The robotic hovercraft is a nearly frictionless robotic platform. A robotic hovercraft, or HoverBot, travels almost without friction because it does away with one of the greatest sources of drag, spinning wheels and motors. Moving through the air at low speed generates such little drag that a HoverBot gradually slows down when no longer being propelled. It’s quite the opposite situation for a small wheeled robot; it stops on a dime after cutting power to its drive motors. Low drag conditions mean driving a HoverBot requires a consideration of Newton’s Laws of Motion, so the controlling program no longer plans in terms of distance and heading. Instead, it plans in terms of time and acceleration.

Onwards and Upwards,  
Your near space guide

Figure 1. We don’t need wheels where we’re going.

Materials
Your HoverBot kit contains the following parts.

(1) Correplast sheet 16" by 16"
(1) Correplast sheet 14" by 6"
(1) 4-AAA battery holder
(3) EDF-50 ducted fans
(4) 6-32 bolt 2-1/4" long
(4) 6-32 nylocks
(1) 10 mm thick sheet of Cellfoam 88 (3" X 6")
(1) 1/2" thick sheet of blue foam (2" by 4")
(1) 1/4" plastic tube (5" long)
(2) 4-40 bolts, 3/4" long
(8) 4-40 nylocks
(6) 4-40 flat head 3/8" long
(1) 0.02" thick sheet of styrene (3” by 6”)
(1) Sheet of 0.7 mil plastic drop cloth (enough for two skirts)
(5) 1k resistors
(5) 1N4001 diodes
(5) Relays
(5) 2N3904 NPN transistors
(2) Printed circuit boards
(10) Small nylon stand-offs
(10) 2-56 bolts, 5/8" long
(10) 2-56 nylocks
Ten feet of #24 AWG wire
Ten inches of 1/16 heat shrink
(1) 1 by 40 pin single row header

You will need to provide 2-inch wide mailing tape.

Tools
You will need the following tools to turn your kit into a driving, thinking HoverBot.

Exacto knife (or utility knife)
Metal straight edge
Pencil
Drill (a Dremel works very well)
Hot glue gun and glue sticks
Small screw drivers
Small pliers
Heat gun
Wire cutters
Wire strippers
Soldering iron and solder
Sharpie marker

A hot cutter is recommended, but not necessary to make the mount for the drive or lift fans.
A circle template is easier to draw circles with than a compass.

Top and Bottom Decks
The plan is to build two decks, a top and bottom deck. The bottom deck houses the lift fan, nozzle, and skirt. The top deck houses the batteries, robot controller, fan electronics, and drive fans. Separating the two decks are bolts and plastic spacers. Now is the time to align all the holes in both decks and to prepare the bottom deck for the fans and skirt.
It’s best to cut out and drill the holes in both the top and bottom decks before moving on to complete the bottom deck. That way the holes in both decks align. So begin by cutting the two pieces of 5/32 inch thick Correplast to the shapes and sizes illustrated below. A utility knife and metal straight edge work will best for this. Use a T-square to lay out the lines and the HoverBot decks will remains square. Don’t worry about cutting out the circle in the center or drilling the four holes in the corners at this time. Just mark their locations (the circle in the center is dead center of the decks).
Note that you can locate the center of each deck by drawing diagonal lines from the corners (they will intersect in the center) or you could use a ruler and measure to the center. After marking the center of each deck, place a 1-3/4 inch circle template at the center point of each deck and draw the circle on the Correplast. This hole marks where the fan will blow air to float the HoverBot. Use a small bladed Exacto knife and carefully cut out the fan holes. Next stack the top deck on the bottom deck and align their fan holes. The stacked decks should look like this.

![Diagram of stacked decks](image)

**Figure 5.** Center the top deck as perfectly as possible, but never let the fan holes get out of alignment. It’s more critical the fan holes line up properly than the decks.

There are four holes in the corners of the decks for the riser bolts. These holes must line up if the lift fan is to sit vertically in the HoverBot. Therefore, after aligning the top and bottom decks use several pieces of masking tape to hold them in alignment while drilling the riser holes. A Dremel is one of the easiest ways to make these holes. The risers are #6-32 bolts, so a 1/8 inch drill bit will suffice to make these holes. The exact positions of the riser holes is not critical, but keep them at least 1-1/2 inches from the edge of the bottom deck. After drilling the first hole, place a bolt through it to help keep the decks in alignment while drilling the remaining holes. After drilling the riser holes, separate the decks and set the top deck aside.

**Further Work on the Bottom Deck**
The bottom deck is complete when you attach a plastic sheet to the bottom of the deck. That sheet forms a thin plastic bag that inflates with air blown by the lift fan. Called the skirt, it forms a seal to the ground that only allows a thin cushion of air to escape from it. That thin cushion of air lifts the HoverBot and prevents it from contacting the ground. Without that contact to the ground, the HoverBot experiences far less drag than a traditional robot.
Figure 6. The inflated skirt only lets a thin cushion of air escape from beneath. And even though it’s thin, it lifts the HoverBot off the ground and into a low friction environment.

Before attaching the skirt, the bottom deck must be prepped. So push the four #6-32 bolts (2 inches long) through the bottom deck with the head of the bolts on the bottom face of the bottom deck and the threaded portion of the bolts protruding through the top face of the deck. To prevent the bolts from ever coming loose, lock each bolt into place with a nylock. With a nylock, each bolt on the bottom deck will look like the bolt in figure 7.

