International Medical Aspirator

Final Design Report

Engineered by:

Kelly Smith

Melissa Jamison

Mary Constantine

Advised by:

Dr. Barbara Ressler

May 11, 2007

Abstract

Engineering World Health (EWH) is a non-profit organization that creates technology for developing countries. EWH has asked students to design an aspirator that will be used in hospitals of developing countries. An aspirator is a medical suction device that is used in surgery to remove fluids from the body. The device we designed was created from locally available materials in order to allow the device to be assembled and repaired at the international locations easily. This aspirator operates on electrical, and hand power. The materials we used to create the aspirator is a refrigerator compressor, collection jar, and tubing for the electrical power and PVC piping, rubber stopper, and the barb of a pipe connector to create the hand powered option. The students responsible for this project are Mary Constantine, Melissa Jamison, and Kelly Smith. They are being advised by Dr. Barbara Ressler.

TABLE OF CONTENTS:

Acknowledgements:

Dr. Barbara Ressler

Dr. Donald Pratt

John Meyer

Steve Frank

Matt Stover

Donahue’s Heating & Cooling

Engineering Department

1 Introduction

1.1 Description

An aspirator is a medical suction device used to remove fluids from the body during surgery. This aspirator was designed for hospitals in the developing world. Currently many hospitals cannot provide the proper medical treatment because there is a lack of technology and resources. Currently in the United States an aspirator can be purchased for approximately $750, in our design we created an aspirator that costs $67.16. Developing countries are unable to afford this expensive technology, and also need an alternative that costs less and can be maintained in the developing area. This design has enabled hospitals to have this technology so they can perform advanced surgeries in there hospitals. Since the aspirator was designed specifically for the developing world, the aspirator has a range of applications, multiple powering options, and a picture manual for its construction and use.

Engineering World Health (EWH) is a non-profit organization that creates technology for developing countries. EWH has asked that the aspirator fulfill many criteria. One very important aspect of this project is that the tips, tubing and collection jar can all be reused. The easiest way to sterilize these items is by using an autoclave, which uses high temperatures and pressures to sterilize these items. When we chose a type of tip we chose a surgical steel that can easily be autoclaved and reused many times, and therefore reduces cost for the hospitals.

Another important design aspect of this project is the ways in which the aspirator is powered; versatility is very important, especially in remote areas where electricity is not available or is unreliable. Therefore, the more powering options, the more hospitals can use this product. In response to this need, we are designing the aspirator to run on electrical, and hand power.

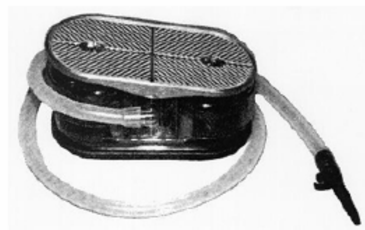
In order for our system to be universal, we created a picture manual. The manual shows a variety of materials that can be used for each component of the aspirator. These materials can be interchanged depending on the resources available. This manual explains the process of assembling our aspirator. This allows the manufacturer to easily replicate our design.

1.2 Literature Review

Foot Powered

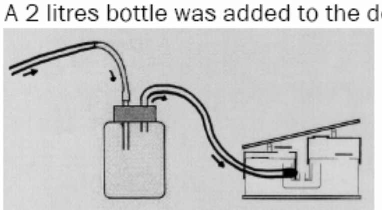
PUMP, SUCTION, MECHANICAL (Twin Pump) + collection bottles

EHOEPUMS1B-	*Indicative price/unit :*	*376,70 €*



DEFINITION

The "Twin Ambu®" suction pump is an emergency mechanical aspirator with a high aspiration capacity, which can be operated either by hand or by foot.
A 2 litres bottle was added to the device for allowing its use in surgery and anaesthesia.



The aspirator shown above is a mechanical aspirator that can be powered by mechanical means of foot or hand. The aspirator is designed to be used in surgery while anesthesia is in use. The tubing that is used in this model is an autoclavable material silicon which has dimension of 8mm diameter and is 10 meters long. The collection bottle has a volume of 3 liters.

Full Size Hospital Aspirator:

- Suction
- Capacity: 30 liters/minute
- Vacuum: up to 85kPA, up to 640 mmHG
- Nominal Voltage: 230 Volts, 50/60 Hz
- Nominal Power/ power consumption: 0.45A, 100Watt(230 Volt)
- Dimensions: 1000mm x 470mm x 680mm
- Weight 21 lbs

This aspirator is a disposable suction system that offers a real alternative to reusable jars. It offers optimal safety, straightforward use and is multifunctional. The disposable self-supporting suction liner is free from PVC. This ensures environmentally friendly disposal. The hydrophobic bacterial filter has two functions it closes in the event of overflow of liquid or foam, thus preventing contamination of the inside of the pump, and additionally it is highly efficient protection against bacteria.

http://www.ardo.ch/downloads/saugtechnik/SEKRETSAUGER-E.pdf#search=%22aspirator%3A%20medical%20use%22

<u>Portable Aspirator AC/DC Suction Unit (Emergency care in Hospitals, and Ambulances):</u>

- Capacity: -550mm Hg Vacuum 15 liters/minute
- Power: 220V AC and in-built maintenance free 12V battery, 55W
- Jars: Autoclavable 0.5 liter collection jar and easy change of bacterial filter in autoclavable re-usable housing.
- Dimensions: 37 x 15 25 cms. Weight: 6 kg
- Battery Backup: 40 mins on full charge
- Includes an AC adapter and cigarette lighter socket cable for use in ambulance/car

http://www.narang.com/ems_emergency_medical_products_supplies/suction_units_emergency.php

Hospital Aspirator:

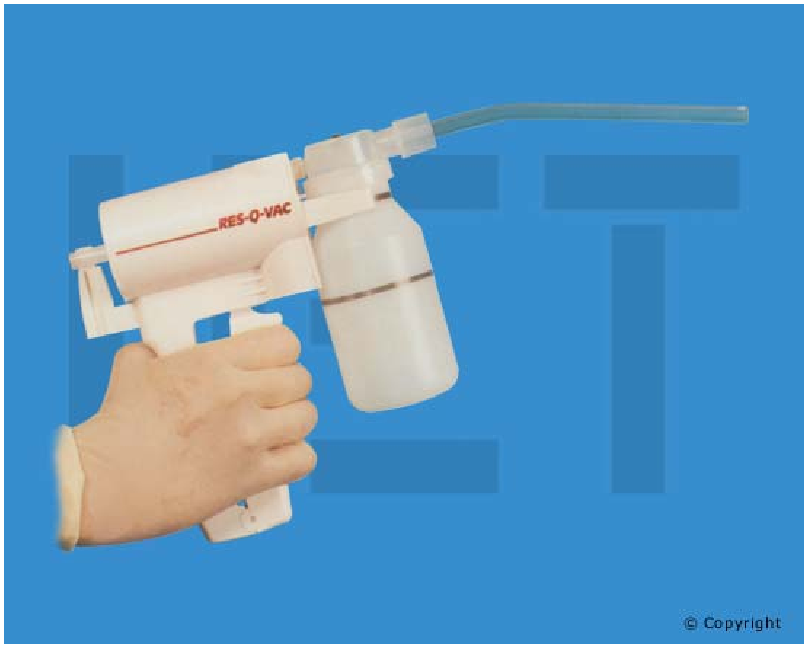
Regulate tracheal suction or drainage with the Schuco portable, pump-controlled vacuum aspirator. Provides precise performance from 0 to 22 HG. Large, easy-to-read tilted gauge is calibrated in mm and HG. 32-ounce plastic collection/overflow bottle incorporates a positive vacuum trap and is fitted with 52" of surgical tubing. Motor is a 1/10 hp shader pole unit with 115V/60 cycle power.
Cost: $316 + $465 (case of 70 jars) = $781
Allied Health Care Products

Portable Battery Powered Aspirator:

- 3 hour run time on battery at max. vacuum
- 20-550 mm Hg vacuum range with greater than 30 LPM flow
- Fully charged in 8 hours
- Will run on AC or battery

Retail price $725.00
http://www.dotmed.com/listing/107114/name/GOMCO+OptiVac%20G%20180+Aspirator+For+Sale/

Hand Held Aspirator for Paramedics, Air Medivac & First Responders:



- Stroke Volume per activation: 30mL
- Maximum Suction: > 550mm Hg
- Maximum Suction after 2 Activations: >400mm HG
- Peak Air Flow (50ms): 20L
- Size: 4.49” x 7.10” x 2.15”

http://www.narang.com/ems_emergency_medical_products_supplies/suction_units_emergency.php

For our final model of the aspirator, we incorporated several aspects from the different models shown above. First, all the parts in contact with bodily fluids are autoclavable; so that they can be sterilized and reused. Second, the suction was no more than 85KPa. Third, we would like to incorporate multiple power sources: electric and hand-powered. Finally, we made our aspirator portable and adaptable to different hospital environments.

1.3 Solution

The solution that we developed for the medical aspirator incorporates both an electrical and a hand powering option. Our electrical option involves the use of a refrigerator compressor to create the suction, which is wired to a capacitor and uses a 250V or 110V (depending on compressor) power source. The hand-powered option we created is similar to a reverse bicycle pump. It has a plunger that can be pulled up and down, a flapper valve, and finger valves. On the upstroke, the finger valves are closed which opens the flapper valve and creates a negative pressure difference and on the down stroke the finger valves are opened and the flapper valve closes also. This results in a pressure difference that creates the suction.

From our literature review, we looked at electrical, battery, and hand-powered aspirators that are already in use. While we eventually decided that a battery option was not necessary or easily implemented with our electrical design, we did look at the electrical and hand-powered options. When working in the hospital with an electrical aspirator, if the power shut off then the aspirator would just be powered by a generator. If electricity was not an option, the hand-powered option could be used. Either case does not require a battery.

The electrical aspirators that we found would be reliable and good options if they were to be placed in hospitals in the United States or another developed country. However, since we are working with developing countries, we needed to look at options that could be built from local parts and labor. Our main component, the refrigerator compressor, is a part that may not even need to be bought but could be taken from a refrigerator. The wiring of the compressor is straightforward enough that a picture manual is all that is required for proper installation. In addition, replacing parts and making repairs would not be difficult. Finally, the cost of our design is considerably less than an electrical aspirator that could be bought in the United States.

