Micro-Hovering Air Vehicle

Submitted to Dr. Paul Oh of Mechanical Engineering & Mechanics and the Senior Design
Project Committee of the ECE & MEM Department

Drexel University

Team: ECE-24, MEM-23

Name (Printed)	Department	Drexel ID	Signature
Justin Gallagher	MEM	10111465	
Michael Joyce	MEM	10110743	
Elan Kazam	MEM	10112678	
Long Huynh	ECE	10112432	
Teng Myauo	ECE	10111448	

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Abstract

When emergency situations arise, such as the events on 9/11,visual information needs to be gathered and assessed as quickly as possible so that rescue workers and emergency personnel can get the situation under control and save the lives of people in danger. Often in these situations human beings cannot safely obtain this information and have therefore typically relied on land based robots with wireless cameras to relay pertinent information. However these robots are limited by their inability to maneuver over large obstacles or climb up stairs. Our work consists of designing an aerial robot that can rise up and hover while transmitting streaming video to an operator who is controlling the height of its elevation. This robot will most likely consist of two counter-rotating propellers (to eliminate angular moment) surrounded by a protective shroud (nacelle), outfitted with self-adjusting baffles under the airflow of the propellers. The shroud will protect both the robot and the environment (i.e. civilians, animal life) and will also house the wireless camera, power supply, and sensor suite used to control the baffles, which in turn maintain the stability of the craft. Important tasks include evaluating propeller motor combinations that best optimize our thrust to weight ratios, designing the nacelle, and programming the PIC 16F84 micro controller to adjust the anti-pitch baffles.

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I. Introduction

Situational awareness is important in both military and civilian tasks and often demands acquiring visual information. Examples include surveillance, border patrol, and search-and-rescue where video or images, like aerial photos, are used to assess and identify things like hazards, damages, survivors and structural integrity. While conventional unmanned aerial and ground vehicles are useful for acquiring situational awareness in open, clear and uncluttered spaces, they are ill suited for near-Earth environments like forests, inside buildings and tunnels or caves. Conventional unmanned aircraft are too large or cannot fly safely in such environments. Ground vehicles are often ineffective in cluttered and rugged terrain; search-and-rescue missions using ground robots at the World Trade Center often failed because they couldn't maneuver past large rock piles.

A. Problem Background

Recently robots and teleoperated platforms have been deployed in areas that may be too dangerous for people. Missions in structurally damaged infrastructures like those pictured to the right can be potentially fatal. Such damage, a result of natural disasters, fire, or terrorism, often poses enormous problems for first responders. In the Mexico City earthquake of Sept. 1985 (*Figure 1*), 135 rescuers died. Also scores of fire fighters and policemen died, were injured or suffered respiratory problems in World Trade Center rescue efforts (Orfinger).

Figure 1: Mexico City Earthquake

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Tasks, like image acquisition, can be performed using robots without risking human life. The robot pictured in the right is equipped with a wireless video camera (*Figure 2*). It can maneuver over rock piles and capture photos. The photos can help structural engineers assess building integrity or enable rescue workers to locate victims.

Figure 2: Ground Surveillance Vehicle

While such ground robots are promising, they often are slow or fail to maneuver over stairs and large rock piles. Aerial platforms like model helicopters do not have such problems and can potentially fly in and around buildings or through tunnels, caves and mineshafts, and hover to acquire image data. Given this advantage, various rotorcrafts have been transformed into robots with sensor and embedded control retrofits. These include model helicopters (left), ducted fans (middle) and contra-rotating craft (right) shown in *Figure 3*.

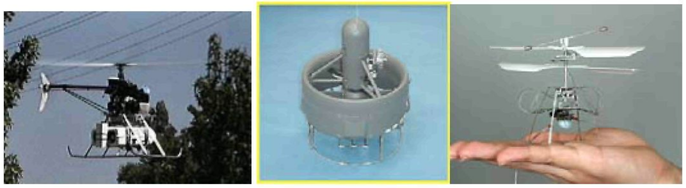

Figure3: Various Robotic Rotorcraft

To be an asset to the soldier or civilian rescue worker, the vehicle should be easy to operate, flies safely and slowly, is backpackable, can hover and wirelessly transmit video or photos. Lighter-than-air vehicles like blimps have potential but often are too voluminous to fly in buildings and are very sensitive to gust. Current fixed and flapping wing vehicles cannot hover. This leaves rotating wings as the only modalities to fly but rotorcraft have issues. They are difficult to operate and their spinning rotors are dangerous. As such, any design effort must be in eliminating these issues.

B. Problem Statement

The figure on the right is a concept drawing for hover-and-stare (*Figure 4*). Here, the vehicle would hover 10 feet and wirelessly transmit video. This height is the standard separation between two floors. This would enable the responder to view the situation at least one floor above without the need to climb stairs. Stairs in structurally damaged buildings are often very dangerous to climb. *The problem statement* is to design, construct and demonstrate a vehicle that:

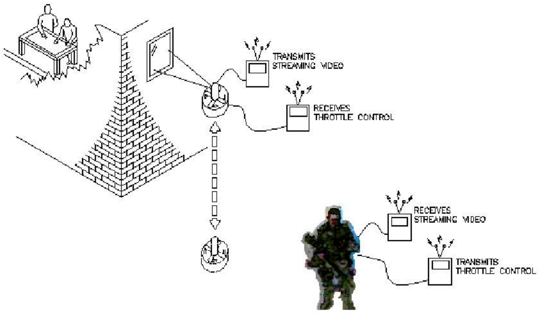

Figure 4: Concept Drawing of Hover-and-Stare

- ♦ Can hover-and-stare
- ♦ Is backpackable
- ♦ Can be flown by an operator with less than 2 hours of training
- ♦ Flies safely and slowly

C. Constraints on the Solutions

The problem statement at hand has challenging constraints but can be addressed by the team. First, constructing a hovering vehicle demands skills in aerodynamic design. Team members **Elan Kazam** and **Justin Gallagher** have excelled in fundamental fluid mechanics and dynamics courses. They are currently taking studying aerodynamics under **Prof. Ajmal Yousuff**, who has agreed to provide design assistance as needed. Second, designing a proper propulsion system for the vehicle demands expertise in sizing motors, specifying power sources and selecting propellers. Team members **Long Huynh** and **Teng Myauo** are electrical engineering majors who have studied and designed circuits involving electric motors. Team member **Michael Joyce** has several years of experience working with many different small gas engines and motors. He also worked with electric ducted fans while doing a co-op at Unisys. Additionally, one team member's grandfather has been an airplane hobbyist for over 50 years and can be tapped to help select small gas engines.

