DESIGN AND ANALYSIS OF A SMALL FORM FACTOR DESKTOP COMPUTER ENCLOSURE

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DESIGN AND ANALYSIS OF A SMALL FORM FACTOR DESKTOP COMPUTER ENCLOSURE

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Morehead State University, 2013

Director of Thesis: ______________________________

The directive of this thesis is to review the current market offerings, or lack thereof, of performance oriented small form factor desktop computer cases for gaming and enthusiast applications. Based on these findings a design for a new product offering is to be developed for manufacture. The design of the new case is to be such that it solves some of the issues associated with high performance and compact computer systems, which maintaining a level of quality of construction and serviceability not currently available from an off-the-shelf product. Also taken into consideration are thermal design, efficiency of space, serviceability, cost to manufacture, manufacturing methods,

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Accepted by the faculty of the College of Science and Technology, Morehead State University, in partial fulfillment of the requirements for the Masters of Science degree.

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Date

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As a very busy professional and entrepreneur, I must give a special thanks to my wife for her continued and unwavering support. With a walking, talking and curious one year old at home, developing and writing a thesis is a continued challenge. And I thoroughly believe that it wouldn't be possible without her and my family. Always backing me up and cheering me on, my family is my driving force behind everything I do, including this study.

I would also like to convey my gratitude and respect for the faculty and staff of Morehead State University, especially the Applied Engineering and Technology Department. Dr. Zagari, Dr. You, Dr. Chapman, Mr. Mason, and others during my time as an undergraduate student have played a significant role in my success and motivated me to where I am today. I feel as though the tools and lessons that I have learned at Morehead State University and my MSU *family* are invaluable and priceless to me.

TABLE OF CONTENTS

Table of Contents

CHAPTER ONE: INTRODUCTION

In science and technology, one of the many characteristics that are being focused on is making devices smaller and more powerful. While these two characteristics generally contradict one another, computer technology in integrated chips and circuitry are being developed on a nano-scale, much smaller than ever before. For example, the Intel 20 nanometer flash technology recently released in its latest solid state drives (Intel, 2013). The phones we carry around in hand are veritable power houses when compared to the "super computers" of the late 1940's and early 1950's. This decrease in size and increase in capability also applies to our desktop computers.

Take for example the Electronic Numerical Integrator And Computer (ENIAC) shown in Figure 1, in 1946 it was the world's first programmable computer. It was the size of a small cottage and did little more than add, subtract and hold ten-digit decimal numbers in memory (Burks, 1981). Even though this was a monumental accomplishment, imagine walking in the scene of this photo and handing the engineer in the foreground the latest iPhone 5 from Apple. The capability and size of that hand-held device is magnitudes greater than that of the technology available just 67 years ago.

Figure 1: The ENIAC, the first general purpose computer was the size of a small cottage. Photo courtesy of US Army.

Laptops are prime examples of powerful technology housed in a small package. However, when a laptop is not a sufficient or a cost effective choice, many users turn to desktop computers. This is particularly true for users who are involved in graphics-intensive software activities such as video editing, animation and gaming. In such applications a desktop is more expandable/upgradeable and cost effective (dollar amount to performance) than a comparable laptop or notebook. (Fleischer, 2008)

Purpose

As the desire for ultra-compact gaming and home theater computers increases, so does the amount of engineering required to make the smaller technology work effectively. The purpose behind this research is to develop an ultra-small form factor desktop computer case for use with the latest and most powerful hardware currently available on the market.

This in depth look into the development of a compact PC case will help evaluate the design for manufacturability, form and function. It also looks at the features demanded from end-users and the design compromises and accommodations made to develop such a unique product.

Objectives

Objective 1: The objective is to design an ultra-small form factor gaming/home theater case that is both elegant in design and cost effective to manufacture.

Objective 2: Design a case that is less than 10 liters in volume that can enclose standard computer components, including a full length dual-slot graphics card.

Objective 3: Analyze the air flow and thermal properties of said design.

Objective 4: Design the case such that it meets or exceeds current products on the market in quality and performance. A product comparison will be used to compare and contrast the design characteristics of three (3) other comparable cases.

Assumptions

It is assumed that most users will select from a specific collection of computer components for their builds and the case is designed with these component specifications in mind. Though there is a wide variety of computer hardware available, the focus market in this study buys from the high-end performance oriented category which, while still varied and numerous, is a relatively smaller collection of product offerings.

It can also be assumed, that since developing a product to bring to market will go through several design cycles and revisions, this study will focus on the preliminary stages of the project with a certain degree of inference to the final outcome. However, since the process and methods behind the preliminary stages are what is under study, this thesis purpose remains valid. The final outcome is merely additional information in a wider scope.

Limitations

Due to the variety of user preferences and requirements, this particular design study will focus on a group of the PC community which are the enthusiasts and mid to high-end gamers. While a very specific group to study, this group in and of itself is very diverse in hardware requirements and personal taste in regards to aesthetics.

Also, as aforementioned in the Assumptions, this study is limited to the scope of the preliminary stages of the product development process and methods. Further study into the final product will require additional time for proper market acceptance data and retail validity analysis.

Significance of the Study

The PC continues to become more engrained into our lives and that holds true with the gaming industry. Previously, console gaming units such at the Sony PlayStation 3, Microsoft Xbox 360 and Nintendo Wii were more popular and grossed more per year in game sales than PC, as is evident in Figure 2.

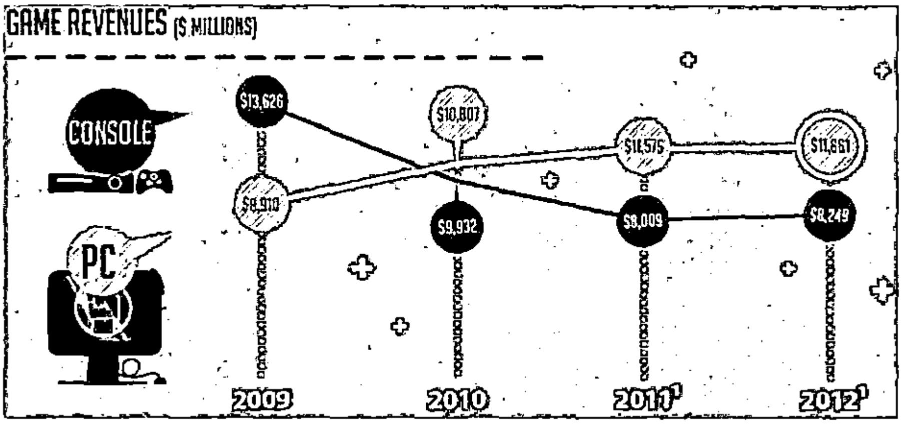


Figure 2: Gaming revenues per platform. Courtesy of Newzoo Market Studies.

Currently, game revenues for the PC versus the console argument have reversed since a peak year for consoles in 2009 at $13,626 million. The PC gaming market began to grow and then console sales declined. One must keep in mind that the console revenue numbers include sales of all console platforms such as the PlayStation, Xbox and Wii. While the PC stands alone as a category in and of itself. That makes the comparison even more impactful as evidence of the ever growing PC enthusiast and gaming community market.

This direct comparison between the PC and console is also evident of what consumers are demanding of their PCs. Coming from the compact size of a console, many PC users want all the capabilities and performance of a PC, but want it contained within a console-sized machine. The days of big and bulky full tower PCs are limited.

Definition of Terms

1. Standard Form Factor – This term identifies that a component or piece of computer hardware fits within the dimensional and electrical guidelines as determined by industry leaders, such as Intel. This standardization allows for greater compatibility of hardware from various manufacturers (Intel, Form Factors, 2009).
2. Small Form Factor – Also known as SFF, small form factor is in reference to the volume of a computer system or hardware specifically designed for optimal use of space (What is Small Form Factor?, 2011). The unofficial definition of a SFF PC is one of a volume equal to or less than 20 liters.
3. Motherboard – This is a computer component where most computer hardware interface. The motherboard contains sockets and ports for the CPU, PCI devices, USB, system memory and many more inputs and outputs.
4. Graphics Processing Unit – Also known as GPU, the graphics processing unit contains a processing chip and dedicated memory that is designed to process graphical and physics calculations. Some GPUs are integrated into the CPU or motherboard, but for this study a GPU is assumed to be a dedicated PCI device and is an add-on hardware.
5. Central Processing Unit – Also known as the CPU, the central processing unit acts as the hub for all activity on the computer.
6. Solid State Drive – Also known as an SSD, a solid state drive is a storage device that is based on flash memory rather than spinning disks like a traditional hard

disk drive. The advantage to a SSD drive is its rapid read/write speeds that are as much as ten times faster than its spinning disk counterpart. Most SSD drives are compact, fitting the 2.5" drive standard, also known as a laptop drive. Capacities of SSDs are growing, but generally range from 32 gigabytes (GB) to 512 GB.

7. Hard Disk Drive – Also known as an HDD, a hard disk drive is a means of data storage using an array of stacked spinning plates and moving reader heads. These moving parts are one reason they are not as fast for random access as an SSD. HDDs come in two common form factors, 2.5" and 3.5" and in capacities up to 4 terabytes (4,000 GB).
8. Optical Disc Drive – Also known as an ODD, an optical disc drive is a device that reads and/or writes CD, DVD and Blu-ray discs. These come in two form factors, slim-line and 5.25". Both form factors come in a tray-load (most common) and slot-load type disc loading configuration.
9. PCI Riser – A PCI riser is an extension or adapter that allows relocation of a PCI-based card from the traditional location on the motherboard. PCI risers can be flexible ribbon cables or rigid PC boards. A riser may raise the height of a card, angle it 90 degrees to parallel with the board, or both. Ribbon cable-type risers require shielding to prevent interference from electromagnetic disturbance.
10. "Enthusiast" – In the context of the computer industry, an enthusiast is a computer user or system builder that has a vested personal and/or professional interest in high performance computer technology or low level programming

and hardware technology. Enthusiasts are often avid gamers, programmers, folder (distributed computing) and graphic/media designers.

11. Cable Management – This is a term used amongst computer system builders and enthusiast to refer to the organization or cable routing in a computer/electrical enclosure. Good cable management is discernable by neatly bundled cables, routing of cables for ease of access to hardware, good appearance and proper air flow. Cable management is often limited by the design of the computer case and the patience of the builder.
12. Manufacturability – The feasibility and effectiveness of a designs ability to be machined, formed or otherwise made is referred to as manufacturability. A design with good manufacturability can be readily and cost-effectively made using conventional machinery, materials and methods with limited amounts of special tooling or equipment.
13. Home Theater Personal Computer – Also known as an HTPC, a home theater PC is a computer that performs multiple media functions and often replaces numerous components traditionally found in a home theater setup. An HTPC may play DVDs and Blu-ray discs, stream video from Netflix and YouTube, or music from Pandora, and can even act as a gaming center and network attached storage device (NAS). With more online content available, home theater computers have grown in popularity.

CHAPTER TWO: REVIEW OF LITERATURE

Enthusiast Market

The computer enthusiast community consists of professionals and hobbyists whose interests fall heavily into the unique, performance oriented and high-end computer hardware, software and related technologies. Each individual's purpose and application in this market varies from the casual gamer to the professional programming experts and consultants. However, the enthusiast market shares a common characteristic of being deeply involved with computer technology and lifestyle (Compact Gaming PC, 2012).

Figure 3: Not uncommon for enthusiast users are multi-monitor setups which require significant amount of GPU power. EVGA.

The gaming community is much easier to distinguish and most members of the enthusiast community will consider themselves gamers. In fact, a large portion of the population play games and/or consider themselves gamers.

According to a study done by the Entertainment Software Rating Board, 67% of all households in the United States play video games on some platform. Of this percentage, the average age of a gamer is 34 years of age (Video Game Industry Statistics, 2012). This puts the average gamer well within the professional and gainfully employed age range.

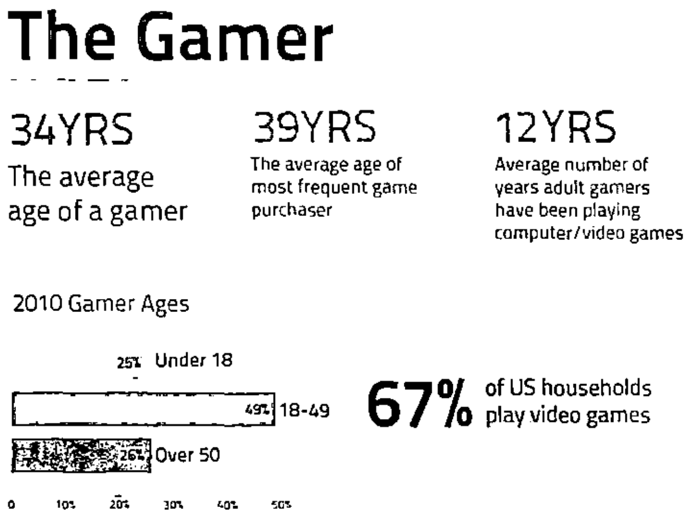


Figure 4: Gamer statistics in the US, ESRB Rating Group.

Though the group this case design study focuses on are not always gamers, the gamer statistic is an accurate representation of the general enthusiast market due to the common thread of computer technology in gaming. And considering the majority of enthusiasts play games on their PC or console, there is a direct correlation and is a fair assessment of the enthusiast market.

Existing Product Comparison

While the market of computer cases is heavily saturated by numerous manufacturers, there are only a few that have a presence in the enthusiast-grade small form factor category. However, more manufacturers are taking interest in the small form factor market and developing new products with compact size in mind (Rybicki, May 2007).

However, even fewer of the cases in question in this comparison are available for purchase as the case only. They must be purchased as a complete system with all the hardware and software preconfigured. The biggest of these companies is Alienware by Dell Computers. There are also smaller system builders like Falcon Northwest and Digital Storm. While these manufactures do focus on the larger full size and miniature towers, they are three of only a few who offer a unique small form factor option.

The design developed in this thesis is intended to be a conceptual competitor to cases offered by the aforementioned manufacturers. It is stated to be a conceptual competitor, because while the features and quality of the case design central to this thesis may be superior, the capacity for high volume manufacturing is not currently advanced to the level of the aforementioned manufactures nor is it intended to be.

Alienware X51 by Dell Computers

The first case under review is the slim small form factor system titled the X51 by Alienware Computers. Alienware computers is a high-end division of Dell Computers that specializes in very powerful graphics processing PCs and gaming hardware. They also have a line of very powerful laptop computers, capable of graphic intensive processing, similar in performance to their desktop counterparts (SFF Gaming Desktops, 2012).

The X51 enclosure has been equated to a gaming console in form and relative size. While still significantly larger than a Microsoft Xbox 360 or Sony Play Station 3, it does bare a resemblance in styling and stance.

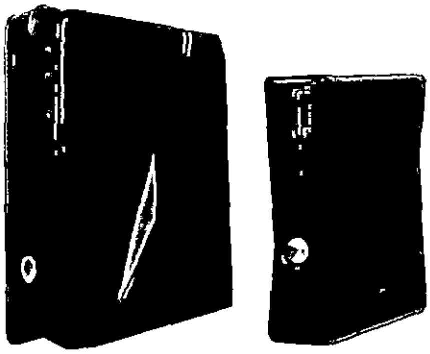


Figure 5: Alienware X51 and Microsoft Xbox 360 side-by-side shows similar styling and form. LegitReviews.com.

The case for the X51 is what is considered to be a slim mini tower. It requires a riser card to relocate the graphics card, or any PCI device, at an angle of 90 degrees from the traditional location. This puts the graphics card perpendicular to the motherboard, allowing for the form factor's slim design. This is a common trait amongst all the cases to follow. However each executes the overall layout with some significant variations.

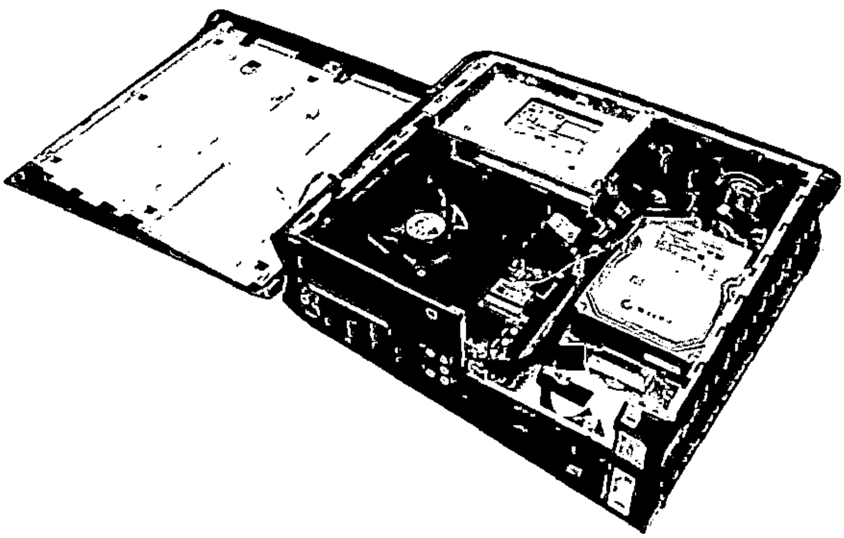


Figure 6: An inside look at the X51 shows the layout with the GPU removed. LegitReviews.com.