The hand-powered options that we found in the literature review were either foot pedal aspirators or hand-held handle aspirators. The first idea might be a viable option but we did not pursue this option because the hand power option was easier to design. The second option is a more complex system than our design, would be harder to repair, and would require more parts. Our design requires few parts that are easy to find and easy to replace. On the other hand, it does require more energy to use. Another advantage is that our hand held aspirator is very inexpensive.

The two major alternatives that we considered for the hand-powered option were a modified turkey baster or a modified fireplace bellows. The turkey aspirator's primary issue is the disposal of fluids and the speed with which it could be used. Another issue is that it does not create a large enough suction. It, however, is a very simple design. The fireplace bellows could be designed to work, but the durability over time is questionable. In a hot and humid climate, the wood could warp and the leather could crack.

2 Design Process

Our initial idea after researching was to create a fan powered prototype. We tried to do some initial analysis on the pressure differences needed to create appropriate suction. The problem we ran into was that we needed to know the Reynolds number so we could determine the type of flow that we have. After creating a working model using a refrigerator compressor, we determined that our flow was laminar and we could use the pipes without bends equation to determine our flow rates and pressures needed to suction the fluid from the body refer to appendix II for calculations. From our analysis we determined that pressure was the independent variable because this was the only variable we could control. We then decided from our analysis that pressure was our main concern, the reason we decided this was if the pressure went above 640 mmHg, the aspirator could potentially harm the patient. We did some initial testing on the refrigerator compressor to determine that it was creating vacuum pressure that was in our range of below 640 mmHg. We found that our compressor's average pressure was between zero and four hundred mmHg, so we decided to move on with this idea and construct a working model.

3 Implementation

3.1 Construction

The first prototype was of a fan powered suction device. When the fan was in operation inside the box, theoretically it would cause a pressure difference; and, allow suction of the blood into the collection jar. (Pictures of this prototype can be found in Appendix I) A problem in this design is the type of fan blade that we chose and the type of box we made. The fan blade was designed for model airplanes. When we tested the device with this fan blade, we discovered that it did not work; there was not enough pressure difference created. Then the team researched for other fan blades. The type of fan blade that was required for the pressure difference was called a squirrel-cage blower. The squirrel-cage blower was designed for a large scale operation. A smaller version of this would need to be specially-ordered. Specially-ordered pieces do not meet our specification of locally available materials in developing countries.

The second problem with the design was the box. The box did not have enough sealant in order to maintain the pressure difference. The holes that connected to the tubing were too big. The hole by the fan was too small. This prototype was complicated and hard to operate; thus, we decided we need to redesign.

After we decided that our first prototype was not going to work; we decided to try using a used refrigerator compressor. We obtained the used refrigerator compressor fairly easily; most refrigerator repair companies were willing to give away their old refrigerator compressors.

The first stumbling block we came across was that we could not find any adequate wiring diagrams for a refrigerator compressor. After talking with John Meyer, we were able to obtain assistance from one of the mechanical technicians on campus who aided us with the wiring of our compressor. Once the wiring was complete and the compressor turned on, we decided that it would be helpful to build a testing apparatus that would help keep all of our testing supplies together in one cart. Once, the compressor was working and all wiring was safely attached we began testing.

Our next major stumbling block was the compressor died after only thirty seconds of use. We had noticed previously that there was a bad smelling gas coming from the exhaust of the compressor. We later found out that the compressor may have been lacking oil, which may have caused our compressor to stop working. We then decided to obtain a second compressor. This compressor was a little older, and the electrical posts were bent and rusted which resulted in poor electrical connections. First, we tested the compressor to see if it would work correctly and it did turn on. So we decided to make a more permanent connection by soldering the wires to the posts. Once we tried to solder the wires to the posts, we decided that the solder may interfere with the other posts, and we should use alligator clips to test if the compressor works. The compressor relay sparked when we tried to turn the compressor on. So we decided to order a compressor from E-bay, and we wired the compressor with the help of Matt Stover. The one difference with this new compressor is that it runs on 110V instead of 240V. The compressor specifies the voltage needed for wiring. The previous two compressors were powered by 240V. The only difference in wiring the two is the arrangement of wires in the plug, so the wiring can be universal for the different power requirements for the compressors.

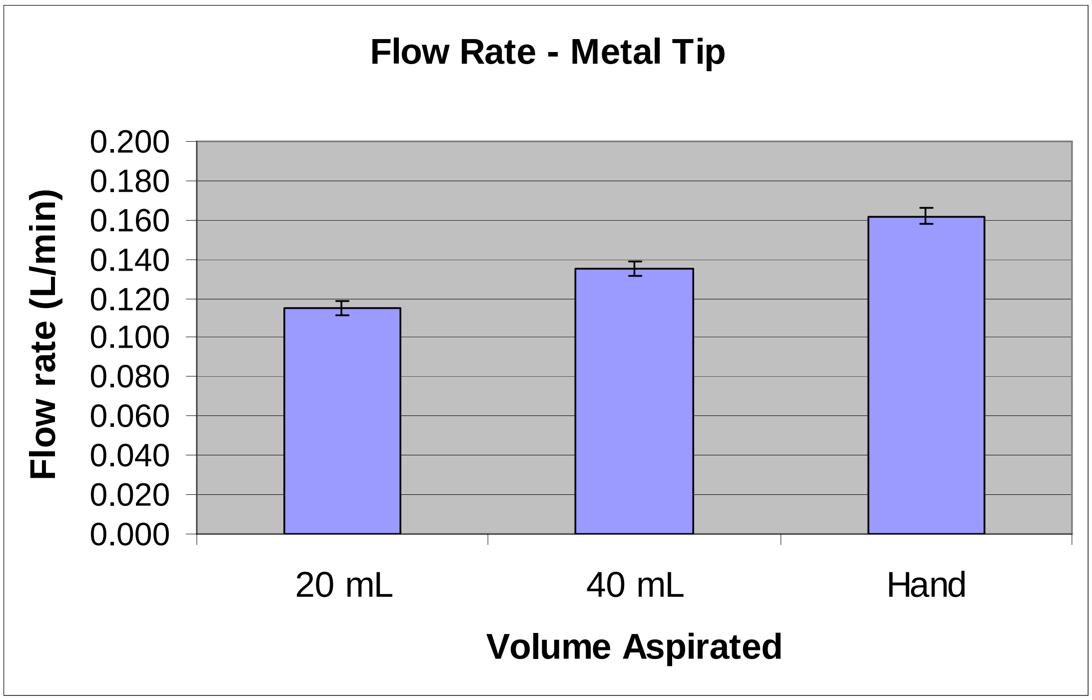
3.2 Operation

In order to meet our objectives for the year we needed to complete some testing on our prototype. Testing was done with both the compressor and the hand pump. During all testing runs we used a stainless steel tip with a 3/16 inch outer diameter. We also used a 48% glycerin 52% water mixture to simulate the viscosity of blood heated to 96˚F-102˚F. We decided to operate thirty trials of each test. This allowed us to perform statistical analysis on our results.

One of our objectives for this project specified that the suction pressure needed to be below 640mmHg. As noted in the table below, the average pressure for each trial is well below the maximum pressure. When testing 40mL, we obtained a maximum pressure of 400mmHg. This pressure was still well below the maximum required. We assumed that at any one time during a surgery, 40mL of fluid will not be removed from of the patient. Therefore, the 40mL aspirated served as an upper limit and demonstrated that our system will not accumulate enough pressure to injure the patient.

Amount of Fluid Aspirated (mL)	Average Pressure (mmHg)	Pressure with +/- standard deviation	Maximum Pressure (mmHg)
20	298.1	.0041	640
40	381.6	.0055	640
Hand	76	.030	640

Another objective for this project required that the product should operate off of three sources; electric, battery, and hand. We opted to not use the battery power source because the cost of the battery and the converter would well exceed our objective of keeping the total cost under $100. After completing our testing trials, our system, both electric and hand power, sufficiently removed the desired fluid. The testing results are shown below for the flow rate:



In all three trials, the flow rate for each was about the same. The average flow rate varied from 0.118L/min to 0.160L/min; this is a difference of 0.042L/min. The standard deviation error bars display that our data had a tight fit; meaning that our data is consistent.

For a complete documentation of all of our data for testing, please refer to Appendix.III.

4 Schedule

Originally, our project was scheduled to be completed well in advance; in the middle of February. We were mostly on schedule in January; however, we changed the format of our design in the middle of designing. This pushed back schedule. We needed to find a new way to make an aspirator. With the new design, the testing required was adjusted. While we were testing for flow rate and pressure, we encountered some problems; thus, our schedule continued to be pushed back. Please see attached Gantt Chart Appendix IV for timeline information.

5 Budget

The final cost of our product was $67.16. This price includes the materials needed for the hand pump and for the compressor powered by electricity. The hand pump costs a total of $19.97. The electrical power cost total was $20.08; this included the cost of a compressor. Usually a compressor can be obtained for free. With this taken into consideration it places the cost of the electrical power at $16.59 and places the total cost of our product at $54.67. Below is a table of our expenses for our project:

Electrical Power			
Refrigerator compressor		$	12.49
Electrical Components		$	16.59
	TOTAL	**$**	**29.08**
Hand Power			
1 1/2" ID PVC pipe		$	3.72
Assorted Parts		$	16.25
	TOTAL	**$**	**19.97**
Jar & Tubing			
Mason Jar		$	2.00
Tubing		$	3.85
Check Valve		$	9.95
Assorted Parts		$	2.31
	TOTAL	**$**	**18.11**
	FINAL COST	**$**	**67.16**

The difference between producing this prototype and a full-scale model is nothing. Our prototype is sufficient to be the product. The only difference in cost is that the pieces may cost more or less depending on, where they are purchased. The overall cost should still be less than $100.

