MVWT 2003

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Contents

1 Introduction

MVWT 2003 has seen much progress toward the construction of twenty-four hovercraft and their surrounding environment. This documentation was written to assist future developers towards completion of the project. This information includes the hovercraft construction procedures and design plans for the roof testbed. In addition, information has been included detailing the different considerations that led to the current design of the hovercraft. It is our hope that this information will make it possible for anyone to make as many of these hovercraft as they might want.

2 Hovercraft

2.1 Design Summary

The hovercraft base is a round $7\frac{1}{2}$" in diameter plastic plate turned upside down, so that the rim of the plate forms a plenum chamber. The pressure rise is provided by a downward thrusting electric ducted fan acting through a two-inch hole near the edge of the plate. Two more electric ducted fans on either side of the lift fan provide thrust for the craft. The on board processing is powered by a 200 MHz Sharp Zaurus, a Linux based handheld computer.

2.2 Specifications and Parameters

Parameter	*Hovercraft value*
Mass	800 g
Moment of intertia	31,603 g cm^2
Distance between thrust fans	17.8 cm
Maximum fan thrust	0.7 N
Cost (without GPS)	$860
Lift Fan Battery lifetime	35-40 minutes

3 Component Construction

3.1 The Plate

The CNC machine referred to is the one in the ME shop, in the subbasement of Spalding. Please ask John or Rodney, the staff, before attempting to use it on your own.

Figure 1: CNC Machine and John

1. Use a sander to grind off the lip on the bottom of the plastic plate.
2. Insert the hovercraft plate fixture into the CNC.
3. Find the center of the fixture. *Note: The center finder is very expensive. John or Rodney should be present for this step.*
4. Fasten the plate to the CNC hovercraft plate fixture by clamping the fixture ring around the lip of the plate.
5. Tool 1: # 28 straight flute drill
   Tool 2: $\frac{1}{4}$" four flute end mill
6. Set tool heights for drill and end mill.
7. Run the program (located in Appendix B).

8. This process may be repeated without any need to reset the center location or drill heights as long as the fixture and the tools are not adjusted.

Figure 2: Plate on CNC Machine

3.2 Lift Fan Holder

1. Use a bandsaw to cut a piece of $\frac{1}{16}$" sheet aluminum into a square $2\frac{1}{4}$" on a side. Use a grinder or file to remove sharp edges.

2. Insert the lift fan holder fixture into the CNC.

3. Find the center of the fixture. *Note: The center finder is very expensive. John or Rodney should be present for this step.*

4. Use fixture clamping arms to clamp the $2\frac{1}{4}$" square aluminum sheet into the fixture.

5. Set up tools in the same manner as when CNCing the plate, being sure to set tool heights.

6. Run the program (located in Appendix B).

7. When the program pauses, bolt the sheet down through the freshly drilled holes.

8. Remove the clamping arms.

9. Hit "start" and the program will continue to completion.

10. This process may be repeated without any need to reset the center location or drill heights as long as the fixture and the tools are not adjusted.

11. Use tin snips to cut through one side of the lift fan holder. This gives it the flexibility to fit around the rim of the fan.

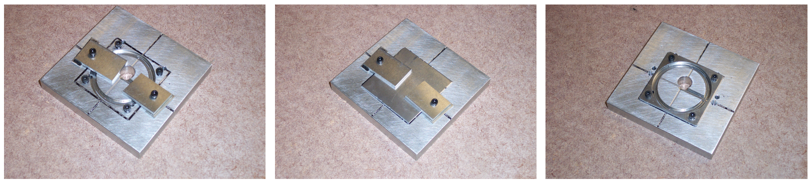

Figure 3: Lift Fan Holder

3.3 U-channel Fan Mounts

1. Use a bandsaw to cut U-channel into sections with a width slightly less than that of the fan.
2. Use a grinder or file to remove any burrs on the PVC.
3. Press U-Channel section against the inner wall of the U-channel Drill Fixture and C-clamp it in place.
4. Drill holes in the U-channel using a hand drill with a #28 drill. Use the hole guides in the U-channel Drill Fixture to drill the holes in the proper locations.

3.4 Elastic Straps

1. Cut a 6” length of elastic strap.
2. Cut a small hole in one end of the elastic strap.

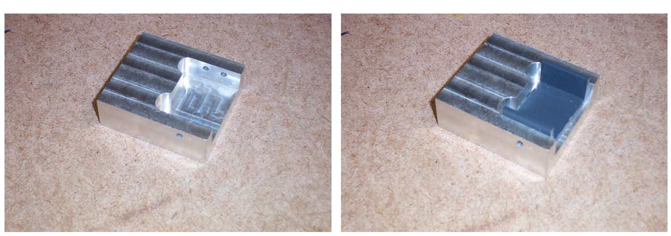

Figure 4: U-Channel Drill Fixture

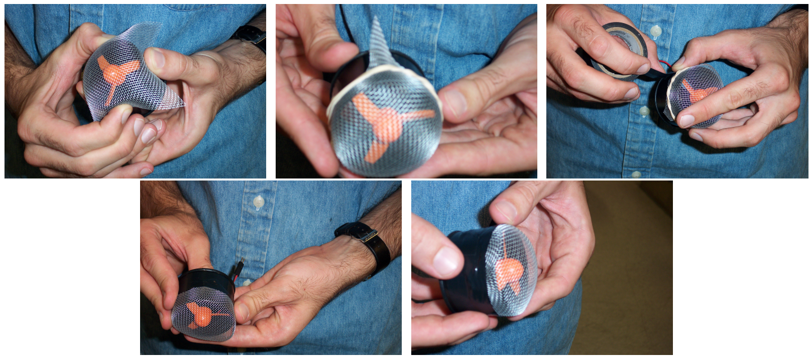

Figure 5: Safety Cage Assembly Process

3. Attach grommet through this hole.

4. Cut two small holes next to each other in the other end of the elastic strap.

3.5 Fan Safety Cages

1. Cut a square of aluminum mesh approximately 4 inches on a side.

2. Pull the four flat sides of the mesh against the side of the fan.

3. Push a rubber band down around the mesh to hold it in place against the fan.

4. Cut off any large sections of aluminum mesh sticking out the other side of the rubber band.

5. What portion of the aluminum remains sticking out should be attached using electrical tape. Once affixed, remove the rubber band and apply more tape to hold the aluminum mesh more firmly.

6. Put safety cages on all the fans: the thrust fans and the lift fan.

3.6 Flexifoam

Foam padding is necessary to protect and cushion certain parts of the hovercraft. Please cut a sheet of flexifoam into the following shapes:

1. A 2.5" x 4" rectangle.

2. A circle approximately 2.5" in diameter with holes aligning with the holes in the lift fan holder.

3.7 Sensor Hat

The hovercraft was designed to be highly compact, cramming all of the essential components onto a small surface. The sensor hat solves this problem by providing an extra mounting surface. It is a $\frac{1}{8}$" plexiglass plate measureing 7" by 9". It attaches to the bolts that hold the elastic for the thrust fans. It should be noted that it relies on the lift battery for a third support location and should not be heavily loaded when the lift battery is not present. There is a clearance hole for a $\frac{1}{4}$-20 bolt at it's center (this allows a standard webcam to be mounted) and an array of clearance holes for $\#4-40$ bolts spaced at $\frac{5}{8}$", providing mounting locations for sonar and IR sensors.