Figure 7. This riser bolt will never come loose. The nylock bolts it tightly to the bottom deck. Visible in this figure is the skirt taped to the bottom deck (your HoverBot’s skirt hasn’t been attached yet).

To protect the plastic skirt from damage by the head of the riser bolts, apply a piece of packaging tape over the head of each bolt (this is on the bottom face of the bottom deck). Next, cut four pieces of ¼ inch diameter plastic tube 1.3 inches long. These tubes slide over the riser bolts to act as spacers between the top and bottom deck.

The skirt cannot attach directly to the bottom deck because the Correplast has an edge sharp enough to cut its plastic sheet. Therefore, cover the edges of the bottom deck with two-inch wide mailing tape to form a bumper as illustrated below.
Figure 8. It’s easier to wrap a layer of mailing tape over the raw edge of the Correplast bottom deck if you have an extra set of hands. The tape will adhere strongly to the Correplast.

Lift Fan Clamps
The lift fan (the fan that lifts the HoverBot on its cushion of air) mounts between the top and bottom deck. To hold it in place, there is a Styrofoam ring glued to each deck that will trap the lift fan when the decks come together.

Cut two 3-inch squares from the 10mm thick Cellfoam 88 (the hard white polystyrene foam in the kit). Then draw and cut a 2-1/8 inch diameter hole in the middle of each square. The clamps are glued centered to the decks over the large central holes where the lift fan blows its air. Glue the first fan clamp to the bottom face of the top deck and the other to the top face of the bottom deck as shown in figure 9. Use hot glue and carefully align the holes in the fan clamps to the holes in the decks. Notice that the hole in the deck is slightly smaller than the diameter of the hole in the fan clamp. That prevents the fan from dropping out of the HoverBot. Test fit the clamp by placing a fan inside. It should look like figure 10.

Figure 9. It’s easy to remove the lift fan from the HoverBot because the two Styrofoam bands (fan clamps) are holding it in place.
Figure 10. The bottom of the top deck with its white foam fan clamp hot glued to it. The ducted fan sits inside the clamp. The nuts and wires appear in this image because it was taken after its HoverBot was completed.

After gluing the fan clamp on the **bottom deck**, use a sharp Exacto knife and cut out two notches ½ inches wide. The nylocks from the lift nozzle assembly (which is built in the next step) attaches to the bottom deck inside these gaps.

Figure 11. On the left and right sides of the lift fan clamp are gaps for the nylocks from the lift nozzle assembly. The nylocks and part of the nozzle are visible.

**Lift Nozzle**

For the skirt to fill with air while allowing a thin cushion of air to escape and lift the HoverBot, the outside edges of the skirt must be lower than its center, as illustrated in figure 6. The HoverBot uses a simple, lightweight 20-thousandths inch thick polystyrene plastic and two spacers to pull the center of the skirt close to the bottom deck. The shape and dimensions of the nozzle are shown in figure 12.

Figure 12. The HoverBot requires two of these nozzle plates.
Draw two octagon shapes on the sheet of 20-thousandths inch thick polystyrene plastic using the dimensions shown in figure 12 above. The round opening in each octagon is centered and 1-3/4 inches in diameter. Cut out the octagons and their center circles with an Exacto knife or scissors. Stack the two nozzle plates on top of each other and drill two holes, one centered on each side, in the nozzle plates with a 1/16 inch drill bit.

The nozzle plates are held the proper distance from the bottom deck with two bolts and spacers. Use two #4-40 bolts ¾ inches long, two #4-40 nylocks, and two 1/4 inch diameter styrene plastic tubes. Cut two pieces from the plastic tube, 3/8 inches long.

Center one of the nozzle plates over the lift fan opening in the bottom deck and mark the location of the two spacers. Then drill two 1/8 inch holes in the bottom deck for the spacers. Test the nozzle by stacking the two nozzle plates, running the #4-40 bolts through them, stacking the plastic tubes over the bolts, and then attach the nozzle plates to the bottom of the bottom deck. The nozzle will look like the image below.

Figure 13. The nozzle plates are being held 3/8 inches away from the bottom deck with the 4-40 bolts, spacers, and nylocks. In this image, the bottom deck is upside down.

Making the Skirt
The skirt is made from 0.7 mil-thick plastic drop cloth and there is enough material for two skirts is included in the HoverBot kit. Find a large flat surface to work on and cut the skirt material into two equal pieces. Set one piece aside and lay the HoverBot’s bottom deck over the center of the skirt material. Use a Sharpie and neatly draw the outline of the octagonal-shaped bottom deck. The rest of the skirt depends on this outline, so draw it accurately.
Figure 14. In this photograph from an early version of the HoverBot, the riser bolts have not been added to the bottom deck yet. However, you’ll draw the outline of the bottom deck onto the 0.7 mil plastic after attaching the riser bolts to the bottom deck.

Don’t cut out the skirt yet!

Use the straight edge to draw a 1¼ inch wide border around the octagon. If the straight edge is 1¼ wide, then lay one side of the straight edge up against the edge of the octagon drawn on the plastic and draw a larger, concentric octagon using the opposite edge of the straight edge. That way you don’t have to measure 1-1/4 inches beyond the first octagon to draw the second larger, concentric octagon. Otherwise, carefully measure 1¼ inches from the edge of the octagon to get the dimensions of the larger, concentric octagon.