6 Conclusion

The medical aspirator that we designed functions satisfactorily. We were able to meet five of the six objectives. As we have already discussed, we decided not to have all three powering options that we mentioned in our objectives. We eliminated the battery option because we decided it was not necessary to the project and it would have exceeded the cost objective of $100 (USD). We were able to successfully design the electrical and hand-powered options. The total cost of the aspirator, including all powering options, was $67.16 (USD), which is below our $100 (USD) objective.

The next objective we met was the suction pressure remained below 640mmHg.The suction pressure did not exceed 400 mmHg during testing.

We have several different sizes for aspirator tips as well as two material types (metal and polymer); therefore, we met our objective of manufacturing two different aspirator tips for different fluids.

Our next objective was to compile a clear and understandable picture manual so that a local worker would be able to assemble our aspirator. We have completed this objective for our electrical option, but we have yet to put together a complete picture manual for our hand power option.

We met our last objective, which was to create a list of materials for our aspirator that could be interchanged with other similar items. The reason for this is that a refrigerator compressor does not need to fit any specifications, and the collection can also be made of any container with a sealed lid. Also, some other options for the hand power include using a metal tube instead of PVC if the PVC piping is not locally available.

In the process of designing and building our aspirator, we learned how to apply our knowledge and expanded our knowledge. We were able to take concepts from fluid mechanics to calculate the expected values for pressure and flow rate. Once we started testing, we recorded the values of pressure and flow rate that we found. From this, we were able to develop a model of our system that could be used to calculate flow rate given a constant pressure or vice versa. We also learned how to wire a refrigerator compressor with a capacitor, a switch, and a plug.

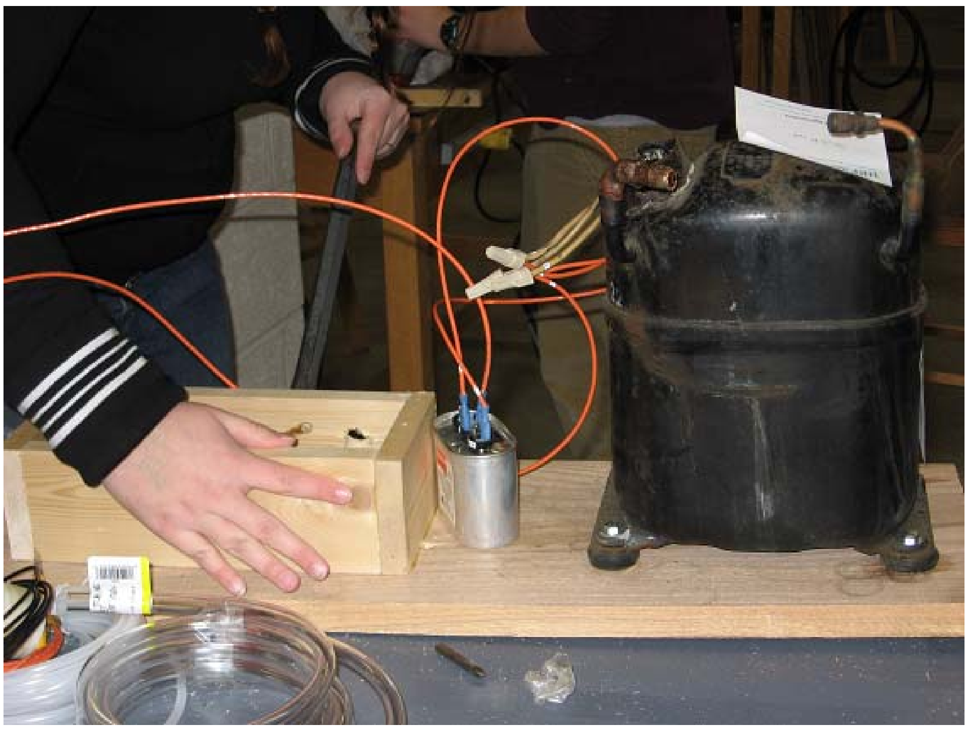
7 Recommendations for Future Work

Future work that could be completed would include testing the life of the compressor. We do not know how long the compressor will last without overheating, so it is important that hospitals have the hand power back-up during operation just in case the compressor were to stop working. We also did not have time to address the possible problem of the amount of oil and the frequency of changing the oil to keep the compressor running well. Another test that should be done is to determine whether the compressor can run in hot climates, and if this would affect the performance of the compressor. We also wanted to test with the polymer tip, and see if there were any changes in the results. The last test that we wanted to complete was to look at more options for the hand power.

Appendix:

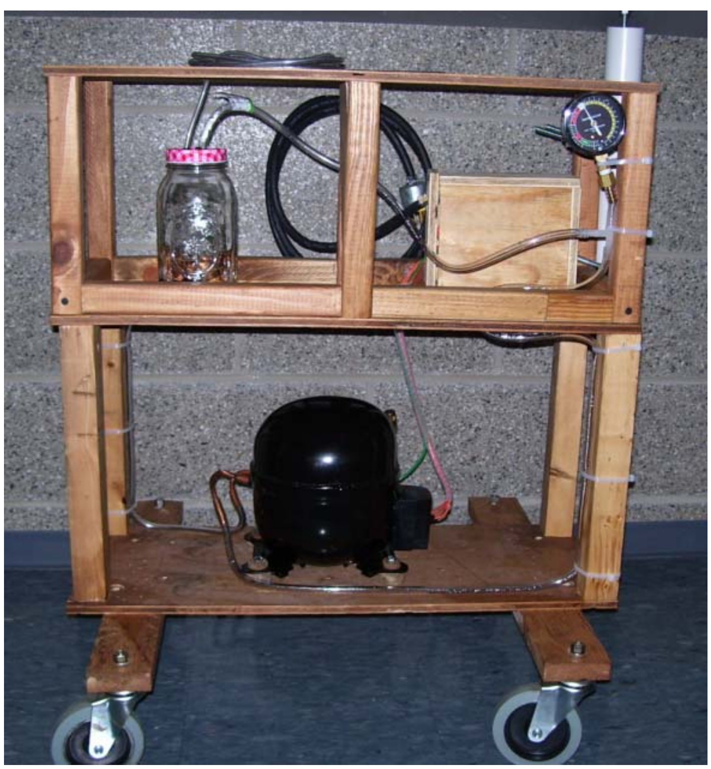
Fan Prototype:

Compressor Prototype #1:



Compressor Prototype #2

Compressor Final Prototype:



Compressor Testing 2 40 mL 4/10/2007

Test #	Temp (F)	Pressure (mmHg)	Time (sec)	Amount (mL)	Flowrate (L/min)
1	100	398	17.66	40	0.136
2	100	375	18.32	40	0.131
3	100	380	17.16	40	0.140
4	100	375	17.96	40	0.134
5	100	380	17.31	40	0.139
6	98	390	16.54	40	0.145
7	98	375	17.75	40	0.135
8	98	380	18.18	40	0.132
9	98	375	17.96	40	0.134
10	100	375	18.22	40	0.132
11	100	375	17.03	40	0.141
12	100	375	17.04	40	0.141
13	99	395	17.78	40	0.135
14	98	380	17.94	40	0.134
15	98	380	18.44	40	0.130
16	96	375	17.89	40	0.134
17	100	375	18.07	40	0.133
18	99	380	17.62	40	0.136
19	98	380	18.12	40	0.132
20	96	390	17.76	40	0.135
21	96	390	16.26	40	0.148
22	96	380	17.53	40	0.137
23	96	400	19.27	40	0.125
24	100	375	18.74	40	0.128
25	100	375	18.26	40	0.131
26	100	380	18.36	40	0.131
27	98	380	18.75	40	0.128
28	98	380	16.23	40	0.148
29	96	380	17.19	40	0.140
30	96	400	18.49	40	0.130
				Min	0.125
				Max	0.148
				Mean	0.135
				Range	0.023
				StDev	0.005573

Compressor Testing 3 full submersion of tip 40 mL

Test #	Temp (F)	Pressure (mmHg)	Time (sec)	Amount (mL)	Flowrate (L/min)
1	100	300	6.69	40	0.359
2	100	290	6.49	40	0.370
3	100	250	6.3	40	0.381
4	100	275	6.66	40	0.360
5	99	250	5.99	40	0.401
6	98	275	6.55	40	0.366
7	98	250	6.72	40	0.357
8	97	250	6.83	40	0.351
9	96	300	6.31	40	0.380
10	104	290	6.73	40	0.357
11	104	275	6.86	40	0.350
12	104	275	6.81	40	0.352
13	104	275	7.39	40	0.325
14	102	250	5.71	40	0.420
15	102	250	5.98	40	0.401
16	102	275	6.34	40	0.379
17	102	250	5.79	40	0.415
18	100	275	6.61	40	0.363
19	102	275	6.8	40	0.353
20	101	250	6.61	40	0.363
21	101	250	6.39	40	0.376
22	101	275	6.57	40	0.365
23	100	275	6.85	40	0.350
24	100	250	6.54	40	0.367
25	100	275	6.66	40	0.360
26	99	275	6.61	40	0.363
27	98	250	6.53	40	0.368
28	100	250	6.87	40	0.349
29	100	250	6.47	40	0.371
30	99	250	6.75	40	0.356
				Min	0.325
				Max	0.420
				Mean	0.368
				Range	0.096
				StDev	0.020