Third, vehicle stability demands designing control systems, selecting and interfacing sensors and programming embedded microprocessors. Long Huynh and Teng Myauo have been trained at Drexel and are well versed in designing and simulating controllers in Matlab. Prof. Paul Oh (team advisor) has been giving the team hands-on training working with embedded devices and sensors. Long Huynh and Teng Myauo have recently built and tested an accelerometer sensor suite interfaced to an 8-bit microcontroller (see *Figure 5*). Such a suite is envisioned to provide state data needed to stabilize the vehicle. Fourth, building the vehicle will demand both manufacturing resources and machining skills. The Drexel machine shops in the Hess Building provide the necessary tools. The PRISM Robotics Lab in the mechanical engineering department has the tools to construct electronic circuits and program devices. Elan, Justin and Michael have the machining and circuit construction skills to fabricate the vehicle.

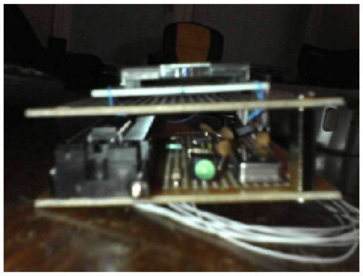

Figure5: Accelerometer Sensor Suite

The net effect is while the constraints may be challenging, the team has the skill and resources to overcome them. Drexel provides an ideal place to attack the stated problem given its access to knowledgeable faculty, computer facilities, as well as work and lab spaces. Lastly, Prof. Oh has graciously provided some discretionary funds to purchase materials as needed.

II. Statement of Work

Our specific aims are to create a vehicle that can hover–and-stare at a height of 10 feet. The craft must less then 9 inches in diameter so that it can be backpackable. The system must be stable and safe enough that an operator can learn to fly it with less then 2 hours of training. In order to achieve these goals we must do the following:

1. Formulate vehicle aerodynamics

The fundamental equations of motion for rotorcraft capable of carrying a 0.5-pound payload will be derived. The dynamics of helicopters and contra-rotating and ducted fan vehicles will be compared. Matlab simulations to highlight the effect design parameters have on performance will be performed.

2. Optimize motor, battery and propeller configurations

Using test rigs designed and built by our team we will evaluate the thrust to weight ratio of all possible combinations of the motors, batteries and propellers we have purchased. From this data we will determine what combination(s) are most efficient and will satisfy our requirements.

3. Research and design a control system
In order for the vehicle to hover-and-stare it will require a control system that will enable it to maintain a stable position in the air autonomously. This systems needs to be able to maintain a stable enough position such that useful pictures can be obtained by the camera.

4. Develop Safety Shroud (nacelle)
Because this vehicle is will need to operate in close quarters it needs to be safe to operate in the presence of people and obstacles. This means that a shroud must cover its propeller(s) such that there is no blade exposure that could cause injury to a person. This same shroud will also protect vehicles blades and vulnerable parts in the event of a collision.

A. Alternative Solutions

Currently there are several alternatives that address some of the issues that our problem statement faces. The first alternative is the *gas powered helicopter*, pictured to the right (*Figure 6*), which typically measure from around 3-5 feet in length. The advantages to this setup are high thrust and extreme stability, which is achieved with a gas engine and rudder, respectively. The blades and rudder have variable pitches to counter act disturbances during regular flight. The disadvantages are the use of gas engine, size of vehicle and the learning curve. Gas engines have large amounts of thrust; however the gas fuel only powers the engine and no other electrical components. In addition gas engines require maintenance due to their sensitivity to weather conditions which require carburetor and performance adjustments. These engines also produce high amounts of heat, noise and exhaust. These ailments could burn electrical components, hinder stealth operations and render camera images cloudy. The sizes of the propellers are too big for backpackable situations and are also exposed making them dangerous. The training time to learn to operate gas helicopters takes years of flying experience as well as computer simulations.


Figure 6: Gas Powered Helicopter

Smaller alternatives are aircrafts such as the *Vectron Black Hawk*, which uses a series of small motors and propellers to achieve hover (*Figure 7*). This aircraft is small in size and quiet; however it doesn't produce much thrust and rotates due to angular momentum, which causes instability. The advantage to using a multi-motor configuration is that the voltage supplied to each motor is varied in order to stabilize the vehicle. The Vectron Black hawk is 13 inches in diameter and uses a tethered controller to vary the thrust applied. The stability of the Black Hawk is controlled using a joystick that emits infrared light to control the voltage


Figure 7: Black Hawk

supplied to each of the motors, making distant or non-level flight hard to control. Also these motors are not pitched alternatively causing angular momentum to spin the vehicle.

Figure 8: Ultra-Light

The third alternative is the *Vectron Ultra-Light*, which uses a single propeller and infrared light emission to achieve flight (*Figure 8*). This vehicle is very small in size, safe and utilizes its own angular momentum, however is does not produce much thrust. The Vectron Ultra-Light is 9 inches in diameter and uses pitch blades on the body to produce more thrust. The primary blade is encompassed by the outer duct, minimizing injury if human interaction occurred. Again the Vectron fails to produce enough thrust to be able to maintain any additional payload and is limited to the range of the infrared light emission.

Figure 9: Coaxial Setup

The last alternative is the Air Scoot, which uses a coaxial motor propeller setup and RC control to achieve hover (*Figure 9*). This vehicle utilizes the two propellers to counteract the angular momentum, and variable pitch to stabilize flight. The advantages of this vehicle are the additional thrust produced by the coaxial propellers and variable pitching for stabilization. The Air Scoot has excellent range because it will allow the operator to control from a distance via remote control. The disadvantages are that the propeller diameter exceeds our requirement by three times the size that would allow the system to be backpackable. In regards to safety, the propellers are exposed, making humans susceptible to injury as well as damage to the vehicle itself.

B. Method of Solution

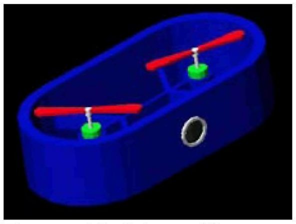

Figure 10: Micro-Hovering Air Vehicle

None of the alternatives described in the preceding section completely solve the problem statement. We propose to create a Micro-Hovering Air Vehicle, shown to the right (*Figure 10*), which will hover from aided human lift to a desired height and wirelessly transmit streaming video.

Nacelle

This will be comprised of a nacelle measuring approximately 9 inches in diameter. This nacelle will be made of a lightweight plastic. It will serve to both protect the blades from damage during a collision and to protect people from injuries due to the blades.

