Team 9
Oil Sniffer
Design Review #2

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EXECUTIVE SUMMARY

Rolls-Royce has been recognized as the world's number one turbo jet engine maker. When their engines are in use, sometimes some of the oil in the ball bearings of the engine bleeds into the compression system, which eventually ends up in the cabin of the airplane, causing customer discomfort. Henceforth, Rolls-Royce has asked our team to look into developing a device that detects oil particles in the air of aircraft cabins. This will be accomplished by determining if there is sensor technology that can fulfill the requirements at a reasonable cost and then implementing it into a handheld detection device. This report provides a thorough explanation of the final design and the validation of this design.

The final design specifications govern that it is low in cost, has low power consumption, has a simple output, is small in size, and is durable. The concept that was chosen for our final design was a simple rectangular box, because it could accommodate different sensor sizes, while being able to hold all of the sensor components and is easily manufactured. Also, an Arduino microprocessor was used so that output data could be stored and downloaded for analysis purposes. Of the options researched the best sensor for this application is a micro hotplate sensor. Design for manufacturing and assembly enabled this product to be easily mass produced. Drop tests were used to validate the durability of the final design.

The final design met the customer requirements and engineering specifications. Although a sensor was not chosen research determined that a microhotplate sensor should be used.

ABSTRACT

Commercial aircraft travel can be an uncomfortable experience for some due to cabin odor. At times, the source of the problem is oil in the air supply taken from the engine compressor. The rationale for the "oil sniffer" is the need for a non-subjective method of measuring commercial aircraft cabin odor. Current particulate sensor technologies are both bulky and cost prohibitive for use during flight. This portable device will be developed by determining the acceptable limit of oil particulates in cabin air, and the feasibility of applying existing sensor technologies into the detection of oil particulates in the air.

PROBLEM DESCRIPTION

Rolls-Royce, a leading provider of power systems and services, has been recognized as the world's number one turbo jet engine maker. They have invested more than ₤3 billion in research and development over the past five years to promote new inventions and to maintain their position as the leader in advance technology, especially in civil aerospace. One of their strategies is to add value for their customers with aftermarket services that will enhance the performance and reliability of their product. They always seek to improve customer satisfaction, especially in airline industry in which is one of their biggest markets [1].

Questions have arisen about the quality of air inside the aircraft cabin and its effect on the health of passengers and cabin crews since people began traveling in pressurized, climate controlled aircraft. The number of people traveling by commercial aircraft has increased dramatically over the years, including young and elderly passengers having a diverse range of sensitivities and susceptibilities to potential health risks and uncomfortable feelings associated with cabin odor.

The typical modern generation airplane uses 50% filtered re-circulated air and 50% of outside air. Only about one-fifth of the air from outside that is drawn into the engine enters the core. At times, the source of the cabin odor problem is oil that is leaking from the bearings that support the shaft of the fan. As the seal of this bearing wears out, due to high pressure and temperature conditions, oil particulates mix with air in the compressor stages and are carried through the bleed system. This system provides air at the proper temperature and pressure required to meet the needs of all pneumatic services on the airplane.

The objective of this project is to develop a non-subjective method of measuring commercial aircraft cabin odor due to oil particulates in the air. Current particulate sensor technologies are both overly complex and expensive. A portable handheld device will be developed to determine the acceptable limit of oil particulates in cabin air, and the feasibility of applying existing sensor technologies into the detection of oil particulates in the air.

INFORMATION SOURCES

The Internet

A few key websites have the attention of the team. The first is the home for the Airliner Cabin Environment Research team. This team is backed by FAA funding and is comprised of eight colleges researching various aspects of cabin conditions including research on various sensors

[2]. The second is the website for The United Kingdom Parliament, which has a large document on cabin air. Of particular interest in this document is a section that describes the elements of healthy cabin air [3]. Last, a general survey of existing devices and possible sensors was conducted.

In addition, the US Environmental Protection Agency (EPA) provides some significant information that helps to develop team's understanding associated with various kinds of existing air pollutants and their effects to human health [4]. In addition, research conducted by Boeing regarding airplane cabin environment that discusses the issues pertaining to flight attendant comfort gives more insight about how an airplane cabin environment ventilation system works, including contaminant buildup in the cabin, spread of disease and cabin odor [5]. Lastly, an article from the Civil Aviation authority provides information on oil contaminants in cabin air supplies and identifies pentanoic acid as a possible source of the odor [8].

Information Gaps

The key gap after our research is a numerical high level of odor in the cabin air. This is subjective, and elusive to define. Some data was found on health studies regarding the oil, but none seemed to be dealing with the oil after it was partially combusted.

Some of the sensors examined are still under development, so not all data on them is available or finalized.

CUSTOMER REQUIREMENTS AND ENGINEERING SPECIFICATIONS

To determine the customer requirements and engineering specifications, a QFD diagram was developed. This allows different aspects of the design to be compared, so that the most important aspects can be determined. The results of this process are the QFD located in Appendix A. Below is a description of the information in the QFD.

Customer Requirements

The first task in developing the QFD, is determining who the customer is. We identified airline companies as the customer. Next, a list of twelve customer requirements were obtained through discussion with out sponsor, these requirements ranged from the appearance of the device to its accuracy (see Table 1). To determine the importance of each of the customer requirements, we compared all of the requirements to every other requirement and determined which was more important. These comparisons were then used to determine the relative weight of each requirement, which will be used to determine overall importance of each requirement (see Table 1).

FAST Diagram

To develop our engineering specifications, we need to make sure that we are thinking about all the processes that this device is going to have to go through. A good way of organizing our data and brainstorm is develop the FAST diagram as seen in Appendix D. This helped us take the next step in determining our engineering specifications.

Low Cost	1.0
Accurate Measurements	0.9
Durable	0.8
Simple to Use	0.7
Quick to Use	0.6
Light	0.4
Cheap Batteries	0.4
Ergonomically Friendly	0.3
Long Lasting Batteries	0.3
Compact	0.2
Easy to store	0.1
Aesthetically pleasing	0.1

Table 1: Customer Requirements and Relative Weights

Engineering Specifications

At this point in the design process, the engineering specifications have been set, and enough information is known as to whether they can be met. From the customer requirements and the fast diagram a list of engineering specifications were generated (See Table 2). This section is a break down of all the engineering specifications in order of importance according to the QFD (Appendix A), and how they meet these customer requirements.

The first engineering specification is that the device has to cost less than $1000. This requirement was expressed by our sponsor and is directly related to the low cost customer requirement. From our research, it appears that producing a low cost device is feasible.

The second engineering specification is the sensitivity of the sensor to particles in the air. This specification came from the necessity for an accurate device. Originally we decided that the sensor had to detect at least 30 ppm. Through further research it is known that sensors are available with much higher sensitivities than our specification requires (frequently around 1 ppm). The specification could change once sufficient data has been found about the sensitivity of the human nose to the oil that is being detected.

The third engineering specification is the need for at least 2% repeatability. This requirement stemmed from the necessity for an accurate device. If the device cannot give consistent results, then it is not a good way to measure the oil levels.

The fourth engineering specification is a weight constraint. The device is supposed to be hand held, ergonomically friendly, light and easily used by a flight attendant during flight. The weight requirement was set at a maximum of 5 lbs.

The fifth engineering specification is the time it takes to respond. We decided that it is important that the device responds in less than 5 seconds. This ensures a quick response for ease of use during flight. Actual response time will depend on the sensor and internals.

The sixth specification is the volume of the device. This came from the customer's desire for a small, easily stored device. We decided that the device had to be no more than 0.25 ft^3. Current design concepts indicate that this specification will be satisfied.

The seventh specification requires that the device be capable of detecting a range of odor. One of the customer requirements is to make this device easy to use, so we are limiting the output to be whether the odor level is high, medium and low. The simple output facilitates ease of use.

The eighth specification is that there is minimal zero drift. This is a direct correlation to a necessity for accuracy from this device and will also keep the cost low. It was decided that there should be less that 5% zero drift in this device over a year. This will give the device a good deal of accuracy and will also help keep the price low, because there is less cost in calibration. Achieving this specification will depend on the sensor that is chosen.

The ninth specification is that a certain percentage of the devices produce last at least 10 years. This is a measurement of durability and cost. We decided that at least 40% of the devices should last 10 years or more. This is a good level to strive for and gives good information on the devices durability. This is a hard specification to test, because the device is only in our control for a short period, but some tests could be run to make sure that this specification is met.

The final specification is that there is low power usage. This is in response to the desire for using cheap, long lasting batteries and will also affect the price of the device. We decided that as long as this device runs on less than 12 W is desirable. This will allow the use of conventional batteries, and possibly even rechargeable batteries, keeping down cost while providing the power that is needed.

Cost	$1000
Particles Detected	30 ppm
Repeatability	2%
Weight	5 lbs
Read-Out Time	5 sec
Volume	.25 ft^3
Levels Detected	3 levels
Zero Drift	5%
Percent that Last over 10 years	40%
Power Usage	12 W

Table 2: Engineering Specifications and Targets

Correlation Between Customer Requirements and Engineering Specifications

After the engineering specifications were determined, both these specifications and the customer requirements were put into the QFD (Appendix A) so that the correlation could be determined between each customer requirement and each specification. These correlations were then used with the relative weights obtained earlier to rank customer requirements.

Benchmarking
By benchmarking competitors' products, target values for each of the engineering specifications were determined as goals for this project. Research on current devices is ongoing, and two devices have been found and benchmarked.

First is the Enmet Omni-4000 [6]. This device uses replaceable sensor blocks for measuring various gases, and is calibrated through replacement of the sensor blocks. It costs around $1500, and an additional $400 for the hydrocarbon sensor. It can measure hydrocarbons in the range of 20-500ppm.

Second is the Photovac 2020ppbPRO [7]. This device uses a photoionization detector (PID) and can measure hydrocarbons in the range of 10ppb to 40ppm. It is around $6400 and measures various contaminants at levels lower than required for this project. One notable feature is its filtering system for accurate calibrations while in service.

Patent Search
Patent 6941193 is a sensor system for measuring and monitoring air quality, it is targeted towards commercial HVAC systems. The key part of interest is "A portable pollution sensor device that measures and monitors leading indicators of indoor air quality and the extent of pollution is used in conjunction with the ceiling grid mounted sensor modules." [from patent document] This portable sensor unit does not have any GC functionality, but it does store a collected data and can be plugged into an LAN and accessed remotely. This product is very similar to the oil sniffer, but lacks the required GC function.

Patent 5445795 covers a range of volatile organic compound vapochromatic sensing devices. Although none of the VOCs that are characteristic of the oil in question are covered in this patent, it appears it is possible to tailor a vapochromatic sensor to react to most any VOC. The use of this a vapochromatic crystal would remove the need for any electronics, but would remove the ability to store any data.

Patent 7056474 is a hydrocarbon sensor and collector, owned by Visteon. When the system senses HCs in an air flow, it redirects the air flow to a purgeable HC collecting element. This could solve the problem instead of just measuring it, when used in the bleed air ducting. The HC sensor in the system is a MOS sensor. The MOS sensor measures total HC.

Patent 4755360 is catalytic converter for the bleed air. This device is intended to remove any oil that is present in the bleed air, removing the need for our device. Patent 5791982 is a system for improving the well-being of humans in a commercial aircraft. The system only monitors carbon dioxide, oxygen, humidity and air pressure, and attempts to keep these variables within pre-set acceptable limits. It does not monitor any air contaminates or include any filtering.

PROJECT PLAN

The Sponsor outlined the "Oil Sniffer" project in four parts: research current technologies; determine acceptable limits of oil particulates in cabin air; determine the feasibility of applying existing sensor technologies into the detection of oil particulates in air and incorporate best suited technology for the final prototype or mock up.

Since Design Review #2, we have continued our research, and current information indicates that there is no suitable sensor in our price range. Useable sensors only take an aggregate measure of volatile organic materials in the air and do not differentiate between materials. In this case no positive identification could be made without a series of filters that would isolate certain aspects in the air that are found in the oil such perfume, alcohol or smoke. Through our research, though, we also found that there is not an appropriate filter system available. Once this information was found, our sponsor decided that the direction of our project needs to change focus from sensor technology to a structural analysis of our final prototype casing.

Following Design Review #3, the major tasks are developing a finite element analysis model (by November 17^{th}), prototype CAD model refinement (by November 17^{th}), building the prototype (by November 17^{th}), manufacturing CAD model development (by November 29^{th}), and continued research of available sensors.

The project plan is summarized in the Gantt chart shown in Appendix B.

PROBLEM ANALYSIS

Sizable issues have arisen in this project. Since there is not an applicable sensor, a new direction has been taken. We now have two main objectives: rigorous engineering design of the handheld product and further sensor research.

The CAD design of the device case should run smoothly. Issues in CAD will be resolved quickly by working on the model together. The finite element analysis (FEA) of the model has many unknowns and many possible issues ranging from outright model failure to unrealistic results. Team experience in this area is limited to an introductory understanding of methods and software. With this in mind, we expected that the FEA will be an iterative process involving model refinements to give the best results possible. Our plan is to start early and to stay on schedule.