Compressor Testing 1 with laytex tubing 4/6/2007

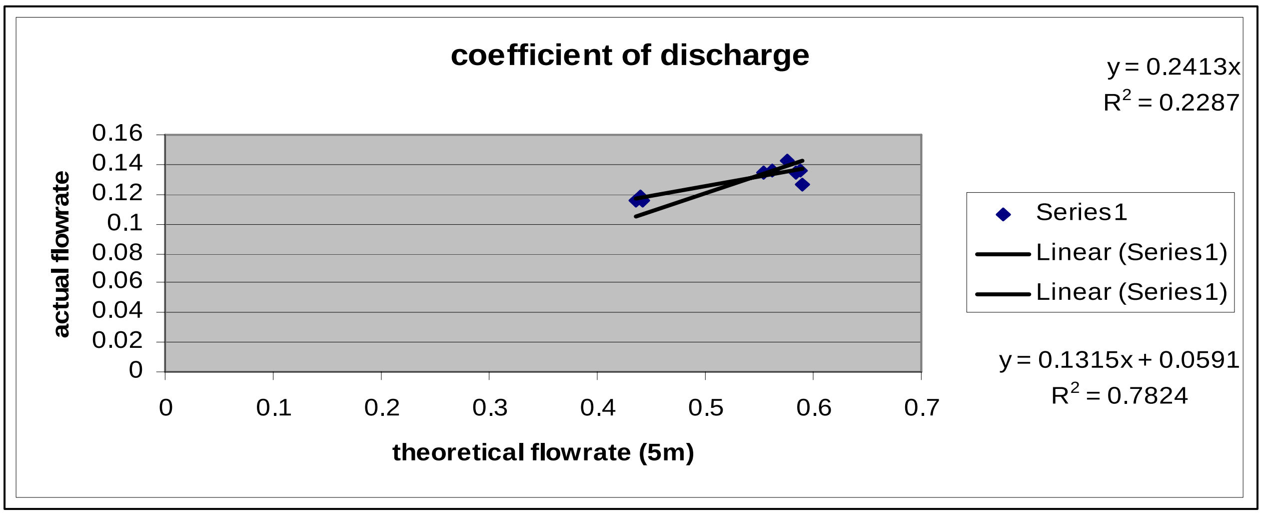
Test #	Temp (F)	Pressure (mmHg)	Time (sec)	Amount (mL)	flowrate (L/min)
1	99	225	10.95	20	0.110
2	96	210	10.62	20	0.113
3	96	215	11.88	20	0.101
4	96	210	12.31	20	0.097
5	94	240	11.15	20	0.108
6	94	225	11.23	20	0.107
7	94	250	11.29	20	0.106
8	100	250	11.54	20	0.104
9	100	250	11.3	20	0.106
10	100	250	11.02	20	0.109
11	100	250	10.51	20	0.114
12	100	250	11.29	20	0.106
13	100	250	10.89	20	0.110
14	98	250	10.66	20	0.113
15	98	248	10.53	20	0.114
16	98	250	11.15	20	0.108
17	97	250	10.66	20	0.113
18	97	248	11.21	20	0.107
19	96	248	10.51	20	0.114
20	96	250	10.59	20	0.113
21	98	248	11.06	20	0.108
22	98	248	11.73	20	0.102
23	98	248	11.56	20	0.104
24	97	248	11.57	20	0.104
25	97	248	11.65	20	0.103
26	97	247	11.17	20	0.107
27	96	248	11.29	20	0.106
28	96	248	10.62	20	0.113
29	96	248	10.81	20	0.111
30	96	248	10.85	20	0.111
				Min	0.097
				Max	0.114
				Mean	0.108
				Range	0.017
				StDev	0.004313

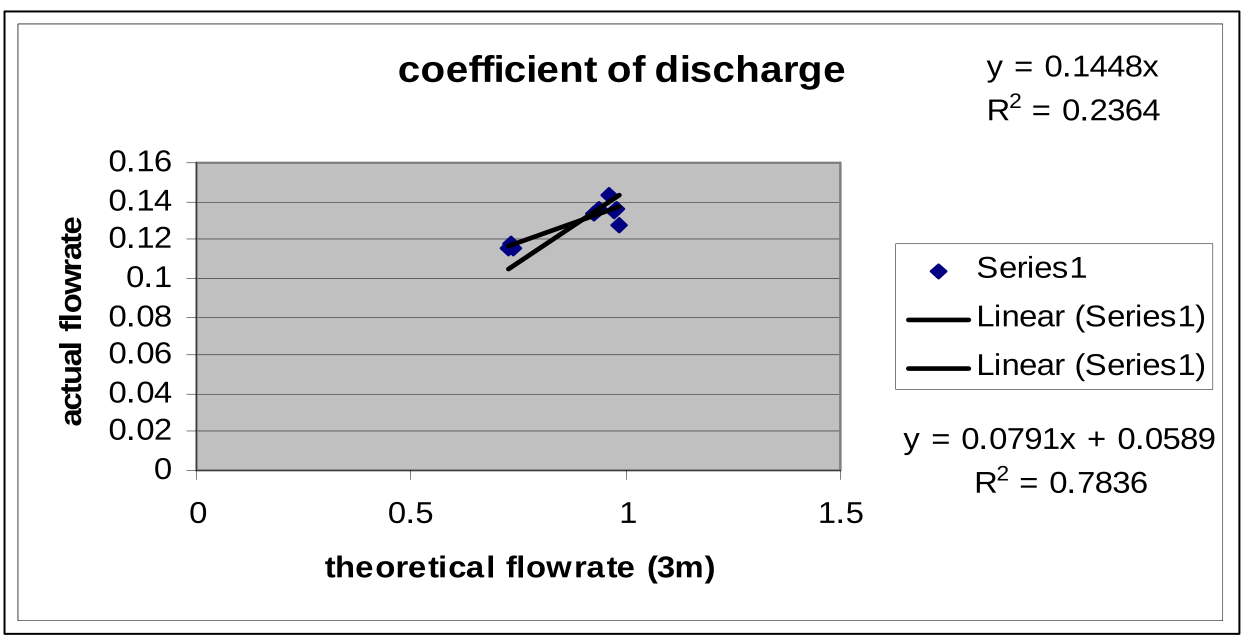
Compressor Testing 1 vinyl tubing 4/10/2007

Test #	Temp (F)	Pressure (mmHg)	Time (sec)	Amount (mL)	flowrate (L/min)
1	100	300	10.49	20	0.114
2	100	295	10.99	20	0.109
3	100	295	10.72	20	0.112
4	100	298	10.2	20	0.118
5	100	295	9.72	20	0.123
6	100	300	11.07	20	0.108
7	100	300	10.52	20	0.114
8	99	300	10.75	20	0.112
9	99	300	11.2	20	0.107
10	98	300	11.24	20	0.107
11	98	300	10.65	20	0.113
12	98	300	10.07	20	0.119
13	98	300	10.12	20	0.119
14	97	300	10.39	20	0.115
15	96	300	9.93	20	0.121
16	100	300	10.12	20	0.119
17	100	300	10.38	20	0.116
18	100	295	10.11	20	0.119
19	99	295	10.66	20	0.113
20	98	295	10.65	20	0.113
21	98	295	10.22	20	0.117
22	98	300	10.16	20	0.118
23	97	295	10.05	20	0.119
24	97	295	10.57	20	0.114
25	96	300	10.31	20	0.116
26	96	300	10.26	20	0.117
27	100	295	10.56	20	0.114
28	100	300	10.5	20	0.114
29	99	295	10.08	20	0.119
30	98	300	10.59	20	0.113
				Min	0.107
				Max	0.123
				Mean	0.115
				Range	0.017
				StDev	0.004068

Compressor

Pressure (mmHg)	Mean flowrate (L/min)	theoretical (5m) (L/min)	theoretical (3m) (L/min)
295	0.116	0.436	0.727
298	0.118	0.44	0.734
300	0.115	0.443	0.739
375	0.134	0.554	0.924
380	0.136	0.562	0.936
390	0.143	0.576	0.961
395	0.135	0.584	0.973
398	0.136	0.588	0.98
400	0.127	0.591	0.985