Propulsion

The propulsion system is comprised of two motors, two propellers and a power source. The dual motors will counter each other's rotation such that the vehicle does not spin because of angular momentum in one direction. The propulsion system must have enough power to lift its own components, i.e. the motor, battery and propeller/ducted fan as well as our auxiliary components and a half-pound payload. This is not easily achieved due to the fact that we have a very limited area for wing span/propeller. The challenge to this problem is the fact that its optimization involves multiple variables that all depend on each other, thus there is no clear method of optimization. Approximate lift can be calculated using simple Bernoulli equations such as $\frac{1}{2}\rho V^2 A$, where ρ is the density of air and V is the velocity of air and A is the approximate area of the duct (Munson pg.108). The velocity of air can be calculated by multiplying the rpm of the propeller, which is measured with a tachometer, by the known pitch of the blades. Our motors will run off lithium polymer power cells due to their light weight and ability to dissipate power at 8 times their charge rate

Control System

Our stabilization will be an intricate setup of sensors, a microcontroller, servo motors and ducts or baffles. The sensor included on the hovering vehicle will be an accelerometer to measure the pitch at which the craft is angling to during flight. The microchip will process this data from the accelerometer onboard and direct the servo motors to move accordingly to stabilize flight. In the design of the Micro-Hovering Aerial Vehicle we desire a microcontroller that is capable of controlling our mechanical solution for stability, servomotors, and the Pulse Width Modulated (PWM) DC motor applications. The design requires a microcontroller to have the memory capacity to hold enough program memory to handle the aforementioned applications. Another criterion is that the chosen microcontroller must be fast enough to handle the aerodynamic perturbations that the vehicle shall be faced with. The microcontroller must have the capability to handle fast clock speeds so it would be able to analyze on the spot readings and compute in a matter of microseconds. The servo motors will be linked up to the ducts/baffles so that the wind velocity displaced by the propeller can be channeled such that the pitching moment becomes zero and stabilization is achieved. Transmitters will be used to control all of the vehicle's operations and an onboard receiver will be implemented.

Video Transmission

The interface for our video transmission will be connected using a personal computer. We will use a micro camera that is lightweight and readily available on the market today. Existing software will be implemented to view the video wirelessly from our vehicle. A wireless receiver and transmitter will be used in order to send and receive the video from the vehicle to the computer.

C. Feasibility

The feasibility research for our project is concentrated into two main areas. The first area of concentration is the propulsion system. We need to determine whether or not it is possible to achieve enough thrust with a propeller(s) diameter less than 9 inches to lift a motor, battery, necessary components and our half pound payload. A

Component	Weight (kg)	#	Total (kg)
Motor	0.085	2	0.17
Batteries	0.035	1	0.035
Controller	0.029	1	0.029
Nacell	0.04	1	0.04
Camera	0.015	1	0.015
Servos	0.007	2	0.014
Misc	0.029	1	0.029
Total			0.332
Weight (N)	**9.81**	**0.332**	**3.25692**

Table 1: Example for Sum of Weight

rough estimate yielded the following results:

The table above (*Table 1*) illustrates one example of how to sum up the weight of the vehicle, this particular table assumes the use of two motors, i.e. the KM280s. These motors are capable of rotating at roughly 15000 rpm with a 4"x 2" propeller. Using this rpm we estimated the thrust using the following equation: $\frac{1}{2}\rho V^2 A$ in this case ρ is 1.21 kg/m^3 and V is 12.7, were V=rps*pitch and A (m^2) is the exit area of the air, roughly twice the area of the propeller. Our calculated thrust comes out to be roughly 6 newtons meaning a thrust to weight ratio of 1.8:1, thus this configuration should be able to lift it self.

Another aspect in analyzing the feasibility of the design project is based upon previous design examples, which deal with the stability of hovering vehicles. Defining equations of flight as well as studying control systems will be needed. In using simulation tools such as MICROCONTROLLER and SIMULINK, we will be able to develop a program in MICROCONTROLLER and/or construct the system architecture in SIMULINK to model flight with the system equations (Balderud). In studying and understanding previous models we can further develop simulations more specific to our design to help better understand the stability issues at hand. This simulation can then show the user that hover is viable within our design specifications.

D. Analysis, Testing & Validation

Analyzing the data from *Table 2* in Appendix A, *Table 3* in Appendix A was developed for the ease of decision making. From *Table 2*, the best fit microcontroller for our proposed project would be the Peripheral Interface Controller (PIC)16F84 (PIC pin diagram and block diagram shown in Appendix A, *Figures 11 & 12* respectively). As seen from *Table 2*, the features of the PIC are sufficient for our proposed design criteria stated previously (Section II Subsection B).

The PICMicros are one of the most efficient microcontrollers in terms of operation speed/instruction per clock cycle of all the research devices listed in *Table 2*. Options such as Electronically Erasable Programmable Read Only Memory (EEPROM) program store, directly controlled Liquid Crystal Display (LCDs), interrupt capability, and maximum program size of 8K allowing for complex applications (microcup.com) outlines the PICs wide range of control. Since our design shall need to have as much programming memory as needed for control functionality such as PWM DC motor control, powering the servos, integrated with the accelerometer, etc. we research the PIC to be the best fit microcontroller to our desired control tasks that does not exceed our specifications. This being important since the surplus of options being wasted would not justify the extra cost per chip.

Although the Intel 80C31, Motorola 68HC05Cx, and Atmel AVR all have more control storage capability and Random Access Memory (RAM), but cost more and run at slower speeds than the PIC16F84. The BASIC Stamp was ruled out of our decision process after all the data was compiled because it was obvious that the BASIC was sub-par compared to the four other microcontrollers listed. The BASIC is the most expensive, slowest, and has the smallest memory capacity. In analyzing the data the two microcontrollers that stood out were the

PIC16F84 and the Atmel AVR because they both have more than enough capability to perform all the functions and operations specified for our project (Predko, 790). The deciding factor in choosing the PIC16F84 was the learning curve criteria. Since the PIC16F84 is the most widely used microcontroller, there are many resources readily available to help guide and facilitate the overall process, including tutorials from Dr. Oh and his current research students. Based on the analysis of all the listed microcontrollers, the PIC16F84 will best suit our needs and be fully capable of performing our desired tasks at a low cost of $5.95/chip.

To ensure that our proposed design will work successfully, several analyses and testing will be accomplished and backed with analytical data proving or disproving accuracy of assumptions. One test rig shall be built to evaluate the thrust of the motor/propeller configuration in order to verify the thrust to weight ratio is greater than 1 ensuring proper lift conditions (see *Figure 13* in Appendix B). Another test rig shall test response time and sensitivity to the controller implementation (see *Figure 14* in Appendix B). A final test rig shall be developed to test and verify the speed controller's functionality, the integrated speed controller shall be able to regulate the signal to the motor to perform hover-and-stare (see *Figure 15* in Appendix B).

