Lab notebook for independent study class
"Building a Micro Helicopter that actually flies"

May 18th, 2000

Status before semester

I have built a prototype autonomous micro helicopter during fall 1999 semester for class "How To Make (Almost) Anything" which is documented in detail at http://www.media.mit.edu/~stefanm/HowTo/ZeroGEye.html. Due to late arrival of essential electronic components, the prototype had to be built within 24 hours. Many problematic issues were ignored for the sake of having a prototype with limited functionality. The main point was to show that such a micro helicopter can be built and should work, especially the autonomous control loop between sensors and actuators, no flying capability was required (too difficult for the short time). During the final class presentation and later, I have showed a successful control loop in action: as soon as the sensor measures a deviation from the user defined hovering position, the flaps are activated to steer it back to its initial position in space.

However, the helicopter has not flown yet on its own. The web documentation mentions that "…Although all subsystems and elements are working properly, including propulsion, control, radio link, etc., I first want to charge the batteries properly, and then make sure the helicopter can't crash easily. To do that, I will build some kind of scaffold or suspension." Therefore, the list of future improvements includes:

1. Make carbon fiber ring around propeller and flap hinges to protect the propellers and increase the efficiency of the fan (see later: "Hiller" effect of a shroud)
2. Replace the balsa flaps with carbon fiber ones to make them more stable
3. Get real clavises (lighter, more stable)
4. Replace styrene fuselage square tube with carbon fiber one
5. Hang vessel from ceiling and/or walls with rubber bands for test flights
6. Find reason for occasional stalling of servos, which makes them draw up to 600-800 mA current
7. Mount camera and transmitter
8. Look for a head lock gyro or magnetic heading sensor and additional serial back channel
9. Test other absolute position sensors, like the (wired) Polhemus tracker
10. Think about simple sensor scenarios which are independent from a ground station, like measuring optical flow of an upwards looking Artificial Retina chip
11. Add a speech interface to the PC software, e.g., using IBM ViaVoice

Most of these issues (1 to 5) deal with the fact that the prototype is mechanically weak. A crash would probably destroy several parts. Increasing the mechanical strength of the elements by replacing balsa and plastic parts with custom-made carbon fiber parts is an obvious and common solution.

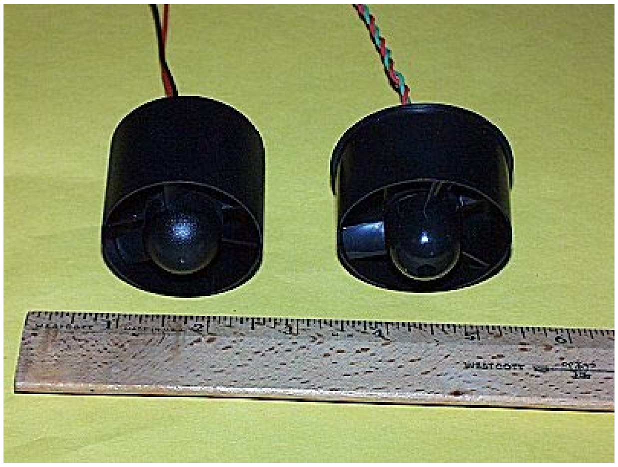
Other points deal with inherent design problems (8, 9), e.g. that the sensor errors of the gyro will eventually add up to an extend that would make the helicopter crash. How long it could keep it from rotating of the yaw axis is not clear.

However, the most important fact is that the helicopter doesn't fly in its current configuration. Although the thrust of the propulsion system (91grams) would be enough to lift it (82 grams), practical tests showed that the lift is less than expected. There are several possible reasons: the new battery does not (yet) deliver enough current; the wiring eats up too much of the current; the aerodynamic properties of my construction (flaps!) limit the thrust.

Main goal for this semester is therefore to find the reason why it is not flying, and to get rid of initial design flaws (gyro, flaps, etc.) In order to solve the former problem, other propulsion options should be explored (more efficient ducted fans, multiple propellers, other battery types, etc.) To solve the latter, other sensors should be considered (e.g., micro compass).

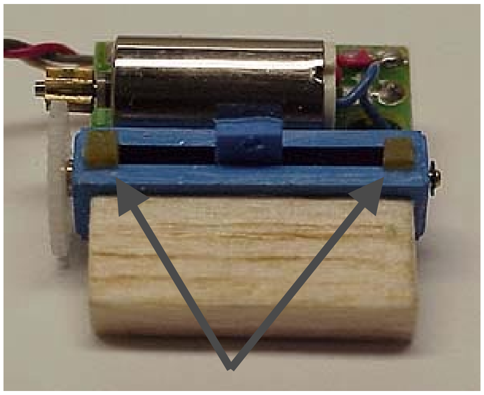
2/14/2000

I have gotten a new and smaller ducted fan EDF200 from **Robert Wagoner,** Electric Jet Factory (http://www.ElectricJetFactory.com/index.html?itemedf200.html). It is supposedly much better than the two ones I already have. I will test the thrust of it along with the other propellers on the new scales I bought (Soehnle Ultra). To do so, I have to build something out of balsa wood to mount them; I just bought the balsa.



New EDF 200 (left) compared to old Cox/Estes. It is even smaller in diameter, but uses the same motor with a different nominal voltage..

I have also fixed an expensive micro servo that seemed to be stuck, and I got information about enhancing it (http://www.rcmicroflight.com/nov99/technik_servo.asp). It is part of a newsletter called *RCMicroflight*, and I have subscribed to this very helpful publication.



Modification of WES servo: with these rubber parts (reed arrows), it is less likely to get stuck at the end

2/16/2000

Did some thrust measurements with the EDF200. The motor looks like the one from Cox/Estes fan, a Mabuchi FK-130SH (http://www.mabuchi-motor.co.jp/mot/motor1/fk-130rhsh.html), but it is probably a different version (different nominal voltage). It is supposed to be a shaver motor with nominal 4.5V.

Robert says on his web page: It has a weight of "1.2 oz. with motor and can produce 4.0 oz. of static thrust on 6 cells." That would be 115 grams of thrust at 7.2V. He used 6x 250 mA (AAA) NiCds, drawing 5.4A. Max Ampere for this motor is 8A.

The tests were conducted with a 1000W HP lab power supply.

Thrust measurements: The ducted fans were mounted on a bent aluminum tube that is reinforced with plywood at the corners. The whole construction was taped onto the Soehnle scales that can measure the thrust with an accuracy of 0.1 grams. The HP power supply can deliver 0-20V, 0-120A, max 1000W.

Results of motor 1:

Volts	Ampere	Grams trust
3	5.1	31.6
5	10.5	62.7

These numbers are different from Robert's factory data: the current that the motor draws is much higher, and the thrust much lower. After having tested this propulsion set with voltages up to 9V, it dies.

I ordered four replacement motors from Robert ($4 each) and asked for his opinion on my data.

03/04/2000

Kai Huber (http://home.t-online.de/home/e-huber) sends me extensive comments about my web page of the Zero-G-Eye (FFMP prototype).