Don’t cut out the skirt yet!

Draw a third and larger octagon around the two concentric octagons already drawn on the plastic sheet. The largest octagon is the outline of the skirt and where it is cut out. Now you have three nested octagons that should look like the image below.

Figure 15. The smallest octagon is the size of the bottom deck, 16 inches across. The next octagon is 2-1/2 inches larger in diameter (1-1/4 inches larger in radius) and marks where the skirt will tape to the edge of the bottom deck. The last and largest octagon is 2-1/2 inches larger than the inner octagon. It where the skirt is cut out.
Use the Exacto knife and straight edge to cleanly cut out the plastic sheet. A pair of sharp scissors will do in a pinch if you cut carefully along the line.

![Figure 16. The bottom deck on top of a plastic sheet to verify the skirt is properly sized and even all the way around. Note that this image came from an early test of the HoverBot. Your HoverBot will only have four riser bolts (and not the two additional ones seen in the front of this bottom deck).](image)

**Attaching the Nozzle to the Skirt**

The nozzle must be attached to the skirt before the skirt can be attached to the underside of the bottom deck. So remove the nozzle from the bottom deck and set aside its mounting hardware (bolts, nuts, and plastic spacers) where you won’t be lost. Locate the center of the octagonal skirt by drawing two lines across the skirt material from opposite corners. Their intersection will be the center of the skirt. At that intersection, center the one piece of the plastic nozzle and only draw the outline of the round hole of the nozzle on the plastic skirt.

![Figure 17. Only when the diagonal lines were near the center were they drawn on the skirt. Therefore, there are no lines drawn across the entire skirt. There’s no reason you can’t have corner to corner lines in your skirt, they might even look neat if drawn in a variety of colors.](image)
The skirt is sandwiched between the plates of the nozzle and then the nozzle bolts to the bottom deck with spacers. However, the plastic skirt won’t stand up to bolts and air blasts, so reinforce the plastic sheet with some packing tape, on both sides of the plastic sheet. Apply enough tape to cover a three inch square of plastic. That way the reinforcement doesn’t extend much beyond the nozzle plates.

![Figure 18](image)

**Figure 18.** Don’t add any more tape than necessary. The taped area of the skirt should not extend much beyond the nozzle plates, however, don’t worry about measuring the size of the tape at a microscopic level of precision.

After applying the tape, use a sharp Exacto knife and cut out the round hole drawn on the skirt. This is where excess air will jet out of the nozzle and lift the HoverBot.

![Figure 19](image)

**Figure 19.** Use an Exacto knife to carefully cut out the nozzle hole in the center of the reinforced skirt.

Lay the skirt on the underside of the bottom deck and rotate the skirt and deck so their octagonal shapes line up. Then lay one of the nozzle plates on top the skirt and verify its mounting holes (the two side holes already drilled into the nozzle plates) line up with the holes already drilled in the bottom deck. Double check your alignment before marking.
the location of the two nozzle mounting holes on the skirt. Afterwards, drill or cut the holes carefully so you don’t tear the skirt.

Now sandwich the skirt between the two nozzle plates and then run the bolts through the plates.

![Image](image198x476to414x639.png)

**Figure 20.** The plastic skirt is sandwiched between the top and bottom plates of the nozzle. After slipping the plastic spacers over the bolts, the nozzle will be bolted to the underside of the HoverBot’s bottom deck.

Slide the spacers on the nozzle bolts and attach the nozzle to the bottom deck and with its bolts and stand-offs. Use nylocks to permanently attach the nozzle to the bottom deck so vibration from the fans will not loosen the nuts, causing the nozzle to drop off.

![Image](image198x199to414x361.png)

**Figure 21.** This is the underside view of the skirt and mounted nozzle. Notice there’s a gap between the nozzle plates and the bottom deck. This gap is where air will fill the skirt to make it billow and hug the ground.

**Mounting the Skirt to the Deck**

Now it’s time to attach the edges of the skirt to the bottom deck. The skirt folds over the edge of the bottom deck and then tapes to the top surface of the bottom deck. The skirt will be taped one octant at a time to attach it as evenly as possible to the bottom deck.
Recall there are three concentric octagons drawn on the skirt. The outline of the second largest octagon is the one that lines up with the edge of the bottom deck. However, do not tape the entire length of the octant to the upper side of the bottom deck just yet. Tape only the center six inches or so of the octagon face to the deck at this time. The rest of the face will be taped down later. At this time, try to minimize the wrinkles in this one octant of the skirt. Excessive wrinkles may degrade the skirt’s ability to seal well with the floor beneath the HoverBot.

**Figure 22.** The edge of the skirt’s second octagon is aligned to the edge of the bottom deck as closely as possible. A piece of clear packing tape tapes this octant to the upper face of the bottom deck.

Next tape the skirt’s opposite octant to the opposite side of the HoverBot’s bottom deck. Again, align the edge of the second largest octagon to the edge of the bottom deck and keep your work neat. Only tape the middle six inches of the octant - do not let the tape extend to the ends of the octant.

Repeat two more times by taping the two octants at right angles to the two octants already taped down. As with the previous two octants, only tape the middle six inches of the octants to the bottom deck. You are only taping the alternating skirt octants to the bottom deck at this time.

