Polytechnic University's
Unmanned Aerial Vehicle Design

Journal Paper
AUVSI Undergrad Competition

Presented By
Thomas Szumczyk
Ravindra Persaud
William Cheung
Pedro Placido
May 16, 2005

Photo of Polytechnic University's UAV

ABSTRACT

This paper describes Polytechnic University's accomplishments in developing, designing and testing a radio controlled airplane that was modified to be fully autonomous for the entry into the 2005 3rd Annual undergraduate AUVSI Student UAV Competition. This year's entry is a Hanger-9 Alpha 40 size trainer which is capable of autonomous flight, navigation of a specific course by means of GPS coordinates and collection and transmission of real time data and imagery to the ground were the information can be exploited. The end result has been a plethora of off-the-shelf products which have been integrated together to create a workable autonomous system that is designed to complete the task presented by the AUVSI competition.

INTRODUCTION

The goal of the 3rd Annual undergraduate AUVSI Student UAV Competition is for an unmanned radio control aircraft to be launched whether manually or autonomously to navigate a specified course and through the use of onboard payload sensors locate and evaluate several man-made objects before returning back to home and landing. Polytechnic University's 2005 design is a fully functional prototype of an Unmanned Aerial Vehicle intended for this reconnaissance operation and is a continuing legacy of Polytechnic's involvement in the UAV field. Since last years competition, the strategy has been to create a simple design thus using a smaller airframe than last years model which was a ¼ scale J-3 Piper Cub and upgrading to real time video downlink to eliminate the need for data processing on the ground. Using Micropilot's MP2028g autopilot system for a second year in a row, this year's prototype is now capable of operating fully autonomously from takeoff to landing on preprogrammed missions as well as in-flight changes and navigates a course by following selected waypoints which are given through GPS coordinates. Unlike last years design which utilized a digital camera, this year throughout a whole mission, the prototype will feed down real time footage of the flight and is programmed to locate potential targets through a panning motion of the video camera tagging them with a GPS coordinate and defining their orientation according to the aircrafts heading. As a result, this prototype has been specifically tailored for the competition hosted at Webster Field in St. Inigoes, Maryland by the Association for Unmanned Vehicle Systems International.

OVERALL DESIGN APPROACH

The system is comprised of an airframe from Hanger-9 which is an Alpha 40 size trainer that is designed to carry a payload of sensors for target recognition; an autopilot system developed by MicroPilot for autonomous take off, landing and flight; a single normal monochrome surveillance video camera with varifocal lens and a 900MHz Amateur band FM transmitter for real time video and downlink; lastly a pair of MaxStream 2.4GHz wireless data modems for a real time data link for flight communication. Joining together these systems is a ground station that will monitor all real time data through a PC and laptop which are linked in a network. This network will attempt to use computer written code to analyze the real time video feed and locate and evaluate several man-made objects autonomously in order to complete the reconnaissance mission created by 2005 AUVSI competition.

DETAILED DESIGN DESCRIPTION

Aircraft:

Airframe- In considering the flight conditions, one of the major concerns of the airframe is whether it has the capability to carry a payload and withstand a sufficient amount of wing loading. In addition, the airframe must be practical and prove to have real life applications such that it is small and undetectable as well as quiet for covert military reconnaissance missions. In considering a suitable plane, Hanger-9's 40 size Alpha Trainer was chosen.

The Alpha Trainer is a ready-to-fly trainer suited for the first time R/C flyers as well as educated, seasoned, veterans. Everything comes already installed that is the engine, servos and receiver and assembly is incredibly quick. The Alpha Trainer has a wingspan of 63 inches, wing area of 710 in^2, and a wing loading of 17.0 oz/ft^2. In addition the Alpha is 25.2 inches in length and has an empty weight (without fuel) of 63 oz. Using the wing loading and wing area, it can be calculated that the maximum allowable weight of the plane is approximately 112 oz. or 7 lbs. The total weight of the plane can be seen in the last line of table 1. A detailed manufacturer's specification sheet of the aircraft can be seen in Appendix A.