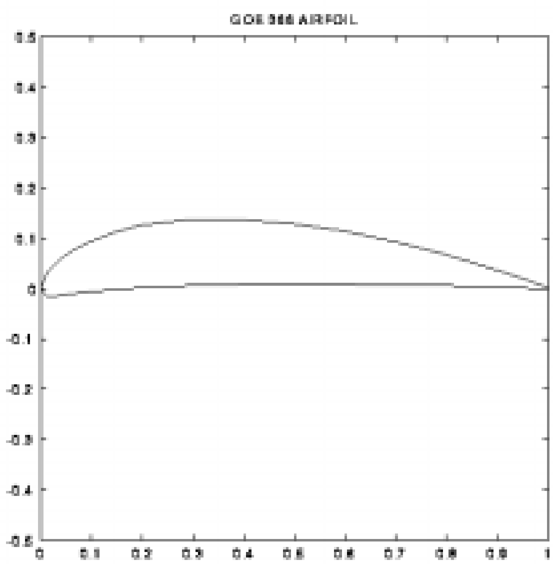
Ducted fans: He thinks that impellers are not useful because their efficiency is by far the lowest of all propulsion options. The problem is that the lift is the product of the diameter of the airflow (diameter of ducted fan) and the air speed (which is itself product of propeller RPM and its pitch). The smaller the diameter, the faster the air has to be to produce enough lift. Since the system is not moving in the air, but standing still (100% "slip"), there is an enormous drag between the surrounding still air and the highly speed up air of the impeller, especially since it is twisted, which reduces the efficiency furthermore.

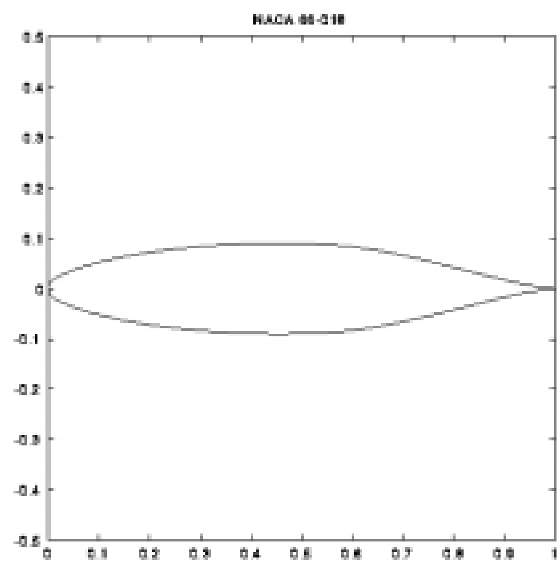
Coreless and brushless motors: He also thinks that coreless motors are heavier than conventional ones because they have heavier permanent magnets. He thinks that 1A current is very low, most of the slow flyers draw 3A. He thinks that WES is charging a too high price: coreless motors can be bought much cheaper. (LEMO-SOLAR has a "bag of motors" for DM25.) He also thinks that brushless motors have a problem with our normal ESC: they do not like the clocking of the voltage, and the built in electronics are clever enough to prevent from any overload (slowflyer usually overload the motor heavily). Additionally, they often are made very stable, double ball bearings, etc. which makes them heavy.

Video transmitter: He thinks FM transmitters are worse than UHF, but 10 times lighter. The FM signal might interfere with the FM radio receiver. Furthermore, he thinks that the battery of the video system has to be separate from the motor batteries.

Flaps: Most importantly, he estimates that in my prototype, 30% of the trust is being used to compensate for the torque reaction. Currently, the flaps have no airfoil and therefore would probably need a pitch angle of 30 degrees. The airflow from the propeller is twisted in the other direction, so that the air hits the flaps almost perpendicularly. The airflow will be very turbulent, and this part of the air stream (30%) does not provide for any thrust anymore.

One option to change that would be using a half-symmetric airfoil for the yaw flaps (e.g., Goe366 or 367, see below), so that the dynamic lift helps the flaps to compensate for the torque reaction. With this airfoil, the pitch angle does not have to be that big. He also suggests a symmetrical airfoil for the other four flaps, e.g., NACA symmetrical (see below), so that the drag will be minimized if they are in perpendicular position. Furthermore, the hinge point of the flaps has to be at 30% of the flap depth (not 50%) in order to making them torque free. Torque free servos are very important since I have already experienced stalling (and breaking) servos in my prototype. (Perhaps 25%? See http://www.patents.ibm.com/details?&pn=US05746390__)





However, the best solution for the flap and thrust problem would be using two propellers, counter rotating. He has built a prototype and sends me a picture and an animated GIF (see below): 4 balsa rotors 85mm long (diameter rotor 170mm), pitch angle 15 degrees. At 5V and 500mA the propellers lift themselves, and at 10V and 1.5A they have a lift of 100 grams, he estimates. He suggests for me 4 balsa rotors 100mm long and 25mm wide (chord), 3mm deep, with an airfoil (or Depron, a more robust Styro (http://mx8.xoom.com/gjkool/whatisdepr.htm), or balsa with rovings?). Guessing from his pictures, he is using acetal gears, module 0.5 bevel gears, 2mm fixed carbon axles and Teflon tubes
(Conrad electronics, http://www.conrad.de/cgi-bin/conshop/ConShop.pl?TK_PAR[USER_ID]=0403035190952389053&TK_EV[SHOWPAGE]=&TK_PAR[PAGEID]=2170&TK_PAR[MEDIUM]=62).
He uses an MK421A (at Norbert Ladenburger for DM10, http://www.ladenburger-slowfly.de/), a cheap motor that at max 6V draws 1A. Other motors might work also.

With coaxial counter rotating rotors, no thrust is being used for torque reaction compensation. The downside is the necessary gear: having three axles instead of one makes it very unlikely that it will be as efficient as my current one (97%).

Coax counter rotating rotors by Kai Huber. The rotor airfoil design is not very sophisticated, e.g., not taking in account downwash from upper rotor. The pitch angle and probably the airfoil itself should be different for the upper and lower rotor.

He also suggests using only three symmetrically profiled flaps instead of four, and mixing the signals beforehand in the transmitter or computer. This is a good idea, but it works only if the vessel has an additional sensor for heading (compass), and an additional back channel to the computer. The advantage would be reducing the servo and flap weight to 75% as well as getting rid of the inherently unstable control loop between high gain gyro and yaw servo. The disadvantage would be increased weight due to compass, A/D converter and transmitter.

03/05/2000

EDF-200 replacement motors arrived, did some more thrust measurements:

Results of motor 2 (in brackets: result of motor 1):

Volts	Ampere	Grams trust
1	1.5	5.1
2	3.2	18.1
3	5.3 (5.1)	33.7 (31.6)
4	6.7	42.8
5	8.7 (10.5)	57.1 (62.7)

I stopped at this point, because the motor was getting very hot. I think it this ducted fan takes much more current that what I can give (max 1A), and is probably much louder than bigger propellers. There is still the difference in thrust to the data I got from Robert that I can only explain with a missing intake lip (see below).

I might do more tests with 6 cell NiCd batteries later.

