KASE

The Laptop Cooling Case

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Abstract:

This report describes the final design and analysis of a laptop cooling case as a marketable product for a group of entrepreneurial marketing student based out of California Polytechnic State University San Luis Obispo. Background market research and empirical measurements were taken in order to confirm that this would be a marketable product worth designing. Then previous solutions were researched in order to identity weaknesses and strengths. After rigorous research, it was determined that a passive cooling system, in which channels directed airflow to the computer fan would be the best system in terms of functionality, performance, and cost. A variety of models were constructed and tested, as theoretical calculations could not be relied upon to divulge the correct information regarding the structure. This was a critical design progression that accumulated into the final design concept. This project combined different principles of mechanical, manufacturing and computer engineering as well as marketing and business techniques to provide a final design that would be a viable product to sell.

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Introduction:

Within the past decade, laptops have become one of the most popular ways to conveniently stay connected on the move. Laptops give users many of the features that desktop computers have, while simultaneously providing the luxury of easy transportation. However, as with most innovative technologies, there are trade-offs. Laptops require a lot of processing power and as a result, a large quantity of heat is generated within the structure. This heat escapes through vents so that the laptop is not negatively affected. However, the laptop itself does little to protect the user's lap from these expelled heats. At its mildest, users find the heat uncomfortable but in some extreme cases, users have been severely burned.

We are proposing a solution to this problem, in the form of a case that will protect a user's lap from expelled heat. In addition, we aim to cool the laptop so that it may operate at more reasonable (lower) temperatures. For this project, our customers are senior business students, with an emphasis in marketing (entrepreneurship). It is their intention to market this product and, depending on the findings of our design experiments, sell it for profit. Ultimately, our target market is people that commonly transport their laptop. We found that this mainly includes people on business trips or college students. Since there is such a large range and variation in laptops on the market, we decided to specify our design for Apple's 13 inch MacBook Pro. This is one of the more popular laptops on the market for its aesthetic appeal, ease of use, and functionality. Our customers distinctly specified that the product should be aesthetically catered to the "Apple Style", passive, durable, protective, and specifically fitted to a MacBook Pro.

Problem Statement:

We aim to design a case that will protect a user's lap from the heat of a laptop. In addition, we aim to cool the MacBook Pro in order to increase the lifespan. The product should be aesthetically catered to the "Apple style", passive, durable, protective, and specifically fitted to a MacBook Pro.

Background:
Before we started designing any solution, we first investigated the claim that people find the heat of their laptop uncomfortable. The combination of our market research and our empirical measurements provided us with substantial evidence that this is an issue worth investigating.

Market Research:
We worked with a group of business students who intend to market the product, so the design was greatly influenced by what they thought would be the most profitable. We came up with a few initial designs to show the business students what would be functionally feasible. This gave them a few ideas of different ways the case design could be approached. From these designs, we came up with a set of questions which can be viewed in the appendix, pg. 27. These basic questions were asked to our target market of students and people that frequently travel.

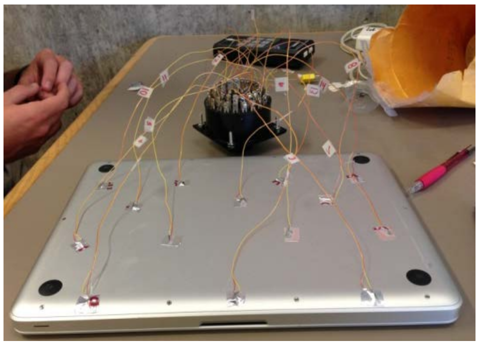
Our findings were fairly unanimous from everyone we talked to, which made picking our design a relatively simple task. It was clear that people wanted something that would keep their lap cooler while being as compact and manageable as possible. It was also noted that people did not want a collapsible design because they were worried about the moving parts breaking from frequent use. The market also felt that they would like a case that had a built in angle because it would feel more comfortable. Another very important fact that was brought up by the MacBook Pro users was that they did not want to take away from the visual appeal of the laptop. When asked about a passive vs. active system, most people were opposed to an active system because of the added complexity, noise, weight, and use of their laptop battery.

Below is a summary of the research survey. Our market desires a design that:

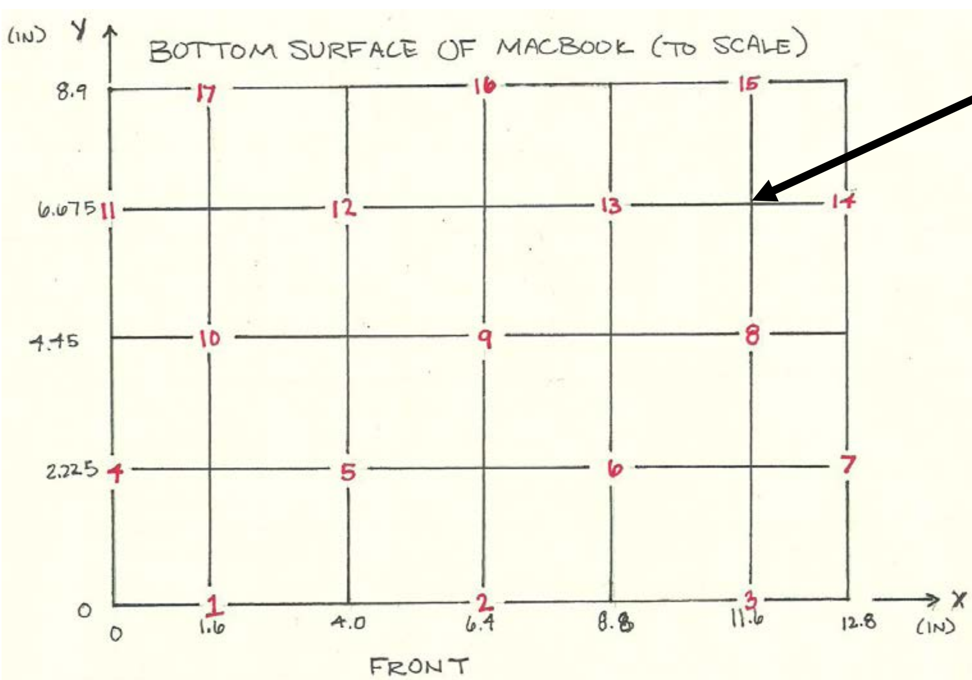
- Is as simple as possible.
- Has clean and sleek lines, similar to the MacBook Pro.
- Is a passive system.
- Incorporates a fixed angle.
- Is durable and compact.

Empirical Measurements:

The main measurement required to confirm the potential problem was a detailed temperature profile of the bottom surface of the MacBook Pro. To do this measurement, we assembled a rotary switch with 17 thermocouple wires. Each of these wires was attached in a grid manner to the bottom surface of the MacBook Pro. Measurements were taken at each location in time intervals relevant to the normal usage of the computer. The experimental setup and data are shown below. The rotary switch assembly and setup can be seen in the appendix, pg. 27.



Grid In Which Measurements Were Taken:



General Location of the CPU – which is the main source of expelled heat.

