Final Design Review

Standardizing 1RU Chassis to PCBA Interfaces

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June 3, 2021

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Statement of Disclaimer

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Abstract

Cisco currently designs a variety of custom chassis for different types of servers, routers, and switches. Our senior design project aims to reduce the number of custom chassis Cisco develops by standardizing the perimeter mounting locations for the printed circuit board assembly on the chassis. The purpose of this report is to document our selected project direction and support the decisions with appropriate evidence. In addition to research on the customer's needs, the product, and the technical background used to understand the project scope, our group has come up with a way to analyze and compare mounting locations for various designs. Our team focused on the Quake chassis family to compare new designs with existing tooling and created a guideline for future standardization. We completed a MATLAB script that compares existing and future chassis hole locations to tooling locations in order to determine the best tooling set for a given chassis. We also made a document that analyzes hole locations based on the different depths of the Quake chassis families. We hope that our research and analysis will become a future guideline for designers to implement common features for PCBA mounting locations and chassis interfaces.

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1. Introduction

Cisco needs a way to standardize the 1RU (one Rackmount Unit) chassis to save cost and reduce the number of custom chassis needed to be manufactured. Our senior design group, consisting of Bryce McNeil, Leia Tashiro, John Liu and Sarika Singhal will further develop a design guideline for Cisco hardware and mechanical engineers by researching and analyzing current designs to find new solutions for the 1RU chassis. Our background research covers similar products, patents, and industry codes, standards, and regulations. The objective section of the report covers the problem statement and quality function deployment to better understand the design parameters we need to satisfy our sponsor's request. Through our analysis process, our group reviewed 42 CAD files of current Cisco chassis designs that utilize the standard 1RU chassis concept to identify any patterns in hole locations and other chassis interface features so we can develop a written guideline and interactive tool for the designers. Our group also produced MATLAB tools to create chassis and tooling standardization cases. For our next steps, we will complete our MATLAB tool and standardization documents to send to Cisco design engineers for use and to give us feedback. We will also conduct background research to understand our project, then identify the risks to focus our goals, and lastly explain our standardization process as well as our shift to focusing only on the 18 Quake chassis. We will then we explain the purpose of our standardization document and its goal for Cisco. After, we will cover the basis of our MATLAB tool and how we hope it will utilize existing tooling as Cisco produce's more chassis designs. Finally, we get our updated design direction approved, list the challenges faced, and conclude our findings.

2. Background

Before creating a standardization guideline or MATLAB tool, it is important to understand our product, our sponsor's needs, and customer needs. Here we use current products on the market, as well as patents and industry standards as tools to assess the scope of our project.

2.1 General Information

The 1RU chassis represents a class of product that occupies one Rackmount unit in a Telco rack. 1RU chassis are the enclosure for servers, switches, and routers. 1RU is a standard unit of measurement for a 1.75-inch-high rack unit. For our project, we analyzed 1RU chassis with a constant width of 19 inches and variable depths. The height of the chassis is standardized throughout the data center industry; however, the depth and length can vary depending on varying sizes of PCBs that a product may have [1].

After speaking with Cisco, it became apparent that standardizing mounting hole locations on the perimeter of the chassis would simplify the staged stamping process and therefore reduce costs. PCBs are currently mounted onto the chassis via screws using either toadstools or standoffs. Both have their pros and cons. Toadstools are formed into the sheet metal and are sometimes tapped for threads. They take up more space than a standoff but are cheaper to manufacture. Standoffs, on the other hand, are an additional part that are press fit into the sheet metal assembly and take up less space. This method, however, requires an extra step of press fitting inserts into the sheet metal as well as the cost of the part, so toadstools are preferred. In the re-design, we will utilize toadstool mounting method as much as possible if common hole locations are found.

2.2 Standardization

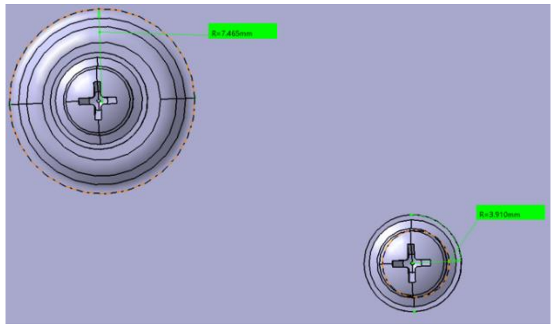


Figure 1. Toadstool (top left) and Standoff (bottom right)

Standardization can be used across all industries in a variety of applications. In surgical rooms, removing unnecessary tools from a surgeon's tray reduces instrument error rate and as well as overall maintenance. One common strategy for improving the quality of life of medical workers is to create a checklist that is handed over to the next staff member so that they are reminded of exactly where the patient is in their hospital visit [2]. When plotting the utilization of instruments per tray vs. total instruments per tray, utilization drastically increases when the number of instruments decreases. Similarly, for our case, it is obvious that with hole standardization, the number of unique hole punching patterns required decreases and the utilization for each of those punching patterns increases. The tools in the surgical scenario are parallel to the tooling used for stamping a set pattern of holes. With more utilization of one stamping pattern, the error rate decreases for that pattern tool and so does the cost. Another cost saving benefit of standardization is maintenance. In the surgical room after each procedure, all the tools must be sterilized. Stamping patterns are similar since the tooling requires maintenance. If there is less tooling, the amount of overall maintenance required also decreases [3].

Another example of a standardization benefit comes from Korea's implementation of similarly shaped and colored bottles across seven major brewing companies. By streamlining the design for everyone, they avoided costly sorting and exchanging procedures which saved them about 40 million dollars annually. This practice, also known as inventory pooling, helps to improve companies' logistical performance. Our project shares the same strategy that the brewing companies pursued. By creating a standard for chassis to follow, there will not only be cost savings, but also simplified manufacturing [4].

As previously mentioned, our group's primary goal is to standardize the perimeter hole locations. All the perforations and threading in the chassis are stamped in stages since stamping all cut outs at once would cause major deformation in the sheet metal. This allows us to standardize a set of hole locations in one stamping stage. Other stamping processes also take metal stress into account during manufacturing. In the production of magnesium alloy cups, a smaller radius size was achieved through a two-stage cold stamping process. The first punch creates a cup with a large inner cup radius and the second punch indents the same area of metal to create an even smaller radius as shown in Figures 2 and 3. The stamping process required two stages to prevent fracturing of the alloy. In our chassis manufacturing process, we will also want to avoid fracturing the sheet metal by utilizing multiple stages of stamping [5].

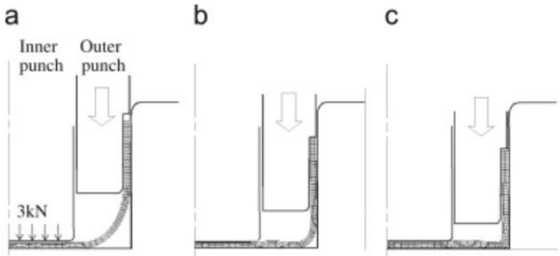


Figure 2. First Stage Inner Punch with Second Stage Outer Punch [5]

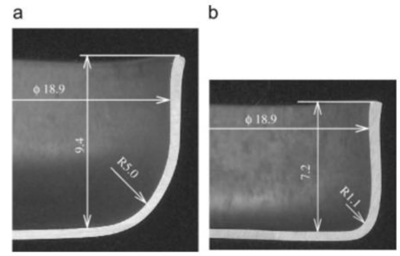


Figure 3. Large to Small Bend Radius [5]

Sheet metal parts are often deformed during the machining, assembly, and measuring stages of the manufacturing process. It is important that the process is optimized so that issues are minimized during the tooling process. One approach for this problem is using a radial basis function (RBF) neural network to learn the 'best' locations to work with a sheet metal part [6]. This neural network has helped to inspire us in our MATLAB script to optimize new chassis designs.

Another important element of sheet metal forming is the material and surface coating used. Steel is a useful material in sheet metal forming as it has a low weight and great energy absorption. Unfortunately, steel's strong adhesive traits lead to a large amount of wear on the tooling. To combat this, a diamond like carbon (DLC) coating is used on the surface of the steel pins. DLC is a relatively expensive coating, so it is unlikely to be used in our future chassis design, but it gives us a good idea at the level of adhesion we need to combat to increase the longevity of our chassis [7].

2.3 Product Research

There are numerous key factors that are analyzed before a rack mount purchase. These include size, flexibility, manageability of cables, usable space post mounting, weight capacity, and cooling efficiency. As mentioned before, rack mounts have standardized heights and widths, but varying depths. Individual PCBs dictate the required chassis depth. Balancing material waste and maximizing the number of PCBs each chassis can be used for will be one trade off that our team will have to consider. Ensuring that our mounting locations do not interfere with PCB's design traces, impedance, or signal integrity is another constraint for our design.

Table 1. Similar Products and their Associated Specs

Product Name	Dimensions	Weight
Cisco Network Convergence System 5000 Series [8]	Height: 1.72 in (4.3688 cm) Width: 17.44 in (44.2976 cm) Depth: 19.3 in (49.022 cm)	20.5 lbs. (9.29kg)
Cisco 9200 Switch for 24 ports [9]	Height: 1.73 in (4.4 cm) Width: 17.5 in (44.5 cm) Depth: 13.8 in (35.0 cm)	12.12 lbs. (5.5kg)
Cisco 4431 Integrated Services Router [10]	Height: 1.73 in (4.39 cm) Width: 17.25 in (43.815 cm) Depth: 19.97 in (50.72 cm)	22.4 lbs. (10.2 kg)
Cisco 4331 Integrated Services Router [10]	Height: 1.75 (4.455 cm) Width: 14.55 in (36.957 cm) Depth: 11.60 in (29.464 cm)	9.14 lbs. (4.2 kg) + 1.2 lbs. (0.66 kg) external PS
Arista DCS-7050S-52-R 7050S Series 52x 10G SFP+ Rear to Front Airflow Switch [11]	Height: 1.75 in (4.4 cm) Width: 16 in (40.64 cm) Depth: 19 in (44.5 cm)	17 lbs. (7.71 kg)

Table 1 displays five other products that are similar to the 1RU chassis that we will be working with. As mentioned above, the height and width of all chassis remains relatively constant, but the depth varies depending on the internal PCB.

2.4 Patents

There are five relevant patents to our design problem that can be found in Table 2 below. The first patent listed in the table is for a 1RU server but focuses on air flow and heat transfer in the chassis design [12]. Our design task centers around a 1RU server chassis, but heat transfer is a design consideration. Cisco does not patent their mechanical engineering chassis designs, but there are a few relevant categories that our proposed standardized chassis would cover. These classifications are G06F1/181 and G06F1/183. G06F1/181 describes enclosures while G06F1/183 describes "internal mounting support structures" such as "printed circuit boards (PCBs) and internal connecting means." Patents 2, 3, and 5 all contain these two classifications. Both Oracle patents consider internal mounting support, but Patent 3 has an additional classification, G11B33/128, that centers on recording devices mounted to the chassis [13].

Table 2. Relevant Patents

Patent Name	Classification	Company	Date Created
1. Compact Rackmount Server [12]	• H05K7/20736 Forced ventilation of a gaseous coolant within cabinets for removing heat from server blades	Sun Microsystems Inc.	September 13, 2007
2. Compact Rackmount Storage Server [14]	• H05K7/1487 Blade assembly, e.g. cases and inner arrangements • G06F1/183 Internal mounting support structures, e.g. for printed circuit boards, internal connecting means	Oracle America Inc	September 7, 2010
3. External Storage for Modular Computer Systems [13]	• G06F1/183 Internal mounting support structures, e.g. for printed circuit boards, internal connecting means • G11B33/128 Mounting arrangements of constructional parts onto a chassis if the plurality of recording/reproducing devices	Oracle America Inc	July 17, 2007
4. Computer System for Highly Dense Mounting of System Components [15]	• G06F1/184 Mounting of motherboards • G06F1/187 Mounting of fixed and removable disk drives • G11B33/128 Mounting arrangements of constructional parts onto a chassis of the plurality of recording/reproducing devices	VA LINUX SYSTEMS, California Digital Corp	December 3, 2002
5. Computer Enclosure with Input/Output Module [16]	• G06F1/181 Enclosures • G06F1/183 Internal mounting support structures, e.g. for printed circuit boards, internal connecting means	Hongfujin Precisio n Industry Shenzhen Co Ltd, Hon Hai Precision Industry Co Ltd	March 29, 2011

Cisco has tasked us with examining chassis primarily used for routing and switching, but there is potential our focus can grow to include other product types. In the table, Patent 4 does not have either the G06F1/181 or G06F1/183 classification [15]. The patent is still relevant to our background research because it carries the same classification as patent 3, G11B33/128, and additional classifications centered on mounting technical hardware. From these patent classifications, a future, standardized 1RU chassis can be properly patented and classified.

2.5 Industry Codes, Standards, and Regulations

When stamping holes, the cut out must be eight to ten percent of the sheet material thickness. Hole piercing is a repeatable process by hard tooling with size tolerances of 0.002". Hole to hole location punching can also be held at ±0.002" [17]. One consideration for hard tooling is the compressive force required to punch a hole. Newton's third law states that for every action force, there is an equal and opposite reaction force. From this understanding, the same force applied to the steel sheet will also be applied to the tooling. Therefore, we want to ensure perforations in the tooling have a cross section greater than or equal to the thickness of the sheet metal we are punching holes into. This ensures a large area to decrease the pressure and subsequent force on the hard tool. During the stamping process, 90-degree angles are doable, however, the "spring back" of metals due to their hardness properties restricts formation of angles less than that.

Taking GD&T into consideration, we want to specify our tolerances for the toadstools and standoffs. An important tolerance that will be called out throughout our mounting location drawings will be the perpendicularity of the holes. Our datum will most likely be the PCB mounting surface. Tight tolerances and cost will have to be weighed in our considerations as tolerances have a direct relationship with cost. Screws are still functional when they are not perfectly perpendicular to a surface, so extremely tight tolerances are not necessary for our project. When using this tolerance, the location and specification of the threaded hole is determined from the thread profile form maximum material condition (MMC) [18].

Before the product can go to market, it must pass safety and compliance guidelines. For this section we focused on American and European guidelines since other country guidelines are based off these standards. Cisco's products comply with the following safety standards: UL 60950-1 and EN 60950-1. UL 60950-1 and EN 60950-1 are the American and European safety standards applicable for information technology and focuses on preventing fires and injuries [19]. Cisco servers also comply with the following electromagnetic interference (EMI) and electromagnetic compatibility (EMC) standards: FCC Part 15 (CFR47) Class A and EN 55032 [20]. Both the FCC's and European Union's EMI and EMC standards cover telecommunications and information technology.

2.6 Manufacturing

Based off the volume of production, a stage die or progressive die is used to produce the chassis. In a stage die, the stamps are manually pressed, whereas in a progressive die, the stamps are automated. An advantage of using a staged die is having the option to produce different hole patterns within the same die. This is because inserts can be easily added to either reduce or add the number of holes in the chassis. The downside to this is the production rate decreases due to the increase in time of each die being manually pressed.

In a progressive die, each die is used to manufacture at least 10,000 chassis a year. Although the cost of a progressive die is approximately $200,000, the cost of labor is reduced completely, and the rate of production is increased. Furthermore, depending on the volume of production, up to four similar chassis designs can reside in a single progressive die.

Different manufacturing methods are used to create different types of holes in sheet metal. The two main types are toadstools and standoffs. A toadstool is made by undergoing three stations during the tooling process and has more expensive tooling compared to a standoff, which only undergoes one station. However, looking at the overall cost, standoffs are more expensive on account of the extra labor cost necessary to install inserts into the chassis.

Standardizing the chassis design has the potential to save at least $600,000 (based on example prices given during Flex meeting) since a standardized chassis reduces the need for individual chassis dies used in the progressive die. Additionally, standardization reduces the number of inserts used in the mother tool. Finally, we asked the Cisco manufacturers what features they noticed as potential areas for standardization since they would have likely noticed potential patterns during manufacturing. They suggested we investigate the rackmount hole locations, port openings, chassis cover features, and chassis attachments. We plan to take these suggestions into consideration as we progress further in our project.

3. Objective

Cisco needs a way to standardize the mounting locations on the Cisco 1RU chassis perimeter to cut costs annually and reduce the number of custom chassis that need to be manufactured. Manufacturing a 1RU product to fit each unique PCB/PCBA is extremely expensive, and it is vital that a more modular design is implemented.

3.1 Problem Statement

Currently, Cisco has over 40 different PCBs with customized chassis that utilize standardized tooling. Our sponsor has asked our team to come up with a way to design a chassis that will serve multiple PCBs with an emphasis on the mounting locations.

To visually understand our problem statement, Figure 4 depicts a boundary diagram of our proposed problem. The dashed lines indicate the area we will be focusing on and the two types of circles indicate the two common types of holes we will encounter. Over the course of our project, we will review existing Cisco chassis CAD files and make recommendations on hole placements around the chassis perimeter.

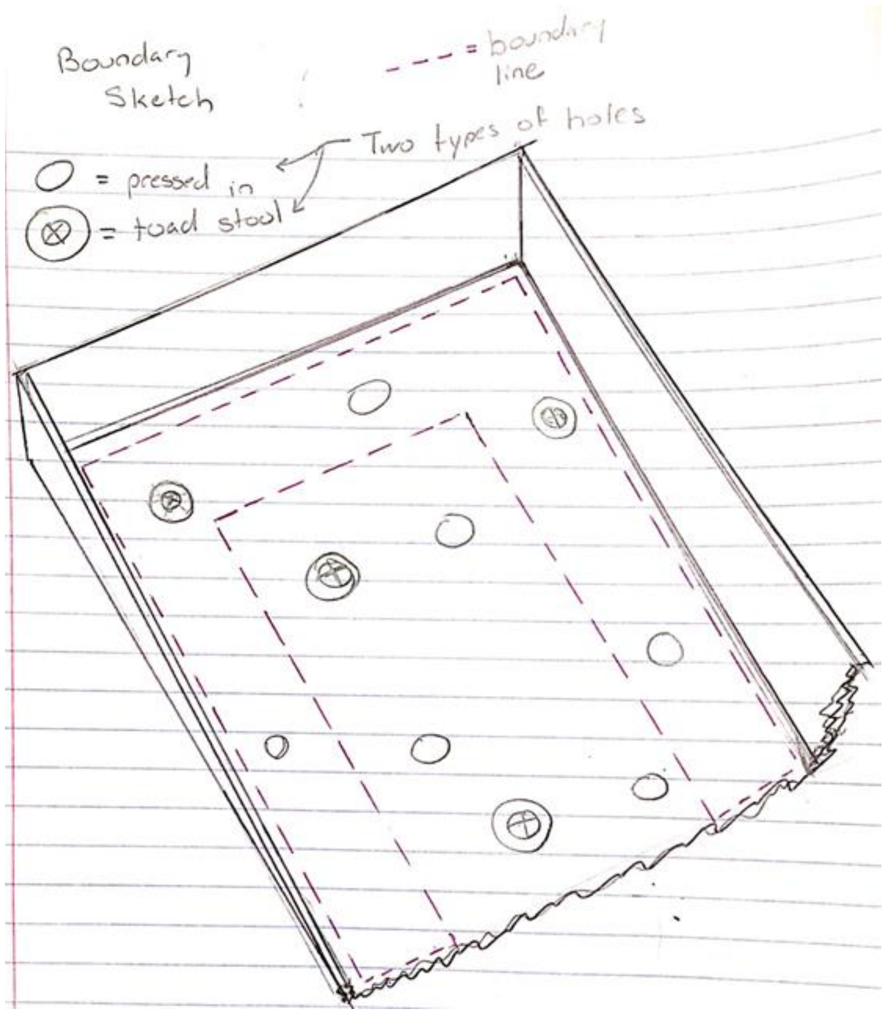


Figure 4. Boundary Diagram of 1RU Standardization Problem

3.2 Quality Function Deployment

Before receiving and analyzing chassis CAD files, we first explored our sponsor's needs and wants. Quality Function Deployment (QFD) is a structured way to identify the customers primary needs and wants quickly and effectively. The QFD can be represented visually as a House of Quality. Table 3 is a list of wants and needs for the rack mount based on our preliminary conversations with Cisco. These would ultimately be the basis for our engineering specifications.

Table 3. Sponsor Needs and Wants

Wants/Needs	Why this is Desired
Common Geometry	-1RU chassis have a standard height and width -Reduce drastic alterations to avoid unexpected assembly/manufacturing consequences
Safe Assembly	-Ensuring no one gets hurt in the process of manufacturing or handling this design
Good Ergonomics/Easy Assembly	-Minimize the chances of error in assembly that could prohibit proper functionality
Simplified Production	-Cost savings in hard tooling
Manufacturability	-Meeting specifications for outsourced vendors to design the chassis in mass production
Transportable	-The chassis is getting shipped from an external vendor to be used by Cisco
Maintenance Friendly	-Want to be able to maintain chassis to avoid constant replacement
Cheap	-All cost reductions help Cisco in the long run
Durable	-Needs to house the PCB and prevent damage to the PCB

The House of Quality (HOQ) helps identify specific design parameters to accurately meet the needs and wants of the sponsor. For the 1-9 criteria in the WHO section, a 1 indicates little relevance and a 9 indicates extreme importance for a given customer requirement. For the rest of the chart, a 1-5-point scheme is followed where a 1 indicates a low correlation and a 5 indicates a high correlation. The initial HOQ was created from the wants and needs of our sponsor, seen in Table 3. Our full House of Quality diagram can be found in Appendix A.

Analyzing our House of Quality, the compact design specification has strong relationships with a lot of customer wants and needs as well as dimensions and geometry. We plan to narrow our focus to mounting location placement by analyzing pattern possibilities in multiple CAD files. Our HOQ also shows that good airflow has negative relationships with important specifications like cost, assembly, and common mounting locations so it is reasonable to work on these issues separately. Utilizing the information from the HOQ, we set up an engineering specifications table that gauged the tolerance, risk levels, and compliance of each parameter as seen in Table 4.

Table 4. Engineering Specifications Table

Spec #	Parameter Description	Requirements or Target	Tolerance	Risk	Compliance
1	Compact	19-inch (483 mm) width	±4 in (102 mm)	H	S
2	Mounting Locations	Minimize perimeter locations	N/A	H	A, T
3	Versatility	Usable for more than 3 different PCBS	Min	H	A
4	Toadstool/Standoff Usage	# of toadstools > # of standoffs	Max	H	A, T
Spec #	**Parameter Description**	**Requirements or Target**	**Tolerance**	**Risk**	**Compliance**
5	Good Airflow (Thermal Management)	Temp of server does not exceed PCB component max. temp	N/A	M	A, T
6	Easy assembly	No specialized training required	N/A	M	I
7	Production Cost	Decrease by minimum of 10%	Min	M	A, I
8	Drop Durability	Intact after an 84 in drop (48U height)	Min	M	A, T, I
9	Manufacturing Time	Decrease by minimum of 10%	Min	L	A, I
10	Weight	25 lbs. or less	Max	L	S, I

The criteria for the risk column are defined as follows; H = high risk (upmost importance for this project), M = medium risk (should be considered in final design, but not fully emphasized), and L = low risk (can be considered negligible for the scope of the entire project). The criteria for the compliance column are defined as follows; A = Analysis of certain parts/regions of the chassis, T = Testing of certain specification, S = Similarity to existing products, and I = Inspection of entire chassis. A description of specific risks from high to low is included below.

1. Having a compact chassis is a high-risk specification. While standardizing hole locations, the varying depth prevents some holes from ever overlapping. This makes it impossible to create one standardized chassis for all PCBs while maintaining a compact design. A compact chassis design for each PCB is necessary for organizing the rack units in small spaces, but it also forces variation across all chassis.
2. A high-risk specification is the mounting locations which covers most analyses that we are tasked with completing. Normalizing the mounting locations and allowing for unique PCBs to fit into a single chassis design will reduce manufacturing times and production costs greatly.
3. Versatility of the chassis is another high-risk specification. Creative usage of embossed toadstools and standoffs will help us maximize the versatility of our chassis. This is also important for most of our analyses as it will directly affect standardization of mounting holes.

4. Deciding between a toadstool or standoff mounting method will be critical in cost savings. This high-risk specification will affect our analysis when we make cases for standardized holes. The stress that each manufacturing process will apply on the chassis and the relative proximity of holes will also be considered when choosing a mounting method. This parameter is high risk because of its impacts on manufacturing quality as well as cost.
5. Thermal management is another medium-risk specification. As we standardize mounting locations, we must also take into consideration the LED locations, port locations, connectors, PS locations, and fan locations. Ensuring that the overall temperature of the chassis and PCB assembly is at an appropriate temperature during operation. Overheating of the assembly could become a fire hazard risk, jeopardizing other 1RUs and potentially putting lives at risk.
6. Another medium-risk specification includes ease of assembly. This is a safety concern because a complicated assembly will increase the risk for installation errors and potentially cause PCBs to slide out from the chassis. Since chassis are sometimes carried around and mounted individually in data centers, we want to reduce the risk of injury to any technician or to the board and chassis.
7. Production cost is a medium risk specification as one of the primary goals of this project is to provide Cisco with a cheaper alternative to the current method of chassis manufacturing. Our goal is to lower production costs of the chassis that we have analyzed by up to 10% by creating a baseline chassis design that minimizes time spent machining and still allows all PCBs to fit within their appropriate chassis.
8. Drop durability is a medium risk specification as Cisco is already performing drop tests for their current chassis to ensure that the interior components remain in good condition if an accident were to occur with installation. We want to ensure that our chassis design will be as durable if not more durable than the current chassis.
9. A low risk would be manufacturing time since our analysis will not have large effects on it. The same number of chassis need to be produced to accommodate each PCB even if the hole locations are standardized. Our results will slightly decrease manufacturing time by reducing manufacturing error through tooling simplification.
10. Weight is a low-risk specification as we were given no guidelines for how heavy the chassis can be and have not been worried about internal components (outside of the PCB) at any point in our project.

As of March 2021, the scope of our project changed to be heavily focused on developing an official standardization document for the Quake chassis family. Alongside this document, we developed a more general MATLAB script that compares a tooling layout to current or new chassis based on their hole locations. These new engineering specifications will more accurately measure Cisco's needs as we aim to standardize new chassis hole locations. Table 5 lists the new specifications and includes explanations below.

Table 5. Updated Engineering Specifications Table

Spec #	Parameter Description	Requirements or Target	Tolerance	Risk	Compliance
1	User friendly	Document is clear and intuitive based on internal feedback	> 67% positive survey results	H	T, S, I
2	Effective Documentation	Document is aesthetically pleasing	N/A	H	A, T, S
3	Tool assesses ranking for various chassis sets	Tool output ranks commonality of various chassis sets	N/A	H	A, T

1. The documents we are providing Cisco consists of a MATLAB tool, instructions, and standardization documents. Having documents that are easy to follow and understand will help users give feedback that will help improve the tool as well as the documentation. Our team will be using a Google survey to determine if our documents are user friendly.
2. The official standardization document needs to look professional as it will be used by Cisco as a guideline for future chassis hole locations for the Quake family. The document being aesthetically pleasing means it will be easier to understand for potential customers and easier to explain for Cisco.
3. Outputting ranks for each chassis allows Cisco to clearly see how well their design matches up to previous designs. It also gives Cisco the opportunity to leverage previous tooling layouts when they are designing new chassis.