It should be noted that the sensor hat is currently in the earliest stages of prototyping. It appears that the $\frac{5}{8}$" spacing between the #4-40 clearance holes is not quite appropriate for the sonar mounts (although appears as if it will just barely work).

Immediately visible problems are:

1. Blocked Airflow: Future designs should remove more material above the lift fan to improve air flow.

2. Sensor Blocking: When used in conjunction with a vision system hat, it appears that some sensors may be peripherally blocked.

3. Battery Replacement: The sensor hat currently makes it much more difficult to change batteries.

4. Vision System Hat: Currently the spacers between the vision system hat and the sensor hat are simply 4 bolts sticking straight up. Each bolt has 2 nuts tightened down against each other that provide the base of support for the vision system hat. In the future a more permanent riser should be manufactured to more firmly hold the vision system hat in place.

The manufacture of the sensor hat is simple. The CNC code can be found at the end of this document. $Careful$: the code is currently flawed. The $\frac{1}{4}$-20 bolt must be removed at two points during the procedure to avoid damaging the tools. To CNC a sensor hat, simply clamp a 7" by 9" piece of $\frac{1}{8}$" plexiglass into the CNC fixture such that the four #6-32 threaded holes are under the corners of the plexiglass. Run the program until pauses, remove the clamps, bolt it to the fixture through the $\frac{1}{4}$-20 and #6-32 holes. Allow it to run again, being very wary of the $\frac{1}{4}$-20 bolt at the center.

4 Zaurus Setup

4.1 Preparing the SecureDigital Card

This is only necessary if updating or replacing the card. If several identical Zauri are to be prepared, this step only needs to be done once.

1. Open the folder "M:/MVWT/zaurus files" where M: refers to \\pcfiles.cds.caltech.edu\mvwt.

2. Copy the folder "rootfs" onto the SecureDigital card.

3. Open the folder "SDRoot" and copy all the contained files into the base directory of the SecureDigital card.

4.2 Installing software

1. Turn on the Zaurus and go through its setup process (calibrate the screen, set times, etc.).

2. Insert the SecureDigital card into the Zaurus.

3. Go to the "Documents" tab, click the "qpe-terminal_1" package, click the "Install" button, and install to RAM. When the installation is complete, close all open windows by clicking the X button in the upper-right corner.

4. Go to the "Applications" tab and open the "terminal" program. Type `cp -R /mnt/card/rootfs/* /` to copy over configuration files, install the wireless network card driver, install minicom, and allow telnet connections over the network.

5. In order to allow remote access, the root password must be set. Still in terminal, type the command `passwd`. When prompted for the new password, type `mvwt2003`, using the Zaurus's function key to type the numbers. Confirm the new password and close the terminal when finished.

6. Open the "Wireless LAN Setting" under the "Settings" tab. Set "Specific ESSID" to "caltechmvwt," and set "Network Type" in "Infrastructure". Press OK to save the settings and close the window.

7. Open “Network & Sync” under the “Settings” tab. Under “Services”, click the “Add” button. Select “LAN - TCP/IP” and click “Add”. Select the “Specify TCP/IP Information” radio button, then go to the “TCP/IP” tab and input the following settings:

IP	–	192.168.1.2## where ## is the number of the Zaurus
Subnet Mask	–	255.255.255.0
Broadcast	–	192.168.1.255
Gateway	–	192.168.1.1

   Now under the ”DNS” tab, input the nameservers below:

DNS Nameservers	–	131.215.42.28
	–	131.215.9.49

   Under the “Proxies” tab, select “No Proxies.” Click “OK” in the upper-right corner to save the settings.

8. Still under the ”Settings” tab, click ”Light & Power.” Turn off the backlight and set the Zaurus to suspend after 3600 seconds.

9. Now install the FTP daemon by clicking the troll-ftpd_package under ”Documents”. The installation process is identical to that of the terminal.

10. Unmount the SecureDigital card by clicking the ”SD” icon in the lower right and selecting ”Eject SD-card”.To remove the card, press it until it clicks, then release and it will pop out like a push-on, push-off switch. Reboot the Zaurus (Settings→Shutdown→Reboot) to load the wireless card drivers and configuration settings.

5 Atmel Interface Board

5.1 Overview

The Atmel interface board provides the low-level interface between the Zaurus PDA and the various actuators and sensors on the hovercraft. The Atmel microcontroller communicates with the Zaurus via the RS-232 serial port and is responsible for reading the gyro, magnetic heading sensor, and accelerometers as well as generating PWM control signals for the fan speed controllers.

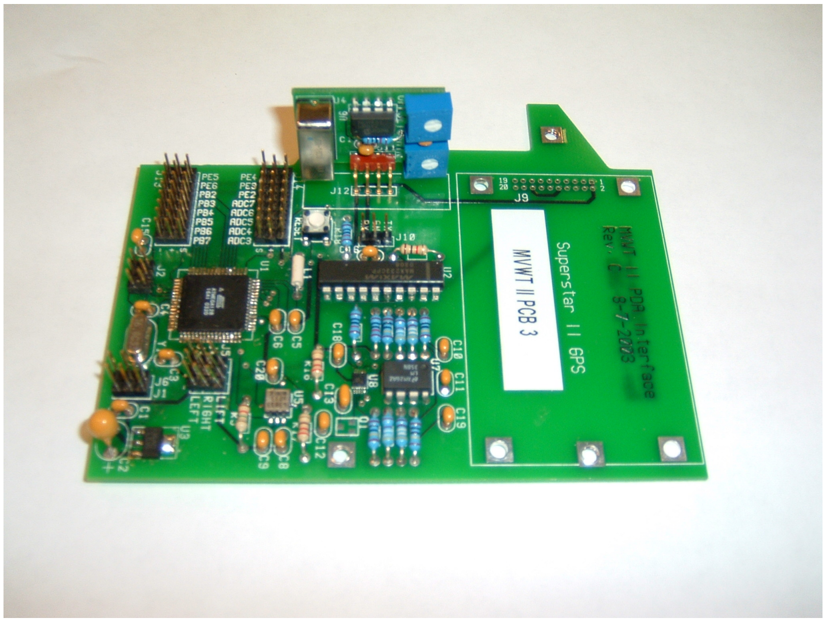

Figure 6: Completed Interface Board

5.2 Hardware Description

The interface board is built around a Atmel ATMega128. The ATMega128 is a microcontroller using Atmel's AVR 8-bit RISC architecture running at 16Mhz. It includes a UART for serial communication, an 8-channel 10-bit ADC, 8 external interrupts, and a number of 8-bit and 16-bit timer/counters. More information on the ATMega128 can be obtained from the Atmel web site, www.atmel.com. The web site www.avrfreaks.org has a wealth of information about programmers and compilers for AVR microcontrollers.

5.2.1 Power Supply

The interface board is powered from the same 7.2V battery that powers the lift fan. The regulated 5V supply is provided by the LM2940IMP (U3). The choice of output filter capacitor (C2) is important. The LM2940 requires the ESR of the cap to be within a certain range. Refer to the LM2940 datasheet for more information.

5.2.2 ATMega128

The ATMega128 requires very few external components to operate. L1, C5, and C6 filter noise from the ADC's supply and internal reference, as recommended by Atmel.

5.2.3 RS-232

RS-232 level conversion is done with a Maxim MAX233.
IMPORTANT: R1 is necessary because the ISP and UART share the same I/O pins on the ATMega128. R1 allows the programmer to override the output of the MAX233 during programming. Because of this, the serial port will not work when to programmer is connected.

