimited rates. From the preliminary design code, it was found that the batteries would have to provide 340 Wh of total energy for the duration of the mission. This sized the battery pack to be as shown in Figure 4.

The battery pack consists of 13 TP2100-3S Thunder cells like the silver one seen above in Figure 4. Each cell has a capacity of 2100 mAh. This brings the total energy level of the pack to 343 Wh, which is within the preliminary prediction. Exact propeller sizing has not yet been conducted; however preliminary analysis indicates a 9x8 pusher propeller which will be foldable to fit inside the sonobuoy launcher tube. After wing deployment the motor will spin up, and the centrifugal acceleration will open the propeller.

III Predicted Flight Test Performance

To conduct a preliminary performance analysis of the Sono-scout, a complete performance code was developed. It analyzed airframe geometry to provide appropriate sizing for the required performance characteristics. Since the actual weight of the various payloads that Sono-scout is required to carry is not yet set, the code was run with payload weight as a variable.

The performance code swept through multiple cruise speeds and endurance times to show the effects of increasing these variables on total system weight and performance. Figure 5 shows the relationship between payload weight and total vehicle weight for varying cruise speeds. For these conditions, endurance was held constant at 1.5 hours.

A. Wing Loading

Because of the requirement that the vehicle must fold into a sonobuoy tube, the wing area is severely limited. Sono-scout has the maximum wing area that can fit inside the sonobuoy tube without implementing complicated multiple flying surfaces. This means that wing loading will reach a maximum point, which acts as a constraint on the maximum wing loading. Assuming a 1.5g maneuver envelope and that a wing of this type can produce a maximum CL of 1, the lift equation can be used to obtain this limit for the various speeds. This appears as the red limit line in Figure 5.

It can be seen from Figure 5 that the for the assumed one pound payload, it would be possible to increase Sono-scout's cruise speed to 55 knots or even 60 if the requirements changed. These performance trades are being presented because no hard requirements have been established. These trades can assist in the development of the optimum requirements given the size constrains on the Sono-scout. Another noteworthy trend is the relationship between payload weight and vehicle weight for varying endurance times. Figure 6 shows this relationship.

It can be seen in Figure 6 that reducing the endurance of the vehicle has large implications in the total weight. More communication with the customer should be undertaken to establish which direction they would like to see the performance of the Sono-scout increase. These trends, however, are important because they show what is possible in terms of cruise speed and endurance performance and the resulting total vehicle weight penalties.

B. Controls

The Sono-scout has long wings swept 30 degrees which was partly done to move the neutral point aft. Sweeping the wings 30 degrees had the added advantage of enabling the use of elevons on the wings for pitch and roll control. Using elevons instead of ailerons and elevators eliminated the need for the horizontal and vertical tail surfaces to be moving, allowing a much simpler deploying mechanism. It also reduced the number of actuator servos needed. In the final configuration, the tail surfaces would only be used for stability damping and not control. The vertical surface is positioned on the bottom of the fuselage because the air is theoretically less turbulent, allowing for more effective damping with less of a surface, thus reducing parasite drag slightly. The tail surfaces are not yet sized, however, additional room is available should they be required to grow. The elevons will be actuated using COTS servos initially developed for the hobby industry. Servos such as these are currently in use with the Desert Hawk and Dragon Eye programs. Figure 7 shows the size and orientation of the Hitec HS-125 servo and the elevon for the left wing in the deployed position.

C. Pitot Probe

For atmosphere measurement, static pressure will be measured internally and a pitot probe extended out the front of the payload nose cone into the free stream to measure the dynamic pressure. This has the additional benefit of aligning the payload when connecting, but does impinge slightly on the payload volume available. One advantage of this type of probe is that it does not have to be deployed in flight, making it cheaper and more reliable. Other options for probing the free stream were analyzed, such as having a deployment mechanism to extend the probe into the free stream after launch or having a mechanical linkage that extended the probe as the wings extended. These options were deemed too complicated and risky. If the pitot probe extension mechanism failed, the autopilot would have no airspeed or altitude measurement and would be unable to fly the mission.

To control the vehicle, an autopilot from Jennings Engineering would be used. This autopilot is currently in widespread use with the Dragon Eye and Desert Hawk (FPASS) programs as well as other prototype UAVs currently flying. The autopilot is capable of being tuned to accommodate most vehicles, and is the baseline choice for the Sono-Scout.