Our continued research will run into the same issues prior research ran into. These issues include incomplete online data and unresponsive vendors. Unresponsive vendors will be dealt with through repeated contact and multiple contact methods. Some devices were originally found unsuitable because they are currently under development or too expensive. These devices will be researched further but issues may arise with confidentiality of data regarding them. Due to issues of time and legal resources further research of these devices will have to be discontinued but will be mentioned as possibilities.

CONCEPT GENERATION

The team brainstormed different ideas, with the main idea of a block-shaped enclosure, and tried to branch off from that. We focused on different configurations and possible scenarios for the device. The devices we sketched out included variations on: sensor locations, air sampling methods, output methods, form, internals, power source, intended style of use, and size. We then assessed each design and decomposed ideas into components in the morphological chart (Figure 2).

Device Types

There were two main types of designs, vapochromatic and electronic.

Vapochromatic [15,16] devices use a substance that changes color in the presence of a given substance. Research has shown there are crystalline substances that have a visible color response to hydrocarbons. It is unknown what level of contamination leads to a color change, and if current crystals will change in response to the oil in question. In addition, their prices and availability are unknown. The devices could either be a disposable card with a spot of the sensing substance and a color key, or a permanent card if the sensing substance changes back when put in clean air.

Electronic devices cover a wide range of forms. These devices were the main focus of our brainstorming session. Many forms have been conceived, and sketches can be found in Appendix C. From these sketches, three main forms (as seen in Figure 1) are recognized, and are expounded upon below. Internals and sensors for these devices are also discussed.

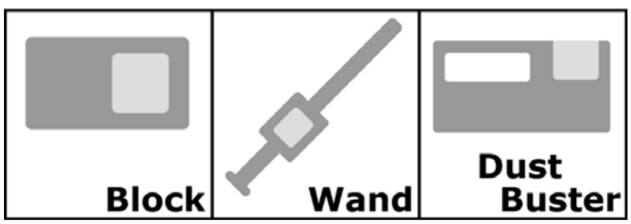

Figure 1: 3 Main Forms

The block is the most compact of all the concepts. Our original plan was to use an externally mounted sensor or a fan to sample air across a MOS sensor, but the simple block shape may be used with most of the air sampling methods, sensors and internals. This form is size limited because a large block will be unsightly and cumbersome to use.

The dust-buster form picks up where the block left off. The handle and larger volume could accommodate large components without feeling bulky.

The wand can be seen as a combination of the block and the dust buster, but we feel it to be separate. The basic idea of the wand is to have a handle on a small device. The basic wand shape could be very short to keep the device compact, or longer to make reaching over the passenger less awkward. Either of the wand shapes would use an external sensor to sample air.

Functional Decomposition.

We have split up the device's functions into 6 main categories. These categories and the possibilities for each are shown in the morphology chart (Figure 2).   The morphology chart is very important to our design process, and was used heavily in our concept selection process.

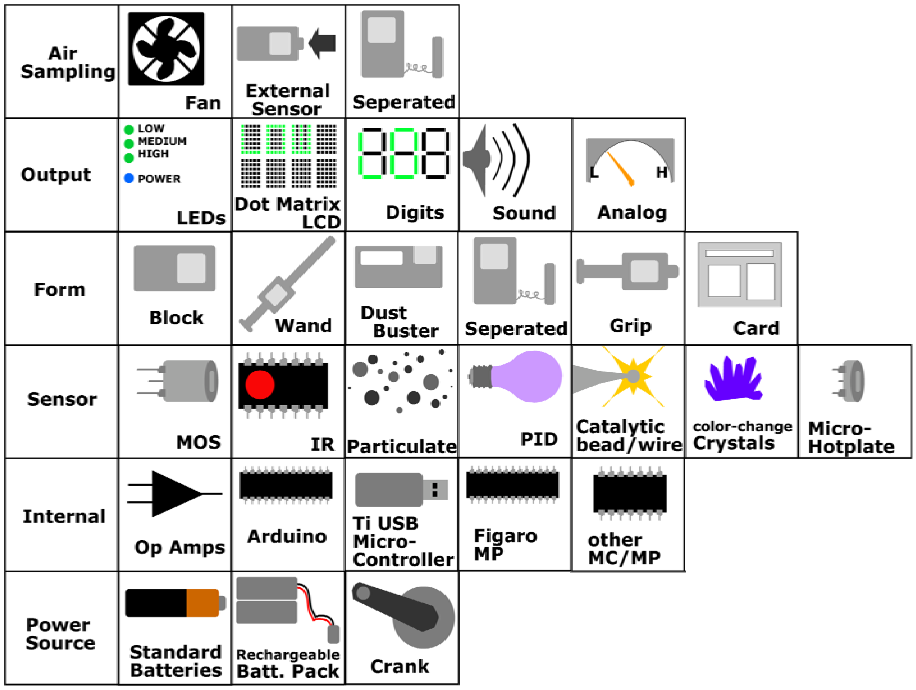

Figure 2: Morphology Chart

CONCEPT SELECTION PROCESS

Method

There were two main processes at work in concept selection, first we generated Pugh charts for sensor technologies and general device forms. With these in mind we proceeded to a focused group discussion. We worked with the morphology chart (Figure 2) and combined what we felt were the best components into one full concept. Below we expound on the choices we made, in the order we made them.

Selections

Sensor selection. The sensor was the keystone part. Sensor research is ongoing, but for the alpha design we chose to use the City Tech Cap25 metal oxide semiconductor (MOS) sensor, it has a solid range that can reach 1ppm. It has low power consumption (under 350mW) and reasonable voltage requirements. The drawbacks to this sensor is that it requires some software to interpret the results and is sensitive to a wide range of air contaminates like cigarette smoke, in addition to volatile organic compunds (VOCs). Also, each sensor would need to be conditioned and calibrated before use which would add to production costs. We used the sensor Pugh chart (Figure 3) and our research to choose this sensor. The Pugh chart was helpful in comparing what we knew about sensor technologies and what information gaps still exist (shown with question marks in the chart).

The vaporchromatic substances are very promising, but not enough data is currently held to determine if they are applicable to the project. Particulate sensors are also promising, they cost less than the MOS sensors, but their functionality is still in question. We are currently waiting to hear back with additional information on the Sharp brand particulate sensor. The infrared (IR) and photo ionization differential (PID) were left out of the Pugh chart due to their price range. The catalytic bead/wire sensors found in research cannot detect reliably in the range we expect to be working in.

The Applied sensor Air Quality Module (AQM) is an integrated solution, with its own micro-controller and firmware. The company also advertises application-specific customization. This device would greatly simplify the project if it would work, but both emails send to Applied Sensor have gone unanswered.

PID sensors are available from multiple manufacturers, and with varying properties. Some, like the one used in the benchmarked 2020 device from Photovac have gas chromatograph abilities, while others like the Citytech PID [22] only measures aggregate VOCs.

Brand	City Tech	Figaro	Sharp	Applied Sensor	
Name	Cap25 [11]	TGS 2602 [12]	GP2Y1010AU [13]	Air Quality Module [14]	
Type	MOS	MOS	Particulate	MOS	Vapochromatic
Cost	S	?	+	?	?
Range	S	S	?	?	?
Power needs	S	S	S	?	+
Repeatability	S	S	?	?	?
Ease of use	S	-	?	+	+
Size	S	S	-	-	+
Speed	S	S	+	?	?
Total +	0	0	2	1	3
Total -	0	1	1	1	0
Total	0	-1	1	0	3

Figure 3 – Pugh Chart for sensor selection

Internals selection. With the sensor in mind, and with information recently received from sensor manufacturers, the need for a microprocessor was clear. The Arduino [9] processor system was chosen by group discussion for the prototype due it its low cost and easy programming. We are unsure of the use of this processor for production units.

Air sampling selection. In the first few concepts we completely left out an air sampling method, but quickly realized this was very important. We chose to sample directly from the vent via a nipple to reduce contaminating the sensor with other airborne material like residual cigarette smoke on a passenger. The nipple is convenient because it will form a seal around a number of different vent shapes and sizes. Further research needs to be done on a nipple material.

Power source selection. The selected sensor requires a stable 5V to its heater, 1V for the actual sensor, and the pre-fabricated Arduino prototyping board requires 9V. We chose to run everything off of a single 9V battery. The 9V size is compact at an inch wide and just under 2 inches tall, and would be easy to replace. However, the mAh (milli-amp hour) rating on 9 volt batteries seem to vary greatly and might pose a problem in terms of battery longevity.

Form selection. Selection of a form was done last, with a combination of a form Pugh chart (Figure 4) and group discussion. The card scored highest in this Pugh chart, but it is only applicable to the vapochromatic sensor. We think the block will work well with the other selections we have made.

Customer Requirements	Weight	Block	Dust Buster	Wand	Seperated	Grip	Card
Low Cost	1.0	S	S	S	S	S	S
Accurate Measurement	0.9	S	S	S	S	S	S
Durable	0.8	S	S	S	S	S	-
Simple to Use	0.7	S	S	S	S	S	S
Quick to Use	0.6	S	S	S	S	S	S
Light	0.4	S	-	S	S	S	+
Standard Batteries	0.4	S	S	S	S	S	0
Ergonomically Friendly	0.3	S	S	S	-	+	+
Long Lasting Batteries	0.3	S	S	S	S	S	0
Compact	0.2	S	-	-	-	-	+
Easy to Store	0.1	S	-	-	S	S	+
Aesthetically Pleasing	0.1	S	-	+	-	S	+
	Σ_+	0	0	1	0	1	5
	Σ_-	0	-4	-2	-3	-1	-1
	Σ_{TOT}	0	-4	-1	-3	0	4

Figure 4: Pugh Chart for concept generation

SELECTED CONCEPT (Alpha Design)

Our selected concept is not just one of our sketches, but a combination of the best parts found in brainstorming. The prototype will be in a "block shape" form with a dimension of 4"x 2"x 1" (length * width * thickness). The air duct material is made from silicone material so it can be fitted onto an air jet fan. We chose a MOS sensor to detect the level of oil particulates in the air. The signal will then be carried out to the micro processor as an input, processed, and is sent to output LEDs. There will be three LEDs (high, medium, low) to differentiate the oil levels in aircraft cabin, as shown in Figure 5.

MOS sensor is selected since it has high sensitivity not only to air contaminants emitted by cigarette smokes, but also to low concentration odorous gases such as ammonia and sulfuric acid. In industry, MOS sensors are commonly used for automotive air quality sensor. It also has long life, low cost, and low power consumption compared to other sensors being considered, as shown in the morphology chart (Fig. 3). Arduino is an inexpensive micro processor that is able to be easily assembled by hand. It requires specialized software and can be easily connected to a computer using USB connection to create, compile, and upload code in a microprocessor board. It can take inputs from variety of sensors and controlling a variety of lights, which corresponds perfectly with what we need it for. These devices, including output LEDs, will be powered with standard 9 volt battery. The schematic diagram of our prototype and layout of subsystems interaction are shown in Figure 5 and Figure 6 below, respectively.

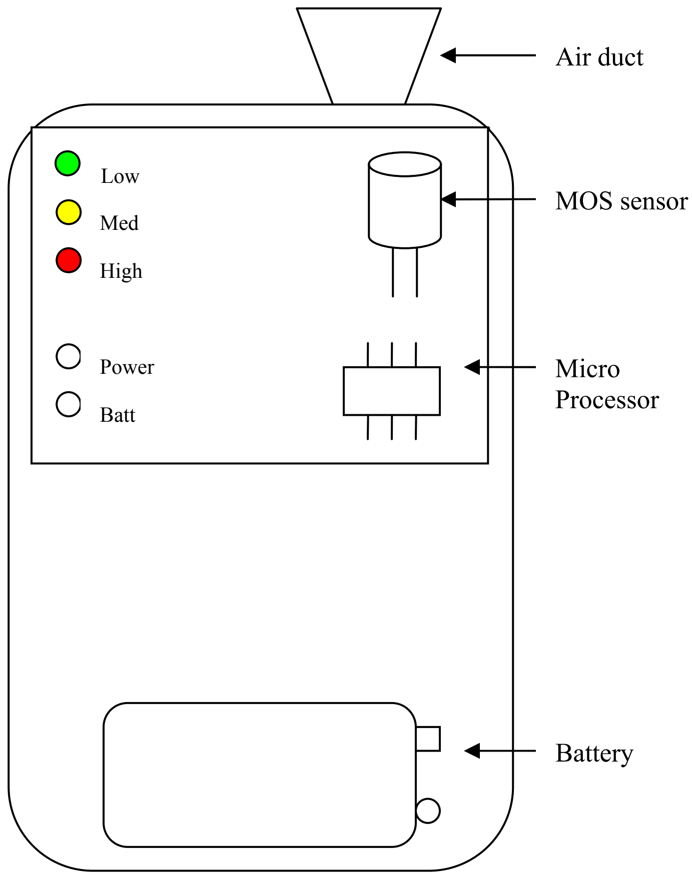

Figure 5: Alpha Design

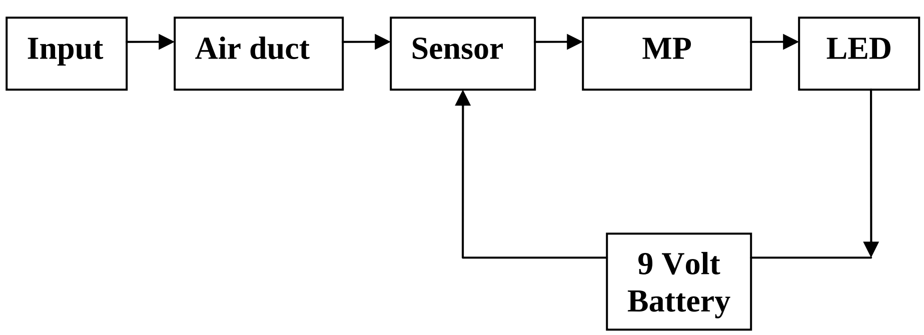

Figure 6: Subsystems Interaction

Engineering Design Parameter Analysis

The output method for the device is the same as the alpha prototype. 5mm LEDs were chosen for their high visibility over the 3mm variety, where as 8mm and larger were too large. The LED output is long lasting, with a useful lifespan exceeding thousands of hours with proper voltage input [19]. Due to recent heightened anxiety when flying we decided to avoid red LEDs for high or low battery as not to alarm passengers that glance at the device. The FMEA chart Appendix E) brings surface wear to the foreground. This is an important consideration for labeling the output LEDs. We decided to incorporate the labels in the plastic of the device itself so they cannot wear off.

