LOW COST, FLEXIBLE PLATFORM FOR *IN SITU* REMOTE SENSING

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Abstract

Current military Unmanned Aerial Vehicles are mostly designed for remote sensing and intelligence gathering purposes. This demonstrates technologies that may be transferred from the military sector to civilian and commercial uses, such as resource monitoring and survey applications. The design of an unmanned aerial vehicle is presented in this paper, with an emphasis on the minimization of operational costs and the maximization of applicability to the civilian market.

Unmanned air vehicles have been used in military applications for decades, starting as target drones and developing to long range reconnaissance aircraft and, in recent years, to combat roles. However, the civil applications of unmanned aerial vehicles have lagged the military and only recently have there been significant efforts to develop commercial designs.

The same aspects that make unmanned aerial vehicles attractive to the military, such as no on-board human presence, long mission lengths and an increased aircraft work-load, are also attractive to prospective commercial operators as they transfer over to cost savings.

The primary goal of this design was to create a platform that would be capable of being fielded using current technology. As a result, while no single technology used in the design is revolutionary, the combination of these technologies, and their integration into a single platform capable of performing the desired mission in a commercial/civil context is an area of development that is new, and relatively unexploited.

1 Introduction

Currently, in commercial remote sensing and surveying applications, light aircraft are modified to carry a specific set of sensors. As a result these aircraft are restricted to missions based on their sensor payload. In the case of companies that specialize in conducting these surveys, many fleet aircraft must be maintained to accomplish the different survey missions. Such a fleet of aircraft could be replaced by a lesser number of unmanned aircraft that are capable of accepting different, mission-specific payload packages and carrying them for longer periods than would be feasible for a piloted aircraft.

2 Purpose

The area of remote sensing at present is split into two areas. Space-borne solutions allow large areas of land to be observed at a time. The drawbacks of space-borne sensors are the high associated costs and the difficulty in acquiring local detailed information. The other area is that of *in-situ* observation, whether ground-based, semi-airborne or airborne, that allow this more in-depth observation of a local region in order to supplement orbital imagery.

Since this local data to be collected is not always the same and could include photography, magnetic gradiometry, or thermal imagery, a platform must be able to accommodate a variety of sensors in order to be customized to the specific task. This platform would also need to be less expensive than existing methods in order to be a viable alternative.

Many of these existing methods have drawbacks which include either a low survey speed, as in ground based surveying, or high operating cost such as fixed-wing or rotary-wing manned aircraft. Semi-airborne systems currently suffer from a combination of these two problems since the ground-based sensors must be placed before the receiver aircraft can acquire any data. Any systems designed must look at the inherent strengths and weaknesses of each method in order to determine the ideal type of data collection method.

3 Conceptual Design

3.1 Platform Selection

In the present work a platform that is capable of being flexible and able to carry a variety of sensors had to be selected. When examining the options, three major types of platforms were identified;

- Ground-Based
- Airborne
- Semi-Airborne

These three platforms are all capable of conducting many different types of surveys in a target area. Each platform type had to be evaluated using a common set of parameters. A study comparing the three platform types of electromagnetic surveys was used for this evaluation [1].

3.1.1 Ground-Based Platforms

These are the slowest of the three types of surveys as the sensors must be moved over the ground or installed directly. However, the benefit is a much better data quality and better sensitivity.

3.1.2 Airborne

These surveys are the fastest to conduct as the sensors are moved over the survey area at high speed. However, they suffer from decreased data quality and sensitivity. Nevertheless, they are ideal for single surveys of an area.

3.1.3 Semi-Airborne

These platforms are a hybrid of the other two previous types, using fixed ground-based sensors coupled with an airborne receiver to collect the sensed data. However, the fixed sensors need to be placed before the survey can begin. Nevertheless, they are ideal for long-term monitoring of an area.

Based on the desired applications of such a platform, specifically the need for a small number of surveys to be carried out quickly, airborne platforms fill this requirement better than the other two platforms. That being said, such an airborne platform could still be used in a semi-airborne system with provisions to mount a receiver and data acquisition system.