03/06/2000

The 10x 3V lithium batteries arrive. (After having sent me the wrong product, the retailer sends it to the wrong ML room number...)

They are 3V (probably 750mAh) primary lithium cells, 10.6 grams. 9V are 33.3 grams, which is only 1.8 gram more than the NiCds. At a 1A load, they give probably only 425 mAh, which is more than **ten times** better than the NiCds (http://www.rcmicroflight.com/jan00/cloud9_01.asp). The only downside is the price: each 20 minute flight will cost in average $18. However, I have bought some for $9 (3x $3) (http://www.filmshop.com).

03/06/2000

Reading the new RC Microflight: new trends in microflight are: IR (infrared) transmitter/receiver sets, and proportional magnetic actuators instead of electro motors. Several new products based on these technologies will come available soon. They will be even lighter than the current radio/electric components, but have downsides like lower range and less omnidirectional (IR).

03/07/2000

Asked **Robert Wagoner** why he gets that much thrust out of an EDF-200. He suggests using a rubber rounded intake ring, fuel tubing, 1/8 or 3/16 inch diameter. (A shroud is supposedly increasing the thrust of a ducted fan by 40%! See below for details.)

03/13/2000

Talked to **Marc Doyle** from *Dupont* about battery options. He says that there are no secondary batteries with specs 1.1 A, 9 V, <30 grams, but he was looking only at single cells, no 9V blocks, and they are usually lower current.

He thinks that there is no problem with discharging Lithium cells with very high currents: they will produce heat and give only live a fraction of their normal time.

He says also that Lithium Thionyl Chloride batteries from small US government battery vendors (SAFT, Battery Engineering) might be best, but he does not know if they have the small ones that I need.

Web search:

- *Battery Engineering*: http://www.batteryeng.com/prod_lithium_thionyl.htm
- *Saft*: http://www.saft.fr/plithium/html/sftlp16a.htm
- *Tadiran*: http://www.tadiranbat.com/index2.htm
- *Lisun*: http://www.lisun.com/main/chanp/er14505m/14505m.htm)

I don't think that either of these can deliver the current I need for the required weight. I have emailed *Battery Engineering* for details.

03/13/2000

Current measurements with 8x 50mAh NiCds (Sanyo) vs. 3x 750mAh Lithium CR2 (also Sanyo)

	NiCd	Lithium
Receiver and gyro		
(no yaw servo)	28 mA	same
+ 1 servo	max 320 mA	same
+ 2 servo	max 520 mA	same
Motor full alone	max 910 mA	max 750 mA
	(decreasing fast!)	(decreasing slow: 1 mA per 2sec)
Motor full + 2 servos	1010 mA	?
Volts initially	10.6 V (?)	9.51 V
Volts after ca 60 secs	?	8.71 V
Weight	31.5 g	37.7 g, incl. heavy wires

It seems like these lithium primary batteries are limited to 0.75A max current. However, since their nominal capacity is 15 times higher than the NiCd, they hold way longer. However, given the 1.1A current that my propulsion system draws, they are not an option right now.

03/14/2000

Talked to **Steve McClure** and **Sean Riley** from *Battery Engineering*. They do not have Lithium Thionyl Chloride batteries (LiSoCl2) that can do 9V/1.5A/<30g, and they don't believe that it exists. They suggest looking for lithium manganese dioxide cells, or looking for high rate, wound anode, Li/SOCl2 cells (http://www.greatbatch.com or http://www.tadiranbat.com/)

03/16/2000

Investigating the gear problem of counter rotating propellers, like in Kai Huber's prototype:
What should be the ratio for a motor gearbox, with the WES DC 5-2.4?

> WES drive: 6/40 teeth, 1:6.67, 20 cm propeller
> 6/48 teeth, 1:8.00, 23 cm propeller
> Rolf Daruk: 6/93 teeth, 1:15.6, 39 cm propeller
> (http://w1.421.telia.com/~u42106598/picture2.html)
> Question: How does a system with two 15cm propellers compare to single propeller systems: is it proportional to propeller diameter or total disk size? Very unclear. Probably just testing!

Ordered the following gears from SDP/SI (http://www.sdp-si.com/): All are metric, module 0.5, and acetal (some with brass inserts)

Bevel gears:
- 1:1 16 teeth, A 1M 4MYZ05, bore 3mm (1-142) x6
- 1:1 20 teeth, A 1M 4MYH05, bore 3mm (1-142) x6
- 1:2 20 teeth, A 1M 3MYH0520, bore 3mm (1-146) x3
- 40 teeth, A 1M 3MYH0540, bore 4mm (1-146) x3

Spur gears:
- Acetal:
  - 40 teeth, A 1M 2MYZ05040, bore 4mm (1-113) x1

45 teeth, A 1M 2MYZ05045, bore 4mm (1-113) x1
48 teeth, A 1M 2MYZ05048, bore 6mm (1-113) x1
52 teeth, A 1M 2MYZ05052, bore 6mm (1-113) x1
56 teeth, A 1M 2MYZ05056, bore 6mm (1-113) x1
70 teeth, A 1M 2MYZ05070, bore 6mm (1-113) x1
80 teeth, A 1M 2MYZ05080, bore 6mm (1-113) x1
90 teeth, A 1M 2MYZ05090, bore 6mm (1-113) x1

Acetal with brass inserts:

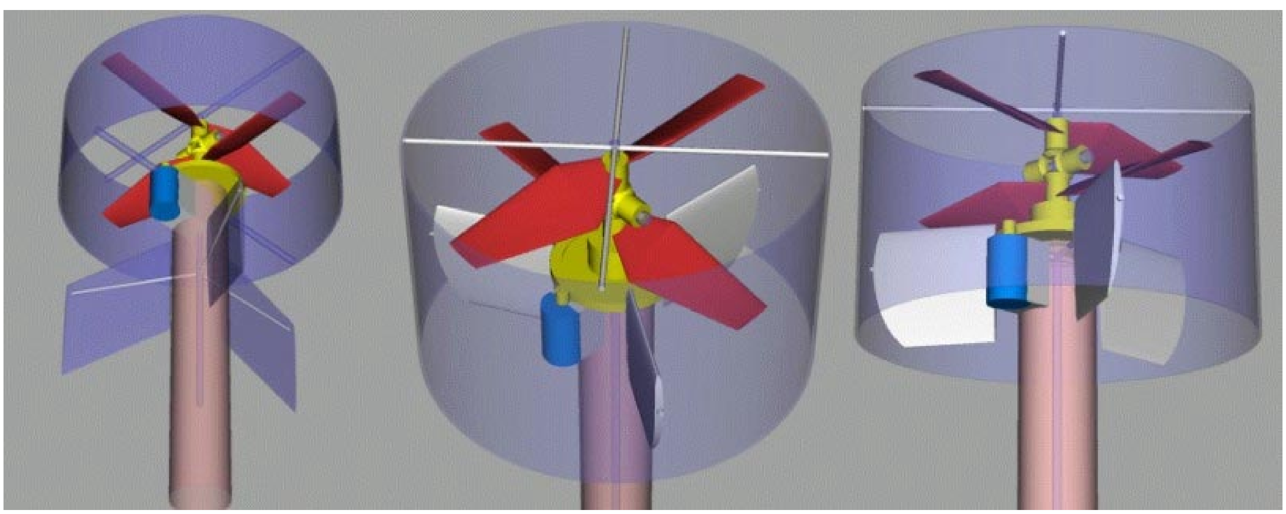
40 teeth, A 1Z 2MYZ0504004, bore 4mm (1-111) x1
45 teeth, A 1Z 2MYZ0504504, bore 4mm (1-111) x1
48 teeth, A 1Z 2MYZ0504806, bore 6mm (1-111) x1
(52 and 56 are not in stock)
70 teeth, A 1Z 2MYZ0507006, bore 6mm (1-111) x1
80 teeth, A 1Z 2MYZ0508006, bore 6mm (1-111) x1
90 teeth, A 1Z 2MYZ0509006, bore 6mm (1-111) x1