5.2.4 ISP Header

The interface board includes Atmel's standard 6-pin in-circuit programming header (J2) to allow the ATMega128 to be easily programmed without removing it from the board.
IMPORTANT: R1 is necessary because the ISP and UART share the same I/O pins on the ATMega128. R1 allows the programmer to override the output of the MAX233 during programming. Because of this, the serial port will not work when to programmer is connected.

5.2.5 Gyro

The gyro circuit is designed as a separate 4-pin module so that it can mount vertically on the main PCB with a right angle connector. The sensor used is a Tokin CG-16D ceramic gyro. The output of the gyro module is 1.1mV/deg/sec ±20% referenced around 2.4V. The offset at zero angular rate can vary as much as ±300mV from gyro to gyro. To compensate for this and provide a voltage between 0V and 5V as required by the ADC, the signal from the gyro sent through a simple differential amplifier built around an MCP601 op amp. R2 adjusts reference input to the amplifier to correct offset in the output of the gyro module. R4 allows the gain to be varied from 1 to 10. C7 filters out high-frequency noise in the gyro module's output.

5.2.6 Magnetic Heading Sensor

The magnetic heading sensor allows the hovercraft to get an absolute heading to complement the GPS position data when running without the vision system. The sensor used is the HMC1052, a 2-axis magnetoresistive sensor made by Honeywell. The compass circuit is taken directly from Honeywell *AN214 Reference Design: Low-Cost Compass*. Currently, the interface board only returns the raw ADC readings from each axis. The functions to calibrate the compass and calculate the heading will run on the Zaurus, but have not yet been written.

5.2.7 Accelerometers

The interface board includes an Analog Devices ADXL202E 2-axis accelerometer to measure acceleration in the forward/backward and side-to-side axes. The ADXL202E can measure ±2g acceleration. The output of the ADXL202E is a fixed-frequency square wave with duty cycle corresponding to the acceleration. ±1g of acceleration corresponds to approximately ±12.5% duty cycle. The time high for each channel and the total period (which is the same for both channels) are measured by the ATMega128 and sent to the Zaurus, where the actual acceleration is calculated. C8 and C9 set the bandwidth of the accelerometers. R5 sets the period of the output square waves. Details on choosing C8, C9, and R5 are in the ADXL202E datasheet.

5.3 PCB Fabrication

The PCBs for the interface board were fabricated by Advanced Circuits, www.4pcb.com. The schematics and PCB layouts are all on the M: drive. Advanced Circuits requires that you submit a zip file containing gerber files for each copper, soldermask, and silkscreen layer. The zip file of the most recent revision of the board is mvwtrevc.zip. If more boards need to be ordered Advanced Circuits should still have the tooling and artwork on file. The order information is:

Customer Number: 21310
Quote Number: 68973
Part Number: mvwt2
Revision: C

Our salesperson at Advanced Circuits is Lydia Arriaga, (800)289-1724 x302, lydia@4pcb.com.

5.4 Assembly

Assembly of the interface board is straightforward. The gyro board is tab routed so it will snap off of the main PCB. It mounts vertically to the main

PCB with a 4-pin right-angle header.

5.4.1 Zaurus Serial Cable

Cut the serial down so its just long enough to reach from the Zaurus to the 3-pin RS-232 header on the interface board. The pinout of the cable is:

Red Data from the Zaurus to the ATMega128. Connects to RX on the interface board.

White Data from the ATMega128 to the Zaurus. Connects to TX on the interface board.

Brown Ground.

5.4.2 Soldering the Surface Mount Components

Soldering the surface mount components can be difficult. Here's a method that is fairly quick and easy:

1. Apply a thin coat of flux to the pads. The liquid flux with a brush applicator sold in the EE stockroom is ideal for this.

2. Place the component in approximately the right location with tweezers or needle-nose pliers. The flux will help keep it from sliding around.

3. Carefully poke at the component with something small (a piece of wire works well) until it is aligned on the pads.

4. Make sure the soldering iron is clean and tinned and place a small dab of solder on the tip.

5. Holding the component in place with your finger, touch the tip of the iron to one of the pads at a corner of the component. The solder should wick into the joint. Be careful because the blob of solder can pull the component out of alignment as it cools.

6. Do the same for a pad at the opposite corner, so the component is held securely in place.

7. Apply more flux over the pins of the component to ensure they are completely covered.

8. Fill some solder wick with flux. Filing the last half inch to inch or so seems to work well. Put enough solder on it so that is is completely soaked, but not so much that forming a blob of solder.

9. Gently press the end of the solder wick against the board with the soldering iron so that the solder is molten. Using the soldering iron, carefully slide the solder wick up against the pads/pins of the component.

10. If all goes well, a small amount of solder will wick into each joint. Move down the row of joints while repeatedly sliding the wick up against them. Do not drag the wick across the joints, as this will form solder bridges.

11. When finished, inspect the joints carefully to make sure they are all soldered and there are no solder bridges. If there are any suspicious looking spots, just apply more flux and go over them again as before.

5.5 Programming the ATMega128

5.5.1 Development Tools

For developing software for the ATMega128 we used the free WinAVR set of tools and Atmel's AVRISP programmer. WinAVR includes a port of gcc to the AVR architecture which runs under windows. It also includes avrdude, command-line software to program the microcontroller. The WinAVR web site is winavr.sourceforge.net. The AVRISP is a simple, inexpensive programmer that allows programming of the microcontroller in-circuit through the 6-pin ISP header.

5.5.2 Programming the Fuse Bits

Before the interface board will boot for the first time, the fuse bits of the ATMega128 need to be programmed. The fuse bits are used to configure peripherals, set the clock source, etc... For more information on the fuse bits, refer to the programming section of the ATMega128 datasheet. The values of the fuse bytes for use with the interface board are:

Low Fuse Byte 0xFF
High Fuse Byte 0xC9
Extended Fuse Byte 0xFF

The procedure to program the fuse bits with avrdude and the AVRISP programmer is:

1. Setup the programmer as in the section on writing the program flash.

2. Use `avrdude -p ATMEGA128 -c avrisp -t` to open the programmer in terminal mode.

3. `w lfuse 0 0xff` to write the low fuse byte.

4. `w hfuse 0 0xc9` to write the high fuse byte.

5. `w efuse 0 0xff` to write the extended fuse byte.

5.5.3 Writing the Program Flash

1. Connect the AVRISP programmer to the serial port on the computer.

2. Power the board and plug the programmer in to the ISP header. Make sure pin 1 on the programmer (indicated by red wire/small arrow on the connector) goes to pin 1 on the PCB (the square pad).

3. When the programmer is plugged in its light should blink a couple times then remain green (the programmer draws its power from the board). If not, try turning the power off and on again.

4. Compile the source to an srec object file that avrdude can recognize. With the standard WinAVR makefile this can be done with `make srec`.

5. Use `avrdude -p ATMEGA128 -c avrisp -e` to erase the flash. `-p` specifies the device being programmed, `-c` specifies the programmer to use, and `-e` erases the flash.

6. Program the flash with `avrdude -p ATMEGA128 -c avrisp -i mvwt2.srec`. `-i` specifies the object file to use.

6 Force Map Generation

6.1 Overview

The force mapping setup measures actual fan thrust as a function of control input to the fan controller. A modified interface board (the force mapping board) is used to slowly ramp up the fan speed while measuring the output from a load cell connected to the fan.