Component	Weight (oz)
Alpha Trainer w/fuel	84
Autopilot & Housing	1.7
Two batteries	11.2
Data Modem	3
Video Camera & Harness	3.6
Video Transmitter & Harness	3.1
Total	106.6

Table 1-Overall weight of entire system

Wing- The wing on the Alpha trainer has a very interesting design that makes it excellent for UAV application. The Alpha is equipped with a flat bottom airfoil as opposed to a symmetrical airfoil (Figure 1).

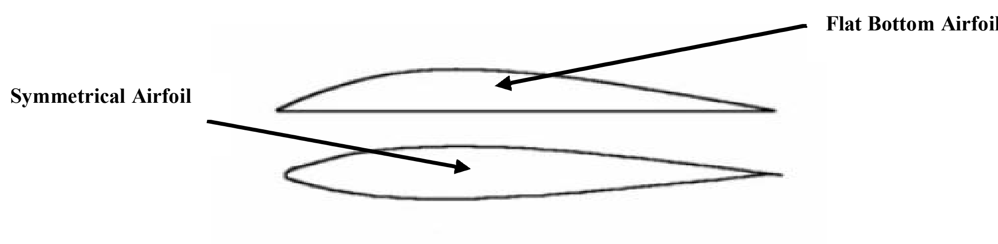


Figure 1

To understand what kind of impact this has on the plane a brief understanding and some background on the dynamics of the plane in flight is necessary. Airplane wings develop lift when the air flows faster over the curved top of the wing than it does over the wing's straight bottom. Bernoulli's Theorem states (paraphrased) that since the air on the bottom of a flat-bottom wing is moving more slowly than the air on the top side of the wing (curved surface), it must have a greater pressure and therefore tends to push the wing upwards. Hence the wing develops lift. Other model aircrafts have wings that are nearly symmetrical airfoils which demand that the airfoil must have a positive angle of attack to the leading edge of the wing.

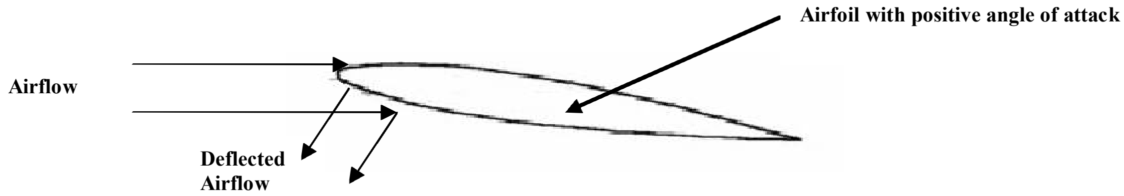


Figure 2

It can be said that since Flat-Bottom airfoils generate lift using both Newton's Third Law and Bernoulli's Theorem for a given wing area, a flat-bottom wing produces more lift at a given airspeed and angle of attack than a symmetrical wing at the same conditions. This extra lift produced by these wings allow the Alpha to takeoff, fly, and land more slowly, in addition to making it nearly impossible to accidentally stall.

Landing gear- The Alpha's tricycle landing gear configuration involves a wheel at the nose of the airframe. With the wheel at the nose the Alpha provides easier ground steering (taxing) and more stability during takeoff and landing.

Power Plant- The engine installed in the Alpha 9 is a .46 Evolution Engine (EVOE100). The propeller design consists of a 3-bladed prop made of plastic with a spinner in front. The Evolution Engine uses 10 % or 15% nitro and a detailed manufacturer's specification sheet can be seen in Appendix A. This engine allows for easy start up and is considerably quiet compared to gas engines in addition to less vibration.