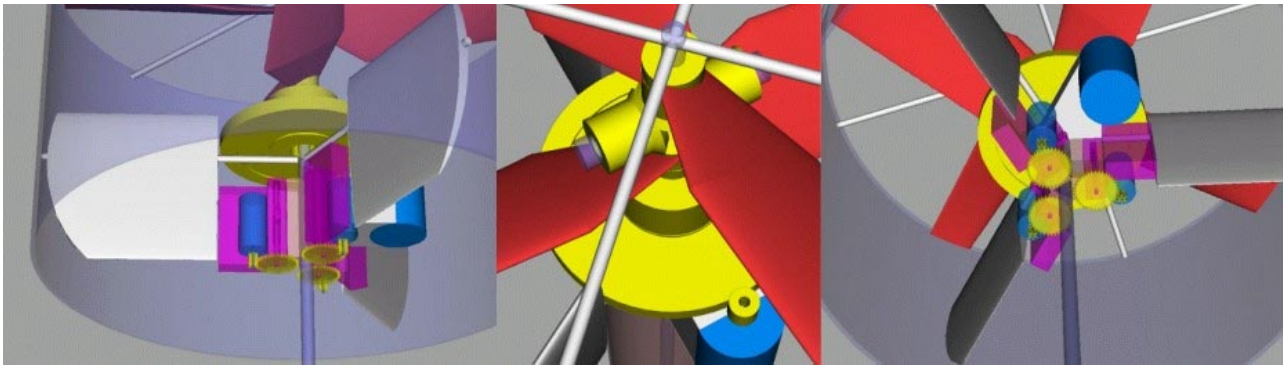
03/17/2000

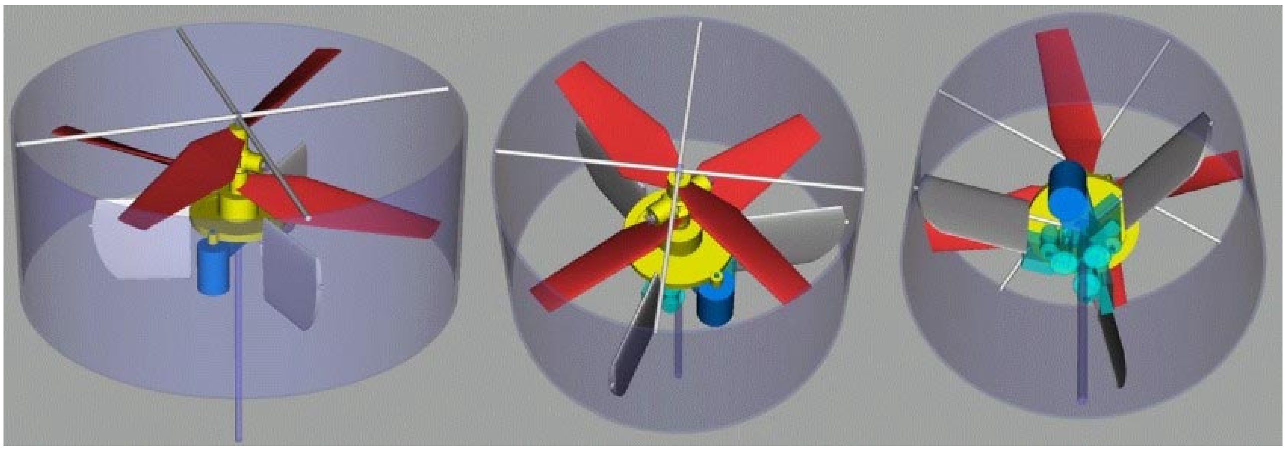
Started to design FFMP2: two concentric propellers, counter rotating, 3 flaps, and outer hull.

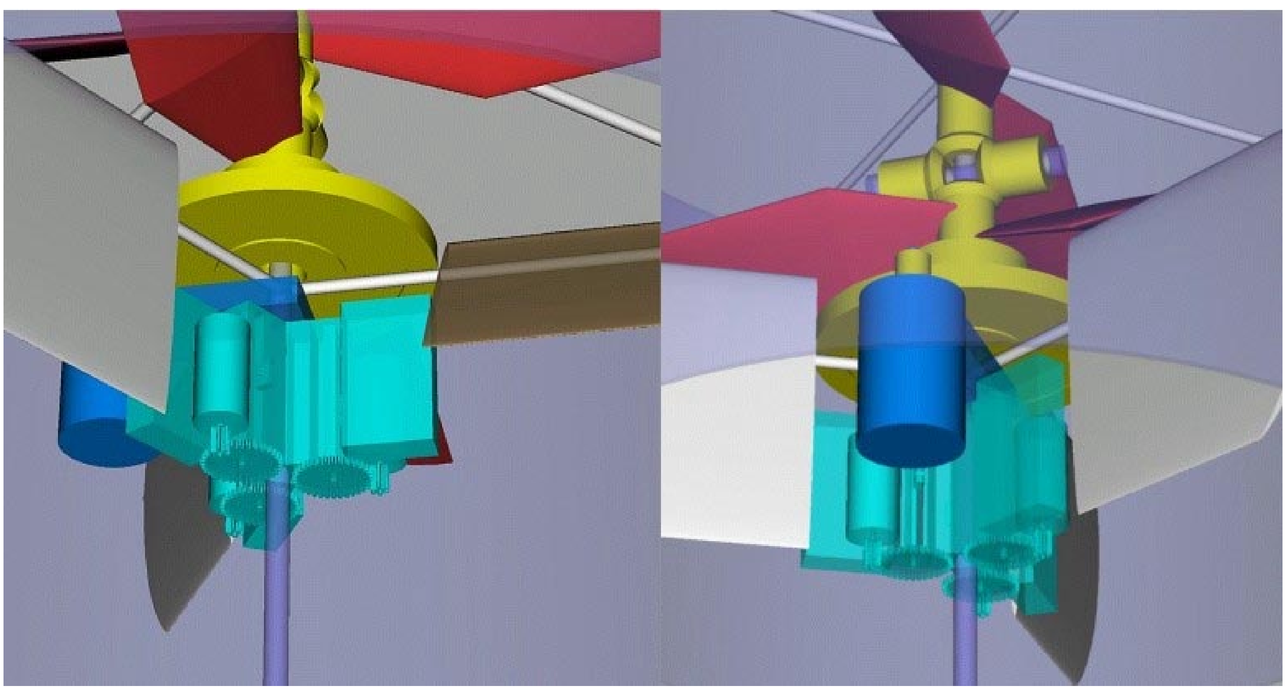
The screen shot sequence illustrates the continuing evolution of new designs. The first designs had a rotor diameter of 105 mm, which obviously is not realistic. It was changed to 160 mm. Other changes include the mounting position of the three flaps: first, they were mounted outside the hull below the motor, but then moved up right underneath the rotor. Then the 3 WES servos were added, and the mounting of the main motor had to be changed in order to avoid a collision with the servo pushrods and clavises. Further design ideas would be to move the three servos lower to make more space. This is also good for creating a low center of gravity, which is essential for this construction.