6.2 Data Format

At each power level the force mapping board sends an ASCII data point in the format `command, thrust,` to the serial port. `command` is dimensionless power level the board is sending to the fan. `thrust` is the value the board read from the ADC for that particular command. Each data point is on a new line. The output of the force mapping board can be copied directly from the terminal window into a *.csv (comma-separated value) text file which can be read by Excel.

6.3 Force Mapping Board Software

The force mapping program starts as soon as the ATMega128 boots. It does the following:

1. Set the current power level of the fan controller.
2. Wait a certain amount of time to allow the thrust to stabilize.
3. Take 8 ADC readings of the load cell output.
4. Average together the ADC readings and send them to the serial port.
5. Increase the current power level and repeat. Stop when the fan is at max power.

There are `#define`'s in the source code to setup:

- Time to allow the thrust to stabilize.
- Period of time to take the 8 readings over.
- Size of each step in power level.

6.4 Procedure

1. Connect the load cell amplifier to the `ADC3` input of the force mapping board.
2. Connect the fan under test to `LEFT` output of the thrust mapping board.
3. Connect the thrust mapping board serial port to the computer's serial port.

4. Place the fan to test in the force mapping jig.
5. Open a terminal window on the computer.
6. Apply 28V to the load cell amp.
7. Apply 7.2V power to the thrust mapping board and fan controller.
8. The ATMega128 should boot and begin sending data points. If not, reset it.
9. The thrust map will show up in the terminal window in comma-separated value format. Copy it into a text file and save it as *.csv.
10. Run the thrust mapper a few more times with the fan disconnected and weights on the jig to get some data points to convert the ADC values to actual thrusts.

7 Hovercraft Assembly

7.1 Thrust Fans

1. Bolt the u-channel and the elastic to the plate. The bolts should go through the two holes in the elastic and the elastic should be sandwiched between the u-channel and the plate. Bolt in holes 7 and 8 or 9 and 10 using $\frac{1}{2}$"#6-32 bolts.
2. Attach the other end of elastic to the top of the u-channel through the grommet with a $1\frac{1}{4}$"#6-32 bolt and a nut.
3. Repeat for a second u-channel and elastic strap on the other side of the plate.
4. Slide the fans into the u-channel, allowing the elastic to keep them in place.

7.2 Lift Fan

1. Slide the lift fan holder around the bottom rim of the lift fan.
2. Push the flexifoam circle around the bottom rim of the lift fan.
3. Align the bolt holes in the flexifoam and the lift fan holder.

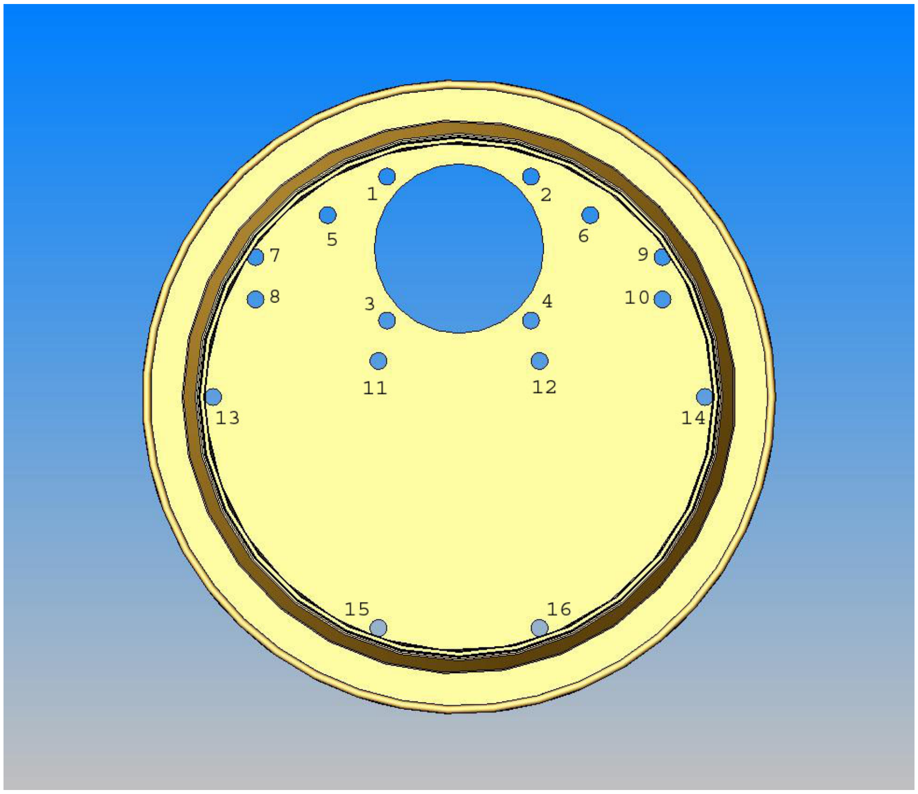

Figure 7: Hole referencing for the plate.

4. Using $\frac{1}{2}$" #6-32 bolts, bolt the lift fan holder to the plate through holes 1 - 4.

7.3 Zaurus

1. Configure the Zaurus using the instructions in Section 4.
2. Label the Zaurus with its number. Label all its corresponding parts, as well.
3. Leaving the flip-top on, position the Zaurus on the hovercraft.
4. Put the flexifoam rectangle between the Zaurus and the PCB.

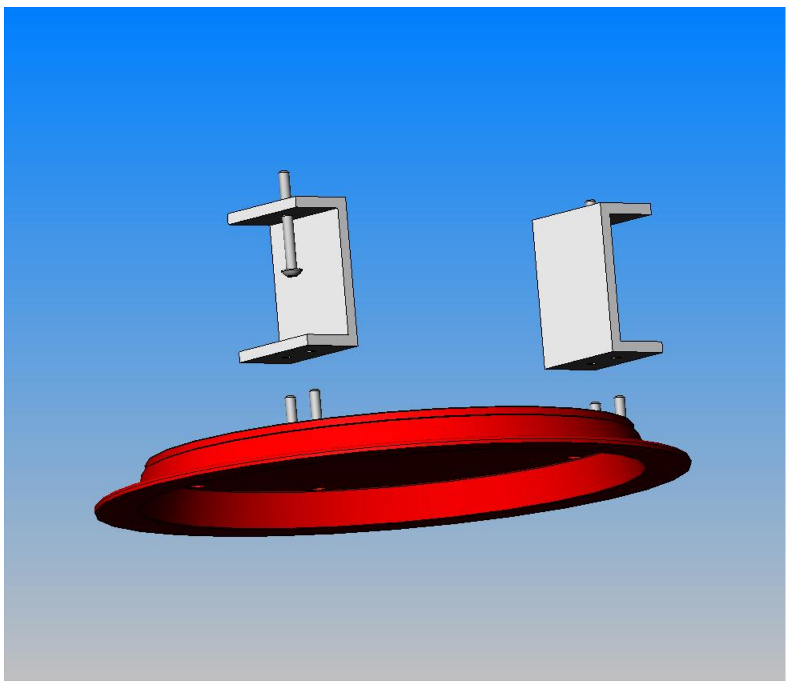

Figure 8: Attaching U-channels to the plate. Note: Elastic not shown here.