3.2 Airborne Platform Selection

The selection of airborne platforms as being ideal is only part of the selection process as there exist many types of airborne platform. These fall into two categories based on how they generate lift; aerostatic and aerodynamic platforms.

Aerostatic platforms are essentially airships with either rigid or non-rigid bodies. They use a gas to generate lift through buoyancy. Rigid-body airships allow more freedom in terms of design at the expense of added weight.

Aerodynamic platforms can be broken down into three main types:

- Rotary-Wing
- Fixed-Wing
- Tilt-Rotor

Each type of aircraft provides very different capabilities the end-user. Fixed wing aircraft are capable of much higher speeds and can be designed to be inherently stable, however rotary-wing aircraft are capable of hovering and flight at very low level.

3.2.1 Rotary-Wing

Rotary-wing aircraft generate lift through rotating a set of wings through the air. The need to develop lift directly means that they require a great deal of fuel, though they are able travel very slowly or even hover over a location. They are capable of taking-off and landing without large area requirements. However, they do require powerful engines and complex drive coupling components which can increase maintenance costs. There are some dynamic stability issues in rotary-wing aircraft, and there is some risk in using them in certain environmental conditions.

3.2.2 *Fixed-Wing*

Platforms that generate lift through air flowing over the wings. These aircraft are capable of generate significant amounts of lift without large amounts of power, keeping their fuel efficiency high for the amount of payload carried. In addition, a design can be made inherently stable in flight and capable of adapting to changes in the centre of gravity.

3.2.3 *Tilt-Rotor*

Tilt-rotor aircraft are a hybrid of the previously mentioned platforms, capable of taking-off vertically as a rotary-wing aircraft and achieving the high flight speeds attainable with a fixed-wing design. However, few of these types of aircraft are in full production so understanding any nuances in the design of this type of platform is difficult without many years in active use.

Based on a comparison of the relative merits of each of the airborne platform types, and considering how each is capable of meeting our system requirements, it was found that a fixed-wing aircraft best fit the demands placed on an easily-transportable, flexible and low cost remote sensing platform.

3.3 Systems Specification

3.3.1 *Weight*

The maximum take-off weight of the aircraft was determined to be 1,000 kg. The Canadian Aviation Regulations (CAR) specifically CAR 606.02(8) [2] states that an "aircraft owner will have: subscribed for liability insurance covering risks of public liability in an amount that is not less than (a) $4,700,000, where the maximum permissible take-off weight of the aircraft is 1,043 kg (2,300 lbs) or less." Since minimizing operating costs is important to the customer, keeping the required cost of liability insurance to a minimum while still allowing a variety of payload configurations is desired. In addition, the decision to use this weight was determined from both research into airborne surveying platforms already in use and discussion with some of the companies that use such devices.

Research into payload systems demonstrated that the upper bound on possible sensors would be 250kg. This was based on the heaviest combination of two possible common sensor packages. The payload in turn accounts for 25% of the aircraft's total operating weight, which allows 750kg for all other systems on board. With this weight determined, it is possible to size the aircraft for power and lift requirements.

3.3.2 *Takeoff Distance*

Since the purpose of this aircraft is to be able to take-off in unprepared areas a short take-off distance is of importance. There are two main methods of measuring take-off distance. These are the distance the aircraft travels before it loses contact with the runway, and the distance the aircraft travels before it is capable of clearing a 15.2m (50ft) obstacle. Take-off distances of other aircraft used in geophysical surveying were researched. These results are shown in Table 1, along with the final target values decided upon.

Table 1 – Take-off Distance of commonly Used Aircraft for Geophysical Surveying[3]

Aircraft	Start-Up/Take-Off Distance (m)	50ft Obstacle Clearance (m)
Cessna 310	341	419
Cessna 320	261	576
Cessna 210 T	190	369
Target Value	190	304

From this information the shortest start-up take-off distance was chosen in order to be competitive yet realistic. According to FAR 23 regulations the 15.2m (50ft) obstacle clearance distance must not be more than 1.6 times the start-up take-off distance. Thus, a 15.2m obstacle clearance of 304m must be achieved, rather than 369m.