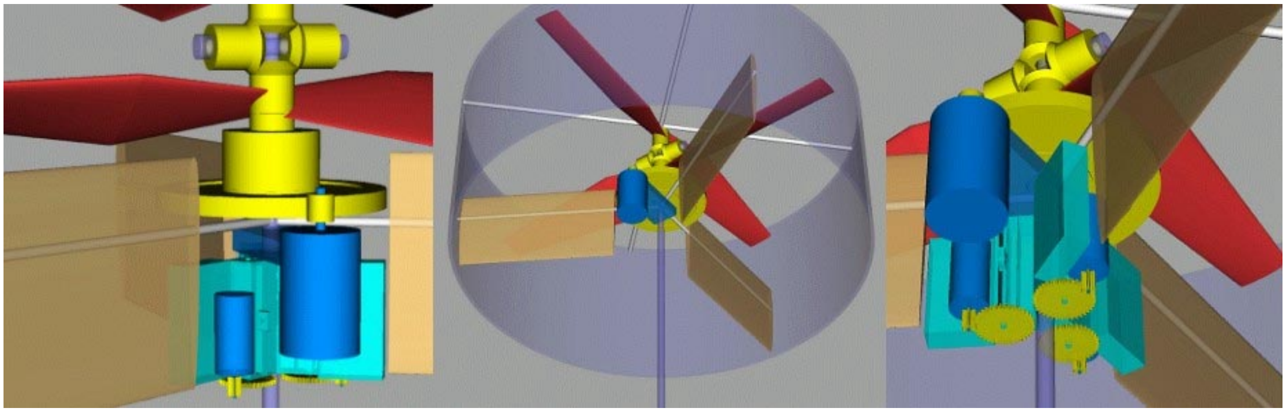
Not shown is an even more advanced design, based on the assumption that the two rotors are driven with separate motors that would control yaw with different RPMs. Like that, one could avoid any flaps and have two servos just moved the lower part of the fuselage to move the center of gravity. (See design suggestion of James Iverson, further below.)









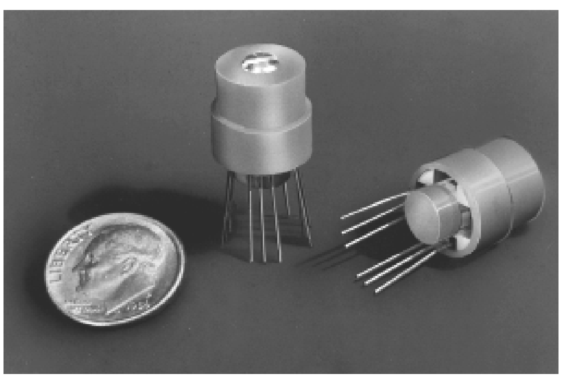


All parts are modeled in original size after the real components: servos, gears, motors, rotors. Design studies made with Rhinoceros.

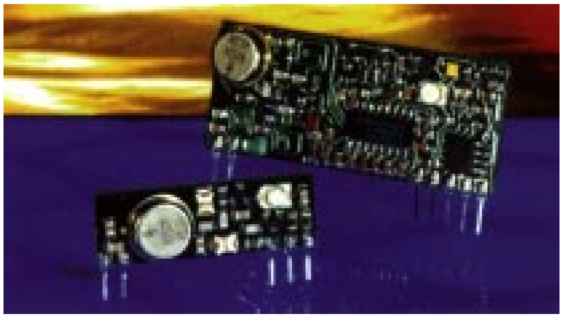
03/17/2000

Discussed compass scenarios with **Vadim Gerasimov** and **Joe Paradiso**:

Vadim thinks it is the best to use a small analog Dinsmore compass and digitize the signal on the helicopter with a PIC (12C672). This PIC outputs serial signal, and the Abacom transmitter (TXM-418-F, only 2 grams light) can send this serial stream to a receiver (SILRX-433-F). We will test this with my Dinsmore compass and Vadim's already set up transmitter board (a PIC that digitizes 4 analog signals and sends it with the same Abacom transmitter). This solution might be the lightest: Vadim thinks we can solder the compass to the PIC directly, without a board. The surface mount version of this PIC is tiny, and the compass is 2.25 grams. The Dinsmore compass works with tilt +/- 15 degrees, but is unfortunately damped so that at 90 degrees change takes 2.5 seconds.



Dinsmore analog compass modules



Radiometrix/Abacom wireless serial transmitter/receiver

Another option could be the Vector 2X. It is 11.3 grams, but already outputs digital serial signal. The other disadvantage is that is has to be leveled completely, otherwise the signal will change.

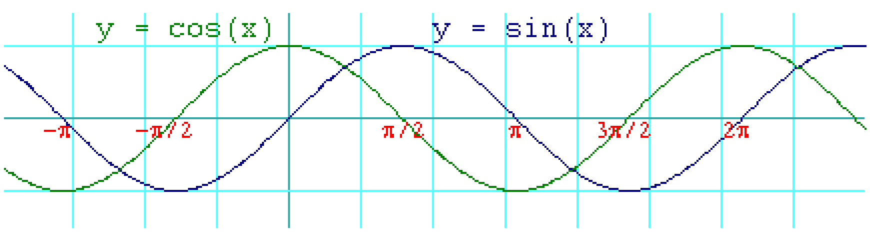
Joe Paradiso uses the Honeywell compass HMC2003 (analog out), which isn't drift stabilized. The compass module that has serial output (HMR3000) is 22 grams (too heavy).

Web search:

- General http://www.hobbyrobot.com/sensors/
- Dinsmore analog (2.25g) http://www.robotics.com/arobot/compass.html
- Vector 2X digital (11.3g) http://www.hobbyrobot.com/sensors/vector.html
- Honeywell digital (22g) http://www.ssec.honeywell.com/products/magsensor_index.html

03/21/2000

Tested the Dinsmore analog compass (1525) with Vadim. It works nicely with his digitizing PIC and the Abacom transmitter and receiver (http://www.abacom-tech.com/). It outputs 2 signals, sine and cosine if one makes 360 degree turn. Its reaction is reasonably fast, however, it seems to be sensitive to vibrations and shaking. It requires 5V, and outputs 2 analog signals 2.5V +/- 0.4V (the 1655 version is 2.5V +/- 0.75V, perhaps I order this one).