Time Interval Designation:

1. MacBook Pro just turned on and powering up
2. 10 minutes after being on and idle
3. Netflix and YouTube video is started*
4. 10 total minutes of videos streaming
5. 20 total minutes of videos streaming
6. 30 total minutes of videos streaming

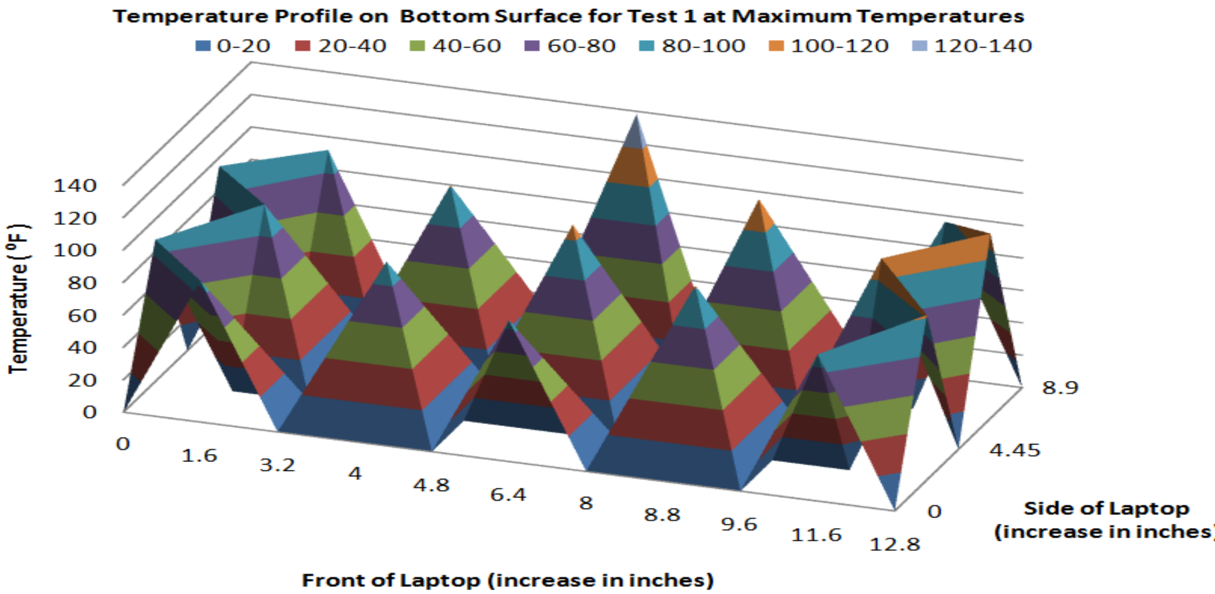
*The video streaming is to model the computer at its normal usage capacity.

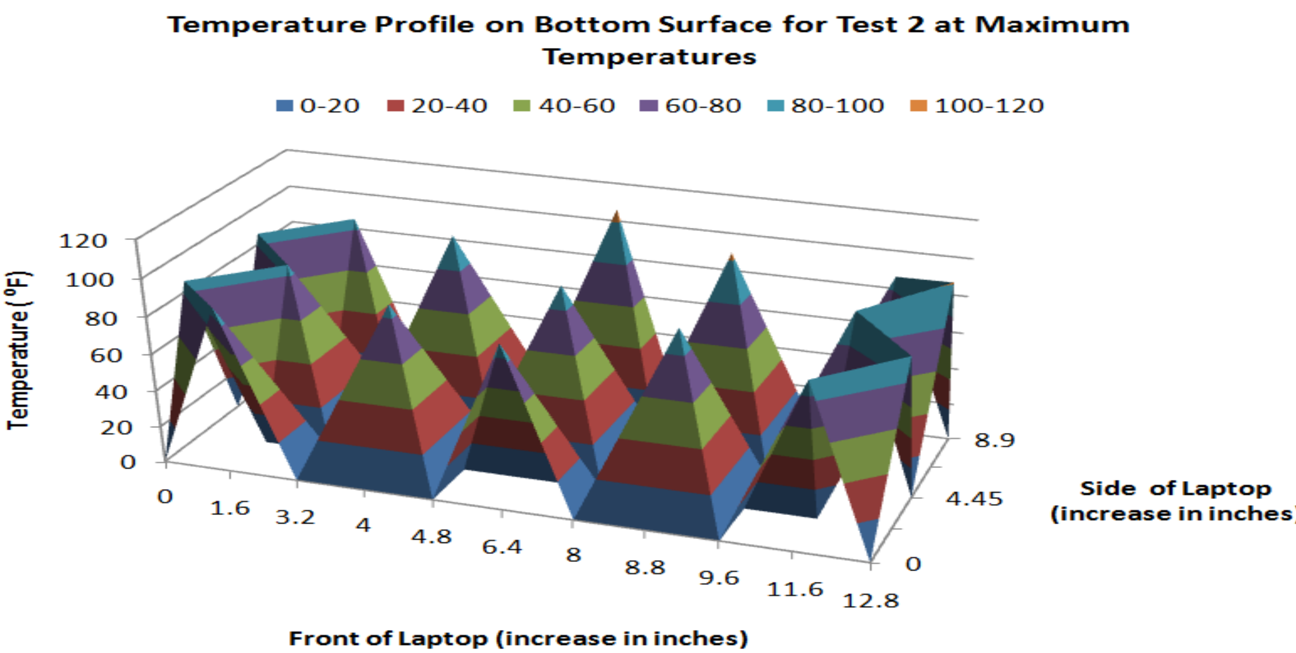
Test Specifications:

Specifications	**Test 1**	**Test 2**
Temperature of the air, T_∞	79.9 ^oF	74.2 ^oF
Temperature of the wooden table, S_{urface}	94.4 ^oF	91.1 ^oF
Laptop purchase date/age	June, 2009 ~ 3.25 years old	October, 2012 ~ 1 month old
Internet connection	Wireless	Ethernet cable
Battery plugged in	Yes	No

The main purpose of conducting two separate tests was to show the difference between the physical state and age of the computers. A new computer is going to run cooler than a computer that is a few years old. An older computer collects dust inside and the system begins to slow as it is filled with more files, giving the computer a larger load and making it heat up more. The two computers we tested were both MacBook Pros, one of them was about 3.25 years old and the other was about a month old. The one month old computer is also a newer model MacBook Pro that has retina display, this retina display model is supposed to run a couple degrees hotter than older models but some people are saying that they are getting very hot right out of the box.

Graphs of Maximum Temperatures (Final Time Interval):





Conclusions about Data:
The temperatures on the older laptop were overall higher than on the new laptop. The temperatures on both laptops increased over the interval times and seemed to reach a steady state while streaming Netflix and YouTube videos.

Our team decided to measure the temperature of a hot shower in order to understand the temperatures that a human being would physically find comfortable. The average temperature of a "hot shower" is about 105^{o}F. For test 1 (the 3.25 year old computer), most of the temperatures under the CPU were well above the 105^{o}F for all of the time intervals in which the laptop was streaming videos. The specific data for these measured temperatures can be seen in the appendix, on pg. 27. It is clear that there is a valid need for some sort of lap protection as most of these temperatures are uncomfortable for a user's lap.

We also looked at the optimum temperature range of the central processing unit (CPU) of the average computer. Keeping the CPU in its optimum range will help keep the computer running longer and prevent damage or unexpected shutdowns. The Intel Penryn p 8600 2.4 GHz Core 2 Duo, commonly found in the MacBook Pro, is designed to operate between 32 and 221˚F. This maximum temperature is higher than our measured temperature values. However, the longevity of the life of the MacBook Pro is still shortened because of these increased temperatures. Because of this, it is our continued intention to additionally cool down the laptop.

Previous Solutions/Methods:

Many of the previous solutions address elements of the solution that we wanted to ultimately design. Many of the products on the market act as either a universal “platform” that protect the users’ lap, or as a case to protect against scratching. The methods behind protecting the users’ lap vary from utilizing a fan within a heat sink, to a mat in which the user can cool down and then place on their lap. The main price range for these products are $20-$50 which gives an idea as to how many people are willing to spend on this issue. There are a few distinct design choices that seem to hinder the market from purchasing these products:

- Active system: The products with fans require tapping into laptop power. The fan can be heard once it is on and in many cases with the MacBook Pro, it does not work that well, according to our research.
- Bulky: While some of the products worked well, they are too bulky to be used during travel.
- Simple cover: These protect from scratches, but they do not protect much from anything else. In addition, most of these covers are made out of polycarbonate, which is an insulated material. While this does help protect the users lap, it contacts the heat expelled from the laptop, which negatively affects the electronics within the computer.

Although there didn’t seem to be any products that directly addressed the design we wanted, there are elements that would help optimize our possible design.

- Incorporated angle, or “wedge shape” for user comfort.
- Heat sinks aspects – utilization of fins and ventilation.
- How the protective cases attach to the laptop.