3.3 Manufacturing Considerations

Some considerations to make when designing for manufacturability are the tolerances between hole locations and the different features of a chassis. The rule of thumb for the recommended distance between holes is 2.5 times the thickness of the sheet metal plus the radius of the larger hole. The minimum distance between other holes is the thickness of the sheet metal.

After multiple meetings with Cisco design engineers, our group decided that analyzing chassis within the same family would best satisfy the initial scope of this project. This was advised by the designers because more features and hole locations will be common to one another. Another benefit is that standardization within the same family will increase use of shared tooling as it is impractical to create shared tooling for all chassis. If this can be accomplished, multiple chassis will be produced within the same production line and Cisco will be able to save costs and space on the factory floor.

Another manufacturing consideration is that some chassis holes are datums and primarily used to locate the part during the stamping process. In the stamping process, every part follows its own datum structure to be correctly located and constrained within each stage. As mentioned earlier in the report, locating pins are used to detect the parts in space using two holes or datums on the part. This may be critical when standardizing holes within different chassis because datum holes are commonly stamped in the first stage and within the perimeter area. For this project though, the design engineers mentioned our group will not need to consider this since the project aims to investigate Quake family chassis, which already share the same datum.

From our meetings with Flex, one of Cisco's manufacturers, we also learned that Cisco chassis are manufactured using a mother tool concept. This tool has interchangeable dies that are used to make the individual chassis. The same tool can be used for chassis of different dimensions.

3.4 Current Goals

Our current deliverables include an official standardization document and a MATLAB script that aims to tell the user the best existing tooling layout for a new chassis design. The standardization document utilizes direct comparisons between Quake files to recommend improvements to Cisco. The MATLAB script observes the current layout of Cisco tooling and compares hole locations with those of newer chassis to determine the best layout for engineers to start with. With these tools, we hope to provide Cisco a more efficient pathway for their 1RU manufacturing process.

4. Receiving and Analyzing Chassis CAD Files

With 42 chassis to analyze, our team has ideated methods of determining standardized hole locations. Patterns across the CAD files allowed us to group the chassis by themes and a MATLAB script will allow us to mathematically determine optimal hole locations for a given chassis design. These CAD files come from different chassis families and subfamilies. Further standardization recommendations, however, were challenging to bring forward due to manufacturing and safety restrictions.

4.1 Exploring A Physical Cisco Chassis

Prior to receiving Cisco's chassis CAD files, one team member received a physical Cisco product. This team member disassembled the server on a Zoom video call since we were unable to physically meet due to COVID-19, so all team members had an opportunity to look at the physical chassis and gain a better understanding of what the CAD files would model. After the Zoom call, the other three team members constructed miniature chassis models to be used as a reference when looking at CAD files. Images of the Cisco chassis and miniature chassis models can be found in Appendix B.

4.2 Receiving CAD Files

We received CAD step files from Cisco via Box, a Cisco shared drive platform. Throughout October, Cisco engineers would upload chassis CAD files to the shared drive. We received approximately six files a week and in total have 24 CAD files. Each of us were responsible for 6 to 7 files. To analyze these files, we used SolidWorks and had one team member double check the hole locations. In February, we received 18 new CAD files that are analyzed in Section 5.

4.3 Locating Chassis PCB Holes

To eliminate any confusion and disagreements, we designated an origin location that will be applied for similar chassis. The (0,0) point will be placed in the interior bottom left corner, as depicted in Figure 5. We chose this point because the chassis differ in width and depth and this location standardizes our data. Since each chassis was designed by individual engineers, they built their CAD designs using multiple orientations. For example, one chassis top view would depict the X-Y plane while another chassis would use the X-Z plane. However, all chassis lids have the name "Cisco" engraved at the bottom center. Thus, the chassis was rotated until the chassis lid was visible and Cisco could be properly read. That edge became the X-axis and the left, perpendicular edge became the Y-axis. We agreed to keep all measurements in millimeters because we expect similarly placed chassis holes to differ by ±0.01 mm when measuring hole locations.

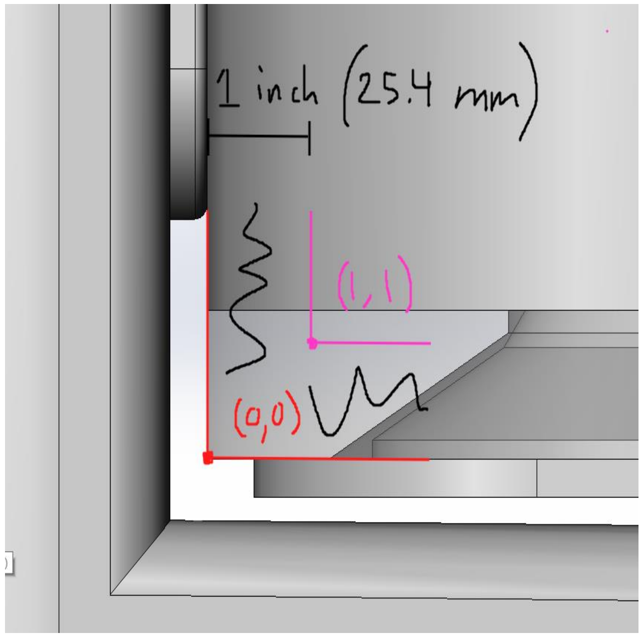


Figure 5. Origin Location for Every Chassis

Before conducting any analysis, we first recorded the location of all the holes in the chassis using the designated origin. Although our initial scope focused on holes around the PCB perimeter, we believe it would be in our best interest to record every hole's location for future analysis. Holes along ±25.4 mm of the PCB's perimeter were designated as perimeter holes. All other PCB holes are classified as interior holes. For every file we recorded the following: Chassis front and back view, Origin, Chassis ID, X Coordinate, Y Coordinate, Unit, Hole Type, and Notes as seen in Table 6.

Table 6. Sample Hole Location for Data Collection

Chassis (Back View)	PCB in Chassis (Front View)	Image of Origin	Chassis ID	X Coordinate	Y Coordinate	Unit	Hole Type	Notes
[image]	[image]	[image]	skyfox	52.09	77.12	[mm]	standoff	perimeter

The Chassis (Back View) depicts all chassis holes on the back panel of the sheet metal. The chassis front view shows the PCB's shapes. The Chassis ID identifies the official name of the chassis. The X and Y coordinates depict the hole's center point in relation to the origin. The unit for all measurements is in millimeters. The hole type detailed whether the identified hole is a toadstool or standoff. The Notes column was used to share any additional details. For the complete list of hole locations for every chassis, refer to Appendix C.

After collecting data for each chassis file, we compiled a plot with all the perimeter hole locations to try and identify any immediate trends. Figure 6 depicts this.

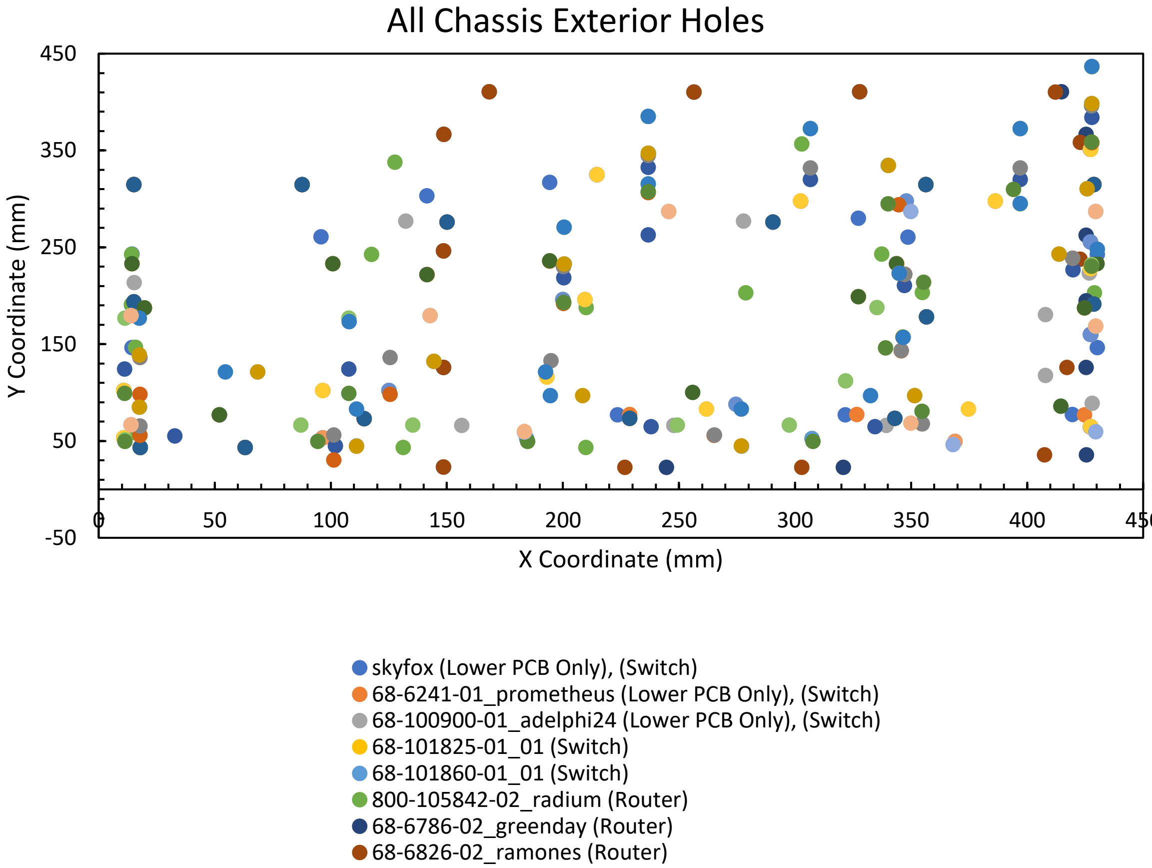


Figure 6. Plot of Perimeter Hole Locations from All Chassis Files

From Figure 6, we observe that the width (X Coordinate) of the chassis never exceeds 432 mm, and the length (Y Coordinate) never exceeds 339 mm. In the X-direction, there is a region between 30 to 85 and 430 mm onwards where no holes are present. Additionally, Figure 6 shows that while not every chassis is similar, there are clusters of similar chassis points. Table 7 assigns groups to chassis with similar hole locations.

Table 7. Similar Chassis Grouped by Perimeter Hole Location

Group Number	Chassis Name
1	68-6241-01_prometheus
	68-6276-Gryphon
2	68-101825-01_01
	68-101860-01_01
3	68-6786-02_greenday
	68-6826-02_ramones
4	68-100901-01_adelphi16
	68-100902-01_adelphi40
	68-100903-02_adelphi12
5	68-101864-01_02
	68-101865-01_02
	68-101866-01_02

Table 6 shows two major trends. First, most chassis in the 68- series share a lot of overlap. All five groups have chassis names that start with "68- ". Second, chassis with similar naming conventions share similar hole locations. These naming conventions are Greek mythology (Group 1), rock bands (Group 3), adelphi (Group 4), and 68-10186_ (Group 5). These naming choices allow us to narrow down the groupings more quickly for similar chassis. Figures 7 through 11 below show the overlapping holes for each group. In Figure 7, all but three 68-6276-Gryphon holes overlap with 68-6241-01_prometheus. All of the holes in these chassis were standoffs.

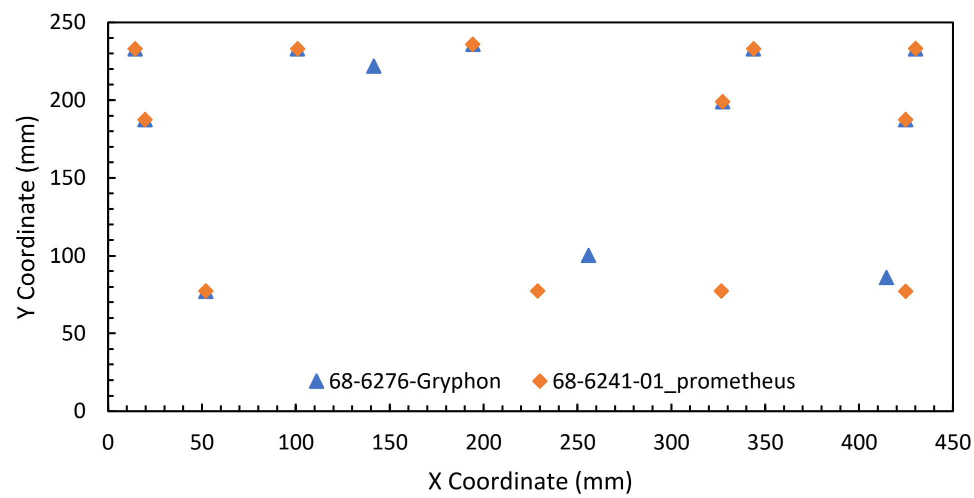


Figure 7. Group 1 Chassis Overlap

In Figure 8, all the holes overlap. The only difference between the chassis was the number of connecters placed beside the PCB. Both would be a great candidate for trying to fit both PCBs in a single chassis. The hole center points differ by about ±0.02 mm.

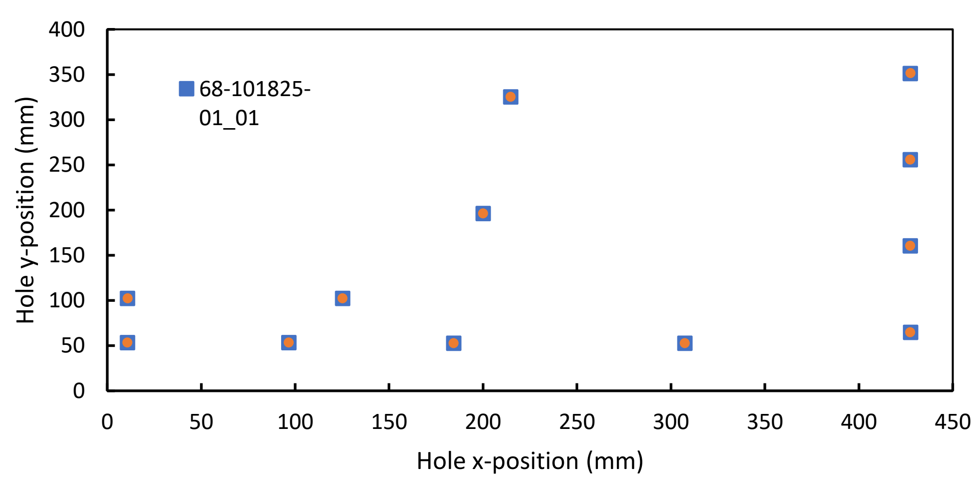


Figure 8. Group 2 Chassis Overlap

In Figure 9, three 68-6786-02_greenday holes (2 central holes and 1 on right-middle) do not have a 68-6826-02_ramones counterpart. Many chassis holes have an exact overlap, but those that do not can have their positions averaged to make a case for standardization.

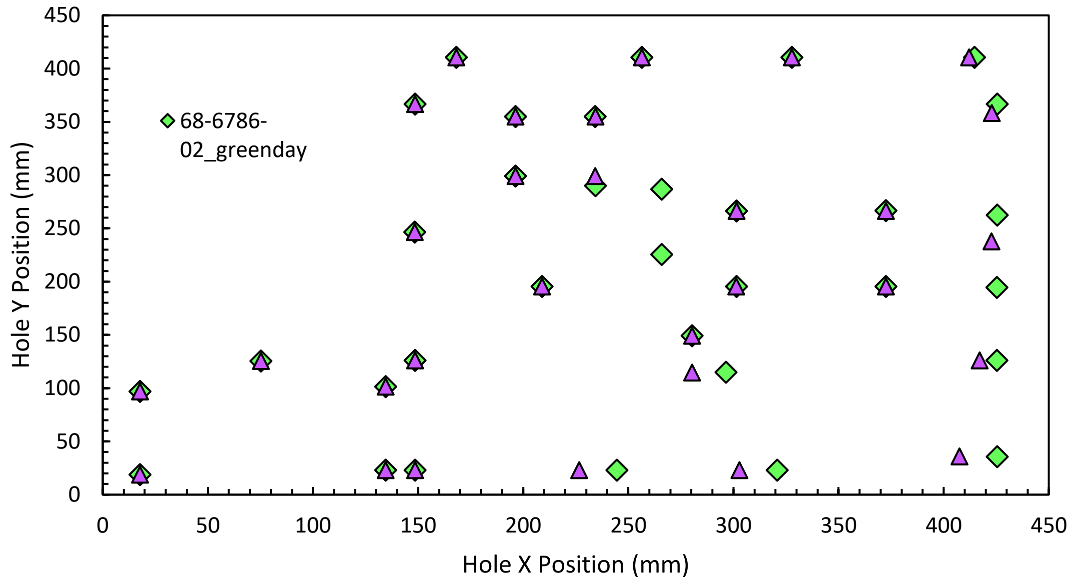


Figure 9. Group 3 Chassis Overlap

In Figure 10, nearly all three chassis had perfect overlap. The region beyond 360 mm in the X-direction differed. In this region 68-100901-01_adelphi16 and 68-100902-01_adelphi40 were similar. A case for a standardized manufacturing method for chassis can be made in which all three chassis undergo the same manufacturing process for holes before the X coordinate 360 mm, excluding the three 68-100903-02_adelphi12 holes between 150mm and 350mm in the X-direction. For the remaining holes, two chassis can be made, one for 68-100903-02_adelphi12 and another standardized set for 68-100901-01_adelphi16 and 68-100902-01_adelphi40.

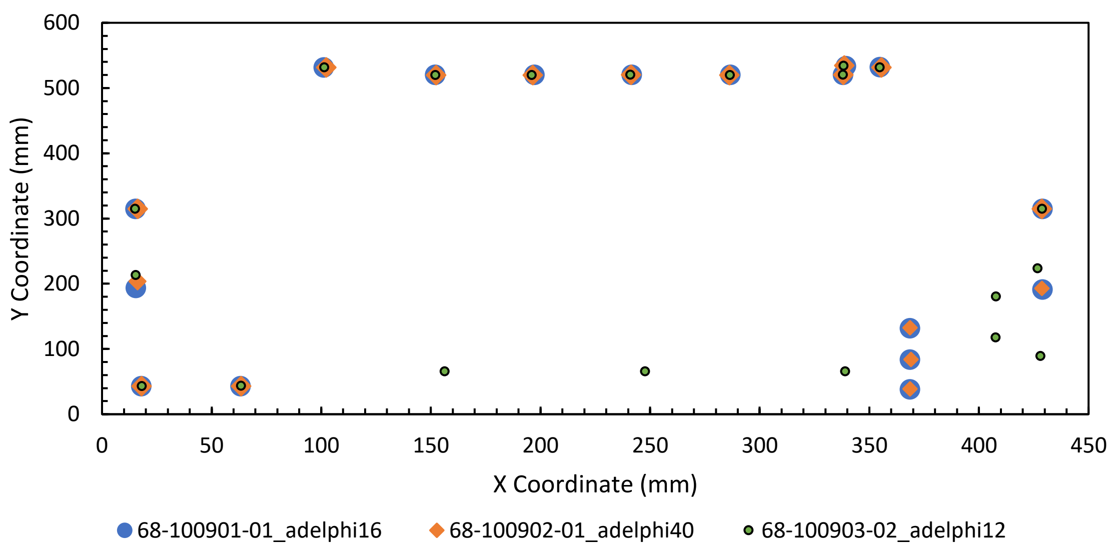


Figure 10. Group 4 Chassis Overlap

In Figure 11, all except for two holes from 68-101864-01_02 overlap. It is possible to standardize the machining process used to make the chassis. Apart from four holes, all three PCB chassis can be manufactured with a standardized set of holes. Additionally, it is possible to standardize the two sets of holes for 68-101865-01_02 and 68-101866-01_02.

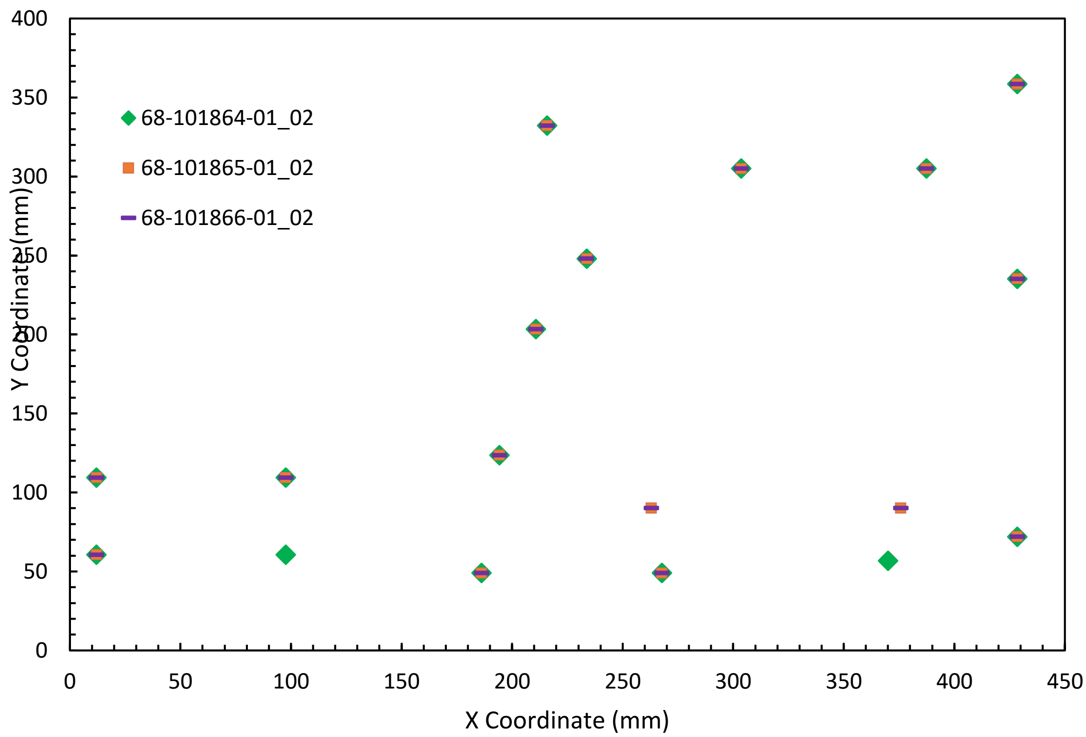


Figure 11. Group 5 Chassis Overlap

After investigating perimeter hole data, we decided to look for potential patterns in our interior hole data. Figure 12 plots all the chassis interior holes, and no pattern is apparent.

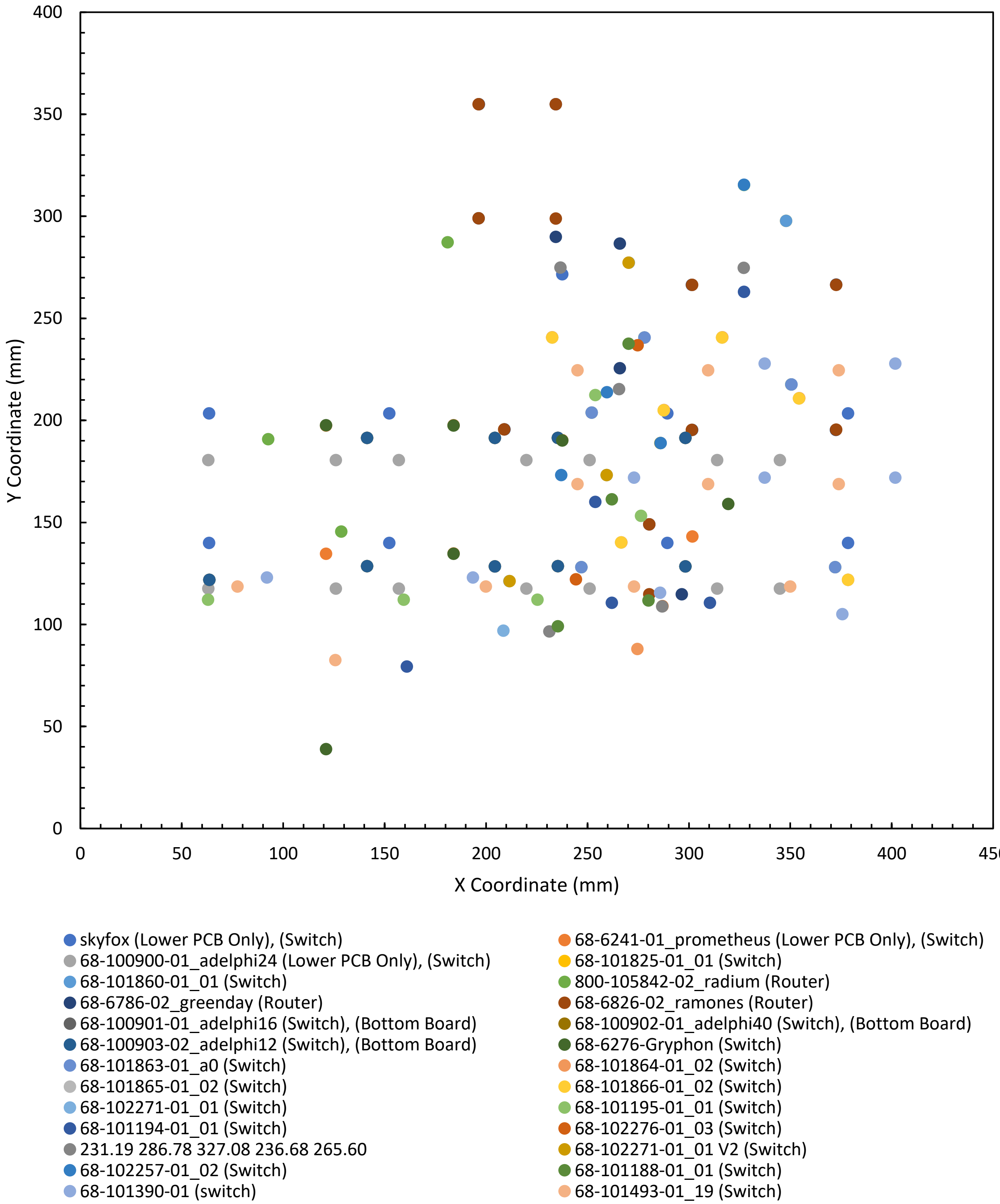


Figure 12. Plot of Interior Hole Locations from All 24 Chassis Files

4.4 Standardized PCB Hole Locations by Theme

From Figures 6 and 12, an immediate solution for a single standardized chassis is neither clear nor possible. Instead, we decided to group the chassis by themes to single the data and determine any trends and cases for standardization. The themes we chose are change in origin, PCB shape, and Switches vs Routers.