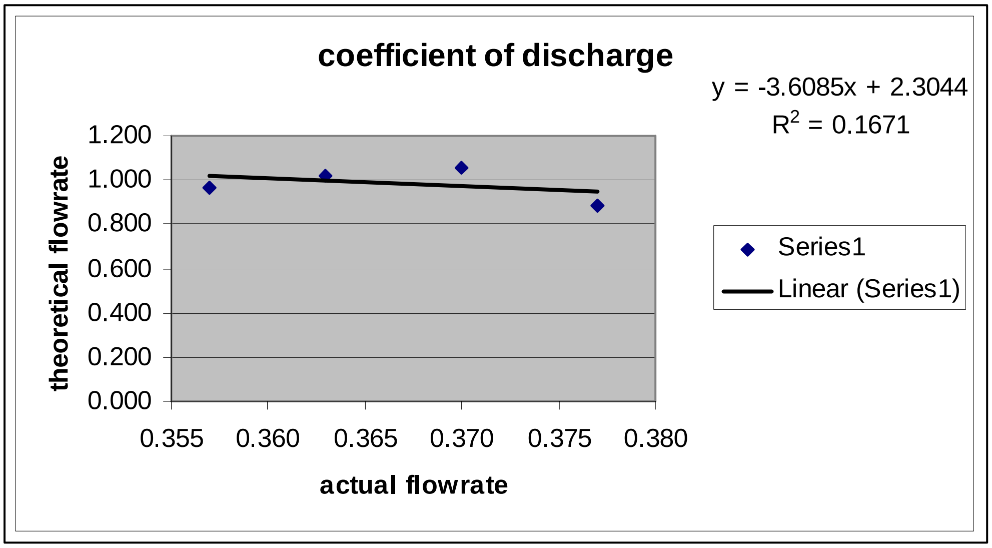




Aspirator 26

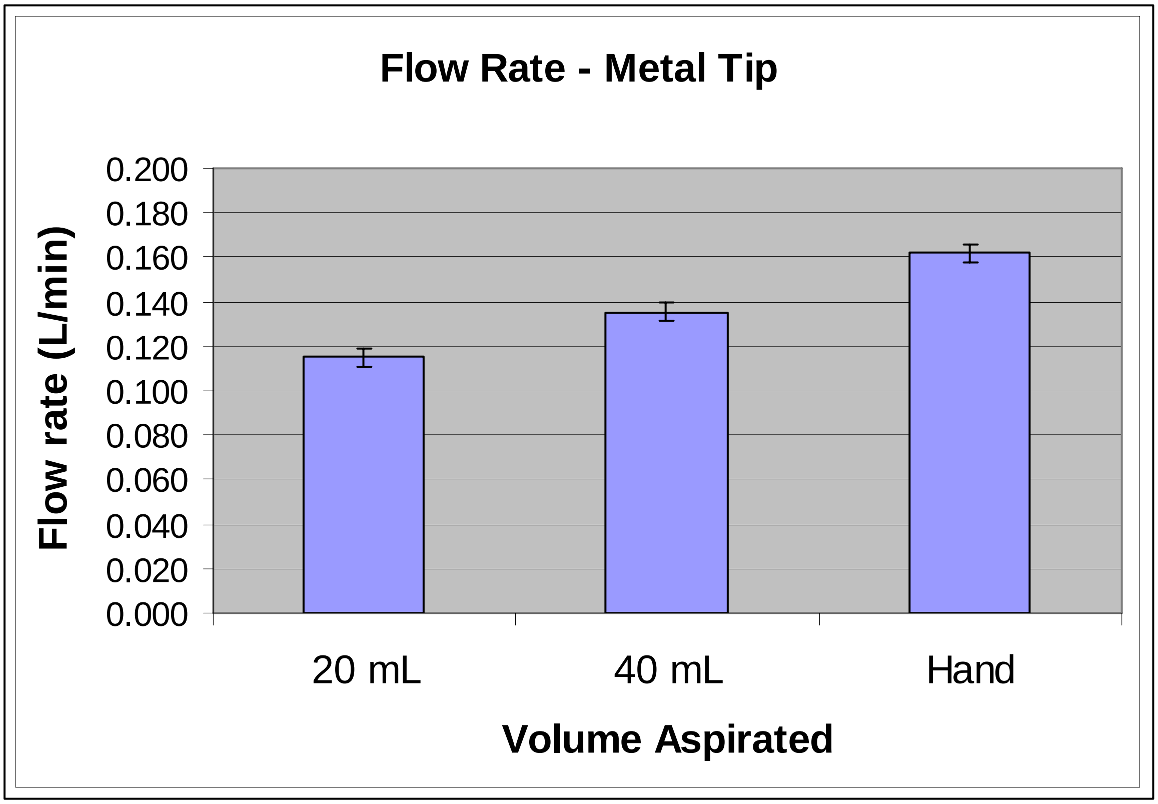
Hand

Pressure (mmHg)	actual flowrate (L/min)	theoretical flowrate (L/min)
250	0.377	0.880
275	0.357	0.968
290	0.363	1.020
300	0.370	1.056

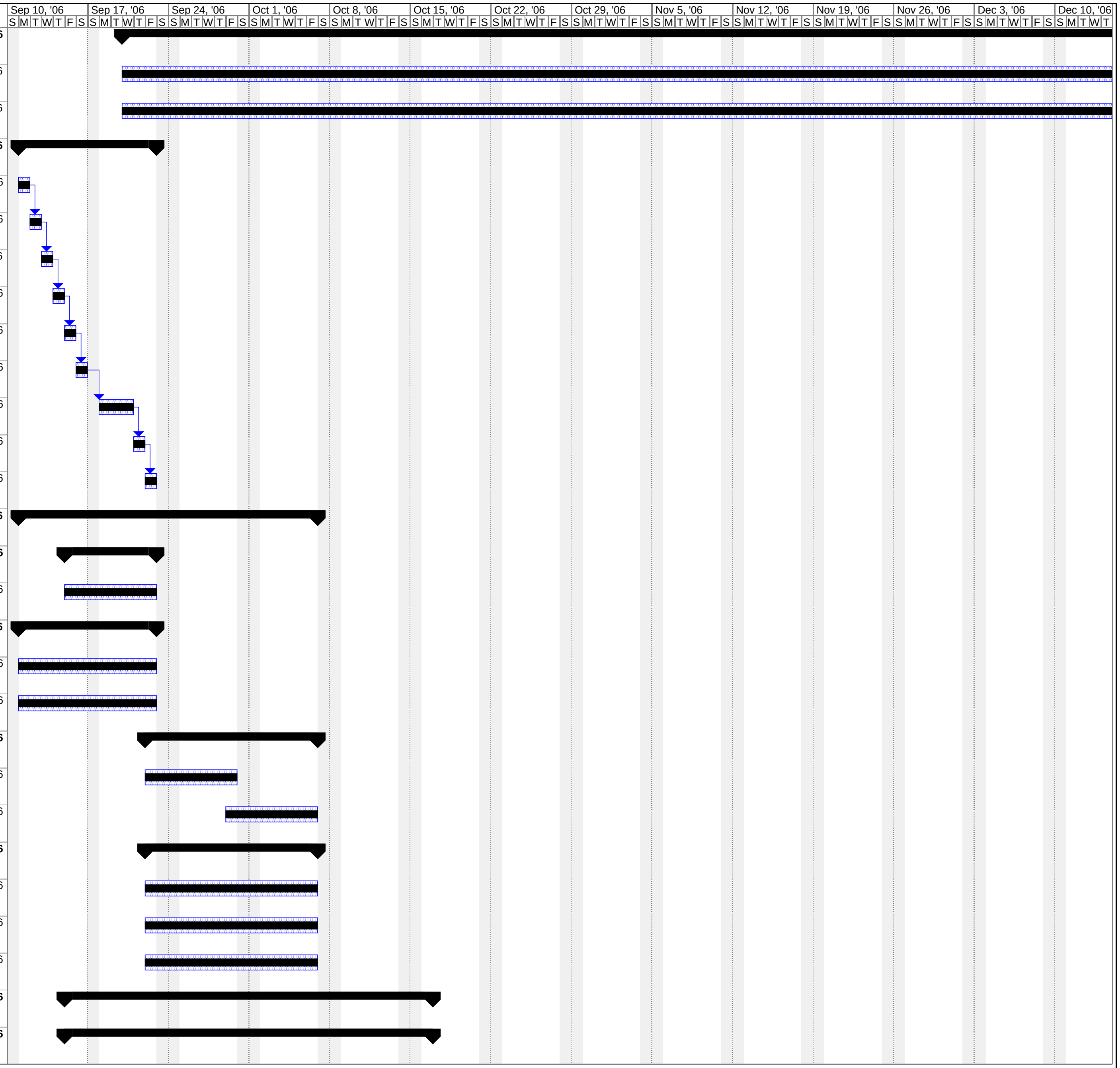


Hand Power: Test #1

Test #	Temp (F)	Pressure (mmHg)	Time (sec)	Amount (mL)	flowrate (L/min)
1	100	50	4.71	10	0.127
2	100	60	5.64	15	0.160
3	99	60	5.70	13.5	0.142
4	98	75	4.13	11	0.160
5	97	50	5.00	13	0.156
6	96	75	3.85	10	0.156
7	95	60	4.89	10	0.123
8	95	75	3.45	10.5	0.183
9	94	90	3.42	9	0.158
10	94	80	4.55	12	0.158
11	102	80	4.72	10	0.127
12	101	80	4.73	14	0.178
13	100	90	3.78	10	0.159
14	99	75	4.99	11	0.132
15	98	80	3.82	10	0.157
16	98	60	4.38	11	0.151
17	97	75	4.22	10.5	0.149
18	97	60	4.30	12	0.167
19	96	60	4.59	11.5	0.150
20	96	85	4.37	11	0.151
21	95	100	4.00	10	0.150
22	95	60	3.99	10.5	0.158
23	94	90	3.64	18	0.297
24	94	90	3.73	10	0.161
25	101	100	4.32	12	0.167
26	101	100	3.72	12	0.194
27	101	75	4.92	13	0.159
28	100	80	4.35	12	0.166
29	100	90	3.97	11	0.166
30	99	75	5.19	13	0.150
				Min	0.123
				Max	0.297
				Mean	0.160
				Range	0.174
				StDev	0.030


Flow Rate - Metal Tip
Flow rate (L/min)
0.200
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
20 mL
40 mL
Hand
Volume Aspirated