After the system has been successfully tested and passes the test rigs' verification, stand alone flight tests shall be performed to verify that the device shall be able to hover, as well as perform successful hover-and-stare while being stabilized to take streaming video. These tests shall also test the integrity of the wireless signal transmission from the camera to the PC. Once these tests have been repeatedly verified, student volunteers as well as Drexel security guards shall be polled to train in the flight of the system. After tutorials have been given, they shall demonstrate the operations of the Micro-Hovering Aerial Vehicle and evaluate the ease of use through written testimonials.

Other tests shall also be performed to test the safety of such a vehicle, safety to others as well as protection to outside variables. One test shall demonstrate that the shroud allows protection to the person from the rotary blade by taking video of person(s) brushing along the vehicle and showing no ill effect to the person. This partly also demonstrates the protection to internal propulsion mechanisms.

III. Project Management Timeline

Time management is an important issue concerning our design. Since the project span is less than 9 months in duration we need to productively manage our work and resources. *Tables 4, 5, & 6* in Appendix C display the Gantt Chart concerning time management in this design project for the Fall, Winter, & Spring terms respectively.

Our design team is constituted of five (5) engineering students, three (3) of which are studying Mechanical Engineering while the other two (2) study Electrical Engineering. *Table 7* in Appendix C depicts current work/study concerning the design of the Micro-Hovering Aerial Vehicle. Since Mike is well versed in motor and propeller/ducted fan research and analysis, he has spent the majority of his time researching flight parts (i.e. motor and propeller/configurations) as well as the feasibility research concerning previously engineered rotary aircrafts. Justin and Elan have experience in design and manufacturing and have worked on test rig design/development along with Mike. Justin has also used his time to research previously designed rotary aircrafts.

Teng, being well versed with control systems along with such tools as Matlab and SIMULINK, has used his time to research previously designed rotary aircrafts they the system of equations describing their motion. Along with this research he has also developed simulations emulating rotary aircrafts as well as integrating controllers for stabilization. Long, having familiarized himself with microcontrollers, through course work and research, has begun tutorials concern the programming of the PIC. Teng and Long, ECE, have ample experience in circuit analysis/design/development and Teng has mil-spec-2000 certification for soldering. This allows them to also concentrate their time in constructing evaluation circuit boards for the PIC as well as sensors, such as the accelerometer.

IV. Economic Analysis

Through research of different design approaches, a preliminary budget report has been generated for the design and manufacturing of the Micro-Hovering Air Vehicle in regards to our proposed design approach. The complete budget is a culmination of three (3) separate budgets: Prototyping Budget, Personnel Budget, and Services Budget. The pie chart shown to the right (*Figure 16*) displays the budgeting breakdown for the total costs incurred in the design, testing and fabrication of the project. The Prototyping (Part 1 and 2), Personnel, Services and Complete Budget are shown in *Tables 8, 9, 10, 11, & 12* respectively in Appendix D.

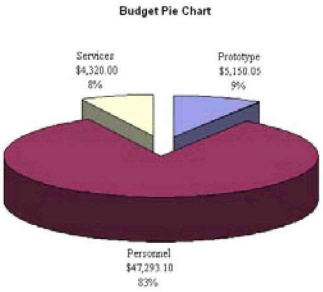

Figure 16: Budget Pie Chart

V. Societal and Environmental Impact Analysis

The design of the Micro-Controlled Aerial Robots shall be beneficial in many marketable platforms, which may have various sociological impacts. In the arena of assisting search and rescue efforts, the system designed may be used to locate victims involved in accidents, in the event investigation is too dangerous for EMS. The device shall not only be limited to the location of victims but it shall also be able to carry a designated payload, which shall be able to transport medical supplies to those victims. In the case of industrial use, the device shall be able to survey and take relevant data of situational awareness. For example, the device may be used in coalmine surveillance for unstable mine digs or evaluate the air quality in the cavernous regions.

In the development of such a vehicle, there exists human-machine interaction. These vehicles being designed are non-autonomous. Human controlled architecture is an integral aspect of the efficient functionality of such a vehicle. This shall require human operators to be properly trained to use such a complex device. Specifically, first response personnel (i.e. EMT, firefighters, and policemen) would be affected immediately and a working relationship would be consequential in the progress of the aerial vehicle.

Another aspect is educational training, which would be the study of the complex device. The complex device is a non-linear system which will require an educational structure for students to further research non-linear and control systems associated with the development of such a device. This will require the knowledge of higher order systems, controllability, system integration and various manufacturing processes. All which can be taught by appropriate Drexel faculty or assisted by current undergraduate or graduate students with the appropriate background.

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Appendix A: PIC Tables

Controller / Criteria	PIC 16F84	INTEL 80C31 (8051 Family)	Motorola 68HC05Cx	ATMEL AVR	PARALLAX BASIC STAMP
Programming Language	Assembly C, C++, PICBasic, Drop N Burn	Assembly C, C	Assembly C, C++	C Compiler	PBasic
Control Store	1024 Words of Program Memory, 64 bytes of Data EEPROM	4 KB of Control Store	0-16 KB of Control Store	4 KB of Control Store	256 Bytes
Speed Range	0-20 MHz	0.5-12 MHz	0-4 MHz	0-16 MHz	4 MHz
Cost	$5.95	9.25	$7.09	$8.42	$16.53
I/O Pins	13	14	18-29	32	8
RAM	68	128	256	544	12
Timers/Interrupts	TMR0 - Timer Overflow, Interrupt on Change	Two 8/16 bit timers: Multiple Internal-external Inturrupt Source	16 bit Timer: Internal Interrupt	Three 8 bit Timers: Internal Interrupt Source	Timer: No Interrupts
Flash	Enhanced Flash Program Memory	None	None	Flash Program Memory	None
Learning Curve	Short	Medium	Long	Medium	Short
Additional Features	In Circuit Signal Programming, Watchdog Timer, Code Protection, WM	Serial I/O, External Memory Interface	Serial I/O, PWM	In System Programming, Serial I/O, External Memory Interface	In System Programming, Serial I/O

Table 2: Microcontroller Specification Comparison Chart

Criteria \ Controller	PIC 16F84	INTEL 80C31 (8051 Family)	Motorola 68HC05Cx	ATMEL AVR	PARALLAX BASIC STAMP
Ease of Programming	3	2	2	4	6
Control Store	5	2	4	6	1
Speed Range	6	2	1	3	1
Cost	6	4	4	4	1
I/O Pins	5	5	6	3	4
RAM	3	4	5	6	2
Timers/Interrupts	4	1	3	6	2
Flash	6	1	2	5	1
Learning Curve	6	2	2	3	3
Additional Features	2	2	4	3	2
Total:	**46**	**25**	**33**	**43**	**23**