Now tape the alternative octants of the skirt to the deck. Fold one of the free octants to the deck, line the edge of the middle (second largest) octagon to the edge of the deck, and tape the middle six inches of this octant to the deck. Then repeat this for the remaining three octants.

Now fold up each corner as neatly and symmetrically as possible and apply a small piece of tape to it as shown in figure 23.
Figure 23. Keep each corner neat as you tape it down. You don’t need much tape at this time; you’ll finish taping the entire skirt to the deck after taping all the corners between the octants to the bottom deck.

After taping the skirt’s eight corners to the bottom deck with a bit of tape, apply additional tape to the skirt to completely seal the skirt. Evenly distribute any loose bits of skirt around the bottom deck as you finish taping it. This completes the bottom deck. Set it aside while you work on the top deck.

Figure 24. Make sure the packaging tape covers any possible openings that could let air escape from the skirt and bottom deck. Also, attempt to keep the skirt as evenly spaced and wrinkle free as possible.

Further Work on the Top Deck
The top deck contains the drive electronics, batteries, and drive fans. These items mount to the top deck so there is no need to create openings in the bottom deck that could let air escape.
**Adding Drive Fans to the Top Deck**

There are two ducted fans, the drive fans, mounted to the top side of the top deck that act as the wheels and motors of the HoverBot. There are no commercially available brackets for these ducted fans; therefore, you’ll have to make brackets with two blocks of blue Styrofoam.

![Figure 25. The dimensions of the drive fan brackets. The brackets are Styrofoam and easy to cut with a hot knife. The Hobby Lobby sells the perfect electric knife next to the Cellfoam 88.](image)

Cut two blocks of Styrofoam to one inch deep and two inches wide. The ducted fan is 2-1/8 inches in diameter, so find or make (on an index card and a compass) a circle template 2-1/4 inches in diameter. Use the circle template to draw a semicircle at the face of the block (the two inch wide face) that drops ¼ inches below the top of the Styrofoam block as shown in figure 25. If you don’t have access to a template, then hand draw an arc in the front of the Styrofoam block (while it’s not vital the arc be part of a perfect circle, draw it as closely as possible). Try also to draw the semicircle as centered as possible.

Then use a hot knife to cut out the semicircles out of the top of the Styrofoam blocks. Without a hot knife, it’s more difficult to cut out this arc since the block is one inch deep. Without a hot knife, you’ll have to cut out the arc with an Exacto knife and finish with sandpaper.

Glue the ducted fans into their brackets with a little hot glue. Be careful, the ducted fan’s plastic housing is made of flexible plastic and tends to warp when squeezed. And when warped, the blades of the fan will not spin freely since they will rub against the wall of the jacket. So apply some hot glue into the semicircular canal in the bracket and gently set the fan into the bracket. Note that it does not take much hot glue to hold the ducted fans into place. The fans will push the HoverBot, but not so strongly, that they can rip themselves out of their brackets.

Then mount the ducted fans and brackets to the top side of the top deck with hot glue. The brackets position the fans on the edges of the top deck as shown in figure 26.
Now test fit the top deck to the bottom deck.

- Slide the plastic spacers over the riser bolts in the bottom deck
- Place the lift fan into the lift fan bracket on the bottom deck
- Pass its lift fan’s wires through the opening in the top deck
- Mount the top deck on the bottom deck

As you mount the top deck, its lift fan will slip tightly over the top of the lift fan. Make sure the top deck sits flush to the spacers on the riser bolts and that the lift fan is snugly trapped between the lift fan clamps glued to the top and bottom deck.

Figure 26. A front view of drive fan glued to a Styrofoam block and mounted to the outside edge of the top deck.

Figure 27. The top deck is stacked above the bottom deck with the four risers and their spacers. Holding the lift fan in place is the Cellfoam 88 fan brackets glued to the top and bottom deck.
**HoverBot Electronics**

The EDF-50 ducted fans draw nearly two amps of current and using a traditional transistor switch would mean losing 0.7 volts of the fans’ voltage and dumping 1.4 watts of heat through the transistor. Therefore, the HoverBot uses DPDT relays instead of transistors or MOSFETs. The relays have a must-latch voltage of five volts but a coil resistance lower than most robot controllers will like. To get around the high current requirements of the relays, the HoverBot drive electronics uses 2N3904 transistors to source the current for each relay. The current required to operate the transistor is so small there is very little wasted power (about 210 mW) switching on and off a relay with it. The HoverBot uses five relays in two circuits to control the three ducted fans in the HoverBot.

**Lift Fan Circuit**

The first circuit is the one that controls the main lifting fan. This circuit gives the HoverBot the ability to take-off and land under automatic control (pretty cool). It only takes the HoverBot a second to fill its skirt and lift off or to dump its skirt and land. To reduce the number of different parts, the HoverBot uses the same relay for both the lift fan and the drive fan circuits. The fact that the HoverBot only needs a SPST relay to control the lift fan means the circuit wastes half the relay. While probably not necessary, a reversed biased 1N4001 diode across the relay coil protects the robot controller from the relay coil’s kickback when it shuts off.

![Figure 28. Just a typical relay circuit. The robot controller saturates the base of the 2N3904 with 4.3 mA of current so the transistor will let current flow to the relay coil. The closed contacts inside the relay then route current to the lift fan without a voltage drop to the fan. Note that the schematic only shows the normally opened side of the DPDT relay, the normally closed side is not used.](image)
Figure 29. The relay switch printed circuit board (PCB) for the lift fan. Six components are soldered to it.