III. Payloads

N04-T004 is very vague when specifying payloads it required for various missions. Therefore, when responding to the requirements, it was decided to make the solutions as flexible as possible with the assumption that future conversations with the customer would narrow down the design. Since cost is a huge driver in an expendable vehicle such as the Sono-scout, it has a very novel approach for changing payloads. Each payload will have a nose module specifically configured for optimum performance from the sensor it is carrying. For example, the IR payload will be self contained, allowing it to be swapped with a TV sensor package if the need presents itself. This provides much greater flexibility for mission planning and production. The customer can select how many vehicles they want, and how many of each payload to go with each vehicle. If needs change, the customer is not locked into having a stock of vehicles equipped with payloads they do not need.

A. Flexibility for TV and IR

Having interchangeable payloads also adds flexibility to the system. As technology improves, new modules can be designed and swapped out for the old modules. This future thinking methodology also applies to new technology. If the customer suddenly needs a chemical sensor package to for example, a module can be designed and easily integrated to accomplish the mission.

Because N04-T004 was vague about the payloads that needed to be carried, only two preliminary payload modules were developed: a TV and an IR module for use as baseline configurations. It was discovered that both payloads could be integrated into one payload volume while staying under 1 lb. This was done to prove that TV and IR payloads can be easily carried by the Sono-scout. As the design progresses, these two payloads could be easily separated into two separate payloads should it be specified. In this payload, there are two TV cameras: one forward-looking for dead reckoning navigation by an operator, the other side-looking, indexed at 30 degrees down. The IR camera is an Omega IR camera by Indigo systems. This camera would be indexed with the TV camera at 30 degrees down. A payload switching board is also integrated to control the cameras. Figure 8 shows this payload integrated with the vehicle.

B. Range-Finder Payload

N04-T004 also outlines the need for “RF” and “HS” payloads to be carried. “RF” was assumed to be a range finder payload. It was deemed it inappropriate to specify an exact commercially available off the shelf (COTS) range finder without knowing any specific requirements (max/min range, refresh rate, etc.), however a basic design was created to simulate a current COTS systems available in binoculars. It was also assumed that a range finder payload should be able to move and point at targets while being equipped with a camera to give the operator situational awareness. The simulated model is shown in Figure 9.

C. Camera

The only payload that the Sono-scout will not be able to carry is the “HS” payload which is assumed to be a Hyper Spectral camera. These cameras are not small enough, nor are they light enough to be carried by the Sono-scout. There are COTS cameras such as the IS15 shown in Figure 10; however it is in the 8 lb. range.

IV Systems

The systems of the Sono-scout are as cheap as possible while retaining the reliability for the duration of its one-time-use mission. The areas of systems that must be well designed for this reliability are the flight surface deployment systems, antennas, flight control actuators, and avionics.

The flight surface deployment system has been designed to be as simple as possible. No exact sizing of the mechanism has been made, but preliminary sizing suggests that a torsion spring will give the most opening force for the wing pivots while only occupying a small space inside the fuselage. Figure 11 shows the torsion springs wrapped around the wing pivots.

A. Tension Springs

A possible alternative to torsion springs around the wing pivots could be to implement tension springs and lever arms to the pivots. This system could provide more opening force but would take more space inside the fuselage to accommodate. The horizontal and vertical surfaces would be preloaded with springs so that they would pop out after leaving the sonobuoy tube. The vertical surface tube would be made out of very stiff carbon while the two horizontal surfaces would be made out of a stiff dielectric material and used as an uplink antenna. This is feasible because the orientation of the two horizontal stabilizer tubes is ideal for a dipole antenna. The downlink antenna is not a large drive because it’s smaller size.

To form the material of the flight control surface, stretched latex “sails” are attached to the fuselage and the deployment rod. The sails have thin stiffeners attached to the material to prevent any fluttering at flight speeds. This method was selected for its ability to fold and for its stiffness.

B. Avionics

To form a proven and relatively cheap baseline avionic package for this preliminary configuration the Lockheed Martin “MAV” variant package was chosen. This avionics suite consists of the autopilot mentioned earlier, a communications board, and a GPS board. The system uses its own user interface software for mission planning/updating and observation. Figure 12 shows the position and sizes of the avionics inside the vehicle.