Payload:

Navigation system- The heart of the design lays in the airframes ability to autonomously navigate a course with little to no aid from a human. In order to accomplish this task the same commercial off-the-shelf autopilot system as last year was utilized. The rationalization behind this decision was the fact that it would take many man hours and many students to create a prototype autopilot system within a year timeframe. Thus maintaining the idea of a simple design the autopilot system called MP2028g created by a Canadian based company MicroPilot was the choice for this years design. Much hesitation was made due to this decision because of numerous problems that arose with its use in last year's competition. However since that time, Micropilot has made many modifications in there design with patches for their programming and created an interactive option called Xtender that allows for user input and control over other control surfaces that do not include the typical control surfaces such as ailerons, elevator, throttle and rudder.

The MP2028g offers many options and allows a user to tailor the system to any type of winged vehicle. It also allows for autonomous takeoff and landing, the ability to hold a specific altitude, the use of GPS coordinates for navigation and the ability to navigate using preprogrammed missions. Autonomous takeoff and landing is done with the use of an ultrasonic electrostatic sonar module and sensor. Micropilot simply calculates the distance above the ground knowing that a sound wave moves .9 feet / millisecond. As for autonomous flight, the MP2028g operates on error checking. Using various sensors such as gyroscopes, accelerometers and a pitot tube, the MP2028g uses the real time data obtained while in flight and checks it against the actual data that the user has inputted. PID feedback loops analyze the incoming information and dependent on how correct the gains are, the feedback loops detect deviations and correct them by adjusting the control surfaces accordingly.

The relatively new option that Micropilot has created is an additional software package called Xtender. This feature is particularly important since it allows a user to access other control surfaces. Computer code can be written outside MP2028g code and this then can be translated into the MP2028g through the ADC pins located on the MP2028g board. This feature enables the use of an extra servo which is used for panning the video camera to locate objects on the ground.

Housing-Since the MP2028g is an expose chip it requires some type of encasement from the outside world. Last years design was made of copper which made it heavy and was extremely oversized. Thus an aluminum housing was created this year from a sheet of aluminum flashing because aluminum is very light and easy to work with. The housing was sized according to the MP2028g as well as constrained by the fuselage of the aircraft. A snap on top was made to allow for quick access. Inside memory-foam lined the bottom to isolate any vibration from the plane due to the sensitivity of the MP2028g. To secure the MP2028g from moving around it was fastened to the housing by four screws. The entire housing was secured to the plane by one screw and memory-foam.

Data Transmission- In order to know the aircraft's path and retrieve information from the plane such as the heading and its coordinates while in flight, a wireless link was made between the ground station and the aircraft using radio frequency data modems. These modems run on 2.4 GHz with an operating distance of 3 miles line of sight and are supplied from a company called Maxstream. Micropilot interfaces to the outside world using standard RS-232 protocol data. MaxStream's product offers this and the ability to wirelessly communicate it to the ground by frequency hopping across a broad spectrum on a public frequency band of 2.4 GHz. The change from the 900MHz model used in last years competition was due to video downlink transmitter used this year which operates continuously also in the 900Mhz band. Since both pieces of equipment operate in the same band the possibility of interference exists and in order to increase compatibility, the modem was changed to the 2.4 GHz band. The modem is positioned on the underside of the airframe and is held on by two rubberbands. This design is for easy removal and its location is out of the way. The modem is mounted to a piece of balsa wood which is actually the cover for the lithium battery compartment. Memory-type foam surrounds the modem and an aluminum flashing encases the entire setup to ensure some ruggedness for a hard impact.

Imaging System-

Downlink- Since real time downlink minimizes the processing time of imagery, this years design incorporated a real time video system. Yet with streaming live video, a means of transmission back to the ground is needed. The solution to this problem came from a company called Supercircuits which is a typical surveillance company, where a 900 MHz high power FM wireless transmitter and receiver were purchased. This system was ideal because the transmitter is extremely tiny and weighs practically nothing. It also transmits a distance over a mile line of sight which meets the distance criteria and offers a higher output power operating in the 900 MHz band of the Amateur Radio Service band. Other FCC authorized operating bands were limited in transmitting power and hence range achievable. Lastly the most important condition was the transmission quality. With FM modulation, there is a Signal-to-noise advantage when compared to an AM transmission of equal bandwidth. The transmitter's position is located on the left side of the plane such that it could be installed and removed as a PC card. It is also positioned so the antenna is fixed from moving and is always in visibility range.