3.3.3 *Landing Distance*

Similar to take-off there are two methods for measuring landing distance, roll-out distance and 15.2m (50ft) obstacle clearance. To determine an acceptable target value for these distances the data from competitive aircraft are summarized in Table 2 along with target values.

Table 2 – Landing Distance of commonly Used Aircraft for Geophysical Surveying[3]

Aircraft	Roll-out distance (m)	50 ft Obstacle Clearance (m)
Cessna 310	391	521
Cessna 320	195	627
Cessna 210 T	221	338
Target Value	195	380

Once again the smallest value was chosen as the target value for competitive reasons. Unlike take-off, FAR 23 does not state a constraint on the 50ft obstacle clearance for landing. However, from the data summarized above and methods for estimation described in FAR 23 a 50ft clearance, a distance of twice the roll-out distance seemed reasonable and competitive.

3.3.4 *Climb Rate*

FAR 23 states a minimum climb rate of 91.4m/min (300ft/min). The researched aircraft mentioned in Tables 1 and 2 have climb rates ranging from 390m/min (1,280ft/min) to 552m/min (1,810ft/min). The target climb rate was set at 610m/s (2,000ft/min) in an ambitious attempt to improve upon the performance of competitor vehicles.

3.3.5 *Fuel Reserve*

A fuel reserve is required in case of emergency situations or unexpected circumstances. FAR 23 states a fuel reserve minimum of 30mins. All aircraft used in geophysical surveying that were researched facilitate 30mins of reserve. For these reasons a fuel reserve of 30mins was used in the analysis.

3.3.6 *Cruise Altitude*

The cruise altitude is primarily constrained by the region of controlled airspace which is anything over 3,657.6m (12,000ft). Because there is no person aboard the aircraft it must not enter controlled air space. Therefore a cruise altitude of 3,200m (10,500ft) gives a comfortable operating distance from controlled airspace while still maintaining a reasonable height.

3.3.7 *Cruise Speed*

A target cruise speed of 300km/h was chosen based on the cruise speed of aircraft used for geophysical surveying. Data on the aircraft is summarized below.

Table 3 – Cruise Speed of commonly Used Aircraft for Geophysical Surveying[3]

Aircraft	Cruise Speed (km/h)
Cessna 310	330
Cessna 320	378
Cessna 210 T	295
Target Value	300

The Cessna 310 and 320 are both twin engine aircraft, therefore expecting to match their cruise speed with only a single engine would be unrealistic. Therefore a speed closer to the single engine 210T was more acceptable.

3.4 Payload Sizing

As previously stated the platform must be able to accommodate multiple roles and even mount different sensors at once if possible. When mounting two different systems at once the systems should be complementary to each other. Of the platform systems foreseen, Lidar and either a film or digital photographic system complement each other well.

The digital camera systems capable of complementing Lidar weigh less than 100kg and occupy a volume of approximately 30cm x 60cm x 70cm (LxWxH) for a control unit and

25cm x 20cm x 45cm (LxWxH) for the sensor and require less than 300 Watts of power[4].

With these values the payload compartment must be less than 300kg, have a minimum power supply of 1050 Watts, and have dimension of greater than 150cm x 69cm x 76cm.

To increase the multi-role capability of the platform, it is proposed that the payload section be modular. This would allow for quick interchange between sensor systems, giving the platform the ability to adapt to different roles on a mission to mission basis.

3.5 Power Systems

The basic question of how the aircraft will be propelled through the air, how its internal systems and avionics will be powered and how the payload will be provided for will now be addressed.

The beginning point will be at the system architecture level. A decision must be made as to the overall methodology to be implemented at the vehicle level, with this then percolating down to influence the lower levels in the system, such as the main method of energy storage and the physical method of propulsion.