The two analog output signals that combined give the heading of the sensor.

From the web (http://www.jamesrusso.com/stamp/archive/1998/stamps.9809/msg00717.html), of how to interpret the two analog signals:

"(...) Basically, you take the *arctangent of the ratio* of the two signals from the sensor, then assign the current quadrant based on the relative polarities of the signals. It's the old rectangular-to-polar conversion routine. I used a lookup table with 90 entries (instead of an arctangent computation) to achieve (...) resolution of one degree." (More about *arctangent*: http://www.netpedia.com/coding/vbscript/msvbs/vbs65.htm)

Output table:	*output 1*	*output 2*	*ratio (except borderline cases)*
0 degrees	0	1	0
90 degrees	1	0	∞
180 degrees	0	-1	-0
270 degrees	-1	0	-∞

After talking to Vadim, we decide that the following electronic parts are necessary:

- Test clip to program surface mount PIC
- PIC 12C672, EEPROM
- PIC 12C672, SMD (surface mount, write once)
- LM 2931 5V voltage regulator
- Small electrolyte capacitor ~47 or 100 microF *
- 4MHz ceramic oscillator with caps, SMD
- Abacom/Radiometrix Transmitter and receiver (http://www.radiometrix.co.uk/products/products.htm)

The items with * I have gotten already from 023, but I still have to order them to replace them.

03/26/2000

Ordered TXM and SILRX modules from Lemosint (http://www.radiometrix.co.uk/contact/usa.htm):

- 1x TXM 418 MHz
- 1x TXM 433 MHz
- 1x SILRX 418 MHz
- 1x SILRX 433 MHz

Gave the 418 MHz transmitter to Vadim, since he can use it right now. (Will have to order it again.) Made survey about who is using 433 MHz devices at the lab. Current users:

- Ari Y. Benbasat <ayb@ml.media.mit.edu> (Batcave and Garden)
- Bakhtiar Mikhak <mikhak@ml.media.mit.edu>
- Vadim Gerasimov <vadim@ml.media.mit.edu> (Cube)
- Bernd Schoner <schoner@ml.media.mit.edu> (023)
- Tim McNerney <mc@media.mit.edu> (TX2/RX2 418MHz, with Bakhtiar in Ted Selker's group)
- Stefan Marti <stefanm@ml.media.mit.edu> (Garden)

Whenever there is interference, these people might know.

In general, I will suggest creating a list of ML projects that use radio transmitters of a certain frequency.

03/27/2000

Some of the parts of the SDP/SI order arrived, bevel gears.

Egon Pasztor <egon@media.mit.edu> wants to build a blimp that has some vision stuff on in, for Embodied Intelligence. I tell him to use an SHR receiver, three JMP speed controllers HF-9, DC 5-2.4 motors with gear 1:6.7 and 20cm carbon fiber propellers. He will also buy a Futaba transmitter, and he will need a IRX board to interface the computer with the Futaba. As batteries, I suggest one or two 9V (lithium?) batteries, and one specifically for the video/transmitter. The blimp bag is from West Coast Blimps (http://www.ridgecrest.ca.us/~jpiri/parts.htm), probably a 6' Blimp Bag with White Fins - 4 Panel - Silver.

03/28/2000

Radiometrix parts have arrived. Weight measurements:

- TXM transmitter 1.9 grams
- (TX2, the new transmitter 2.5 grams, from Tim McNerney)
- SILRX reciever 4.0 grams
- Dinsmore compass 1525 1.9 grams
- Dinsmore with wires 5.7 grams

Kai Huber:
Detail question: The horizontal carbon fiber rod of the gear box consists actually of two parts, and they are reinforced with rovings (http://home.t-online.de/home/e-huber/plan.htm#tragfl)

03/30/2000

Rest of the gears from SDP/SI arrived: Spur gears with and without brass insert. Weight measurements:

Bevel gears:
1:1 16 teeth, A 1M 4MYZ05, bore 3mm (1-142) x6: 0.3 grams
1:1 20 teeth, A 1M 4MYH05, bore 3mm (1-142) x6: 0.5 grams
1:2 20 teeth, A 1M 3MYH0520, bore 3mm (1-146) x3: 0.6 grams
40 teeth, A 1M 3MYH0540, bore 4mm (1-146) x3: 1.7 grams
Spur, Acetal:
40 teeth, A 1M 2MYZ05040, bore 4mm (1-113) x1: 1.9 grams
45 teeth, A 1M 2MYZ05045, bore 4mm (1-113) x1: 2.2 grams
48 teeth, A 1M 2MYZ05048, bore 6mm (1-113) x1: 2.9 grams
52 teeth, A 1M 2MYZ05052, bore 6mm (1-113) x1: 3.1 grams
56 teeth, A 1M 2MYZ05056, bore 6mm (1-113) x1: 3.4 grams
70 teeth, A 1M 2MYZ05070, bore 6mm (1-113) x1: 4.4 grams
80 teeth, A 1M 2MYZ05080, bore 6mm (1-113) x1: 5.2 grams
90 teeth, A 1M 2MYZ05090, bore 6mm (1-113) x1: 6.2 grams
Spur, Acetal with brass inserts:
40 teeth, A 1Z 2MYZ0504004, bore 4mm (1-111) x1: 4.4 grams
45 teeth, A 1Z 2MYZ0504504, bore 4mm (1-111) x1: 4.7 grams

48 teeth, A 1Z 2MYZ0504806, bore 6mm (1-111) x1: 7.7 grams
70 teeth, A 1Z 2MYZ0507006, bore 6mm (1-111) x1: 9.3 grams
80 teeth, A 1Z 2MYZ0508006, bore 6mm (1-111) x1: 9.9 grams
90 teeth, A 1Z 2MYZ0509006, bore 6mm (1-111) x1: 11.1 grams

I think the gears with brass inserts are too heavy. Even the normal ones could be made lighter with drilling holes.

Parts from **Tom McCann** (*Sky Hooks Rigging)* arrived: Carbon rods and tubes, DC6-8.5, JST connectors, brass pinions. Weight measurements:

Brass pinions:
6 teeth: 0.2 grams
8 teeth: 0.4 grams
9 teeth: 0.5 grams
10 teeth: 0.6 grams

Stefan Dolch (http://www.braunmod.de), recommended by Kai Huber: He says that he could manufacture two identical propellers, one clockwise and one counter clockwise.

04/05/2000

Ordered rest of electronic components from *Digikey*:

- 1x Test clip to program surface mount PIC (gold)
- 2x PIC 12C672, EEPROM
- 6x PIC 12C672, SMD (surface mount, write once)
- 3x LM 2931 5V voltage regulator
- 10x electrolyte capacitor ~47 microF
- 3x 4MHz ceramic oscillator with caps, SMD

04/06/2000

Phone call from **Stefan Dolch** (13:00, 19 minutes):
He offers me: two propellers, cw/ccw, (20-23 cm diameter, upon my specifications), upper one optimized for static thrust, lower one approximately optimized for downwash of upper one; carbon fiber, balanced: $300, four weeks lead time. Goal is 100 gram thrust, minimized torque reaction (probably not zero). It is not clear if both are optimized for the same RPM or for different. The first would be better, because the propellers can be locked together mechanically with bevel gears. Stefan would prefer having separate control over the two propellers, also because they probably have different power requirements.