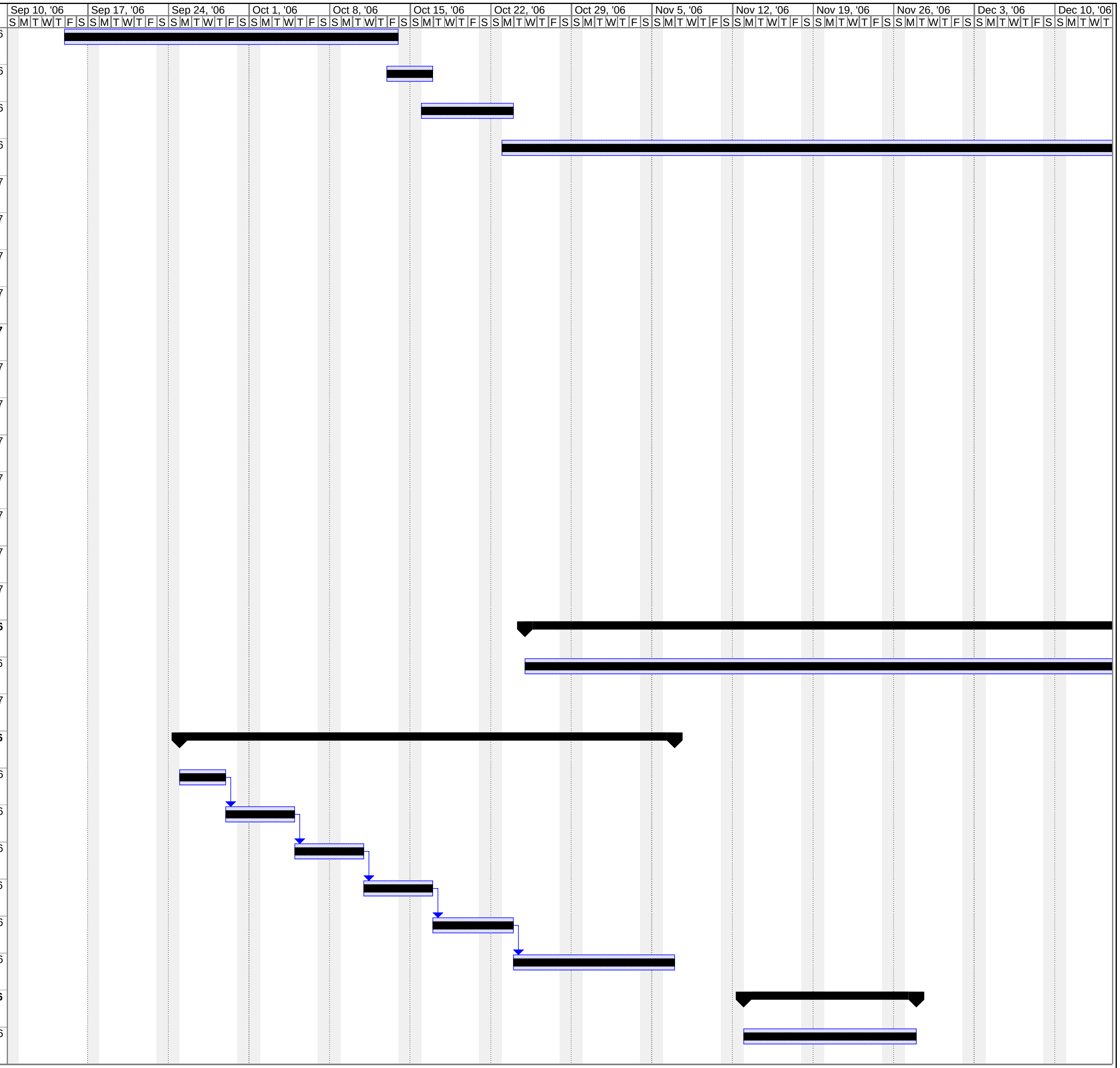
ID		Task Name	Duration	Start
1	✓	**Throughout Project**	**145 days?**	**Wed 9/20/06**
2	✓	Pictures	145 days?	Wed 9/20/06
3	✓	Video	145 days?	Wed 9/20/06
4	✓	**Project Proposal**	**11 days?**	**Mon 9/11/06**
5	✓	Section 1 -Kelly	1 day	Mon 9/11/06
6	✓	Section 2 -Kelly	1 day?	Tue 9/12/06
7	✓	Section 3 -Kelly	1 day?	Wed 9/13/06
8	✓	Section 4 -Kelly	1 day?	Thu 9/14/06
9	✓	Section 5 -Kelly	1 day?	Fri 9/15/06
10	✓	Section 6 -Kelly	1 day?	Sat 9/16/06
11	✓	Melissa and Mary Revision	3 days?	Mon 9/18/06
12	✓	Dr. Pratt revision for information c	1 day?	Thu 9/21/06
13	✓	Dr. Ressler revision for Technical	1 day?	Fri 9/22/06
14	✓	**Research**	**21 days?**	**Mon 9/11/06**
15	✓	**Autoclave**	**7 days?**	**Fri 9/15/06**
16	✓	What materials are autoclav	7 days?	Fri 9/15/06
17	✓	**Vacuum**	**11 days?**	**Mon 9/11/06**
18	✓	pressure -Melissa	11 days?	Mon 9/11/06
19	✓	Suction- Melissa	11 days?	Mon 9/11/06
20	✓	**Manufacturability**	**11 days?**	**Fri 9/22/06**
21	✓	Materials- Mary	6 days?	Fri 9/22/06
22	✓	What skills- Mary	6 days?	Fri 9/29/06
23	✓	**Power Source**	**11 days?**	**Fri 9/22/06**
24	✓	Electrical- Melissa/Mary	11 days?	Fri 9/22/06
25	✓	Battery- Mary/Melissa	11 days?	Fri 9/22/06
26	✓	Hand/Foot -Melissa/Mary	11 days?	Fri 9/22/06
27	✓	**Brainstorming**	**23 days?**	**Fri 9/15/06**
28	✓	**design ideas- Melissa/Mary/Kel**	**23 days?**	**Fri 9/15/06**



Project: Gantt Chart
Date: Fri 5/11/07

Task		Progress		Summary		External Tasks		Deadline
Split		Milestone		Project Summary		External Milestone	

ID		Task Name	Duration	Start
29	✓	Quick analysis on best 3 ide:	22 days?	Fri 9/15/06
30	✓	Pick an idea	2 days?	Fri 10/13/06
31	✓	Material Ordering- Mary	6 days?	Mon 10/16/06
32	✓	Protype building -Melissa/Mary/Kelly	40 days?	Mon 10/23/06
33	✓	Prototype Tesing -Melissa/Mary/Kelly	20 days?	Mon 1/8/07
34	✓	Prototype Re-designing -Melissa/Mary	6 days?	Fri 2/2/07
35	✓	Prototype Modifications- Melissa/Mary	31 days?	Mon 2/12/07
36	✓	Prototype Re-Testing -Melissa/Mary/K	11 days?	Sat 3/24/07
37		**Testing**	**50 days?**	**Mon 1/15/07**
38	✓	Flow rate	4 days?	Mon 1/15/07
39		Check valve testing	5 days	Fri 1/19/07
40		Opperate up to 120 degrees F	5 days?	Fri 1/26/07
41		Endurance / Lifespan Testing	5 days?	Fri 2/2/07
42		What if the power goes out?	5 days?	Fri 2/9/07
43		High Schooler building testing	5 days?	Fri 2/16/07
44		Durability testing	4 days?	Mon 3/19/07
45	✓	**Educational Manual -Kelly**	**120 days?**	**Wed 10/25/06**
46	✓	Pictures for process	120 days?	Wed 10/25/06
47	✓	Primary writing time	43 days?	Mon 1/1/07
48	✓	**Engineering Design Report**	**31 days?**	**Mon 9/25/06**
49	✓	Section 1- Kelly	4 days?	Mon 9/25/06
50	✓	Section 2- Kelly	4 days?	Fri 9/29/06
51	✓	Section 3 -Kelly	4 days?	Thu 10/5/06
52	✓	Section 4 -Kelly	4 days?	Wed 10/11/06
53	✓	Section 5 -Kelly	5 days?	Tue 10/17/06
54	✓	Section 6 -Kelly	10 days?	Tue 10/24/06
55	✓	**Oral Presentation- Fall**	**11 days?**	**Mon 11/13/06**
56	✓	Visual Aids?	11 days?	Mon 11/13/06