As mentioned earlier, the Sono-scout is capable of making the 50+ nautical mile range outlined in the RFP, with the driving factor for this requirement being communications and not performance. The communications board has an uplink and downlink module which will be mounted inside the vehicle so that the modules are flush with the skin of the vehicle. This allows proper cooling to the modules as they get very hot at high power levels. The current baseline control station for the system consists of an antenna, a laptop, and a communications box. A stripped down system could be reduced to less than 7 pounds. This is an area where much more detail is needed to provide a realistic design for a control station that can integrate with the systems of a P-3 or an H-60.

V. Conclusions

The Sono-scout is capable of meeting all the requirements set forth by N04-T004 except the ability to carry a Hyper Spectral camera payload. As outlined earlier, there is some growth potential in the overall performance of the vehicle. It was shown that increases in endurance and/or cruise speed are possible. Independent of how the

Sono-scout grows, it is currently a solution to the RFP that can be rapidly produced using systems that are entirely commercially available off the shelf (COTS). Because the vehicle has a one time use mission, simple and inexpensive manufacturing methods can be coupled with the COTS technology to produce a very cost-effective vehicle.

Acknowledgments

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Appendix

RFP (N04-T004), N04-T004 TITLE: Sonobuoy Tube Launched UAV
TECHNOLOGY AREAS: Air Platform, Ground/Sea Vehicles, Weapons ACQUISITION PROGRAM: Autonomous Operations FNC
OBJECTIVE: Develop a small, expendable Unmanned Air Vehicle (UAV) launched and controlled from P-3 aircraft in direct support of their mission.
DESCRIPTION: The Navy and other government-sponsored agencies use the P-3 aircraft. Due to the diverse missions and limited number of P-3 aircraft, the most economical and expeditious way to enhance operations and assure crew safety would be to incorporate low-cost expendable tactical unmanned air vehicles (UAV's). If UAVs were incorporated into each P-3, a load-out of sonobuoy launched UAV's with interchangeable payloads (i.e., IR, TV, RF, HS, etc.) tailored to the specific mission could be locally launched, be controlled by the on-board sensor operator, and assist the platform in carrying out its mission. It would serve to enhance sensor capability and, in effect, allow the aircraft to operate in several areas at the same time due to the UAV's capability to detect/confirm contact data and relay information to the special missions crew without forcing the aircraft to leave station. The UAV would keep the crew safe because it could penetrate and operate in areas deemed hostile for manned operations. The advantage of a universal "A" size sonobuoy (4.875" X 36.0") expendable UAV with the capability for interchangeable payloads is that the sonobuoy size "A" tubes are standardized throughout the P-3 and H-60 communities, yielding cost and time savings through consolidation of efforts and reduction of redundant technology. Each community would be able to configure aircraft based on mission requirements.
While there are currently commercially off the shelf (COTS) electro-optical (EO) equipment, cameras, receivers, and transmitters small enough to fit into the special mission application, there are no small ("A" size sonobuoy chute) UAV vehicles and associated delivery systems currently in use. Based on current studies, these vehicles would be deployed in airspeeds of 150-250 knots, have 50+ knots of speed, have a flight duration of 1½+ hours, and have a range of 50 nautical miles to meet current P-3 mission requirements. Concept UAV's can be powered or gliders, but can not carry explosive fuels. This capability is 4-5 years from introduction into operational scenarios. Several ongoing industrial programs are examining small, expendable UAVs; "Silent Eyes" is one such program. There are several programs investigating folded wing, glider, safe fuels, and electric motor technologies that could be used with sonobuoy size UAV's. These technologies could be consolidated into a usable package for P-3 and special missions applications.
PHASE I: Develop design approach and demonstrate feasibility to meet the above requirements for a sonobuoy launched UAV.
PHASE II: Develop and produce a prototype UAV capable of launch from Navy P-3 aircraft using the current sonobuoy system. This should demonstrate capability for the aircraft to safely launch the vehicle, interact with it in tactically useful behaviors, and have plug-and-play payloads (EO/IR, RF, etc.).
PHASE III: Produce qualified UAV assets for use by Navy maritime patrol aircraft.
PRIVATE SECTOR USE OF TECHNOLOGY: This technology could be used by other government sectors for homeland defense purposes. It could be used by search and rescue organizations to enable wider area search than can be accomplished by current airborne assets as well as by commercial fishing fleets. In addition, these could potentially be used by fire-fighting organizations to drop into large-scale fires to map the location of hot spots and the forward edge of the fire.