Video Camera- To capture the real time data a common monochromatic surveillance camera with a varifocal zoom lens from Supercircuits was chosen. This camera proved to be ideal due to its size, preassembly in a case and included a pan and tilt platform. It also demonstrates a substantial amount of resolution which is necessary for distinguishing an object from a height of 300 feet. The reasoning behind choosing monochrome over color was for simplifying the design and maintaining a high degree of resolution when compared to a color camera of equal size. It eliminates the need for digitizing the color sub-carrier to create a color image for viewing on the ground thus making the imagery viewed at the ground station more robust. As for the varifocal zoom lens, this feature proves to be useful when field testing and determining what height the plane will hold altitude. Flying at different altitudes requires multiple lenses to obtain the imagery that is necessary for recognition of an object on the ground.

The manual pan and tilt platform which the camera is attached to, is mounted directly to a mini servo. This servo which is controlled by MicroPilot through the use of the Xtender package, acts as a panning feature to pan the camera around to locate an object. By panning the camera a larger surface area can be viewed thus decreasing the flight time. The entire camera system setup is located on the under side of the nose just below the engine. This was the ideal spot since there would be no obstructions such as the nose wheel and the center of gravity would be maintained.

Battery Supply System- In order to power all the electrical components on board the airframe it was necessary to have two power sources. The majority of the equipment required a power supply of 12 volts thus a 3 cell 11.1 volt 1200maH lithium battery pack by Eflite was chosen to supply all the major components of the airframe as shown in the table below.

On Board Electric Equipment		
MicroPilot	4.2 to 27V	~140 mA
Radio Modem	7 to 18 V	400 mA
Video Transmitter	12 V	250 mA
Video Camera	12 V	110 mA

Table 2-Outline of all electrical equipment that uses the primary battery source

From this current consumption, a calculated discharge time of a little over an hour resulted well over the limit needed to accomplish the mission. This battery pack also proved to be half the weight and size than compared to a Nickel Cadmium pack of the same capacity. The location of the battery pack is on the underside of the airframe where a compartment was made to hold the battery to give easy access since it must be removed from the plane while charging for safety issues.

The second power source which is strictly for powering the servos and servo board that control the control surfaces of the aircraft, utilizes a 6volt 1500maH Nickel Cadmium pack from last year. The reasoning behind an entirely different power source for the servos is that the servos would require a voltage regulator to reduce the voltage from 12 volts to 6volts as well as a power draw which spikes rather than continuous flow since servos draw substantial power when they are in use. The location of this pack is inside the fuselage back toward the tail out of the way since its position is not crucial and removal from the plane is not necessary. A diagram showing the power supply system can be seen in the Appendix B.

Ground Station:

Vision System- The video camera on board the aircraft is geared towards taking video feed of the ground at a predefined angle of 60 degrees below the horizon. This video feed is then sent off wirelessly over the 900MHz band to a corresponding receiver at the ground station. The receiver in turn is connected to a capture card made by ATI and this is powered by a standard personal computer. The radio signal is then converted to a TV signal and sent into the system as video input. The video is then broken down to frames and a frame selection process begins by selecting 1 of 10-20 frames. These images are sent off to a program running within the computer which takes each image, processes it with Fourier transform, masks it with another sub image and then is processed. This results in amplification of high intensity points within the image. The algorithm is designed to find high deltas from pixel to pixel. If a set of pixels has a calculated delta that surpasses a particular threshold, then it marks it up on a new image. The end result is a second image with marked points. These points are then processed using a 4x4 matrix to retransform the points from the image into world space. The world space is then reprocessed into GPS coordinates which are attained from MicroPilot's Horizon program which will be running on a laptop simultaneously with the vision system. As Horizon retrieves data of the aircrafts path this information will be networked to the personal computer where the imagery will be matched up with a GPS coordinate and a definition of orientation according to the planes heading.