X51 Hardware Capability

While relatively small, the X51 can house all the hardware required of a modest graphics computer. However, the graphics card is limited to 150 watts, which eliminates most of the high-end GPUs mentioned below, which demand in upwards of 250 watts when under full load. While there is physically room for some of these GPUs, there just isn't the power supply capacity to power them with the included 300 watt external AD/DC power adapter.

In the table below are five different Intel i7 computer configurations, each with a different GPU. For the sake of this study we are only interested in the single GPU configuration, not the multi-GPU SLIs, since the cases under review only house one GPU. The average amount of power drawn while the computer is idle is 97 watts. Then under full load, like graphics processing, video editing or gaming, the power draw goes up considerably. The average power draw of the entire system under load is 375 watts.

Table 1: Total system power draw (watts) for PCs at idle and full load. HardForum.com, Kyle Bennette.

Power Draw

(Total System Wattage - Without Video Card ≈ 67W)

		Idle	Full Load
NVIDIA GeForce GTX TITAN	System Wattage	95W	406W
NVIDIA Geforce GTX 680	System Wattage	99W	329W
AMD Radeon HD 7970 GHz Edition	System Wattage	97W	390W
NVIDIA GeForce GTX TITAN SLI	System Wattage	108W	646W
NVIDIA GeForce GTX 680 SLI	System Wattage	128W	531W

As you can see, the average power draw of a performance oriented PC at full load far exceeds the X51's 240W external power supply. Even assuming it is Bronze 80 Plus rated, which means it runs at or above 80% efficiency, the power supply is only capable of sustaining 240 watts for any continuous cycle time. This means the X51 is under powered for high performance hardware by 130 watts, or 35%. This severely limits the GPU selection for building an enthusiast-grade PC. Moreover, the power supply is not upgradable, so the wattage value is locked and cannot be replaced with any other off-the-shelf power supplies.

Also of concern is the proprietary motherboard configuration. It does resemble the mini ITX form factor (6.7" x 6.7" or 170mm x 170mm), but it would not be compatible with a standard mini ITX motherboard from any other manufacturer. The rear input and output panel is built into the case and does not match other motherboard manufacturer's configurations. Also the slot where the GPU mounts on the motherboard is not in a standardized location. Therefore, replacing or upgrading the motherboard to any other manufacture is not an option without major modifications.

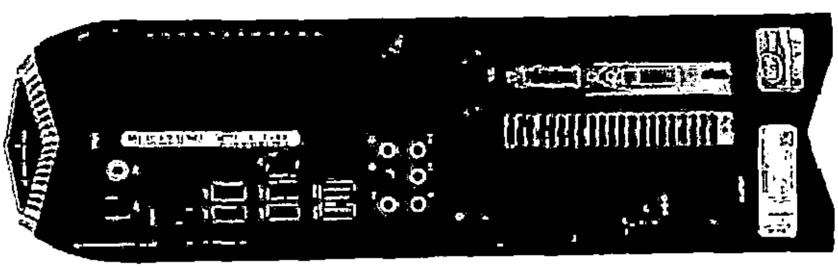


Figure 7: A view of the X51 rear panel showing the proprietary inputs and outputs. LegitReviews.com.

Along with the underpowered power supply, this case severely limits the hardware selection, especially in the high-end graphics cards that exceed 10.0" in length. This includes, from left to right below, the NVidia GeForce GTX690 (11.0"), the recently released

GTX Titan (10.5") and the ATI Radeon HD7970 (11.0"). Granted these GPUs do represent the extreme end of the spectrum as far as size and power requirements, but most high performance graphics cards will be close in size or power requirements, if not similar in both respects.

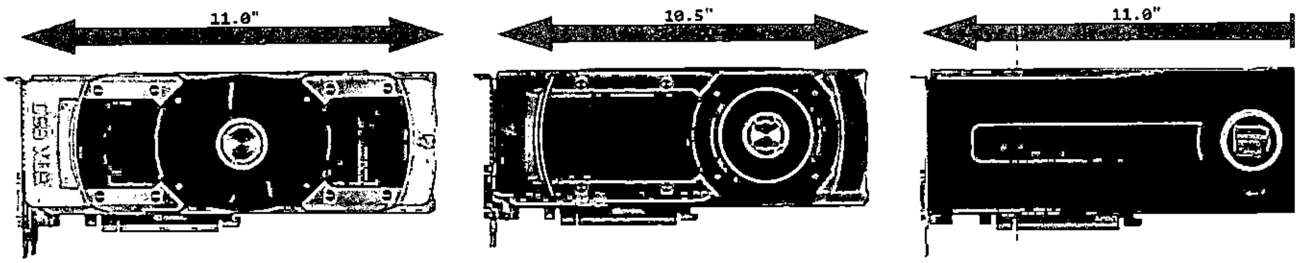


Figure 8: Left to right, NVidia GTX 690, GTX Titan and ATI Radeon HD7970, the three most powerful GPUs currently available. Compiled from NVidia and ATI.

Along with the limited power supply and room for containing and powering high performance graphics cards, the X51 case is only available when purchasing a complete preconfigured system from Dell. Pricing for these systems start at $599.99.

Tiki by Falcon Northwest

Falcon Northwest is a custom PC builder that provides customers with preconfigured computers that they can customize and upgrade to their preferences. They focus mostly on full mATX and ATX towers (larger motherboard size and mini ITX), but do offer a small form factor mini ITX option. They call it the Tiki. In size and layout it is very similar to the Alienware X51. It is a slim design that uses a PCIEx16 riser to relocate the GPU parallel with the motherboard. However, it's styling and component capabilities are quite different than the X51.

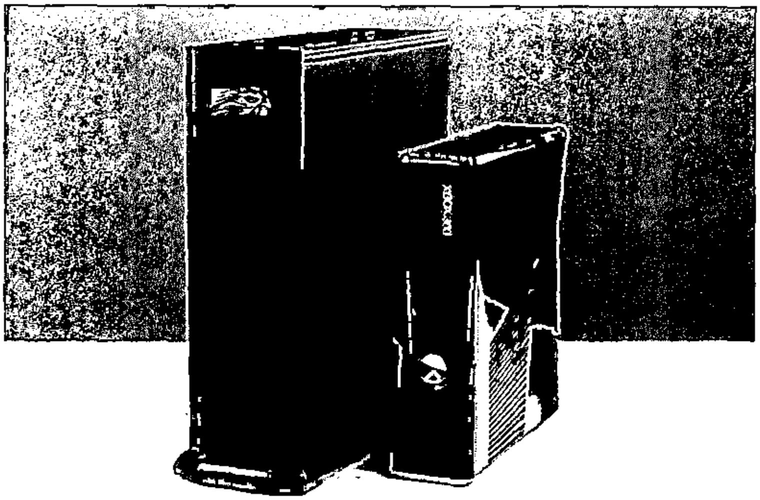


Figure 9: The Tiki and Xbox 360 share similar features, though the Tiki is larger. Republic Of Gamers.

Again, using the Microsoft Xbox 360 for a common size comparison, you can see Tiki is relatively compact. It is however, wider than the X51 and significantly heavier with its granite anti-tipping base. It offers a clean front panel with all USB3.0 ports and optical drive slot located on the top of the case. This case cannot be oriented horizontally without modifications.

Tiki Hardware Capabilities

Where the X51 utilizes a proprietary Dell motherboard, the Tiki case allows for using a standard mini ITX motherboard that is readily available off-the-shelf from a variety of manufacturers. This gives the customer the ability to upgrade or otherwise replace the motherboard easily with standard components. In fact, this standardization is carried out through the rest of the case, including the power supply. The power supply is an SFX form factor that is available from multiple manufacturers in various wattages up to 450 watts.

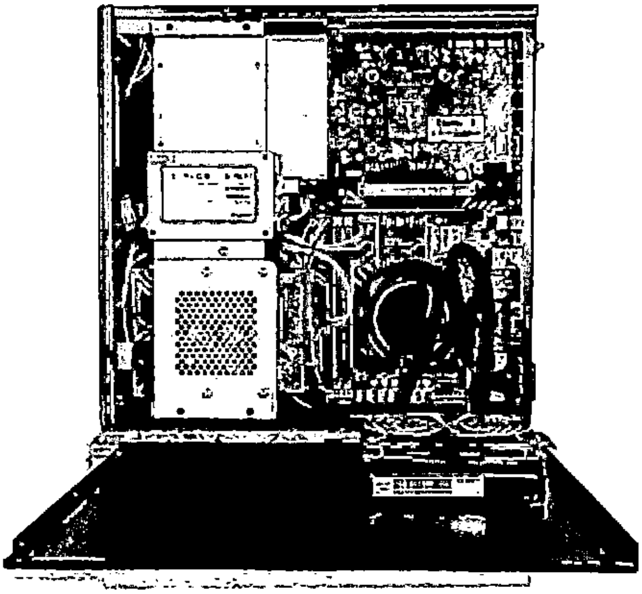


Figure 10: With the side panel removed you can the tight configuration of components. PC World.

Along with the aforementioned ITX motherboard and SFX power supply, the case can hold two 2.5" HDDs/SSDs, one 3.5" HDD, a GPU up to 272mm (10.7") in length and an included all-in-one enclosed water cooler. Also known as an AIO water cooler, an all-in-one water cooler is a self-contained pump, reservoir, radiator and water block that comes assembled and sealed. These have grown in popularity due to their cool and quiet operation and ability to locating the CPU cooling solution in a tight space.

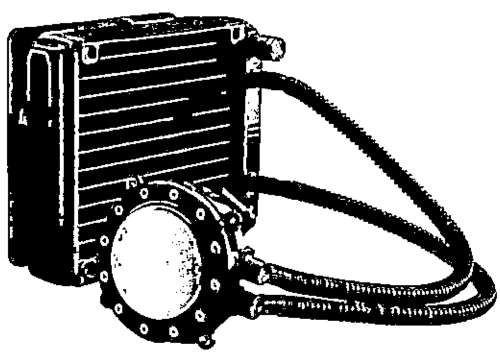


Figure 11: This is a 120mm AIO from Astek designed for use on a CPU. Astek Corp.

The overall layout is again similar to the X51. However, the key differences here are the in the GPU and CPU intake. Where the X51 used ducts to direct airflow from the sides and rear, the Tiki allows air directly through the side panels. This is a small sacrifice in aesthetics for a great improvement in thermal performance. This is especially important on this case due to its capacity to contain and power some of the biggest and hottest graphics cards available. However, the Tiki case is not available separately and you must purchase a complete system starting at $1,599.99 to obtain it.

Bolt by Digital Storm

The Bolt by Digital Storm is a lesser known maker of preconfigured computers that offers a small form factor tower option. Made mainly from steel and plastic, the Bolt differs greatly from the X51 and Tiki.

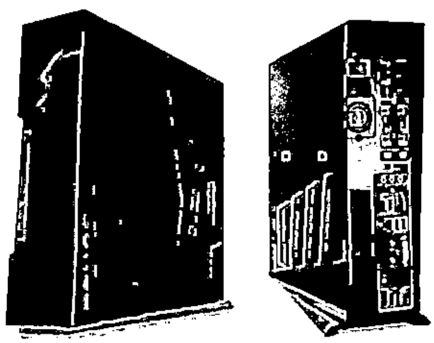


Figure 12: A front and back isometric view of the Bolt reveals its unique styling. Legit Reviews.

Compared to the Xbox 360, the Bolt is relatively compact. It is similar in size to the Tiki, but actually 0.4" thinner. Because of this thinner design and layout, some sacrifices had to be made in order to make the case design work physically and thermally.

Bolt Hardware Capabilities

Even though it shares similar dimensions as the Tiki, it holds quite a bit less hardware. The first sacrifice made is in the power supply. Because of the location of the storage drives and optical drive, the power supply had to be thinner to fit behind the GPU. The supply they implemented is a Digital Storm proprietary 1U server power supply. It is cooled by two 40mm fans, which are significantly noisier and less efficient than larger fans, like the 80mm fans found in SFX power supplies or the even larger 120mm fans in ATX power supplies. For data storage the Bolt can hold one 3.5" HDD and two 2.5" SSD/HDD. This is a similar drive configuration to the Tiki.

The Bolt does have plenty of room and power for the latest high-end GPUs. Thanks to the 500 watt supply, there is ample power for nearly any system configuration currently available. And the space allotted for the GPU allows for cards up to 285mm in length. However, the location of the power supply directly behind the GPU does cause heat issues. The back of the GPU can reach temperatures of over 92 degrees Celsius, or 198 degrees Fahrenheit. This can cause overheating of the GPU due to lack of sufficient airflow over the back of the card and overheating the power supply causing the fans to run at 100%, in turn generating noise.

Side By Side Comparison

As the three cases reviewed previously show, there are limitations to current small form factor offerings. The main limitations are CPU cooling capacity and the ability to use full length high-end graphics cards required for complex video processing and gaming software. The challenge is to include all these features, as well as the storage drive capacity while maintaining a compact size that remains serviceable and is available individually without having to purchase a complete prebuilt computer.

In Table 2, you can see a side-by-side comparison of the three cases. The weakest design is the Alienware X51, being under powered and lacks the storage drive mounting capability of the others. While still a gaming platform, the 240 watt power supply and single 3.5" drive mount prohibit this from being a true enthusiast grade case design.

Table 2: A product comparison between current market offerings. Curt Adkins.

		Width (mm)	Depth (mm)	Height (mm)	Volume (Liters)	Mother Board	CPU HSF Clearance (mm)	GPU Length (mm)	2.5" Drive Mounts	3.5" Drive Mounts	Optical	Power Supply	Price
ALIENWARE	X51	95	318	343	10.4	Dell "ITX"	69	243	0	1	1	Ext. 240W	N/A
Falcon Northwest	Tiki	102	356	356	12.9	ITX	79	272	2	1	1	SFX 450W	N/A
DIGITALSTORM	Bolt	92	356	356	11.7	ITX	57	285	2	1	1	1U 500W	N/A

Moving forward the design of the M3A2, the case under study, must meet and/or exceed the features set forth by the Tiki and Bolt and do so in a cost effective manner. It is also import that the quality of the design, material selection and finish are high enough to warrant the higher retail prices associated with performance-oriented hardware.

Software Review

CAD - Solid Works Professional 2012

The main 3D modeling software used for this project is Solid Works Professional 2012 by Daussault Systems. This software is an industry standard for 3D modeling, product design, finite element analysis and product renderings (Daussault Systems, 2013). Part drawings, assembly models and rendering are all executed within the Solid Works Professional 2012 platform.

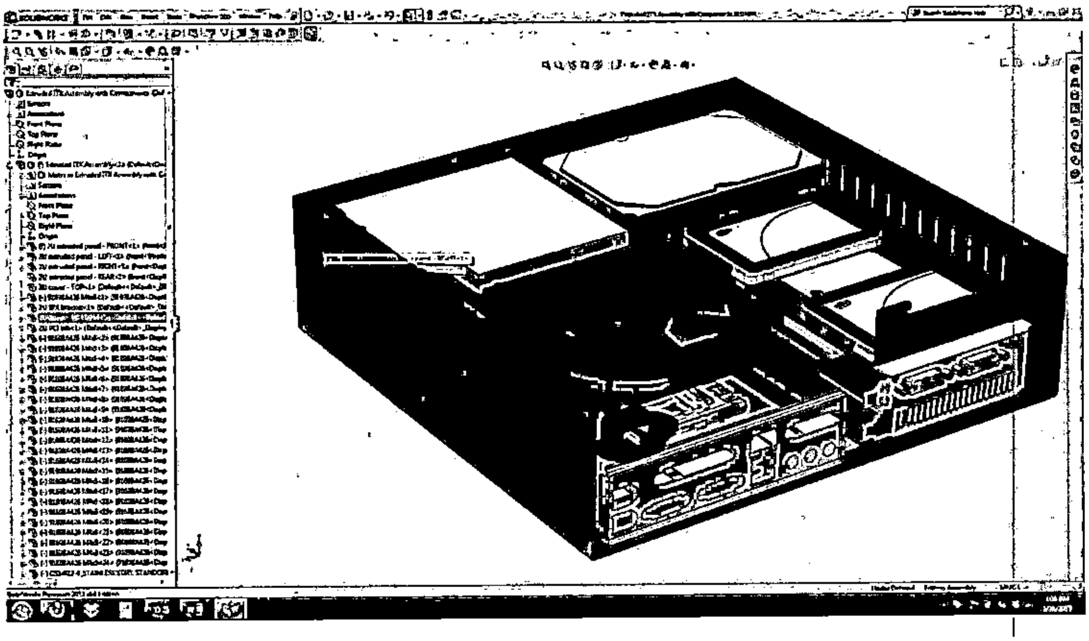


Figure 13: The M3A2 Beta case assembly with computer components installed. Curt Adkins.

This software is critical to effective product design for its ability to realistically model a part both geometrically and mathematically. This means not only does the rendering capability of PhotoView 360, the included plug-in, allow us to see how the product will look in finished form, it also offers quantitative analysis of each individual part and collective assembly for fluid and thermal dynamic studies.

The quantitative data can be used to determine the weight of part, based on volume and material density, as well as material characteristics such as strength and air flow simulation. The weight data plays a particularly helpful role in cost analysis, by applying current weight to cost values of certain materials. In this case, the main material is aluminum.