The architectures considered include conventional fossil fuel systems, all electrical, hybird-electric and fuel cell arrangements.

Each of these were evaluated in terms of their ability not just to meet the power draw requirements of the platform, but to take on a form complementary to the activities of the platform.

There are both internal and external constraints on the choice of power system architecture. The constraints consist of those required by the platform, in terms of power and endurance, those required by the end-user, such as ease of maintenance and access to spare parts, and those that are a by-product of meeting the first two sets of constraints, such as the mass and size of the system itself.

For the sake of brevity each architecture proposed will now be discussed, with their advantages and disadvantages highlighted and a decision on their applicability to the current design made.

3.5.1 Fuel cell power unit

The development of fuel cells over the last thirty years has recently allowed their use in automotive and stationary generator applications. They consist of a fuel cell that combines two chemical reactants, their respective storage tanks and electric devices to convert the electricity produced to other forms of power. While the fuel cell itself is relatively low in mass, the fuel storage tanks and electric motors currently available are not.

The most common reactants in fuel cells are hydrogen and oxygen. The hydrogen is stored in one of two ways, either as a compressed gas, 34.47 kPa to 68.94 kPa, (5,000-10,000 psi) or in a liquid state, held in an insulated tank. The oxygen required is recovered from the atmosphere. This architecture is eliminated here on the basis of commercial viability, with the requirement for specialty fuels that are difficult to obtain in remote areas, or even at most small airstrips being a concern. Both fuel storage methods are expensive, due to the rarity of their use and the energy it takes to compress and/or liquefy the hydrogen.

3.5.2 Electric power unit

An electric only architecture is made up of a bank of batteries and an electric drive motor to provide shaft power output. The batteries are charged before take-off and depleted over the flight. There are two very important obstacles preventing the use of this arrangement. The first is the susceptibility of battery capacity to environmental temperature, with many cell compounds losing an order of 10% or greater of their potential energy density within a 20^{o}C range of temperature[5]. The second is simply the number of cells required to store the 8 hours of power required for the aircraft to operate. This would add an excessive weight penalty to the implementation of this architecture.

3.5.3 Hybrid-electric power unit

A hybird-electric power architecture would consist of three main components. An electric motor to provide mechanical power output, a conventional fossil fuel engine to create the power and an array of batteries to store excess power when it is not required. The conventional engine is sized to the mean power output, and is supplemented with stored power from the batteries to mitigate the duty-cycle demanded of the system.

The following is a schematic of a "typical" duty cycle:

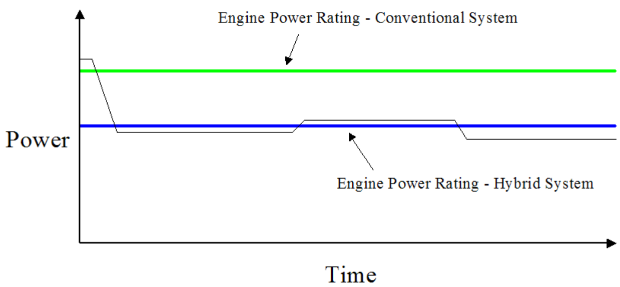

Figure 1 - Comparison of Engine Sizing, Conventional vs. Hybrid System

As the above figure shows for the hybrid system to supply the required take-off power, a number of batteries will be required. Given the data on the energy density of different battery types in the table below it quickly becomes evident that the extra power will require the addition of multiple kilograms of battery mass just for take-off, especially because the power shortage will be of the order of tens of kilo-Watts for a number of minutes. However, given the relatively constant nature of the survey duty cycle, these batteries will not be relied upon again to supply large amounts of power, creating a "dead" mass to be carried for the rest of the mission. Due to this fact and the relatively high power density of an internal combustion engine as compared to a battery, the use of a conventional architecture can be justified because it allows more of the carried mass to be active in the operation of the aircraft. For this and the additional available performance, a conventional architecture is selected as the most applicable for use aboard this unmanned aerial vehicle. If unusable weight is going to be carried for the duration of the mission, that added weight might as well have the potential to add to the performance of the aircraft.