Safety:

One of the key issues throughout the entire year of design and testing has been safety. Since the project has been a learning experience much consideration has been taken in keeping everyone who has worked on the project safe. During the design phase much care was taken when students worked with any piece of machinery or tools necessary for cutting either wood or aluminum. Proper knowledge of the use of the tools was talked about before proceeding to work with them. During the testing phase great concern was shown at the field to avoid any mishaps. For one, the field were the aircraft was tested was most of the time a vacant field which ensured that if the plane were to malfunction and crash that no person be hurt. The second issue was keeping the plane always within eye range and never allowing it to pass behind the ground station where students where operating. Third, a large amount of time was given to showing everyone how fuel the plane, which switches to turn on and off, and how to start the plane. Starting the plane was a very important since the propeller is a plastic prop which is sharper than a wood prop. The best approach was to use a battery powered hand starter which is placed on the spinner of the engine in order to ensure no hand contact with the prop. Lastly an extensive preflight checklist was followed to ensure that everything was ready and up to working condition before mission operation. (See Appendix C)

Since the primary battery source is a lithium battery a great deal of research was done on them to understand the dangers and what precautions to take if a problem is to arise. Lithium batteries for radio control use have come a long way in a year and many batteries are now much user friendly and less dangerous however certain misuse can still make the battery pack an unsafe object. To illustrate this, appendix D is dedicated toward the proper use of lithium batteries. While charging the battery pack a temperature gauge is attached to the pack to monitor temperature while charging to make certain that the pack does not over heat and catch on fire. As an added safety bonus a metal container was made to act as a containment unit to enclose the pack if it is to catch on fire.

RESULTS

The outcome of this years design has been for the most part successful. Despite the weather and ability to get to the field for testing, the idea of creating a simple design that is at the same time effective has proven to be an excellent prototype. The first attempt at designing the system to fit the aircraft was very successful. Only several small alterations were made to the airframe to continue with the idea of an off-the-shelf product. One example was that the throttle servo had to be moved slightly in order to allow for the micropilot box. Aside from alterations to the plane, a large problem that occurred was vibration as in last years design. The vibration from the engine was transferring into the micropilot box upsetting the gyros on the MP2028g which was made apparent through the use of the Horizon software. This was easy solved by adding more damping with the memory-foam. As for the camera picture quality it seemed for a moment that more damping would be required after the start of the engine but as soon as the throttle was increased from idle to full throttle the frequency increased allowing for the picture quality to go from jumpy to normal. Yet this was only tested on the ground and not in the air due to one of the 2.4GHz chips burning out requiring the need to purchase a new one and leaving the team with the MaxStream 900 MHz modems from last year. As stated earlier, there was a conflict between the MaxStream modems and the video transmitter only allowing us to work with one at a time. Since the autonomous flight was the primary objective no time was given to the camera downlink thus leaving the team with a vision system that was not tested.

As for the aircrafts flight, alterations had to be made to the Micropilot program Horizon to tailor the autopilot to exactly fit the aircraft. The numbers that where preinstalled into the MP2028g did not account for the extra weight that the plane had to carry thus such things like cruise speed and climb speed had to be increased. Along with those changes the error checking PID feedback gains had to be adjusted accordingly and this was done through trial and error while in flight rather than mathematically finding them as last year. By taking off manually and observing the plane while the MP2028g was in command, the gains were increased or decrease in increments of 25% at first and the percentage was decreased as the planes flight improved. The following order of control surfaces was followed to obtain the correct gains.