The purpose of shifting the origin to the bottom left hole was to determine if there were any patterns based on origin choice. To convert the points to the new origin, we first identified the bottom left hole coordinate from every chassis in our data. Then we created a formula on Excel that converted this point to (0,0) and all other points to be in relation to this origin. Figure 13 shows a plot of the holes with the new origin.

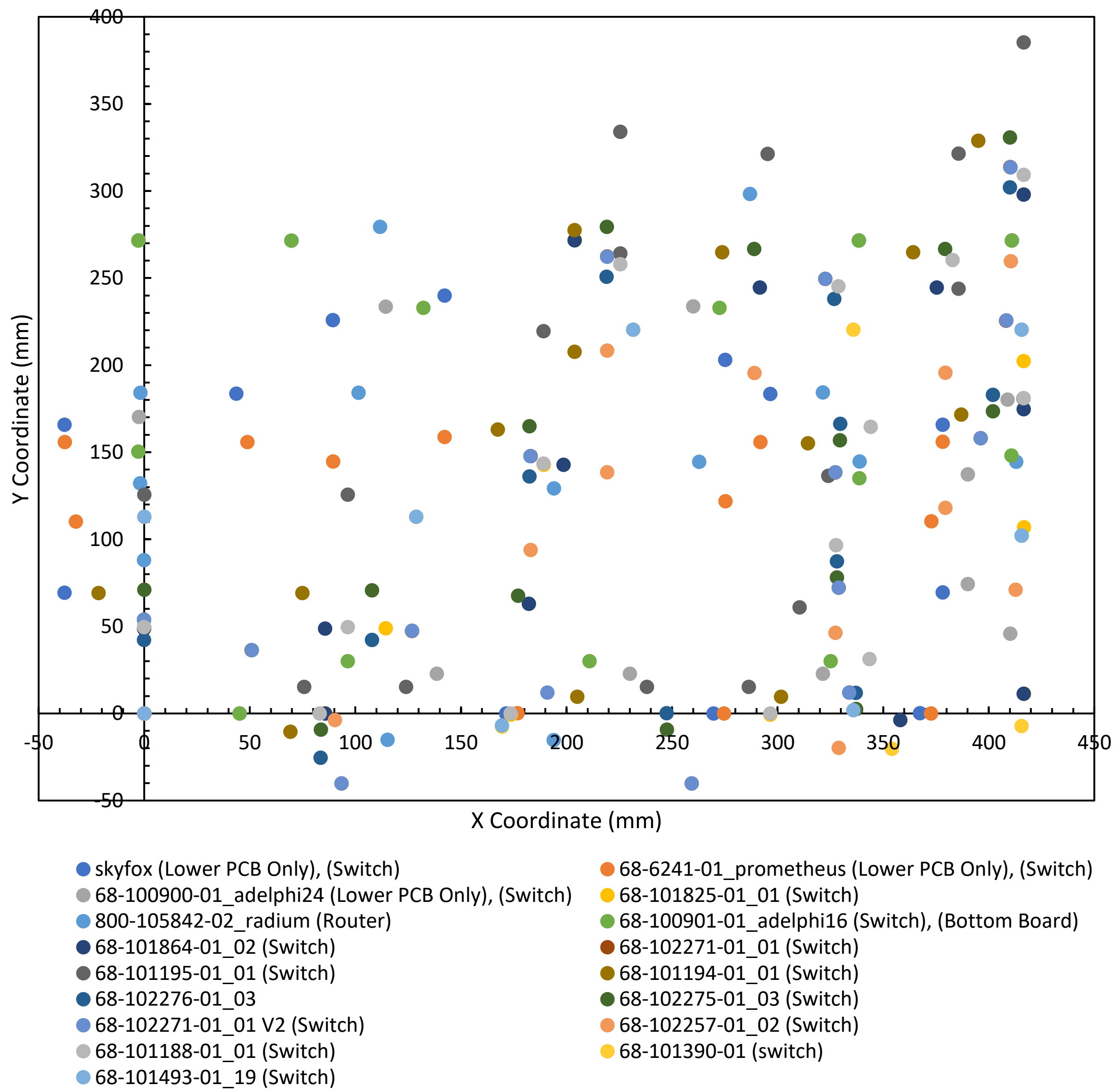
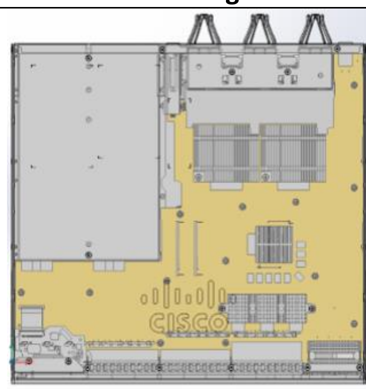
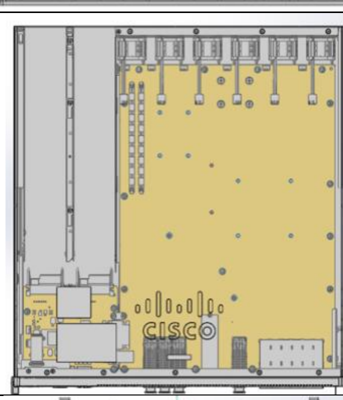
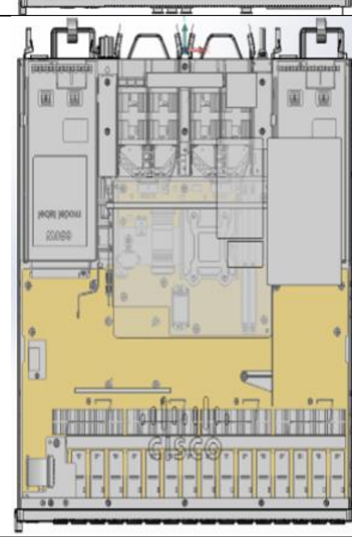


Figure 13. Plot of Hole Locations with an Origin at the Bottom Left Hole

To prevent cluttering the plot with overlapping data, one chassis from each group determined in Table 6 is present. This made it easier to read the plot and determine a pattern. Unfortunately, changing the origin did not yield a pattern. There were no set dimensions between holes regardless of 2D chassis drawings dimensioned with an origin at the chassis corner or bottom left hole's center.

The second theme we investigated was PCB shape. While collecting the initial data, we noticed similar PCB shapes seemed to have overlapped hole mounting locations. In Table 8 we identified the different PCB shapes, found in Appendix C, and their respective chassis.

Table 8. Chassis Sorted by PCB Shape

PCB Shape	PCB Image	Chassis ID
Boot Shaped (1 PCB)		68-101-863-01_a0
		68-101-864-01_02
		68-101-865-01_02
		68-101-866-01_02
		68-101-825-01_01
		68-101-860-01_01
Boot Shaped (2 PCBs)		68-678-02_greenday
		68-6826-02_ramones
Rectangular (2 PCBs)		skyfox
		68-6241-01_prometheus
		68-6276-Gryphon

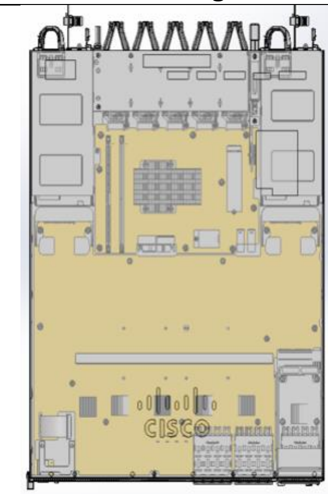
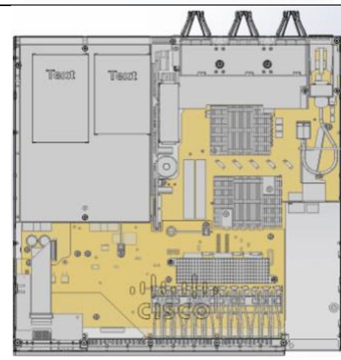
PCB Shape	PCB Image	Chassis ID
Overlapping Rectangular (2 PCBs)		68-100901-01_adelphi16
		68-100902-01_adelphi40
		68-100903-02_adelphi12
		68-100900-01_adelphi24
Z Shaped (2 PCBs)		68-102271-01_01
		68-101195-01_01
		68-101194-01_01
		68-102276-01_01
		68-102275-01_01
		68-102271-01_01 (V2)
		68-102257-01_02
		68-101188-01_01

Table 8 displays the breakdown of chassis ID categories for each generic PCB shape. Most of the chassis display the boot shaped (1 PCB) and Z shaped (2 PCBs) patterns. Some chassis categories contained more PCBs as indicated by the number in the parenthesis next to the shape type. By overlapping mounting hole locations based on PCB shape we were able to analyze whether using this method of categorizing was effective.

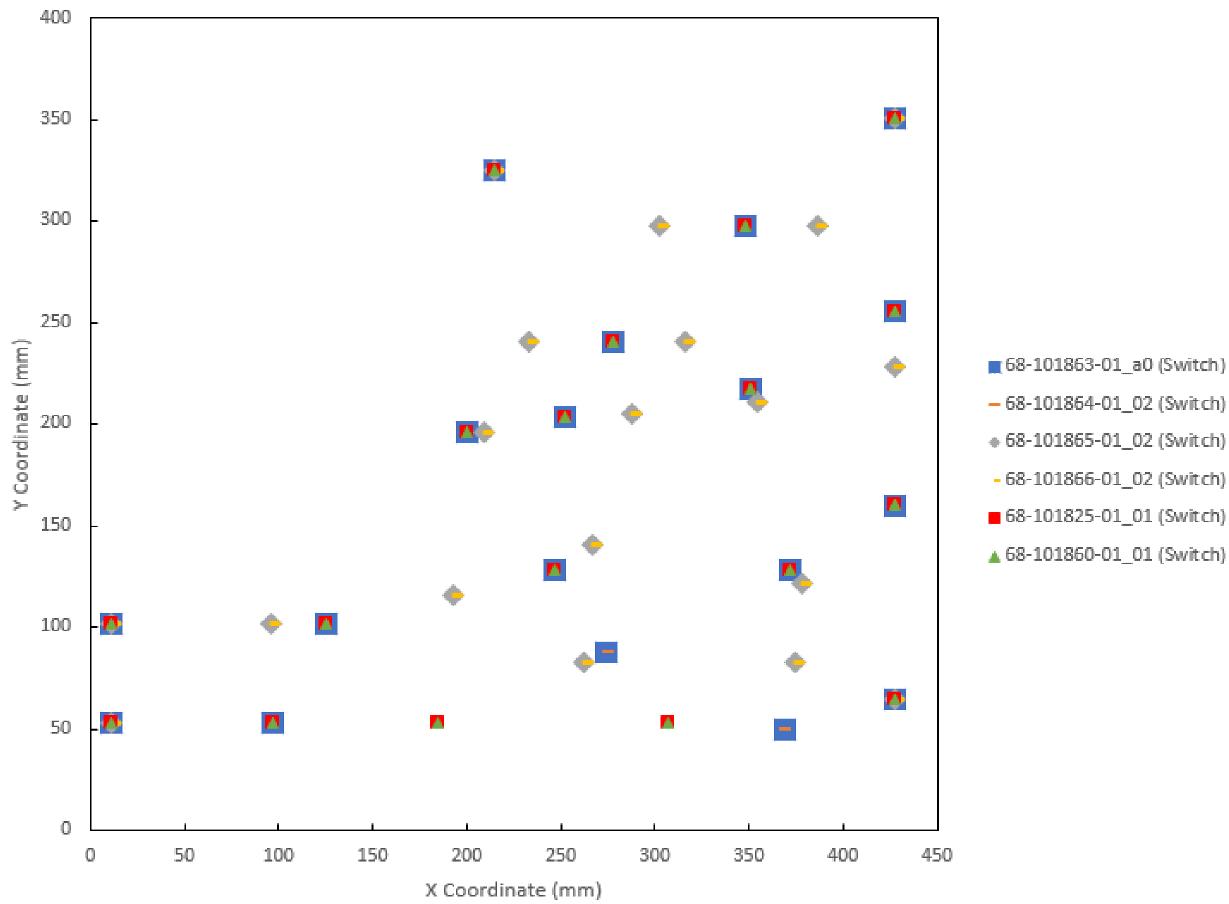


Figure 14. Boot Shaped PCB Mounting Hole Location Comparison

Figure 14 displays all the boot shaped PCB hole locations. This shows the most promising group of PCBs of overlapping mounting hole locations. For example, 68-101864-01_02 and 68-10185-01_02 are nearly identical as established in Figure 11. We also see that 68-101863-01_a0, 68-101860-01_01, and 68-101825-01_01 all overlap consistently.

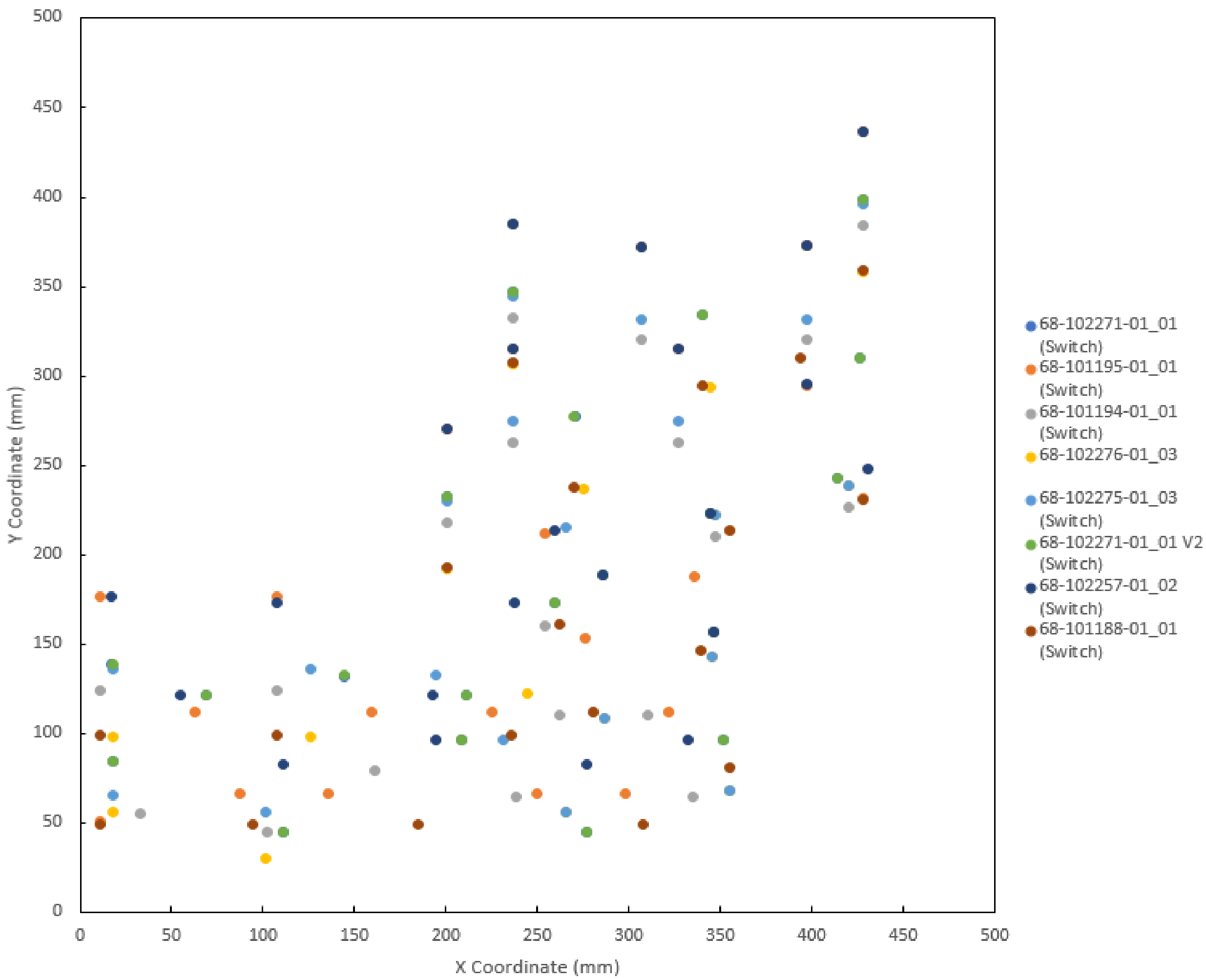


Figure 15. Z Shaped (2 PCB) Mounting Hole Location Comparison

Eight PCBs fall into the characterization of a Z shape. Figure 15 the hole locations are relatively scattered but shows lines of dots on the same X-axes around 50 mm increments.

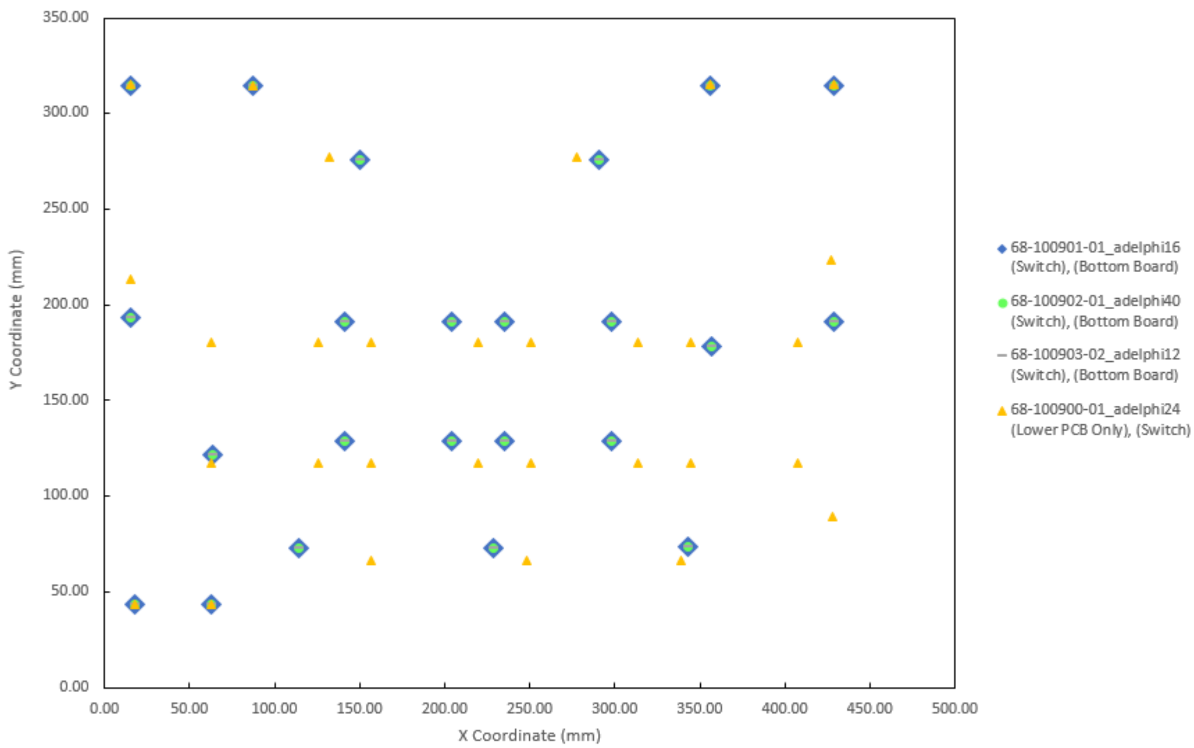


Figure 16. Overlapping Rectangles (2 PCBs) Mounting Hole Location Comparison

In Figure 16, adelphi16, adelphi40, and adelphi12 completely overlap one another. Adelphi 24 is the outlier of this category with almost no overlap with any of the other chassis.

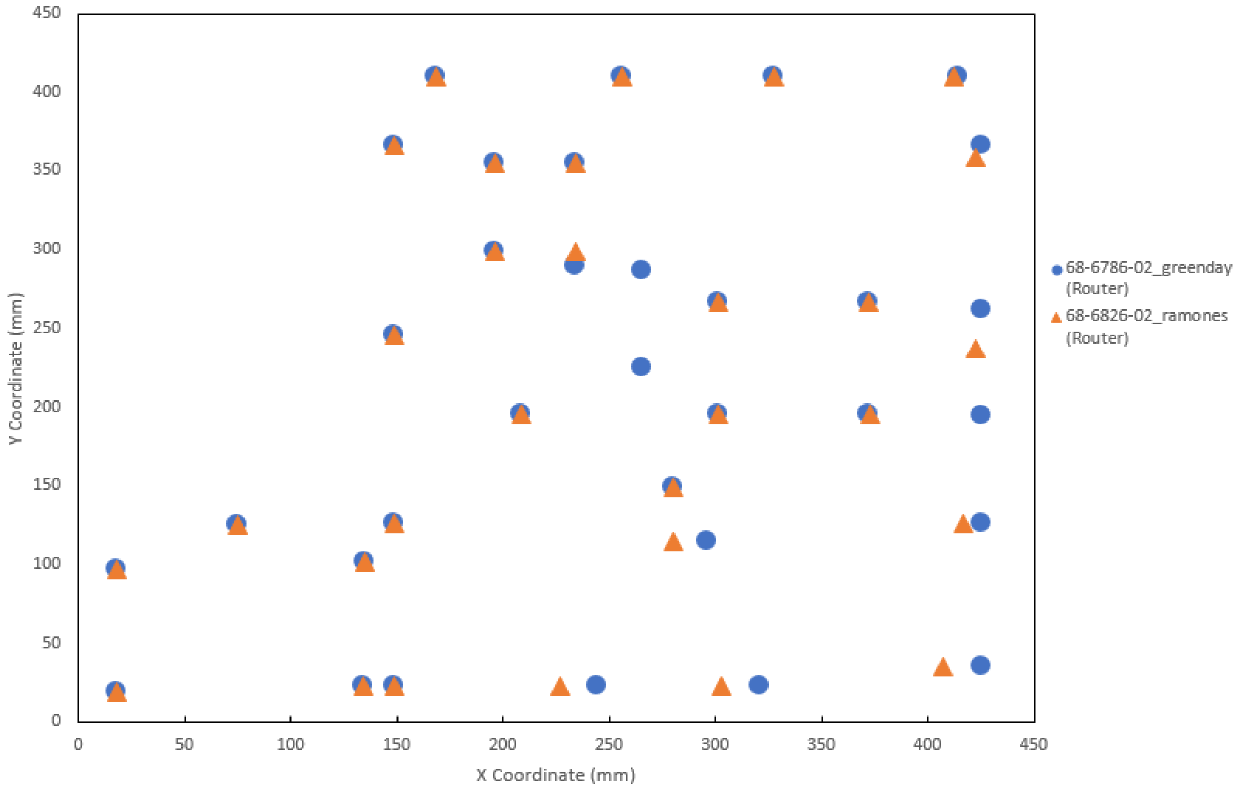


Figure 17. Boot Shaped (2 PCBs) Mounting Hole Location Comparison

In Figure 17, we see many overlapping points. Categorizing the boot shaped (2 PCBs) is the same as categorizing the chassis by name as shown in Figure 9. Since a lot of points are similar, as mentioned before in the Theme 1, these two chassis have a greater chance at standardization.

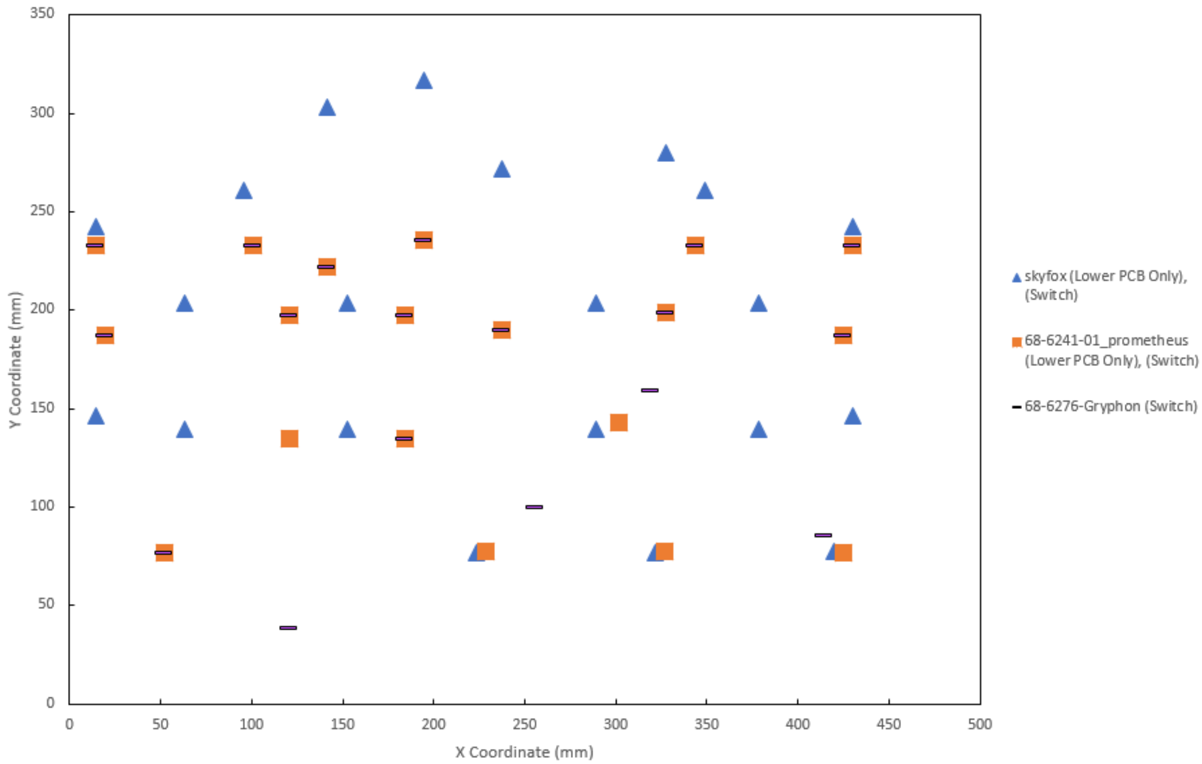


Figure 18. Rectangular (2 PCBs) Mounting Hole Location Comparison

In Figure 18 we see about 90% overlap between the gryphon and prometheus chassis. Since a lot of points are similar, these two chassis have a greater chance at standardization. Skyfox shows slight correlation but could be standardized for a few hole locations towards the bottom of the PCB.