The three large holes in a row on one end of the PCB are strain relief for the wires connecting the circuit to the robot controller. The four larger pads in the corners of the PCB are its mounting holes.

Figure 30. This is the placement of parts for the lift fan circuit. The arrangement of three wires of the circuit’s control cable (the three wires on the right side) is the same as a servo.

Parts List for the Lift Relay Circuit Board
NEC DPDT relay EC2-5NJ
1N4001 diode
2N3904 NPN transistors
1/4W 1k-ohm resistors
#24 gauge stranded wire
Two 1 by 2 pin receptacles (cut out from a 1 by 20 pin receptacle)

Assembling the Lift Fan Circuit

First, make the 1 by 2 receptacles
- Pull out the third pin from the end of a 20 pin receptacle (there are two in the kit)
● Cut through the empty third socket (making a 1 by 2 pin receptacle with a raw edge)
● Sand the raw edge smooth (not electrically necessary, but important for looks)
● Sand the raw edge of the remaining receptacle smooth
● Pull the third pin from the end out of the shorter receptacle
● Cut through the empty third socket
● Sand the raw edge smooth
● Sand the raw edge of the remaining receptacle smooth

**Solder the components to the printed circuit board**

Note: After soldering a component, clip its leads. They should be flush with the cone of solder holding them to the printed circuit board.

● Bend leads of 1k resistor (brown, black, red, gold or brown, black, black, brown, brown), insert into board, and solder to PCB (resistor can be soldered in any orientation)
● Bend leads of diode (1N4001), insert into board with silver band closest to wire strain relief), and solder to PCB (the line in the top silk has the correct orientation)
● Widen leads of transistor (2N3904), insert into the board with flat face of transistor aligned with flat face in top silk (as shown in figure above), and solder
● Insert orange relay into board and solder
● Insert and solder the 1 by 2 receptacles

**Assemble the lift fan control cable**

● Cut three pieces of wire one foot long
● Strip ¼ inch of insulation from one end of all three wires
● Twist the ends of each wire tightly
● Insert the stripped end of one wire into its strain relief hole (from underside of board)

Note: insert the first wire into the hole marked GND. Use a black or green wire if there are multiple colors of wire. If the wires are the same color, then a black or green piece of heat shrink tubing will be used later on this wire.

● Bend wire over and insert into solder pad marked GND
● Solder the wire

![Figure 31. The wires being soldered to the lift fan circuit are strain relieved as shown above.](image-url)

● Repeat for the +5V wire and the Signal wire
- Strip ¼ inch of insulation from the other end of all three wires
- Twist the ends of each wire tightly
- Tin each wire

Note: Tin by heating end of wire with a soldering iron and apply just enough solder to soak into the wire. The wire will be stiff but not dripping with solder.

- Cut one piece from the 1 by 20 pin header that is three pins long
- Insert the three long pins of the header into a receptacle

![Image of a 1 by 20 pin header]

Figure 32. The receptacle can be the I/O ports of the robot controller, a piece of scrap, or the receptacle for the H-Bridge. By inserting the long pins into a header, the pins are held in the proper orientation during the next steps.

- Quickly tin the pins on the short pin side

![Image of a header with labels: Signal, +5 volts, Ground]

Figure 33. Each pin in the header has a function (the view of this header is head on). The center pin is the +5V pin in order to protect the robot controller and/or lift circuit if the cable is accidentally plugged in backwards.

- Cut ¼ inch of heat shrink tubing and slide over the tinned (and cooled) wire

Note: If the wires are all the same color, slide piece of black colored heat shrink over the ground wire and lighter colored heat shrink over the other two wires.

Note: Push the heat shrink down the wire so it can’t get hot during the next steps. This prevents the heat shrink from shrinking on the wire while you solder it to the header pins.
Figure 34. These three wires will be soldered to the short side of a three pin header. The three pin header was removed from the receptacle only to show the wires are soldered to the short pins. Note that this is a servo cable, so your wires will look different.

- Place the tinned ground wire in contact with the short side of the ground pin of the three pin header

Note: Trace the wire back to the printed circuit board to verify it is the ground wire (that it is the wire soldered to the pad marked GND).

- Tin the soldering iron (melt a small amount of solder on the tip of the soldering iron)
- Heat the tinned wire and the header pin until the solder melts and they fuse together
- Repeat for the +5V wire and solder it to the center pin
- Repeat for the signal wire and solder it to the remaining end pin
- Slide the heat shrink tubing over the soldered header and shrink
- Remove the header from the receptacle

Figure 35. Your finished cable will look similar to this one.
The lift fan cable plugs in one of the robot controller’s output ports (an input port will not work). Which port is used is not important as you can modify the HoverBot program to use that particular port to cause the HoverBot to lift off and land.

**Lift Fan Battery Pack**

Rather than solder the lift fan’s battery pack to the circuit, solder a two-pin header to the end of the battery pack cable. This allows the battery pack to be plugged into the circuit board after the HoverBot top deck is assembled.