Addendum to Appendix: Visual Basic Sizing Iteration Code

```
Sub Sizing_Macro()
'This program will iterate towards a final weight for the sizing parameters entered.
Dim weight1 As Double
Dim weight2 As Double
```

```
Dim number As Double
number = 5
Sheets("Propulsion").Select
Range("B12").Select
Selection = weight1
weight1 = 100
Do While (number > 0.05)
Range("F22").Select
Selection.Copy
Sheets("Sizing").Select
Range("C17").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
:=False, Transpose:=False
Range("D27").Select
Sheets("Propulsion").Select
Range("F21").Select
Application.CutCopyMode = False
Selection.Copy
Sheets("Sizing").Select
Range("H17").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
:=False, Transpose:=False
Range("C21").Select
Application.CutCopyMode = False
Selection.Copy
Sheets("Propulsion").Select
Range("B8").Select
'Elevation = Worksheets("CA").Cells(Cellpos1, 7).Value
weight2 = Selection
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
:=False, Transpose:=False
Range("C25").Select
number = weight1 - weight2
If number < 0 Then
number = number * -1
End If
weight1 = weight2
Loop
End Sub
```

References

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[7] Raymer, D. P. *Aircraft Design: A Conceptual Approach – Third Edition*, AIAA, Washington DC, 1999.