Furthermore, the rendering capabilities are vital to predetermine market acceptance and feedback before a physical product is manufactured. Rendered images with realistic textures and shading give sample groups an accurate view of what the product may look like for gathering end-user feedback, which greatly affects the product design. This is a consumer product where both form and function play a critical role in success.

CAM - SheetCAM TNG

When parts have been completely designed and are ready for the manufacturing process analysis phase, (i.e. prototyping), the geometric data of each part is input into the computer aided machining/manufacturing software, also known as CAM software. For this project, the main CAM software is a 2.5 dimension-based program called SheetCAM TNG. This software is most effective on machines with two to three axes and where the part design requires no three dimensional simultaneous axis control. This means, it is meant for machines like routers, plasma cutters, lasers and etching machines that do pocketing, contouring and drilling.

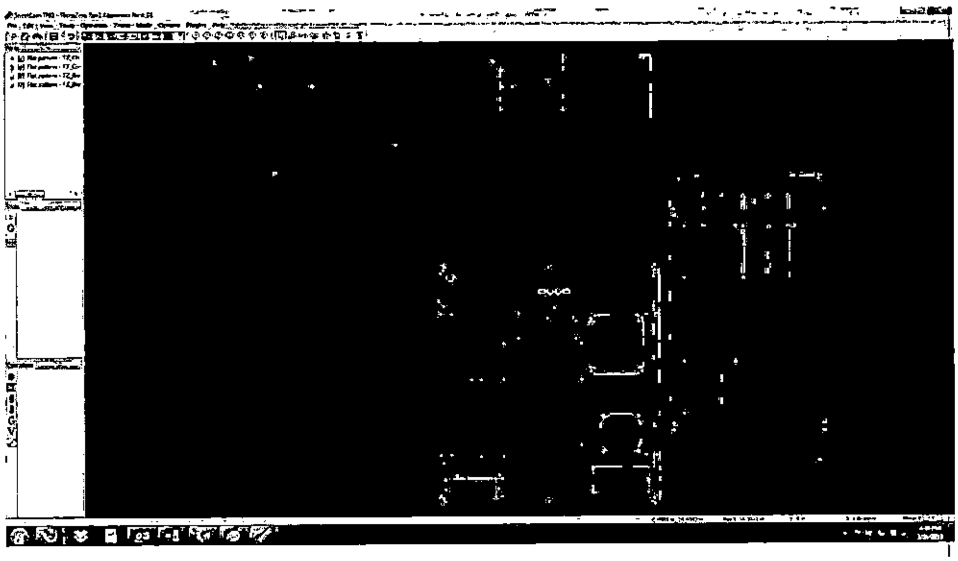


Figure 14: M3A1 prototype flat layouts for CNC plasma cutting. Curt Adkins.

SheetCAM TNG is the software than generates the machine code (also known as G-Code and M-Code), which is numerous lines of code that the machine will interpret into movement and action (SheetCAM TNG, 2013). This in turn produces the part. While not a fully automated process, the SheetCAM TNG software allows tool paths to be generated from two and three dimensional drawings of particular format.

The format required for SheetCAM TNG is a standard Drawing Exchange Format, or *.DXF. This format is a relatively universal format amongst most CAM software that represents the part by line vectors and splines. SheetCAM uses these lines to generate tool paths for forming the parts as the machine removes (or adds) material along these paths. Each movement along every path and every action in between is represented by a line of code. This file format can be a standard text file, such as *.TXT or *.TAP. However, this code must be properly interpreted to effectively machine a part.

NC - Mach3

Once the various lines of code are generated for a part the text file is then imported into the numerical control software, or NC software. This software translates the G-code into movement of the machine axis and tooling. For this project the NC software of choice is the multi-axis capable Mach3 NC control software by Artsoft Software Inc. (Mach3 NC Software, 2013).. This software communicates the G-code data to the stepper motor drives and actuates the machine axis and spindle according to the program.

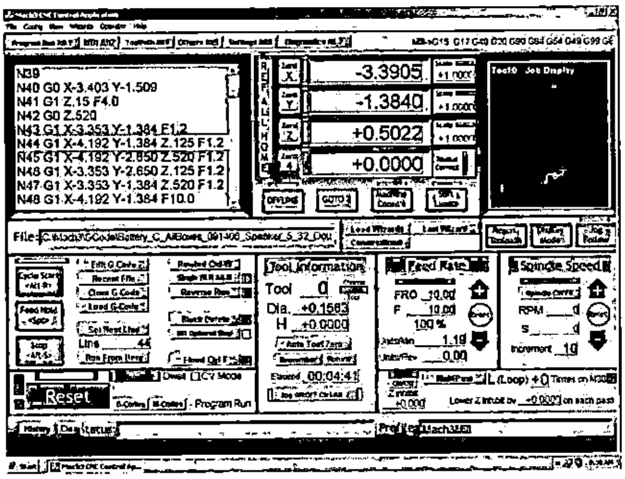


Figure 15: The Mach3 home screen as various feedback displays and controls for the CNC router. Artsoft.

The user interface of the Mach3 displays all required data for the machining process such as the current machine location and status, next lines of code and input buttons for basic program controls (Stop, Hold, Cycle Start, etc.). There are also override features such as spindle speed and feed rate adjustment dials for making adjustments while the program is in progress and the machine is cutting material.

The Mach3 software, while relatively low cost, is a very effective piece of software for basic machining capabilities. The graphic user interface for this project has been specifically designed for use with the intended machine; a CNC router with water-cooled spindle. The large and simplified interface has been optimized for use with the machine's ELO Entuitive touchscreen monitor control panel.

While the CAD and CAM software is located on a high-powered laptop for its processing capabilities, the NC software Mach3 must be installed on the machine's own control PC. This PC does not require the same high specifications of that of the CAD/CAM PC. This is due to the lower baud-rate requirements (45MHz) of the machine's control PC and its single purpose nature. In other words, the numerical control of the four axis machine, while not multitasking, does not require a multithreaded CPU or high powered graphics processor.

Hardware Review

CNC Router/Mill

As a platform for simulating real-world machinability a small CNC router was selected as a scaled down emulator for a full scale CNC machining center one might find in a manufacturing facility. This machine will serve to develop a physical prototype and test the manufacturability of the design, backed by data collected from reality.

The router operates on a similar principle as its full sized counter parts. It consists of three axes; the X, Y and Z. This is a fixed table design with the spindle head mounted to a moving gantry. Each axis is actuated by a 381oz/in high resolution stepper motor. The stepper motors are driven by a four axis stepper motor driver by Gecko called the G540. This driver is connected to each motor by a serial DB9 cable and also to the control PC with Mach3 by a parallel DB25 cable (G540, 2013).

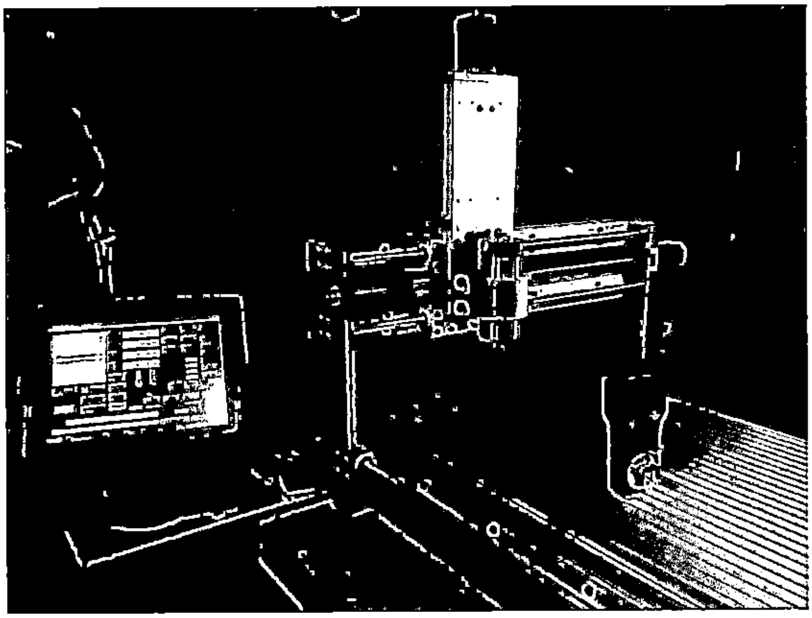


Figure 16: CNC router build in progress; tuning the motors. Curt Adkins.

CNC Router Technical Specifications:

- Work Area: 26"(X) x 41" (Y) x 6"(Z)
- Spindle: 1.5kW Water-cooled, 8000-24000 RPM, 220VAC, ER11 collet
- Motors: Nema 23, 380 oz./in.
- Driver: Gecko G540 with 48VDC/12.5A power supply

Router/Mill Tooling

Cutting aluminum at high spindle speeds (8000 - 2400 RPM) requires special tooling, beyond what a normal low speed mill uses (400 – 1000 RPM). To match the higher spindle speeds for proper chip load, the machine must operate at higher feed rates, shallower depth of cut and fewer flutes. The recommended tooling, the types of tooling used in this study are both helical up-cut carbide mills. The first of the two for rough cutting is the Onsrud O-Flute router bit, designed specifically for aluminum. The second for finishing cuts and detailing is the Destiny Tool Viper 2-Flute router bit.

Figure 17: Left to right, an Amana 2-fluted up cut router bit, and an Onsrud O-flute up cut router bit. Compiled from Amana and Onsrud.

Press brake

For bending and forming various sheet metal parts on the prototypes a heavily modified Grizzly 30" press brake is used. This simple manual brake allows more complicated parts to be formed by means of an actuated lower die and removable upper fingers. The press brake shown below has been modified with an adjustable back-stop for repeatability, as well as a reinforced lower die for added sheet metal thickness capacity.

CHAPTER THREE: METHODOLOGY

Method of Design

The M3A2 Beta Model

Taking into consideration the aforementioned small form factor cases currently offered as part of a complete system, a new design has been developed addressing some of the design issues and emulates and/or improves upon the good features of the existing products. In addition, this product is meant for retail individually rather than part of a complete system.

The Beta model, meaning the first series of prototypes made for broad testing, is a culmination of research and development, first-hand experience and market input. But essentially the idea started as a basic need for a smaller, higher performance, high quality all aluminum desktop computer case to fit the needs of performance-oriented users and their high-end computer systems. No such product exists that meets all the user requirements and that is available for retail as a sold-alone product.

Designing Around Components

The physical design of the case frame itself was not developed first. In fact, the component layout was first developed to determine how to most efficiently arrange and orient standard high-end computer hardware as to make the best use of space in three dimensions. While the general shape of the case is in consideration at this point, the aesthetics and overall form were ignored to focus on efficiency of space usage.

To start, a short list of the bare essential components required for a functional computer system is drawn. These components dictate the absolute minimum component requirements for any computer system, regardless of the intended purpose of the PC.

Also, given the intended application of demanding graphical processing, an additional component bill of material was developed to determine what must be included for a performance-oriented graphics processing computer. These requirements exceed that of a basic PC and bring with them certain design challenges to overcome, such as air flow, heat dissipation and clearance for larger power supply and GPU.

1. Motherboard
2. CPU with Heat Sink and Fan (HSF)
3. Storage Device
4. Power Supply
5. GPU

With the list of required components, a three dimensional assembly model was created to view and measure how the parts fit together and where there may be voids that may be utilized. This is a trial and error process that required many variations of the assembly to optimize the volume required of each component and minimize unused space.

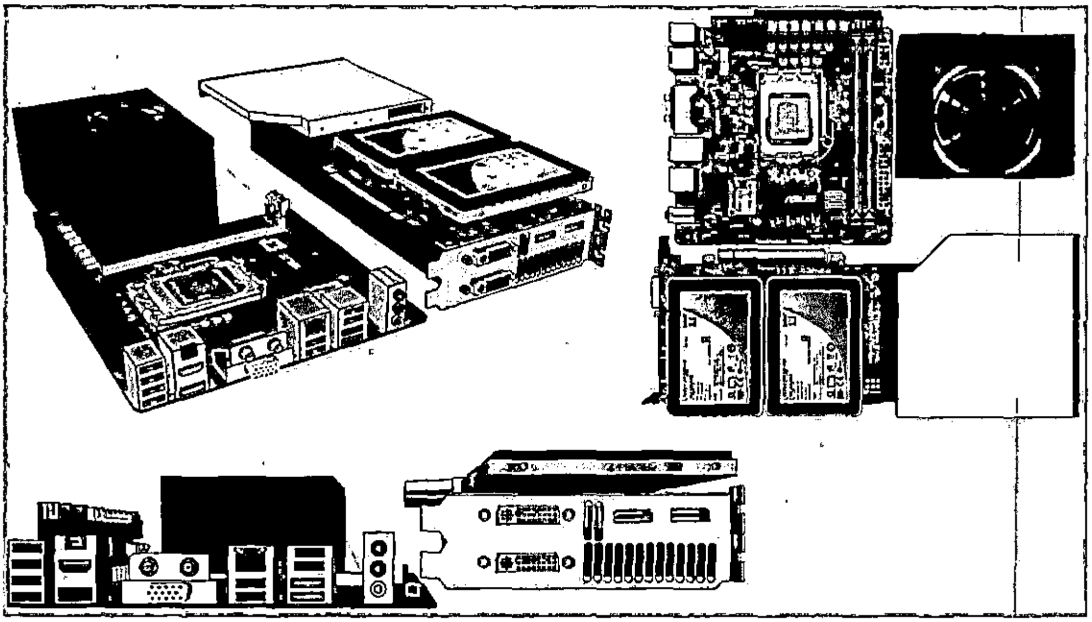


Figure 18: Various views of the M3A2 component assembly; earlier revision. Curt Adkins.

As you can see in Figure 19, an early component assembly model for M3A2 Beta, all components are placed close together and in such a way to minimize unused space. This ultimately keeps the volume and overall size of the case down. Shown above are two 2.5" SSDs, one slim optical drive, one SFX 450W power supply, one Asus mini ITX motherboard and one NVidia GTX 580 graphics card. These components are typical for what a gamer or enthusiast would use.

However, in regards to the use of an optical drive, with more software being installed from online downloads, optical drives have become less necessary. None the less, one was considered in the design to be able to accommodate users who wish to retain this component. Omitting the optical gives the user the option to replace with another 2.5" SSD/HDD.

Material Selection

The X51, Tiki and Bolt are all made from steel. However, the M3A2 is superior to these three by its use of an aluminum construction. As is seen in Table 3, aluminum is much lighter than steel and is roughly one-third the density of steel at 2700 kg/m^2 compared to steel's 7800 kg/m^2 (Avallone, 2007). The light weight of aluminum construction makes the case easier to carry than a comparable case made from steel.

Also of key importance is the thermal conductivity of the material the case is constructed off. Aluminum is generally five times better at conducting heat than steel. This allows the case to release radiation heat absorbed into the side panels more readily than an equivalent case design of steel. This assists in keeping internal temperatures low by offering an additional means of dissipating the heat from inside the case to the external environment (ambient temperature).

Table 3: Materials comparison of various characteristics. Lincoln Electric.

Physical Properties (1)

	Aluminum	Steel	Stainless
Density (kg/m^3)	2700	7600	7880
Modulus of elasticity (10^3 MPa)	69	200	200
Melting point (°C)	660	1350	1426
Specific heat (J/kg.°C)	940	496	490
Electrical conductivity (% IACS)	62	10	2
Thermal conductivity (W/m.°C)	222	46	21
Coefficient of linear expansion (10^{-6} °C^{-1})	23.6	12.6	16.2

Also important to consider is the ability form and machine the material selected for the construction of the case. While both steel and aluminum are known to be readily machinable, aluminum has the advantage in machinability (Metal Processing Properties, 2013). As seen in Table 4, aluminum has a slightly lower Brinell hardness rating of 95 compared to that of steel, which is 126. This equates to a slightly softer material that is more readily machined. Depth of cut, surface speeds and ultimately chip load of the tooling can be greater than when machining a comparable part from steel, which yields longer tool life and shorter cycle times.

Table 4: Side by side comparison of 6061 aluminum and 1018 mild steel. Engineers Handbook.

ALLOY PROPERTIES MECHANICAL		WROUGHT Al 6061-T6	MILD STEEL 1018
Tensile Strength	psi X 10^3	45	63.8
	MPA	310	440
Yield Strength	psi X 10^3	35	53.7
	MPA	241	370
Elongation	(% in 2")	12	15 - 18
Young's Modulus	psi X 10^6	10.3	NA
	MPA X 10^3	71	NA
Shear Strength (MPA)	psi X 10^3	30	NA
	MPA	207	NA
Hardness	Brinell	95	120

The downside to using aluminum comes at its significant cost over other materials, such as steel. As Table 5 shows, aluminum is five times more expensive per weight than steel. However, its physical and mechanical properties lend itself well to be selected for such a computer case. Also, being less dense, the cost is negated some by being able to achieve comparable physical and mechanical properties of a steel construction with less material by weight.

Table 5: In this table the cost of aluminum is clearly greater, by 5 times by weight, than steel. Metal Market Place.