The shape of our design remains nearly unchanged from our alpha plan. A main reason behind the brick shape is the shape of the internals; both the battery and microprocessor assembly are rectangular. We determined that 4 inches wide would be the cutoff for being considered hand held; with our device solidly under this limit. Larger than 4 inches wide could be awkward to hold and might require some form of handle. The brick is also the simplest shape and is very common among hand held electronics, so it should be visually familiar and not intimidating (unlike some of the benchmark devices).

Dimensions for the case were determined through measuring the components that it must contain. We took the sensor size as the size of the largest sensor we found. Obviously this will allow the use of any other sensor with little or no redesigning.

The case prototype will be rapid prototyped using a 3d printer. For mass production, high density polyethylene (HDPE) would be used due to its high fracture toughness (Table 3). One downside to HDPE is that it becomes brittle at low temperatures but this should not be a problem in the aircraft cabin [17].

Name	Abbrev	Young's Modulus [GPa]	Fracture Toughness [MPa √m]
Low density polyethylene	LDPE	0.15-0.24	1-2
High density polyethylene	HDPE	0.55-1.0	2-5
Polypropylene	PP	1.2-1.7	3.5
Polyvinyl chloride	PVC	3.0-3.3	2.4

Table 3: Common Plastics Table [17]

The FMEA (Appendix E) chart drew attention to proper design for the battery compartment. We found Duracell provides a comprehensive set of design tools [18]. Important notes include proper ventilation for batteries, proper low voltage cutoffs to prevent over-discharge (which can lead to battery leakage), design for proper battery installation, and the need for a separated battery compartment. These are all things that we are now aware of.

DFMA

When designing a piece for mass production, it is important to make design choices that will make the production process smoother. Many times, this can be done by changing small details.

For our design, one key difficulty is designing the housing for easy manufacturing. To facilitate easy injection molding, edges will be rounded, draft angles added, and side pins eliminated. Rounded edges are important to the look and feel of our device, in addition to easy molding. Draft angles will be added internally to what will become the sides of the unit, with a seam running circumferentially. This seam will also allow a side mounted USB port without the need for any side pins.

To facilitate easy assembly, we plan to minimize part count especially fasteners and modularize internals. First, our prototype has two circuit boards, one for the LEDs and one for the processor, in the mass produced device, these two could be made as one. There are features on the Arduino board that will not be used in this project and could be removed for production. This is an application of both modularization and minimizing parts. In an effort to reduce fasteners the case will be produced with a mortise and tenon in the front to reduce two screws. The circuit board could also be held in place with integrated snap fit posts to further reduce screws and time spent assembling.

Final Design Description

The final design prototype of the handheld oil sensor device is in the basic shape of a rectangular box with rounded edges. The dimensioned drawing is shown in Appendix G**.** The display is comprised of a series of LEDs indicating whether the device is on, whether the device is detecting a low, medium or high level of oil contamination, and whether there is low battery power. The box will be in two halves that are attached at the top with a mortise and tenon joint, and two screws in the rear. At the front of the device there is a grid of holes that act as an inlet for air. At the bottom of the device there is grid pattern of holes that acts as the outlet for air and a method of cooling for the internal circuitry of the device. There is a panel, secured by a snap fit, on the back of the bottom of the device to facilitate access to the batteries. One side of the box will have a USB port for connecting the device to a computer for downloading data. Inside the housing there will be a circuit board to which the sensor is connected to the Arduino processor, battery power supply and LEDs. To operate the device once it is turned on the LEDs will indicate the oil levels detected. If a series of data points are needed the device can be left on for multiple flights and data downloaded to a computer using the USB port.

The Bill of Materials and Parts List for the final design are given in Appendix F. The housing of the final design will be made of high-density polyethylene plastic (HDPE). There will be silicone rubber strips applied to the sides of the housing to act as ergonomic comfort grips for the device.

Prototype Description

The prototype is a one to one scaled version of the final design. Some design features in the final design are modified for the prototype for simplification of the construction process. Differentiating features between the prototype and the final design include fastening methods and safety considerations and optimization of components. Table 4 provides a comparison of features and the justification.

The prototype will simulate the functionality of the final design. The simulation of the sensor by data input through the USB port will provide adequate verification of the response of the device. The LEDs on the prototype will provide the same output of the final design. The prototype contains the core components of the final design except the sensor. Ongoing research will determine the best suitable sensor which has not been determined at this time.

Our prototype will resemble our final design, with only a few internal differences. The prototype case will have 2 different pieces, which made with stereo lithography (rapid prototyping process), which will be screwed together. The final design will use a mortise and tenon joint at the top and two screws at the base. The prototype will have two circuit boards. One board on the bottom will be the Arduino circuit board which will hold the sensors, resistors, and USB connector. The other board is holding five LEDs and is connected to digital output of the Arduino board. The final design will have one board with all the components on it. Two rubber strips are going to be glued to the sides of the box for the final design, but will not be present on the prototype (see Table 4).

Final Design	**Prototype**	**Justification**
One circuit board	Two circuit boards: Processor board and LED indicator board	Asymmetry.
Snap fit fasteners; Only two screws used to secure case halves	Five Screws to secure case halves and circuit boards	Cost reduction of eliminating screws; Faster assembly times
Auto-shut-off capability	On –off push button switch	Prevent circuit damage
Low battery indicator	None	Ensure accurate measurements
Independent access Battery Compartment	Battery enclosed with components	Protection of circuit board from battery leak

Table 4: Comparison of Features between Final Design and Prototype

Prototype manufacturing

The first task was to design and build the led array. Each LED would be controlled by a digital output pin on the Arduino board. The digital pins act as switches, being in either a high (regulated to 5-5.6 V) or low (0V). The 5mm LEDs operate at 2V, so a resistor in series with each LED was required. The resistor required using ohms law, assuming the led is ohmic in its operating range; the calculates minimum resistance required was 180 Ω (see Eqn 1) to feed the LED its peak current, 220 ohm resistors were chosen on the advice of an employee of Purchase Radio Supply, who was well acquainted with LEDs. The 220ohm resistor would not detract noticeably from the light output, and ensure the longest life from the LEDs.

$$R=(V_R - V_L)/I_{Lmax} \qquad \text{(Eqn. 1)}$$

The system was then soldered up on a prototyping board, making sure to orient the LEDs properly, and leaving extra long leads to plug into the Arduino pins. The schematic of the system is seen in Figure 7. The hardware is now complete.

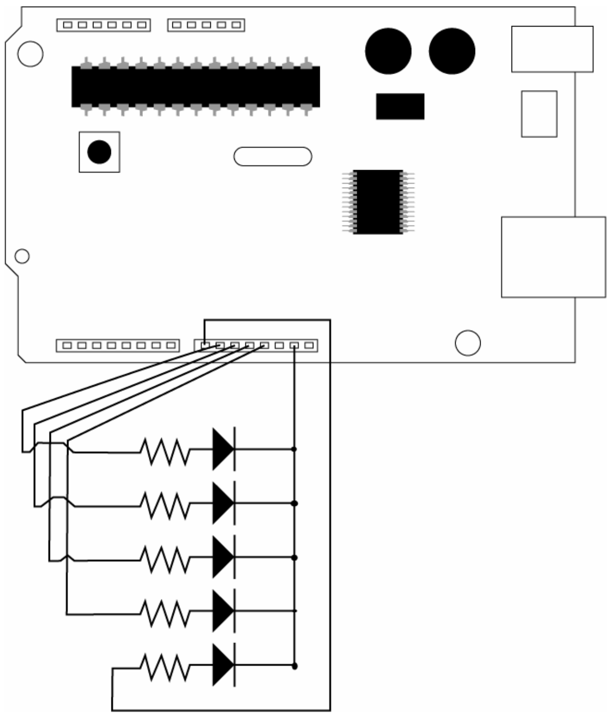

Figure 7 – Schematic of internal electronics

The Arduino system uses the wiring language for its code. After reading up on its use and structure, we made code (See Appendix J) that could use the analog to digital conversion pins to read in 0-5V from a sensor. The code can also take in a value from 0 to 9 from the USB to simulate a sensor for the purpose of demonstration and debugging. The Arduino processor itself can store 512 data points, there is at least one company producing external memory units for the Arduino system that use Secure Digital (SD) cards which could be used to increase the memory to 2Gb or more. A 2Gb memory would allow a lifetime of data to be stored.

The power system is very simple. The positive 9 volt battery lead is connected to the switch, with the lead from the other switch pin and the negative battery lead are plugged into the proper pins on the Arduino board. The Arduino documentation states that the power may be back fed in this manner being sure to switch the jumper near the USB to the external power setting.

The case was made using stereo-lithography. The tolerances and quality of the University of Michigan's rapid prototyping system was low and resulted in a mediocre case, with a rough surface finish and generally low quality. Some time with fine file and a hobby knife was required to get everything fitting properly. The screw holes had to be tapped because the prototype was too brittle to use self tapping screws.

The final steps of manufacturing were to trim the LED board with a hack saw and file so it fits properly in the case and connect it up according to the pin settings in the code (See Table 5). These can be changed, keeping in mind not to use digital pin 13 because it has a series resistor in it already. A type B USB connector was added which was not connected in our prototype.

LED	PIN
HIGH	9
MEDIUM	10
LOW	11
POWER	12
LOW BATTERY	8

Table 5 – Pin designations

Initial Manufacturing Plan:
For the prototype stereo lithography will be used. Stereo lithography process produces 3D rapid prototype parts a layer at a time by using the light of a solid-state laser to trace the cross sectional slice information of the 3D CAD data onto the surface of a container of liquid photopolymer. This material quickly solidifies when the laser beam strikes the surface of the liquid. The self-adhesive property of the material will cause the layers to bond with one another to form a complete three dimensional object that replicates our 3D CAD drawing. The material that we are going to use is Somos 9420 EP White since it has physical and thermal properties that are similar with the high-density polyethylene that is going to be used as our final design material (Table 6).

Rapid prototyping technology will allow us to save time and money by decreasing the time-to-market and avoiding costly modifications to production tooling. The product will have temperature tolerance, flexibility and elasticity that mimic the final design product. Below is the comparison between both materials.

There are several differences between the prototype and the actual design. The final design will have a "snap-fit" attachment to reduce the cost of having screws and to ease battery replacement. It will have an auto-shut-off capability to prevent circuit damage. The battery will have its own compartment that will contain any battery leak from the circuit board. A small piece of foam is going to be added in the battery compartment to prevent it from moving and sliding around. Further research on the circuitry needs to be done to allow the producer to have a cheaper and more economical circuit board.

	High-Density Polyethylene	Somos 9420 EP White
Density	.918 – 1.4 g/cc	1.13 g/cc
Tensile Strength	10 - 50 MPa	17 – 20 MPa
Water Absorption	1.5%	0.93%
Hardness (Shore D)	55 - 69	70 - 74

Table. 6: Materials for prototype and final design

The box for the final design is going to be made using injection molding for mass production purpose. This process involves injecting the polymer melts into the hollow mold cavity with high pressure. An injection molding machines consist of two basic parts, an injection unit and a clamping unit. The injection unit melts the polymer resin and injects polymer melt into the mold. The unit may be ram fed or screw fed. Clamping unit is the part that holds the mold together, opens and closes it automatically, and finally ejects the finished part. Injection molding cycle comprises of four steps: melting of plastic resin, injection of melt into the mold, cooling of the mold, ejection of the part. The accuracy of injection molding process is limited by standard machining tolerance of .003 inch plus an additional of .005 inch for high density polyethylene material, which will yield total of .008 inch tolerance. The schematic diagram of injection molding machine process is shown in Figure 8.