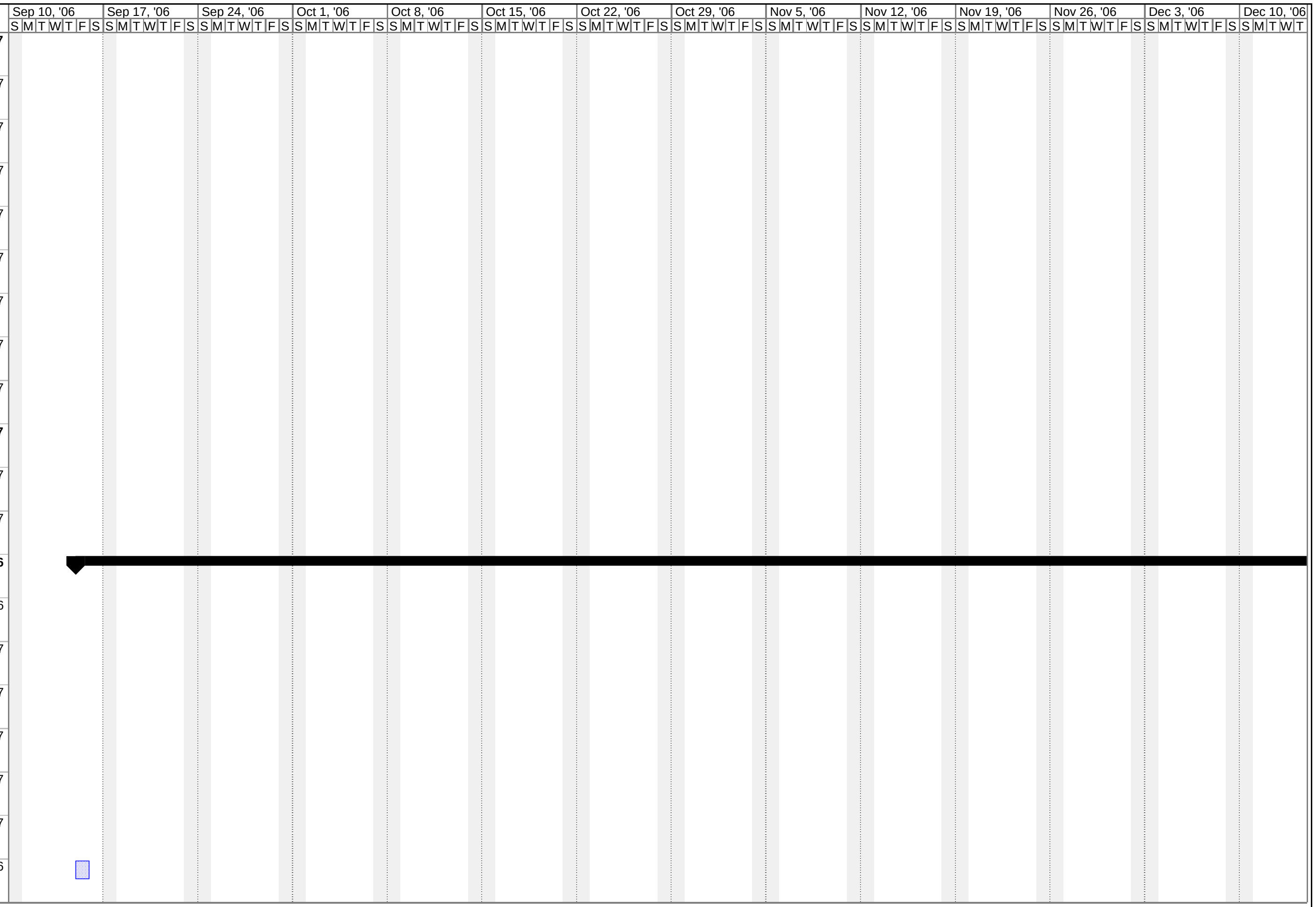


Project: Gantt Chart
Date: Fri 5/11/07

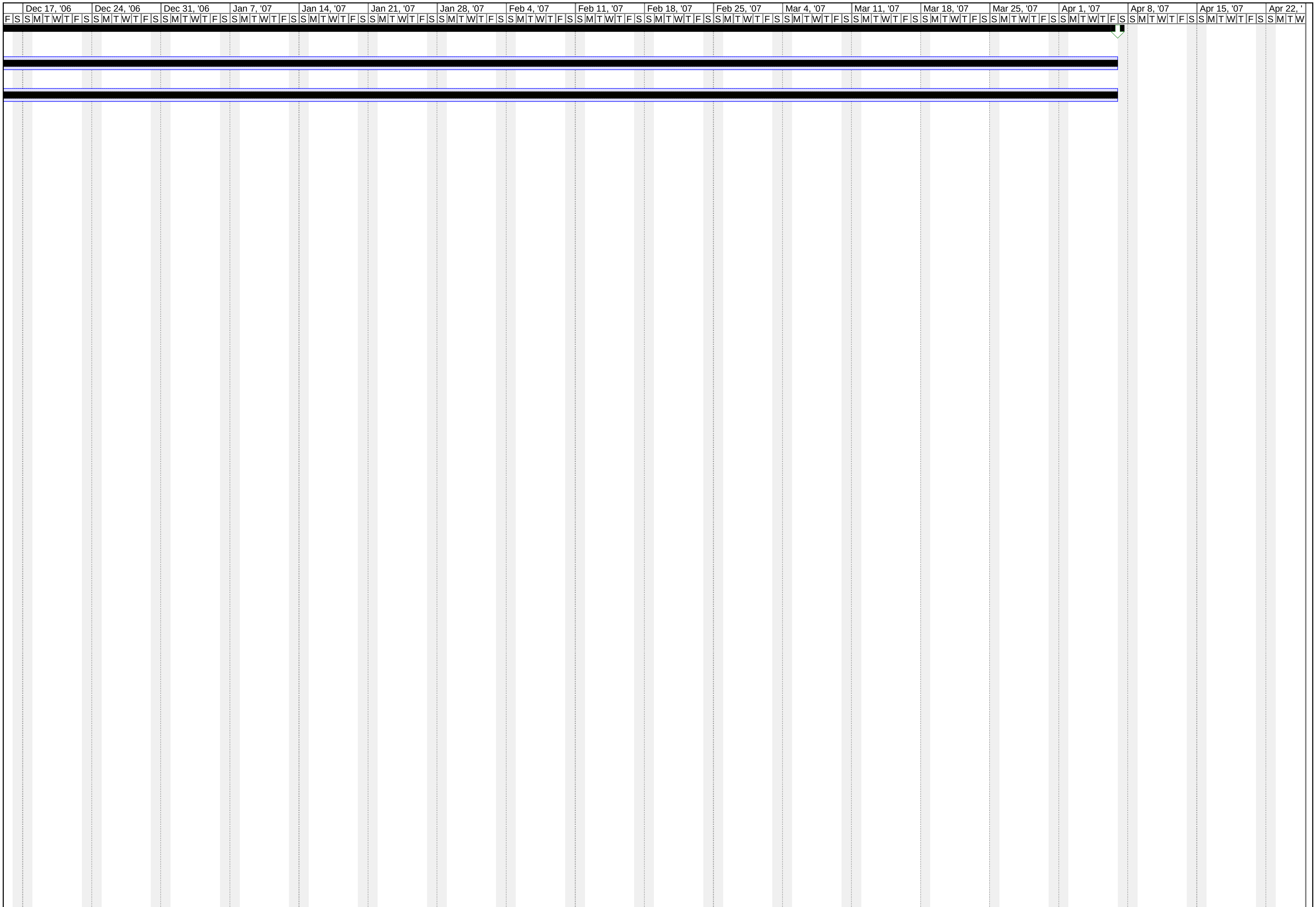
Task		Progress		Summary		External Tasks	
Split		Milestone		Project Summary		External Milestone	

Deadline

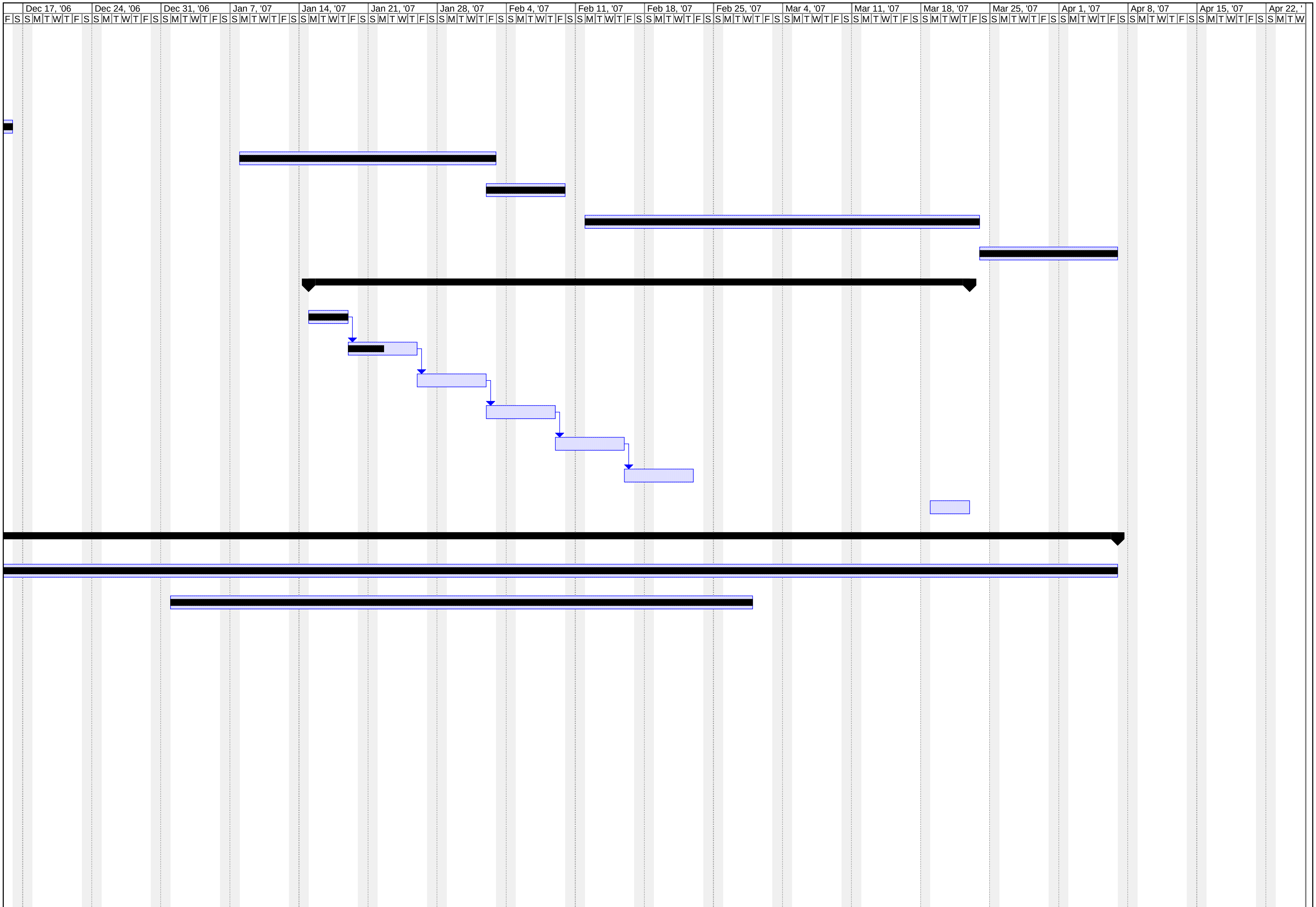
ID	Indicators	Task Name	Duration	Start
57	✓	**Final Written Report**	**19 days?**	**Mon 3/12/07**
58	✓	Section 1 -Kelly	3 days?	Mon 3/12/07
59	✓	Section 2 -Kelly	3 days?	Thu 3/15/07
60	✓	Section 3 -Kelly	3 days?	Mon 3/19/07
61	✓	Section 4 -Kelly	3 days?	Thu 3/22/07
62	✓	Section 5 -Kelly	3 days?	Mon 3/26/07
63	✓	Section 6 -Kelly	1 day?	Thu 3/29/07
64	✓	Section 7 -Kelly	1 day?	Fri 3/30/07
65	✓	Review	3 days?	Fri 3/30/07
66	✓	**Final Oral Presentation**	**16 days?**	**Tue 4/3/07**
67	✓	Visual Aids?	16 days?	Tue 4/3/07
68	✓	20 minuits in length	16 days?	Tue 4/3/07
69		**Spare Time**	**149 days?**	**Fri 9/15/06**
70	✓	Prototyping	20 days?	Mon 12/18/06
71	✓	Testing	10 days?	Mon 2/5/07
72	✓	Re-designing	8 days?	Mon 2/19/07
73	✓	Re-manufacturing	5 days?	Fri 3/23/07
74	✓	Re-Testing	7 days?	Thu 3/29/07
75	✓	Extra testing time incase we switc	16 days?	Fri 2/23/07
76			1 day?	Fri 9/15/06