Comparison of Common Structural Shapes and Grades of Three Metals			
Property	**Aluminum 6061-T6**	**Carbon Steel A36**	**Stainless Steel 304, Cold-finished**
Extrudability	Very Good	Not Practical	Very Limited
Weldability	Fair, But Reduces Strength	Good, No Strength Reduction	Good
Cost by Weight	$1.50 / lb.	$0.30 / lb.	$1.40 / lb.
Cost by Volume	$0.14 / in.^{3}	$0.084 / in.^{3}	$0.42 / in.^{3}
Cost Index	2.5	1.0	4.7
Corrosion Resistance	Good	Fair	Very Good
Tensile Yield Strength	35 KSI	36 to 50 KSI	45 KSI
Stiffness	10,000 KSI	29,000 KSI	27,000 KSI
Elongation	8 to 10%	20%	30%
Density	0.098 lb. / in.^{3}	0.283 lb. / in.^{3}	0.284 lb. / in.^{3}
Strength-to-Weight Ratio	2.8	1.0 to 1.41	.2

Based on the findings above, the main material that the case is to be constructed of is aluminum. More specifically, the alloys 6061 and 6063 have been chosen for their machinability characteristics and strength. The 6061 alloy is readily available in many profiles to cut to length and machine into the part. The 6063 has been selected based on the process by which these particular profiles are formed.

Table 6: Aluminum alloys are compared to determine which is best fit to machining. Metal Market Place.

Number and Characteristics	Major Alloying Elements (percent)	Temper and Thickness		Tensile Strength - ksi Ultimate Min	Tensile Strength - ksi Ultimate Max	Tensile Strength - ksi Yield Min	Tensile Strength - ksi Yield Max	Elongation Percent
6005								
Mechanical properties similar to 6061. Used in structural applications. (Preferred over 6061 for extrudability)	Si 0.6 - 0.9 Mg 0.40-0.6	-T1	Up thru 0.500	25.0	–	15.0	–	16.0
		-T5	Up thru 0.124	38.0	–	35.0	–	8.0
			0.125-1.000	38.0	–	35.0	–	10.0
6060								
Has better extrudability than 6063. The minimum mechanical properties (with the exception of minimum welded properties), response to finishing processes, and corrosion resistance are similar to 6063.	Si 0.30-0.6 Mg 0.35-0.6 Fe 0.10-0.30	-T1	Up thru 0.125	22.0	–	16.0	–	8 0
			Up thru 1.000	22.0	30.0	16.0	25 0	8.0
		-T61	Up thru 0.124	30.0	–	25.0	–	8.0
			0.125 - 1.000	30.0	–	25.0	–	10.0
6061								
Most versatile of heat-treatable group. Will take considerable forming in T4. Good corrosion resistance. Used in transportation and structural applications	Mg 0.8-1.2 Si 0.40-0.8 Cu 0.15-0.40 Cr 0.04-0.35	-0	All	–	22.0	–	16.0	16.0
		-T1	Up thru 0.625	26.0	–	14.0	–	16.0
		-T4, T4510 and T4511	All	26.0	–	16.0	–	16.0
		-T42	All	26.0	–	12.0	–	16.0
		-T51	Up thru 0.625	35.0	–	30.0	–	8.0
		-T6, T62, T6510 and T6511	Up thru 0.249	38.0	–	35.0	–	8.0
			0.250 and Over	38.0	–	35.0	–	10.0
6063								
The most popular extrusion alloy. Takes a good surface finish, is corrosion-resistant, and can be heat treated for strength.	Mg 0.45-0.9 Si 0.20-0.6	-0	All	–	19 0	–	–	18.0
		-T1	Up thru 0.500	17.0	–	9.0	–	12.0
			0.501 - 1.000	16.0	–	8.0	–	12.0
		-T4 and T42	Up thru 0.500	19.0	–	10.0	–	14.0
			0.501 - 1.000	18.0	–	9.0	–	14.0
		-T5	Up thru 0.500	22.0	–	16.0	–	8.0
			0.501 - 1.000	21.0	–	15 0	–	8.0
		-T52	Up thru 1.000	22.0	30 0	16.0	25.0	8.0
		-T6 and T62	Up thru 0.124	30.0	–	25.0	–	8.0
			0.125 - 1.000	30.0	–	25.0	–	10.0
6463								
Designed to accept a bright dip finish through anodizing or polishing. Decorative trim applications; machine and heat-treatable. (High purity form of 6063)	Mg 0.45-0.9 Si 0.20-0.6	-T1	Up thru 0.500	17.0	–	9.0	–	12.0
		-T5	Up thru 0.500	22.0	–	16.0	–	8.0
		-T6 and T62	Up thru 0.124	30.0	–	25.0	–	8.0
			0.124 - 0.500	30.0	–	25.0	–	10.0

The side panels of the case design (front, back, left and right) are extruded 6063 aluminum profiles while the top and bottom covers are 6061 aluminum plate. In addition to these parts, there are internal brackets that must be bent and formed. The 6000 series alloys are not the ideal alloy for this process. Therefore, a softer 5052H32 has been selected for its form ability and still moderate machinability qualities.

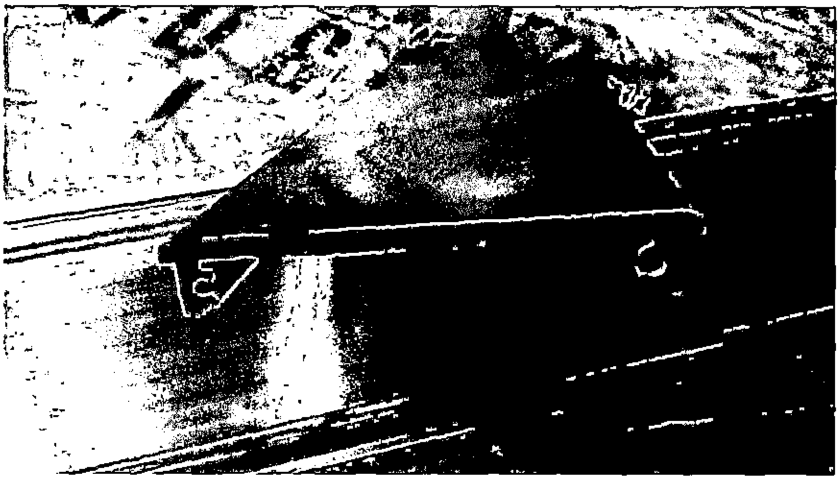


Figure 19: The extruded aluminum profiles used for the side panels is 6063 allow. Curt Adkins.

These aluminum profiles are designed to offer a rigid structure for the case and eliminate much of the machining and bending processes required of basic case manufacturing. As noted in Table 6, 6063 is best suited and the most popular choice for extrusions.

Design for Optimal Thermal Performance

As one would suspect, high performance computer components generate large amounts of heat. The chip sets involved in these types of computers are built to withstand the heat to an extent and are pushed to their limits by their creators by increasing the voltages that stress the circuitry to its threshold. The heat generated must be controlled and done so with heat sinks and fans, or HSF. The HSF is generally aluminum, copper or a combination of both due to their metallurgic abilities to draw and dissipate heat easily.

On full sized computers where empty space is generally plentiful, it is simple to install a large HSF or water cooling system to decrease the temperature delta between idle and load conditions. However, the nature of small form factor dictates that the case design must be optimized for best possible thermal performance (Rosenfeld, 2009). Good air flow through the case and giving each component access to cooler external air is critical and allows the case design to utilize smaller components intended for compact enclosures.

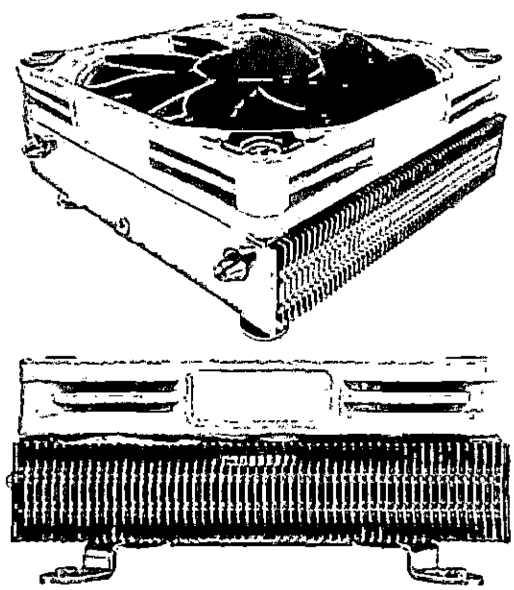
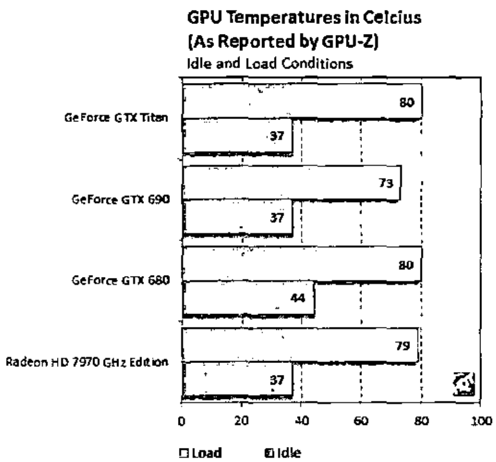


Figure 20: The NH-L9, by Noctua, is a 37mm tall CPU cooler design specifically for small form factor and low profile applications. Noctua Inc.

The method of design for optical thermal performance applies to the GPU as well. The GPU is more often the hottest component in a computer system when in use, gaming or otherwise active. The issue of heat is combated by most manufacturers in a similar manor, by implementing large heat sinks and blower fans. Using the same GPUs from Figure 8; Graph 1 shows the thermal behaviors of each GPU at idle and under load conditions. With an average load temperature of 78 degrees Celsius, this is clearly a source of major heat inside the case (Intel, Small Form Factor Chassis Design, 2006).



Graph 1: A comparison of GPU temperatures at both idle and load conditions. Tom's Hardware.

In Figure 22, you can see the exploded view of a high end Asus graphics card. With this style of cooler, also known as non-reference, the outer most part, the fans and shroud blow across the copper heat pipes with aluminum fins. The heat pipes, being directly attached to the chip, are loaded with heat drawn from the processor and dissipated about the fins.

This is the same concept for any heat sink fan. Temperature delta is critical to this concept, meaning the greater the delta between the intake air temperature and the temperature loaded on the heat sink fan, the more effective. In other words, blowing cool air across the HSF is more effective at cooling the GPU than blowing warm air.

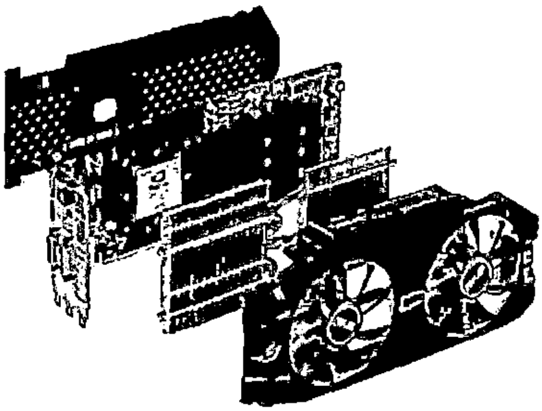


Figure 21: A typical non-reference style GPU cooler exploded view. Asus Inc.

This means it is best to draw air from outside the case, which will undoubtedly be cooler than the air within. Therefore, the M3A2 has the GPU positioned such that the fans can intake air directly from outside the case through a large vented area on the bottom panel, see Figure 23. Unlike the X51 there are no components in the way of the fan intake, which is critical for the hotter high performance cards.

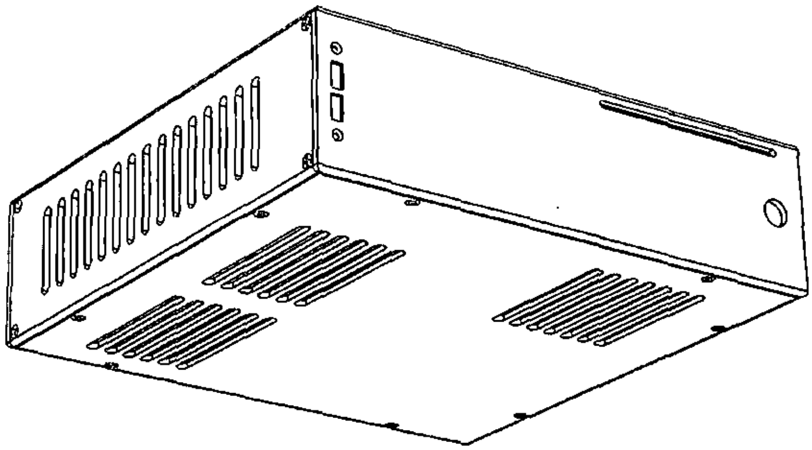


Figure 22: Bottom view of the M3A2 showing the long slotted GPU intake on the left. Curt Adkins.

Having direct air flow access also applies to the CPU and its heat sink and fan. With the amount of heat generated in such a small enclosed space, having fresh external air forced in creates a positive pressure inside the case forcing cooler air in and warmer air is displaced out. The M3A2 continues this concept on the top of the case with a large slotted intake for the CPU and a secondary position for another 120mm 12VDC fan for forcing cool air in (Intel, Small Form Factor Chassis Design, 2006).

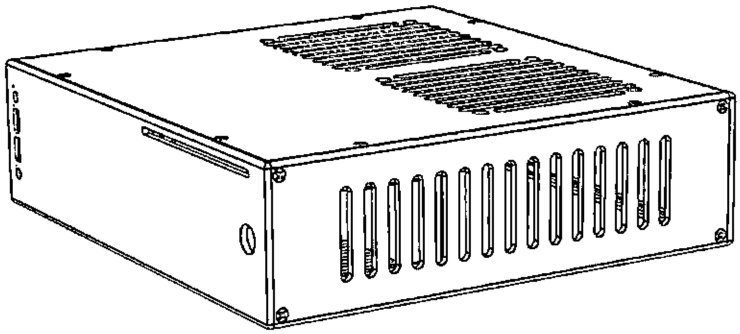


Figure 24: The M3A2 side panels allow warm air to be forced out. The right side (shown) also acts as the exhaust for the SFX power supply. Curt Adkins.

Graphics Card

The most common performance oriented graphics cards in Figure 8 are no longer than 280mm or 11.0". There is a model called the HD6990 that is 317mm or 12.5" in length, but it has been phased out by the shorter and less power demanding GPUs in Figure 8. With this in mind the M3A2 is designed to accommodate them with some margin for future cards and cable management. The inside dimension of the case and total graphics card length clearance is 300mm. This gives in additional 20mm clearance for even the longest cards. This length is partially dictated by the width of the motherboard (170mm) and the width of the SFX power supply (125mm) which is a total of 295mm when placed side by side. Based on that stack-up of the motherboard and power supply, the minimum measurement for the case front to back internally is 300mm, to include 5mm clearance for variation and fitment.

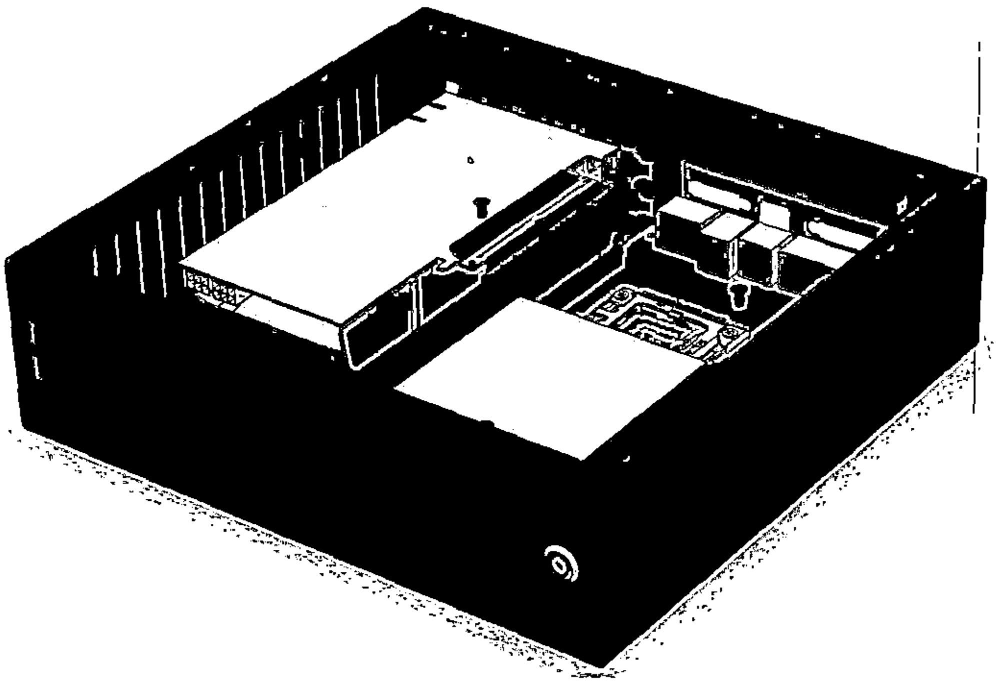


Figure 25: Highlighted in green are the GPU and the PCIEx16 rise and spacer. Plenty of room GPUs up to 300mm. Curt Adkins.

The intake of the GPU is facing downward. This allows the GPU to intake cooler air from outside the case directly through the large slotted vents on the bottom panel. See Figure 23.