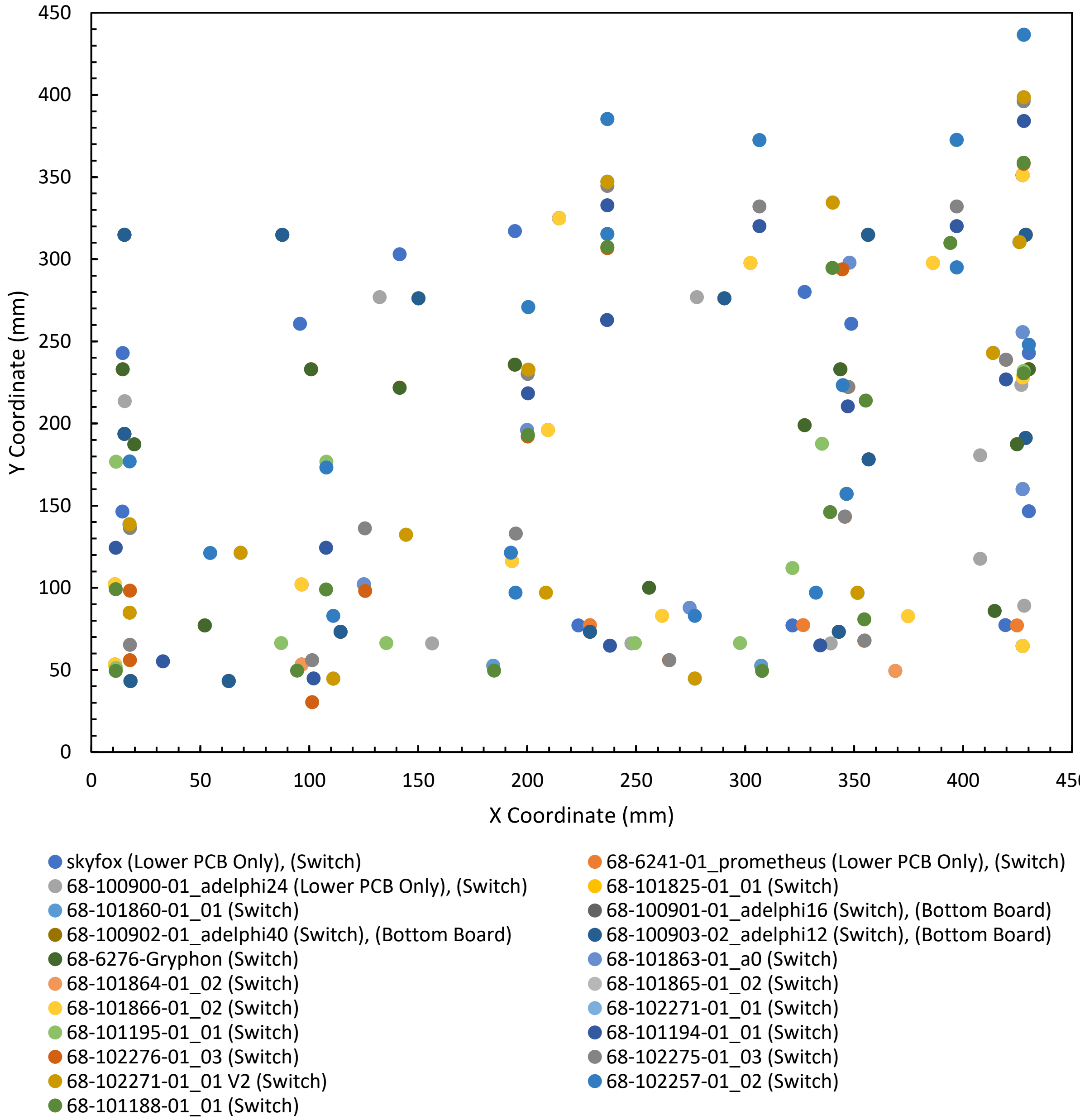


Figure 19: Plot for Switch Perimeter of Hole Locations

The last theme our group investigated was grouping the hole locations based on server type. The first server type was switches and out of the 24 server files Cisco sent to us, 21 were switches. Based on Figure 19, there is a weak correlation between all the data, thus concluding further analysis.

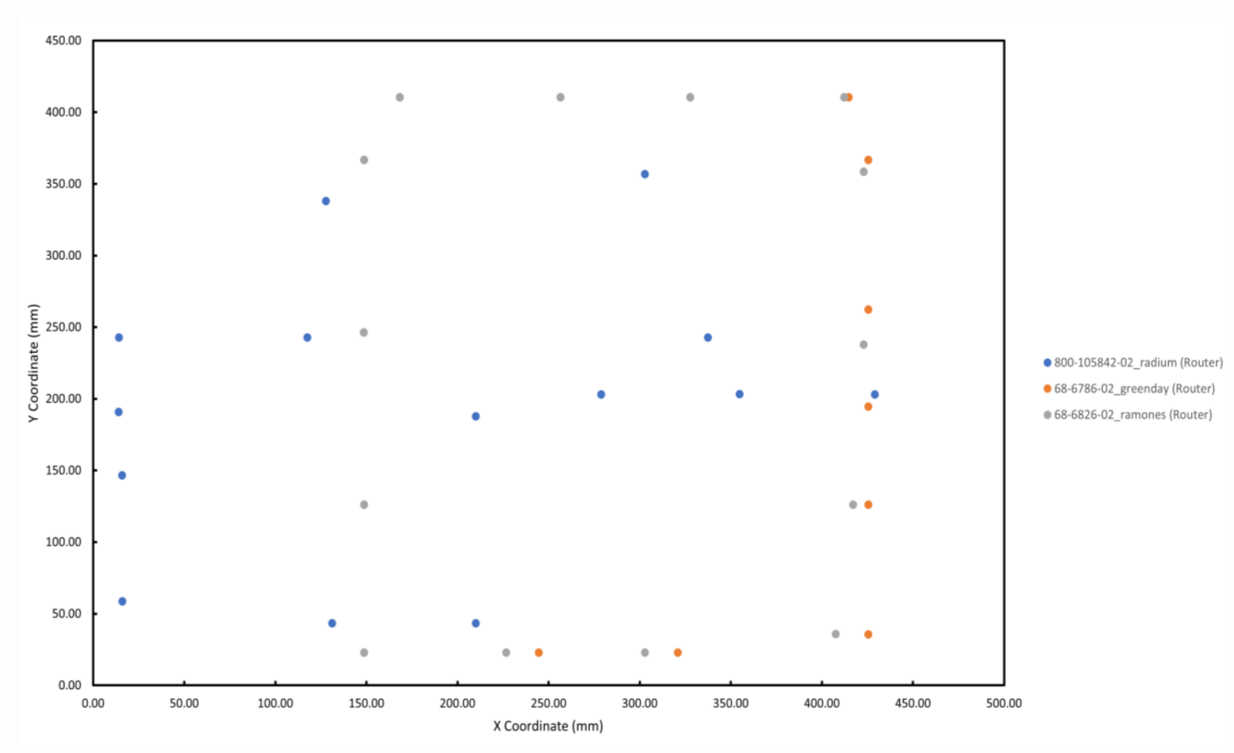


Figure 20: Plot of Hole Locations for All Routers

The second server type was routers which made up 3 out of 24 of our received chassis. As shown in Figure 20, two of the three routers have a strong pattern, but since the sample was so small our group decided not to further investigate the theme.

From our investigation, we decided that "Theme 2: PCB shape" would be the best method for standardization. PCB shapes allowed us to sort the chassis into smaller groups (5-8 chassis) and we were able to see strong overlap between chassis. Moving forward, we hoped to use this method for hole standardization documentation. However, after consulting with design engineers, we learned that the randomness of the chassis provided insignificant results since so few were from the same family/subfamily. Additionally, a major potential source of error is our choice in origin. The distance from the interior bottom left corner to any hole could vary from chassis to chassis as it is dependent of chassis length. Given the time frame of this project, it would not be possible to conduct a full analysis and subsequent documentation to justify a standardized hole placement for each PCB shape. Instead, we will be provided a new set of chassis from the same family to create standardization documentation. It is worth noting for future standardization endeavors that PCB shape offers the most commonalities across chassis families.

5. Quake Files & Analysis

After consulting Cisco design engineers, we decided to work with a new set of 18 chassis within the Quake family. In our previous chassis analysis, we examined chassis from eight different families and had very little success in a path to documentation because some chassis holes, although they had similar locations, had differing functions that would make it impossible to standardize. Working exclusively with Quake files provided us a chance to create valuable standardization documentation and a MATLAB tool targeted for future Quake products. This same analysis and deliverable method will then be applied to other chassis families and established standardization documentation can be used for creating future chassis families.

5.1 Locating Quake PCB Holes

For the Quake family, Cisco provided us with chassis engineering drawings and CAD files. These drawings depicted all chassis dimensions and the datum hole. In all Quake files, the datum was placed at the bottom left hole as seen from the chassis top view. For our Quake analysis, we set our origin at this same location to reduce a potential source of error and match provided engineering documentation. For every mounting hole in each CAD file, we recorded the following: Chassis (Front View), Quake Subfamily, Chassis ID, X Coordinate, Y Coordinate, Unit, Hole Type, and Notes as seen in Table 9.

Table 9. Sample Hole Location Data Sheet for Quake Files

Chassis (Top View)	Quake Subfamily	Chassis ID	X Coordinate	Y Coordinate	Unit	Hole Type	Notes
[image]	Hornet	700-115811-03_A1	111.76	15.88	[mm]	Toadstool	Perimeter

The Chassis (Top View) depicts the top view of the chassis matching the engineering drawing's orientation. The Quake Subfamily and Chassis ID identify where the chassis belongs. The X and Y coordinates depict the hole's center point in relation to the origin. Figure 21, below, shows the chassis origin in the bottom left corner as well as the abundancy of toadstools. To match with our previous chassis, the unit for all measurements are millimeters. The hole type identifies if the hole is a toadstool or standoff. The notes share additional details such as if the hole is an interior or perimeter hole. For the complete list of hole locations for every Quake chassis, refer to Appendix D.

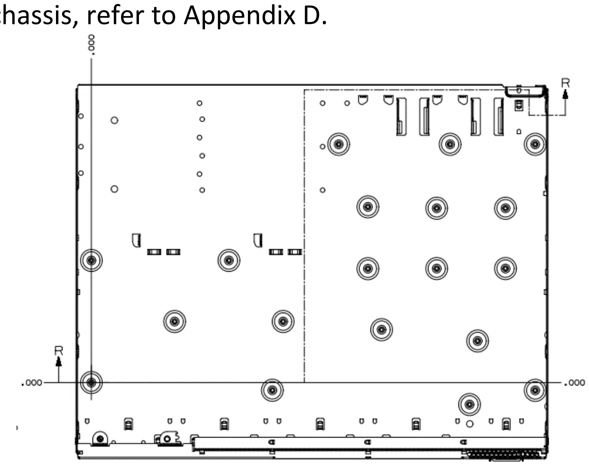


Figure 21. Cisco's Quake Chassis Origin

5.2 Quake Hole Analysis

Unlike the last set of chassis, Quake chassis only contain toadstool holes. After collecting data for all Quake chassis holes, we composed a plot that depicts every documented hole to recognize any immediate trends. This is depicted in Figure 22.

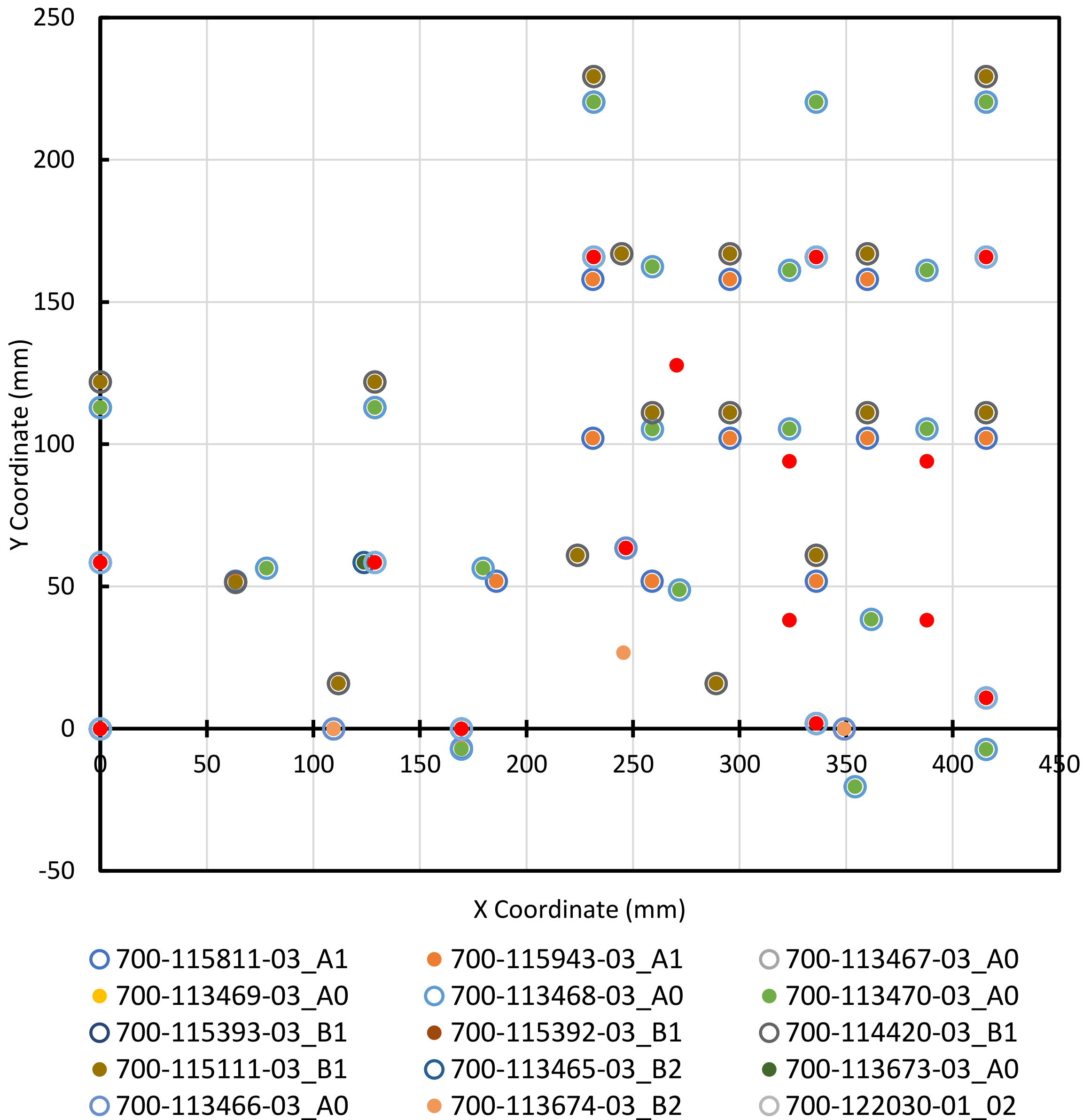


Figure 22. Hole Locations for All 18 Quake Chassis

From this plot, it is apparent that there are no holes past 415 mm in the X-direction or 230 mm in the Y-direction. Although the chassis CAD files does not contain a PCB, it can be interpolated from this plot that Quake PCBs form a boot shape with 1 to 2 PCBs. The chassis holes that directly overlapped with each other are part of the same subfamily. Moving forward we will use one chassis from each subfamily to represent the subfamily and reduce overlaps. Table 10 shares which chassis corresponds to each subfamily.

Table 10. Quake Chassis Sorted by Subfamily

Quake Subfamily	Chassis ID's
Hornet	700-115811-03_A1 700-115943-03_A1
Enforcer 2X25G	700-113467-03_A0 700-113469-03_A0
Enforcer 4X10G	700-113468-03_A0 700-113470-03_A0
Gunner Non-POE	700-115393-03_B1 700-115392-03_B1
Gunner POE	700-114420-03_B1 700-115111-03_B1
Vore Classic Non-POE	700-113465-03_B2 700-113673-03_A0
Vore Classic POE	700-113466-03_A0 700-113674-03_B2
Vore CR Non-POE	700-122030-01_02 700-122032-01_03
Vore CR POE	700-118668-01_07 700-122031-01_05

Although the chassis share similar naming conventions, at first glance, there are no obvious trends among the chassis IDs. Using the information in Table 9, Figure 23 plots hole locations based on chassis subfamilies.

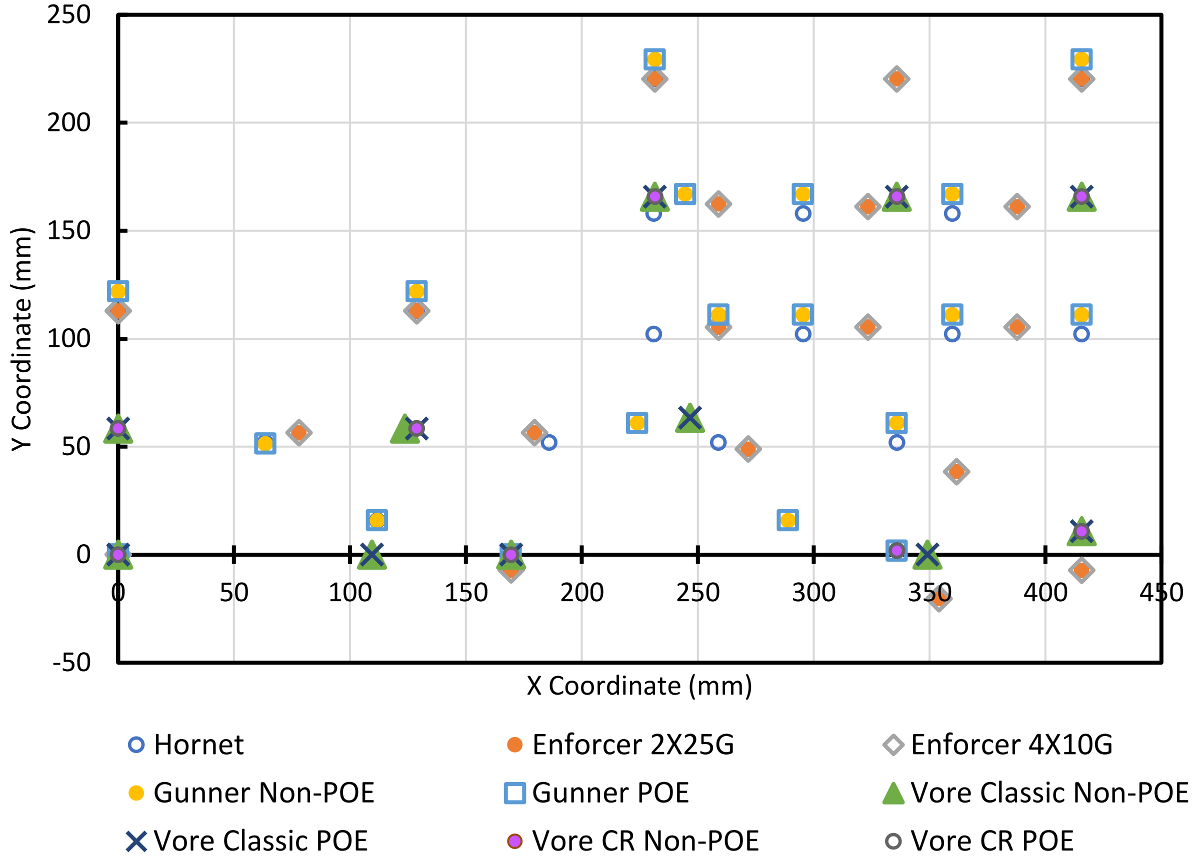


Figure 23. Quake Hole Locations Based on Chassis Subfamily

From Figure 23, chassis in the Vore subfamilies aligned rather closely as do chassis in the Gunner and Enforcer families, respectively. Points that should be considered for standardization are those with three or more points in a single location and then 1+ point(s) within 5-10 mm.

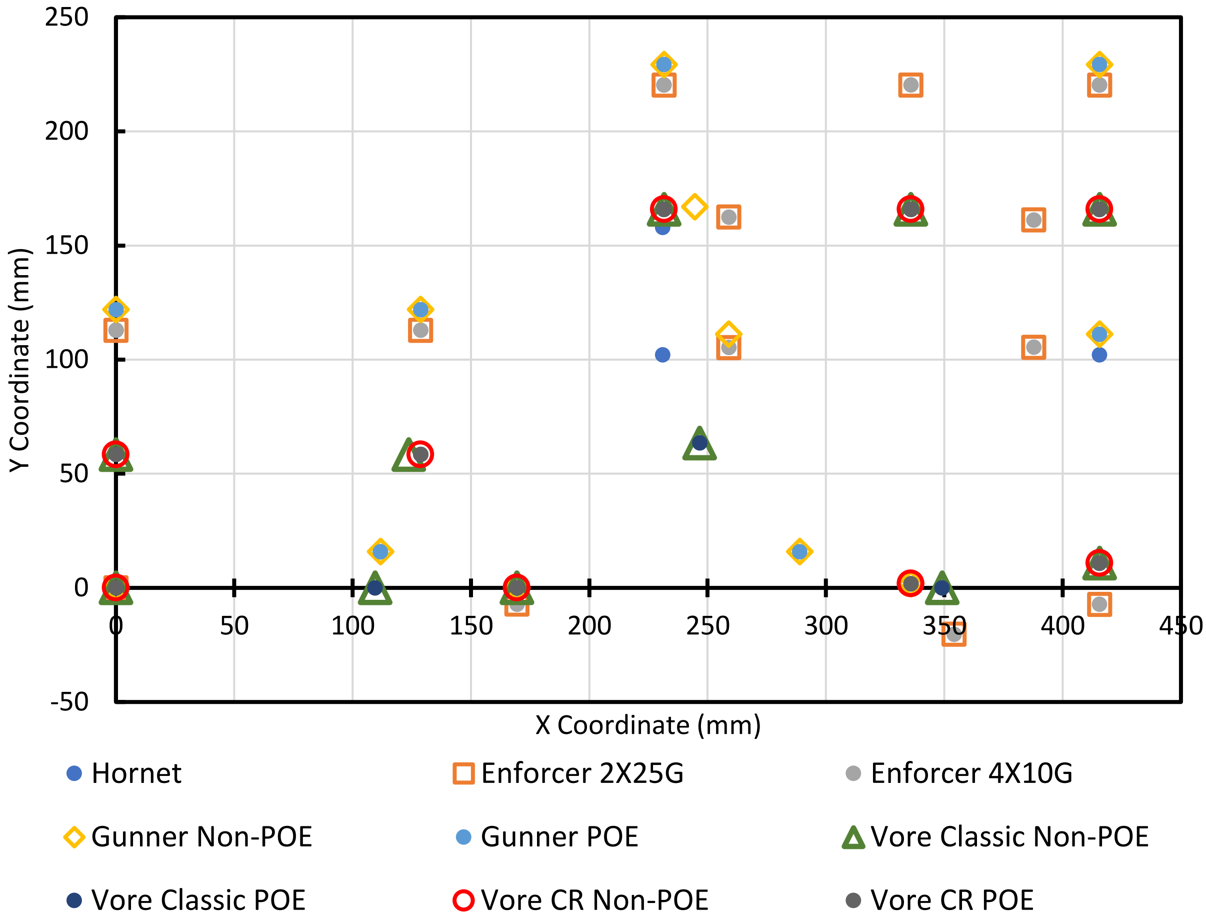


Figure 24. Quake Hole Locations of Perimeter Holes

From Figure 24, all Vore chassis as well as Gunner, Hornet, and Enforcer have potential for standardization as certain hole locations lie within 5-10 mm. With this information, we chose to split Quake chassis based on depth.

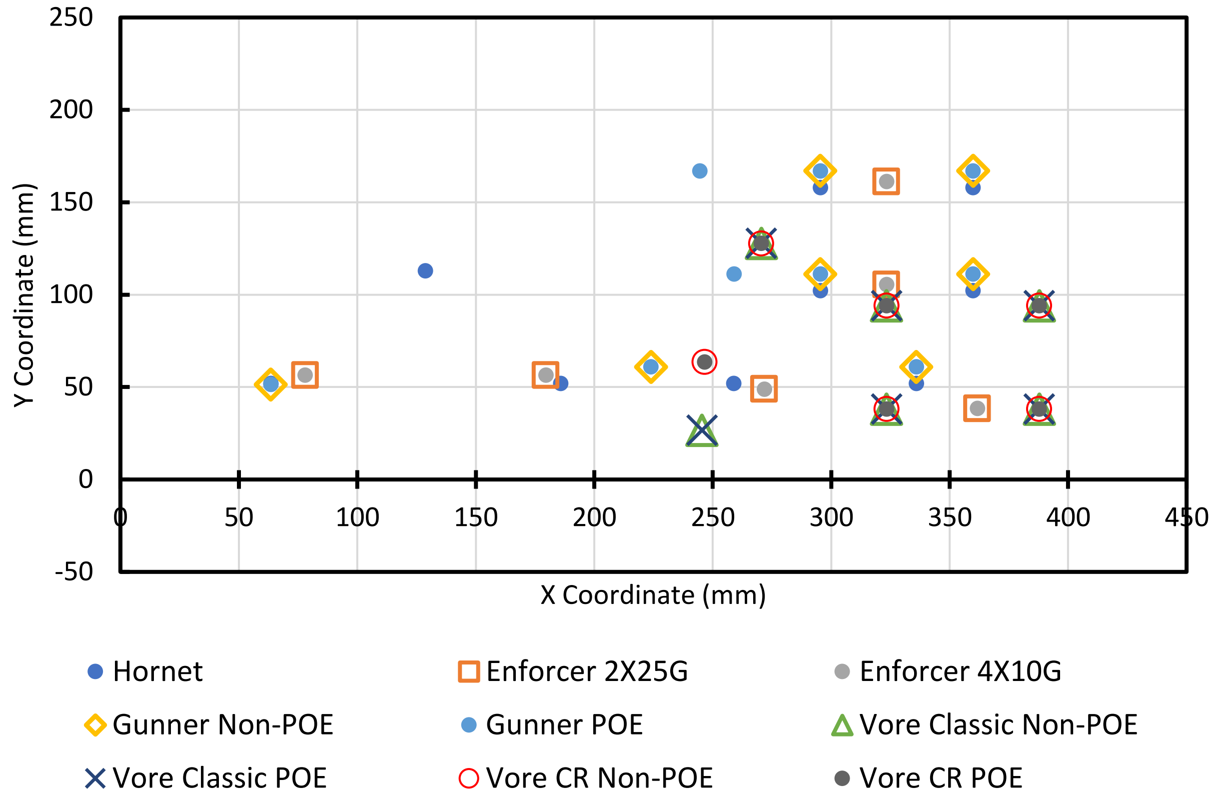


Figure 25. Quake Hole Locations of Interior Holes. Graph was scaled equally to Figure 24 to better represent the typical location for an interior hole.

Based on the overlapping holes in this plot, there are more opportunities for standardization in interior holes rather than perimeter holes. From our data collection, we noticed some chassis had a longer depth (Y-axis) than others. We decided to investigate chassis size as a potential area of standardization. Figure 26 plots hole locations for chassis whose holes reach 230 mm in the Y-direction.