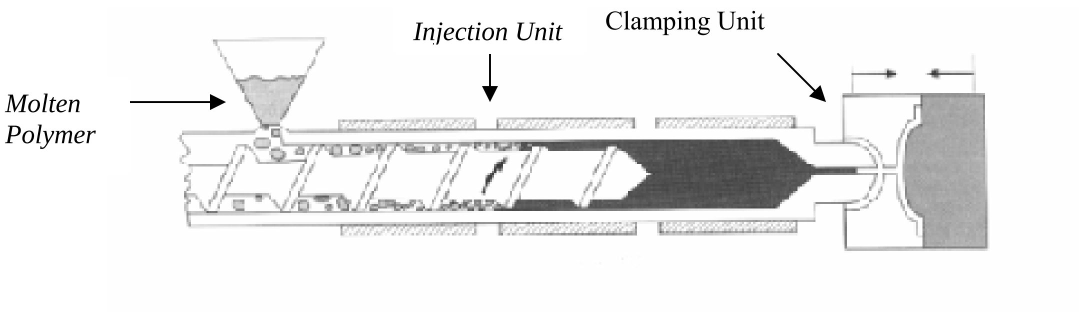

Figure 8: Injection molding schematic

Description of Validation Approach

The next step of the design process is to develop tests that will ensure the engineering specifications are met by the prototype. At this point in the design process, not all of the engineering specifications can be tested. This is because an applicable sensor has not been found. However, validation approaches for the engineering specifications that will not be tested directly have been devised.

Testable Specifications

The weight will be determined by using a simple scale. Since the sensor will not be available, its weight will be estimated and added to the weight of the other components. The weight of the piece that would be manufactured will be estimated by determining how much plastic will be used to construct the casing and calculating it's weight using the known density of the material.

The volume will be determined by measuring the parameters of the case and calculating the volume. This will be the same as the volume of the injection molded part that would be used for mass production.

Non-Testable Specifications

The particle detection specifications would be determined by placing the prototype in conditions that are similar to that of an airplane cabin. This would be done by placing the prototype into an air tight container that is at ambient temperature and pressure. In a separate container, a known amount of the bearing oil would be heated and blown into the container where the prototype is being held. This would be done several times, to see how the prototype would respond to different levels of oil. In addition, tests would be run by blowing cigarette smoke or other contaminants into the container, to ensure that the prototype would only respond to the oil and not to other things in the air. Finally, tests would be run by placing the oil into the container along with the contaminants, to ensure that the contaminants will not alter the readout of the prototype. In addition, if a MOS sensor were to be used with no filter system, there would have to be some additional tests which would include a more statistical approach. The sensor would be tested in many environments to see if the readout from the sensor has a characteristic change that is indicative of the oil being present. This may or may not validate this specific sensor.

The read-out time would be determined by running the device 20 times and finding the average response time and standard deviation.

The cost would be determined by adding the cost of all the components, including labor costs to run injection molding machines.

The power usage would be determined by attaching both an ammeter in series with the circuit and a voltmeter in parallel with the circuit. Then, using these values the power usage would be calculated. This, like the read-out time analysis, would be done 20 times to find an average power usage and standard deviation.

The read out levels would be determined by finding what levels are considered high, medium and low, then a setup similar to the set up used when determining the particle detection specifications would be used to calibrate the device accordingly. First, different amounts of oil would be heated in an air tight container, starting at the oil's smell threshold value (approximately 3 ppm) and slowly increased from there. This would then be smelled by a test group of people to determine what is considered a high level, a medium level and a low level. Once these levels are determined the prototype would be placed into an air tight container that is at ambient temperature and pressure. Then, in a separate container, these known amounts of oil would be heated and blown into the container holding the prototype. The sensor would then be calibrated to give a corresponding output.

The repeatability would be determined by running the prototype several hundred times under the same conditions and subsequently doing a statistical analysis.

The zero drift would be determined by using the device several times over a long time span (at least a few weeks) to see if the value detected when there is no oil in the air is actually zero.

The percent that lasts longer than 10 years would be determined by a series of drop tests and repeated use, over a several month period of time.

Test Results

To validate the case design a series of drop tests were run using Solid Works software. The program developed a mesh of the model that was made up of approximately thirty thousand elements. The model was given material properties that were the same as the HDPE, except that the overall mass of the model was increased to make the total weight 1.46 N (.327 lb). This was to take into account the mass of the internal components that were not included in the drop test model.

Once all of the material values were defined, a 1.2 meter (3.9 ft) drop test was simulated on 4 different points: the end with the vents, the end without vents, and two corners. These drop angles were chosen, because these are the most likely sides to have failure (due to low cross sectional area resulting in concentrated forces and therefore higher stresses). The drop tests on either end resulted in stress of no more than 0.02 MPa, while the drop test on the corners gave stresses about 0.15 MPa. All of these values are reasonable for the selected material (which has a yield stress of 2.4 MPa, as a conservative estimate, and relates to a safety factor of 16), and would not result in failure of the model (See Figure 9). These models were validated by running the drop test again with a mesh that was twice as fine, which resulted in the same stresses as found from before. This shows that these test results are accurate (see Appendix I for all 4 drop test results).

The limitation of this form of test, however, is that it does not test the stability of the inner components. It would not be accurate to run this type of model with the inner components modeled, because the most likely mode of failure due to drop would be the pieces being jarred loose, and this cannot be modeled in a solid modeling program.

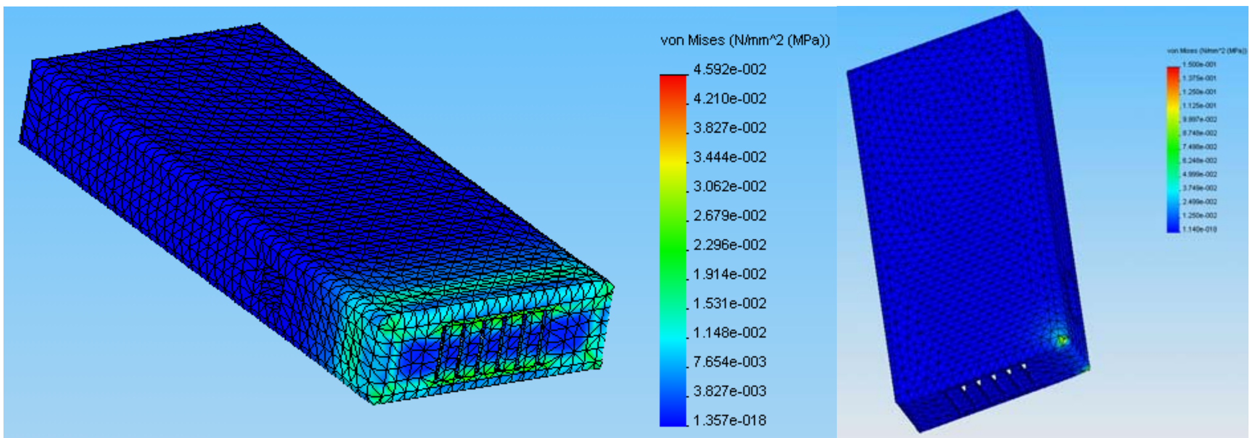

Figure 9: Drop test show stresses that are below .1 MPa

Engineering Changes

It was recognized that the airflow exit vents were positioned relatively close to the front where the sensor would not be positioned. This position would allow considerable airflow to exit the device without passing over the sensor. We determined, based on current design and layout of components, moving the exit vents to a position 20 mm away from the front would compensate and mitigate air flow loss. A recommended change is that the toggle switch can be change to a soft push button switch for purposes of ergonomics and aesthetics.

Discussion

Overall the final design for the hand held oil-sensing device met the customer requirements and engineering specifications. The final design is low in cost, has a simple output, is small in size, has low power requirements, and drop testing proved the final design to be durable. Although an appropriate sensor was not purchased, further research has led to the conclusion that a micro-hot plate sensor or micro-gas chromatographer would be suitable for the device. The micro-hot plate sensor is still in initial research and development phases. Once the sensor is fully developed it can be implemented into the design.

Some improvements can be made to the final design that would make the device more effective. Once the micro hot plate sensor is developed the design of the internals of the hand held oil sensing device can be streamlined, and redundant features eliminated. For example, the Arduino processor board has extra pins that are not used by our device. Instead of using the Arduino processor a processor board can be designed and manufactured especially suited for the device containing only features that are needed. The Arduino processor can only store 512 data points. Extra memory (e.g. 2GB) can be integrated into the device for extensive amounts of data collection. Instead of using USB cables for downloading data a wireless data acquisition system can be integrated into the design. Thus, increasing the ease of use of the device. Also, to eliminate the need for replacing batteries frequently a rechargeable batter can be installed. The device could then have a recharging base station where it is kept fully charged when not in use. These improvements make the device more user friendly and ease the integration of the device into airplane operation.

RECOMMENDATIONS

Our team has accomplished the task of developing a non-subjective method of measuring aircraft cabin odor. We have developed a portable handheld device that has low power consumption, easy to manufacture, durable, lightweight, and able to store data up to eight minutes. Unfortunately, we can not incorporate any sensor in our prototype since the most suitable sensor, called micro hotplate, is currently still under development.

Micro Hotplate Gas Sensor
Micro hotplate device is one of the important applications of the microelectromechanical sytems (MEMS). It is fabricated in complementary-metal oxide semiconductor (CMOS) technology using bulk micromachining techniques. CMOS is a major class of integrated circuit consists of microprocessor, microcontroller, static RAM, and other digital logic circuits (See Figure 10).

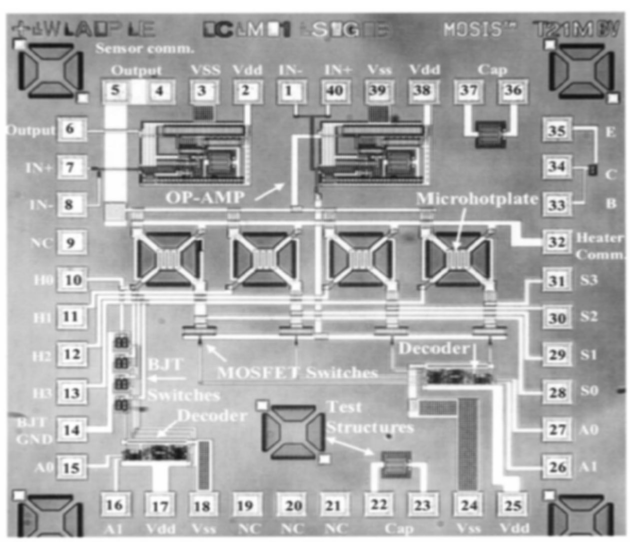

Figure 10: Micrograph of integrated gas sensor system

The micro hotplate sensor has several advantages, including low power consumption, low fabrication cost, small size, high quality, and reliability. This device uses polysilicon layer for resistant-heating element which is combined with integrated electronic circuits to form a monolithic gas sensing system. The micro hotplate also incorporates an aluminum-heat spreading layer to achieve uniform temperature across its sensing element and thin dielectric layers for fast thermal response. Micro hotplate gas sensor elements are characterized using both electrical and infrared thermal imaging method. Its coefficient of resistance (TCR) and thermal efficiency are measured by heating the device externally with a temperature-controlled hotplate and known power level.

Adsorption of gas species onto the surface of a metal-oxide semiconductor can produce a substantial change in its electrical resistance. This sensor often responds to wide range of gas species, therefore it can only be partially selective. Grain size of a particular metal-oxide film is affected by growth temperature. An array of micro gas sensors with different film structures (different grain sizes) can be used to achieve different response signatures of different gases. The combination of different gas sensing elements with integrated electronics that can address individual element and output a signal is necessary to determine gas classification. The circuit is needed to measure the response of each array element.

We recommend reworking and modifying our circuitry because there are some components in the arduino microprocessor that we don't use and the micro hotplate can not be incorporated directly to the current micro processor. Other improvement can be done by using lithium-ion rechargeable battery instead of using the standard 9 volt battery, since rechargeable battery is lighter and has longer lifetime. It also prevents frequent battery replacements which make our device also environmentally friendly. The data storage can be enhanced by adding an external memory to the device.

Micro-gas chromatography

A micro-gas chromatograph [24] is another possible sensor that could be integrated into the device. It is also still in the research and development phase. The sensor is 8.5 x 9 x 2.2 mm in size, which is smaller than a one-cent coin. It has been proven to be capable of detecting organic vapor air contaminants in the low part per billion range, and in less than 90 seconds. These are the capabilities of a first generation device, as further research and development is conducted the device performance will improve.

Microelectronic nose

Brief contact was made with the Argonne National Laboratory about a Microelectronic nose they are developing [23]. Their representative said that it would work very well, but did not share any details.

CONCLUSION

Volatile organic compounds, in particular pentanoic acid, were identified as the major odor sources. Hence, micro hotplate sensors were determined as the best available sensor technology for the oil sensing device. The final design accommodates for various sensor sizes. The structural design of the prototype is complete and meets the customer requirements and engineering specifications as verified by drop tests.