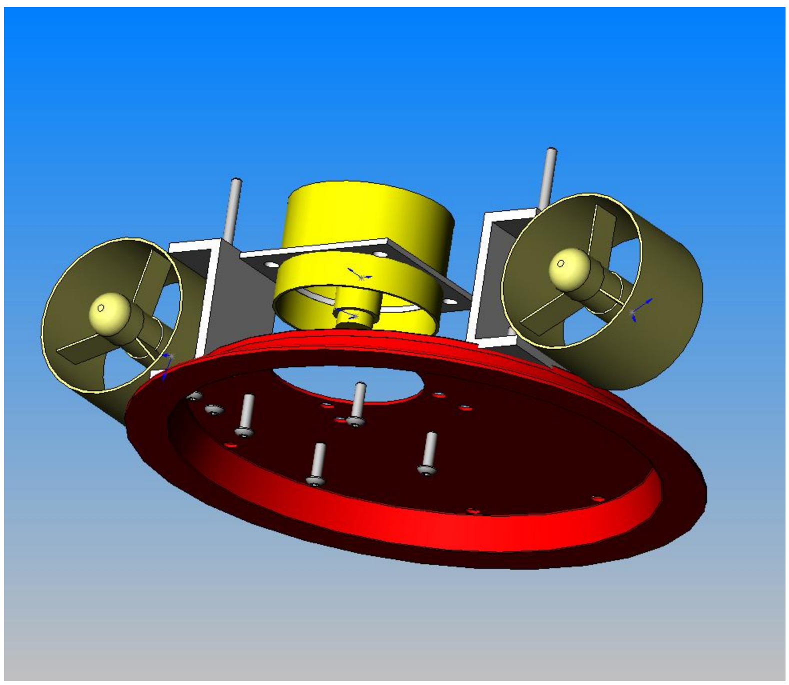

Figure 9: Attaching lift fan.

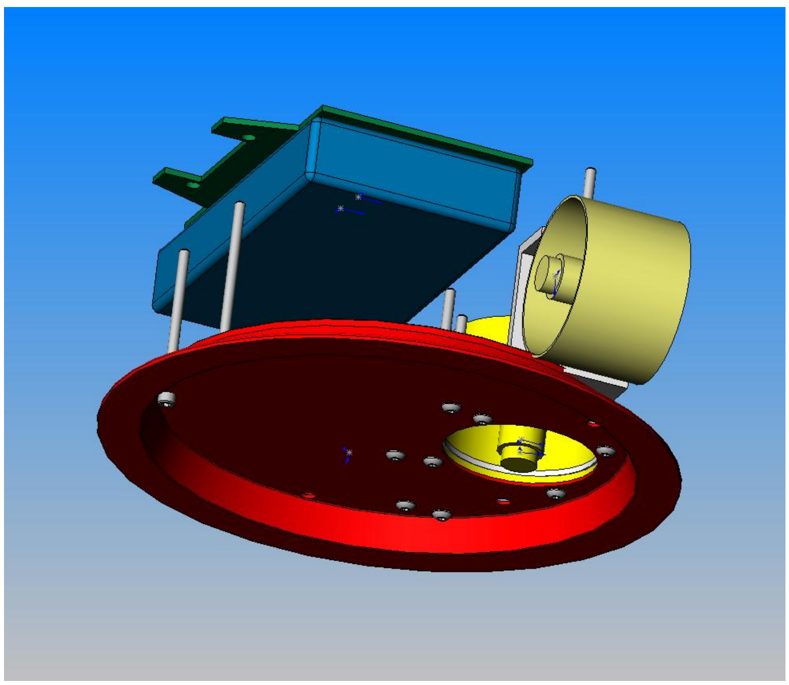

Figure 10: Attaching the PCB and Zaurus.

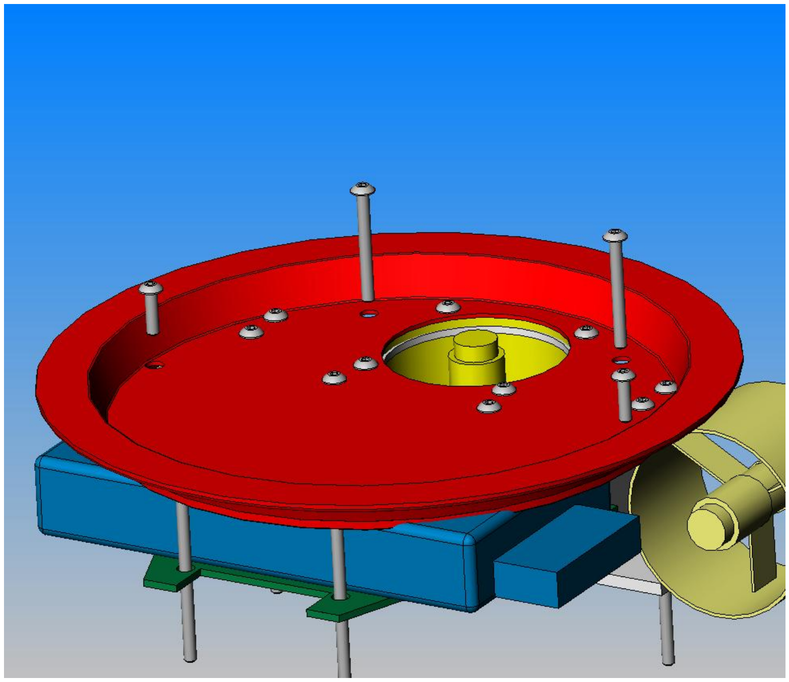

Figure 11: Restraining Bolts.

7.4 PCB

1. After the PCB has been fabricated, bolt it on to the plate with two 1 $\frac{1}{4}$" #6-32 bolts and two 2" #6-32 bolts, gently sandwiching the Zaurus and flexifoam in between. The 2" bolts should be a the rear of the hovercraft (holes 15 and 16). The 1 $\frac{1}{4}$" bolts should go through holes 11 and 12.

2. Attach two rubberbands between the bolts on the back of the hovercraft- one above the PCB and one below. These rubberbands are used to hold on the lift fan's battery.

7.5 Restraining Bolts

Bolts sticking up from the base of the hovercraft are used to keep the Zaurus from slipping out on either side, and to hold the thrust batteries in place. Bolt two $1\frac{1}{4}$" #6-32 bolts in holes 5 and 6, and two $\frac{1}{2}$" #6-32 bolts in holes 13 and 14.

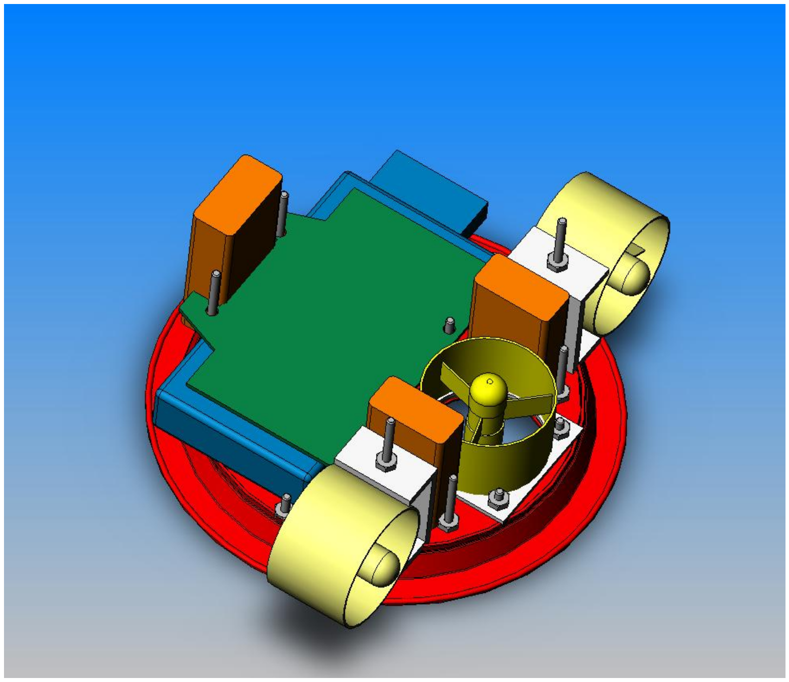

Figure 12: Finished Hovercraft

8 Testbed: Roof

The size of the roof made it the optimal location for a large game of Roboflag. However, its dirty, rocky and highly uneven surface was a problem for the hovercraft. To solve this problem the MVWT II team designed a simple and easily removable testbed for use on the roof.