Figures

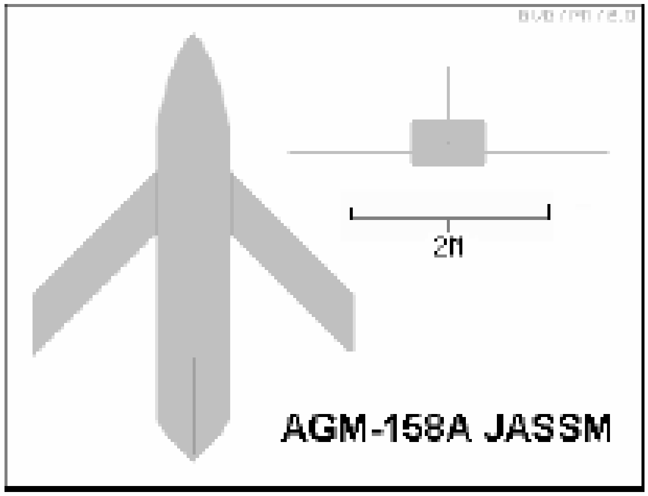

Figure 1 General Arrangement of JASSM

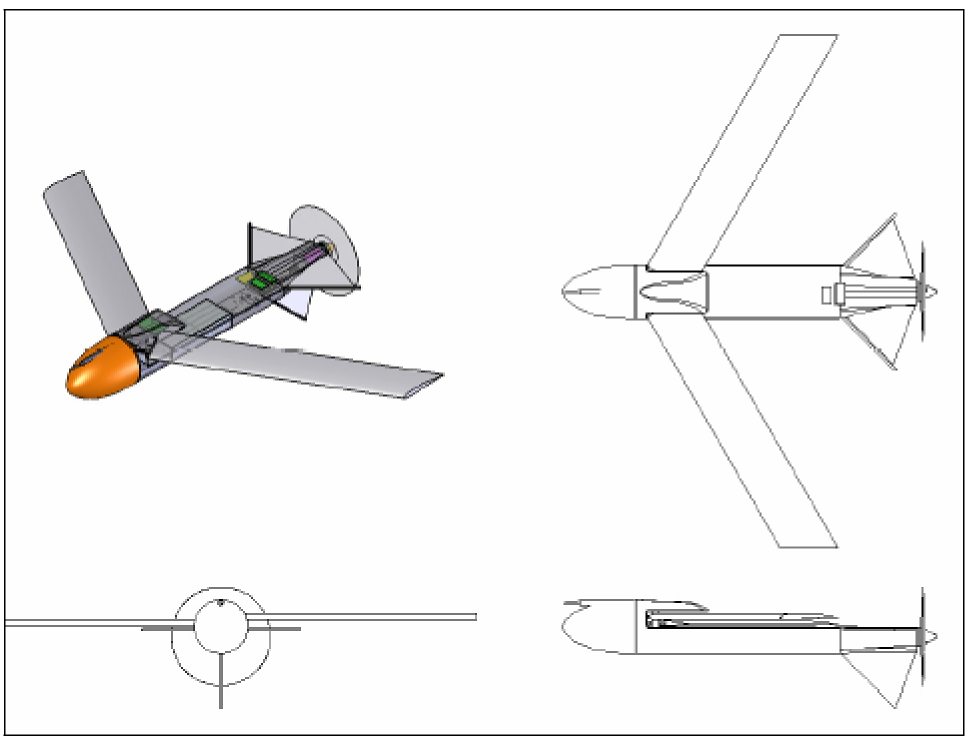

Figure 2. General Arrangement of Sono-Scout

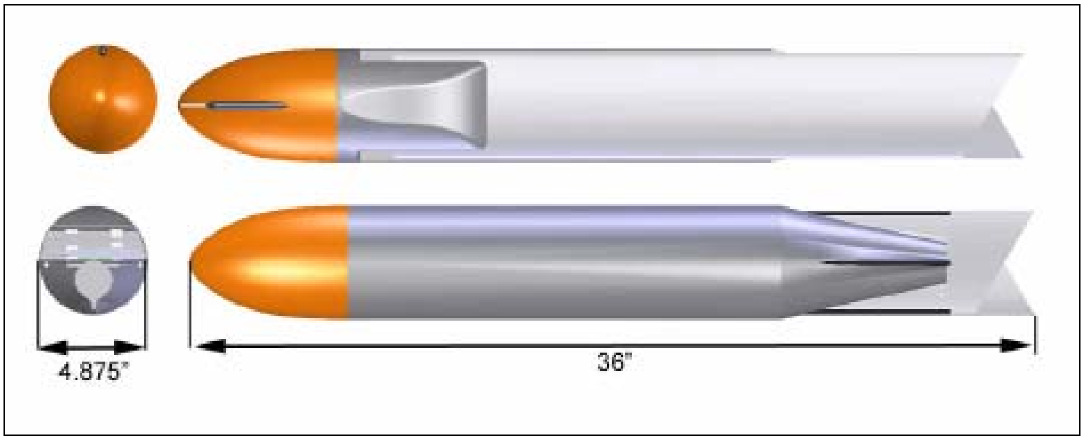

Figure 3. Sono-Scout in Folded Position