Previous Products:

- “The Tilt” $65 –an active system that is specifically designed for MacBook Pro.

http://www.kickstarter.com/projects/themadminds/the-tilt-multimedia-stand-for-the-macbook-pro

- “iPearl” Cover $50 – protective cover with collapsible stands, made out of polycarbonate.

http://ipearl-inc.com/mcover.html

- “Targus Cooling Mat” $30 – active platform intended for any laptop, no means of securing laptop to surface.

http://www.targus.com/us/productdetail.aspx?sku=pa248u

Design Development:

<u>*Functional Design Requirements and Features:*</u>

Requirements: “Our design must…”

- Protect the lap from the extreme temperatures expelled from the MacBook Pro.
- Cool the laptop so as to increase its lifespan.
- Not weigh more than 3 lbs.
- Not add a lot of bulk to the computer (not increase the dimensions of the computer by more than .25 inches in width and length; and more than 1 inch in height.

Features: “Our design should…”

- Look sleek, thin, aesthetically appealing.
- Be durable to avoid cracking or fatigue.
- Secure and protect the laptop’s bottom surface from scratching and minor bumps.

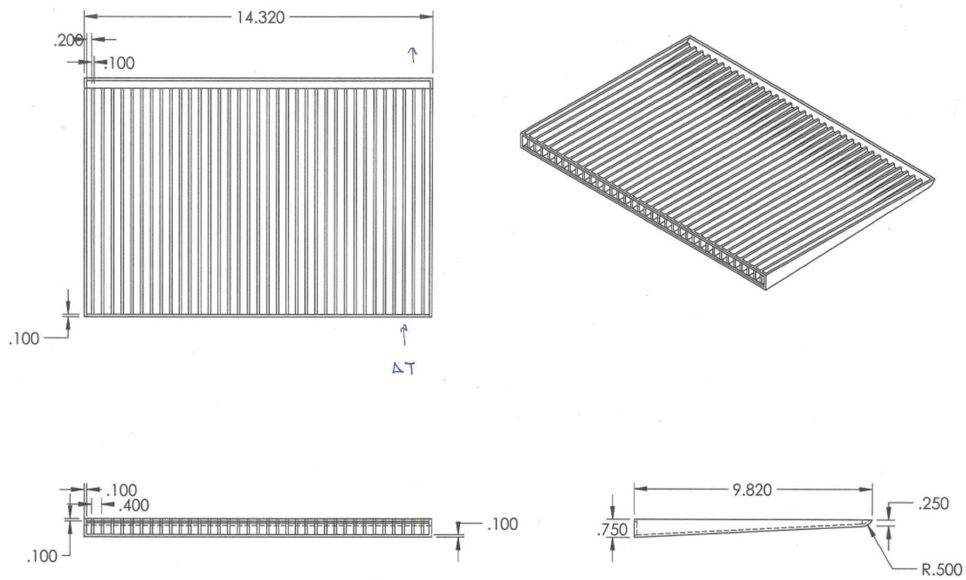
<u>*Initial Brainstorming of Potential Solutions:*</u>

In order to get a better understanding of how these designs would physically look and feel to the user, we built models of our two main design ideas to represent the form and basic function. Neither of the built models are to scale, as the intention was to use these models in more market research. Other design possibilities were either sketched or created using SolidWorks.

- Design 1: collapsible stands and hinges for multiple incline angle positions ranging from .5-2 inches


- Design 2: fixed angle design with few fins and closed off in the front, on both sides, on the top and most of the back

- Design 3: several fins with an open top

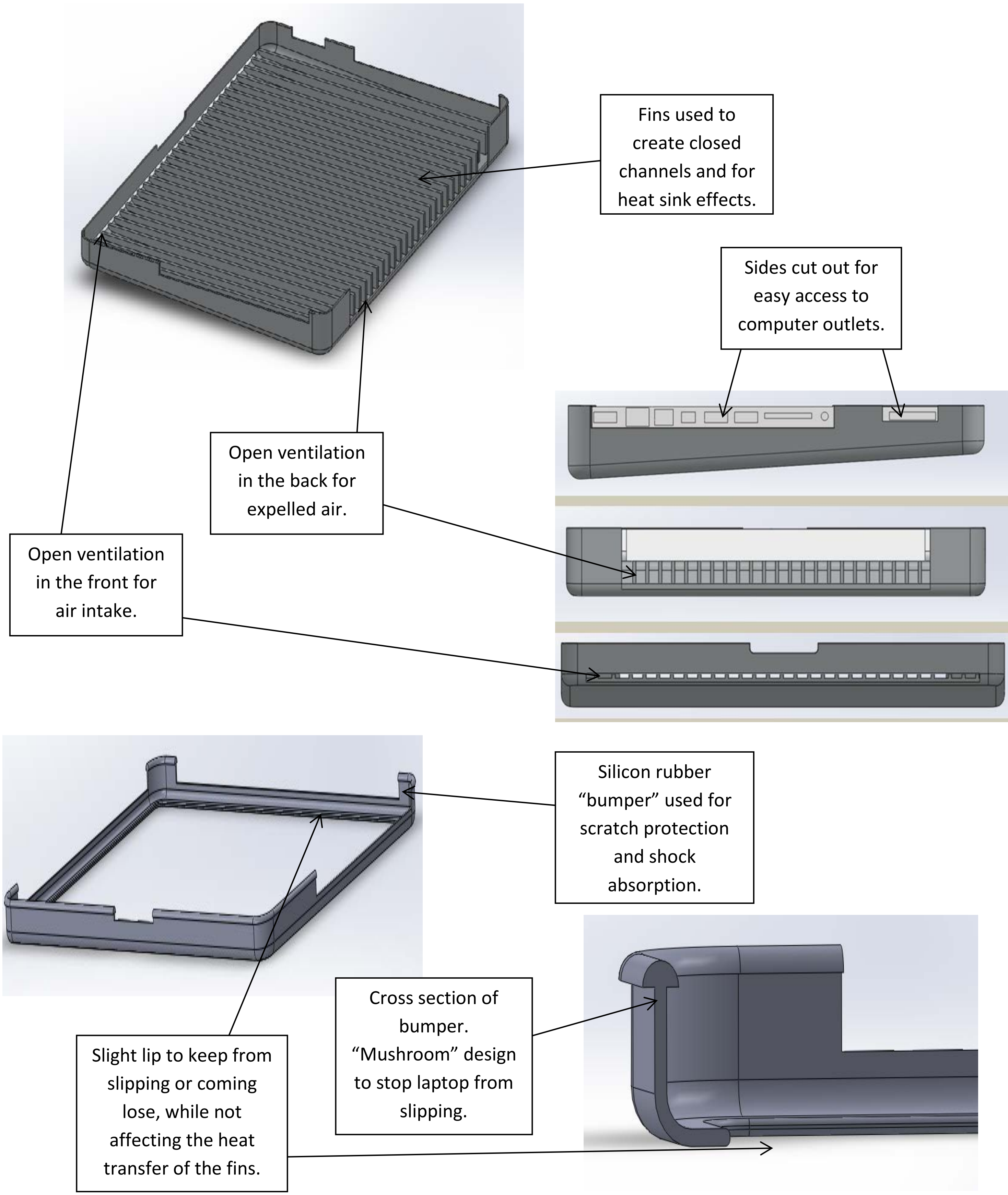


These designs were used to gather more information from the target market. Questions such as: “What do you like about each design?”; “What don’t you like?”; “What would be the most important aspect of a product like this?” The majority of the market wanted a fixed angle that was sleek and durable. These design concepts were then used in the creation of our final design concept before any technical analysis.

Final Design Concept:
This was the design concept that we based our initial analysis off of and then modified accordingly. The basic design incorporated the fixed angle base that has ventilation like openings in the front and back. These openings allow the air to enter in the front and exit out the back. In the center of the case is a fin design that creates a closed channel system that helps the air enter through the front and expel out the back. These fins pull the heat off the bottom surface of the laptop and, in the process, it will be cooled by the ambient air flowing through the channels.

The second part of the design is the silicon rubber bumper that fits around the edge of the laptop. Once secured on the MacBook Pro, the aluminum casing can be pressed on. The rubber serves as protection from scratches, a buffer from drops, an easier solution to manufacturing, and a secure fit with room for thermal expansion along with some other minor improvements. If the whole apparatus were to be dropped, the rubber will absorb some of the impact and ultimately protect the laptop.