6 = Most Desirable, 1 = Least Desirable

Table 3: Microcontroller Decision Matrix

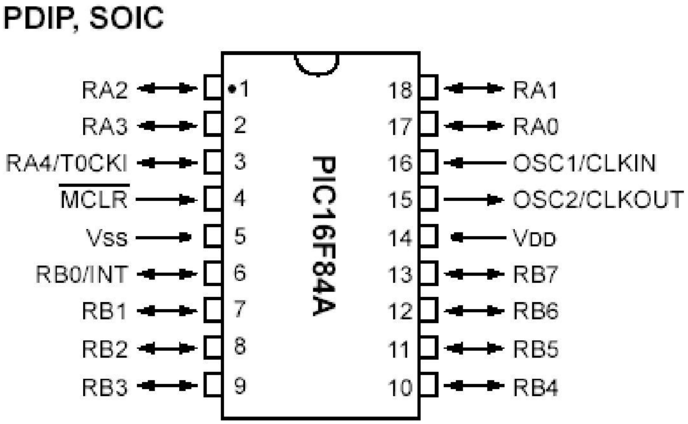


Figure 11: Pin Diagram of PIC16F84

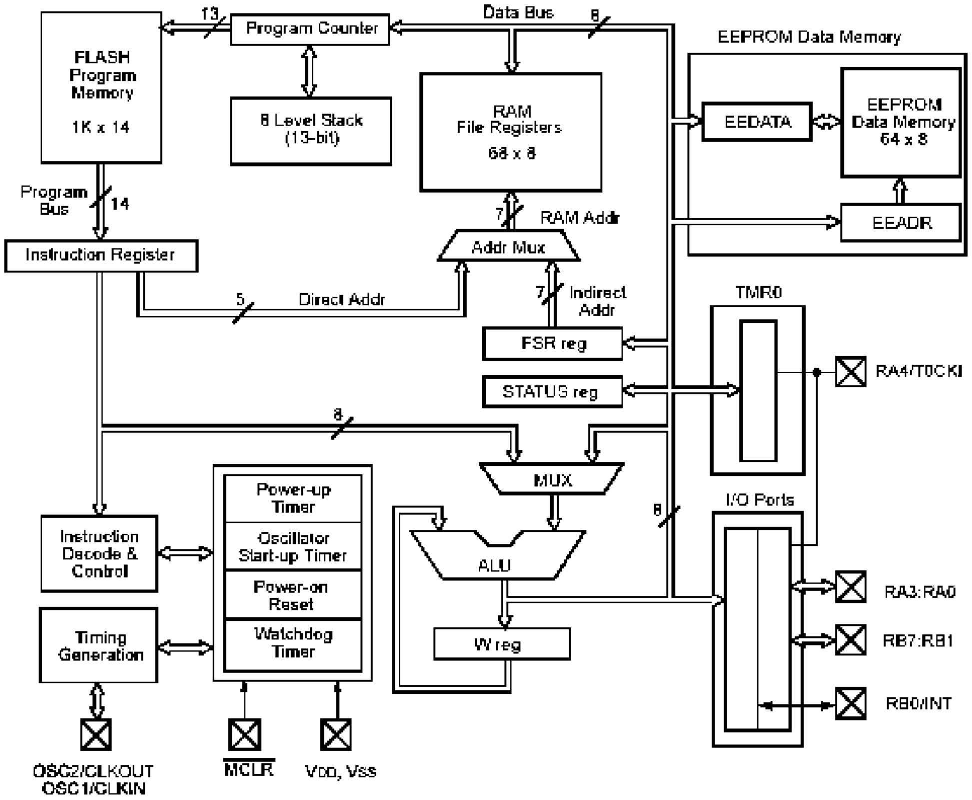


Figure 12: Block Diagram of PIC16F84

Appendix B: Testing Rigs

Figure 13: Thrust Calculation Experiment

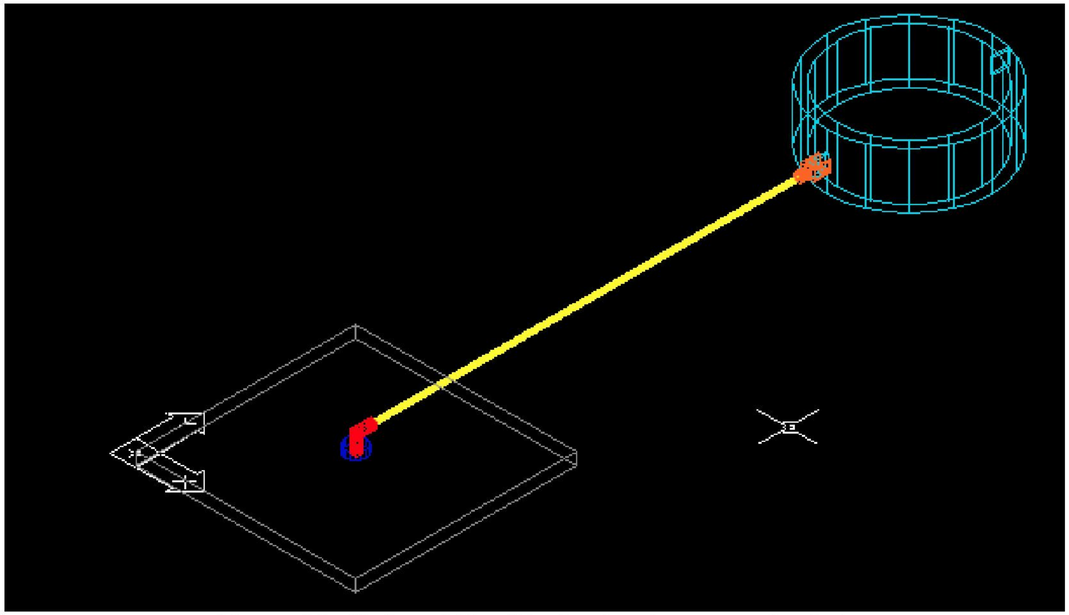


Figure 14: Tethered Test Rig for Accelerometer Analysis

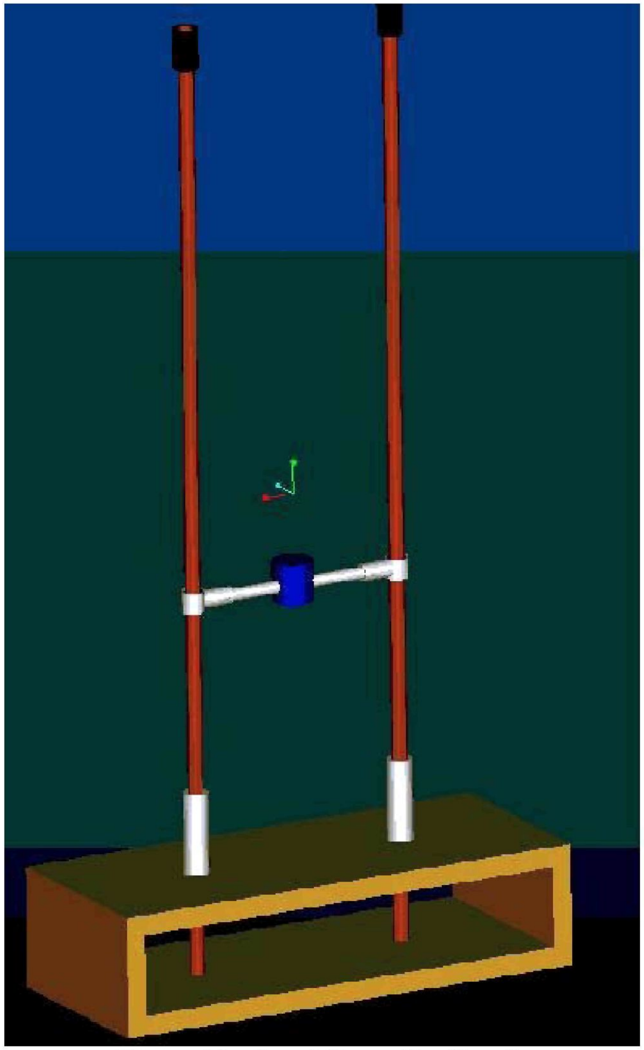
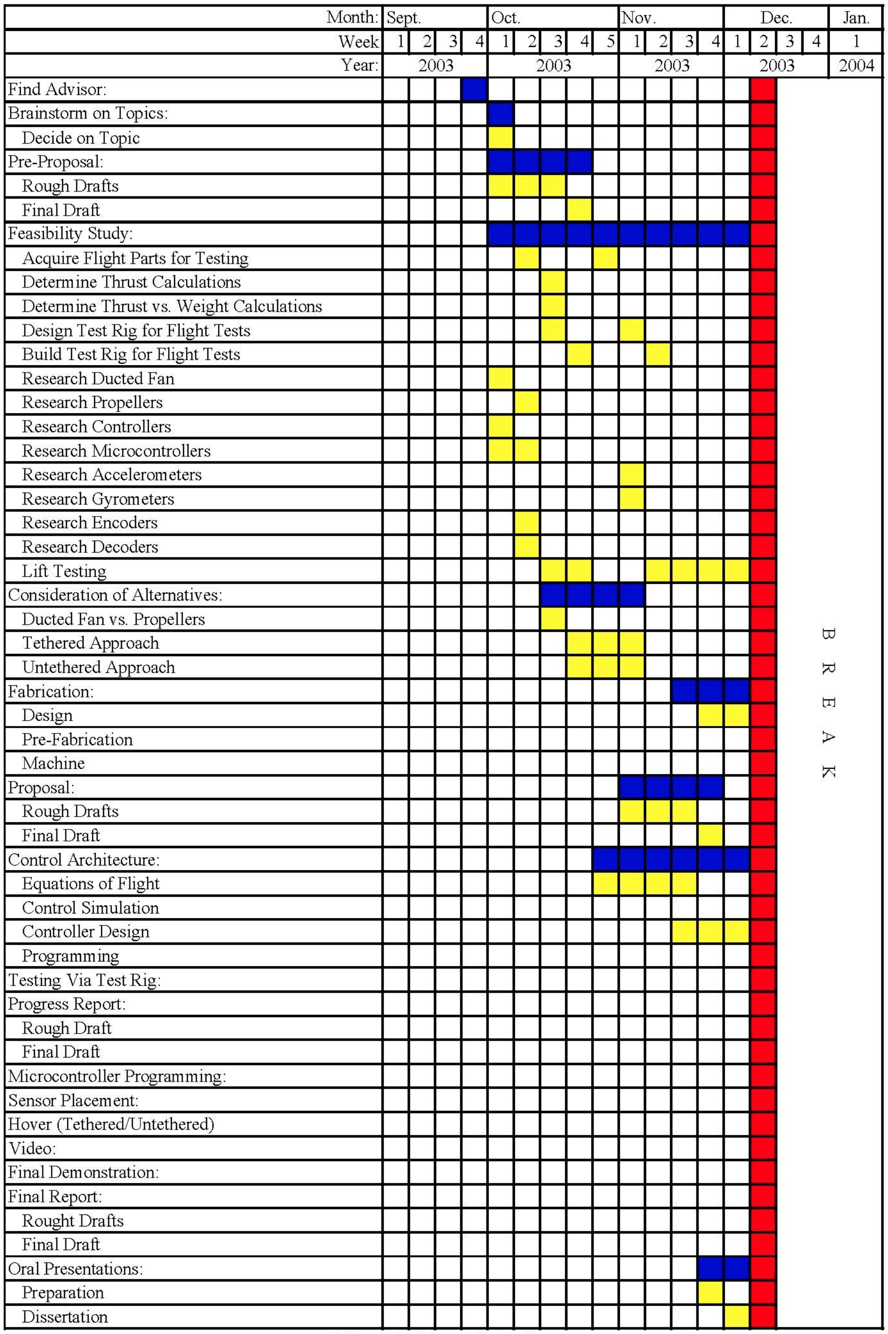


Figure 15: Speed Controller Test Rig

Appendix C: Project Management (Gantt Chart)



Month:	Sept.				Oct.					Nov.				Dec.				Jan.
Week	1	2	3	4	1	2	3	4	5	1	2	3	4	1	2	3	4	1
Year:	2003				2003					2003				2003				2004
Find Advisor:				🟦											🟥	BREAK		
Brainstorm on Topics:					🟦										🟥			
Decide on Topic					🟨										🟥			
Pre-Proposal:					🟦	🟦	🟦	🟦							🟥			
Rough Drafts					🟨	🟨	🟨								🟥			
Final Draft								🟨							🟥			
Feasibility Study:					🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟥			
Acquire Flight Parts for Testing						🟨			🟨						🟥			
Determine Thrust Calculations							🟨								🟥			
Determine Thrust vs. Weight Calculations							🟨								🟥			
Design Test Rig for Flight Tests							🟨			🟨					🟥			
Build Test Rig for Flight Tests								🟨			🟨				🟥			
Research Ducted Fan					🟨										🟥			
Research Propellers						🟨									🟥			
Research Controllers					🟨										🟥			