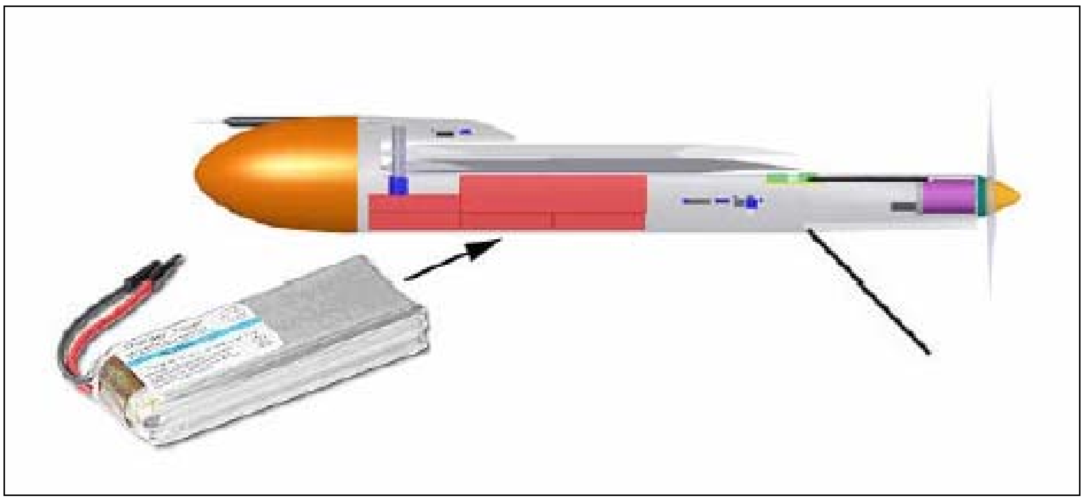

Figure 4. Battery Size and Location

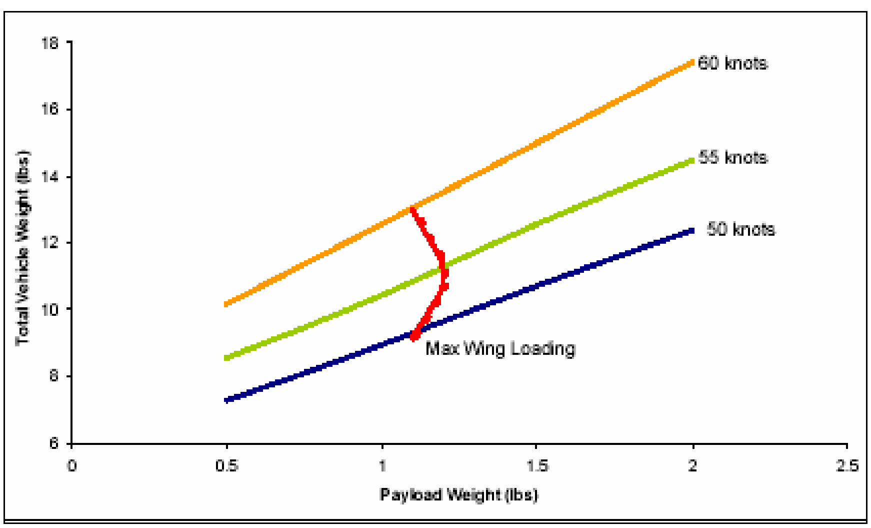

Figure 5. Vehicle Weight vs Payload Varying Cruise Speed

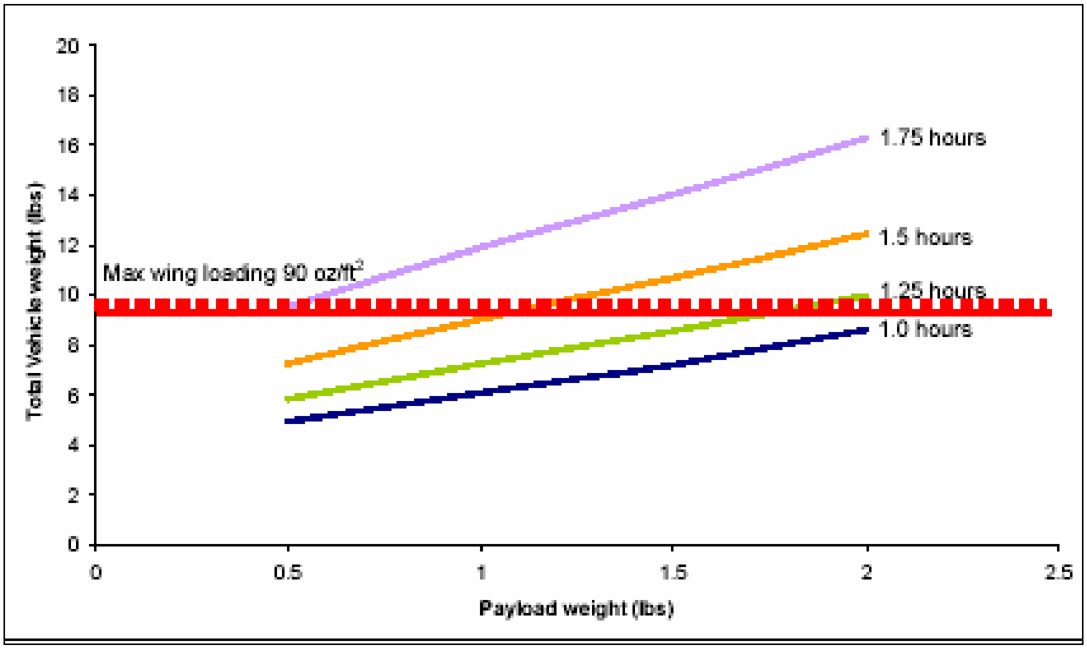