Table 4 - Energy Density by Battery Type[6]

Battery Type	Specific Energy W-h/kg	Specific Power W/kg	Energy Efficiency In Percent
Lead/Acid	40	130	65
Aluminum/Air	200	150	35
Lithium/Iron-Disulfide	>130	>120	----
Lithium/Polymer	200	100	----
Nickel/Cadmium	56	200	65
Nickel/Iron	55	130	60
Nickel/Metal Hydride	80	200	65
Nickel/Zinc	80	150	65
Sodium/Sulfur	100	120	85
Zinc/Air	120	120	60
Zinc/Bromine	70	100	65

3.5.4 Conventional fossil fuel power unit

Within the realm of conventional fossil fuel engines there are three choices. The first is a turbine, the second a basic piston engine and the third a Wankel engine. The method used to differentiate between these three engines is two fold. The first is the power-to-mass density of each engine style, comparing the power delivered for each kilogram of added mass. The second is the availability of components and the consumption of fuel over one survey mission. Turbine engines, be it a turbo-jet, turbo-fan or turbo-prop, have the best power-to-mass ratio, followed by Wankel engines and then piston engines. The opposite order is found when examined in terms of fuel consumption per-kW of power produced. Due to the excessive amount of fuel they consume, the lack of high power performance requirements for this aircraft, and the high initial costs involved with turbines, they were eliminated from the comparison. Of the two remaining engine types a Wankel would be idea as they have a well struck balance between fixed mass, power output and fuel consumption. However, it was found that there are no currently commercially available production Wankel engines in the correct power rating for this application, without requiring multiple engines. Therefore, a piston engine, the Textron Lycoming LIO-360-C1E6, was selected. This engine is currently in production and has the correct power output to meet the take-off and cruise requirements of the design. The use of this engine implies that the platform will be propeller driven. The basic engine characteristics are as follows:

Table 5 – Engine Specifications[7]

Engine:	Textron Lycoming LIO-360-C1E6
Cylinders:	4
Configuration:	Horizontally Opposed
Rated Continuous Power:	149 kW @ 2,700 rpm
Overall Dimensions:	49.5x87x85.5cm
Dry Mass:	153 kg

The choice of control surface actuation was a much more straightforward process. The control surfaces will be powered electrically by linear actuators, instead of hydraulics. Although more than able to provide the power, they are simply too heavy for this application. The control surfaces will be articulated directly by the actuators for the sake of weight savings and design simplicity.

3.6 Control System

The selection of a control system for the aircraft was mainly driven by what is currently commercially available. An autopilot system, from Micro-Pilot was selected for its ease of customization. This autopilot comes complete with gyroscopes, compass, altitude and airspeed sensors. It also has an ultrasonic altitude sensor for fine distance measurements when close to the ground, allowing automation of take-off and landing. There is also the on boad capability to interpret Global Positioning System (GPS) L1 signal data.

The system relies on two antennae for command and control; a GPS antenna and a satellite communications antenna. A ground station may be used to control the platform via an Iridium satellite network connection on the 1,616 – 1,626.5 MHz band. A dedicated antenna is used to provide a 2,400 bps switched-circuit data-transfer rate.

An Iridium transmitter was selected because of the extensive coverage of the network over remote areas, and the fact that hardware for this network has already been implemented in aerospace data transfer applications.

3.7 Airframe Preliminary Configuration Layout

With a fixed-wing platform selected, the design of such an aircraft was undertaken. Keeping in mind the system requirements, the design must be capable of high-lift and, most importantly, be capable of accepting centre of gravity positions that can vary significantly.

Since the payload accounts for 30% of the total system mass, and the payload may not be easy to centre in the aircraft, the overall concept of the airframe is a three surface configuration. Such aircraft possess three lifting surfaces, a canard, the main wing and a tail [8]. The main benefits of such a system design is the potential to allow a lower trimmed drag for the aircraft than a conventional design. In addition, there are favourable stability and control characteristics for such a design [9].