A type of carpet padding called Berber Max was determined to be the optimal material. It is relatively smooth and can easily be rolled up to be moved aside. Its only problems are a susceptibility to ripping and an inability to even out larger bumps. While tedious, it appears that putting tape along the edge of each roll is enough to take care of the ripping problem. The problem with large bumps is much more serious. The best solution we could come up with was to cut holes in the areas with larger bumps and cover the Berber Max with black plastic. This has only been tested on a small scale, but there is no reason to believe that it wouldn't work if implemented on the entire testbed.

Wooden boards with thin strips of carpet padding are used as bumpers around the perimeter of the testbed. Once the carpet padding is unrolled, they are placed along the outer perimeter. The bumpers protect the hovercraft from leaving the playing area as well as hold the carpet padding in place.

9 Design Considerations

As with all projects, there are tradeoffs. Optimizing the design requires researching the available options and choosing the best one.

One of the most crucial decisions for MVWT II was what kind of lift fan to use. How could the hovercraft hover high enough to clear the gravelly surface on top of the roof? How could it also be large enough to hold the necessary computing components? Could the hovercraft be made to hover for 40 minutes? Can we overcome these problems simply by finding a smoother roof? An extensive survey of the roofs of campus buildings determined that smoother roofs have large bumps between roofing panels . Any hovercraft at a reasonable hovering height would get caught on these bumps. Increasing the hover height would require higher air flow from the lift fan. In addition to a high hoverheight, we looked into the option of having a flexible and durable skirt that would assist in the gliding over the bumps. Unfortunately, while this helped the hovercraft get over the bumps, there was still a significant increase in friction.

These problems led us to develop a testbed on the roof that could support a simple, lightweight hovercraft. Most importantly this testbed needs to be removable to keep it from being a fire hazard. It would be smoother than the roof and would compensate for the bumpiness.

The main advantage of a lightweight hovercraft is the cost. Less weight means we can use less costly fans that require less power. Less power means that fewer batteries are needed. Our primary limit in shrinking the craft was the size of the computer platform. A handheld computer seemed to work best for this purpose.

9.1 Lift Fan

Selecting the right fan turned out to be more difficult than we had anticipated. Stronger fans require more power and money. More power requires more batteries. More batteries weigh and cost more, and once again, more weight requires a stronger fan. With some fans we were able to make hovercraft hover a centimeter above the ground, but this would have been very expensive. After deciding on a smooth testbed, the goal was then to make the hovercraft as small as it could be. The fan we decided to use is ≈ 2" in diameter. There were only two fans available in this size. We chose the EDF-50 fan for it's low power consumption.

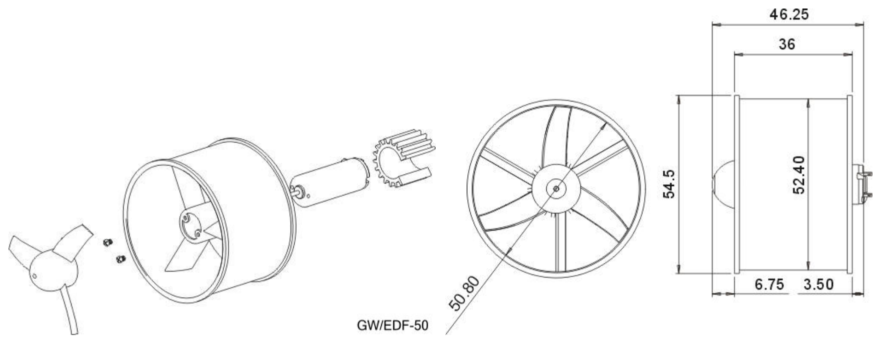

Figure 13: Lift and Thrust Fans (measurements in millimeters)

9.2 Thrust Fan

We chose to use the same fan for thrust as for lift. It was lightweight, and provided adequate thrust (some could even argue there was too much thrust!).

9.3 Batteries

After deciding on the fans, we knew we had to find the densest, lightest, smallest batteries we could find. The fans run on 7.2 Volts and pull about 3 Amps on full thrust. We wanted the lift fan to run continuously for 40 minutes. We also wanted to avoid ordering a custom battery to save on cost. As such we decided to go with mass produced Lithium Ion Battery packs designed for the model airplane industry.

$$40minutes \times \frac{1hour}{60minutes} = \frac{2}{3}hour$$
$$3A \times \frac{1000mA}{A} = 3000mA$$
$$\rightarrow \frac{2}{3}hour \times 3000mA = 2000mAh$$

9.4 Base

Determining the shape of the base was our main focus for the beginning of the summer. We wanted to maximize the distance between the thrust fans. At the same time, we wanted the hovercraft to be stable, and simple to build. It would have been simple to try different design variations with a rapid prototyping system, but sadly Caltech does not have one. Because of this, we chose a simple base design using plastic plates in which holes were created using a CNC machine. Full size hovercraft used for racing are usually designed to be twice as long as they are wide. This would give us a smallish moment arm (between the thrust fan and the center) in comparison with the length of the hovercraft. The Kelly's are about twice as wide as they are long to make use of a large moment arm.

10 Future Work

Unfortunately, there are things that the MVWT 2003 team could not complete over the course of the summer.

1. Determine if the Zaurus are an effective as a means of controlling the hovercraft.
2. Determine if current fans are strong enough to work as lift fans. Fans have appeared to get weaker after running for 40 minutes as a lift fan.
3. Build an additional 12 hovercraft.
4. Thrust map all fans.
5. Characterize all gyros.
6. Make improvements to sensor hat. (see 3.7)

A Bill of Materials

A.1 Physical

Qty	*Description*	*Distributor*	*Part Number*
1	Zaurus 5500, Handheld Computer	Sharp	SL-5500
1	Serial Cable for Zaurus	Sharp	CE-170TS
1	Compact Flash Wireless LAN Card	Linksys	WCF12
3	Electric Ducted Fan	GWS	EDF-50
3	Fan Speed Controller	GWS	ICS-100
3	Aluminum Mesh, 3.5” Square	Physical Plant Stockroom	
	Flexifoam	JoAnneFabrics	
2	7.2 V, 950 mAh battery	Duralite Batteries	PPD-7092
1	7.2 V, 1800 mAh battery	Duralite Batteries	PPD-7092
1	7.5” Plastic Plate (Primary Plate)	Walmart (Arrow Plastic)	290
2	1 3/8” wide PVC U-channel, 1.88 base by 0.79 leg length	McMaster-Carr	85065K49
2	Washer Grommets	McMaster-Carr	9604K22
2	1” Wide Elastic Strap	JoAnne Fabrics	
1	2.5” square of 1/16” 6061 Al sheet metal	Materials Warehouse	
2	1/2” of 1” x 3/8” Brass Stock	Materials Warehouse	
2	2” #6-32 bolts	Physical Plant Stockroom	
8	1 1/4” #6-32 bolts	Physical Plant Stockroom	
8	1/2” #6-32 bolts	Physical Plant Stockroom	
18	#6-32 Nuts	Physical Plant Stockroom	