Research Microcontrollers					🟨	🟨									🟥			
Research Accelerometers										🟨					🟥			
Research Gyrometers										🟨					🟥			
Research Encoders						🟨									🟥			
Research Decoders						🟨									🟥			
Lift Testing							🟨	🟨			🟨	🟨	🟨	🟨	🟥			
Consideration of Alternatives:							🟦	🟦	🟦	🟦					🟥			
Ducted Fan vs. Propellers							🟨								🟥			
Tethered Approach								🟨	🟨	🟨					🟥			
Untethered Approach								🟨	🟨	🟨					🟥			
Fabrication:												🟦	🟦	🟦	🟥			
Design													🟨	🟨	🟥			
Pre-Fabrication															🟥			
Machine															🟥			
Proposal:										🟦	🟦	🟦	🟦		🟥			
Rough Drafts										🟨	🟨	🟨			🟥			
Final Draft													🟨		🟥			
Control Architecture:									🟦	🟦	🟦	🟦	🟦	🟦	🟥			
Equations of Flight									🟨	🟨	🟨	🟨			🟥			
Control Simulation															🟥			
Controller Design												🟨	🟨	🟨	🟥			
Programming															🟥			
Testing Via Test Rig:															🟥			
Progress Report:															🟥			
Rough Draft															🟥			
Final Draft															🟥			
Microcontroller Programming:															🟥			
Sensor Placement:															🟥			
Hover (Tethered/Untethered)															🟥			
Video:															🟥			
Final Demonstration:															🟥			
Final Report:															🟥			
Rought Drafts															🟥			
Final Draft															🟥			
Oral Presentations:													🟦	🟦	🟥			
Preparation													🟨		🟥			
Dissertation														🟨	🟥			