I will email him, if price is OK, my diameter decision (20 or 23 cm), if lead time is ok. No decision made yet by now (5/15/2000).

04/07/2000

Digikey parts have arrived: PICs (SMD and normal) test clip, caps, and oscillators.

04/11/2000

James Iverson, B.S.: email thread.
James suggests copying the Hiller flying platform (see below). It uses two motors mounted co-axially to counteract torque. The first axle is inside the second, bypassing the beveled gears of Kai Hubers construction. It is self-stabilizing to a certain degree, and would result in lower total weight with the advantage of having a shroud to protect the props. With the wing-inlet effect (of the shroud) increasing total lift by 40%, he would see a great gain in lift capacity. He calculates 2x 91grams plus 40% = 254 grams lift. With that much lift, I could even use 3x 800mAh Tadiran (51 grams). They can give 2A output and would result in 25 minutes flight time. James also suggests using a flexible pipe underneath the rotors and move a pipe with two servos to direct the airstream instead of flaps.

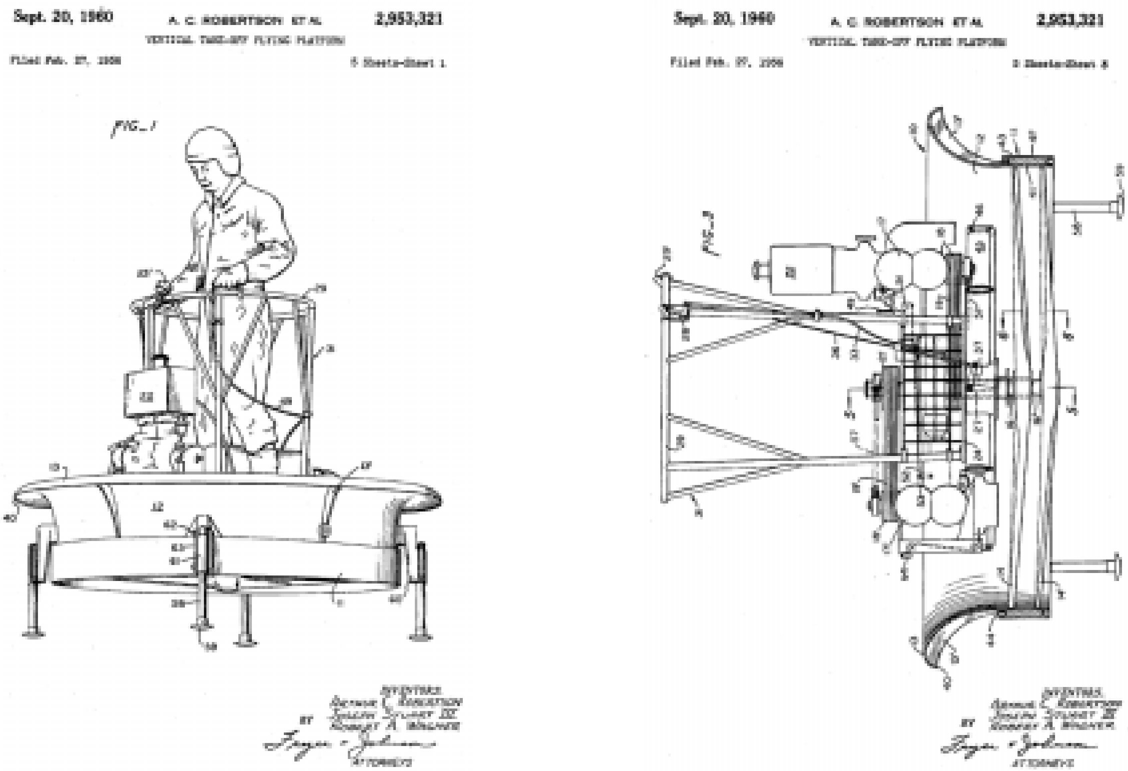
Shroud: His point about the shroud could be valid, since **Robert Wagoner** suggested a lip that would increase the thrust of his ducted fan. James' explanation: "The opening to the duct is a flared bell shape. The lip curls outward from the center. As air is drawn into the shroud, a portion of it is drawn in radially from the sides across the lip of the inlet. This creates a Bernoulli effect on the top surface of the lip. It also creates certain stabilizing effects as the craft translates through the air." The question is how to downscale the shroud from the original Hiller design. Low Reynolds numbers might change the aerodynamics crucially.

Pendulum fuselage: Might work to avoid flaps, but this assumes that there indeed are two motors so that the yaw can controlled by differential RPMs, since there are no flaps for yaw control anymore. Furthermore, this requires stronger servos, since the servos actually have to bend the fuselage against the airstream. It is not clear if it is better to have a tube that deflects the airstream or just move the center of gravity to one side or another.

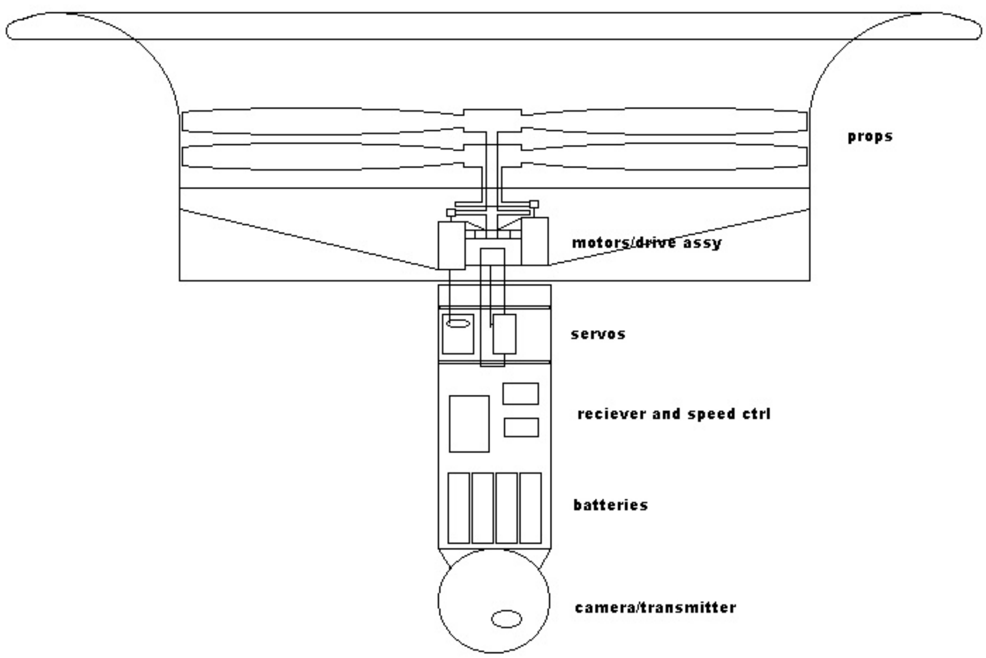
James offers me to build a custom made shroud for me. He will make one for himself with inner diameter of 200 mm. That is definitively too big for what I had in mind, but he might help me with a smaller one. I asked him how he would calculate it. He says, " Calculating the curvature would be a big, big, job, also a point of diminishing returns. I just estimated mine. My shroud assembly is constructed of a carbon fiber framework covered by clear mylar. This allows the led assy on one rotor tip to be seen through the shroud." (He plans to mount a set of LEDs in a vertical row to the tip of one of the rotors, so that he can modulate them and create a display matrix as the led bar sweeps across your field of view, similar to ticker boards. With multicolor LEDs one could create some interesting graphics. The lights spin in a lateral circle creating a ring of light around the vehicle. Could be a cool advertising gimmick. Concerts and sporting events would use them. "Drink Coke!" in a glowing ring over your head!)