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BIOS

Weta Jayadi

Weta, a native of Indonesia, is a senior undergraduate student in University of Michigan, Ann Arbor majoring in Mechanical Engineering. He is expected to graduate in December 2007 and is interested in finding a job in a consulting company. His father works as an entrepreneur in a steel manufacturing company, thus providing a great contribution to facilitate his interest in mechanical system. Weta is focusing in manufacturing design and processes. To develop his knowledge in that area, he has taken Strength of Material, Manufacturing Process, Lean Manufacturing, and Automotive Engineering as his technical electives. He worked for 8 months in Engineering Research Center at UM assisting in development of an optical mirror alignment system.

Vanita Mistry

Vanita was born in England and moved to Pittsburgh seven years ago. She is currently a senior mechanical engineering student at the University of Michigan. Vanita chose mechanical engineering as her field of study because she wants to work in the product development aspect of the automotive industry. Vanita divides most of her free time between friends, working at the Michigan Union Billiards Room, and working as an undergraduate research assistant for the MSE department.

Seth Kirkendall

Seth was born and raised in Dearborn MI. He is 21 years old. His father is a mechanical engineer and a great inspiration to Seth. Seth grew up around bicycles and motorcycles, having mechanical inclinations sense childhood. He started working at a bike shop at the start of high school and still works odd weekends there. Even in high school there was really no question about what field he wanted to go to college for. Seth's dream job would be a rally car driver on the WRC, but he is content to be an engineer and take naps in a hammock on weekends.

Rennel Melville

Rennel is a senior who will graduate the University of Michigan in December 2006. He will complete his undergraduate career with degrees in Mathematics and Mechanical Engineering obtained through the Atlanta University Center's Dual Degree Engineering Program. After spending the first three years of the program at Morehouse College in Atlanta Georgia, he transferred to complete the engineering requirements at the University of Michigan.

Rennel's focus is design and is particularly interested in gas turbine technologies and heavy equipment machinery. He has chosen technical electives involving Finite Element Methods, Computer Aided Mechanical Design, Welding processes and Vibrations. He has successfully completed five summer internships; one with Halliburton Company and four with Rolls-Royce Corporation.

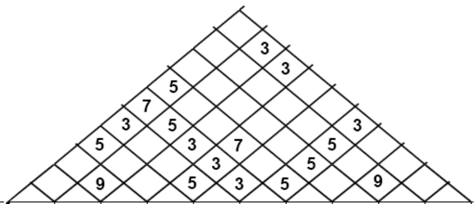
His favorite extra curricular activities include biking, running and soccer. He currently volunteers an average of 15 hours per month in a community bible education program. Rennel is a native of Trinidad and Tobago and severely misses his tropical home during the cold winters of Michigan. Once per year he visits home to enjoy some family, sun, fun, sand and sea. One of his favorite quotes is "Be more concerned with your character than your reputation, for your character is who you really are, while you reputation is merely what others think you are."

Brad Rodgers

Brad was born in Midland, MI and is 22 years old. He always enjoyed math and science throughout his high school career. In his senior year of high school, it was suggested that he apply to be an engineer, since application of things learned in class interested him the most. He applied to several schools within the state of Michigan and was lucky enough to be accepted into the College of Engineering at the University of Michigan. As soon as he began taking classes there, he knew that mechanical engineering suited him best, because he was very interested in the dynamics and kinematics that were involved in his freshmen physics course. Brad is now a senior at the University of Michigan and is currently applying for jobs in engineering companies, but he is fairly certain that within 10 years he will be in full time ministry as a youth leader at a church. Only time will tell though.

APPENDIX A – Quality Function Deployment Diagram (QFD Diagram)

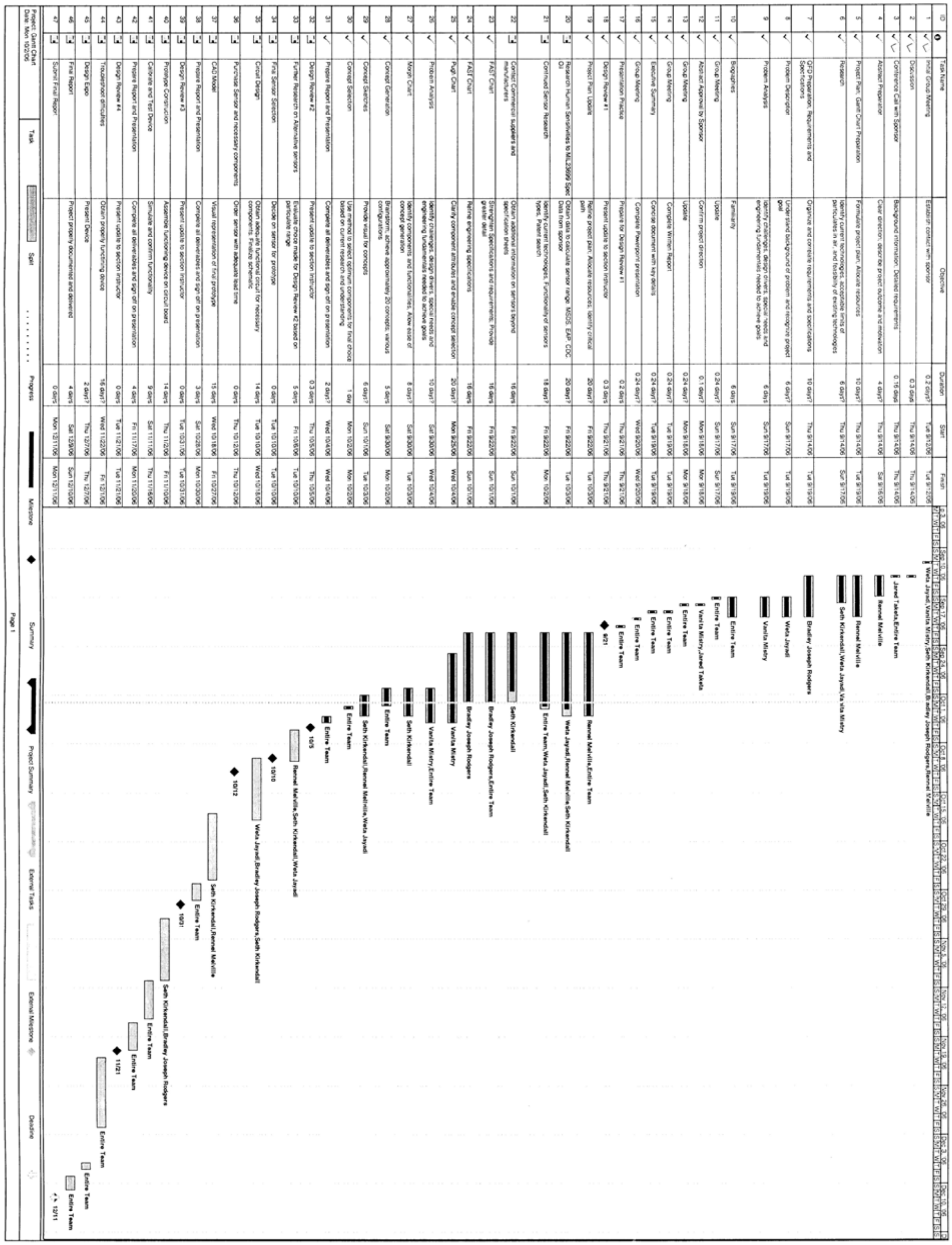
1	Not related
3	Weakly related
5	Neutral
7	Moderately related
9	Strongly Related



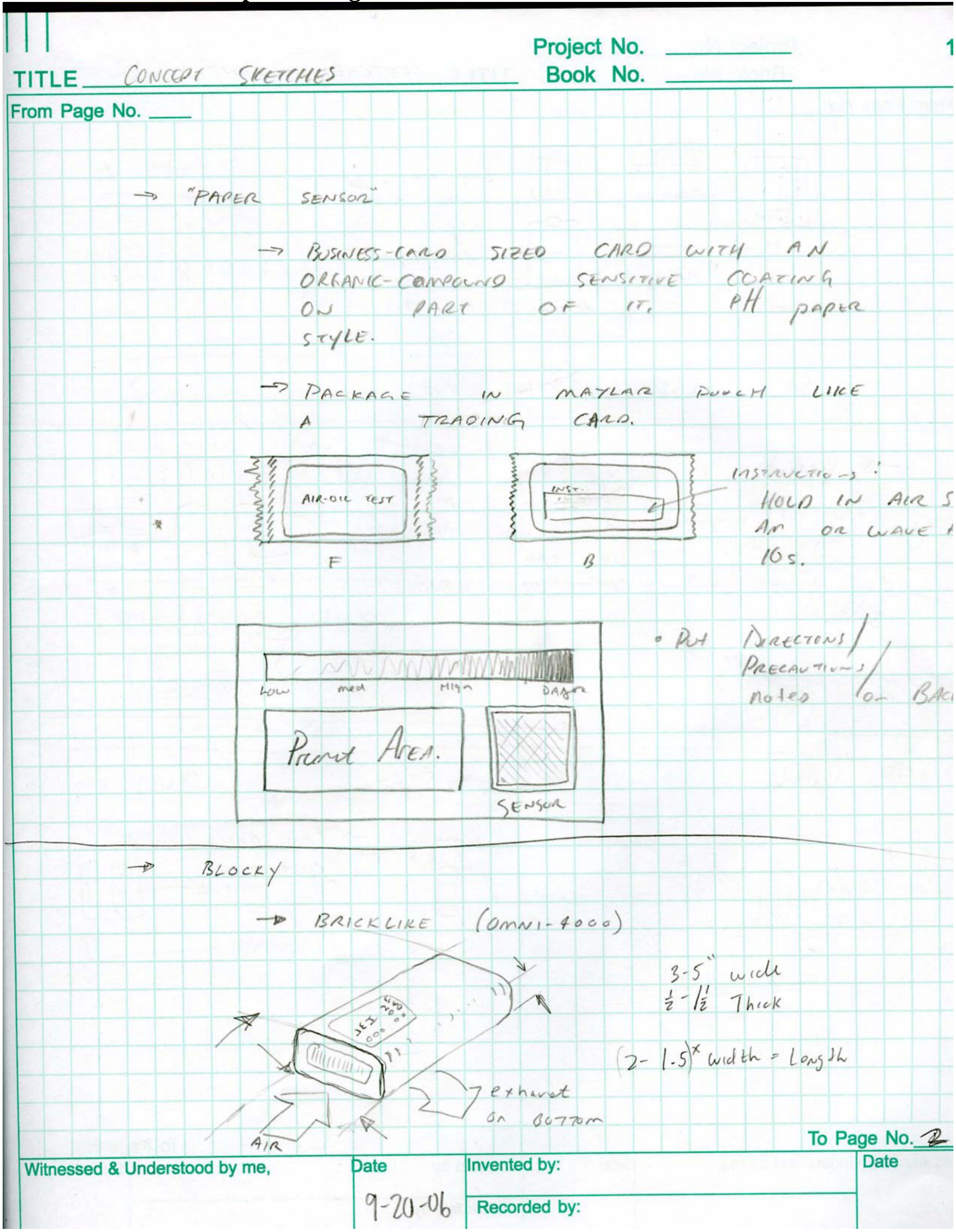
USER-PERCEIVED QUALITY

Part Characteristics / Customer Requirements	Normalized Importance to Customer (Relative Weight)	Particles Detected	Weight	Volume	Read-Out Time	Power Usage	Cost	Levels Detected	Repeatability	Zero Drift	Percent That Last Over 10 Years	TOTAL - CUSTOMER REQUIREMENTS	RANK	Importance	Enmet Omni 4000	2020 ppbPRO by Photovac
Low Cost	1.0	9	7	7	7	3	9	5	7	7	3	61	1	0.25	1	1
Accurate Measurements	0.9	9	3	1	5	3	9	7	9	9	3	49.5	2	0.21	5	5
Durable	0.8	1	7	5	1	1	5	1	5	1	9	21.6	5	0.09	3	4
Simple to Use	0.7	3	1	1	7	3	5	9	5	5	1	27.3	3	0.11	2	2
Quick to Use	0.6	7	1	1	9	5	7	5	7	3	3	27	4	0.11	5	5
Light	0.4	1	9	7	1	1	5	3	3	1	5	12.4	6	0.05	4	4
Standard Batteries	0.4	1	3	3	5	9	7	1	1	1	3	12.4	7	0.05	1	1
Ergonomically Friendly	0.3	1	7	9	1	3	3	1	1	1	1	8.1	9	0.03	2	5
Long Lasting Batteries	0.3	7	3	5	5	9	7	1	1	1	3	11.7	8	0.05	4	3
Compact	0.2	5	5	9	1	3	5	1	1	1	5	6.2	10	0.03	4	3
Easy to store	0.1	1	3	9	1	1	5	1	1	1	1	2.3	11	0.01	4	3
Aesthetically pleasing	0.1	1	1	5	1	1	3	1	1	1	3	1.5	12	0.01	2	3
Units		ppm	lbs	ft^3	s	W	$	#	%	%	%					
Enmet Omni 4000		20	2.2	0.05	---	---	1900	480	---	---	---					
2020 ppbPRO by Photovac		0.01	1.9	0.07	<3	---	6400	---	---	---	---					
Target (Plan)		50	<5	1	5	12	1000	3	2	>5	40					
Total		28.6	25.8	24.6	27.2	20	38.4	24	29.4	23	21.2					
Rating (%)		12%	11%	10%	11%	8%	16%	10%	12%	10%	9%					
Ranked Importance		2	4	6	5	10	1	7	3	8	9					

APPENDIX B – Gant Chart



APPENDIX C – Concept Drawings



TITLE SKETCHES P3 Project No. ____
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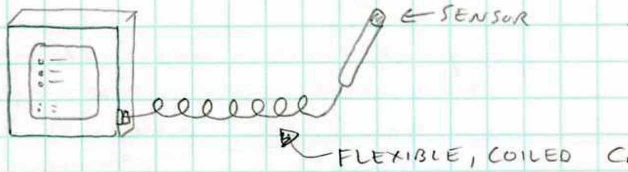
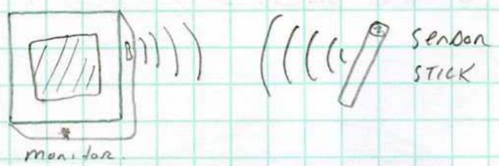
→ "MIC"

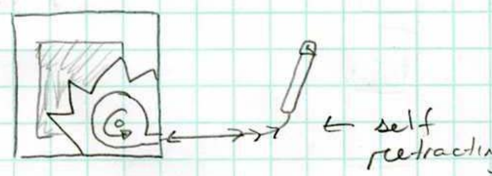


* EASY FOR PASSENGERS ON WINDOW SIDE, PASS SENSOR TO THEM.