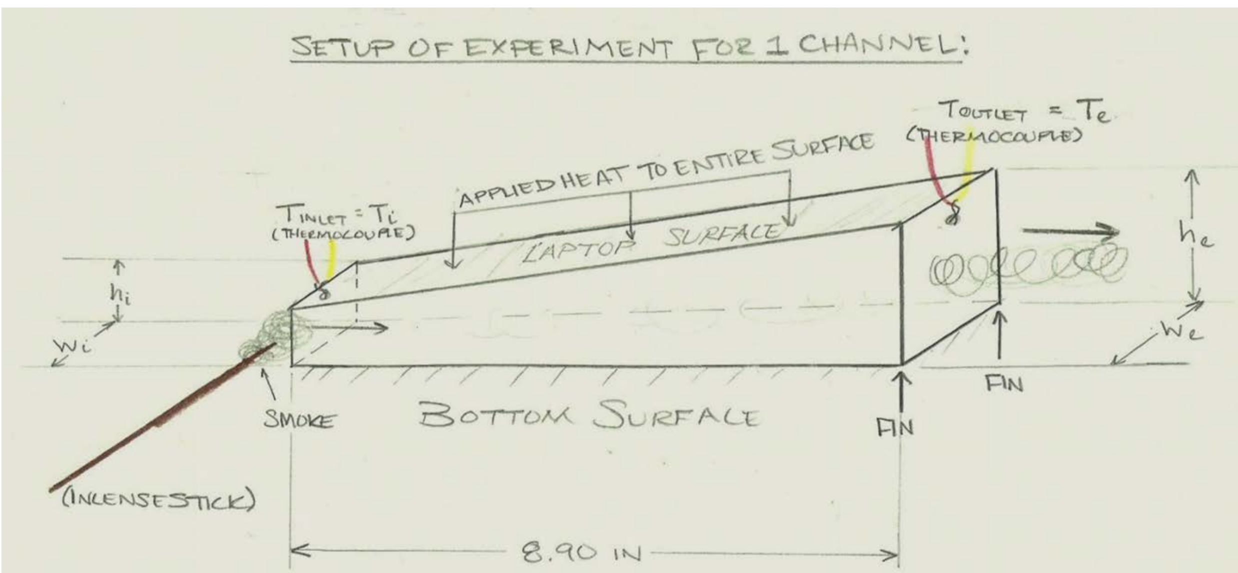
__Final Design Concept Drawings:__



Fin Analysis:
The next step included making rough prototypes to test if our design concepts were fully functional and viable. We designed and ran a series of experiments in order to determine the quantity and dimensions of the fins. We carried out the experimental plans with different fin configurations, spacing length and quantity. This had to be determined empirically, because the theoretical calculations had several large unknowns with the heat transfer aspect of the design, such as thermal contact resistance. Heat transfer is largely empirical, which is why it was clear that we had to create and conduct our own experiments.

The Experiment:
In order to effectively conduct this experiment, several models were built with the expected dimensions of the intended design. The variables of this experiment were the height of the back outlet vent, which is also the back height of the fins, the width of the channels and the number of fins.

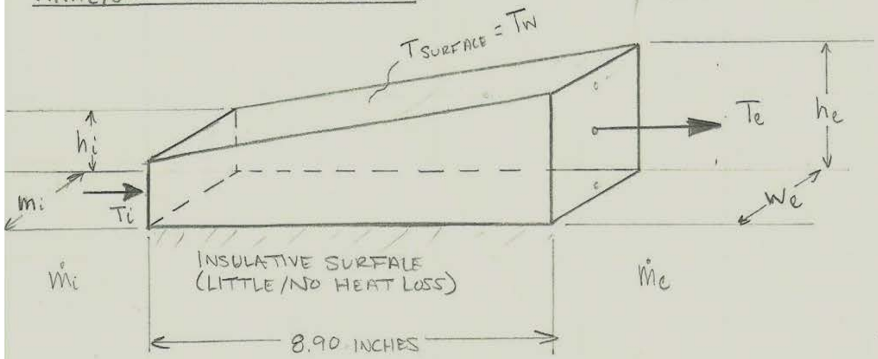
The “Time of Flight” method measures the velocity of the air flowing through the channels. A simulation was created in which a running MacBook Pro was set on the top surface and the temperatures at the inlet and outlet vents were measured. Once the system has reached a steady state, the smoke from an incense stick was placed in front of the inlet vent. The time it took for the smoke to expel from the outlet vent was recorded. This time was then used to calculate the velocity of the airflow through the channels.



The Analysis:

ANALYSIS FOR EXPERIMENT:

TAKE SWEEP OF MEASUREMENTS



POWER LOST FROM THE SYSTEM:

$q = \dot{m}_e \underbrace{C_p (T_e - T_i)}_{\text{KNOWN}}$

$\dot{m} = \rho A_{\text{cross section}} V$ → ASSUME: STEADY STATE, COMPRESSIBLE

$A_{x\text{-sect}} = W_e h_e$

$\therefore \quad q = \underbrace{[\rho C_p (T_e - T_i)]}_{\text{CONSTANT}} \underbrace{W_e h_e}_{\text{VARIABLE}} \underbrace{V_e}_{\text{MEASURED}}$ (T_∞)

THE HIGHER THE RATE OF HEAT TRANSFER (q), THE MORE POWER THE SYSTEM IS EXPELLING. A HIGHER "q" IS BETTER FOR THE LAPTOP.

ρ → DENSITY OF AIR = .04196 lbm/IN³ @ 300K

C_p → HEAT CAPACITY OF AIR = .240 BTU/lbm°F

T_e → OUTLET TEMPERATURE (°F)

T_i → INLET (AMBIENT TEMPERATURE) (°F)

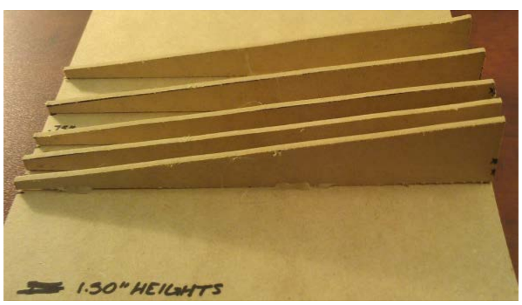
W + h → DIMENSIONS OF CHANNEL OPENINGS (INCHES)

V → VELOCITY (IN/SEC)

The Results – Empirical Art:

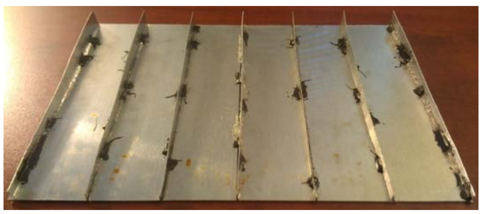
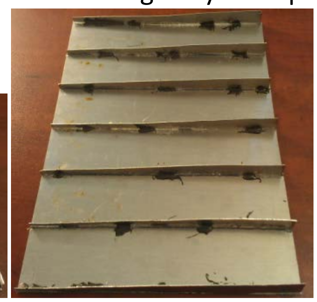
First Test:

The first models tested how the angle in the back and the width of the channel affected the airflow out the back. We had two models, one with a height of .75" and the other with 1.50" in the back. For each angle we had different widths of channels progressing from .25" to 1.50." Ideally we wanted the design to use the smallest, sleekest height possible, so this test showed us how much of a difference the height in the rear affected the airflow. To test these models, we placed incense sticks into the opening of the channels and watched the behavior of the smoke as it traveled through the channels. The smoke did travel faster through the higher angle, but the smaller angle smoke traveled almost as quickly so we decided that it was a sufficient angle. We also noticed that the wider channels had better and faster airflow through them. However, all of the channels worked to some extent, so we built another variation of the model with .75" in the back and a more detailed progression of channel width.