- Cut one piece from the 1 by 20 pin header that is two pins long
- Insert the two long pins of the header into a receptacle
- Tin the short pins
- Tin the bare leads of a three cell “AAA” battery pack
- Slide short pieces of heat shrink tubing over the battery pack wires
- Place a battery pack lead in contact with a tinned header pin

Note: Which header pin you solder each battery wire is not important

- Heat the tinned wire and the header pin until the solder melts and they fuse together
- Repeat for the other wire and header pin solder them together
- Slide the heat shrink tubing over the soldered header and shrink
- Remove the header from the receptacle

![Figure 36. The completed battery pack leads look like this.](image)

**Drive Fan Circuit**

Unlike the lift fan circuit, the drive fan circuit uses both sides of its DPDT relays and like other H-Bridges, it requires two input pins to operate each drive fan. Two input pins have four combinations of outputs. When both input pins are set the same (both either HIGH or both LOW), the voltage across the fan output are the same so there is no voltage difference to drive the fan’s motor. Setting the input pins opposite to each other (one
HIGH and the other LOW), creates a voltage difference across the fan output and fan motor spins either clockwise or counter-clockwise.

<table>
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<th>Input #1</th>
<th>Input #2</th>
<th>Fan</th>
</tr>
</thead>
<tbody>
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<td>LOW</td>
<td>No Spin</td>
</tr>
<tr>
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<td>HIGH</td>
<td>Forwards</td>
</tr>
<tr>
<td>HIGH</td>
<td>LOW</td>
<td>Backwards</td>
</tr>
<tr>
<td>HIGH</td>
<td>HIGH</td>
<td>No Spin</td>
</tr>
</tbody>
</table>

Table 1. The H-Bridge (consisting of two relays) for each fan requires two input signals to control the direction the fan spins (and therefore the direction of its thrust).

Figure 37. This is the schematic for one of the drive fan’s H-Bridges (this circuit is duplicated on the PCB for the other drive fan).

Figure 38. The two pairs of four holes at the bottom of the printed circuit board are the strain relief of the wires connecting the circuit to the robot controller. The four larger pads in the corners are for mounting the PCB to the top deck (however, only two of them are used).
Figure 39. Watch that you do not solder the transistors and diodes backwards when you assemble the relay H-Bridge. The H-Bridge circuit is very similar to the Lift Fan circuit.

Parts List for the H-Bridge Circuit Board
Four NEC DPDT relay EC2-5NJ
Four 1N4001 diode
Four 2N3904 NPN transistors
Four 1/4W 1k-ohm resistors
#24 gauge stranded wire
Two 1 by 2 pin receptacles (cut out from a 1 by 20 pin receptacle)

Assembling the H-Bridge Circuit
Make the 1 by 2 receptacles
● Pull out the third pin from the end of a 20 pin receptacle (there are two in the kit)
● Cut through the empty third socket
● Sand the raw edge smooth
● Sand the raw edge of the remaining receptacle smooth
● Repeat a second time to create another two pin receptacle

Solder the components to the printed circuit board
Note: After soldering a component, clip its leads. They should be flush with the cone of solder holding them to the printed circuit board.
• Bend the leads of 1k resistor (brown, black, red, gold or brown, black, black, brown, brown), insert into board, and solder to PCB (resistor can be soldered in any orientation)
• Bend leads of four diode (1N4001), insert into board with silver band closest to wire strain relief), and solder to PCB (the line in the top silk has the correct orientation)
• Widen leads of four transistor (2N3904), insert into the board with flat face of transistor aligned with flat face in top silk (as shown in figure above), and solder
• Insert four orange relay into board and solder
• Insert and solder the 1 by 2 receptacles

Assemble the H-Bridge control cable
• Cut four pieces of wire one foot long
• Strip ¼ inch of insulation from one end of all four wires
• Twist the ends of each wire tightly
• Insert stripped end of one wire into its strain relief hole (from underside of board)
• Bend wire over and insert into solder pad marked GND
• Solder the wire
• Repeat for the +5V wire and the two Signal wires
• Strip ¼ inch of insulation from the other end of all four wires
• Twist the ends of each wire tightly
• Tin each wire

The next steps assume your HoverBot is using a CheapBot controller and that the Toshiba H-Bridges ARE NOT soldered to the circuit board. The HoverBot relay H-Bridge replaces the Toshiba H-Bridges that come with the CheapBot kit.

• Cut two strips from the 1 by 20 pin header that are seven pins long
• Insert the header into a receptacle
• Select one end to start with and tin pins 1, 2, 4, and 7 (tin the short pin side)

![Figure 40. Only four of the pins in the seven pin header have a function. The header plugs into a CheapBot robot controller in place of an H-Bridge.](image)

• Cut ¼ inch of heat shrink tubing and slide over the tinned (and cooled) wire
• Place the tinned ground wire in contact with the short side of the Signal-1 pin of the seven pin header
• Tin the soldering iron (melt a small amount of solder on the tip of the soldering iron)
• Heat the tinned wire and the header pin until the solder melts and they fuse together
• Repeat for the Signal-2, Ground, and +5V wires
• Slide the heat shrink tubing over the soldered header and shrink
• Remove the header from the receptacle
• Repeat for the other H-Bridge cable

Figure 41. The completed seven pin header that will plug into the CheapBot robot controller in place of a Toshiba H-Bridge.

Modifying a CheapBot Robot Controller
DO NOT solder the Toshiba H-Bridges to the robot controller. Instead, solder a seven pin receptacle in place of the H-Bridge. Afterwards you can still plug the Toshiba H-Bridge into the receptacle (if you want to use it to control a traditional robot). Otherwise, follow the direction for the CheapBot robot controller and assemble it.