Table 4: Fall Term Gantt Chart

Month:	Jan			Feb.				Mar.				
Week	2	3	4	1	2	3	4	1	2	3	4	5
Year:	2004			2004				2004				
Find Advisor:											🟥	
Brainstorm on Topics:											🟥	
Decide on Topic											🟥	
Pre-Proposal:											🟥	
Rough Drafts											🟥	
Final Draft											🟥	
Feasibility Study:											🟥	
Acquire Flight Parts for Testing											🟥	
Determine Thrust Calculations											🟥	
Determine Thrust vs. Weight Calculations											🟥	
Design Test Rig for Flight Tests											🟥	
Build Test Rig for Flight Tests											🟥	
Research Ducted Fan											🟥	
Research Propellers											🟥	
Research Controllers											🟥	
Research Microcontrollers											🟥	
Research Accelerometers											🟥	
Research Gyrometers											🟥	
Research Encoders											🟥	
Research Decoders											🟥	
Lift Testing											🟥	
Consideration of Alternatives:											🟥	
Ducted Fan vs. Propellers											🟥	
Tethered Approach											🟥	BREAK
Untethered Approach											🟥	
Fabrication:	🟦	🟦	🟦	🟦	🟦	🟦	🟦				🟥	
Design	🟨	🟨									🟥	
Pre-Fabrication			🟨	🟨	🟨	🟨	🟨				🟥	
Machine											🟥	
Proposal:											🟥	
Rough Drafts											🟥	
Final Draft											🟥	
Control Architecture:	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟥	
Equations of Flight											🟥	
Control Simulation		🟨	🟨	🟨	🟨						🟥	
Controller Design						🟨	🟨	🟨			🟥	
Programming	🟨	🟨	🟨	🟨	🟨				🟨	🟨	🟥	
Testing Via Test Rig:							🟦	🟦	🟦	🟦	🟥	
Progress Report:			🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟥	
Rough Draft			🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟥	
Final Draft										🟨	🟥	
Microcontroller Programming:											🟥	
Sensor Placement:											🟥	
Hover (Tethered/Untethered)											🟥	
Video:											🟥	
Final Demonstration:											🟥	
Final Report:											🟥	
Rought Drafts											🟥	
Final Draft											🟥	
Oral Presentations:									🟦	🟦	🟥	
Preparation									🟨		🟥	
Dissertation										🟨	🟥	

Table 5: Winter Term Gantt Chart

Month:	Apr.					May				June			
Week	1	2	3	4	5	1	2	3	4	1	2	3	4
Year:	2004					2004				2004			
Find Advisor:											🟥		
Brainstorm on Topics:											🟥		
Decide on Topic											🟥		
Pre-Proposal:											🟥		
Rough Drafts											🟥		
Final Draft											🟥		
Feasibility Study:											🟥		
Acquire Flight Parts for Testing											🟥		
Determine Thrust Calculations											🟥		
Determine Thrust vs. Weight Calculations											🟥		
Design Test Rig for Flight Tests											🟥		
Build Test Rig for Flight Tests											🟥		
Research Ducted Fan											🟥		
Research Propellers											🟥		
Research Controllers											🟥		
Research Microcontrollers											🟥		
Research Accelerometers											🟥		
Research Gyrometers											🟥		
Research Encoders											🟥		
Research Decoders											🟥		
Lift Testing											🟥		
Consideration of Alternatives:											🟥		
Ducted Fan vs. Propellers											🟥		
Tethered Approach											🟥		
Untethered Approach											🟥		
Fabrication:											🟥		
Design											🟥		
Pre-Fabrication											🟥		
Machine											🟥		
Proposal:											🟥		
Rough Drafts											🟥		
Final Draft											🟥		
Control Architecture:											🟥		
Equations of Flight											🟥		
Control Simulation											🟥		
Controller Design											🟥		
Programming											🟥		
Testing Via Test Rig:											🟥		
Progress Report:											🟥		
Rough Draft											🟥		
Final Draft											🟥		
Microcontroller Programming:	🟦	🟦									🟥		
Sensor Placement:			🟦								🟥		
Hover (Tethered/Untethered)					🟦	🟦					🟥		
Video:							🟦	🟦			🟥		
Final Demonstration:							🟦	🟦	🟦		🟥		
Final Report:			🟦	🟦	🟦	🟦	🟦	🟦	🟦		🟥		
Rought Drafts			🟨	🟨	🟨	🟨	🟨	🟨			🟥		
Final Draft									🟨		🟥		
Oral Presentations:							🟦	🟦	🟦		🟥		
Preparation							🟨	🟨			🟥		
Dissertation									🟨		🟥		

Table 6: Winter Term Gantt Chart

		Elan	Justin	Long	Mike	Teng
FEASIBILITY STUDY	Research Flight Parts:	1	2	0	10	1
	Research Equation of Lift/Flight:	2	2	1	3	1
	Research Previous Developed Rotary Crafts:	1	3	0	10	2
	Research Micro Controllers:	0	0	9	1	0
	Research Accelorometers:	0	0	3	0	0
	Built Micro Controller Evalution Board:	0	0	3	0	3
	Built Accelerometer Evaluation Board:	0	0	6	0	6
	Reseach Thrust Calculation Experiment:	3	2	0	1	0.25
	Performed Thrust Experiment:	3	2	1.5	2	2
	Test Rig Development:	4.5	6	0.5	5	0
	Research Encoders:	3	4	0	2	0
	Research Manufacturing Processes:	0	2	0	0	0
	Research Transmitters & Recievers:	4	2	0	2	0
Control Architecture	Research Equations of Flight for Rotary Aircrafts:	0	2	0.25	3	2
	Research MoSART:	0	0	0	0	2
	Rotary Aircraft Simulation (MATLAB/SIMULINK):	2	0	1	0	12
	Controller Simulation (MATLAB/SIMULINK):	0	0	0	0	1
	Controller Tutorial:	0	0	5	0	0
	Research of Controller Development:	0	0	2	0	2
	Documentation Write Up(Pre-Proposal, Proposal, Website, etc.:	12	20	10	18	22
	Total:	35.5	47	42.25	57	56.25

NOTE: Numbers listed eqaute to time in hours.