Figure 6. Vehicle Weight vs Payload Varying Endurance Speed

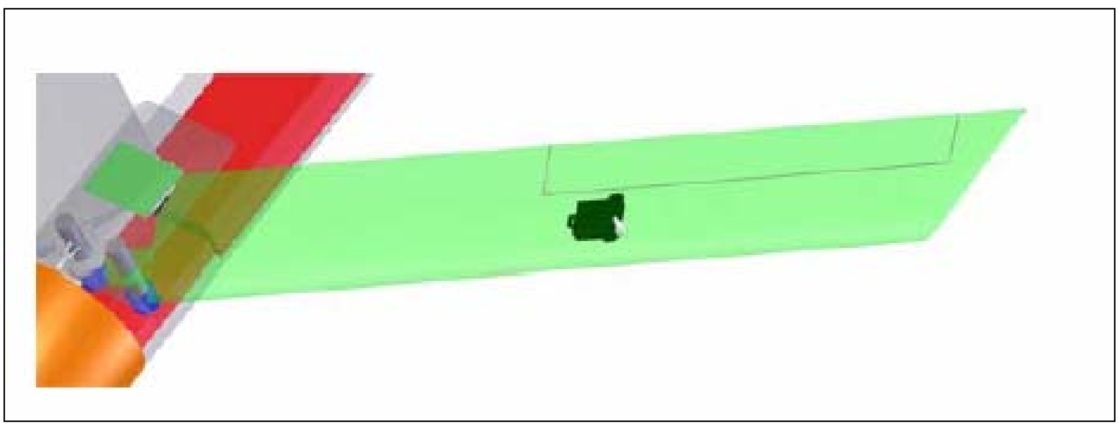

Figure 7 Inboard view of the Elevon and Servo

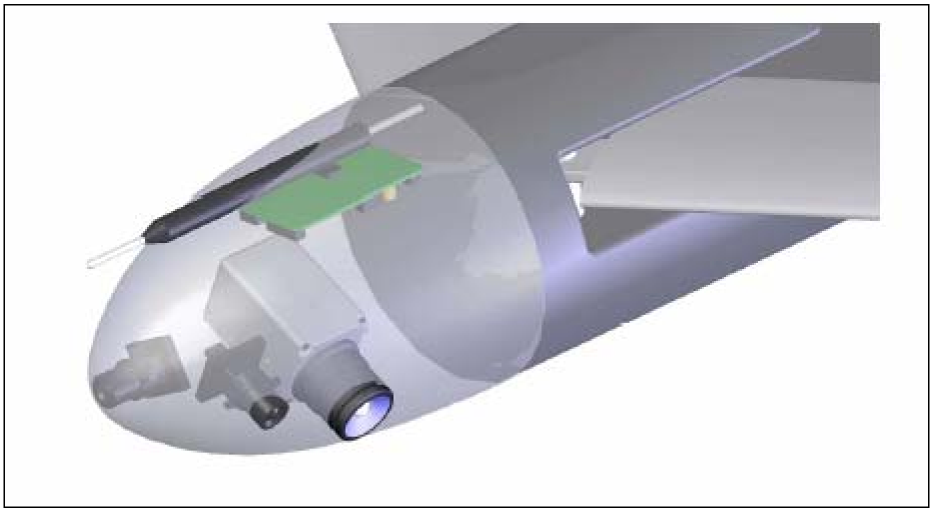

Figure 8 TV and IR Payload Combination

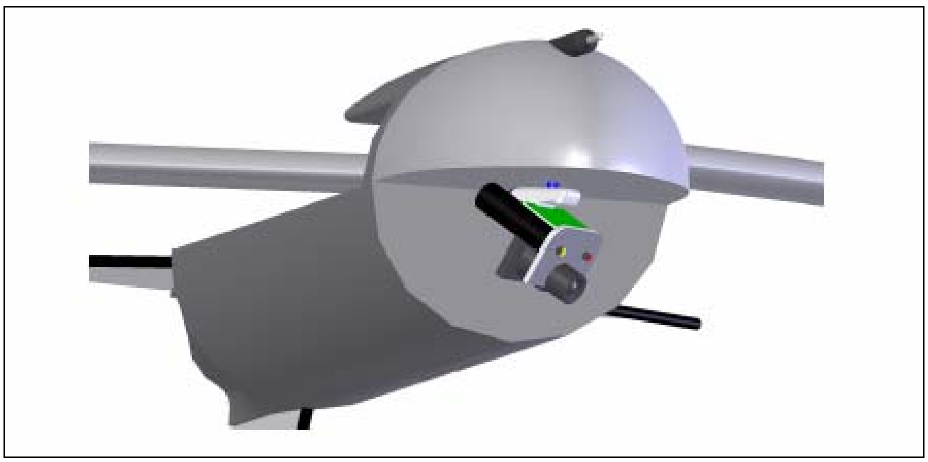