Finally, the propeller and engine placement will be rear-facing and behind the centre of gravity in a pusher configuration. The primary reason for this is that without turbulent airflow from the propeller flowing over the skin of the airframe, the overall drag of the design is lowered [8]. The empennage was designed to follow a T-tail design, where the horizontal stabilizer is placed atop the vertical stabilizer, moving it away from any blanketing flows from the other two lifting surfaces.

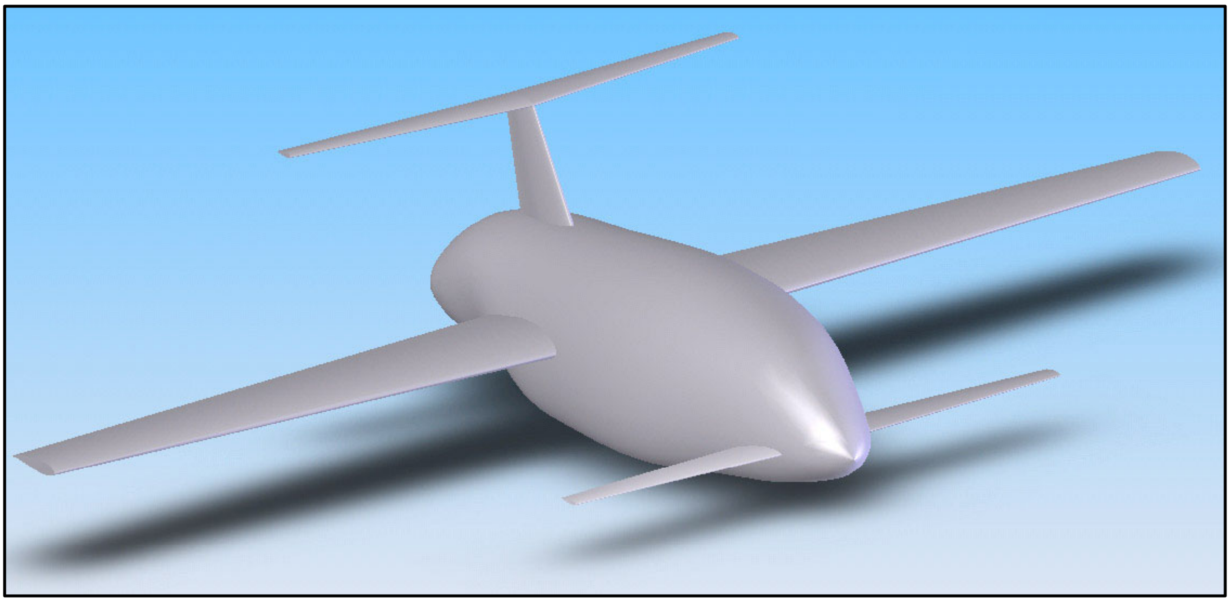

Figure 2 – Final UAV Concept Model

3.8 Aircraft Sizing

The most stringent requirement of the design is achieving an overall take-off distance of 304m while clearing an obstacle. For this case, the power required and the amount of lifting surface area can be determined. A take-off coefficient of lift of 2 was selected as feasible for such a design [8]. Using FAR 23 take-off requirements, the final design was found to need a wing loading of 68.3 kg/m^2 (14 lb/ft^2) and a power ratio of 8 kg/kW (13.2 lb/hp) yielding an aircraft of 14.65 m^2 of lifting area and 125 kW of power.

The wing span chosen is 10.82 m with an aspect ratio of 8 and, in an effort to improve the efficiency of the wing in cruise, a straight taper with a taper ratio of 0.5. The wing also included the use of leading edge slats in order to allow the aircraft to meet its take-off lift requirements.

The remaining surfaces were designed around the concept of the wing providing the majority of the required lift. The final design of the fuselage was based around fitting all the components required for the aircraft inside an area that allows the lifting surfaces to be attached in appropriate places. The fuselage is 640cm long.