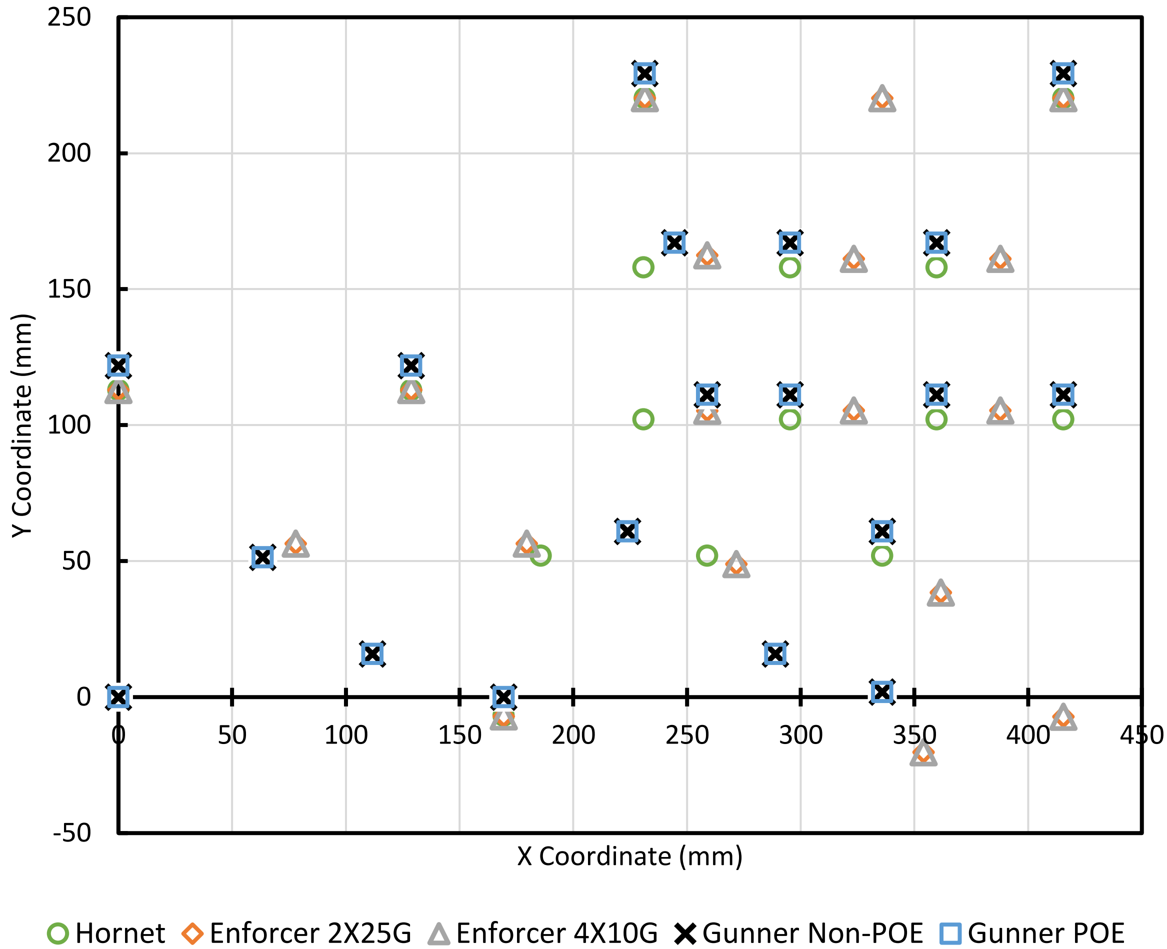


Figure 26. Quake Hole Locations for Chassis with a Depth of 13.6”

From this plot, chassis with a depth of 13.6” (345 mm) consist of Hornet, Enforcer, and Gunner. The Gunner Non-POE and POE chassis have near perfect overlap as well as the Enforcer 2X25G and 4X10G chassis. Hornet holes closely align with the Gunner series with some outliers. Figure 27 plots hole locations for chassis with a shorter depth of 11.2” (284 mm) whose holes reach 166 mm in the Y-direction.

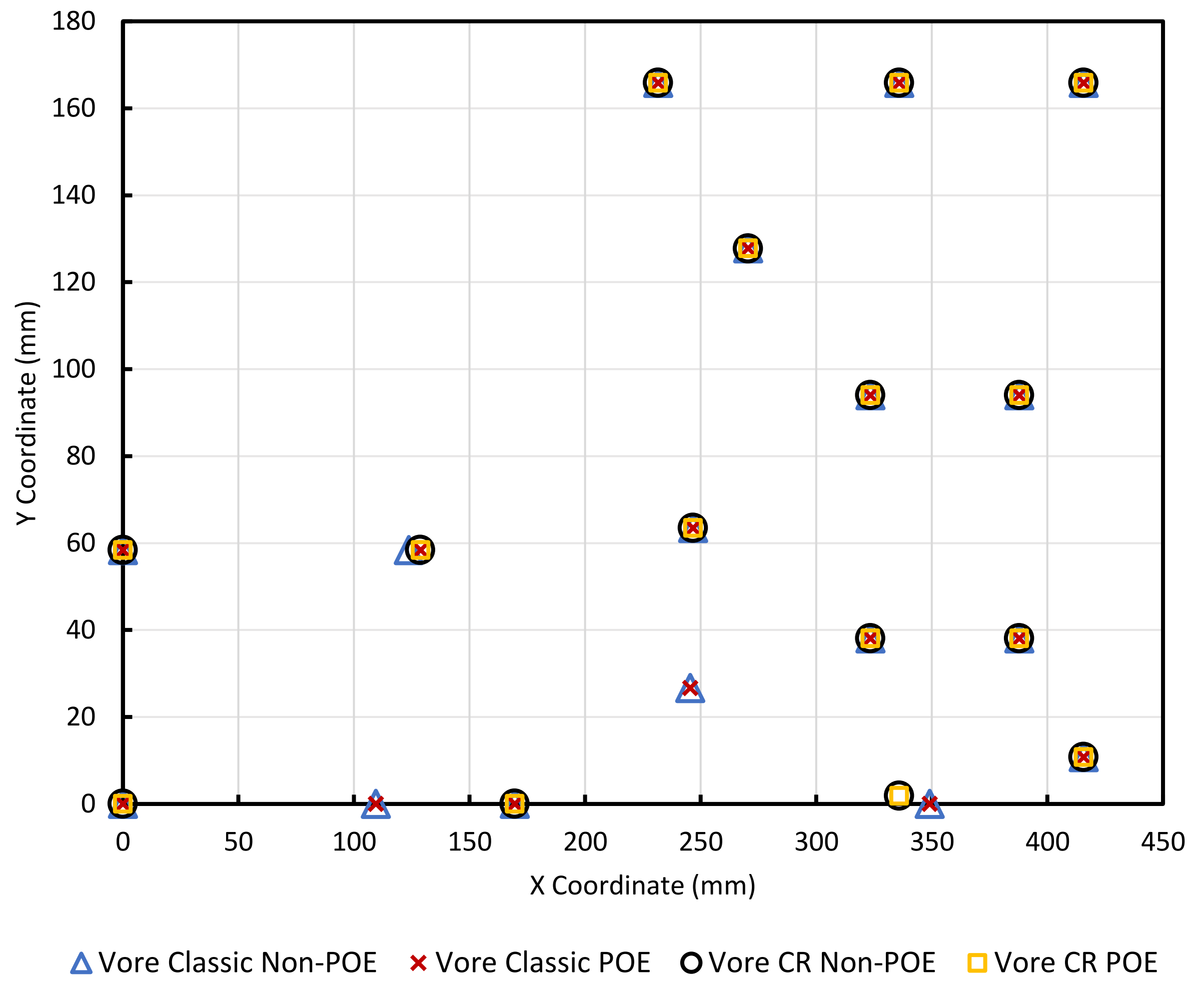


Figure 27. Quake Hole Locations for Chassis with a Depth of 11.2”

From this plot, all 11.2” depth chassis are part of Vore subfamilies. Except for three locations that will be considered for standardization moving forward, all chassis holes are in alignment.

From our investigation, grouping chassis by their depth (Y-axis) has the best potential for standardization and yields more potential for standardized hole locations. For 13.6” depth chassis, the Hornet subfamily will be paired with Gunner chassis. 11.2” depth chassis will only consist of Vore chassis. Additionally, a size-based approach will allow us to split the data into two, which will make it easier to analyze. For our deliverables to Cisco, we will deliver hole standardization documentations based on Quake chassis sorted by depth and subfamily.

5.3 Final Hole Standardization Documentation

Our final analysis took place with the Quake chassis files. These 18 files came from the same family of chassis and were able to be split into nine subfamilies. To properly analyze this data, we split the nine subfamilies among sizing groups to make sure that all holes were measured center-to-center with a designated origin as the bottom left hole when looking top down. An example of the process that was used to record hole locations can be found in Figure 28.

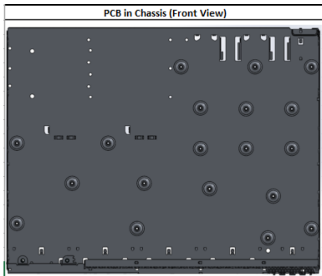
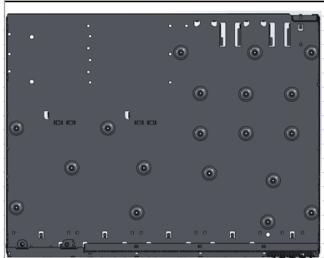
PCB in Chassis (Front View)	Quake Subfamily	Chassis ID	X Coord.	Y Coord.	Unit	Hole Type	Notes
	Enforcer 4X10G	700-113468-03_A0	0.00	0.00	[mm]	Toadstool	
			169.47	-7.11	[mm]	Toadstool	beneath origin
			354.13	-20.32	[mm]	Toadstool	beneath origin
			415.62	-7.21	[mm]	Toadstool	beneath origin
			387.81	105.41	[mm]	Toadstool	
			387.81	161.16	[mm]	Toadstool	
			415.62	220.29	[mm]	Toadstool	
			335.92	220.29	[mm]	Toadstool	
			231.57	220.29	[mm]	Toadstool	
			258.98	162.43	[mm]	Toadstool	interior?
			258.98	105.28	[mm]	Toadstool	interior?
			128.78	112.90	[mm]	Toadstool	
			0.00	112.90	[mm]	Toadstool	
			77.98	56.44	[mm]	Toadstool	interior
			179.58	56.44	[mm]	Toadstool	interior
			271.78	48.87	[mm]	Toadstool	interior
			361.70	38.46	[mm]	Toadstool	interior
			323.39	105.41	[mm]	Toadstool	interior
			323.39	161.16	[mm]	Toadstool	interior
		700-113470-03_A0	0.00	0.00	[mm]	Toadstool	
			169.47	-7.11	[mm]	Toadstool	beneath origin
			354.13	-20.32	[mm]	Toadstool	beneath origin
			415.62	-7.21	[mm]	Toadstool	beneath origin
			387.81	105.41	[mm]	Toadstool	
			387.81	161.16	[mm]	Toadstool	
			415.62	220.29	[mm]	Toadstool	
			335.92	220.29	[mm]	Toadstool	
			231.57	220.29	[mm]	Toadstool	
			258.98	162.43	[mm]	Toadstool	interior?
			258.98	105.28	[mm]	Toadstool	interior?
			128.78	112.90	[mm]	Toadstool	
			0.00	112.90	[mm]	Toadstool	
			77.98	56.44	[mm]	Toadstool	interior
			179.58	56.44	[mm]	Toadstool	interior
			271.78	48.87	[mm]	Toadstool	interior
			361.70	38.46	[mm]	Toadstool	interior
			323.39	105.41	[mm]	Toadstool	interior
			323.39	161.16	[mm]	Toadstool	interior

Figure 28. Hole Data Example of subfamily Enforcer 4X10G

Holes that were located beneath the origin were mentioned and defined by a negative Y coordinate. After collecting hole data, we noticed that for each subfamily the two associated chassis had identical hole locations. This narrows down our data to nine sets of locations which will allow us to be more thorough moving forward. We plotted all subfamilies, all chassis ID's, interior hole locations, perimeter hole locations, 13.6" depth chassis, and 11.2" depth chassis as seen from the figures in Section 5.2. Without a CAD model of the PCB, certain points could not be classified as interior or perimeter holes, so they were labeled as "interior?". From this, sorting the chassis files by the chassis depth is more effective in developing an analysis tool than looking at either perimeter or interior holes with the current state of our CAD models. An example of the 13.6" depth vs 11.2" depth chassis comparison is seen in Figures 29 and 30, respectively.

Figure 29. 13.6" Depth Chassis 700-113467-03_A0 from Enforcer 2X25G subfamily

Dimensions: 17.4" x 13.6"

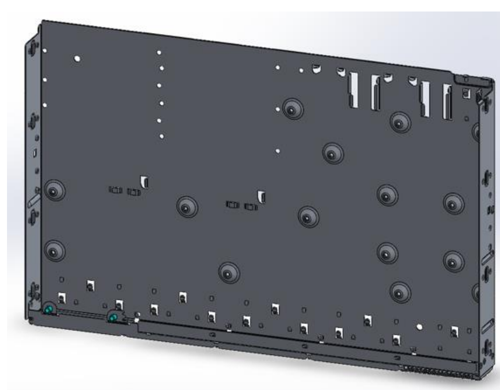


Figure 30. 11.2" Depth Chassis 700-122030-01_02 from Vore CR Non-POE subfamily

Dimensions: 17.4" x 11.2"

Now that we sorted the chassis by length, we created two standardization documents for 13.6” depth and 11.2” depth chassis. Table 11 shows how the chassis will be sorted.

Table 11 Initial Chassis Sorting

Chassis Depth	Chassis Subfamily
Short – 11.2” (284 mm)	Vore Classic Non-POE Vore Classic POE Vore CR Non-POE Vore CR POE
Tall – 13.6” (346 mm)	Hornet Enforcer 2X25G Enforcer 4X10G Gunner Non-POE Gunner POE

Our team created a PDF called “Quake Chassis Standardization” that provides a detailed overlay of hardware images and hole locations for each chassis. The PDF can be found in Appendix E. In it contains both arguments and evidence for specific hole locations. An argument for each chassis depth proposal contains a labeled image of the chassis hardware overlayed with hole drawing locations. Figure 31 below shows the proposed official hole locations for the 11.2” depth chassis. Our final design includes original coordinates, MATLAB generated plots detailing repetition, and 1:1 overlay detailing hardware locations of specific chassis and PCBs. These documents will be used by Cisco as a method of checking before new 1RU production.

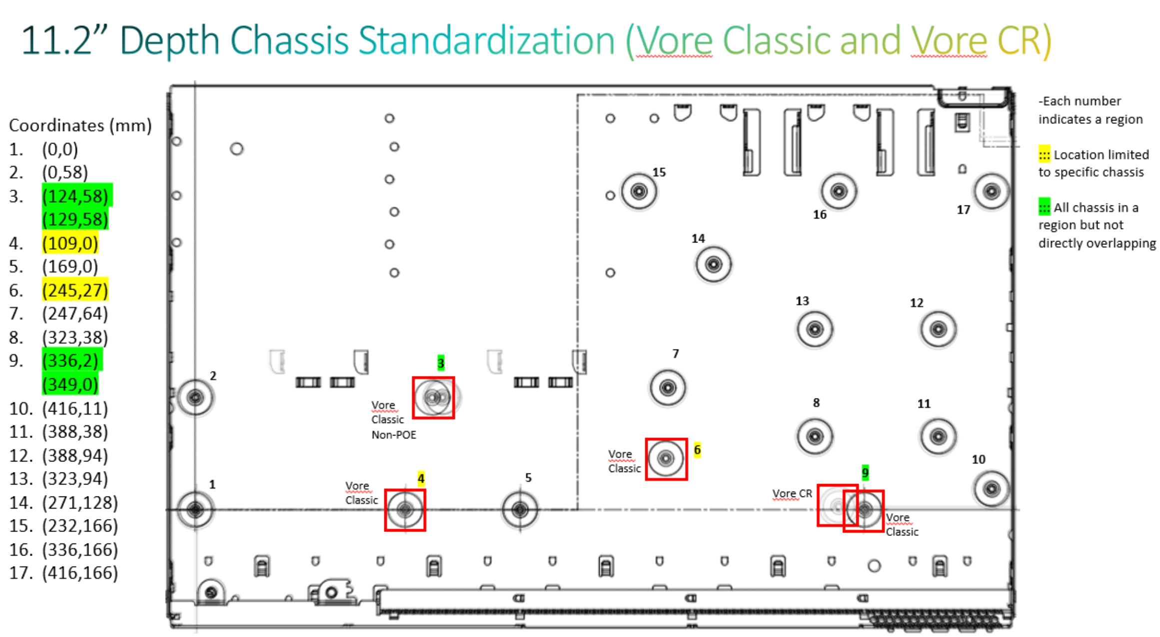


Figure 31. Standardization Document for 11.2” Depth Chassis

In Figure 31, the red boxes indicate cases where the holes differ between Vore chassis. At locations 3 and 9, Vore Classis has a slightly different location than Vore CR. At locations 4 and 6, holes are only present in Vore Classic chassis. Unlike the 11.2” depth chassis, the 13.6” depth chassis had origins that did not overlap when the drawings were aligned by the corner. Since Gunner was developed before Enforcer and Hornet, its origin is slightly lower than the other two. Regardless, we decided the best method for documentation was to align the chassis by corner instead of origin. Figure 32 below shows the proposed hole locations for the 13.6” depth chassis.

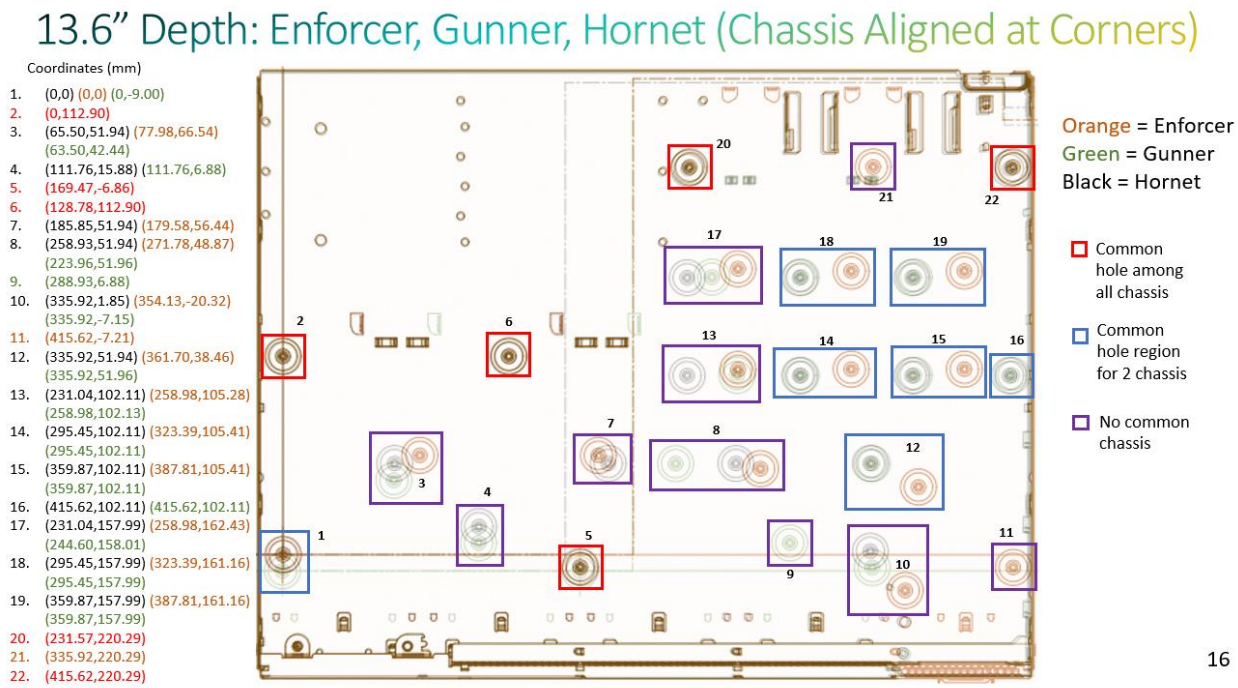


Figure 32. Standardization Document for 13.6” Depth Chassis

In the chassis overlay the orange coordinates indicate Enforcer, green indicates Gunner, and black indicates Hornet. The red boxes in the figure and red coordinates on the left indicate common holes for all three chassis. The blue boxes in the figure specify hole regions common to two overlapping chassis. In their corresponding coordinate number on the left, we used orange, green, and black text to indicate which chassis fell in the designated region. The purple box means no common chassis are present.

6. Hole Optimization MATLAB Tools

After plotting all hole locations on a single chart, it became apparent that a process for deciding the optimal standardized hole was needed. We decided that a MATLAB script would help us scan across the chassis and compare each point to all the other points. By finding parts of the chassis with many holes in a small region, we were able to identify areas of the chassis with potential for a standardized hole location. For each loop of the MATLAB if statement, it identified the number of center hole locations within a circular area. Our initial design for this can be found in Figure 33 below.

Example Code:

```
R=1;
if x1,y1 <= R [mm] from x,y        % finds the points within a radius of a locating point
        Then density=n+1
```

Figure 33. Initial Hole Density Calculator Model

The MATLAB code can be found in Appendix F. Some factors that can be changed are the radius of the circular area that checks nearby holes and the increments that the circular area will move in the X- and Y-direction. We saw a positive correlation between the hole density-to-area ratios and the cluster of hole locations we plotted. The MATLAB script helped mathematically determine optimal standardized hole locations.

The goal of creating this MATLAB script was to automate our current process of visualizing and grouping data. This code can be used to easily locate holes that can be standardized for future designs. This tool was primarily used to visualize our own hole location plots, so we do not believe it is necessary to provide to Cisco. When we started on this assignment, we considered implementing features that would help users choose how they want to group the data. Some ideas that were brought up include: changing the origin so it is located at the hole closest to the bottom left corner of the chassis, grouping the data by server type, and grouping chassis of the same family. To create a script that allows for the origin to change, a loop can run through all the data and translate a set distance that is known in both X- and Y-directions. For grouping the same-family chassis, the code can find similarities in the perimeter hole locations and identify common patterns. Lastly, to group the data based on server type, the file names can either differ for switches and routers or the script can identify based on typical chassis dimensions. We felt that this script was not useful to Cisco early on in development, so we opted for a different functionality.

6.1 Constructing Final MATLAB Script

After meeting with Cisco design engineers, our group decided to change the direction of our MATLAB tool. To suit the needs of Cisco designers, our MATLAB tool ranks sets of tooling hole locations against a set of input chassis hole locations. To do this, our code runs a loop comparing each chassis hole with the holes in a single set of tooling and counts the number of chassis holes that are within an input radius from each tooling hole location. It then runs for every tooling set and ranks them based on whichever tooling set has the highest count and can be found in Appendix G. This concept is shown as an illustration in Figure 34.

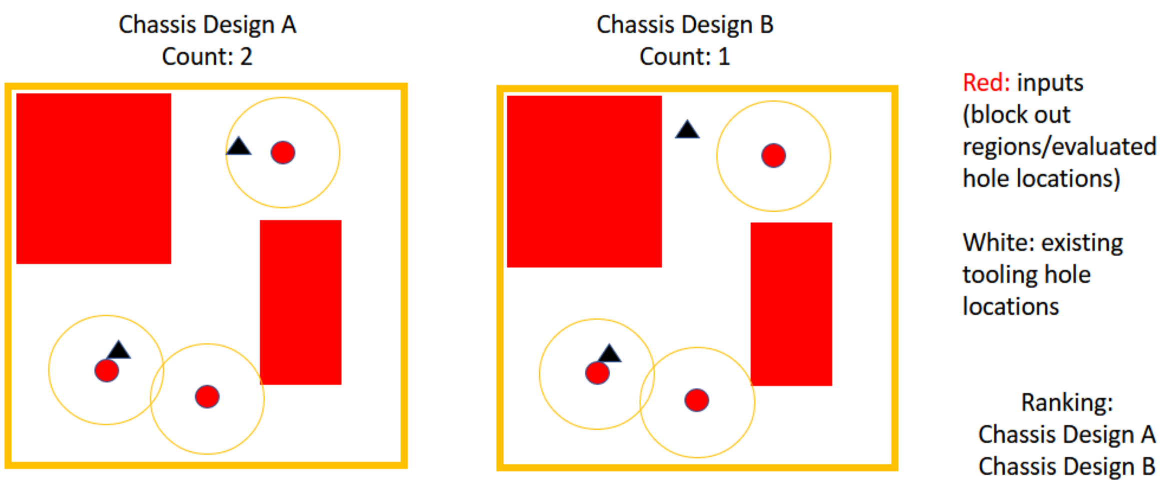


Figure 34. Hole Count Concept Model

From Figure 34, a visualization of the MATLAB concept is shown for two different designs (Design A and Design B). Design A is shown to have a higher count number than Design B because both of the chassis holes (indicated with black triangles) fall within the tooling radius. Whereas in Design B, only one of the chassis holes does, therefore, has a count number of one.

6.2 Final MATLAB Script

Our final MATLAB deliverable contains a tool that compares similar chassis sets and identifies where holes can be standardized. The first draft of the MATLAB tool marks high density locations for potential standardized hole locations. The final tool expands on and modifies the first draft to compare tooling sets with a single set of chassis hole locations and outputs the best matched tooling set.

The first draft of the MATLAB tool runs a main loop for each set of chassis hole locations, which are gathered from an input Excel file. Each hole coordinate will also act as a density circle and the density increases based on the number of points that are within a certain distance from it. Once every hole runs through the loop, the output will then be the list of holes that meet a set density number. A plot will then be graphed with the hole locations of all input chassis, highlighting the list of output holes. Lastly, the list of holes that met a certain density number were averaged. This resulted in a single coordinate that could be a possible standardized location for Cisco to use.

The MATLAB tool compares various sets of tooling hole locations with a single set of chassis hole locations. Like the first MATLAB tool, our input will be extrapolated from two different Excel files, one with tooling data and the other with chassis data. This time with a fixed set of chassis hole locations to reference, it compares each new chassis point with reference tooling points and grades each chassis based on how similar they are to the reference. This MATLAB tool helps Cisco choose which tooling set has the most potential to be reused based on a specific chassis.

Along with the MATLAB tool, our team created instructions for using the MATLAB tool as well as an instructional video to follow along. The user manual, found in Appendix H, includes step by step instructions to help users input data and run the MATLAB tool. The tool lets users grab set data from existing chassis hole coordinates in an Excel file and insert them into another Excel file, which MATLAB will pull data from. Each step in the instructional document includes the action needed to be done, an explanation of why it needs to be done and a screenshot of relevant pictures to help users better understand the procedure. In addition, an instructional video is given to users to watch if any of the steps on the instructional document is unclear.

7. Design Verification

After creating the recommendation summary sheet and MATLAB script, the final deliverables were verified by our sponsors and peers. We ensured the products we gave Cisco fulfilled the purpose of the project and was user friendly.