Figure 9 Range Finder Payload

Figure 10 Hyper Spectral Camera

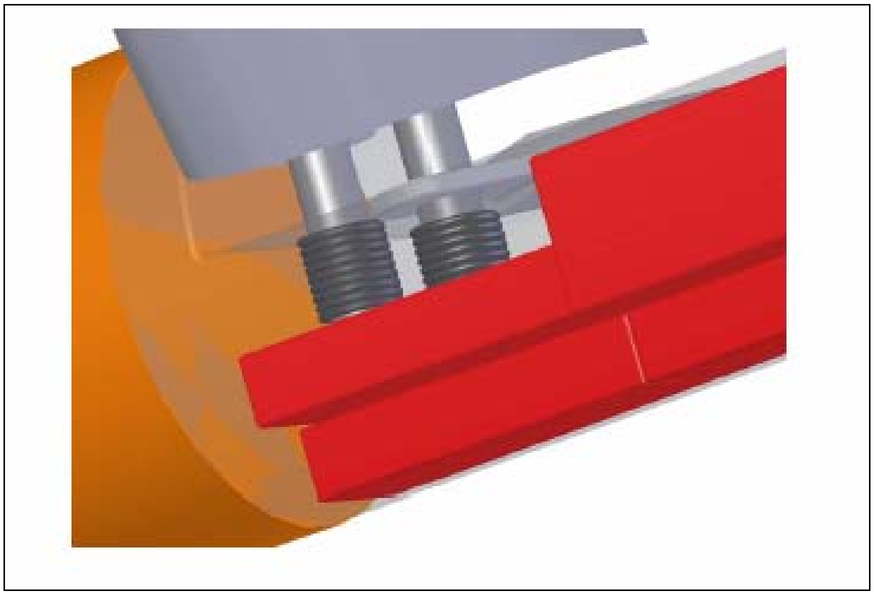

Figure 11 Torsion Springs to Deploy the Wings

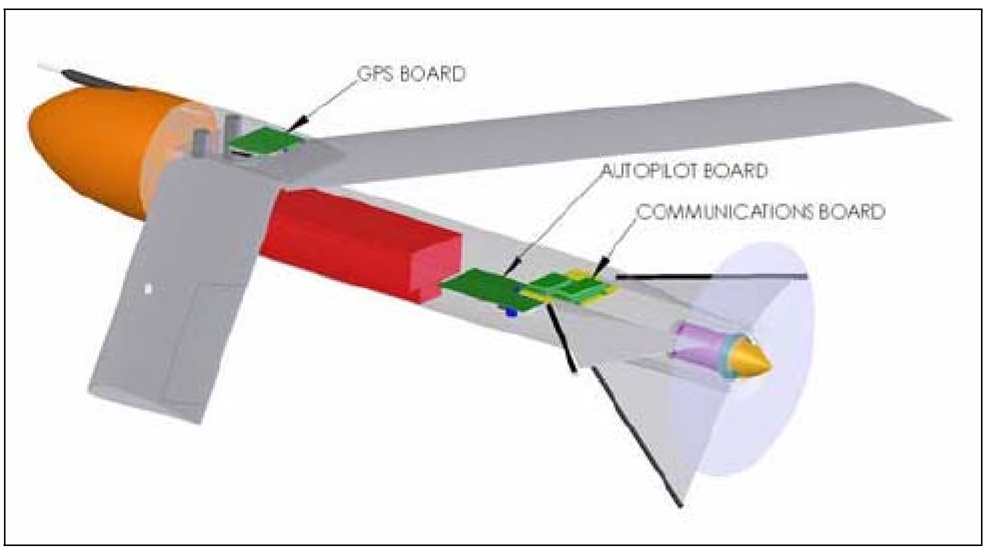

Figure 12 Avionics Locations inside Sono-Scout