1. elevator from pitch, rudder from y accelerometer and ailerons from roll
2. pitch from airspeed and roll from heading
3. pitch from altitude
4. throttle from altitude
5. throttle from airspeed
6. rudder from heading
7. pitch from ultrasonic altitude

CONCLUSION

It has been another successful year for Polytechnic University in the field of unmanned vehicles. Regardless of how much was accomplished, it has been a great feeling for the Polytechnic team to be apart of a real life application and to use the knowledge learned in school whether it was mathematical or just common sense to its full potential. The team is glad to have traveled this far and been able to take the Alpha trainer and turn it into a fully autonomous flying vehicle. Even though the team was not able to test the camera system to its full potential during testing phase and get the results that were needed, the team is proud of the design that was created and believes it to be competition material. A project such as this is difficult to accomplish in a city area and to gather all the students to make a trip out for field testing is a great task. Yet overall our simple design consisting of off-the-shelf equipment has been brought from paper to reality and again another chapter has been created which next years team can build on and improve.

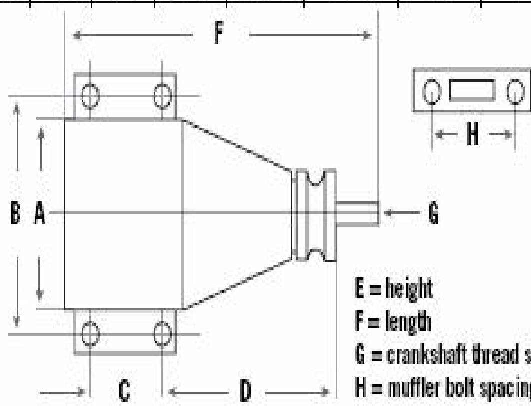
Appendix A

Manufacturer's Specifications

Model: Alpha Trainer
Manufacturer: Hangar 9
Distributor: Horizon Hobby Inc.
Type: ready-to-fly trainer
Wingspan: 63 in.
Length: 25.2 in.
Weight: 5 lb., 4 oz.
Wing area: 710 sq. in.
Wing loading: 17.0 oz./sq. ft.
Engine Installed: .46-size Evolution Engines Alpha A
Radio Installed: JR 4-channel Quattro w/4 NES-527 servos, R700 receiver and JR 600mAh battery pack.
Prop: 10-in., 3-blade Hangar 9 EVOE 100P (included)
Fuel Used: Performance Plus 15% nitro
Street price: $309.99

NT/NX Evolution Engines™ Specifications

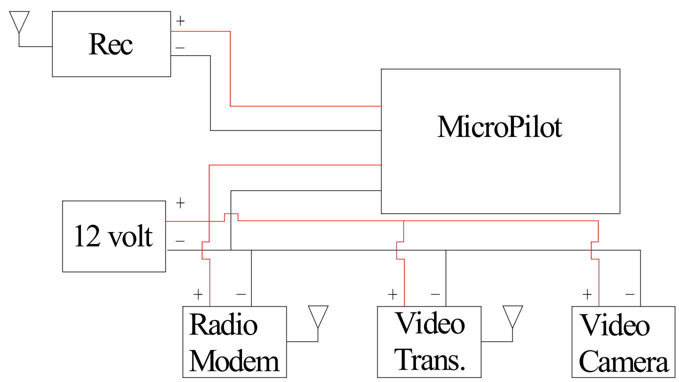
Items	Disp (cu in)	Bore (in)	Stroke (in)	Weight (oz) w/o muffler	Crank K (ISO)	Cylinder	Propeller
EVOE100	.455	.867	.771	16.32	1/4x28	ABC	10x6
EVOE0360	.354	.806	.695	10.30	1/4x28	ABC	9x6
EVOE0400	.392	.805	.771	14.08	1/4x28	ABC	10x6
EVOE0460	.467	.864	.797	13.76	1/4x28	ABC	11x6
EVOE0610	.608	.944	.862	20.10	5/16x24	ABC	12x6
EVOE1100	1.005	1.14	.985	23.20	5/16x24	ABC	14x6