A.2 Computational

Qty	*Description*	*Distributor*	*Part Number*
1	Zaurus 5500, Handheld Computer	Sharp	SL-5500
1	Serial Cable for Zaurus	Sharp	CE-170TS
1	Compact Flash Wireless LAN Card	Linksys	WCF12

A.3 Electrical

Part Number	*Schematic Ref.*	*Qty*	*Description*	*Manufacturer*
ATMega128-16AI	U1	1	Microcontroller	Atmel
MAX233CPP	U2	1	RS232 Transceiver	Maxim
102976-3	J1, J3-6, J10	6	3-pin Header	AMP/Tyco
103186-3	J2	1	6-pin Header	AMP/Tyco
CFR-25JB-1K0	R1	1	1k 5% 1/8W Resistor	Panasonic
LM2940IMP-5.0	U3	1	5V 1A Regulator	
T356K686K016AS	C2	1	68uF 16V Tantalum Cap	Kemet
C315C104M5U5CA	C1,5-9,12,14-21	15	0.1uF Ceramic Cap	Kemet
HC49US16.000MABJ	Y1	1	16MHz Crystal	Citizen America
C320C150J2G5CA	C3, C4	2	15pF 200V Cap	Kemet
1025-44K	L1	1	10uH Choke	API Delevan
CG-16D	U4	1	Ceramic Gyro	Tokin
ADXL202AE	U5	1	2 Axis Accelerometer	Analog Devices
3362P-1-104	R2, R4	2	100k Pot	Bourns
CFR-25JB-10K	R3, R18	5	10k Resistor	Yageo
CFR-25JB-1M2	R5	5	1.2M Resistor	Yageo
MCP601-I/P	U6	1	Single Op Amp	Microchip
LM358N	U7	1	Dual Op Amp	National Semi.
HMC1052	U8	1	Magnetic Sensor	Honeywell
MFR-25FBF-4K99	R6-9	5	4.99k 1% Resistor	Yageo
MFR-25FBF-1M00	R10-13	5	1.00M 1% Resistor	Yageo
C315C102K1R5CA	C10, C11	2	1000pF Ceramic Cap	Kemet
MFR-25FBF-10K0	R14, R15	5	10.0k 1% Resistor	Yageo
C320C224M5U5CA	C13	1	0.22uF Ceramic Cap	Kemet
MMBT2222A	Q1	1	NPN Transistor	
CFR-25JB-220R	R16, R17	5	220 Resistor	Yageo
DF11-20DS-2DSA	J9	1	20-pin Receptacle	Hirose
22-12-2041	J11, J12	1	Connector for gyro board	Molex
104344-6	J13, J14	6	8-pin Single Header	AMP/Tyco
B3F-1000	S1	1	Reset Switch	Omron

B CNC Code

B.1 Hovercraft Plate

```
N0   O17 ⋆ HOVERCRAFT PLATE
N1   T1M6 ⋆ #28 DRILL
N2   G0G40G80G90 X0Y0 E1S2500M3
N3   X0.95 Y-2.725
N4   Z1. H1
N5   G81G99 X0.95 Y-2.725 Z-0.2 R+0.1 F15.
N6   X-0.95 Y-2.725
N7   X-2.9 Y0
N8   X-2.4 Y1.15
N9   X-2.4 Y1.65
N10  X-1.55 Y2.147
N11  X-0.849 Y2.599
N12  X-0.849 Y0.901
N13  X-0.95 Y0.425
N14  X0.95 Y0.425
N15  X0.849 Y0.901
N16  X0.849 Y2.599
N17  X1.55 Y2.147
N18  X2.4 Y1.65
N19  X2.4 Y1.15
N20  X2.9 Y0
N21  G80G0Z0H0
N22  T2M6⋆ 3/16 ENDMILL
N23  G0G40G80G90 X0Y0 E1S2500M3
N24  X0 Y1.75
N25  Z1.H2
N26  G1 Z0.05 F25.
N27  Z-0.07 F5.
N28  X0.906 Y1.75 F15.
N29  G3 X0.906 Y1.75 I-0.906J0
N30  G1 X0.9
N31  G0 Z0H0
N32  M2
```

B.2 Lift Fan Holder

```
N10   O20 ⋆ LIFT FAN CLAMP FIXTURE
N20   T1M6 ⋆ DRILL
N30   G0G40G80G90X0Y0E3S3000M3
N40   X0.8475Y0.8475
N50   Z1.H1M8
N60   G81G99X0.8475Y0.8475Z-0.1R+0.5F5.
N70   Y-0.8475
N80   X-0.8475
N90   Y0.8475
N100  G0Z0G80M9H0
N110  Y7.
N120  T2M6⋆3/16 EM
N130  M0
N140  G0G40G80G90X0Y0E3S3000M3
N150  Z1.H2M8
N160  G1Z0.1F30.
N170  G1Z-0.1F5.
N180  X0.944Y0F10.
N190  G3X0.944Y0I-0.944J0
N200  X0.94Y0
N210  G0Z0M9H0
N220  Y7.
N230  M0
N240  M2
```