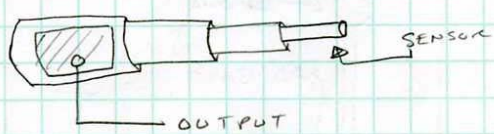
→ WIRELESS MIC



→ RETRACTABLE MIC

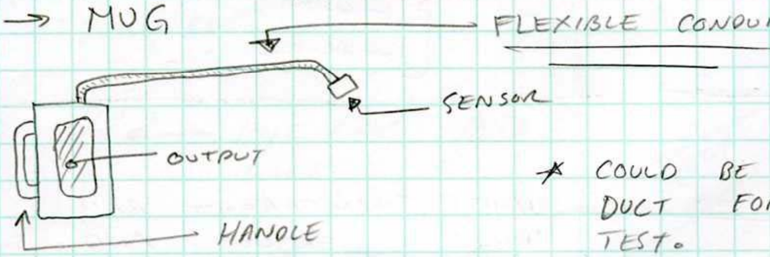


→ extendo stick



* SMALL IF FOLDED
* LONG TO REACH WINDOW

→ MUG



* COULD BE STUCK INTO DUCT FOR WHOLE - PLANE TEST.

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Witnessed & Understood by me,	Date	Invented by:	Date
		Recorded by:	

Project No. ____________

Book No. ____________ TITLE SKETCHES pt

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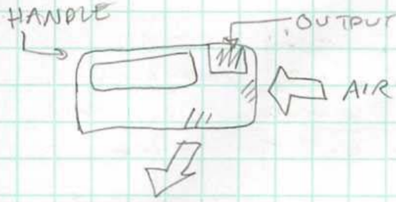
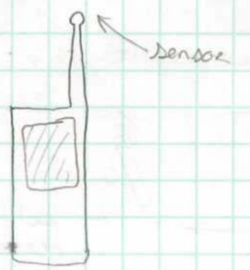


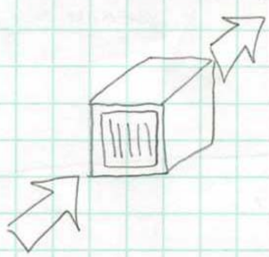
~ * 1ft × 6" × 6"

→ WAKIE TALKIE



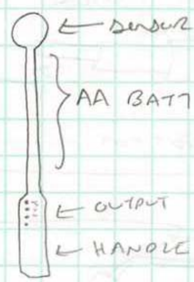
* BELT CLIP
* SMALL ? & too small ?

→ CUBE

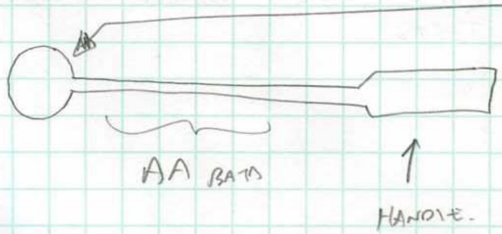


FLOW THROUGH.

WAND → LONG,



GLOW WAND



WHITE TRANSPARENT BALL HOUSES SENSORS AND LED'S GLOWS WITH OUTPUT

To Page No.____

Witnessed & Understood by me,	Date	Invented by:	Date
		Recorded by:	

TITLE FIN. NOTES. / SKETCHES

Project No. ______

Book No. ______

From Page No. ____

meeting: SUNDAY 4 pm 10-1 (OCTOBER 1)

FINANTIAL LEC NOTES:

LAST DAYS FOR: PETTY CASH

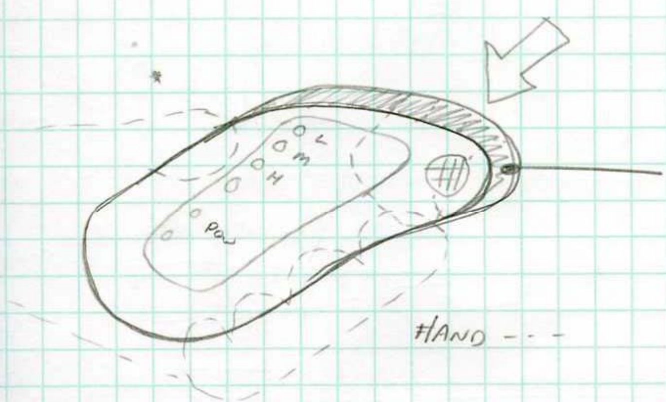
DROP-OFF 1/26/07

PICK-UP 2/2/07

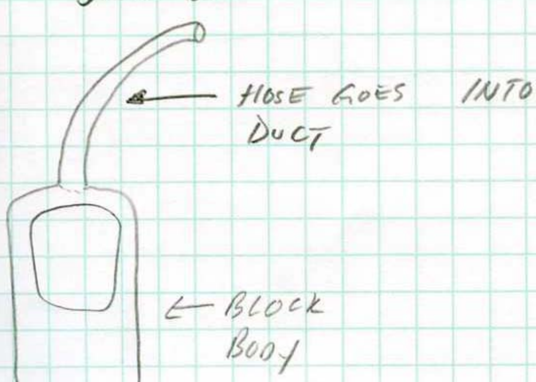
KATHY McCRUMB
2219 GGB

FILL OUT ONLINE FORM & TAKE INV.

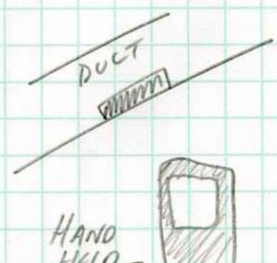
"ERGO"



"JUICE BOX"



"INDUCTIVE DUCT BUG"



+ Sensor is placed in duct permanently

inducts power to sensor, info BACK.

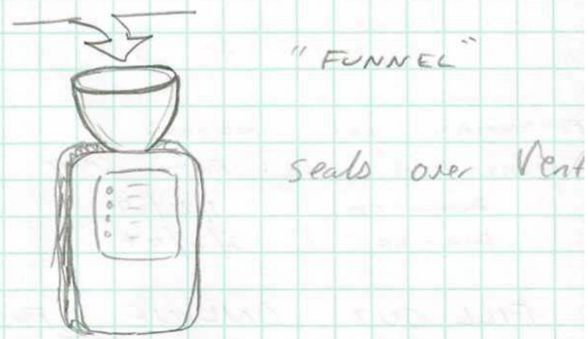
To Page No. ____

Witnessed & Understood by me,	Date	Invented by:	Date
		Recorded by:	

Project No. ________

Book No. ________ TITLE Sketches 6.

From Page No. 5



To Page No.

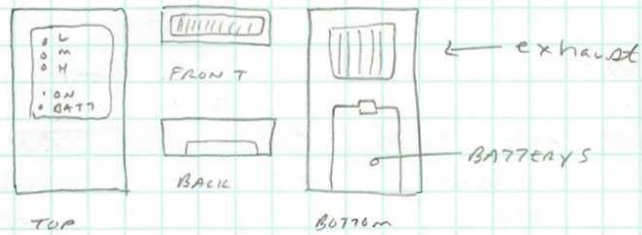
Witnessed & Understood by me, | Date | Invented by: | Date

Recorded by:

Project No. ____________

Book No. ____________ TITLE SKETCHES CONT. P2

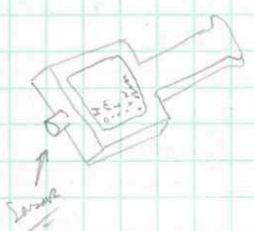
From Page No. ____

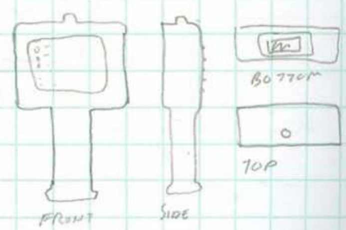


• Small FAN SUCKS AIR PAST SENSOR.

→ WAND

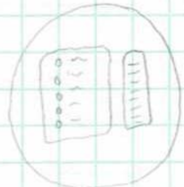
→ SENSOR ON TIP
→ MORE LIKE PHOTOVAC
→ NO FAN
→ BATT IN HANDLE.





→ BALL

→ SPHERE
→



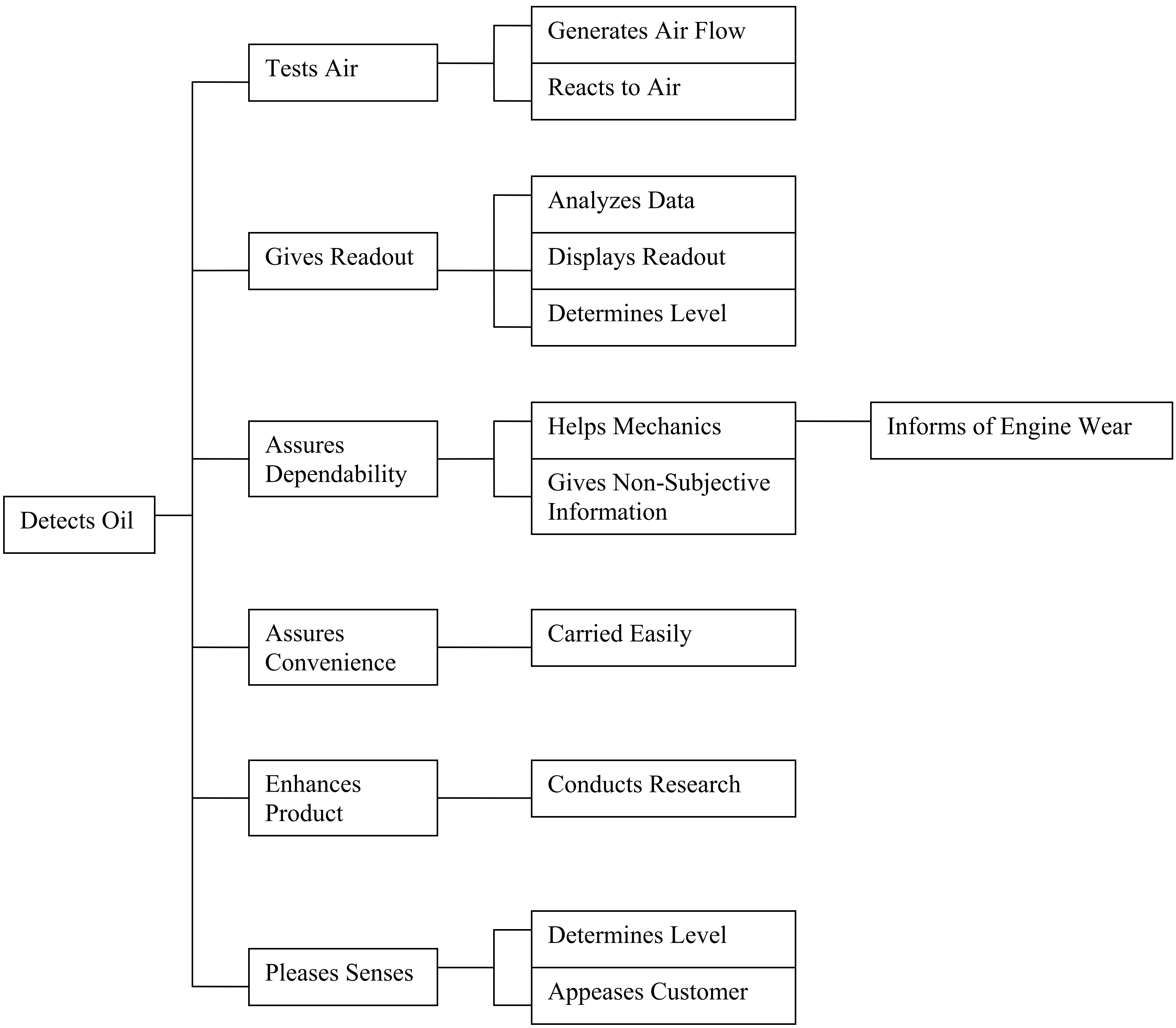
→ STICK

→ EASY REACH OVER CUSTOMER

To Page No. 3

Witnessed & Understood by me,	Date	Invented by:	Date
		Recorded by:	