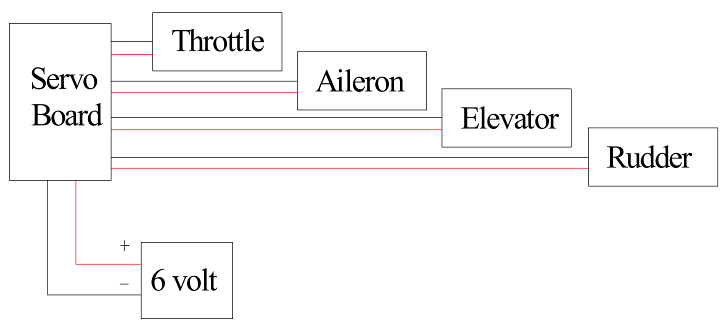
E = height
F = length
G = crankshaft thread size
H = muffler bolt spacing

Dimensions (mm)	A	B	C	D	E	F	G	H
EVOE100	36	44	17.5	52.5	90.5	108	1/4x28	37
EVOE0360	30	38	15	47	78	95	1/4x28	35
EVOE0400	36	44	17.5	52.5	90.5	108	1/4x28	37
EVOE0460	36	44	17.5	52.5	90.5	108	1/4x28	37
EVOE0610	42	55	25	55	100	113	5/16 x 24	42
EVOE1100	44	52	25	64.6	92	139.7	5/16x24	42

APPENDIX B



Rec
+
–
MicroPilot
12 volt
+
–
+
–
Radio Modem
+
–
Video Trans.
+
–
Video Camera



Servo Board
Throttle
Aileron
Elevator
Rudder
+
–
6 volt

APPENDIX C

PREFLIGHT CHECKLIST

- Check battery voltages
- Walk-around check
- Fuel up
- Turn on system
    - Turn on HyperTerminal
    - Initialize micropilot and servos
    - Wait for GPS and servos to lock
    - Close HyperTerminal & open Horizon
    - Connect to aircraft
    - Switch to pilot in command
- Radio range check
- Control throws and direction
- Clear area
- Tie down/ secure plane
- Full throttle stick
- Prime carburetor
- Throttle idle stick
- Install glow driver
- Start engine /warm up / remove glow driver
- Full power check
- Control check
- Switch back to computer in command
- Arm plane
- Start timer
- Takeoff

APPENDIX D

Safety Guidelines and Precautions concerning the Use of 3V Lithium Batteries:

In order to prevent the battery from liking or exploding causing injury, the following precautions must be taken:

• Keep batteries out of the reach of children, especially those batteries fitting within the limits of the truncated cylinder defined in ISO/DP 8124/2.2 page 17. In case of ingestion of a cell or battery, the person involved should seek medical assistance promptly.

• The circuits of equipment designed to use alternative power should be such as to eliminate the possibility of the battery being overcharged (see UL standard for diode use).

• The batteries must be inserted into the equipment with the correct polarity (+ and -).

• Do not attempt to revive used batteries by heating, charging or other means.

• Do not dispose of batteries in fire. Do not dismantle batteries.

• Replace all batteries of a set at the same time. Newly purchased batteries should not be mixed with partially exhausted ones. Batteries of different electrochemical systems, grades or brands should not be mixed. Failure to observe these precautions may result in some batteries in a set being driven beyond their normal exhaustion point and thus increase the possibility of leakage.

• Do not short circuit batteries.

• Avoid directly soldering to batteries.

• Do not expose batteries to high temperatures, moisture or direct sunlight.

• When discarding batteries with solder tags, insulate the tags by wrapping them with insulating tape.

• Improper welding can damage the internal components of batteries and impair their performance.

• Do not place batteries on a conductive surface (anti-static work mat, packaging bag or form trays) as it can cause the battery to short.

• Do not carry or store the batteries together with necklaces, hairpins, or other metal objects.

• Do not pierce the battery with nails, strike the battery with a hammer, step on the battery, or otherwise subject it to strong impacts or shocks.

Acknowledgement

Professor William Mcshane, PhD, PE
Dave Wigley
John Cronin
Polytechnic University