When plugging the Relay H-Bridge into the receptacles, the +5V wire is on the end of the robot controller closest to the motor ports (this is pin #7). The two signal wires (pins #1 and #2) are on the other end, closest to the microcontroller.

Figure 42. In place of the Toshiba H-Bridges, the relay H-Bridge cable plugs (circled in red) into the receptacles on the CheapBot robot controller.
Put It All Together
All the HoverBot’s electronics, the lift fan circuit, drive fan circuit, robot controller, and the battery packs attach to the top deck. Do not bolt them to the bottom deck as that breaks the air tight seal of the skirt and makes it difficult to move the electronics around at a later time. Position the electronics on the top deck so it distributes their weight as evenly as possible. I also suggest placing as many items as close to the center of the deck as possible.

How to Attach Items to the Top Deck

<table>
<thead>
<tr>
<th>Battery Packs</th>
<th>Attach with a pair of #4-40 flat head bolts and nylocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lift Fan Circuit</td>
<td>Attach with four #2-56 bolts, nylocks, and nylon spacers</td>
</tr>
<tr>
<td>Drive Fan Circuit</td>
<td>Attach with two #2-56 bolts, nylocks, nylon spacers, and neoprene foam</td>
</tr>
<tr>
<td>Power Switches</td>
<td>Punch a hole through Correplast and attach with nuts</td>
</tr>
<tr>
<td>Robot Controller</td>
<td>Attach with four #2-56 bolts, nylocks, and nylon spacers</td>
</tr>
</tbody>
</table>

Figure 43. Use two small nylon spacers, #2-56 bolts, nylocks, and a sheet of foamed neoprene for the H-Bridge circuit. A small squirt of hot glue will also help hold it in place. Unfortunately, the relays are too large for the other two #2-56 bolts.
Figure 44. The top view of the HoverBot. Your placement of parts doesn’t need to
be exactly like this one. Also note, your fans haven’t been plugged into the circuit
boards yet like this one.

Extending the Wires of the Ducted Fans
The length of the ducted fan wires are too short to reach the electronics on the HoverBot
top deck. Since GWS nicely terminated the wires, we’ll extend the wires by splicing
additional wire to the middle of each wire. The method described below is an acceptable
method because once the HoverBot is complete, the wires will not be pulled on.

Note: Each fan needs a different length cable to reach its circuit board. Take this into
consideration when extending their cables. There’s no need to splice longer than
necessary wires and end up with large, loose loops of wire like the ones you see in figure
44.

- Cut both wires of the EDF-50 somewhere near the middle
- Strip ½ inch of insulation from all six wire ends
- Tin the bare ends
- Cut the wire remaining in the kit into three pairs
● Strip ½ inch of insulation from all six wire ends
● Tin the bare ends
● Place one tinned extension wire in contact with a tinned ducted fan wire
● Heat with a tinned soldering iron to fuse the wires together
● Slide a short piece of heat shrink over the soldered wire and shrink
● Repeat for the remaining five extension wires and five ducted fan wires

At this point, the ducted fans have extended leads. Now you will splice the nicely terminated ends back on the wire.

● Slide a piece of heat shrink tubing over the extended ducted fan leads
● Place one tinned extended wire in contact with a tinned terminated fan wire
● Heat with a tinned soldering iron to fuse the wires together
● Slide a short piece of heat shrink over the soldered wire and shrink
● Repeat for the remaining five extended fan leads and the terminated fan wires

![Diagram of heat shrink tubing and extension]

Figure 45. The extension to the ducted fan wires is soldered somewhere in the middle of the cable. The exact location is not important. By extending the cable this way, we can retain the nicely terminated cable that GWS includes with the EDF-50 ducted fan.

Power for the HoverBot
I use alkaline batteries, but lithium batteries are much lighter than alkaline batteries and as I understand, they are used in electric airplanes. However, I’m not certain commercial “AAA” lithium cells can provide the two amps of current the HoverBot’s ducted fans need. You will want to experiment with alkaline and lithium cells.

Double Check Connections
At this point, verify the following connections.

<table>
<thead>
<tr>
<th>Connection</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive Fan Circuit</td>
<td>Plugged into the robot controller in place of the H-Bridges</td>
</tr>
<tr>
<td>Drive Fans</td>
<td>Plugged into the receptacles in the relay H-Bridge circuit</td>
</tr>
<tr>
<td>Lift Fan</td>
<td>Plugged into the output of the lift fan circuit</td>
</tr>
<tr>
<td>Lift Fan Battery</td>
<td>Plugged into the power input of the lift fan circuit</td>
</tr>
<tr>
<td>Lift Fan Circuit</td>
<td>Plugged into a robot controller output port</td>
</tr>
</tbody>
</table>
Controlling the HoverBot
The HoverBot has the following functions

1. Lift Off
2. Land
3. Thrust Forwards
4. Thrust Backwards
5. Thrust Counter-Clockwise
5. Thrust Clockwise

Except for lift-off and land, the HoverBot has controls like traditional robots. The key difference is that the HoverBot does not change directions on a dime, it accelerates (this includes negative acceleration). This means that programming the HoverBot to stop by shutting off its drive fans will not stop it. Stopping the movement of the HoverBot (including spin) requires the drive fans produce an opposite thrust to counteract the initial thrust. This is analogous to satellite in space (there are no brakes in space).