APPENDIX D – FAST Diagram



Appendix E - FMEA Chart

Part# & Function	Failure Mode	Effects	(S)	Mechanism	(O)	Current design/tests	(D)	Actions	RPN
Battery Supply power	Power failure	Device stops working	9	Use	9	Low battery indicator	1	None	81
	Corrode	May damage internals	8	Corrosion	2	None	3	Provide proper ventilation	48
	Explode	Harm user	10	Unknown	1	None	1	Investigate	10
LEDs Provide output	Burn out	No output to user	9	Too much power	1	Resistor in series with LED	1	None	9
				Reaches LED life span	1	None	1	None	9
	Scratched lens	Ugly	2	Abrasion	3	None	8	Recess LEDs	48
Sensor Measure contaminate	Clogs	Device stops working	9	Contaminate build up in sensor	3	None	1	Dust filter	27
	Burns out	Device stops working	9	Unknown	3	None	1	None	27
Housing Contain device	Surface scratches	Ugly	2	Abrasion	6	Possible silicone boot	5	Check: surface finish options	60
	Small crack	Ugly	3	Impact or fatigue	3	None	4	Check: wall thicknesses, material properties, stress concentrations	36
	Large crack		4	Impact or fatigue	2	None	2		16
	Rupture		6	Impact or fatigue	2	None	1		12
Circuitry Store data, control sensor,	Power overload	Shortens device life	1	Surge	2	Built in voltage regulation	8	None	16
		destroys device	2	Big surge	1		1		2
	Short circuit	Some to all functions stop	2	Electrolyte liquid entry	8	None	1	Check: seams and assess need for gaskets	16
				Short with metal debris		None		Assemble in clean location	
				PCB failure		None		Check for proper mounting	
	Software failure	Dead	9	Unforeseen operating condition	1	Debug and check for robust design	1	Check with experienced software people	9

- supposed to add NEW S-O-D and NEW RPN after steps are taken to reduce risk.

Appendix F – Bill of Material

Prototype

BILL OF MATERIAL

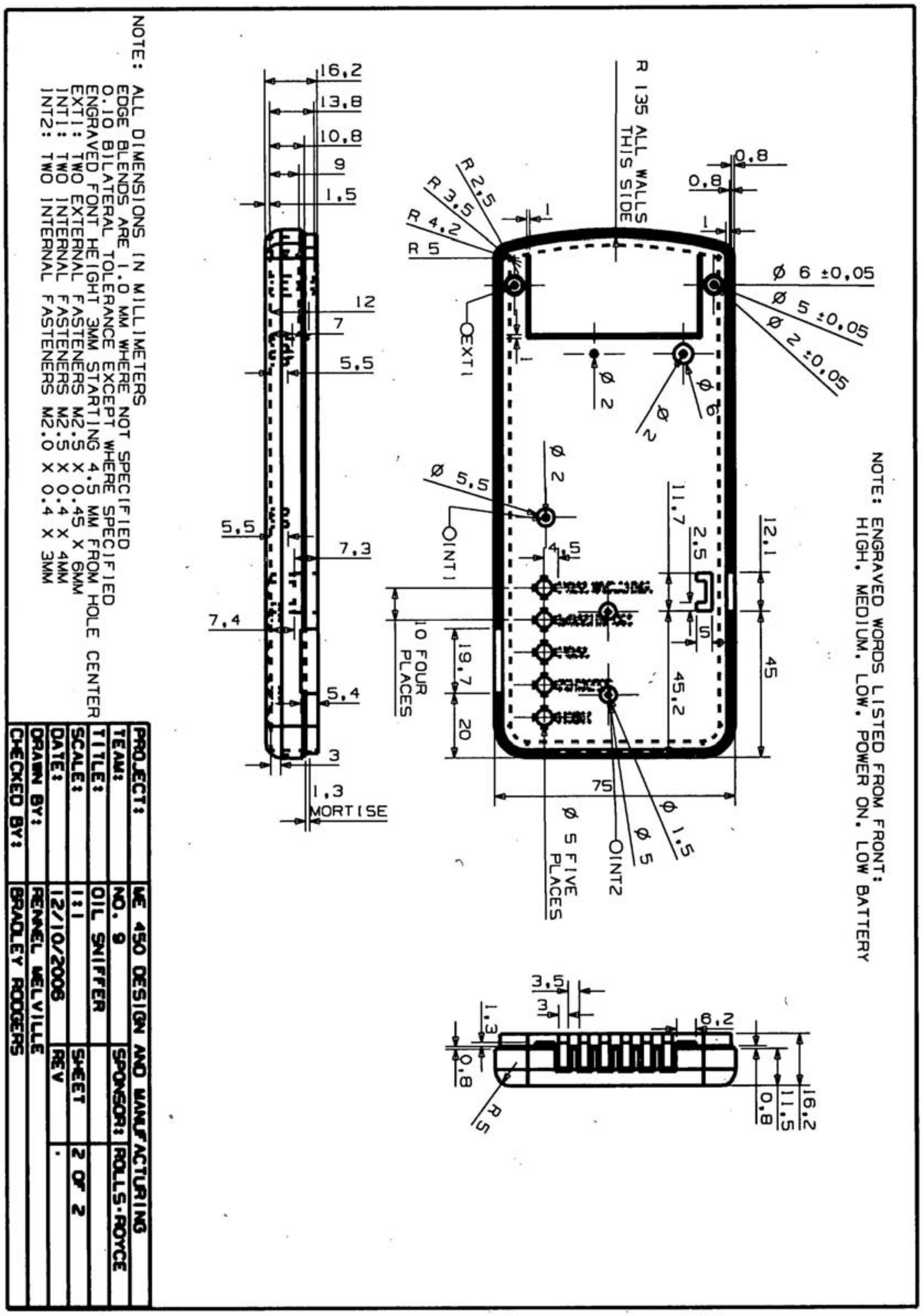
Quantity	Part	Description	Purchased From	Cost ($)
1	Arduino Board	Integrated processing solution	Sparkfun*	32
1	USB extender		Sparkfun*	0.95
1	Circuit Board	Regular PCB	Purchase Radio Supply, AA	3.95
8	LEDs	Red, green, blue colors	Purchase Radio Supply, AA	4
2 pack	Resistors		Purchase Radio Supply, AA	1.98
1	Battery Connector		Purchase Radio Supply, AA	1
1	Plastic Box	Stereolitography	UM 3D lab	54.57
12	Self Tapping Screws	15 mm tap screw	Sparkfun*	2
1	Solder	Lead Free Electronic Solder	X50 lab	0
1 roll	Wire	22 AWG Solid	Sparkfun*	4
		Total Cost		104.45

*www.sparkfun.com

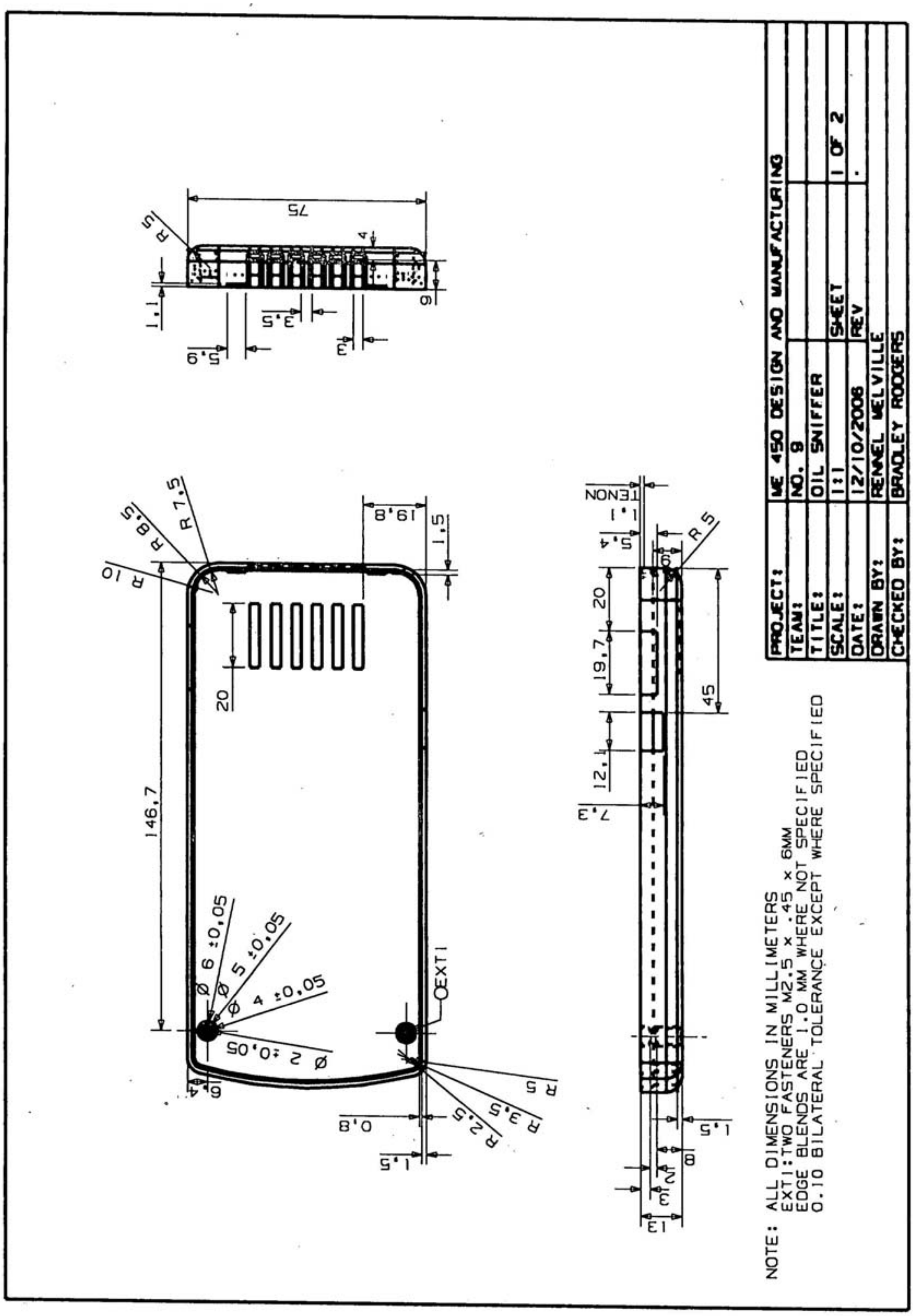
Final Design

Part	Description	Cost
HDPE resin	Polymer for injection molding	$ 73 cts / lb
Circuit Board		$715 / 100 PCBs
Screws	15 mm tap screw	$28.62 / 1000 pieces
Operation Cost	Injection molding machine plus labor	$75 / hour