Power Supply

One area where other cases fell short was the power supply capability. The X51 uses an external power brick that provides only 240 watts of power for the complete system. As shown in Table 1, that is insufficient for the majority of performance oriented systems. Also, the Bolt, while having 500 watts, uses a form factor that is noisy, hot and proprietary. Therefore, M3A2 is designed to use a common form factor power supply with plenty of power; the SFX. While compact, an SFX power supply is available up to 450 watts and is small enough to fit effectively inside the M3A2 and Tiki.

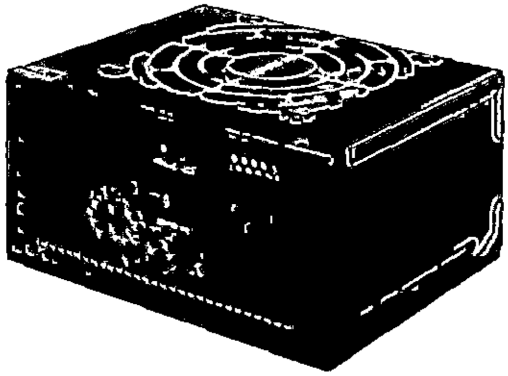


Figure 26:The SFX is compact yet powerful power supply. Courtesy of be Quiet!

The location of the power supply is towards the front of the case on the right hand side. This area is selected to make the best use of space. As seen in Figure 20, with the graphics card on a 90 degree riser card, there is a rectangular void just in front of the motherboard that lends itself to a power supply the size of an SFX.

Since high powered graphic cards draw a lot of power and put load on the power supply, heat can become an issue during graphic-intensive applications. To keep the power supply cool and quiet and prevent the unit from overheating, the power supply is oriented with its intake down directly in line with a large slotted vent on the bottom panel.

Power supplies, such as the SFX and ATX, are designed to intake air from inside the case and exhaust out the back. They are conventionally mounted to the rear panel of the case, making this possible. This also gives the user access to the power plug on the back of the power supply. Since the SFX power supply in the M3A2 is relocated toward the front, the issue of exhaust and the power plug must be addressed.

To allow the user to plug and unplug the computer without having to open the case, the M3A2 is equipped with a power cord extension. One end plugs into the power supply with a 90 degree plug and the other end is an IEC320C14 panel-mounted outlet that is fixed to the rear panel by two M3 machine screws. This emulates the power plug of a traditional layout while still allowing the user to plug and unplug the machine without removing the top cover.

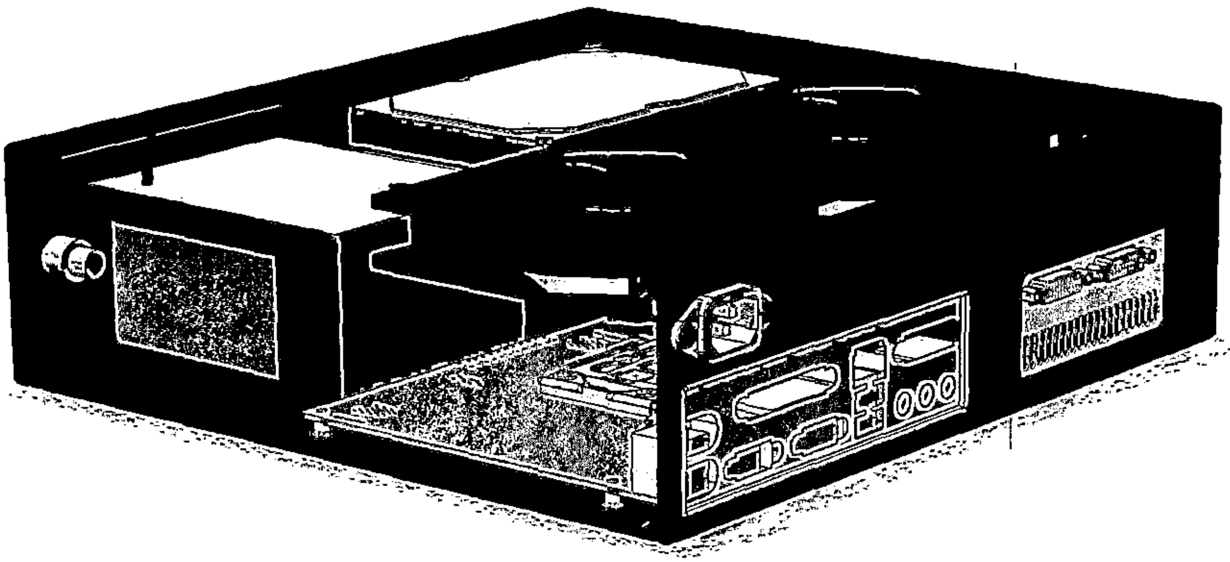


Figure 27: Highlighted in green you can see the power supply and power plug. Curt Adkins.

Conventionally, a power supply mounted to the rear panel of a case exhausts its hot air out the back of the case. In the above configuration, without a shroud or means of ducting the hot exhaust out of the case, the hot air would recirculate through the case, raising the temperature of all the components within. To remedy this problem the bracket which the power supply mounts to also acts as a duct. This duct, seen in Figure 28, contains the exhausted air and redirects to the side vents of the case, forcing it out of the case and away from other fan intake points to prevent recirculation.

Drive Mounts

With the intention of meeting and/or exceeding the technical specifications of the Tiki and Bolt, the goal with the drive mounts was to increase capacity and flexibility. The minimum amount of drives required to equal the Tiki and Bolt are two 2.5" drives and one 3.5", plus one slim optical drive. Fitting these components into the smaller M3A2 required efficient use of space and good part design. Based on the configuration in Figure 20, the best places to locate the drives away from the CPU cooler clearance space above the ITX motherboard is above the power supply and behind the GPU. Fitting the drives into these locations kept the area above the motherboard clear for the CPU cooler.

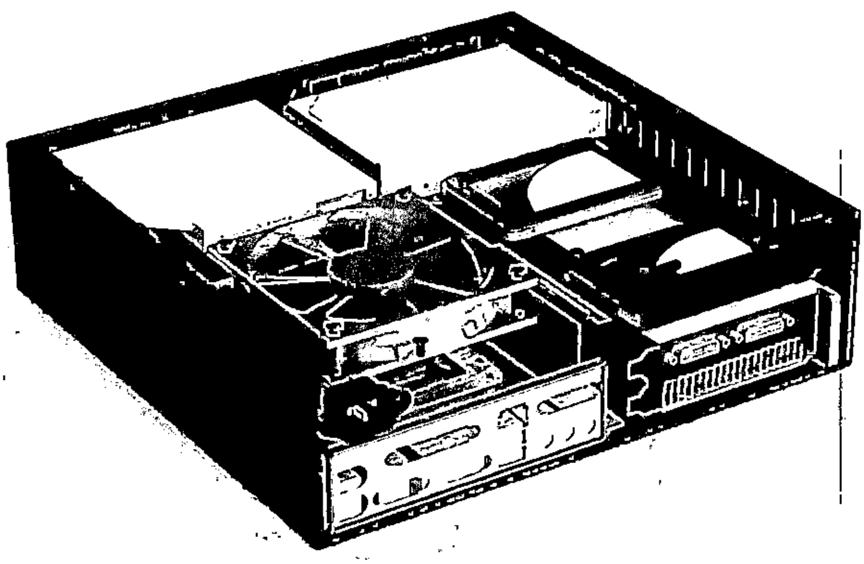


Figure 28: A look into M3A2 with the rear and top panels removed. Curt Adkins.

In Figure 29 you can clearly see the location of the two 2.5" drives on the right above the GPU, the 3.5" drive next to them towards the front of the case, and the optical drive above the power supply off to the left. Notice there are no component interfering with the space above the motherboard.

Take note of the locations of the SSD behind the GPU. There is a space between the two drives and an opening in the drive bracket exposing the back of the GPU. This is due to a particular hot spot created by the GPU. Located on the back of the card, just behind the main chip, it can get very hot. In Figure 30 and 31, thermal imaging from a FLIR camera reveal how hot this location can potentially get.

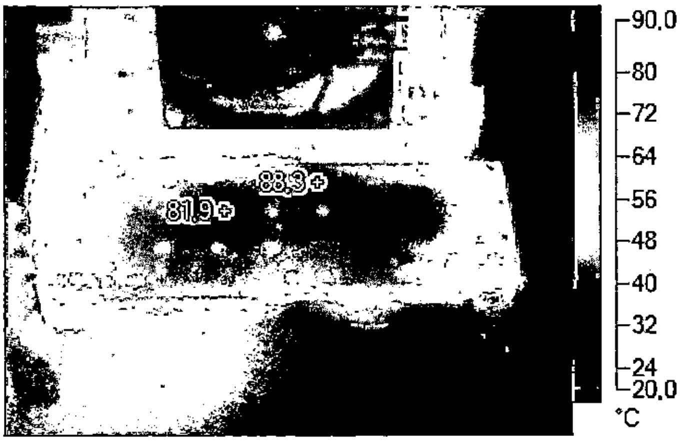


Figure 29: Thermal imaging of a GTX 680 during load conditions reveals dangerously high temperatures. Necere.

Figure 30: Thermal imaging of an HD7970 under load shows similar hot spots as the GTX 680. Necere.

It would be unsafe to locate the SSDs/HDDs directly over this area so they have been shifted away from it. The cutout in the drive bracket over the spot allows for air flow, giving the 120mm fan mounted to the top panel the ability to blow cooler external air directly on to the back of the card.

Community Feedback

A key part of the design methodology is active community feedback through the design process. Continually polling the potential end user allows the design to take on form and function potential customers will deem worthy of purchase. This community feedback is done online on a daily basis by means of an active forum thread on a popular website: hardforum.com. Also known as "[H]ard|Forum", this site focuses on professional and enthusiast computer related topics and is very active in the development and implementation of new and future technologies.

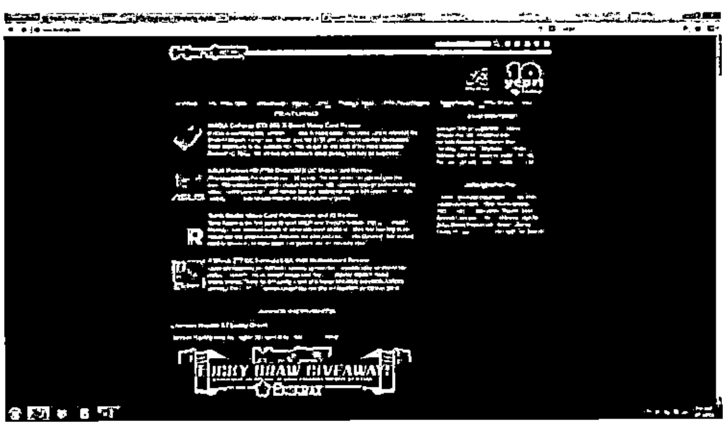


Figure 31: The Hard Forums are a wealth of collective knowledge and first-hand experience. HardForum.com.

Founded by Kyle Bennett in 1999, the website is a platform for hardware benchmarking and testing (HardForum, 2013). Over the years the site has diversified and grown to over 176,000 active members on the forums who average 2.3 posts per day. This equates to a large sample size that yield refreshed data daily. A wide range of science and technology is discussed across the forums, with the majority of topics related to PC hardware and technologies.

A thread for this specific design development exists on the forums and has ongoing communications with numerous members. The thread is kept up to date with the most recent design renderings and specifications as they develop. These include changes made to the design for functional and form purposes as well as to accommodate requests and suggestions maybe by the study group actively involved in the discussion. As of April 16th, 2013, since the start of the thread on March 13th, 2013, there have been over 25,000 views and nearly 500 responses from numerous members and guests of the forum.

Some of the incoming suggestions from polling the enthusiast community include recommendations for special applications, functional improvements, additional aesthetic design features and improved serviceability and access. These suggestions were taken into considering during the design process and the 3D models were revised accordingly.

CHAPTER FOUR: ANALYSIS AND CONCLUSION

Final Beta Design

The aforementioned methodology of design has led to the current M3A2 Beta model small form factor desktop case as it is seen in the following. The M3A2 Beta is smaller in size than the X51, Tiki and Bolt, yet has an increased hardware capacity and improved construction and styling over the other models.

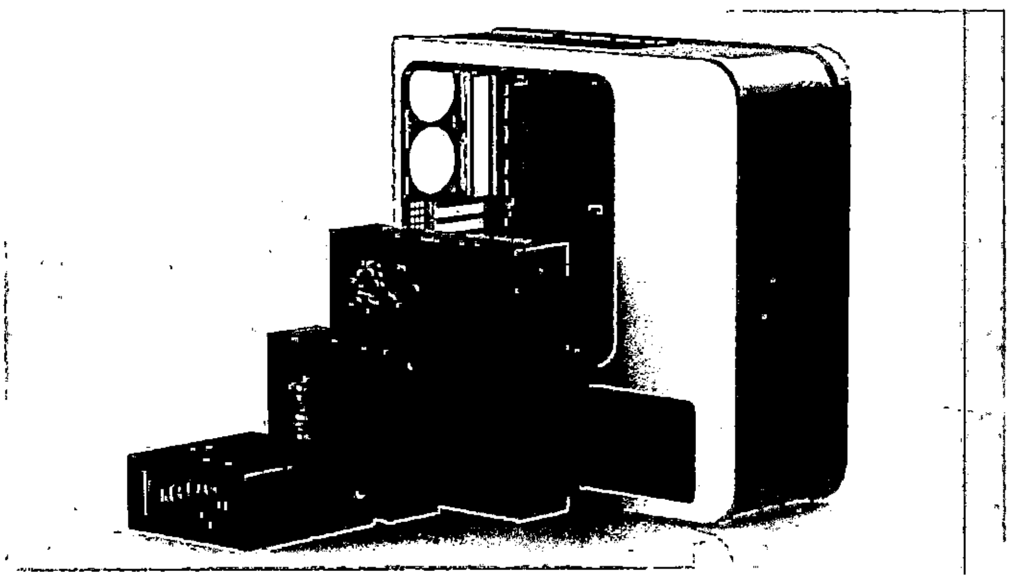


Figure 32: A size comparison from left to right, M3A2 Mini, M3A2 Mini (vertical), M3A2 Beta and a full ATX tower by Silverstone. Curt Adkins.

As is common with all the cases compared and contrasted in the Existing Product Comparison section, each case is designed to be set vertically on the desktop and does not function properly in the horizontal position. Since some users may opt to use the M3A2 in their home theaters, having the option to set the case horizontally and still maintain function without compromise was important.

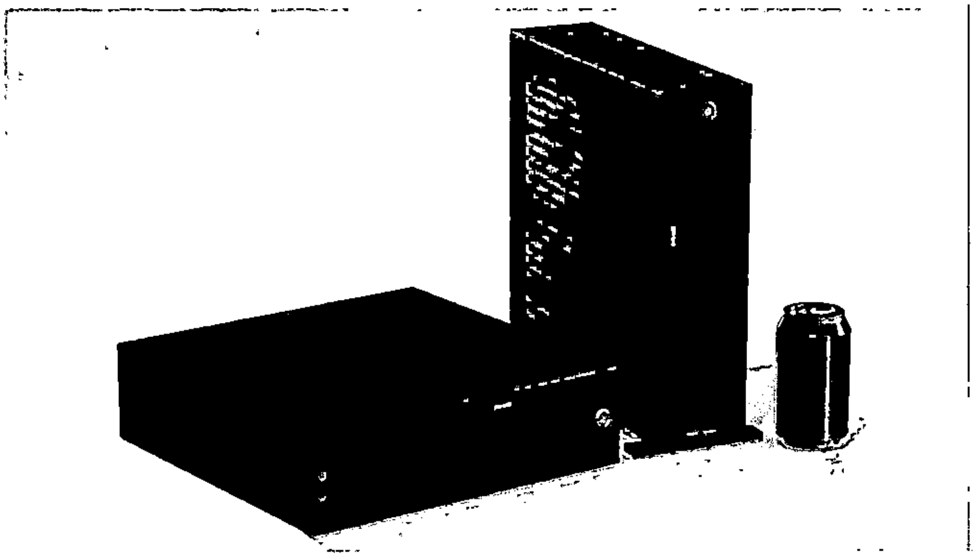


Figure 33: The M3A2 Beta can be used horizontally or vertically. The soda can is for size reference. Curt Adkins.

When the case is in the horizontal position, it rests on four removable rubber feet. These feet act as standoffs to allow proper air flow to the GPU and power supply intake vents on the underside of the case. They also act as vibration dampeners and to prevent unwanted marking or damage to the desk work surface.

Having the case in the vertical position requires additional lateral support to prevent the case from tipping over. With the power supply at the top of the case when in the vertical position, the M3A2 or any similar case is unbalanced and prone to toppling over. This is addressed by means of two aluminum removable feet that extend out from the case for added support. These also act as standoffs to allow sufficient airflow through the vent facing the desktop work surface.

Including both the four rubber feet and the vertical supports allows the customer to select and change how they implement the case. This opens the marketability up to a larger group by expanding the capabilities and features of the case to span multiple user applications and preferences. The added cost may be justified to expand the product appeal.