Appendix D: Economic Analysis (Budgets)

Prototyping Budget for Mico-Hovering Air Vehicle				
Category	Expenses	Cost Per Unit	Total Units	Total Cost/Unit
Flight Parts:				
	Ducted Fan Flight Parts:			
	Ducted Fan	$ 74.50	1	$ 74.50
	Lithium-Ion Polymer Battery 2-Cells	$ 38.90	3	$ 116.70
	Battery Charger	$ 99.90	1	$ 99.90
	Electric Motor	$ 33.50	1	$ 33.50
	Speed Controller	$ 47.90	1	$ 47.90
	Propeller Flight Parts:			
	Propeller (Type 1)	$ 8.40	1	$ 8.40
	Propeller (Type 2)	$ 4.00	1	$ 4.00
	Propeller (Type 3)	$ 3.50	1	$ 3.50
	Propeller (Type 4)	$ 2.40	1	$ 2.40
	Propeller (Type 5)	$ 2.40	1	$ 2.40
	Propeller (Type 6)	$ 2.40	1	$ 2.40
	Propeller Adapter (Type 1)	$ 8.90	1	$ 8.90
	Propeller Adapter (Type 2)	$ 8.90	1	$ 8.90
	Propeller Adapter (Type 3)	$ 4.90	1	$ 4.90
	Propeller Adapter (Type 4)	$ 4.90	1	$ 4.90
	Propeller Adapter (Type 5)	$ 4.90	1	$ 4.90
	Motor (Type 1, Very Small)	$ 9.10	1	$ 9.10
	Motor (Type 2, Small)	$ 9.50	1	$ 9.50
	Motor (Type 3, Medium)	$ 38.90	1	$ 38.90
	Shaft Coupler	$ 8.90	1	$ 8.90
	Lithium Poly Connectors	$ 3.25	1	$ 3.25
	Tool Box for Parts	$ 18.99	1	$ 18.99
Nacelle Manufacturing:				
	Materials	$ 50.00	1	$ 50.00
	Fabrication	$ 350.00	1	$ 350.00
Testing Equipment:				
	Single Arm Tethered Test Rig:			
	Wood Base	$ 2.00	1	$ 2.00
	Universal Joints	$ 19.95	1	$ 19.95
	Curtain Rod	$ 1.00	1	$ 1.00
	Ball bearing	$ 5.00	5	$ 25.00
	Clevis Joint	$ 4.50	4	$ 18.00
	Two Pole Tethered Testing Rig:			
	Bushings	$ 11.98	1	$ 11.98
	Bushing Housing	$ 8.16	1	$ 8.16
	Arm Attachments	$ 6.84	1	$ 6.84
	Arms	$ 6.11	1	$ 6.11
	Carriage	$ 2.93	4	$ 11.72
	Mechanical Motion Testing Equipment:			
	Encoders	$ 65.55	1	$ 65.55
	Adapter	$ 350.00	1	$ 350.00
	Cables	$ 7.00	1	$ 7.00
	Splitter	$ 5.00	1	$ 5.00
	Data Acquisition Board	$ 200.00	1	$ 200.00
	Miscellaneous Testing Equipment:			
	Charger	$ 120.00	1	$ 120.00
	Car Battery	$ 60.00	1	$ 60.00

Table 8: Prototyping Budget (Part I/II)

	PC to Run Software	$ 500.00		$ -
	Pro-Engineer	$ 200.00	1	$ 200.00
	LabVIEW	$ 350.00	1	$ 350.00
	Matlab	$ 199.00	1	$ 199.00
	Microsoft Office Suite	$ 99.00	1	$ 99.00
	Visual Studio	$ 200.00	1	$ 200.00
	PicAll	$ 100.00	1	$ 100.00
	Camera Capture Software	$ 100.00	1	$ 100.00
Data Acquisition Tools:				
	Camera	$ 150.00	1	$ 150.00
	PC for Video Capture	$ 500.00		$ -
	Antenna	$ 10.00	1	$ 10.00
			Prototyping Budget Total:	#REF!

Table 9: Prototyping Budget (Part II/II)

Personnel Budget for Mico-Hovering Air Vehicle

Category	Expenses	Cost Per Unit	Total Units	Total Cost/Unit
Initial Design:				
	Control Systems Engineers (2)	$ 30.55	100	$ 3,055.00
	Mechanical Engineers (3)	$ 24.04	150	$ 3,606.00
Prototype Construction:				
	Control Systems Engineers (2)	$ 30.55	100	$ 3,055.00
	Mechanical Engineers (3)	$ 24.04	150	$ 3,606.00
Prototype Testing:				
	Control Systems Engineers (2)	$ 30.55	70	$ 2,138.50
	Mechanical Engineers (3)	$ 24.04	105	$ 2,524.20
Design Iteration:				
	Control Systems Engineers (2)	$ 30.55	30	$ 916.50
	Mechanical Engineers (3)	$ 24.04	45	$ 1,081.80
Prototype Modification:				
	Control Systems Engineers (2)	$ 30.55	180	$ 5,499.00
	Mechanical Engineers (3)	$ 24.04	270	$ 6,490.80
Documentation:				
	Control Systems Engineers (2)	$ 30.55	230	$ 7,026.50
	Mechanical Engineers (3)	$ 24.04	345	$ 8,293.80
			Prototyping Budget Total:	$ 47,293.10

Table 10: Personnel Budget

Services Budget for Mico-Hovering Air Vehicle

Category	Expenses	Cost Per Unit	Total Units	Total Cost/Unit
Consultants:				
	Professor Dr. Paul Oh	$ 48.00	90	$ 4,320.00
	Professor Dr. Ajmal Yousu	$ 48.00	10	$ 480.00
			Prototyping Budget Total:	$ 4,320.00

Table 11: Services Budget

Complete Budget for Mico-Hovering Air Vehicle

Category	Total Cost/Unit
Prototype Budget:	$ 5,150.05
Personnel Budget:	$ 47,293.10
Services Budget:	$ 4,320.00
Total:	$ 56,763.15

Table 12: Complete Budget Report