Second Test:

For this test we built an aluminum model to simulate the actual material properties of the product. This allowed us to take temperature readings and see if the system was actually working and keeping the bottom of the case cool. We started with a design that was .75" in the back and only had 3 channels all the way across. This gave us the wide channel design that proved to move the air out the back most efficiently. When the incense sticks were stuck into the channels however, we found that the smoke was only traveling through the center channel and would not travel up the side channels. The air was being pulled out the back by the ventilation fan installed in the computer, directly in the center. The temperature measurements we took followed our assumptions about the fan. These findings led us to a different design idea, as the channels were failing to function as we originally anticipated.

Third Test:

We concluded that the temperatures were good with the aluminum design, so we made this next one out of clear plastic. The idea of this was so that we could hold it up and observe how the smoke was traveling through the different channels. We altered the fin design so that we could direct all of the channels to the center of the case, utilizing the work that the computer's fan was already doing. Another design for this test was to make the fins shapeable and moveable so that we could try different designs and configurations. Conformability of the fins was achieved by using thin aluminum fins that could be bent into different shapes and could also be taped town to create a channel.

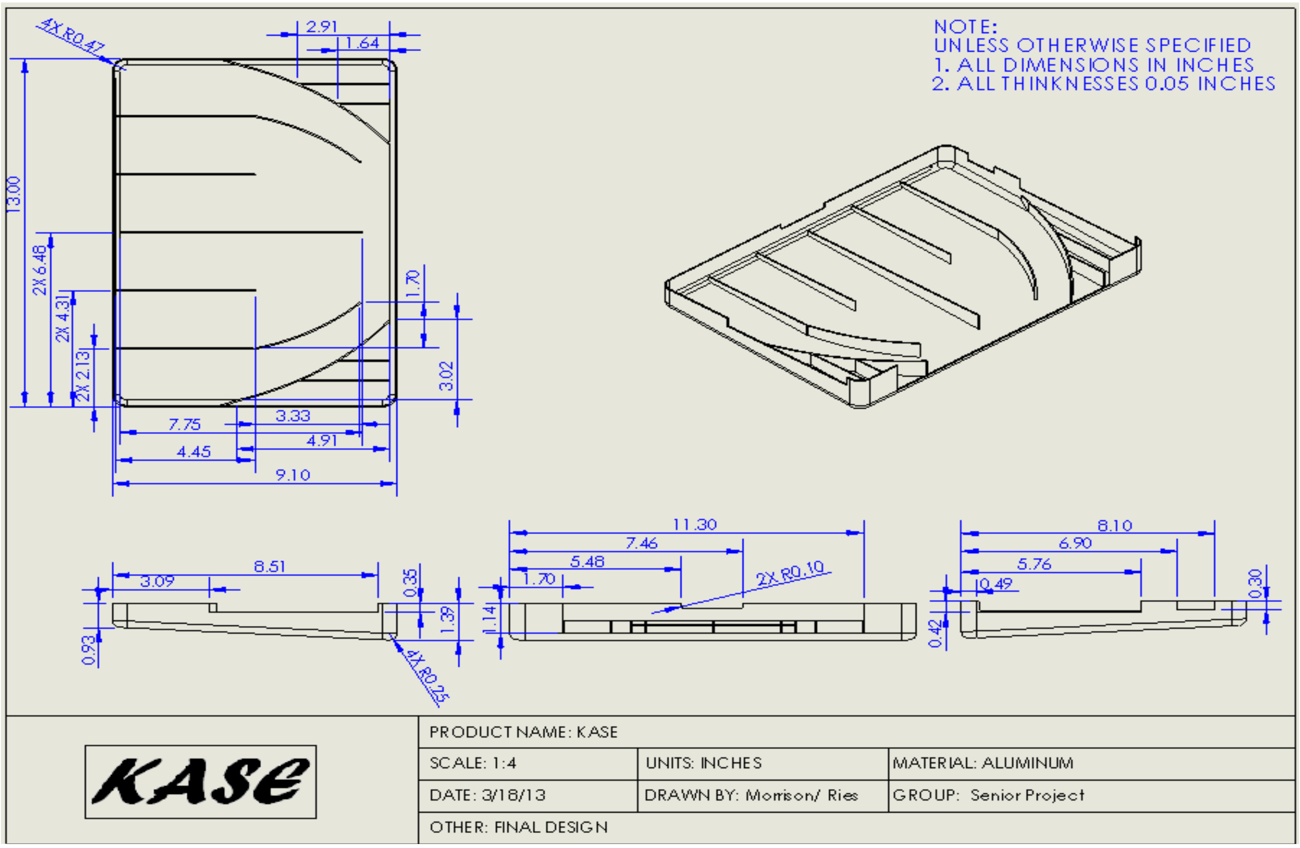


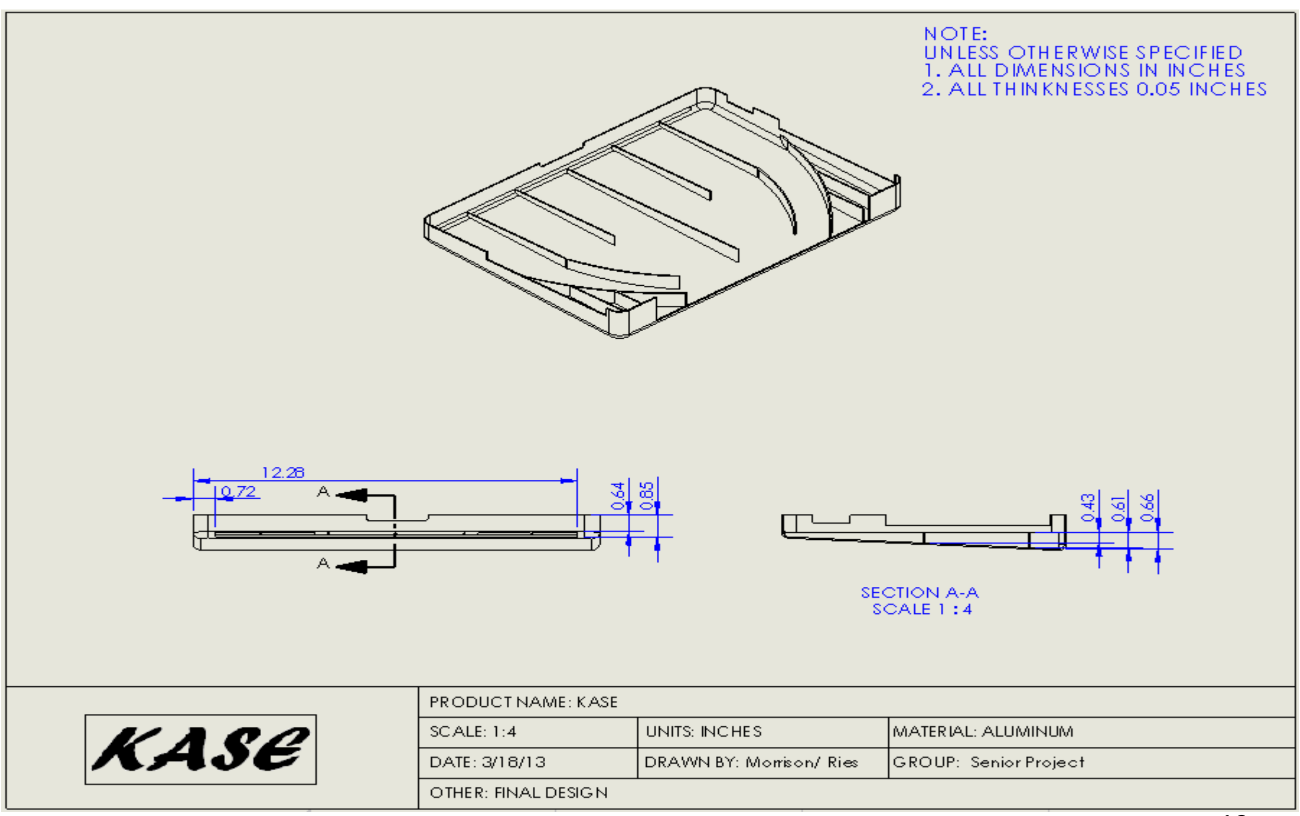
Final Design Model:
With each tweak, we learned something new about the design. Ultimately, the best design involved a collaboration of the pictures shown above. Having a larger channel width in the front and then tapering it down in the back created a sort of "nozzle effect" in which the smoke moved faster through. The design now relies on the work of the fan in the computer to pull the air under the computer.