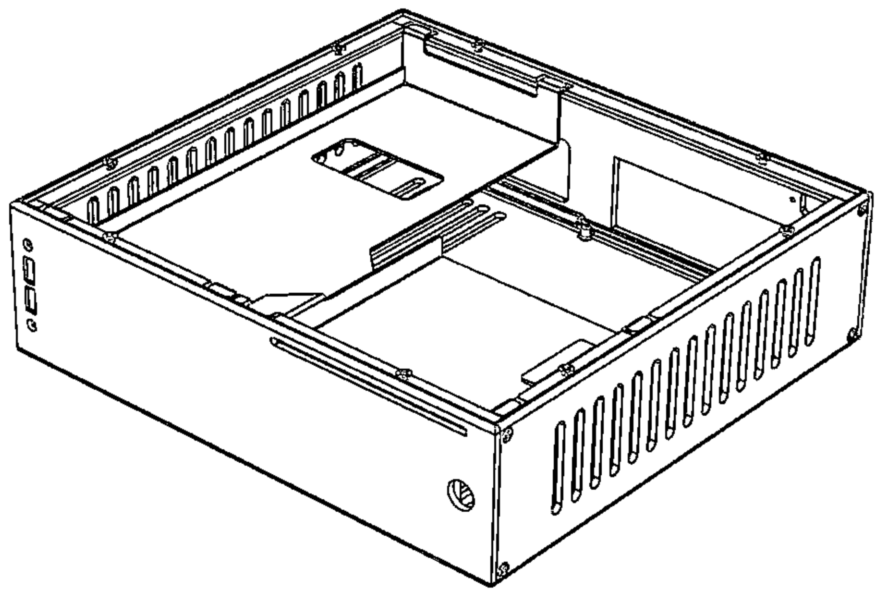


Figure 34: With the top cover removed the drive brackets are visible. Curt Adkins.

With the top cover removed in Figure 35, the drive brackets for the optical drive and the SSDs/HDDs are made evident. Accessing these components is as simple as removing just a few screws on each bracket and lifting the drives out of the system.

Also in the front panel configuration show in Figure 35, considered to be the base model M3A2, you can see the USB3.0 cutouts on the far left, a slotted access hole for the slim slot-load optical drive and a 16mm cutout for the vandal-resistant LED power switch. To better fit the needs of the customer, the front panel may be customized with additional or fewer features.

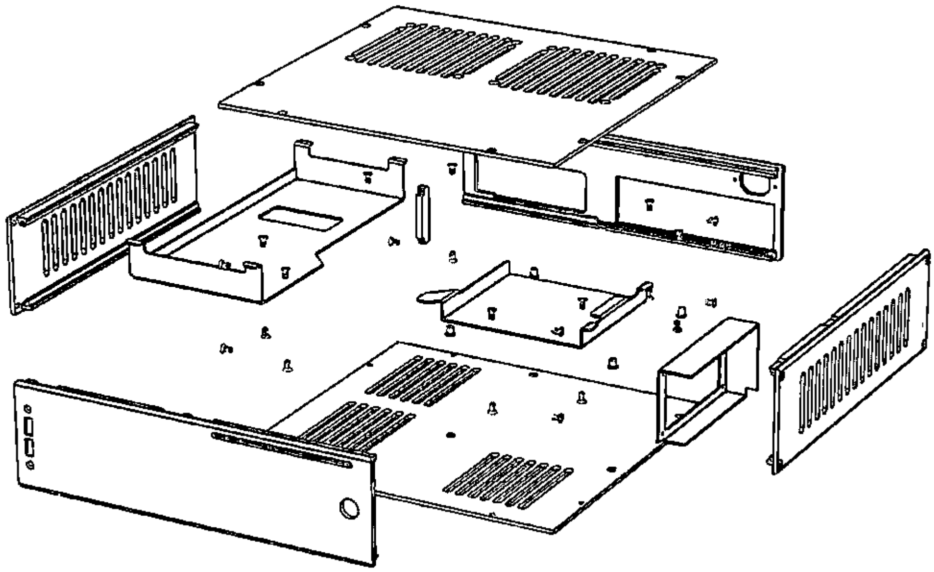


Figure 35: The M3A2 has a simple construction of extruded aluminum and formed parts for easy access. Curt Adkins.

The bolt together design of the case is an improvement over the current riveted designs available from most manufactures. This features allows the case to be shipped disassembled and assembled when the customer receives the unit, as seen in the exploded view of Figure 36. Building the case up piece by piece also allows the user to install the components on the bottom panel (also known as the motherboard tray) and build the case up around the system. This gives the user easier access to assembling a compact small form factor system and still have the ability to reach key access points for connecting hardware and routing cables.

Renderings and Model Views

The overall aesthetics of the case come directly out of the function-before-form philosophy. Meaning, the case was first designed to function effectively as a compact small form factor desktop case. The aesthetic appeal of the case was secondary in the design process. The following renderings show the overall design and appearance of the final beta case.

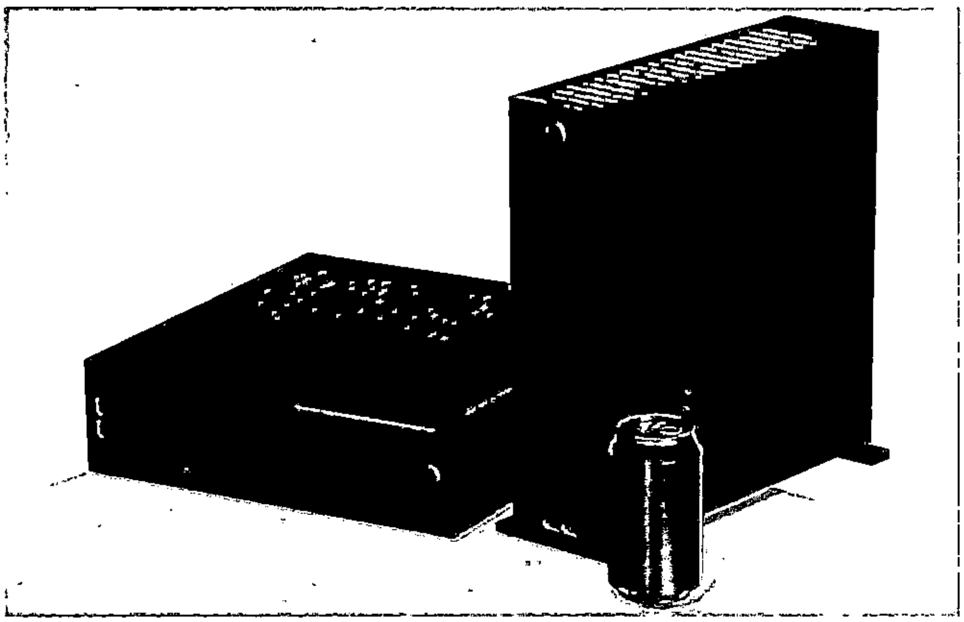


Figure 36: The M3A2 in horizontal and vertical positions. Curt Adkins.

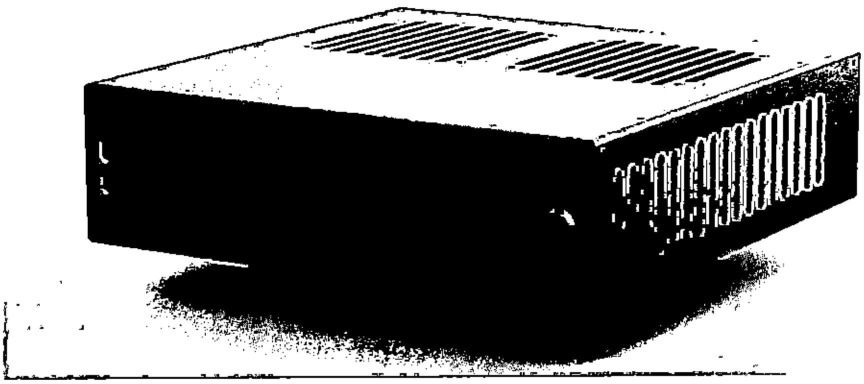


Figure 37: This view show the optional infrared receiver window, located just below the power button. Curt Adkins.

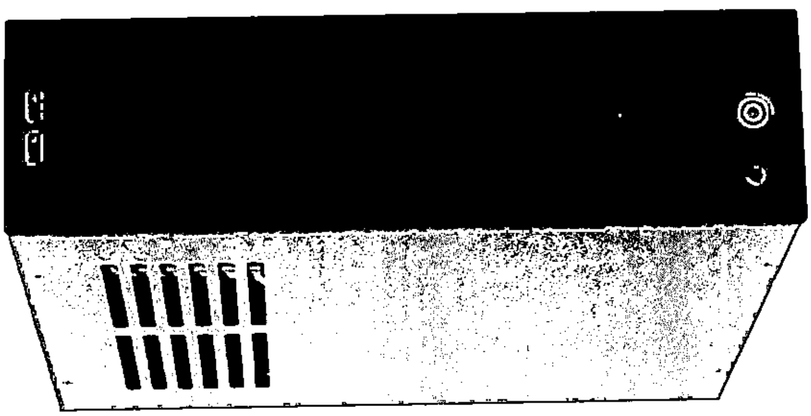


Figure 38: Viewed from below the GPU intake vents are visible. Curt Adkins.

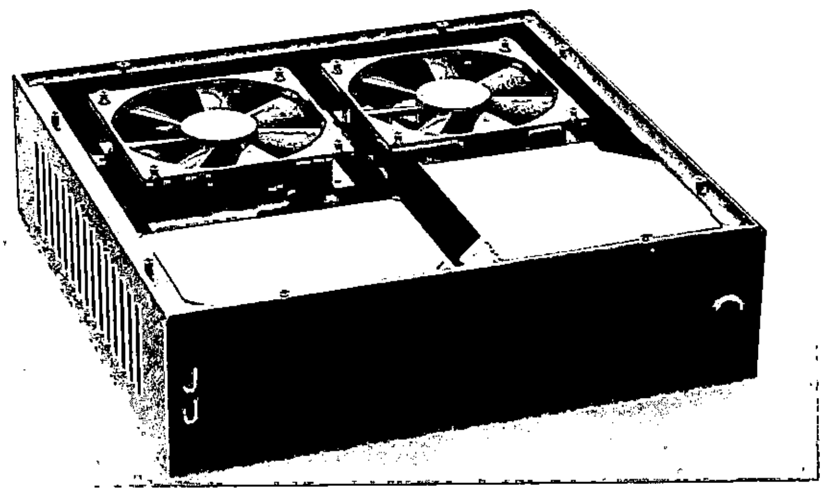


Figure 39: With the top cover off of the case the components are easy to access. Curt Adkins.

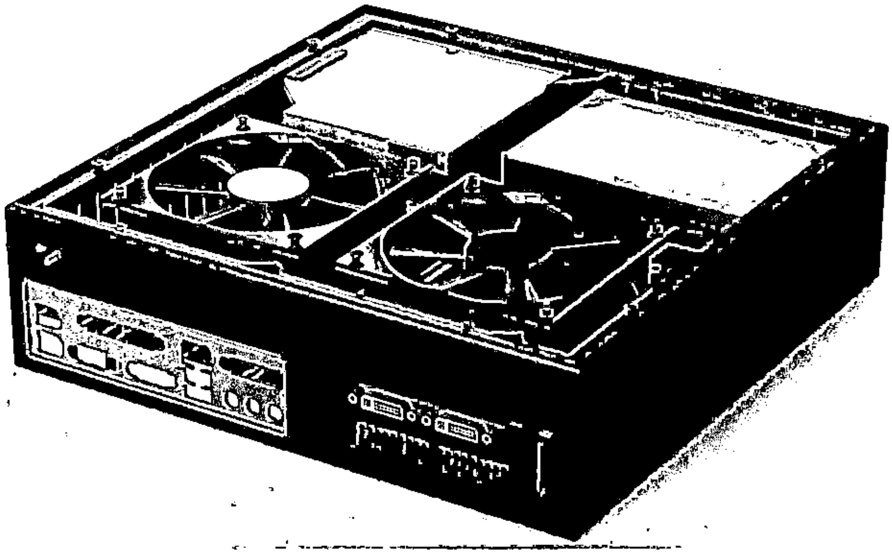


Figure 40: The rear view of the M3A2 reveals the motherboard I/O shield and GPU I/O orientation. Curt Adkins.

Fluid and Thermal Dynamic Studies

One of the objectives was to analyze the case design for air flow and thermal characteristics. These are key features to address in any electronics enclosure, especially those with components that generate significant amounts of heat. Appropriate air flow through the case is paramount to keep components cool within their individual acceptable ranges.

Using SolidWorks 2012 Flow Simulation, we first look at the air flow through the case as defined by the arrows in Figure 42. Main air flow through the case is generated by two 120mm fans on the top of the case. See Figure 40 and 41. Air blows in from the top and migrates through the case, including the CPU heat sink, HDD and SSDs and then exits the side panel vents. Notice there is very little recirculation except with the power supply unit (bottom right). This equates to a positive air pressure within the case, forcing cooler external air in and the warmer interior air out (Fleischer, 2008).

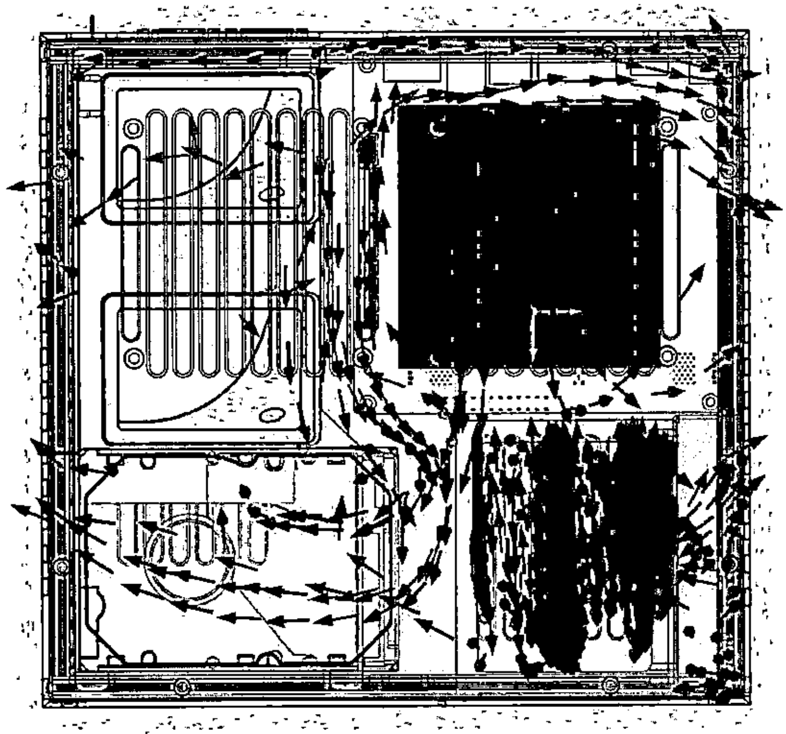


Figure 41: Top view of the flow simulation of the air within the M3A2 enclosure, based on pressure and velocity. Curt Adkins.

When we observe the thermal behavior of the case the hot zones with the highest power consuming components (the CPU and GPU) are easily recognizable in Figure 43. The yellow and red zones designate temperatures that exceed 40 degrees Celsius. In this simulation, the GPU (left) is generating 200 watts of heat and the CPU (right) is generating 95 watts. This equates to full operating load of the system.

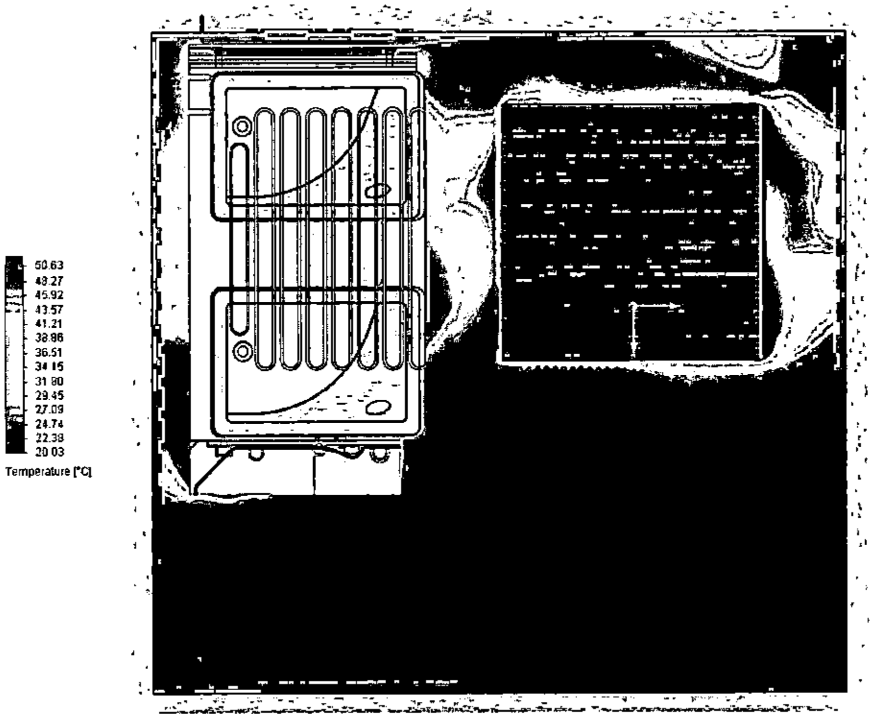


Figure 42: Top view of the thermal dissipation within the M3A2 enclosure. Curt Adkins.