Our design verification plan and report (DVPR) consisted of four different tests, each based on our Google Survey. Our 1st test consisted of us trying out the MATLAB script ourselves to ensure that everything ran smoothly. Test 1 served as the development test which was completed before the initial week of testing. Our 2nd test was a survey with four prototype rounds that were sent out each week. For each iteration, we sent a package to volunteers that included components of our MATLAB code and standardization document. Test 2 in our DVPR was used to gather feedback from the entire Cisco team while they used their free one-month MATLAB trial. After following the MATLAB procedure and reading the standardization documents, the Cisco team filled out a feedback survey. A 3rd test that we offered was a 1-on-1 session with volunteers to guide them as they went through the survey process. We used this to gather immediate feedback to implement. This was also used to find any errors that might occur and questions that people may come up with while going through the procedure and documentation. Our 4th test involved us testing the final MATLAB tool in the last week of the project to verify our confidence of it. Test 4 was used for final verification testing by our own team. After the final round feedback was received and implemented, our team ran through the procedure one last time to verify the tool and voted on the development of our package. The DVPR with original formatting for each test alongside results can be found in Appendix I. We hope that Cisco can utilize and build off the MATLAB script to best work with their chassis manufacturing process.

To ensure our documents aid the designers, we met with them on April 15, 2021, to share our initial findings and recommendations for standardization based on chassis depth. During this meeting we walked through a potential standardization document format and MATLAB testing procedure. Following this meeting we created a four-week prototype schedule that allows for weekly feedback and iteration for the 13.6" Depth chassis, 11.2" Depth chassis, and MATLAB code as shown in Figure 35.

Schedule for Prototype Rounds		
To maximize the MATLAB 30 day free trial we will follow this schedule to get four protototype feedback rounds		
Cisco Team	**Cal Poly**	**# of Days Used**
Monday, April 26 to Friday, April 30	Saturday, May 1 to Sunday, May 2	7 of 30
Monday, May 3 to Friday, May 7	Saturday, May 8 to Sunday, May 9	14 of 30
Monday, May 10 to Friday, May 14	Saturday, May 15 to Sunday, May 16	21 of 30
Monday, May 17 to Friday, May 21	Saturday, May 22 to Sunday, May 23	28 of 30

Figure 35. Schedule for four prototype rounds

The weekdays were dedicated to Cisco engineers and the weekends were dedicated for us to make the necessary changes. During each prototype round the Cisco engineers were tasked with reviewing the material sent to them and providing feedback via a Google Form. The Google Form survey can be found in Appendix J. We tested the standardization document for user friendliness and ease of application to new Cisco chassis. We tested the MATLAB code for repeatability and made sure it was intuitive to the user. To prevent groupthink, we asked our peers to review the documents to make sure they made sense to engineers who may not be as familiar with the material. We received 16 responses over the course of 4 weeks. Ideally, we would have at least 20 responses for statistical significance so it is reasonable to say that we cannot be certain that the results we received are indicative of a larger audience. We hope that the tools receive more critique once they are in the hands of Cisco so that they can be further developed.

After clarifying our project and shifting our design direction, our specifications also changed. The verified design meets all the specifications listed in Table 5. The iteration process allowed our team to modify our tool and standardization documents with each round to make it more user friendly. We were able to verify this using a survey at the end of our test procedure to evaluate the clarity of our tool and documentation. The effective documentation specification was also met by having lots of people look at our project and provide us written feedback on necessary aesthetic improvements. The specification of ranking different chassis sets by outputting rank values in the script was verified by our test procedure and MATLAB script in Appendix G.

The specifications that were not met are listed in Table 4. This is because Table 4 no longer pertains to our team because the scope of our project changed. All the specifications in Table 4 will be affected if the chassis were to be standardized and redesigned. Table 5 is the updated specification table since our project is now specifically focused on standardizing the mounting holes and tooling.

7.1 Standardization Document Verification

The "Quake Chassis Standardization" document provides official hole locations and evidence for Quake chassis. As previously described in Chapter 5.3, the document is split into two sections: 11.2" depth and 13.6" depth. We used the prototype rounds to ask users if the document's layout answered our original problem statement. All survey feedback can be found in Appendix K.

We asked our users if the documents agree with Cisco's current manufacturing methods. All student responses were declared as N/A since they lack proper qualifications. Figure 36 shows that in all four prototype rounds, we mainly received "Good" or "Great". We considered any test with positive results greater than 67% as a success.

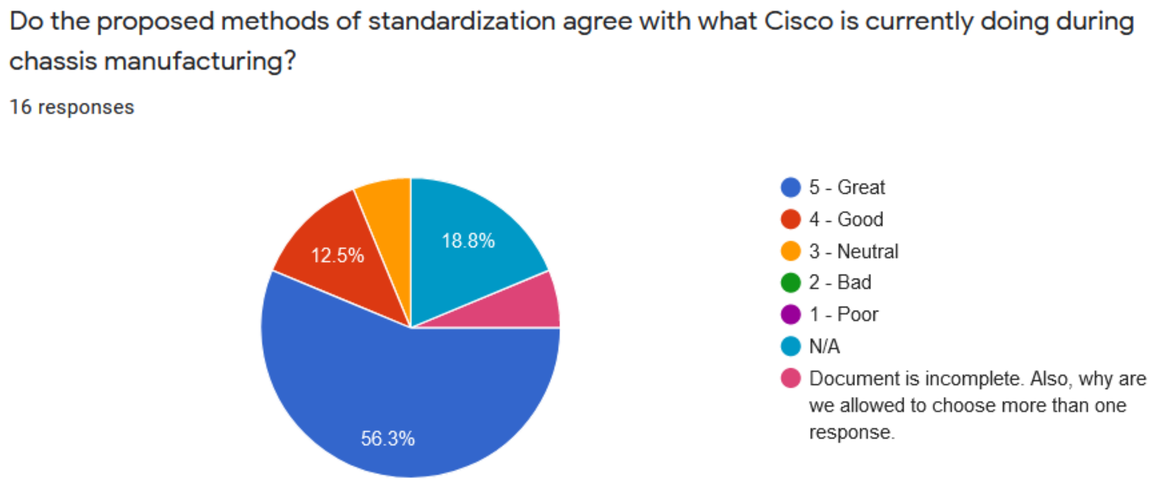


Figure 36. User responses for proposed standardization document matching current Cisco methods. Approximately 69% of users rated the document as good or great.

Next, we asked users if the documents were aesthetically pleasing. Figure 37 shows that in all four prototype iteration rounds, users primarily ranked the document as "Good" or "Great."

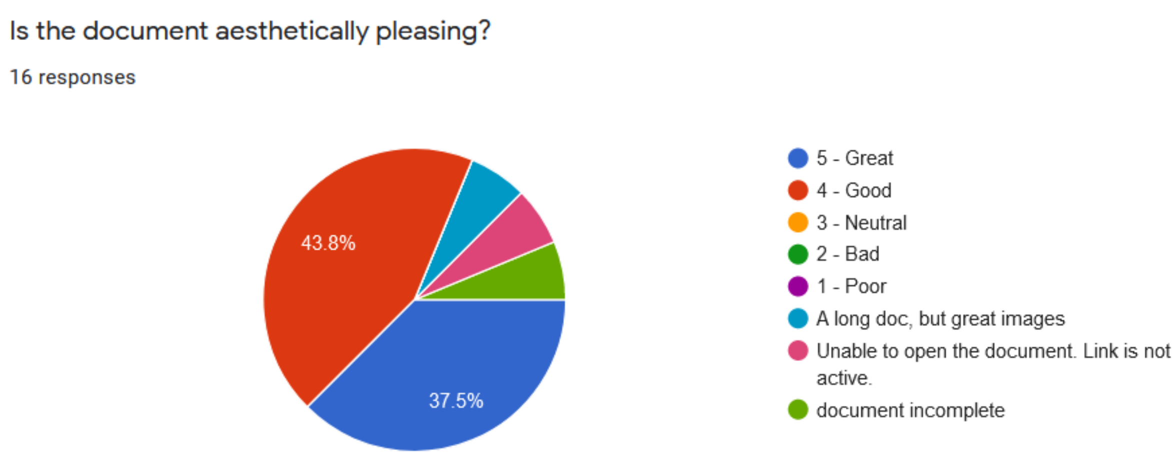


Figure 37. User responses for aesthetics of the standardization document. Approximately 81% of users agreed that the document was aesthetically pleasing.

The primary challenge in creating the standardization document came from not receiving information in a timely manner. To propose official hole locations, we needed the annotated chassis images so we could overlay the hole locations and begin our analysis. Unfortunately, we did not receive Hornet and Gunner images until the middle of Round 2 which resulted in only two weeks of feedback for the second half of the standardization document.

Had we received more responses from Cisco, we would have chosen to present our data split by prototype. This would more accurately show the evolution of the documents based on the specific feedback that we received for each. Unfortunately, since our sample size was low over the 4-week process we chose to keep all data together so that we could preserve statistical significance. Given another prototype phase, we believe it would be beneficial if we persuaded more engineers from Cisco as well as reaching out to our peers and professors.

7.2 MATLAB Code Verification

In order to ensure the MATLAB code ran without errors, we tested the tool ourselves before sending out our tool to the Cisco engineers. After we verified the MATLAB code, we began the four-week prototype iteration where various Cisco engineers evaluated our tool starting on April 26, 2021. An instructions manual was provided during the trial for the engineers to follow and a survey was given at the end. We followed the schedule for MATLAB iterations as shown in Figure 35. For the instructions, the users followed an example and input sample chassis hole locations and two separate tooling set locations. Figure 38 shows an excerpt of the script used in the prototype rounds. The survey asked questions to determine how well the user understood the product and how the script could be improved. We had designated areas for inputs within the code and analyzed whether the script was intuitive to people who have never seen it before. To gauge the effectiveness of the script we focused on whether the inputs and outputs were understood by the user, how foolproof the interface was, and whether the outputs of the script had any beneficial use to the engineers. In Week 2 of the iteration rounds, we had a 1-on-1 session with one of our sponsors to follow the MATLAB procedure to receive immediate feedback.

```
%% Sheet 2
opts1 = spreadsheetImportOptions("NumVariables", 2); %callout for the spreadsheet
opts2 = spreadsheetImportOptions("NumVariables", 2);

%Specify sheet and range for spreadsheets
opts1.Sheet = "Sheet2"; %different sheet per chassis
opts2.Sheet = "Tooling";
opts1.DataRange = "A1:B20";  %Data selection
opts2.DataRange = "A1:B20";

% Specify column names and types
opts1.VariableNames = ["VarName1", "VarName2"];
opts2.VariableNames = ["VarName1", "VarName2"];
opts1.VariableTypes = ["double", "double"];
opts2.VariableTypes = ["double", "double"];

% Import the data
ToolingHoleLocations = readtable("Chassis Hole Locations Test.xlsx", opts2, "UseExcel", false);
ChassisHoleLocations = readtable("Chassis Hole Locations Test.xlsx", opts1, "UseExcel", false);
n=0;
a=1;
ii=1;
increment= 1; % XX size of jumps between locating points [mm]
Matrix_1= table2array(ToolingHoleLocations); %Creating matrix for tooling data set
Matrix_2 = table2array(ChassisHoleLocations); %Creating matrix for chassis data set

out1=[]; %output matrix

for k=1:size(Matrix_1,1)    %runs through tooling holes
    for i= 1:size(Matrix_1,1) % going through each input point
        if sqrt((Matrix_1(k,1)-Matrix_2(i,1))^2+(Matrix_1(k,2)-Matrix_2(i,2))^2) <= Minimum_Distance    %matches similar holes
            n=n+1;
            i+i+1;
        else
            n=n+0;
        end

    end
    out1 = [out1; n, Matrix_2(k,1),Matrix_2(k,2)] ;  %output for chassis
    Density = [n, Matrix_2(k,1),Matrix_2(k,2)] ;  %density output
    n = 0;
end

Sheet2 = sum(out1(:,1)) %number of holes that are within minimum distance [mm] from tooling
```

Figure 38. Example of MATLAB script used for primary analysis tool

We asked our users if the purpose of our MATLAB tool was clear. Figure 39 shows that in all four prototype rounds, we received a majority of "Very clear" responses. We made sure to examine by week for this question as it was the only test that received less than 67% positive results.

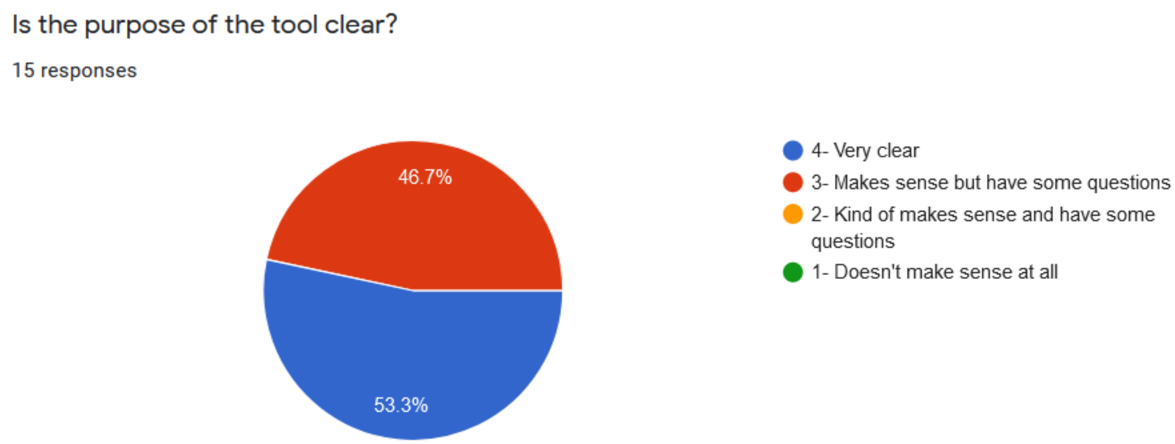


Figure 39. User responses for clarity of MATLAB tool. Only around 53% of users agreed that the purpose of the tool was clear. Fortunately, from the 4th week of iterations, 75% of users found the MATLAB tool "very clear" (6/8 responses). This passed our initial limitation of 67% positive results.

Next, we asked users if the MATLAB was easy to follow. Figure 40 shows that in all four prototype iteration rounds, users primarily ranked the document as "Very easy to follow".

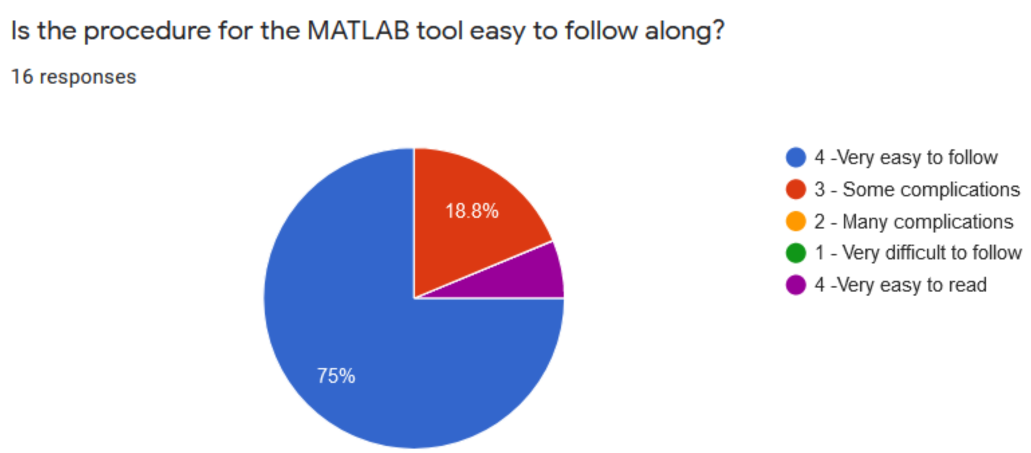


Figure 40. User responses for ease of following along with MATLAB tool. Around 81% of users agreed that our MATLAB tool was "Very easy to follow".

A key challenge during the design verification process were not receiving enough users to test our deliverables. From the first challenge of not receiving enough users for testing, the lesson learned was that our group should not expect more than three users on the first round of testing, especially since Cisco employees are running a busy schedule. Instead, we should open up testing to our peers for increased feedback and perspectives.

8. Risks, Challenges, and Unknowns

One of the risks and challenges was choosing a chassis origin that worked with our initial 24 chassis. The risk came with different team members selecting the chassis origin for their assigned chassis. To address this, we consolidated hole locating to a single group member. By doing so, we reduced any ambiguity for chassis origins. This risk was eliminated for Quake chassis since Cisco provided documents that labeled the origin hole in the bottom left corner.

Risks to consider were the changes in the stress distribution when changing the mounting holes on the chassis. To distribute stresses caused by forming emboss (stretching the metal) or die cutting, the operation is divided into several stages so warping of the part can be minimized. Furthermore, after parts are punched and extruded, there are bending stages used to form the sides of the box. Thus, when holes are too close to each other, stress can easily build up when manufacturing these chassis.

One of the biggest challenges with this design project was iterating design practices and coming up with feasible ideas. During our brief ideation phase, one of the main designs our group focused on was to standardize the mounting holes so that different PCBs could be rotated to fit. This was a good idea at first, but through understanding the design and manufacturing processes it was not feasible. The reason being the design locations for features mounted on the PCB would also be moved, thus making the design more complex. Another issue with this idea is there cannot be any unused mounting holes on the chassis because it can be a fire or electrical hazard. As we progressed into our project, our group made sure to abide by the fire enclosure safety standards from EN 60950 and UL 60950, which address prevention methods for fire spread [19].

Another challenge our team faced when coming up with design solutions was standardizing the interior mounting holes. At first, our focus of standardizing the chassis was on the perimeter holes, but as we continued collecting data, our group noticed some of the interior holes are related to the perimeter holes in order to mount heat sinks, fans, and other large components. With this taken into consideration, our group recollected data including the interior mounting holes to see if it affected our preliminary data. We decided that to standardize these perimeter and interior hole combinations, we need to always consider the interior hole to be perimeter. From this, an even larger space on the PCB needs to be analyzed when attempting to move holes around.

In addition, due to the limitations of the NDA, our team faced challenges in receiving completed PCBs in the chassis CAD files. We were asked to identify perimeter PCB hole mounting locations, but as mentioned earlier, interior holes can also be identified as perimeter holes. This made it difficult to consider other hole locations as there could have been small components prohibiting movement.

As we completed our final MATLAB tool, some issues we faced were not having tooling data to run the code and having different origin locations on the tooling schematics than the chassis, and not having enough Cisco design engineers participate in our MATLAB testing. For a complete list of design hazards, refer to Appendix L.

9. Project Management

Table 12 below shares due dates of important deliverables. The entire timeline of deliverables can be found in our Gantt Chart in Appendix M. Since we were not creating a 1RU chassis from scratch, our design techniques relied on our observations and CAD analysis skills. We used SolidWorks, CATIA, and Fusion 360 to understand and analyze the CAD files we received.

Table 12. Due Dates of Important Deliverables

Deliverable	Due Date
Scope of Work	10/12/2020
Preliminary Design Review	11/15/2020
Critical Design Review	2/25/2021
Complete All Hole Analysis	4/30/2021
Complete Prototype Rounds	5/23/2021
Final Design Review	6/03/2021

The Scope of Work outlined our project's background and scope as the first building block for the rest of our project. The Preliminary Design Review (PDR) discussed our observations and analysis from the original 24 CAD files and a MATLAB tool deliverable. The MATLAB tool automated grouping hole clusters to aid us in creating standardized hole locations. The Critical Design Review (CDR) addressed the results from our original 24 chassis and provided an analysis of 18 new Quake chassis. The Quake chassis were analyzed based on their subfamily, interior and perimeter holes, and chassis length. Next, the CDR addressed what we intended to deliver as well as included a design verification. Our Final Design Review (FDR) deliverable included Quake family standardization documents based on Quake chassis and a MATLAB tool that found the optimal tooling for a selected chassis. We verified our deliverables were user friendly by sharing multiple prototypes and surveys with Cisco engineers and students for consistent feedback. Every week we used the feedback to improve our standardization documents and MATLAB code. Updates included expanding the MATLAB instructions into a user manual and explaining the purpose of standardization in the Quake documents. Refer to Figure 35 for the official prototype feedback schedule. By May 23rd, 2021, we completed all chassis analysis and created a functioning MATLAB tool. Finally, the FDR provides Quake family standardization documentation for all PCB holes in addition to a completed MATLAB script. The FDR incorporated feedback given to us from Cisco engineers that tested our MATLAB script and read our standardization documents.

To evenly split the work, Sarika Singhal and Bryce McNeil focused on chassis hole analysis and documentation while Leia Tashiro and John Liu focused on the MATLAB script. Throughout the project both groups interacted with each other to share feedback and work together on minor deliverables and background information. Every week we met with our sponsor to provide an update with our progress to ensure we were on the right track. Outside of weekly sponsor meetings, we had the opportunity to meet and interview chassis manufacturers and designers. Both groups provided insight that we utilized in our final chassis analysis and MATLAB tool. Since our deliverables were intended for chassis designers, we met with them multiple times throughout the project to update them on our progress and gain valuable feedback.

Our design process allowed us to incorporate Cisco's feedback and create tools that will aid the engineers. The monthly meetings with chassis designers helped keep us on track and remind us of our user's needs. Outside of the core four engineers that always attended, every meeting brought one to two new engineers that provided new perspectives. By splitting the core deliverables into two groups, we were able to check each other's work and ask questions that we might not have thought of had all team members been fully immersed in both deliverables. In future design projects we would want to continue holding weekly team meetings and sharing meeting minutes that contain both a summary and action items. If a future project requires survey feedback for iterations, we will want to create new surveys for each round.

10. Conclusion and Recommendations

The goal of our senior design project was to help Cisco save money by reducing the number of custom chassis manufactured. In the three quarters our team worked on the project, we created standardization documents for Quake family chassis and a MATLAB tool to help create cases for standardization. Our team presented these items to Cisco design engineers and brought to light the possibility of standardizing current and future chassis. Our standardization documents display commonality and differences in hole locations for current Quake chassis with overlayed drawings. The MATLAB tool compares the tooling to different sets of chassis hole locations and ranks them based on a count number. Although we were able to provide guides for standardization, we could not standardize hole locations ourselves due to the limitations of our NDA. Overall, our project was a good start in helping Cisco standardize their 1RU chassis and everything our team aimed to accomplish were achieved.

Our team was able to complete the deliverables our sponsor assigned to us, but if we could do the project over again, meeting with Cisco design engineers sooner could have led to a clear understanding of what they wanted from the start. By doing so, our team would not have completed analysis on data that was later considered inapplicable to Cisco. Another change our team would make is asking Cisco for the correct chassis family earlier. Again, this would help make our data analysis process faster, since we were looking at chassis from differing families in the beginning and trying to group them together.

Having completed our senior design project, our team would advise our sponsor to create a follow up project to have our MATLAB tool function alongside the CAD models. This will eliminate the need to manually measure each CAD model and record the hole locations on an Excel file. Another follow up project would be to use the data that has been run through the code, to find a newly standardized chassis and have it manufactured with actual components inside. The goal would then be to have the chassis physically undergo testing to see if it complies with Cisco's standards. Finally, we would suggest looking for potential standardization of LEDs and connectors along the chassis walls.