We had our final design rapid prototyped in order to provide the marketing students with a physical model. Professors Laiho and Koch allowed us to utilize the machine to build a half scale model of the final design. The SolidWorks file was converted to a .stl and then uploaded to a program called CatalystEX. The rapid prototype took 2 hours and 20 minutes to build our half scale model. It then needed to be put in a cleaning solution bath for a little over an hour to clean off the scaffolding. Once this process was complete, we had a final model to represent the empirical progression that had taken place.

Description of Final Design:

SolidWorks Part:





Forces/ Loads:

Because of the lack of moving parts or complex geometry, the force and load calculations were relatively simple. With the maximum weight of the laptop being only approximately 4.5 pounds, the forces are not very excessive. We looked at the most extreme cases, to see if points of failure would exist. We analyzed the effects of the load on just the bottom surface of the case as both a point load and a uniformly distributed load. We treated the cases like simply supported beams. The analysis for both cases can be seen in the appendix, on pg. 28.

For the point load case, the deflection is only a tenth of an inch. This is not enough to permanently distort the case, nor damage it. This is also a very extreme case in which the entire load is directed at one point. This does not accurately show the actual deflection but it did give us an absolute extreme case.

For the uniformly distributed load case, which is a more accurate representation of the loading, the deflection is even less than for the point load. While this is more accurate, it does not fully represent the entire design because it is just the base and does not take into account the fins and the sides which will add structural rigidity to the part. So the real design has an even smaller deflection than this. Having said this, our design is in no structural danger with how it is being loaded.

Thermal Expansion:

The linear coefficient of expansion was an essential aspect of material selection. If we chose a material with a high linear coefficient of expansion, the case, if heated, would not fit properly on the laptop. In addition, a high linear coefficient of expansion does not allow for uniform stress increases throughout the case. Instead, the case would experience different levels of stress and expand non-uniformly during temperature increase. We calculated the thermal expansion using the most extreme range of temperatures for the computer (221^oF - 32^oF), provided under the specifications given by Apple. The calculations and data for thermal expansion can be seen in the appendix, on pg. 29.

The Factor of Safety is 2.65, which is greater than one, meaning that from a thermal stand point, our structure is sound even in a very extreme environment.

The tables in the appendix, on pg. 30, show various thermal expansions for different temperatures, materials, and lengths. Excel allowed us to quickly change through materials and a wide array of temperatures to simulate different conditions.

Using the equation for linear thermal expansion and the variables in the charts in the appendix on pg. 30, a variety of thermal expansions were calculated using different lengths and temperature ranges for each material consideration. As seen in the earlier calculation for the extreme case, the linear expansions are all very small and should not affect Kase very much.

Environment:
The type of environment the case will be exposed to is rather broad but is not very extreme. The most extreme part is the large temperature swing. These temperature swings cause the material to thermally expand and contract. These expansions and contractions can cause problems because the case could expand far enough that it becomes too large to fit on the laptop. These expansions could also potentially cause stresses in the material that need to be addressed. Another part of the environment is that the case is most likely going to be used daily and will experience the bumps, drops, and wear of everyday use.

After many different designs, that had their strengths and weaknesses, our final design lends itself to fit the environment well, addressing all possible problem areas. The incorporation of a rubber bumper around the laptop and an aluminum shell below helps with these problem areas. The rubber bumper will help to protect the laptop against scratches and serve as a shock absorber for lower impact drops. This design also allows the aluminum to more freely expand and contract without putting excessive stresses on the case. The linear expansion of the rubber is not significant because of the small temperature change range on the perimeter of laptop – almost all the heat increase is located on the bottom. Aluminum was decided on because of the aesthetic look we wish to maintain, sleek and simple, and it has a linear coefficient of thermal expansion that is relatively low for the temperature changes occurring.

Lifespan:
The average lifespan of a person's laptop is 4-5 years, and we expect our product to last at least this long, pending any extreme damage to the case. Seeing as how the case will be made of the same material as the MacBook Pro casing, the material lifespan should be comparable. Aluminum is known to have a high lifespan because it does not rust. The simplicity of the design lends itself to the idea of a longer lasting life.

Proposed Approach to Manufacturing and Marketing:

Materials Selection:

For the body of the case, we considered three materials – polycarbonate, polycarbonate with glass, and aluminum. Our considerations for the case were the aesthetics, manufacturability and durability, both thermally and mechanically. The largest of these considerations was the aesthetics of each material. This is not the most conventional way to select a material; however we had to consider our market. MacBook Pro users buy this particular computer because of the functionality, the brand and the look. Our marketing research showed that a majority of the users will not buy a case that does not fit with the overall style of the laptop itself. In addition, there is only one other product ("The Tilt") that uses aluminum in its design. We believe that this unique approach will add to the desire of the product.

We decided that styling the case similarly to the MacBook Pro, with smooth lines and its aluminum material would ultimately have the best chance of selling. As mentioned earlier the linear coefficient of expansion for aluminum is relatively low and the aluminum is also a great material to use in fins because it will conduct the heat away from the base of the laptop. Aluminum also tends to have a long lifespan, is light weight, and is durable.

For the bumper, the optimal choice is silicon rubber. We found this material by looking at a phone case, and adapting it to our laptop case design. Silicon rubber is very flexible and durable while also being a protective layer for the laptop from scratches. In addition, this buffer layer of silicon rubber acts as a great shock absorber. When it comes to manufacturing, silicon rubber is inexpensive and easy to work with, making it an ideal material for our case.

Fabrication:

We went through a couple different designs in order to come up with a feasible way to fabricate our product. With the help of manufacturing professors Lee MacFarland and John Larson, we realized that the original design with clips on the edges of the case would be extremely complicated to fabricate because of the geometry. They suggested that we keep a similar design but fabricate it in two pieces. The two piece design was still not the most simple product solution, so we designed the "rubber bumper" instead.

Our current design would be fabricated in two parts, the first being the rubber bumper and the second being the aluminum case. The rubber bumper would be produced using an injection mold method which is relatively simple, fast, and cheap. There are various options for manufacturing the aluminum base, including CNC machining, bending of sheet metal or die casting. Machining is very costly in both material waste and labor, while bending sheet metal is not practical for the geometry of the case. Ultimately, die casting is the ideal method of fabrication because of its simplicity, ease of use, quick production, and low operation costs. This method of fabrication is especially suited for a large quantity of small to medium sized castings. According to Martin Koch, professor in Manufacturing Engineering, over 90% of fabricated aluminum parts were made from a die cast.

Cost of Fabrication:

There is a substantial start-up cost with the die casting method. The initial tooling and casts for the case would be fairly expensive; however the incremental cost after this would be low. This process is very similar to injection molding, in that molten metal is forced into a steel mold and then hardened. This is a very fast process and can produce several of these parts in short periods of time.

The silicon rubber bumper will be produced using an injection mold. This process has very similar characteristics to the aluminum die casting, in that it is cheap and fast, with the only downside being the high initial costs for the tooling.

The following is a rough estimate for manufacturing the aluminum base. We used "custompart.net" to get a sense of how much the startup costs for this project would be. We entered a basic set of dimensions, including material, tolerances, area and volume. This data is crude and is not very accurate but it provides us with a general understanding of the price breakdown of fabrication.

Cost of fabricating 100,000 aluminum cases:

- Material: $541,946 ($5.419 per part)
- Production: $119,726 ($1.197 per part)
- Tooling: $120,929 ($1.209 per part)
- Total: $782,601 (**$7.826 per part**)

If we charged $35 per unit, we would have to sell 22,360 units to break even.

Bill of Materials:

The materials list for this product is relatively short because it only uses aluminum and silicon rubber. The value for the price per pound of aluminum also came from custompart.net. The value for the price per pound of the silicone rubber was hard to find, this value of 19 $/lb. seems very high for this material especially compared to the aluminum. The values added for the amount needed are estimates on the conservative side, so we expect that if Kase was to be mass manufactured, these values would be significantly lower.