Due to the air flow shown in Figure 42, the heat generated by the GPU and CPU remains centralized over their respective areas and dissipates quickly into the body of the case as well as out through the side vents. The SSDs and HDDs above the GPU remain well cooled by incoming airflow from the fan just above them and insulted from direct heat from the GPU by their aluminum (5052H32) mounting bracket, which acts as a heat shield.

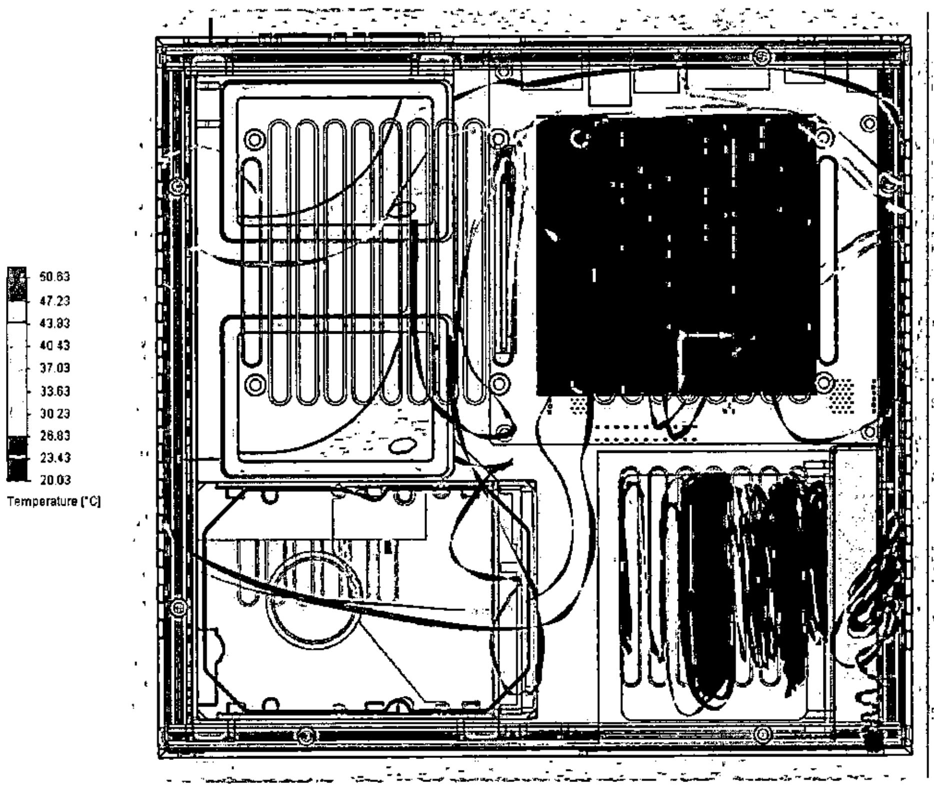


Figure 43: Top view of airflow and temperature simulation. Curt Adkins.

When we observe the simulation of the fluid temperature (air) as a vector of the air flow through the case it becomes apparent how the air draws the heat way from the major components and out of the case. In Figure 44, on the left and right the generally blue flow lines transition to yellows and reds as they pass over GPU and CPU and exit the side vents of the case. This represents not only effective design of the heat sinks of the components, allowing for the heat to be removed by the flowing air, but also effective enclosure design with properly placed and proportionality sized intake and exhaust vents for optimal air flow.

Overall, it is observed that air flow through the case is effectively unrestricted by any one components or internal bracket. Air is allowed for flow relatively freely across the component surfaces, drawing the heat off the heat sinks and into the flowing air. This flowing air is allotted sufficient pathways and openings to reach and exit the appropriated side vents as the design was intended.

As seen in Figure 43, the overall temperature inside the case stays within a reasonable range for safe operation of the components at load conditions. Though this value of operating temperatures varies depending on the model and manufacture, HDDs and SSDs generally run at 28 degree Celsius, air cooled GPUs run at 70 to 80 degrees Celsius at load, and CPUs run at 60 to 70 degrees Celsius at load (Intel, Small Form Factor Chassis Design, 2006). With maximum temperatures shown in Figure 43 to be no greater than 60 degrees Celsius, and each component well within its respective safe operating temperature, the design of the M3A2 is validated to have been designed with an effective means of air flow and thermal characteristics.

M3A2 Compared To Other Products

One of the objects was to design a case that meets or exceeds the features of other cases currently available on the market. We have seen the capabilities of the X51, Titan and Bolt, now in summation we see how the M3A2 compares in both form and function. Table 7 is a side-by-side comparison of the four slim mini ITX cases. They are being compared based on dimensions, volume, and compatibility, capacity for upgrades, additional hardware and price.

Table 7: A product comparison between current products and the M3A2.Curt Adkins.

	Width (mm)	Depth (mm)	Height (mm)	Volume (Liters)	Mother Board	CPU HSF Clearance (mm)	GPU Length (mm)	2.5" Drive Mounts	3.5" Drive Mounts	Optical	Power Supply	Price
sm3 M3A2	90	308	328	9.1	ITX	68	300	2	1	1	SFX 450W	$199+
ALIENWARE X51	95	318	343	10.4	Dell "ITX"	69	243	0	1	1	Ext. 240W	N/A
Falcon Northwest Tiki	102	356	356	12.9	ITX	79	272	2	1	1	SFX 450W	N/A
DIGITALSTORM Bolt	92	356	356	11.7	ITX	57	285	2	1	1	1U 500W	N/A

Dimensionally the M3A2 is thinner than all three cases by an average of 6.3mm. In fact, the M3A2 is smaller in every dimension by as much as 48mm. This equates to a very compact case, which lends itself well to transport and minimal desk space consumption. These differences in dimensions are made more obvious when considering the volume each case exists. The average volume of the X51, Tiki and Bolt is 11.7 liters. That value is 2.6 liters greater than the M3A2, which is only 9.1 liters.

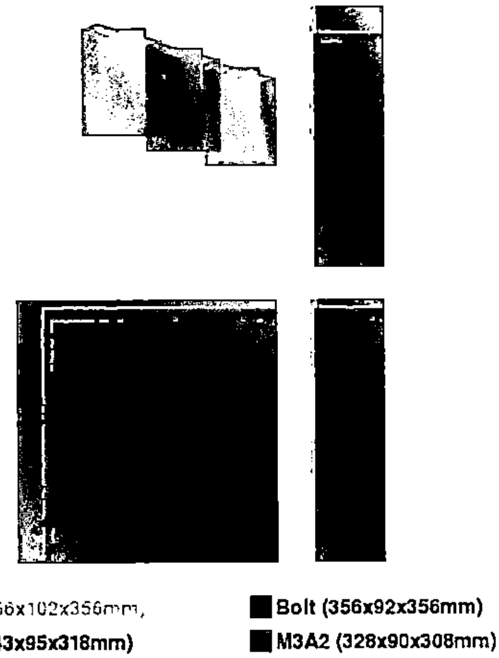


Figure 44: A 3D size comparison of the 4 cases. Sizeasy.com.

To really highlight how compact the M3A2 is, it is best to compare it to the case which is most similar to a proper one-to-one comparison. The Tiki and M3A2 are most alike in hardware compatibility and capacity. However, they are not alike in volume. The Tiki has a volume of 12.9 liters and the M3A2 measures 9.1 liters. The deficit between the two is 3.8 liters. That is nearly the space of two 2L (liter) bottles of soda. Figure 45 shows this size difference clearly.

Figure 45: A 3D size comparison between the Tiki and M3A2 cases.com Sizeasy.com.

When comparing the hardware compatibility, all three cases are very similar in regards to the amount of drive mounts. Except for the X51, all the cases allow for two 2.5" drives, one 3.5" drive and one optical drive. The differences are in the CPU cooler clearance and the GPU length. Being the widest cast, the Tiki allows for the greatest amount of space over the CPU at 79mm. This is required to fit the AIO water cooling inside. The M3A2 in its current revision only allows for a 68mm cooler. However, there are numerous coolers able to meet this requirement, including the stock heat sink and fans that come with all AMD and Intel chips.

Now, two of the most difficult components to design around in a small form factor case are the GPU and the power supply. The case with the greatest amount of GPU clearance is the M3A2 at 300mm. The GPU in the M3A2 is also provided direct access to side panel vents to keep it running cool. The X51, with a GPU clearance of only 243mm, is unable to hold most graphics cards and lacks proper ventilation. All other cards provide sufficient clearance for most graphics cards, but vary in ventilation capabilities. Both the Tiki and the

Bolt provide minimal vents for the GPU and are located at one spot on the card rather than along the entire length. Having ventilation along the entire length of the card is important for use with GPUs with dual fan coolers like the one in Figure 22. The vent locations on the Tiki and bolt are only conducive to single fan "reference" style coolers like the GTX Titan and HD7970 in Figure 8.

The power supply is the final functional design difference amongst the cases. Again the M3A2 and Tiki are very similar, both utilizing an SFX form factor power supply with plenty of power (450+ watts) to power any hardware capable of fitting in the cases. However, the X51 and the Bolt differ in this regard for different reasons. The X51 is severally under powered at only 240 watts. And the Bolt uses a 1U power supply, which are infamous for their heat and noise issues due load conditions. Because of these factors, the Tiki and M3A2 have the advantage in regards to power supply.

Manufacturing Processes

Generating the Machine Code

Assuming all part models and drawings are complete, the first step to making a part of the case is to generate the machine code for all machined parts. All aluminum parts on the case require machining of one form or another. Generating the machine code is done by means of the SheetCAM software.

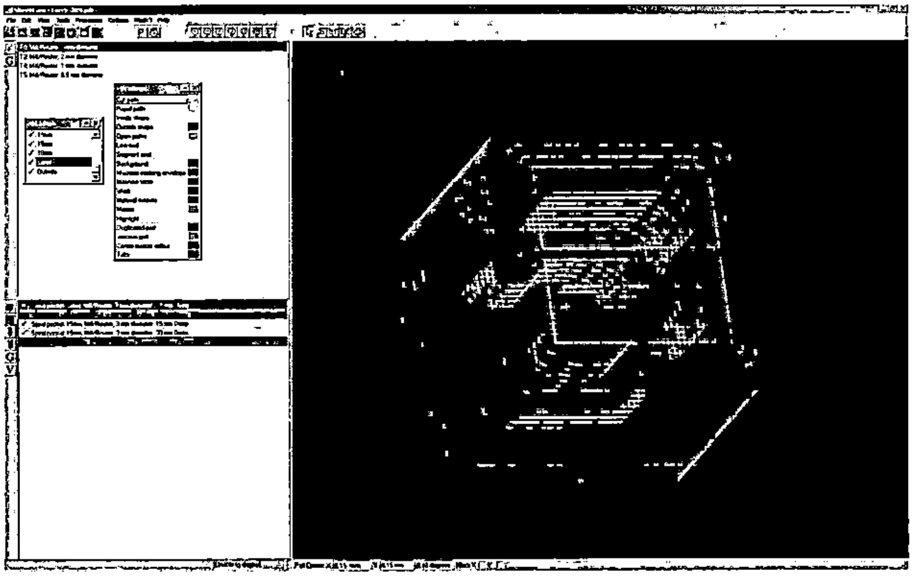


Figure 46: A 3D tool path can be generated from 2D drawings using SheetCAM TNG. Curt Adkins.

In SheetCAM, a two dimensional representation of the part and the subsequent tool paths are loaded in on appropriate drawing layers, as seen in Figure 42. Each operation (i.e. milling, drilling, engraving, etc.) must be designated to its own layer on the DXF file. From each layer and operation is created by selection the tool to be used, setting the parameters of feed, speed and depth of cut and running the post processor specific to the machine's G540 motor drivers to generate a TXT or TAP file.

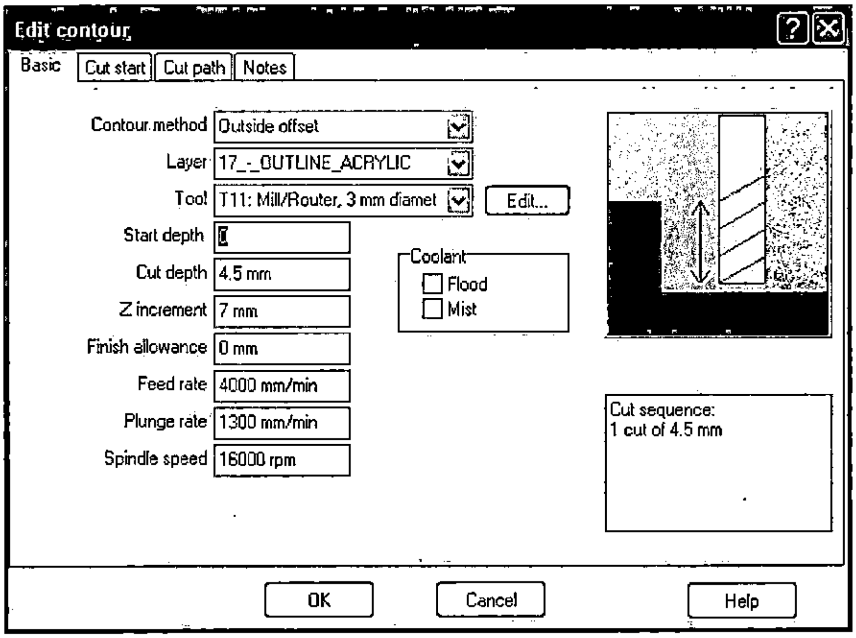


Figure 47: Parameters such as speed, feed rate and depth of cut must be specified per material. Curt Adkins.

Milling of Aluminum

Once the G-code is created by SheetCAM must be loaded into the NC software, Mach3. Within this software it will be translated into motion on the CNC router. All speeds, feeds and depth of cut designated in the writing of the G-code are implemented as specified. However, these parameters may be adjusted during the machining process to fine tune the process in reaction to the cutting conditions.

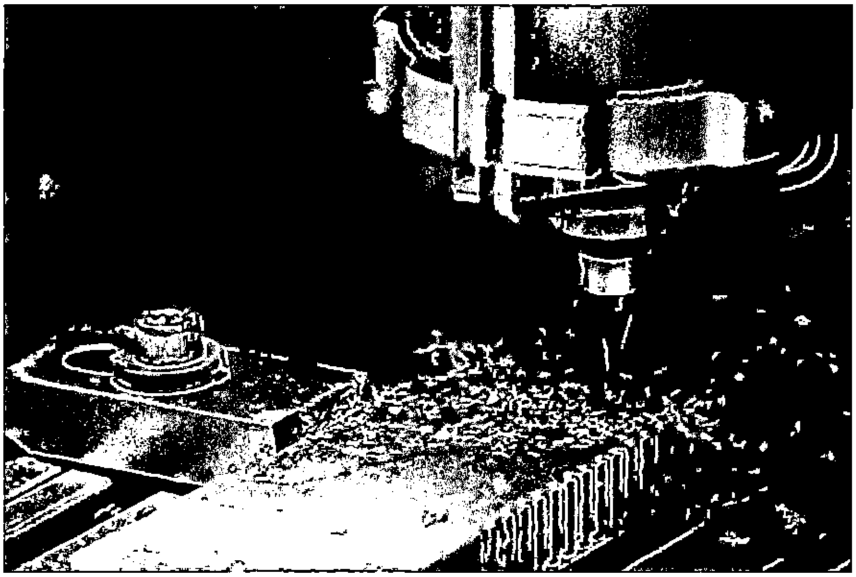


Figure 48: A CNC router is much like a mill, but operates at much high RPMs; 10,000-30,000 RPM. CNC Zone.

Bending, Pressing and Forming

Though the main structure of the case is extruded and requires no bending, the internal parts do require some forming. The optical drive bracket, storage drive bracket and the power supply bracket/duct are all formed 0.063" 5052H32 aluminum sheet. The profile of these parts are cut on the CNC router. Once cut they are bent in the appropriate direction and angle by means of a press brake.

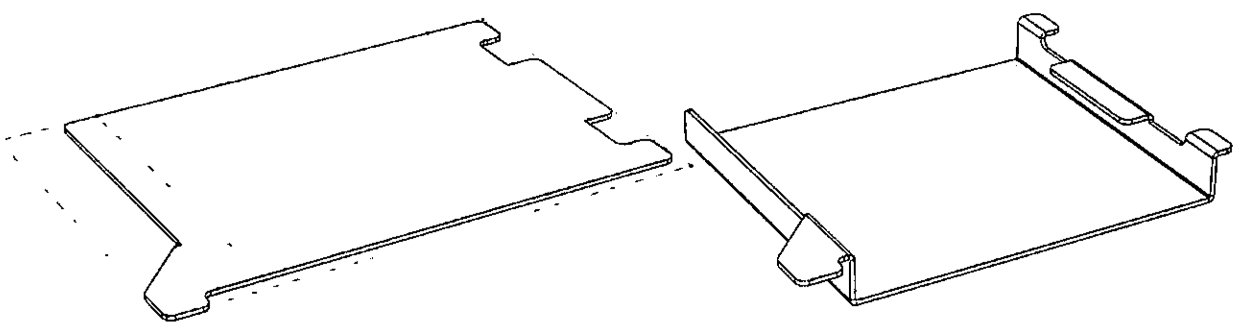


Figure 49: SolidWorks 2012 allows unfolding of solid parts into sheet metal features. Shown is the M3A2 optical drive bracket. Curt Adkins.