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Appendix

A. QFD: House of Quality
B. Cisco and Model Chassis Images
C. Original Chassis Hole Locations
D. Quake Chassis Hole Locations
E. Quake Chassis Standardization
F. MATLAB Script Max Density Hole Locator
G. Second MATLAB Script
H. MATLAB Script User Manual
I. DVP & R
J. Google Form Survey
K. Google Form Survey Results
L. Design Hazard Checklist
M. Gantt Chart

Appendix A: QFD House of Quality

Correlations	
Positive	+
Negative	−
No Correlation	

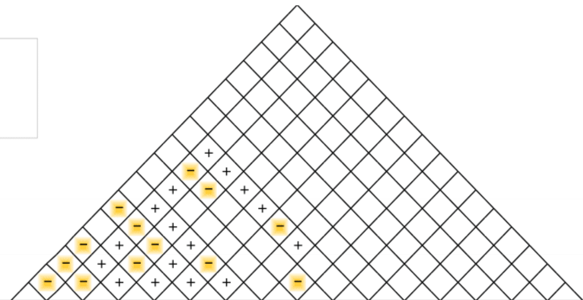
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

QFD House of Quality

Project: Cisco 1RU Chassis

Revision Date: 10/6/2020



WHO: Customers

Row #	Weight Chart	Relative Weight	Cisco	Small Companies	Manufacturers	Technicians	Maximum Relationship	WHAT: Customer Requirements (Needs/Wants)
1		11%	9	3	8	6	9	Dimensions/Geometry
2		10%	6	5	9	5	9	Safe Assembly
3		10%	7	8	2	8	9	Ergonomics/easily mountable
4		11%	9	6	9	4	9	Simplified Production
5		8%	8	4	6	2	9	Quality Control
6		8%	6	2	8	3	9	Manufacturable
7		10%	2	8	7	7	9	Transportable Assembly
8		10%	4	9	3	9	9	Maintenance
9		9%	6	9	2	4	9	Cheap
10		12%	10	7	4	8	9	Durable Assembly
11		0%						
12		0%						
13		0%						
14		0%						
15		0%						
16		0%						

HOW: Engineering Specifications (Tests)

Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Direction of Improvement	▲	▼	◇	▲	◇	▼	▼	▲	▼							
WHAT: Customer Requirements (Needs/Wants)	Good Airflow	Compact Design	Easy to assemble	Common Mounting Locations	Toadstool/standoff usage	Production Cost	Time of manufacturing proces	Durability if dropped	Weight	Ability to fit different PCB's						
Dimensions/Geometry	○	●	○	●	●			●		●						
Safe Assembly			●	○			○		○							
Ergonomics/easily mountable		●					○		○							
Simplified Production		○	●			○				▽						
Quality Control			○				●									
Manufacturable		●	▽		○					○						
Transportable Assembly		●						○	●							
Maintenance	●		▽		○	▽	▽	○	▽	○						
Cheap			○			●	○		▽							
Durable Assembly		●	○			○										
HOW MUCH: Target Values	2 times Max temp of system < PCB max	1.73 feet in length max	Doesn't require special training	4 Mounting Locations	More utilized (#)	Production Cost (lowered by ##%)	Mnfg. time (lowered by ##%)	Chassis doesn't break from 84 inch	Weight - 30lbs or less	1 Chassis Commonized for 3						
Max Relationship	9	9	9	9	9	9	9	9	9	9						
Technical Importance Rating	126.6	493	333.1	127.6	151.4	157.8	171.3	158.4	172.7	162.9	0	0	0	0	0	0
Relative Weight	6%	24%	16%	6%	7%	8%	8%	8%	8%	8%	0%	0%	0%	0%	0%	0%
Curr. Products: k Covergence System 5000 Series	5	5	4	4	4	3	3	2	5	2						
Curr. Products: Cisco 9200 Switch for 32 ports	5	4	4	4	4	4	4	2	5	2						
Curr. Products: › 4431 Integrated Services Router	4	2	3	2	3	3	3	2	3	2						
Curr. Products: › 4331 Integrated Services Router	4	2	3	2	3	3	3	2	3	2						
Curr. Products: SFP+ Rear to Front Airflow Switch	5	2	2	1	3	2	3	2	4	2						
Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

NOW: Curr. Products

Cisco Network Covergence Sys	Cisco 9200 Switch for 32 ports	Cisco 4431 Integrated Services	Cisco 4331 Integrated Services	Arista DCS-7050S-52-R 7050S	Row #
3	3	4	4	3	1
5	5	5	5	3	2
1	1	5	5	3	3
1	1	1	2	1	4
4	4	3	4	3	5
3	5	4	5	5	6
5	5	4	5	5	7
3	3	3	3	5	8
1	2	3	3	3	9
5	5	4	3	5	10
					11
					12
					13
					14
					15
					16

Appendix B: Cisco and Model Chassis Images

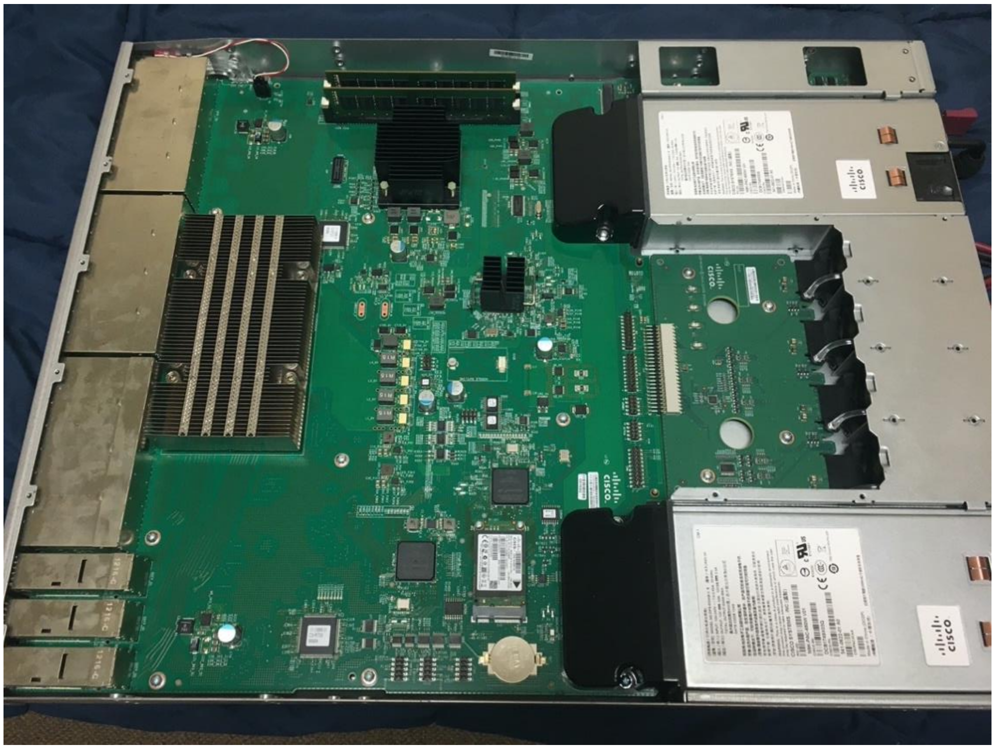


Figure 1. Physical Cisco Server

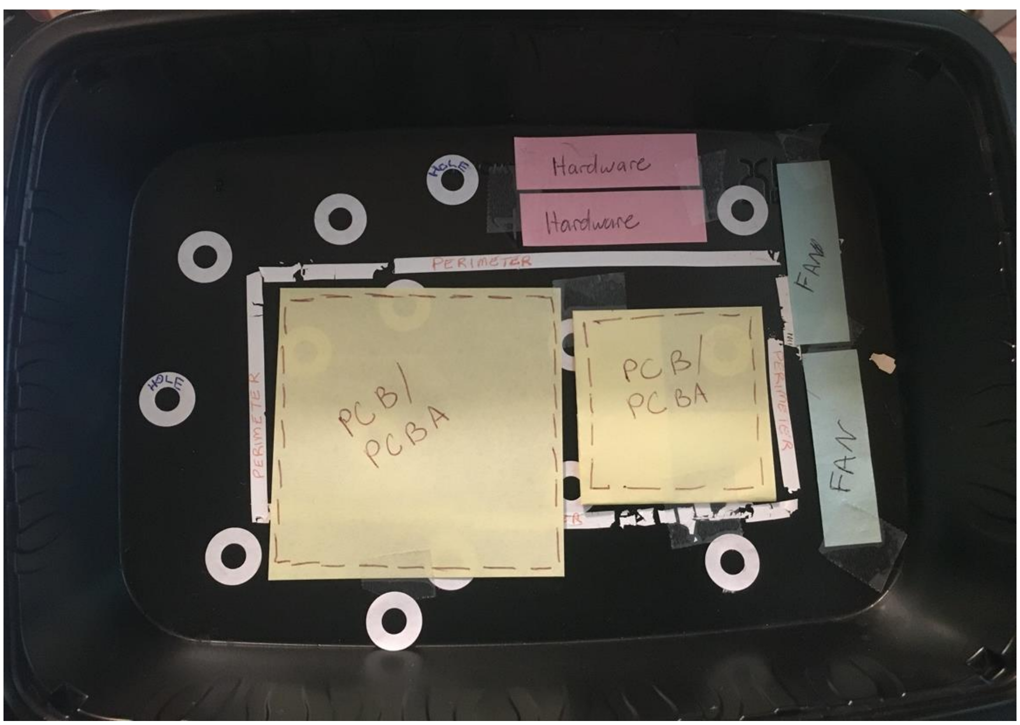
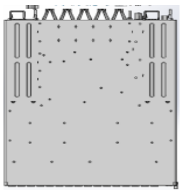
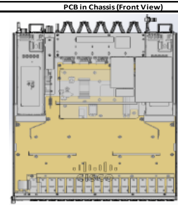
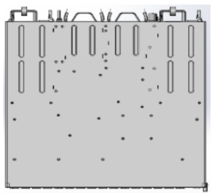
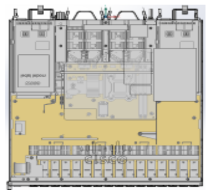


Figure 2: Model Cisco Chassis

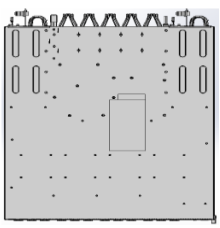
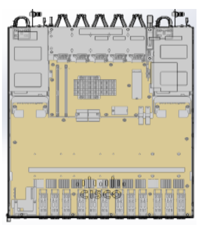
Appendix C: Original Chassis Hole Locations

Chassis (Back View)	PCB in Chassis (Front View)	Image of Origin (Back View)
		

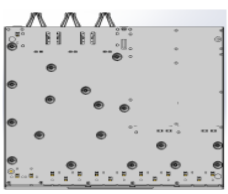
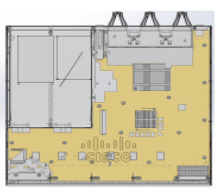
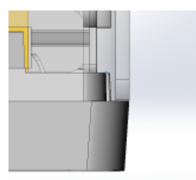
Chassis ID	X Coord.	Y Coord.	Unit	Hole Type	Notes
skyfox (Lower PCB Only), (Switch)	52.09	77.12	[mm]	Standoff	
	14.28	146.45	[mm]	Standoff	
	14.34	242.86	[mm]	Standoff	
	223.54	77.14	[mm]	Standoff	
	321.68	77.11	[mm]	Standoff	
	419.49	77.22	[mm]	Standoff	
	430.22	146.55	[mm]	Standoff	
	430.24	242.84	[mm]	Standoff	
	95.79	260.77	[mm]	Standoff	
	141.43	303.06	[mm]	Standoff	
	194.31	317.10	[mm]	Standoff	
	327.33	280.12	[mm]	Standoff	
	348.67	260.67	[mm]	Standoff	
	63.40	139.90	[mm]	Standoff	interior
	152.30	139.90	[mm]	Standoff	interior
	289.36	139.90	[mm]	Standoff	interior
	378.41	139.90	[mm]	Standoff	interior
	378.40	203.40	[mm]	Standoff	interior
	289.36	203.40	[mm]	Standoff	interior
	152.30	203.40	[mm]	Standoff	interior
	63.40	203.40	[mm]	Standoff	interior
	237.52	271.54	[mm]	Standoff	interior

Chassis (Back View)	PCB in Chassis (Front View)	Image of Origin (Back View)
		

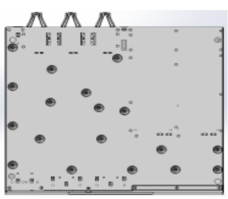
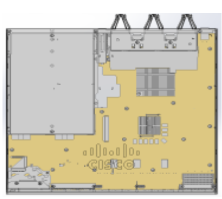
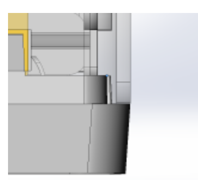
Chassis ID	X Coord.	Y Coord.	Unit	Hole Type	Notes
68-6241-01_prometheus (Lower PCB Only), (Switch)	52.02	77.16	[mm]	Standoff	
	19.69	187.37	[mm]	Standoff	
	14.37	232.94	[mm]	Standoff	
	228.78	77.27	[mm]	Standoff	
	326.59	77.23	[mm]	Standoff	
	424.74	77.15	[mm]	Standoff	
	424.78	187.45	[mm]	Standoff	
	430.16	233.09	[mm]	Standoff	
	343.84	232.97	[mm]	Standoff	
	194.28	235.88	[mm]	Standoff	
	100.89	233.04	[mm]	Standoff	
	327.35	198.98	[mm]	Standoff	
	141.48	221.83	[mm]	Standoff	
	121.07	134.70	[mm]	Standoff	interior
	183.95	134.74	[mm]	Standoff	interior
	301.66	143.14	[mm]	Standoff	interior
	237.52	190.25	[mm]	Standoff	interior
	183.98	197.64	[mm]	Standoff	interior
	121.07	197.55	[mm]	Standoff	interior

Chassis (Back View)	PCB in Chassis (Front View)	Image of Origin (Back View)
		

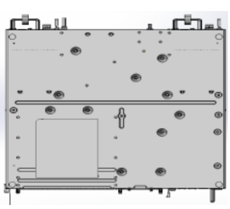
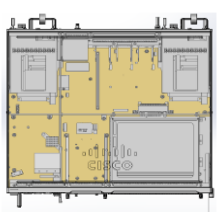
Chassis ID	X Coord.	Y Coord.	Unit	Hole Type	Notes
68-100900-01_adelphi24 (Lower PCB Only), (Switch)	17.82	43.31	[mm]	Standoff	
	63.00	43.36	[mm]	Standoff	
	156.36	66.14	[mm]	Standoff	
	247.85	66.18	[mm]	Standoff	
	339.26	66.11	[mm]	Standoff	
	428.03	89.06	[mm]	Standoff	
	407.85	117.69	[mm]	Standoff	
	407.87	180.56	[mm]	Standoff	
	426.78	223.56	[mm]	Standoff	
	428.82	314.98	[mm]	Standoff	
	356.37	314.98	[mm]	Standoff	
	277.82	276.99	[mm]	Standoff	
	132.25	276.96	[mm]	Standoff	
	87.59	314.90	[mm]	Standoff	
	15.19	315.00	[mm]	Standoff	
	15.35	213.59	[mm]	Standoff	
	63.06	117.62	[mm]	Standoff	interior
	125.93	117.62	[mm]	Standoff	interior
	157.04	117.62	[mm]	Standoff	interior
	219.88	117.62	[mm]	Standoff	interior
	251.03	117.62	[mm]	Standoff	interior
	313.96	117.62	[mm]	Standoff	interior
	344.90	117.62	[mm]	Standoff	interior
	63.06	180.50	[mm]	Standoff	interior
	125.93	180.50	[mm]	Standoff	interior
	157.04	180.50	[mm]	Standoff	interior
	219.88	180.50	[mm]	Standoff	interior
	251.03	180.50	[mm]	Standoff	interior
	313.96	180.50	[mm]	Standoff	interior
	344.90	180.50	[mm]	Standoff	interior

Chassis (Back View)	PCB in Chassis (Front View)	Image of Origin (Back View)
		

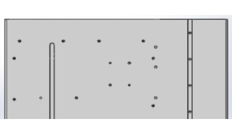
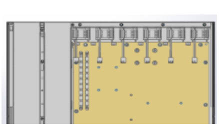
Chassis ID	X Coord.	Y Coord.	Unit	Hole Type	Notes
68-101825-01_01 (Switch)	10.78	53.29	[mm]	Toadstool	
	10.77	102.10	[mm]	Toadstool	
	96.53	53.30	[mm]	Toadstool	
	184.43	52.58	[mm]	Toadstool	
	307.38	52.53	[mm]	Toadstool	
	427.45	64.67	[mm]	Toadstool	
	427.42	160.13	[mm]	Toadstool	
	427.40	255.64	[mm]	Toadstool	
	427.33	351.15	[mm]	Toadstool	
	214.72	325.03	[mm]	Toadstool	
	200.02	196.02	[mm]	Toadstool	
	125.15	102.12	[mm]	Toadstool	
	347.93	297.71	[mm]	Toadstool	interior (connected to heat sink)
	278.06	240.56	[mm]	Toadstool	interior (connected to heat sink)
	350.43	217.58	[mm]	Toadstool	interior
	252.10	203.80	[mm]	Toadstool	interior
	372.14	128.07	[mm]	Toadstool	interior
	246.98	128.03	[mm]	Toadstool	interior

Chassis (Back View)	PCB in Chassis (Front View)	Image of Origin (Back View)
		

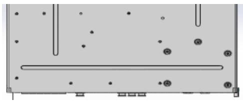
Chassis ID	X Coord.	Y Coord.	Unit	Hole Type	Notes
68-101860-01_01 (Switch)	10.78	53.29	[mm]	Toadstool	
	10.77	102.10	[mm]	Toadstool	
	96.53	53.30	[mm]	Toadstool	
	184.43	52.58	[mm]	Toadstool	
	307.38	52.53	[mm]	Toadstool	
	427.45	64.67	[mm]	Toadstool	
	427.42	160.13	[mm]	Toadstool	
	427.40	255.64	[mm]	Toadstool	
	427.33	351.15	[mm]	Toadstool	
	214.72	325.03	[mm]	Toadstool	
	200.02	196.02	[mm]	Toadstool	
	125.15	102.12	[mm]	Toadstool	
	347.93	297.71	[mm]	Toadstool	interior (connected to heat sink)
	278.06	240.56	[mm]	Toadstool	interior (connected to heat sink)
	350.43	217.58	[mm]	Toadstool	interior
	252.10	203.80	[mm]	Toadstool	interior
	372.14	128.07	[mm]	Toadstool	interior
	246.98	128.03	[mm]	Toadstool	interior

Chassis (Back View)	PCB in Chassis (Front View)	Image of Origin (Back View)
		

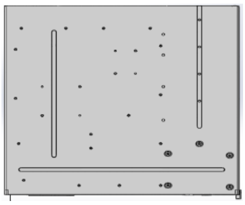
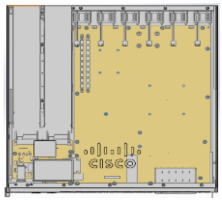
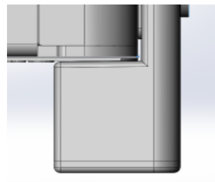
Chassis ID	X Coord.	Y Coord.	Unit	Hole Type	Notes
800-105842-02_radium (Router)	15.98	58.60	[mm]	standoff*	maybe toadstool
	15.88	146.66	[mm]	standoff*	maybe toadstool
	14.05	190.81	[mm]	standoff*	maybe toadstool
	14.15	242.70	[mm]	standoff*	maybe toadstool
	117.49	242.79	[mm]	toadstool	
	127.68	338.05	[mm]	toadstool	
	302.90	356.86	[mm]	toadstool	
	337.36	242.85	[mm]	toadstool	
	429.02	203.14	[mm]	standoff*	maybe toadstool
	354.79	203.25	[mm]	toadstool	
	278.80	203.13	[mm]	toadstool	
	210.03	187.85	[mm]	standoff*	maybe toadstool
	209.95	43.39	[mm]	toadstool	
	131.24	43.41	[mm]	toadstool	
	128.63	145.53	[mm]	toadstool	interior
	92.58	190.84	[mm]	toadstool	interior
	181.07	287.25	[mm]	toadstool	interior
	224.83	328.26	[mm]	??	empty hole? (interior)
	224.62	267.18	[mm]	??	empty hole? (interior)
	280.58	328.26	[mm]	??	empty hole? (interior)
	280.82	266.95	[mm]	??	empty hole? (interior)
	416.30	203.71	[mm]	??	empty hole?

Chassis (Back View)	PCB in Chassis (Front View)	Image of Origin (Back View)
		

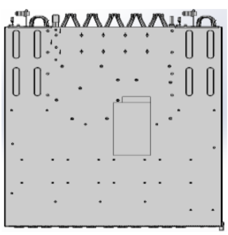
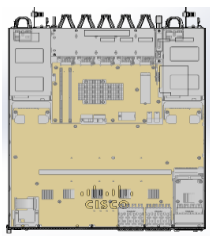
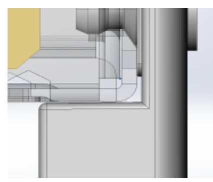
Chassis ID	X Coord.	Y Coord.	Unit	Hole Type	Notes
68-6786-02_greenday (Router)	148.63	22.99	[mm]	standoff	
	244.62	22.92	[mm]	standoff	
	320.85	22.88	[mm]	standoff	
	425.51	35.72	[mm]	standoff	
	425.46	126.07	[mm]	standoff	
	425.42	194.59	[mm]	standoff	
	425.47	262.43	[mm]	standoff	
	425.47	366.83	[mm]	standoff	
	414.74	410.54	[mm]	standoff	
	327.79	410.56	[mm]	standoff	
	256.49	410.49	[mm]	standoff	
	168.30	410.50	[mm]	standoff	
	148.65	366.75	[mm]	standoff	
	148.53	246.40	[mm]	standoff	
	148.63	126.05	[mm]	standoff	
	296.46	114.81	[mm]	standoff	interior
	280.45	149.06	[mm]	standoff	interior



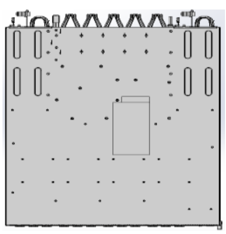
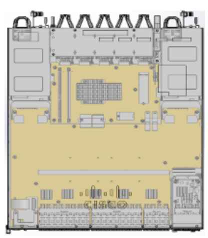
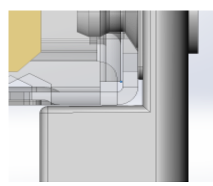
[illegible]	372.54	195.33	[mm]	standoff	interior
	209.07	195.55	[mm]	standoff	interior
	301.60	195.30	[mm]	empty	empty interior
	265.98	225.53	[mm]	empty	empty interior
	372.60	266.56	[mm]	empty	empty interior
	301.51	266.44	[mm]	standoff	interior
	265.97	286.65	[mm]	empty	empty interior
	234.40	289.93	[mm]	standoff	interior
	196.37	299.00	[mm]	empty	empty interior
	234.36	354.97	[mm]	empty	empty interior
	196.43	354.97	[mm]	standoff	interior
	17.83	18.80	[mm]	Toadstool	Left board
	17.83	96.91	[mm]	Toadstool	Left board
	75.38	125.35	[mm]	Toadstool	Left board
	134.65	101.27	[mm]	Toadstool	Left board
	134.62	22.95	[mm]	Toadstool	Left board

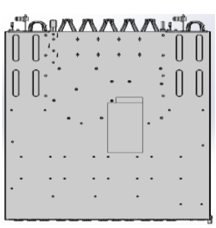
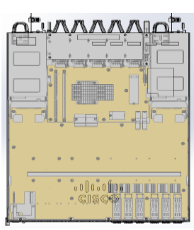
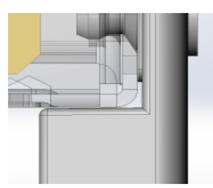
68-6826-02_ramones (Router)	148.63	22.99	[mm]	standoff	
	226.72	22.92	[mm]	standoff	
	302.90	22.94	[mm]	standoff	
	407.55	35.77	[mm]	standoff	
	417.11	126.07	[mm]	standoff	
	422.85	237.80	[mm]	standoff	
	422.96	358.41	[mm]	standoff	
	412.15	410.48	[mm]	standoff	
	327.79	410.56	[mm]	standoff	
	256.49	410.49	[mm]	standoff	
	168.30	410.50	[mm]	standoff	
	148.65	366.75	[mm]	standoff	
	148.53	246.40	[mm]	standoff	
	148.63	126.05	[mm]	standoff	
	280.46	114.75	[mm]	standoff	interior
	280.46	149.07	[mm]	standoff	interior
	372.63	195.42	[mm]	standoff	interior
	301.46	195.38	[mm]	empty	empty interior
	208.99	195.54	[mm]	standoff	interior
	372.60	266.39	[mm]	empty	empty interior
	301.57	266.46	[mm]	standoff	interior
	234.37	298.95	[mm]	standoff	interior
	196.35	298.98	[mm]	empty	empty interior
	234.39	354.98	[mm]	empty	empty interior
	196.36	354.98	[mm]	standoff	interior
	17.83	18.80	[mm]	Toadstool	Left board
	17.83	96.91	[mm]	Toadstool	Left board
	75.38	125.35	[mm]	Toadstool	Left board
	134.65	101.27	[mm]	Toadstool	Left board
	134.62	22.95	[mm]	Toadstool	Left board

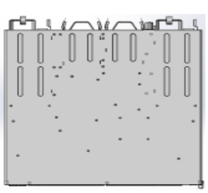
68-100901-01_adelphi16 (Switch), (Bottom Board)	17.93	43.23	[mm]	Standoff	
	63.06	43.23	[mm]	Standoff	
	114.35	73.20	[mm]	Standoff	
	228.79	73.24	[mm]	Standoff	
	342.99	73.26	[mm]	Standoff	
	356.66	178.23	[mm]	Standoff	
	428.74	191.27	[mm]	Standoff	
	428.79	314.79	[mm]	Standoff	
	356.38	314.80	[mm]	Standoff	
	290.45	276.12	[mm]	Standoff	
	150.11	276.13	[mm]	Standoff	
	87.62	314.77	[mm]	Standoff	
	15.20	314.79	[mm]	Standoff	
	15.13	193.60	[mm]	Standoff	
	63.60	121.88	[mm]	Standoff	interior
	141.39	128.56	[mm]	Standoff	interior
	204.32	128.51	[mm]	Standoff	interior
	235.38	128.54	[mm]	Standoff	interior
	298.28	128.49	[mm]	Standoff	interior
	298.28	191.38	[mm]	Standoff	interior
	235.38	191.38	[mm]	Standoff	interior
	204.32	191.38	[mm]	Standoff	interior
	141.39	191.38	[mm]	Standoff	interior

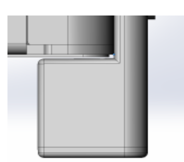




68-100902-01_adelphi40 (Switch), (Bottom Board)	17.93	43.23	[mm]	Standoff	
	63.06	43.23	[mm]	Standoff	
	114.35	73.20	[mm]	Standoff	
	228.79	73.24	[mm]	Standoff	
	342.99	73.26	[mm]	Standoff	
	356.66	178.23	[mm]	Standoff	
	428.74	191.27	[mm]	Standoff	
	428.79	314.79	[mm]	Standoff	
	356.38	314.80	[mm]	Standoff	
	290.45	276.12	[mm]	Standoff	
	150.11	276.13	[mm]	Standoff	
	87.62	314.77	[mm]	Standoff	
	15.20	314.79	[mm]	Standoff	
	15.13	193.60	[mm]	Standoff	
	63.60	121.88	[mm]	Standoff	interior
	141.39	128.56	[mm]	Standoff	interior
	204.32	128.51	[mm]	Standoof	interior
	235.38	128.54	[mm]	Standoff	interior
	298.28	128.49	[mm]	Standoof	interior
	298.28	191.38	[mm]	Standoff	interior
	235.38	191.38	[mm]	Standoof	interior
	204.32	191.38	[mm]	Standoff	interior
	141.39	191.38	[mm]	Standoof	interior

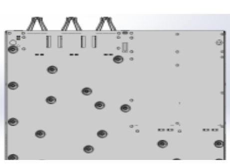
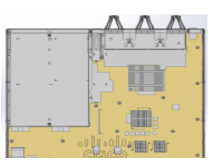
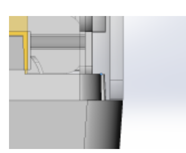




68-100903-02_adelphi12 (Switch), (Bottom Board)	17.93	43.23	[mm]	Standoff	
	63.06	43.23	[mm]	Standoff	
	114.35	73.20	[mm]	Standoff	
	228.79	73.24	[mm]	Standoff	
	342.99	73.26	[mm]	Standoff	
	356.66	178.23	[mm]	Standoff	
	428.74	191.27	[mm]	Standoff	
	428.79	314.79	[mm]	Standoff	
	356.38	314.80	[mm]	Standoff	
	290.45	276.12	[mm]	Standoff	
	150.11	276.13	[mm]	Standoff	
	87.62	314.77	[mm]	Standoff	
	15.20	314.79	[mm]	Standoff	
	15.13	193.60	[mm]	Standoff	
	63.60	121.88	[mm]	Standoff	interior
	141.39	128.56	[mm]	Standoff	interior
	204.32	128.51	[mm]	Standoff	interior
	235.38	128.54	[mm]	Standoff	interior
	298.28	128.49	[mm]	Standoff	interior
	298.28	191.38	[mm]	Standoff	interior
	235.38	191.38	[mm]	Standoff	interior
	204.32	191.38	[mm]	Standoff	interior
	141.39	191.38	[mm]	Standoff	interior



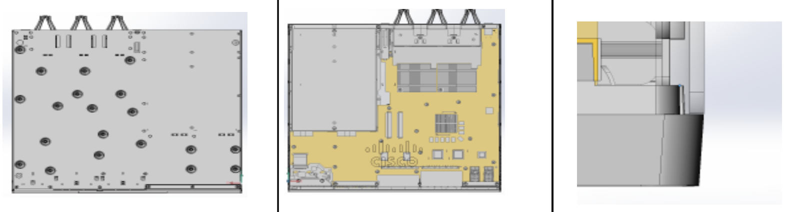


68-6276-Gryphon (Switch)	52.02	77.14	[mm]	Standoff	
	19.69	187.38	[mm]	Standoff	
	14.33	232.99	[mm]	Standoff	
	414.53	85.90	[mm]	Standoff	
	424.74	187.38	[mm]	Standoff	
	430.15	232.99	[mm]	Standoff	
	100.83	232.99	[mm]	Standoff	
	141.45	221.78	[mm]	Standoff	
	194.31	235.90	[mm]	Standoff	
	327.35	198.92	[mm]	Standoff	
	343.66	232.99	[mm]	Standoff	
	255.91	100.13	[mm]	Standoff	
	121.16	38.89	[mm]	Standoff	interior
	183.95	134.68	[mm]	Standoff	interior
	121.10	197.59	[mm]	Standoff	interior
	184.04	197.54	[mm]	Standoff	interior
	237.53	190.17	[mm]	Standoff	interior
	319.35	159.07	[mm]	Standoff	interior