Testing the HoverBot Lift Fan
First, test the lift fan by programming the robot controller to HIGH that the port the lift circuit is plugged into. So, if for example, the lift fan circuit is plugged into Output 0, then write and download the command, **HIGH 0**.
If the skirt fills with air, then the drive fan is plugged in correctly. If instead, the HoverBot wants to suck itself to the floor, then switch the polarity of the ducted fan by removing the fan’s wire from the lift circuit, turning it 180 degrees, and plugging it back in to the lift fan circuit.

Now write the following program and download it into the robot controller

```
HIGH 0
PAUSE 3000
LOW 0
END
```

Your HoverBot will lift off for three seconds and then land.

**Testing the HoverBot Drive Fan**

For the drive fans to generate thrust, their two inputs must be set opposite to each other. This means that if you program the following pairs of commands, the drive fans will not start (or will shut off)

- LOW 2
- HIGH 2
- LOW 3
- HIGH 3

On the other hand, when the inputs are set opposite to each other, the fans begin spinning. Which way they spin depends on how you plugged the fans into their drive circuit. Therefore, you will need to test each fan to see which pair of commands makes it spin in which direction.

For the CheapBot-14 robot controller, the outputs for one fan are 2,3 and for the other 4,5

For the CheapBot-18 robot controller, the outputs for one fan are 0,1 and for the other 2,3

Now, test each drive fan, one at a time with the following commands. Record which fan is beginning controlled and in what direction it spins

**Step 1, download the following three commands**

```
LOW 2
HIGH 3
END
```

**Step 2, download the following three commands**

```
HIGH 2
LOW 3
END
```

Now just repeat this for either 0,1 or for 4,5
Starting from a dead start, when combined, the left and right drive fans can make the HoverBot translate forward, translate backwards, turn clockwise, and turn counter-clockwise.

**Figure 47. Drive fans translating the HoverBot forwards and backwards.**

**Figure 48. Drive fans rotating the HoverBot clockwise and counter-clockwise.**

The subroutines to drive and turn the HoverBot are the same as a traditional robot. So for example, a HoverBot might use the following subroutine to thrust forwards (by thrusting both drive fans forwards).

```
Forwards:
    high 2
    low 3
    low 4
    high 5
return
```

The HIGH 2 and LOW 3 run one drive fan forwards and the LOW 4 and HIGH 5 runs the other drive fan forwards. Which combination of HIGHs and LOWs will run your HoverBot’s drive fans depends on how the fans are plugged into the control circuit board. Therefore, you will have to experiment with your HoverBot settings.

**Warning!**

Although if may not harm your drive fans, don’t slam them from spinning in one direction to another. Give them ½ second of down time before reversing their direction of spin. This means setting both their inputs LOW for 500 milliseconds (there is an example below).
Remember, once the drive fans are shut off (by LOWing both inputs), the HoverBot will not stop. It will continue its present motion until a counteracting force is given. Not only must a counteracting force take place, but also the length of time it must take place will be nearly the same length of time that put the HoverBot into its present state of motion. The reason the counteracting force will be slightly shorter duration is that some drag (although small) will have slowed the HoverBot down.

So code to drive the HoverBot forward and then to stop it will look something like the following

```
LOW 0            ' translate forwards
HIGH 1
HIGH 2
LOW 3
PAUSE 5000       ' for five seconds
LOW 0            ' glide with no thrust
LOW 1
LOW 2
LOW 3
PAUSE 500        ' for 0.5 seconds
HIGH 0           ' reverse thrust
LOW 1
LOW 2
HIGH 3
PAUSE 4750       ' for 4.75 seconds
LOW 0            ' stop the drive fans
LOW 1
LOW 2
LOW 3
```

Notice how long the code above is? Since the commands to translate and rotate are so prevalent in a HoverBot code, it’s best to write them into subroutines and then call them with a GOSUB command.

Sounds simple, right? Well, a HoverBot may have tendency to rotate, even when programmed to only translate. There may be three possible sources of this anomalous rotation.

A. Asymmetry in the skirt
B. Variations in the thrust of the drive fans
C. Counter torque from the lift fan.

Perhaps asymmetry in the skirt produces unbalanced jets from the HoverBot’s lift nozzle. If so, then it’s important to tape the plastic sheet to the bottom deck with as few wrinkles (or at least as evenly spaced wrinkles) as possible. Once taped to the bottom deck, the
skirt is difficult to remove it without damaging it. Therefore, it pays to spend time carefully attaching the skirt.

Perhaps there is a small variation in the thrust between drive fans and that small variation in thrust, in a nearly frictionless environment is producing rotation. Until there is a way to test the thrust of fans, there’s no way to know how closely fans match each other. Since I don’t believe it’s realistic to use a rheostat to adjust the spin of a ducted fan, an asymmetry produced by mismatched fans may be something the HoverBot must be programmed to fix.

Perhaps a small source of the HoverBot’s spin is due to the counter torque of the spinning lift fan. The ducted fan blade spins fast, but has little mass. There’s greater mass in the spinning armature inside the fans motor, but its radius is even closer to the center of rotation. Combined, the torque from the spinning ducted fan and armature should be small compared to the rest of the HoverBot. However, the HoverBot is floating on a nearly frictionless cushion of air and perhaps even a tiny torque adds up over time. This is another potential source of anomalous rotation the HoverBot will have to be programmed to respond to.

25 October 2010