B.3 Sensor Hat

```
N10   O18 ⋆ HOVERCRAFT HAT
N20   T1M6
N30   G0G40G80G90X0Y0E1S2500M3
N40   Z1.H1
N50   G81G99X0Y0Z-0.05R+0.1F5.
N60   G0G80Z3.
N70   X-4.25Y3.25
N80   G81G99X-4.25Y3.25Z-0.05R+0.1F5.
N90   G0G80Z3.
N100  Y-3.25
N110  G81G99Z-0.05R+0.1F5.X-4.25Y-3.25
N120  X4.25
N130  G0G80Z3.
N140  Y3.25
N150  G81G99Z-0.05R+0.1F5.X4.25Y3.25
N160  X2.4Y1.35
N170  X-2.4
N180  G0G80Z3.
N190  T2M6
N200  G0G40G80G90X0Y0E1S2500M3
N210  Z1.H2
N220  G81G99X0Y0Z-0.25R+0.1F5.
N230  G0G80Z0H0
N240  T3M6
N250  G0G40G80G90X0Y0E1S2500M3
N260  X-4.25Y3.25
N270  Z1.H3
N280  G81G99X-4.25Y3.25Z-0.2R+0.1F5.
N290  G0G80Z3.
N300  Y-3.25
N310  G81Z-0.2R+0.1X-4.25Y-3.25
N320  X4.25
N330  G0G80Z3.
N340  Y3.25
N350  G81Z-0.2R+0.1X4.25Y3.25
N360  X2.4Y1.35
N370  X-2.4
N380  G0G80Z0H0
N390  M0
```

```
N400  T4M6
N410  G0G40G80G90X0Y0E1S2500M3
N420  X-3.75Y3.125
N430  Z1.H4
N440  G81G99X-3.75Y3.125Z-0.2R+0.1F5.
N450  X-3.125
N460  X-2.5
N470  X-1.875
N480  X-1.25
N490  X-0.625
N500  X0
N510  X0.625
N520  X1.25
N530  X1.875
N540  X2.5
N550  X3.125
N560  X3.75
N570  X-3.75Y2.5
N580  X-3.125
N590  X-2.5
N600  X-1.875
N610  X-1.25
N620  X-0.625
N630  X0
N640  X0.625
N650  X1.25
N660  X1.875
N670  X2.5
N680  X3.125
N690  X3.75
N700  X-3.75Y1.875
N710  X-3.125
N720  X-2.5
N730  X-1.875
N740  X-1.25
N750  X-0.625
N760  X0
N770  X0.625
N780  X1.25
```

```
N790   X1.875
N800   X2.5
N810   X3.125
N820   X3.75
N830   X-3.75Y1.25
N840   X-3.125
N850   X-2.5
N860   X-1.875
N870   X-1.25
N880   X-0.625
N890   X0
N900   X0.625
N910   X1.25
N920   X1.875
N930   X2.5
N940   X3.125
N950   X3.75
N960   X-3.75Y0.625
N970   X-3.125
N980   X-2.5
N990   X-1.875
N1000  X-1.25
N1010  X-0.625
N1020  X0
N1030  X0.625
N1040  X1.25
N1050  X1.875
N1060  X2.5
N1070  X3.125
N1080  X3.75
N1090  G0G80Z1.
N1100  X-3.75Y0
N1110  G81G99X-3.75Y0Z-0.2R+0.1F5.
N1120  X-3.125
N1130  X-2.5
N1140  X-1.875
N1150  X-1.25
N1160  X-0.625
N1170  G0G80Z1.
```

```
N1180  X0.625
N1190  X0.625G81G99Y0Z-0.2R+0.1F5.
N1200  X1.25
N1210  X1.875
N1220  X2.5
N1230  X3.125
N1240  X3.75
N1250  X-3.75Y-0.625
N1260  X-3.125
N1270  X-2.5
N1280  X-1.875
N1290  X-1.25
N1300  X-0.625
N1310  X0
N1320  X0.625
N1330  X1.25
N1340  X1.875
N1350  X2.5
N1360  X3.125
N1370  X3.75
N1380  X-3.75Y-1.25
N1390  X-3.125
N1400  X-2.5
N1410  X-1.875
N1420  X-1.25
N1430  X-0.625
N1440  X0
N1450  X0.625
N1460  X1.25
N1470  X1.875
N1480  X2.5
N1490  X3.125
N1500  X3.75
N1510  X-3.75Y-1.875
N1520  X-3.125
N1530  X-2.5
N1540  X-1.875
N1550  X-1.25
N1560  X-0.625
```

```
N1570   X0
N1580   X0.625
N1590   X1.25
N1600   X1.875
N1610   X2.5
N1620   X3.125
N1630   X3.75
N1640   X-3.75Y-2.5
N1650   X-3.125
N1660   X-2.5
N1670   X-1.875
N1680   X-1.25
N1690   X-0.625
N1700   X0
N1710   X0.625
N1720   X1.25
N1730   X1.875
N1740   X2.5
N1750   X3.125
N1760   X3.75
N1770   X-3.75Y-3.125
N1780   X-3.125
N1790   X-2.5
N1800   X-1.875
N1810   X-1.25
N1820   X-0.625
N1830   X0
N1840   X0.625
N1850   X1.25
N1860   X1.875
N1870   X2.5
N1880   X3.125
N1890   X3.75
N1900   G0G80Z0H0
N1910   M2
```

C Testbed Materials

The type of carpet padding used on the testbed is called Berber Max. It is a dense, but smooth type of carpet padding. We found that Carousel Custom

Floors (on Green street in Pasadena) was very reliable and reasonable. Talk to Marv at (626) 795-8085.

D Data Acquisition

D.1 Coefficient of Friction

In the past the coefficient of friction was measured using this basic method: the vehicle was placed in a box and attached to the sides of the box with springs of known k. A force was applied by a human to start it into oscillation and the vision system was then used to measure the decay of the oscillation amplitude. That data was then analyzed to find the coefficient of kinetic friction.

To measure the coefficient of kinetic friction of the Bat, the Bat (wearing a hat) was placed on the testbed. The vision system was turned on. The Bat was given an initial velocity, and then vision system data was recorded. Analysis of the data was made easier by a Matlab program.

D.2 Moment of Inertia

The given value for the moment of inertia of the vehicle is approximate. It was approximated by modelling the vehicle in SolidWorks, a computer program used for solid modelling. Each component on the hovercraft was given a weight. From that model (which assumed constant density throughout each part) we approximated the hovercraft's moment of inertia.

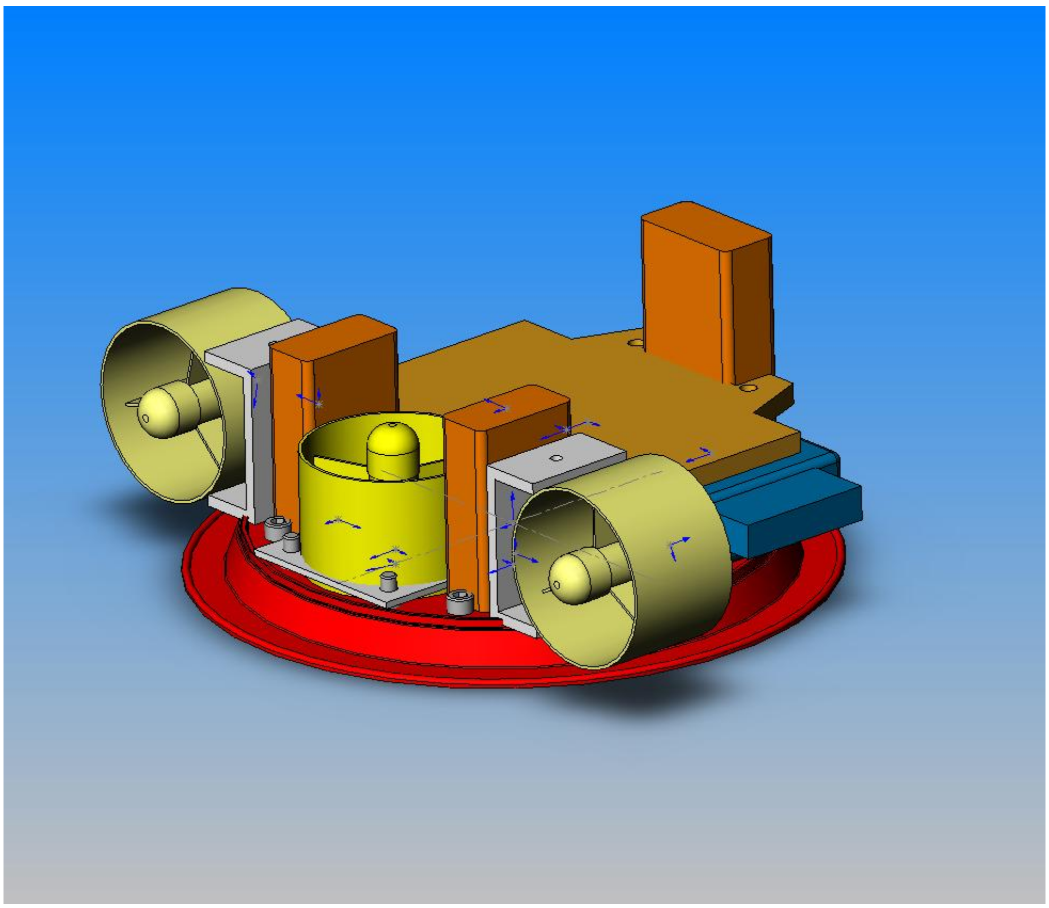

Figure 14: The Bat in SolidWorks