Name	Material	Price Per Pound ($/lb.)	Amount Needed (lbs./unit)
Case	Aluminum	$1.80	1.50
Bumper	Silicon Rubber	$19.00	0.30

Total Cost of Materials for One Unit: $8.40

Conclusion:

Feasibility:

After all of the considerations of this project it seems that the case meets the requirements for it to be a feasible product. Our market research showed us that there is a market because we designed the case so that it would fit into what people would want. This also showed that there is a prospect for success because people would buy it.

The product is also feasible on the engineering side. These factors include the environment, resources to produce, and costs. The environment is relatively mild and the aluminum and rubber will be able to withstand this environment for a long time, probably outlasting the life of the computer. When it comes to the resources to produce and their cost, we discussed manufacturing methods with Professor Martin Koch. He insured us that it was possible and would not be difficult to make the molds for both of the parts. He also assured us that the cost of our materials would be relatively cheap and simple to acquire for mass manufacturing. The only issue is the high startup costs associated with production but this does not really affect the feasibility of producing our product.

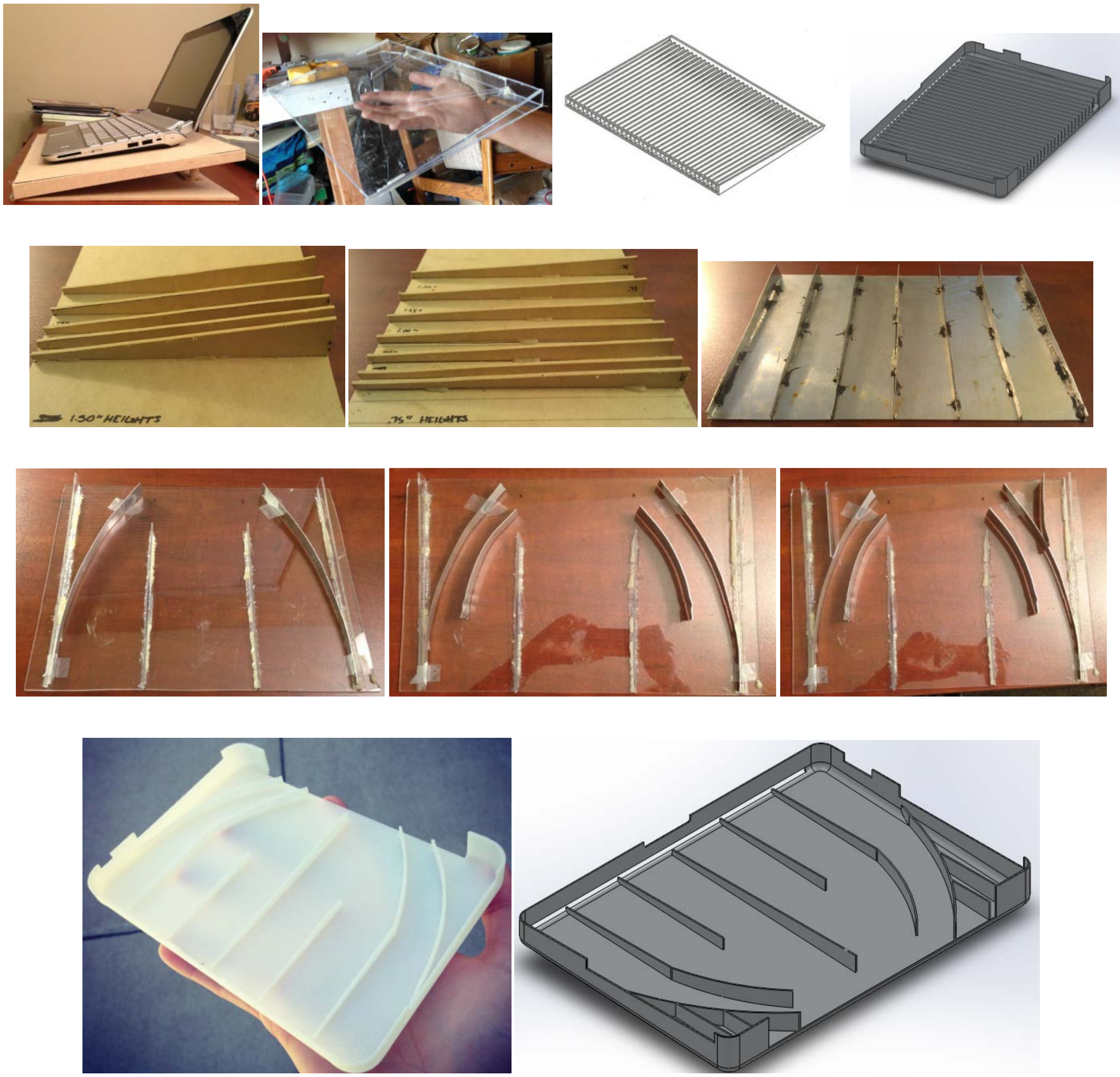
Summary:

To summarize, we have investigated several fields of engineering in order to fully design this product. We did market research to investigate the claim that laptop heat was uncomfortable to users and then we backed up this investigation with our own empirical measurements. We also researched previous solutions to this particular problem and incorporated positive aspects to optimize our design. After fabricating various designs, we narrowed our design concept based off of further market research and feasibility analysis. We then calculated the mechanical stresses and planned heat transfer experiments in order to design the fins. Manufacturing methods and costs (including that of the materials) were estimated and the total cost of one unit was estimated.

This design process incorporates elements of marketing, mechanical engineering, industrial engineering, materials engineering and manufacturing engineering. All of these elements were utilized to the fullest in order to create the solution to the designated problem and our ultimate design. This design will be tested and modeled in the future.

Progression photo:

This is just to display how our design was a product of empirical art.



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Appendix:

Question Set:

1) Do you have a laptop?
2) What kind?
3) What size?
4) Do you use it on your lap?
5) How often and for how long?
6) Do you have any complaints or are there any benefits?
7) If heat is an issue, why wouldn't you buy a product that is already out on the market?
8) Is it more or less comfortable to have your laptop at an angle? –if so, what would you think about a collapsible feature? (Transport reasons)
9) Does anything other than heat make you uncomfortable about using your laptop on your lap?
10) Are you more worried about the heat affecting the performance of your laptop or the heat bothering your lap…?
11) Does your computer ever slip off your lap? Is this something you noticed?
12) What would you think about a sleek and aesthetically pleasing clip-on addition that would prevent the laptops heat from being felt on your lap?

Rotary Switch Assembly and Setup:

- TT-K-30 wiring was used to make the thermocouple wires.
- Wires were cut to length and both ends were stripped.
- On one end of the wiring, the positive and negative wires were twisted together, soldered, and attached to the bottom surface of the laptop with aluminum tape.
- On the other end of the wiring, the positive and negative were separated and shaped into hooks. Then these were attached to the rotary switch with screws.
- The rotary switch was attached to a digital thermometer which was used to read off temperature values.