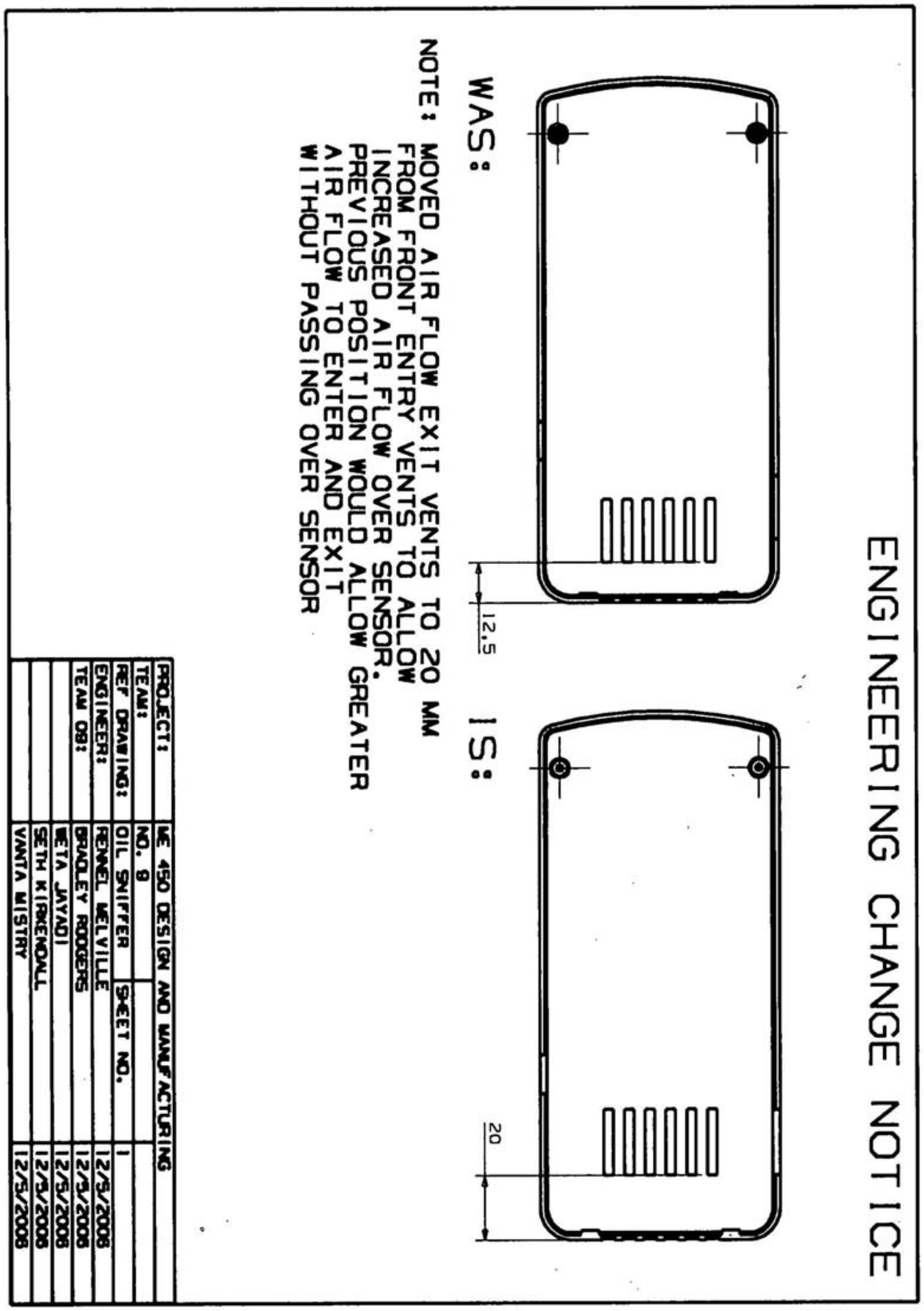
Appendix G1 – Detailed Drawings of Final Design and Prototype



Appendix G2 – Detailed Drawings of Final Design and Prototype

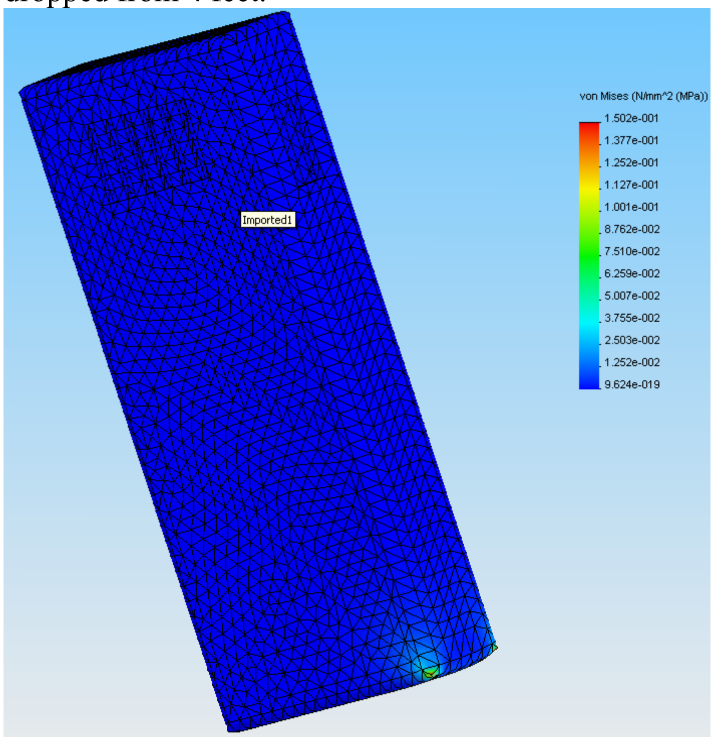


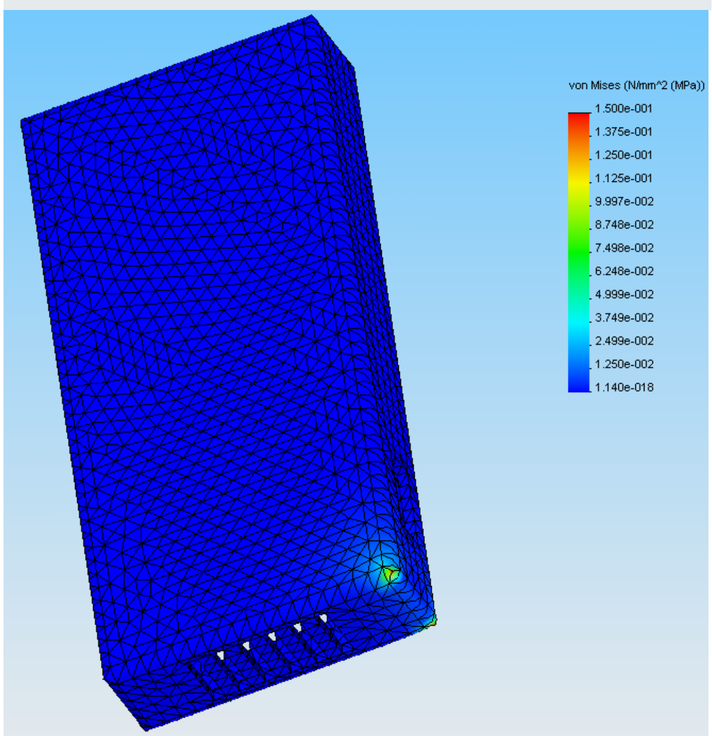
Appendix H – Engineering Change Notice

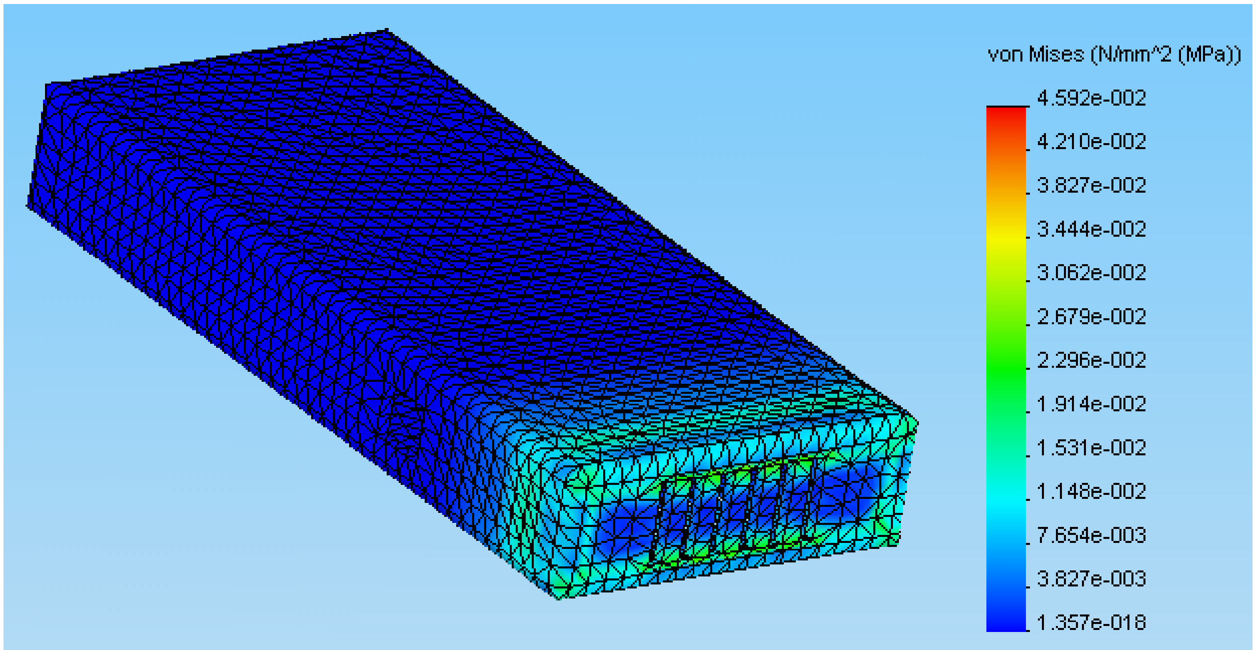


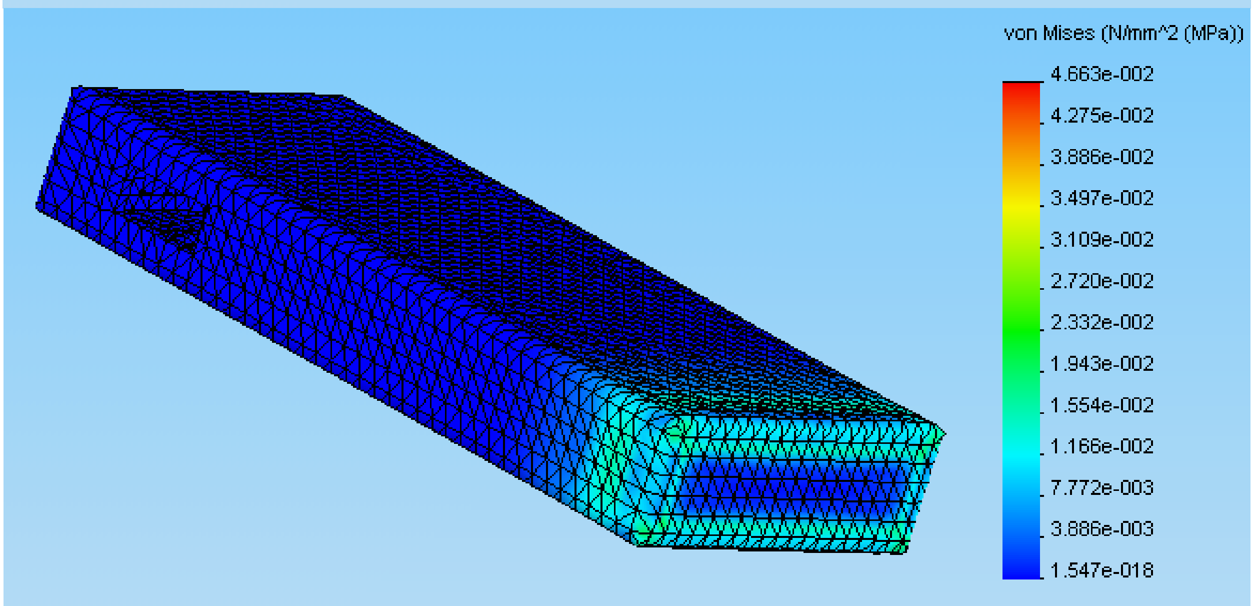
Appendix I – Drop Test Results

Drop test on four different points indicate that the case has adequate thickness and will not fail if dropped from 4 feet.






von Mises (N/mm^2 (MPa))
4.592e-002
4.210e-002
3.827e-002
3.444e-002
3.062e-002
2.679e-002
2.296e-002
1.914e-002
1.531e-002
1.148e-002
7.654e-003
3.827e-003
1.357e-018


von Mises (N/mm^2 (MPa))
4.663e-002
4.275e-002
3.886e-002
3.497e-002
3.109e-002
2.720e-002
2.332e-002
1.943e-002
1.554e-002
1.166e-002
7.772e-003
3.886e-003
1.547e-018

Appendix J : Code

```
//  driver for analog read of vapor sensor

int powled = 12; // power led connected to dpin  12
int lowled = 11; // "low" led commected to dpin  11
int medled = 10; // "medium"                     10
int hiled = 9; // "high"                     9
int batt = 8; // low batery led
int sensor = 3; // sensor on analog pin 3 0-1024
int sv = 0; // sensor read value
int lowth = 48; // ascii values for thresholds =0
int medth = 51; // medium threshhold for sensor =3
int hith = 55; // high threshhold for sensor =7 (scale 1-9)
int mem = 1; // memory storage value
int wc = 1; // write counter

void setup()
{
 pinMode(powled, OUTPUT);
 pinMode(lowled, OUTPUT);
 pinMode(medled, OUTPUT);
 pinMode(hiled, OUTPUT);
 pinMode(batt, OUTPUT);
 Serial.begin(9600); // opens serial connection - for sensor simulation
}

void loop()
{
 digitalWrite(powled,HIGH);
// sv = analogRead(sensor); // to read actual sensor
 Serial.println(Serial.available(),DEC); // reads in a ASCII value from integer input at serial
  sv=serialRead();
  // echo to serial
  Serial.println("feeedback: ");
  Serial.println(sv,DEC);
 if (sv >= hith) { // if above high limit, light up high LED
   digitalWrite(hiled, HIGH);
 } else{
     digitalWrite(hiled,LOW);
 } if(sv >= medth) {// if above med limit, light up med LED
   digitalWrite(medled, HIGH);
 } else{
   digitalWrite(medled,LOW);
 } if(sv >= lowth) {// if above low limit, light up low LED
   digitalWrite(lowled, HIGH);
```

```
  } else {
    digitalWrite(lowled,LOW);
  }
  delay (1000); // 1 sec delay to avoid over-driving sensor, must be changed according to sensor
specs
}
```