Another option is to use the CNC lathe to create a plastic or wooden mould, and then put carbon fiber on this mould.

Even another option would be to use Ted Selkers plastic moulding machine to vacuum a sheet of plastic over a mould.



Hiller original drawings, probably from US patent database



Drawing by James Iverson

04/13/2000

Rogelio Lonzano: 2-hour meeting.
He models the mechanical dynamics of hovering helicopters and hovercrafts. The model of a hovercraft is actually related to my FFMP, since it models the X and Y translational movements (a plane) and the yaw rotational movement. The only additional degree of freedom would be the Z translational movement (going up and down). However, he does NOT model the aerodynamics, only the mechanical dynamics.

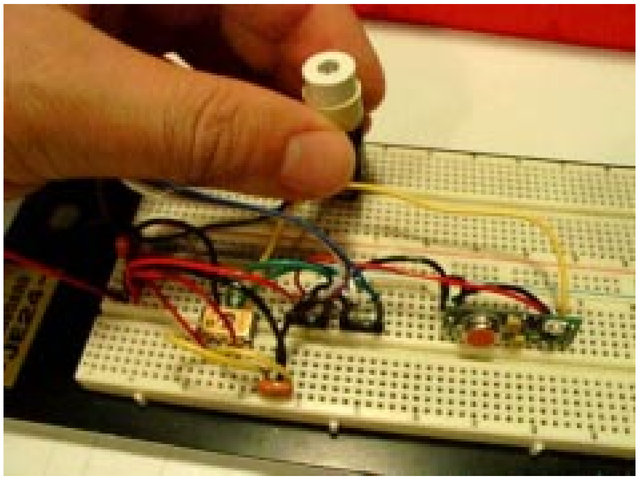
04/16/2000

After having found very interesting details about Cypher in the IBM Patent Database, I browsed some more and found the following interesting pages:

- http://www.patents.ibm.com/patlist?&uref_pno=US05150857 (patents related to Cypher)
- http://www.patents.ibm.com/details?&pn=US05150857__ (first Cypher patent)
- http://www.patents.ibm.com/details?&pn10=US05035377
- http://www.patents.ibm.com/details?pn=US04795111__
- http://www.patents.ibm.com/details?pn=US03955780__
- http://www.patents.ibm.com/details?pn=US05070955__
- http://www.patents.ibm.com/details?pn=US05303879__
- http://www.patents.ibm.com/cgi-bin/viewpat.cmd/US05931411__
- http://www.patents.ibm.com/details?pn=US05297759__
- http://www.patents.ibm.com/details?pn=US05881970__
- http://www.patents.ibm.com/details?&pn10=US05064143
- http://www.patents.ibm.com/details?pn=US04193568__
- http://www.patents.ibm.com/details?pn=US05295643__
- http://www.patents.ibm.com/details?&pn10=US04037807
- http://www.patents.ibm.com/details?&pn10=US04795111
- http://www.patents.ibm.com/details?pn=USD0418805__
- http://www.patents.ibm.com/details?&pn10=US05152478
- http://www.patents.ibm.com/details?&pn=US05915649__ (Roadable helicopter)

04/20/2000

Vadim shows me how to layout compass circuitry on a breadboard to test it.



On the lower left side is the PIC visible (UV erasable), on the right side the Radiometrix transmitter. I am holding the compass. This configuration was for debugging; eventually, all components will be replaced by surface mount equivalents and soldered directly to each other.

05/01/2000

Talk by **Peter M. Todd**: Peter M. Todd, Center for Adaptive Behavior and Cognition Max Planck Institute for Human Development, Berlin, Germany: How much information do we need? Interesting point: what kind of movement of a mobile agent would people interpret as fighting, flirting, etc?

05/09/2000

I helped Egon set up his blimp, a final project for the MIT *Embodied Intelligence* class (same as I took two years ago). He uses the same components as I (four JMP speed controllers, four WES propulsion units, SHR receiver, etc.) He also got an IRX board and soldered it directly to the transmitter. Furthermore, he modified the transmitter, adding a standard switch so that he can switch between trainer mode and normal mode without having to press the button.

I should make similar changes to my transmitter: optimal would be to put the whole IRX board in the transmitter, take the 9V for the IRX directly from the transmitter, and fit it with a network adapter. Like that, one can plug in a serial cable directly into the transmitter, no more cable hassle!

Notes

Mounting a WES 5-2.4 motor: An alternate and neater mounting method would be to make a small 1/32 ply scab that's screwed to the front of the motor with two M1.6 cap screws. Glue this mounting scab to former F-1. Anything RC ready-made, laser-cut 1/32 ply mounting plates, including the M1.6 screws.

ToDo list

- Write code for PIC, test breadboard, solder surface mount parts together, and put them in Aerogel for protection.
- Concentric rotor design: how to mount servos to avoid mounting problems of the main motor?
- Make decision about one or two motors
- Model shroud in 3D program: for big propellers, but also for EDF200 ducted fans I have!
- Make shrouds: ask Ted Selker (Diana) for vacuum machine; James for design
- Print out the relevant US patent database information
- Decide on rotor offer by Stefan Dolch. Would I have to pay the $300?
- Alternative for propeller design: ask Ilan Kroo for propeller advice
- Get the new 8-9 NiMH 100mAh cells from *Cloud9*
- Modify all servos with rubber band particles
- Take photos (better!) of FFMP1, including the ultrasonic sensor
- Take video of FFMP1 which shows automatic control loop (laptop required)
- Make animated GIF of FFMP2 renderings
- Fly wired FFMP1: power with lab supply, or other 8-cell battery
- FFMP1: Do more precise propulsion tests: initial voltage, exact duration of test, load including 2 servos, and thrust measurement
- WES 5-2.4 propulsion unit (isolated): thrust measurements
- WES 6-8.5 motor thrust measurements: how much current?
- EDF-200: Thrust measurements with intake lip: fuel tubing 1/8" - 3/16"
- Propeller/rotor manufacturing:
  - How to make carbon propellers: http://www.unisport.tu-bs.de/~modellflug/klaustrophobia/hints/prop/prop.htm
  - Pixel blades: http://www.planetinternet.be/pixel/pixeli111.htm#R&D Challenges