The structure of the aircraft was chosen to be an aluminum alloy skeleton with a composite skin. Composites were used in an effort keep the aircraft's weight under the 1,000 kg limit.

5 Financial Consideration

A full cost estimation was undertaken for the proposed design and, although many aspects of this analysis can be enlightening, only two figures are provided here for illustrative purposes.

A production run of 200 aircraft was considered, using wage rates and capital costing figures based on North American production. Particular values were attained by examining trends in the costs involved in the production of aircraft of similar composition, while under the influence of a few key factors such as manufacturing methods and financing rates[10].

It was found that a single survey aircraft would cost approximately $711,000 CAD$ to acquire.

6 Design Implications

By designing the UAV's systems as they have been described, three important aspects of interest to the commercial sector are affected.

The first implication of this design on the process of aerial surveys is that a single aircraft is now capable of carrying multiple, different survey payloads. This allows for better utilization of the platform and the maximization of the investment that has been made in the aircraft. This is compared to the current model where a single aircraft is mounted with a single piece of survey equipment, with no interchangeability.

In removing the requirement of a pilot, the expertise required to undertake surveys is greatly reduced. There is a proportional increase in the technical skill required, but this would only need to be applied in a survey set-up and platform maintenance capacity, as opposed to the entire duration of a survey flight, which may be extended, as it is now independent of pilot fatigue.

This argument leads to the final and most influential aspect of the design: the reduction in the cost of conducting survey missions. By removing the pilot from the equation a large operational cost is eliminated, while not being offset by a drastic increase in the aircraft's acquisition and operational costs.

A simple comparison is made in the following tables between current survey aircraft and proposed design.

Table 6 – Rough Platform Acquisition Cost Comparison (CAD$)

Aircraft	Acquisition Cost	Date of Aircraft
Cessna 210 T	$420,000	1979
Cessna 310	$355,000	1978
Cessna 320	$132,500	1963
Bell 206B	$615,000	1996
Proposed UAV	$711,000	NEW

Table 7 – Rough Cost of a Full Endurance Survey Mission (CAD$)

Aircraft	Liters of Fuel per Mission	$/L of Fuel	Cost of Fuel per Mission	Range
Cessna 210 T	302	$0.78	$237	1,260
Cessna 310	386	$0.78	$303	1,186
Cessna 320	386	$0.78	$303	1,371
Bell 206B	344	$0.69	$236	N/A
Proposed UAV	256	$0.78	$201	1,920

Table 8 - Rough Cost of Flight Crew Over Lifetime of Aircraft (CAD$)

Aircraft	Cost of Crew per Year	Years of Service	Total Cost of Crew over Service Life
Cessna 210 T	$109,000	20	**$2,180,000**
Cessna 310	$109,000	20	**$2,180,000**
Cessna 320	$109,000	20	**$2,180,000**
Bell 206B	$156,000	20	**$3,120,000**
Proposed UAV	$0.00	20	**$0.00**

7 Conclusions

This project has taken the need for a low-cost platform capable of carrying a variety of sensors to the point at which a much more extensive development, testing and validation effort will be required in order to complete the design.

The field of remote sensing has been researched, analyzed and the solution of a fixed-wing unmanned aerial vehicle has been identified as the best approach. The choice of a pusher configuration for the aircraft, the selection of a proven aircraft engine, and the accommodation of various sensor payloads has been focused on finding a purpose built solution to this niche in the remote sensing market.

These concepts have been taken and expanded into a preliminary detailed design of the mission critical aircraft systems, including airframe, propulsion and avionics systems. From this point in the design an investigation into the optmization of the materials, processes and the dynamic behaviour of the aircraft should be undertaken if this design is to be brought to the market place.

An analysis of the financial considerations has been included to highlight the advantages of such a solution. This has identified the removal of the need for a flight crew, the reduction of operational costs and the versatility of the design as factors that drastically reduce the life cycle costs associated with *In Situ* Remote Sensing.

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