Shown in Figure 45, the part is cut as a flat piece and formed into its final shape. This flattening of a 3D model is accomplished by calculations built in to SolidWorks 2012 Professional. The contour of the flat part is determined by parameters such as K factor, bend radius or bend allowance. These are measures of how a material reacts to a particular forming die or process. They compensate for stretching and compression of the material at the area being bent.

Mounting the motherboard requires the use of standoffs. These standoff hold the motherboard off the panel they are mounted to. In this case, the motherboard is spaced 4.5mm off the bottom panel. The standoffs used are from Penn Engineering and are referred to as PEMs. To maintain aesthetics on the outside of the case, the standoffs selected are concealed, pressed from the inside of the case and show no signs on the exterior of the case.

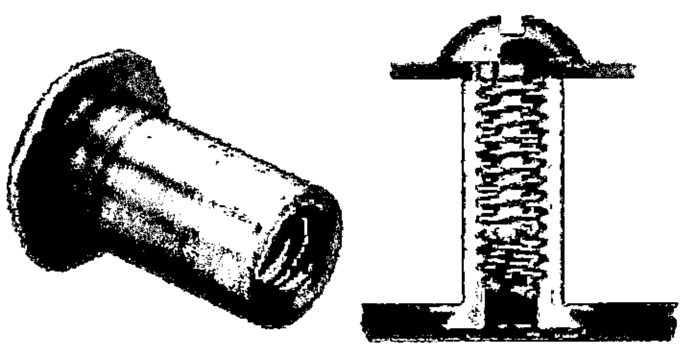


Figure 50: Concealed PEM standoffs allow mounting the motherboard to the bottom panel without showing on the exterior. Penn Engineering.

Finishing

Once all machining and forming is complete, the case must have a finished surface treatment for durability and aesthetic purposes. Among the various options, such as painting, anodizing and power coating, the latter was chosen based on several reasons. Power coating is a process by which a polymer-based powder is sprayed onto a part and baked at a temperature that melts the powder. Once cooled it forms a very durable layer over the aluminum.

Figure 51: This is a power coated part done in textured black. Eastwood.

To prepare for powder coating all parts must be sanded, de-burred and cleaned of contaminants. Parts are then preheated to a temperature of 400 degrees Fahrenheit and sprayed with a generous coating of powder. Parts are then hung in the oven to cure. For the standard color of the M3A2, a black textured powder is selected. This is a popular color in modern computer cases and the textured finish protects against finger prints and can smooth minor imperfections in the parts.

Cost to Manufacture

The original goal was to create 10 M3A2 Beta cases for prototyping and testing. All materials and parts were purchased with that quantity in mind plus extra incase of defects or errors made during the machining processes. Consequently, pricing per part is greater than it would be if purchased in larger quantities. However, the pricing is still such that the retail price exceeds the cost to manufacture, making even the sale of the prototypes profitable.

Materials

The M3A2 is designed to be made as an all aluminum case. Where some manufacturers choose to lower cost by using plastic and steel, aluminum is highly desired for its thermal and weight properties by enthusiasts. The aluminum used for the fabricating the case comes in a variety of forms before it is machined into the appropriate parts.

The aluminum extrusions were made from a foundry in China, cut into 350mm lengths and shipped. The aluminum plates for the top and bottom panels, the aluminum bar stock for the legs and rear PCI mount, and the sheet aluminum for the drive brackets were all ordered from MetalSuperMarketplace.com and shipped to the shop.

Table 8: One of the largest portions of the total cost to make one case is in the aluminum. Curt Adkins.

Material	Alloy	Source	Total Cost	Cost Per Case
Aluminum extrusions	6063	China	$620.00	$56.36
Aluminum plate (3mm)	6061	Metal Super Market	$226.24	$20.57
Aluminum bar (6mm x 25mm)	6061	Metal Super Market	$24.39	$2.22
Aluminum sheet (1.6mm)	5052	Metal Super Market	$78.13	$7.10
			Total per case:	$86.25

Purchased Parts

Along with the raw material to manufacture the case, there are various purchased parts required to complete one unit. These parts were purchased in smaller quantities, enough to produce 10 M3A2 Beta cases and have some extra stock to account for defects or other errors. Most parts are sourced from overseas due to product availability and unit cost.

Table 9: The cost of purchased parts broken into cost per case. Curt Adkins.

Part	Source	Lot Quantity	Lot Cost	Cost Per Case
PC wiring and pins	China	20	$11.89	$0.59
USB3.0 panel ports	China	11	$68.90	$6.26
IEC320 outlets	China	11	$6.98	$0.63
Power switch	China	11	$69.70	$6.33
PCIEx16 Riser	Taiwan	11	$89.76	$8.16
PCIEx16 Spacer	Taiwan	11	$24.13	$2.19
Rubbet Feet	McMaster-Carr (US)	50	$10.13	$0.92
M3 and M4 Screws	McMaster-Carr (US)	300	$24.68	$2.24
HDD anti-vibration mounts	Frozen CPU (US)	50	$11.38	$1.03
PEM Standoffs	Penn Engineering (US)	50	$6.28	$0.57
			Total Per Case:	$28.92

Total Cost to Manufacture

When taking into consideration the cost for the raw materials required for each case and the purchased parts that each case includes, the total materials and costs per case from Table 8 and Table 9 is as follows:

(Material Cost per Case) + (Purchased Part Cost per Case) = Total Cost To Manufacture

$86.25 + $28.92 = ***$115.17 per case***

This value does not take into consideration the labor rate to produce one case. To do so, the amount of time to fabricate each part must be calculated and multiplied by the labor rate. This gives the actual total cost to manufacture from the stand point of a conventional manufacturer.

Table 10: This is the breakdown of the labor cost per part plus the machine time costs. Curt Adkins.

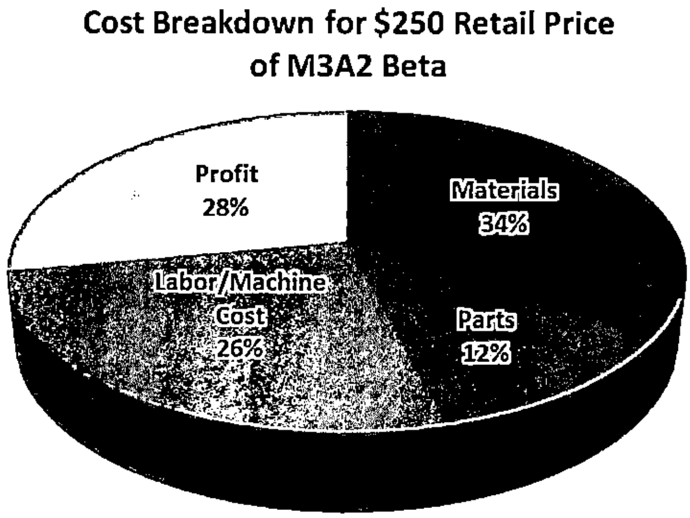
Labor rate:	$30.00/hr
Machine Cycle Rate:	$5.00/hr

Part	Setup (hrs)	Bending (hrs)	Pressing (hrs)	Threading (hrs)	Finishing (hrs)	Total (hrs)	Labor Cost	CNC Cycle Time (hrs)	Machine Time Cost
Front panel	0.083	0	0	0.05	0.033	0.166	$4.98	0.17	$0.85
Rear panel	0.083	0	0	0.05	0.033	0.166	$4.98	0.25	$1.25
Left panel	0.083	0	0	0.05	0.033	0.166	$4.98	0.2	$1.00
Right panel	0.083	0	0	0.05	0.033	0.166	$4.98	0.2	$1.00
Top panel	0.083	0	0	0	0.033	0.116	$3.48	0.2	$1.00
Bottom panel	0.083	0	0.05	0	0.033	0.166	$4.98	0.22	$1.10
Power supply bracket	0.083	0.083	0.05	0	0.033	0.249	$7.47	0.05	$0.25
Storage drive bracket	0.083	0.083	0	0	0.033	0.199	$5.97	0.05	$0.25
Optical drive bracket	0.083	0.083	0	0	0.033	0.199	$5.97	0.05	$0.25
PCI mount	0.083	0	0	0.083	0.033	0.199	$5.97	0.083	$0.42
Vertical stand/feet	0.083	0	0	0	0.033	0.116	$3.48	0.05	$0.25
						Total Labor:	**$57.24**	**Total Machine:**	**$7.62**

Though it doesn't directly apply to the circumstances under which this particular study is being implemented. When the labor and machine time costs are taken into consideration, the cost to manufacture one case is a sum of the parts and materials and the labor and machine time costs.

(Materials and Parts Cost) + (Labor and Machine Time Cost) = Total Cost to Manufacture

\$115.17 + \$57.24 + \$7.62 = ***\$180.03***



Graph 2: The breakdown of the retail price of the M3A2 Beta case. Curt Adkins.

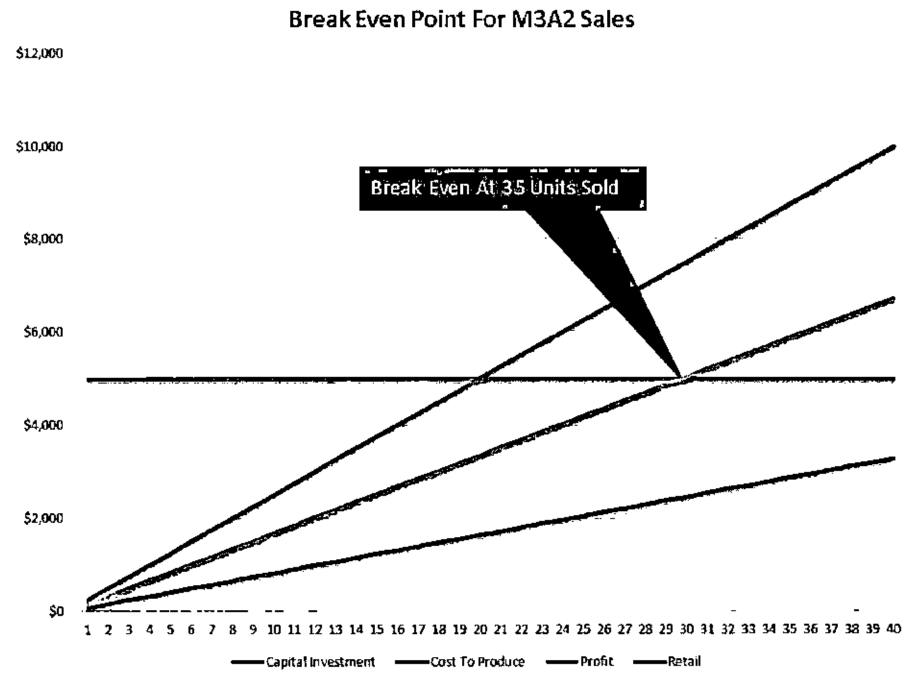
Given the data in Graph 2 with a suggested retail price of \$250.00, the profits after all materials, parts and labor are 28% or \$69.97 per case. This is well within the range of a reasonable profit margin considering that these figures are based on producing in very small quantities of 10 units. Total cost to manufacture will be reduce exponentially with greater quantities due to price breaks on purchased materials and parts, as well as reduce labor cost due to task overlapping.

However, the simulation currently underway involves all parts being manufactured in my personal prototyping home shop. Since the labor and machining time is done in-house, the cost is retained internally and can be considered as part of the profit. For the circumstance of performing the machining operations personally, the profit margin increases greatly from 28%. With only the expenses of materials and parts, using the same retail price, profits increase to 54%, or $134.83 per case.

The cost to produce can also be lowered by means of investment into local aluminum extrusion die and services. Cost for domestic supply of extrusions lowers the cost per case for the extruded profiles 67% over current low quantity overseas suppliers. This is due largely in part to shipping costs and high unit cost at low quantities. This brings the cost for extrusions per case from $62 down to less than $20. This equates to a potential cost to manufacture of $82 per case.

Break Even

To determine when the project is truly profitable, a breakeven analysis is done for forecasted sales of the M3A2 small form factor desktop case. This assumes a continued retail price of $250 and a cost to manufacture of $82 per case. The investment into equipment, tooling and extrusion die is estimated to be $5,000. Based on these values a table was created and a graph generated to visualize that particular point of profitability. The breakeven analysis is performance to determine how many M3A2 cases must be sold to exceed that amount in profits. Therefore, the breakeven calculation is a factor of cost per case to produce, profits realized from each case and multiplied by the number of cases produced.



Graph 3: Breakeven analysis of the M3A2 case project. Curt Adkins.

In Graph 3 we see the breakeven point clearly defined. With a constant initial investment of $5,000 to meet and then exceed, the breakeven point is exceed on the 31st case sold. Due to low initial investment and substantial profit margins exceeding 54%, the breakeven point is obtainable at a relatively low risk.

Conclusion

From the beginning, the focus of this study was to develop a new product; a new compact desktop computer case that is not currently available on the market. The specific requirements of the design set forth previously in the Objectives have all been clearly met or exceeded in the subsequent development of the M3A2. The design is dimensionally smaller than other available products and is of a volume less than 10 liters, 9.1 liters to be exact.

Even with its compact size the M3A2 is still capable of holding the required minimum amount of hardware plus the ability to expand with further hardware additions. Other comparable cases on the market have certain limitations in regards to graphics card space allotment and power supply compatibility. And above all, each of the comparable cases on the market lacks availability beyond purchasing as a complete preconfigured system. The M3A2 is marketed and sold individually, with no obligation towards any preconfigured or proprietary hardware.

The case is designed to be manufactured with conventional machine tools and requires no specialty tooling or processes. This conventional approach keep the capital investment costs into equipment down and offers a level of flexibility for changing the design as the product develops and hits the market. Using a CNC mill/router, press brake, arbor press and miscellaneous manual tools, the M3A2 case can be made in low quantities for less than $120.00 per case.

Analysis of the M3A2 fluid and thermal properties reveals that the design features intended to optimize airflow and component cooling, such top mounted cooling fans and passive side vents, yields that the case design is validated. The simulated airflow pathways and thermal readings are indicative of a case capable of properly housing and cooling high performance computer components within their safe operating temperatures.

The cost to manufacture the case is also within a reasonable range for this quality level of product. While other cases currently on the market are available for less, none possess the features and build quality of the M3A2. Other cases are generally made from steel with miscellaneous plastic parts, whereas the M3A2 is made entirely from machined aluminum. This gives the case higher quality fit and finish as well as the durability and thermal performance that is demanded from a product of this price range.

Producing the case in low quantities is of course more costly that mass production. However, the current retail price still yields a profit margin of 54% such that the manufacturer also acts as the retailer (which is currently the case). The profit margin remains at reasonable levels even when the case is produced by an original equipment manufacturer (OEM) and must be paid for their manufacturing services. This brings the profit margin to 28%. Additional investment into domestic suppliers and larger quantities will yield even great profit margins exceeding 67% at the given retail price of $250 per M3A2 unit.

The retail price has been validated by actual sales. Currently, as of April 15th, 2013, all 10 of the M3A2 Beta cases have currently been sold. Between website sales at

M3Cases.com and a preorder crowd funding campaign on Indieogogo.com, all beta models were sold within 14 days. Currently, the wait list for the next run of M3A2 cases is growing. The popularity of the design is evident in the amount of traffic generated on the M3cases.com website as well as the Hardforum.com discussion currently ongoing.

Plans for the Future

Beta Model Testing

Due to the nature of this project, the scope of its development goes beyond thesis and into the future. With all 10 cases presold preparations are being made to manufacture these cases and the subsequent orders to follow. As the M3A2 Beta cases make they were to the end users feedback will begin to cycle back and be used to further better the design and improve on component compatibility and overall functionality. This real world data is vital to the development of such a product, especially with the end users providing practical information such as fitment, long term durability and overall performance of the case design.

Increased Production

Since all the M3A2 Beta cases sold, more requests for cases have been coming in from as far as Hawaii and the United Kingdom. Requests range from 1 to 100 plus units, each customized to the customer's specific needs. To meet these demands and lower the cost to manufacture, parts and materials will be purchased in greater quantities. This includes the design and purchase of an extrusion die from a foundry in the United States to product the extruded side panels for the M3A2 at a cheaper dollar per pound rate than currently purchasing.

As seen in Table 8, the cost of these extrusions currently accounts for nearly 50% of the cost to manufacture. Committing to a larger volume of aluminum extrusions will reduce the extrusion cost per case by 74%. That alone will reduce the cost to manufacture each case to an estimated $69.37. This in turn will allow the retail price to be lowered for broader market appeal and accessibility.

What the future holds for this project is largely undetermined. However, with the current sales numbers, popularity and internet traffic being generated about this case design, I believe the success of the M3A2 is only limited by the ability to produce them. No doubt, further development will be required as beta testers provide their feedback. Also, subsequent variants of the M3A2 are being developed for other applications, such as industrial computers, VESA monitor mounted versions, miniaturized revisions and many other derivatives of the original design. The future never certain, but the M3A2 appears to have a promising road ahead.

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