Resulting Temperature Measurements:

Test 1:

Place	Interval 1	Interval 2	Interval 3	Interval 4	Interval 5	Interval 6
1	83.0	82.7	82.4	84.5	84.4	87.1
2	83.0	82.6	82.3	84.2	84.4	87.0
3	82.8	82.8	82.5	85.4	91.1	90.5
4	wire broke	83.2	82.7	77.2	84.9	87.4
5	82.4	83.1	84.7	81.7	89.7	92.1
6	82.8	88.2	90.4	92.9	100.7	101.7
7	83.9	90.4	92.7	97.5	100.8	101.7
8	87.9	94.4	100.4	111.6	113.0	111.6
9	85.6	91.1	94.9	105.4	108.1	108.1
10	83.4	87.0	88.6	93.0	95.8	96.3
11	83.4	86.9	88.6	92.3	93.7	94.8
12	83.6	89.5	93.1	99.0	99.5	101.4
13	89.2	96.3	105.0	117.4	117.6	117.1
14	89.2	96.7	104.8	115.4	115.2	114.0
15	87.2	86.0	88.2	92.6	95.6	96.2
16	92.3	100.2	118.2	139.3	**141.1**	138.4
17	84.3	86.3	88.0	90.3	92.4	91.9

Test 2:

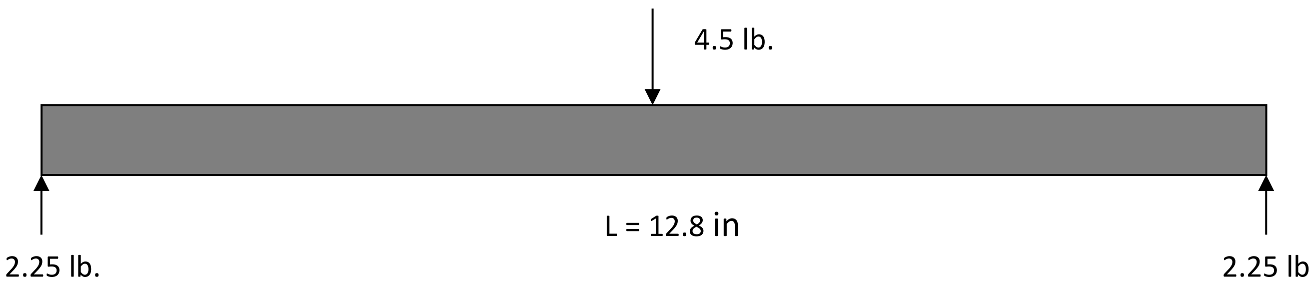
Place	Interval 1	Interval 2	Interval 3	Interval 4	Interval 5	Interval 6
1	80.0	81.5	84.4	86.6	87.9	89.3
2	80.3	81.2	84.1	86.6	88.0	89.2
3	80.4	81.1	83.8	86.8	89.2	90.1
4	79.7	80.5	82.1	82.0	84.3	85.6
5	79.8	80.1	81.8	82.2	84.4	86.2
6	80.2	80.5	83.0	88.1	90.7	92.1
7	80.2	80.2	81.9	85.6	90.3	91.6
8	80.8	83.3	86.0	89.0	93.9	95.6
9	81.3	83.1	85.8	85.8	88.9	91.4
10	81.6	82.8	83.0	81.8	83.7	85.3
11	82.1	83.9	83.7	83.9	84.5	85.6
12	82.3	84.5	90.3	93.0	94.1	96.6
13	83.0	88.1	94.1	99.0	100.5	103.6
14	83.2	88.3	94.2	98.8	100.0	100.8
15	81.8	83.7	84.6	85.2	86.0	86.3
16	84.5	89.2	98.8	102.2	102.9	**106.3**
17	79.9	81.9	83.1	84.4	84.9	85.5

→ Maximum Temperatures

*Temperatures in °F

Force/Load Analysis:

Point Load:



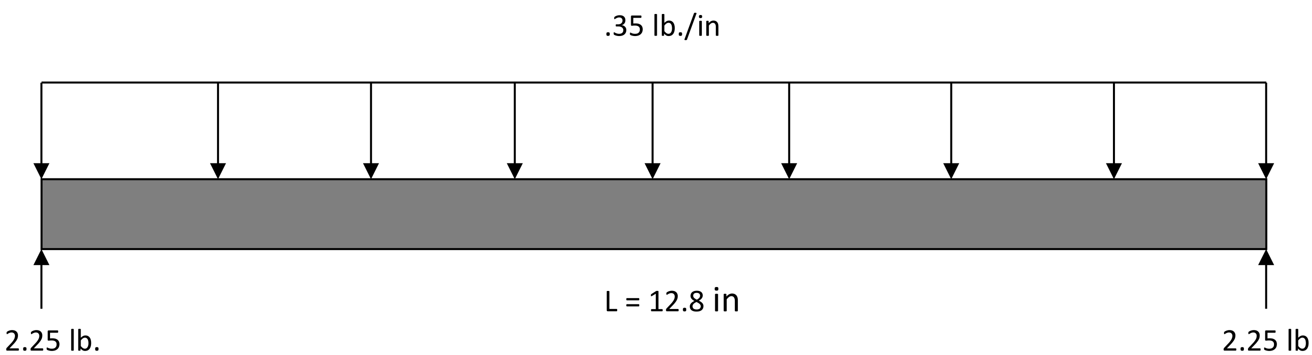
$y_{max} = \frac{FL^3}{48EI}$ where F = 4.5 lb., E = 10.4 x 10^6 psi

$I = \frac{1}{12}bh^3$ where b = 12.80 in, and h = .05 in (thickness of the bottom surface)

$$I = 1.33x10^{-4}in^4$$

$$\boldsymbol{y_{max} = 0.142\ in}$$

Uniformly Distributed Load:



$y_{max} = \frac{5\omega L^4}{384EI}$ where ω = 4.5 lb, E = 10.4 x 10^6 psi

$I = \frac{1}{12}bh^3$ where b = 12.80 in, and h = .05 in (thickness of the bottom surface)

$$I = 1.33x10^{-4}in^4$$
$$\boldsymbol{y_{max} = 0.088\ in}$$

Thermal Expansion Analysis:

For Aluminum	Other Info	Expansion Stress ⟶ Factor of Safety		
$\alpha = 1.23x10^{-3}\ {}^{1}/_{\circ C}$ $E = 10.4\ x\ 10^{6} psi$	L = 12.80 in $\Delta T = 221°C - 32°C$	$\delta = \alpha L \Delta T$	$\sigma = \frac{\delta}{L} E$	$n = \frac{\sigma_{Yield}}{\sigma_{Design}}$
		$\boldsymbol{\delta = 0.029\ in}$	$\boldsymbol{\sigma = 23562.5\ psi}$	$\boldsymbol{n = 2.65} > 1$

Given:

Linear Coefficient of Expansion	(1/°F)
Aluminum	0.0000123
Polycarbonate	0.000039
Polycarbonate with Glass	0.000012

Lengths (in)
8.9
12.8
0.25
0.75

Temperature	(°F)
Max in air	138.4
Max on Metal	117.6
Min on Metal	80
Arbitrary Min	50
Arbitrary max	150

Equation for Linear thermal Expansion:

$\delta = \alpha L \Delta T$

$\delta =$ Thermal Expansion

$\alpha =$ Linear Coefficient of Expansion

L= lengths

$\Delta T =$ Change in temperature

Linear Thermal Expansion for Different Materials:

The column 1 designates the lengths used in each row, while columns 2-6 describe the temperature changes used in each column.

	Aluminum				
Length (in)	For temps: 138.4-80°F	For temps: 117.6-80°F	For temps: 150-80°F	For temps: 117.6-50°F	For temps: 150-50°F
8.9	0.006393048	0.004116072	0.0076629	0.007400172	0.010947
12.5	0.009194496	0.005919744	0.0110208	0.010642944	0.015744
0.25	0.00017958	0.00011562	0.00021525	0.00020787	0.0003075
0.75	0.00053874	0.00034686	0.00064575	0.00062361	0.0009225

	Polycarbonate				
Length (in)	For temps: 138.4-80°F	For temps: 117.6-80°F	For temps: 150-80°F	For temps: 117.6-50°F	For temps: 150-50°F
8.9	0.02027064	0.01305096	0.01305096	0.02346396	0.03471
12.5	0.02915328	0.01876992	0.034944	0.03374592	0.04992
0.25	0.0005694	0.0003666	0.0006825	0.0006591	0.000975
0.75	0.0005694	0.0010998	0.0020475	0.0019773	0.002925

	Polycarbonate with Glass				
Length (in)	For temps: 138.4-80°F	For temps: 117.6-80°F	For temps: 150-80°F	For temps: 117.6-50°F	For temps: 150-50°F
8.9	0.00623712	0.00401568	0.007476	0.00721968	0.01068
12.5	0.00897024	0.00577536	0.010752	0.01038336	0.01536
0.25	0.0001752	0.0001128	0.00021	0.0002028	0.0003
0.75	0.0005256	0.0003384	0.00063	0.0006084	0.0009