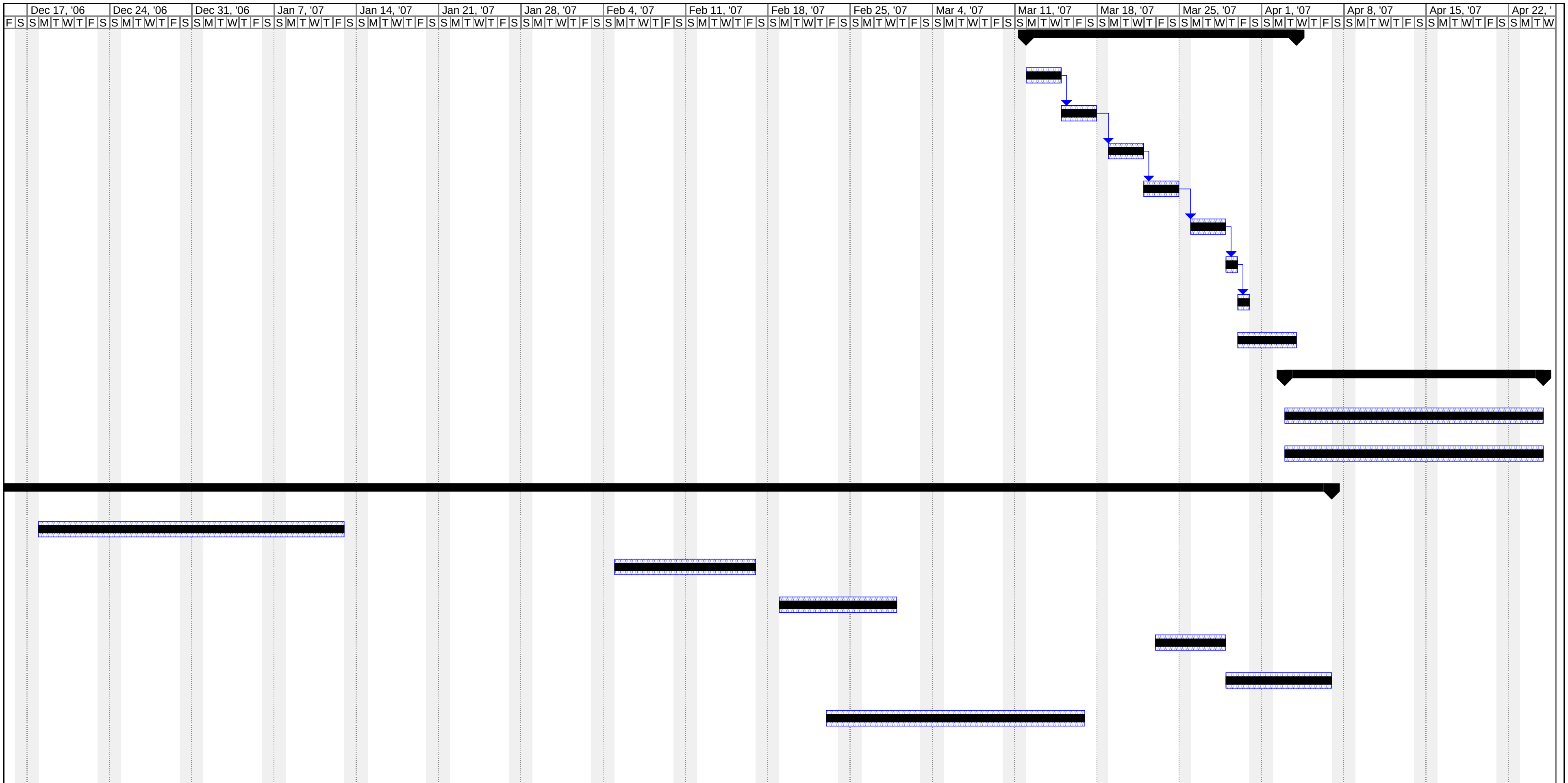
Project: Gantt Chart Date: Fri 5/11/07	Task		Progress		Summary		External Tasks		Deadline
	Split		Milestone		Project Summary		External Milestone		



Project: Gantt Chart Date: Fri 5/11/07	Task		Progress		Summary		External Tasks		Deadline
	Split		Milestone		Project Summary		External Milestone	



Project: Gantt Chart Date: Fri 5/11/07	Task	Progress	Summary	External Tasks	Deadline
	Split	Milestone	Project Summary	External Milestone	



Project: Gantt Chart
Date: Fri 5/11/07

Task	Progress	Summary	External Tasks	Deadline
Split	Milestone	Project Summary	External Milestone	

39 **Check valve testing**
We test a few check valves. Need to find appropreate valve. Further work.
40 **Opperate up to 120 degrees F**
Further Work
41 **Endurance / Lifespan Testing**
Further Work
42 **What if the power goes out?**
Not Needed
43 **High Schooler building testing**
Further work
44 **Durability testing**
Not needed
76
The prototype got redesigned; so tests changed from this orginal form. Also the tasks got assigned to different people.

Fluid Flow Analysis

Known values:

Diameter of tubing:	d = 0.25 in = 0.00635 m
Radius	r = 0.003175 m
Diameter of tip:	d = 0.125 in = 0.003175 m
Radius	r = 0.0015875 m
Diameter of fan:	d = 0.5 in = 0.0127 m
(Graupner speed 400)	
Power of Motor:	P = 0.1 hp = 74.6 W
	$P = \tau\omega = FV$
Voltage of Motor:	V = 7.2 volts
Speed of Motor:	N = 18,500 RPM
Viscosity of blood:	$\mu = 0.001\, N \cdot s/m^2$ @ 20ºC
	$\mu = 0.0027\, N \cdot s/m^2$ @ 37ºC
Density of blood:	$\rho = 1060\, kg/m^3$
Viscosity of air:	$\upsilon = 15.11x10^{-6}\ m^2/s$ @ 20ºC
	$\upsilon = 16.97x10^{-6}\ m^2/s$ @ 40ºC
	$\mu = 1.8132x10^{-5}\ m^2/s$ @ 20ºC
	$\mu = 2.0364x10^{-5}\ m^2/s$ @ 40ºC
Density of air:	$\rho = 1.2\, kg/m^3$

Fan equations:

$$Q = K_q N D^3$$

$$Q = (0.25)(18500 RPM)(0.0127 m)^3 = 0.009474 \frac{m^3}{\min} = 1.57x10^{-4} \frac{m^3}{s} = 9.47 \frac{L}{\min}$$

$$\dot{m} = K_m \rho N D^3$$

$$P = K_p \rho N^2 D^2$$

$$P = (1.9)(1.2\, kg/m^3)(18500 RPM)^2 (0.0127 m)^2 = 125859.4 \frac{kg}{m \cdot \min^2} = 34.96 PA$$

$$\dot{W} = K_{\dot{w}} \rho N^3 D^5$$

$$K_{\dot{w}} = (4476\, J/\min)/(1.2\, kg/m^3)(18500 RPM)^3 (0.0127 m)^5 = 1.7831$$

K = geometric constant

Q = volumetric flow rate

N = fan speed in RPM

$\dot{W}$ = power output

$\dot{m}$ = mass flow rate

D = fan diameter

ρ = air density

Pressure difference caused by fan:

$$P = K_p \rho N^2 D^2 = 34.96PA$$

Pressure difference from the fan to the mason jar:

$$\frac{p_1}{\rho g} + \alpha_1 \frac{\overline{u}_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \alpha_2 \frac{\overline{u}_2^2}{2g} + z_2 + h_{Lmaj} + h_{L\min}$$

$$h_{Lmaj} = f \frac{\overline{u}^2}{2g} \frac{L}{D}$$

$$\frac{L}{D} = 48$$

$$h_{L\min} = K \frac{\overline{u}^2}{2g}, K = 0.3 \text{ (elbow)}$$

$$z_1 - z_2 = 0.1524m$$

$$\frac{p_1 - p_2}{\rho g} = \frac{p_1 - p_2}{(1.2\,kg/m^3)(9.81\,m/s^2)} = \frac{p_1 - p_2}{11.77}$$

$$\alpha_1 = \alpha_2$$

$$\frac{\overline{u}_1^2 - \overline{u}_2^2}{19.62}$$

Pressure difference from the mason jar to the tip:

$$\frac{p_2}{\rho g} + \alpha_2 \frac{\overline{u}_2^2}{2g} + z_2 = \frac{p_3}{\rho g} + \alpha_3 \frac{\overline{u}_3^2}{2g} + z_3 + h_{Lmaj} + h_{L\min}$$

$$h_{Lmaj} = f \frac{\overline{u}^2}{2g} \frac{L}{D}$$

$$\frac{L}{D} = 288$$

$$h_{L\min} = K \frac{\overline{u}^2}{2g}, K = 0.3 \text{ (elbow)}$$

$$z_2 - z_3 = -0.1524m$$

$$\frac{p_2 - p_3}{\rho g} = \frac{p_2 - p_3}{(1060\,kg/m^3)(9.81\,m/s^2)} = \frac{p_2 - p_3}{10398.6}$$

$$\alpha_2 = \alpha_3$$

$$\frac{\overline{u}_2^2 - \overline{u}_3^2}{19.62}$$

Pressure difference from tubing to end of tip:

$$\frac{p_3}{\rho g} + \alpha_3 \frac{\overline{u}_3^2}{2g} + z_3 = \frac{p_4}{\rho g} + \alpha_4 \frac{\overline{u}_4^2}{2g} + z_4 + h_{Lmaj} + h_{L\min}$$

$$h_{Lmaj} = f \frac{\overline{u}^2}{2g} \frac{L}{D}$$

$$\frac{L}{D} = 24$$

$$h_{L\min} = K \frac{\overline{u}^2}{2g}, K \approx \frac{1}{2}\left(1 - \left(\frac{D_2}{D_1}\right)^2\right) \approx \frac{1}{2}\left(1 - \left(\frac{1/8}{1/4}\right)^2\right) \approx 0.4688 \text{ (sudden contraction)}$$

$$z_3 - z_4 = 0m$$

$$\frac{p_3 - p_4}{\rho g} = \frac{p_3 - p_4}{(1060\, kg/m^3)(9.81\, m/s^2)} = \frac{p_3 - p_4}{10398.6}$$

$$\alpha_3 = \alpha_4$$

$$\frac{\overline{u}_3^2 - \overline{u}_4^2}{19.62}$$

Flow Rate:

$$Q = \frac{\pi R^4 (p_1 - p_2)}{8\mu L} \quad \text{(Laminar Flow)}$$

$$Q = \overline{V}A$$

$$\text{Re} = \frac{\rho VD}{\mu}$$

Condition for laminar flow with blood:

$$2300 > \frac{(1060\, kg/m^3)(0.00635m)}{0.001\, N \cdot s/m^2} V$$

$$V < 0.3417 m/s$$

Condition for laminar flow with air:

$$2300 > \frac{(1.2\, kg/m^3)(0.00635m)}{1.832x10^{-5}\, N \cdot s/m^2} V$$

$$V < 5.473 m/s$$

Cross-sectional area of tip:

$$A_c = \frac{\pi D^2}{4} = \frac{\pi (0.003175m)^2}{4} = 7.917x10^{-6} m^2$$

Cross-sectional area of tubing:

$$A_c = \frac{\pi D^2}{4} = \frac{\pi (0.00635m)^2}{4} = 3.167x10^{-5} m^2$$