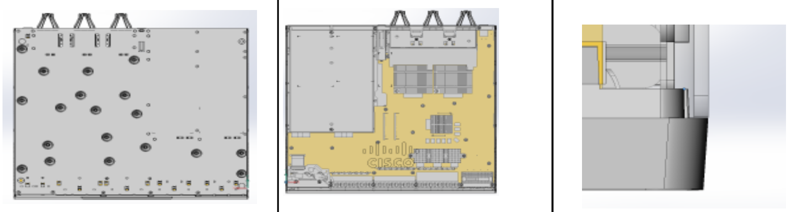




68-101863-01_a0 (Switch)	10.88	53.30	[mm]	Toadstool	
	10.88	102.06	[mm]	Toadstool	
	96.56	53.28	[mm]	Toadstool	
	274.52	87.96	[mm]	Toadstool	
	125.03	102.08	[mm]	Toadstool	
	368.86	49.52	[mm]	Toadstool	
	427.25	64.60	[mm]	Toadstool	
	427.25	159.99	[mm]	Toadstool	
	427.25	255.64	[mm]	Toadstool	
	427.25	351.06	[mm]	Toadstool	
	214.56	324.93	[mm]	Standoff	
	200.01	196.10	[mm]	Standoff	
	347.94	297.83	[mm]	Standoff	
	278.11	240.61	[mm]	Standoff	interior (connected to heat sink)

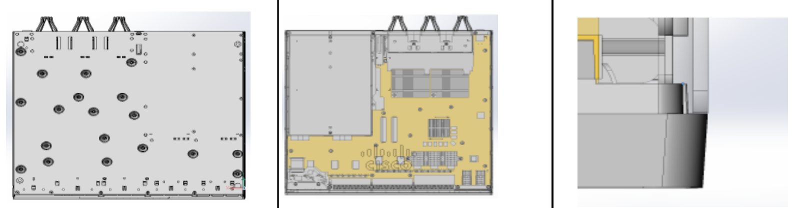
	350.53	217.61	[mm]	Standoff	interior
	252.08	203.87	[mm]	Standoff	interior
	372.04	128.10	[mm]	Standoff	interior
	246.97	128.10	[mm]	Standoff	interior



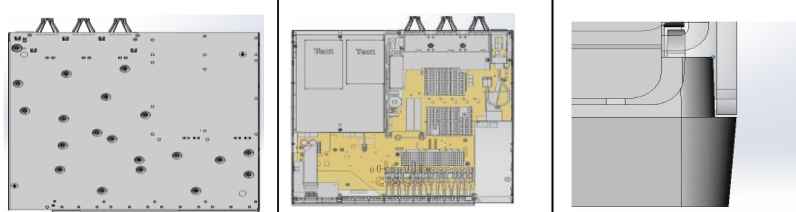
68-101864-01_02 (Switch)	10.87	53.25	[mm]	Toadstool	
	10.84	102.05	[mm]	Toadstool	
	96.56	53.25	[mm]	Toadstool	
	96.56	102.05	[mm]	Toadstool	
	368.91	49.52	[mm]	Toadstool	
	427.40	64.62	[mm]	Toadstool	
	427.40	227.92	[mm]	Toadstool	
	427.40	351.17	[mm]	Toadstool	
	214.65	325.00	[mm]	Toadstool	
	209.53	196.08	[mm]	Toadstool	
	193.04	116.23	[mm]	Toadstool	
	386.24	297.73	[mm]	Toadstool	
	302.44	297.73	[mm]	Toadstool	
	316.42	240.69	[mm]	Toadstool	interior (connected to heat sink)
	232.55	240.69	[mm]	Toadstool	interior (connected to heat sink)
	354.35	210.85	[mm]	Toadstool	interior
	287.70	205.11	[mm]	Toadstool	interior
	378.48	121.89	[mm]	Toadstool	interior
	266.72	140.27	[mm]	Toadstool	interior
	274.62	88.01	[mm]	Toadstool	interior



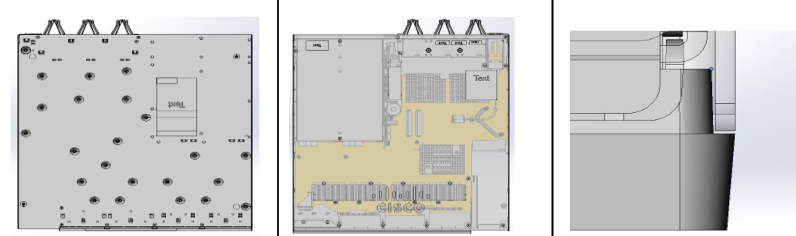
68-101865-01_02 (Switch)	10.80	53.25	[mm]	Toadstool	
	10.75	102.10	[mm]	Toadstool	
	96.45	102.08	[mm]	Toadstool	
	261.89	82.91	[mm]	Toadstool	
	374.71	82.84	[mm]	Toadstool	
	427.40	64.61	[mm]	Toadstool	
	427.40	228.01	[mm]	Toadstool	
	427.40	351.06	[mm]	Toadstool	
	214.76	324.90	[mm]	Toadstool	
	209.48	195.95	[mm]	Toadstool	
	193.10	116.18	[mm]	Toadstool	
	386.25	297.74	[mm]	Toadstool	
	302.39	297.77	[mm]	Toadstool	
	316.38	240.66	[mm]	Toadstool	interior (connected to heat sink)
	232.58	240.56	[mm]	Toadstool	interior (connected to heat sink)
	354.33	210.80	[mm]	Toadstool	interior
	287.62	205.00	[mm]	Toadstool	interior
	378.50	121.84	[mm]	Toadstool	interior
	266.54	140.26	[mm]	Toadstool	interior



68-101866-01_02 (Switch)	10.80	53.25	[mm]	Toadstool	
	10.75	102.10	[mm]	Toadstool	
	96.45	102.08	[mm]	Toadstool	
	261.89	82.91	[mm]	Toadstool	
	374.71	82.84	[mm]	Toadstool	
	427.40	64.61	[mm]	Toadstool	
	427.40	228.01	[mm]	Toadstool	
	427.40	351.06	[mm]	Toadstool	
	214.76	324.90	[mm]	Toadstool	
	209.48	195.95	[mm]	Toadstool	
	193.10	116.18	[mm]	Toadstool	
	386.25	297.74	[mm]	Toadstool	
	302.39	297.77	[mm]	Toadstool	
	316.38	240.66	[mm]	Toadstool	interior (connected to heat sink)
	232.58	240.56	[mm]	Toadstool	interior (connected to heat sink)
	354.33	210.80	[mm]	Toadstool	interior
	287.62	205.00	[mm]	Toadstool	interior
	378.50	121.84	[mm]	Toadstool	interior
	266.54	140.26	[mm]	Toadstool	interior

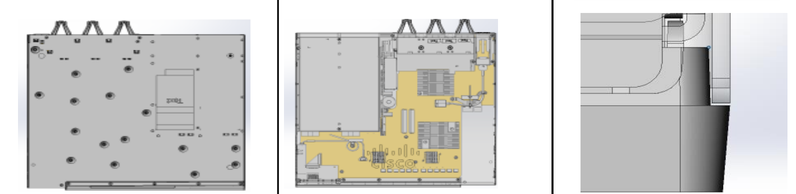


68-102271-01_01 (Switch)	17.58	84.88	[mm]	Toadstool	
	111.06	44.79	[mm]	Toadstool	
	276.95	44.74	[mm]	Toadstool	
	351.58	96.95	[mm]	Toadstool	
	346.54	157.15	[mm]	Toadstool	
	344.82	223.26	[mm]	Toadstool	
	413.78	243.02	[mm]	Toadstool	
	425.83	310.43	[mm]	Toadstool	
	427.82	398.55	[mm]	Toadstool	
	340.18	334.49	[mm]	Toadstool	
	236.83	347.23	[mm]	Toadstool	
	200.65	232.72	[mm]	Toadstool	
	144.38	132.24	[mm]	Toadstool	
	68.49	121.25	[mm]	Toadstool	
	17.48	138.74	[mm]	Toadstool	
	208.51	96.95	[mm]	Toadstool	interior
	211.45	121.26	[mm]	Toadstool	interior
	259.44	173.17	[mm]	Toadstool	interior
	286.00	188.83	[mm]	Toadstool	interior (connected to heat sink)
	270.37	277.32	[mm]	Toadstool	interior (connected to heat sink)

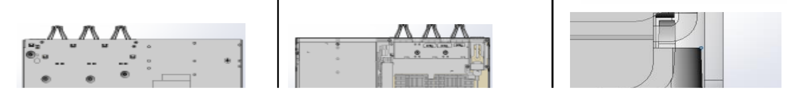


68-101195-01_01 (Switch)	11.32	51.12	[mm]	Toadstool	
	87.14	66.41	[mm]	Toadstool	
	135.34	66.33	[mm]	Toadstool	
	249.36	66.40	[mm]	Toadstool	
	297.60	66.37	[mm]	Toadstool	
	321.78	112.12	[mm]	Toadstool	
	335.33	187.62	[mm]	Toadstool	
	427.79	232.01	[mm]	Toadstool	
	397.03	294.96	[mm]	Toadstool	
	427.83	436.50	[mm]	Toadstool	
	397.02	372.52	[mm]	Toadstool	
	306.60	372.48	[mm]	Toadstool	
	236.80	385.16	[mm]	Toadstool	
	236.77	315.28	[mm]	Toadstool	
	200.47	270.69	[mm]	Toadstool	
	107.79	176.77	[mm]	Toadstool	
	11.31	176.73	[mm]	Toadstool	
	62.97	112.12	[mm]	Toadstool	interior (connected to heat sink)
	159.46	112.13	[mm]	Toadstool	interior (connected to heat sink)
	225.29	112.10	[mm]	Toadstool	interior (connected to heat sink)
	276.44	153.20	[mm]	Toadstool	interior (connected to heat sink)
	253.82	212.36	[mm]	Toadstool	interior
	327.18	315.33	[mm]	Toadstool	interior (connected to heat sink)

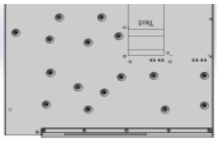
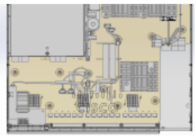
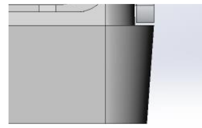
68-101194-01_01 (Switch)	32.82	55.33	[mm]	Toadstool	
	102.03	44.87	[mm]	Toadstool	
	237.95	64.86	[mm]	Toadstool	
	334.49	64.89	[mm]	Toadstool	
	419.73	226.90	[mm]	Toadstool	
	427.88	384.18	[mm]	Toadstool	
	397.04	320.18	[mm]	Toadstool	
	306.57	320.12	[mm]	Toadstool	
	236.73	332.78	[mm]	Toadstool	
	236.70	263.01	[mm]	Toadstool	
	200.31	218.38	[mm]	Toadstool	
	107.74	124.41	[mm]	Toadstool	
	11.16	124.42	[mm]	Toadstool	
	347.17	210.45	[mm]	Toadstool	
	160.99	79.35	[mm]	Toadstool	interior (connected to heat sink)
	262.02	110.58	[mm]	Toadstool	interior (connected to heat sink)
	310.35	110.62	[mm]	Toadstool	interior (connected to heat sink)
	253.81	160.02	[mm]	Toadstool	interior
	327.12	263.01	[mm]	Toadstool	interior (connected to heat sink)



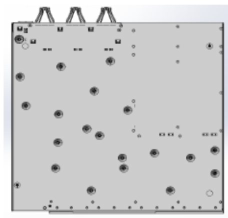
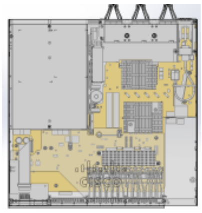
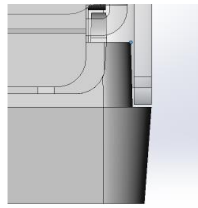
68-102276-01_03 (Switch)	17.75	55.91	[mm]	Toadstool	
	17.72	98.20	[mm]	Toadstool	
	101.28	30.45	[mm]	Toadstool	
	125.59	98.08	[mm]	Toadstool	
	265.15	56.00	[mm]	Toadstool	
	354.72	67.79	[mm]	Toadstool	
	345.80	143.25	[mm]	Toadstool	
	347.34	222.27	[mm]	Toadstool	
	419.66	238.83	[mm]	Toadstool	
	427.84	357.95	[mm]	Toadstool	
	344.61	293.87	[mm]	Toadstool	
	236.78	306.65	[mm]	Toadstool	
	200.21	192.09	[mm]	Toadstool	
	286.92	108.95	[mm]	Toadstool	interior (connected to heat sink)
	274.78	236.88	[mm]	Toadstool	interior (connected to heat sink)
	244.28	122.12	[mm]	Toadstool	interior



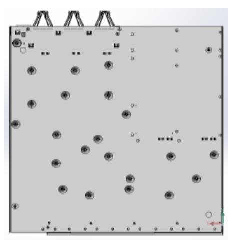
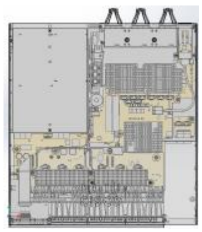
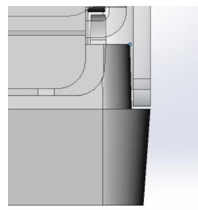
	17.72	65.34	[mm]	Toadstool	
	101.35	56.02	[mm]	Toadstool	
	265.24	56.03	[mm]	Toadstool	
	354.87	67.88	[mm]	Toadstool	
	345.82	143.39	[mm]	Toadstool	
	347.27	222.28	[mm]	Toadstool	
	419.68	238.86	[mm]	Toadstool	
	397.03	332.02	[mm]	Toadstool	

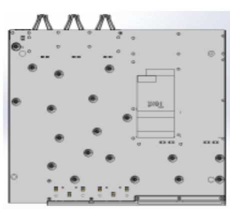
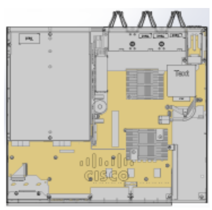
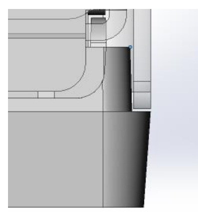
68-102275-01_03 (Switch)	427.80	396.06	[mm]	Toadstool	
	306.59	332.04	[mm]	Toadstool	
	236.79	344.69	[mm]	Toadstool	
	200.24	230.23	[mm]	Toadstool	
	194.83	133.01	[mm]	Toadstool	
	125.54	136.13	[mm]	Toadstool	
	17.76	136.35	[mm]	Toadstool	
	231.19	96.56	[mm]	Toadstool	interior
	286.78	108.85	[mm]	Toadstool	interior (connected to heat sink)
	327.08	274.78	[mm]	Toadstool	interior (connected to heat sink)
	236.68	274.91	[mm]	Toadstool	interior (connected to heat sink)
	265.60	215.34	[mm]	Toadstool	interior

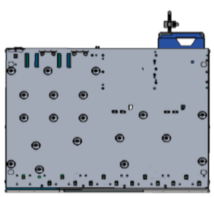
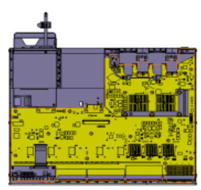
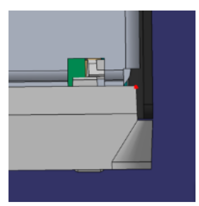
68-102271-01_01 V2 (Switch)	17.57	84.89	[mm]	Toadstool	
	111.04	44.74	[mm]	Toadstool	
	276.89	44.78	[mm]	Toadstool	
	351.49	96.97	[mm]	Toadstool	
	208.56	96.96	[mm]	Toadstool	
	346.47	157.21	[mm]	Toadstool	
	344.92	223.33	[mm]	Toadstool	
	413.68	242.93	[mm]	Toadstool	
	425.89	310.49	[mm]	Toadstool	
	427.87	398.53	[mm]	Toadstool	
	340.20	334.46	[mm]	Toadstool	
	236.82	347.12	[mm]	Toadstool	
	200.51	232.74	[mm]	Toadstool	
	144.39	132.35	[mm]	Toadstool	
	68.51	121.32	[mm]	Toadstool	
	17.54	138.73	[mm]	Toadstool	
	211.54	121.29	[mm]	Toadstool	interior (connected to heat sink)
	259.48	173.22	[mm]	Toadstool	interior
	285.99	188.89	[mm]	Toadstool	interior (connected to heat sink)
	270.33	277.30	[mm]	Toadstool	interior (connected to heat sink)

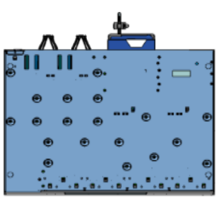
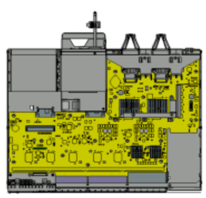
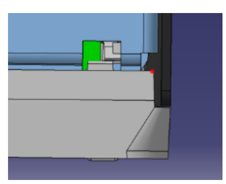
68-102257-01_02 (Switch)	107.86	173.26	[mm]	Toadstool	
	17.52	176.97	[mm]	Toadstool	
	54.54	121.29	[mm]	Toadstool	
	111.04	82.92	[mm]	Toadstool	
	192.47	121.32	[mm]	Toadstool	
	194.61	97.00	[mm]	Toadstool	
	276.91	82.88	[mm]	Toadstool	
	332.52	97.00	[mm]	Toadstool	
	346.53	157.17	[mm]	Toadstool	
	344.89	223.27	[mm]	Toadstool	
	430.24	248.00	[mm]	Toadstool	
	397.03	295.10	[mm]	Toadstool	
	427.96	436.64	[mm]	Toadstool	
	397.05	372.61	[mm]	Toadstool	
	306.59	372.47	[mm]	Toadstool	
	236.81	315.43	[mm]	Toadstool	
	236.77	385.28	[mm]	Toadstool	
	200.49	270.88	[mm]	Toadstool	
	237.01	173.25	[mm]	Toadstool	interior
	286.01	188.87	[mm]	Toadstool	interior (connected to heat sink)
	259.62	213.74	[mm]	Toadstool	interior
	327.22	315.46	[mm]	Toadstool	interior (connected to heat sink)

68-101188-01_01 (Switch)	11.26	49.49	[mm]	Toadstool	
	11.23	99.11	[mm]	Toadstool	
	94.43	49.55	[mm]	Toadstool	
	107.72	99.04	[mm]	Toadstool	
	184.83	49.55	[mm]	Toadstool	
	307.79	49.46	[mm]	Toadstool	
	354.72	80.74	[mm]	Toadstool	
	338.96	146.12	[mm]	Toadstool	
	355.37	214.00	[mm]	Toadstool	
	427.77	230.49	[mm]	Toadstool	
	427.76	358.73	[mm]	Toadstool	
	394.14	309.87	[mm]	Toadstool	
	340.12	294.79	[mm]	Toadstool	
	236.74	307.47	[mm]	Toadstool	
	200.33	193.00	[mm]	Toadstool	
	235.41	99.09	[mm]	Toadstool	interior
	280.05	111.70	[mm]	Toadstool	interior (connected to heat sink)
	262.05	161.28	[mm]	Toadstool	interior
	270.30	237.59	[mm]	Toadstool	interior (connected to heat sink)

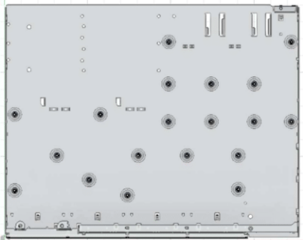
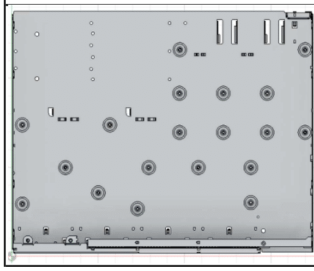
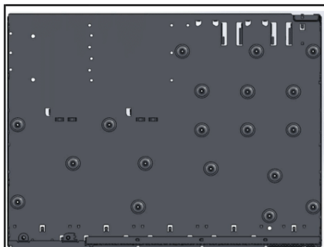
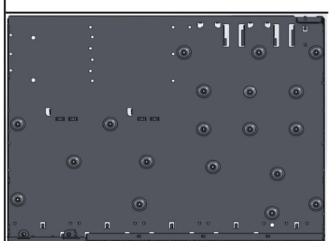
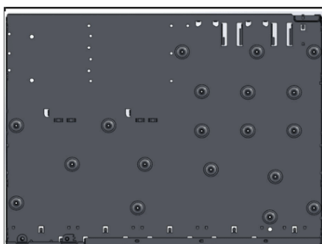




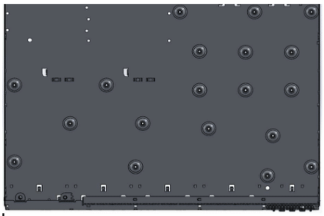
68-101390-01 (switch)	13.99	66.62	[mm]	Toadstool	
	183.46	59.00	[mm]	Toadstool	
	13.99	179.52	[mm]	Toadstool	
	142.77	179.52	[mm]	Toadstool	
	245.57	286.91	[mm]	Toadstool	
	349.91	286.91	[mm]	Toadstool	
	429.61	286.91	[mm]	Toadstool	
	429.61	59.41	[mm]	Toadstool	
	368.12	46.30	[mm]	Toadstool	
	91.97	123.06	[mm]	Toadstool	interior
	375.69	105.07	[mm]	Toadstool	interior
	285.77	115.49	[mm]	Toadstool	interior
	193.57	123.06	[mm]	Toadstool	interior
	337.39	227.78	[mm]	Toadstool	interior
	272.97	171.91	[mm]	Toadstool	interior (mounting comp.)
	337.39	171.91	[mm]	Toadstool	interior (mounting comp.)
	401.80	171.91	[mm]	Toadstool	interior (mounting comp.)
	401.80	227.79	[mm]	Toadstool	interior (mounting comp.)

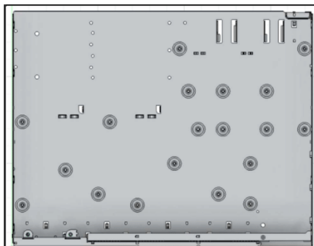
68-101493-01_19 (Switch)	13.99	66.62	[mm]	Toadstool	
	13.99	179.52	[mm]	Toadstool	
	183.46	59.76	[mm]	Toadstool	
	349.91	68.47	[mm]	Toadstool	
	429.61	168.73	[mm]	Toadstool	
	429.61	286.91	[mm]	Toadstool	
	245.57	286.91	[mm]	Toadstool	
	142.77	179.52	[mm]	Toadstool	
	429.61	168.73	[mm]	Toadstool	
	77.49	118.56	[mm]	Toadstool	interior
	125.75	82.49	[mm]	Toadstool	interior
	199.85	118.56	[mm]	Toadstool	interior
	272.92	118.56	[mm]	Toadstool	interior
	349.91	118.56	[mm]	Toadstool	interior
	309.45	224.61	[mm]	Toadstool	interior
	245.03	224.61	[mm]	Toadstool	interior
	245.03	168.73	[mm]	Toadstool	interior (mounting comp.)
	309.45	168.73	[mm]	Toadstool	interior (mounting comp.)
	373.86	168.73	[mm]	Toadstool	interior (mounting comp.)
	373.86	224.61	[mm]	Toadstool	interior (mounting comp.)

Appendix D: Quake Chassis Hole Locations

PCB in Chassis (Front View)	Quake Subfamily	Chassis ID	X Coord.	Y Coord.	Unit	Hole Type	Notes
	Hornet	700-115811-03_A1	0	0	[mm]	Toadstool	origin
			0.00	112.90	[mm]	Toadstool	
			111.76	15.88	[mm]	Toadstool	
			169.47	-6.86	[mm]	Toadstool	
			231.57	220.29	[mm]	Toadstool	
			231.04	157.99	[mm]	Toadstool	
			231.04	102.11	[mm]	Toadstool	
			335.92	1.85	[mm]	Toadstool	
			415.62	220.29	[mm]	Toadstool	
			415.62	102.11	[mm]	Toadstool	
			258.93	51.94	[mm]	Toadstool	interior
			295.45	157.99	[mm]	Toadstool	interior
			295.45	102.11	[mm]	Toadstool	interior
			335.92	51.94	[mm]	Toadstool	interior
			359.87	157.99	[mm]	Toadstool	interior
			359.87	102.11	[mm]	Toadstool	interior
			63.50	51.94	[mm]	Toadstool	interior
			128.78	112.90	[mm]	Toadstool	interior
			185.85	51.94	[mm]	Toadstool	interior
		700-115943-03_A1	0.00	0.00	[mm]	Toadstool	origin
			0.00	112.90	[mm]	Toadstool	
			111.76	15.88	[mm]	Toadstool	
			128.78	112.90	[mm]	Toadstool	
			169.47	-6.86	[mm]	Toadstool	
			231.57	220.29	[mm]	Toadstool	
			231.04	157.99	[mm]	Toadstool	
			231.04	102.11	[mm]	Toadstool	
			415.62	220.29	[mm]	Toadstool	
			415.62	102.11	[mm]	Toadstool	
			335.92	1.85	[mm]	Toadstool	
			295.45	157.99	[mm]	Toadstool	interior
			295.45	102.11	[mm]	Toadstool	interior
			335.92	51.94	[mm]	Toadstool	interior
			359.87	157.99	[mm]	Toadstool	interior
			359.87	102.11	[mm]	Toadstool	interior
			258.93	51.94	[mm]	Toadstool	interior
			63.50	51.94	[mm]	Toadstool	interior
			185.85	51.94	[mm]	Toadstool	interior
	Enforcer 2X25G	700-113467-03_A0	0.00	0.00	[mm]	Toadstool	
			169.47	-7.11	[mm]	Toadstool	beneath origin
			354.13	-20.32	[mm]	Toadstool	beneath origin
			415.62	-7.21	[mm]	Toadstool	beneath origin
			387.81	105.41	[mm]	Toadstool	
			387.81	161.16	[mm]	Toadstool	
			415.62	220.29	[mm]	Toadstool	
			335.92	220.29	[mm]	Toadstool	
			231.57	220.29	[mm]	Toadstool	
			258.98	162.43	[mm]	Toadstool	interior?
			258.98	105.28	[mm]	Toadstool	interior?
			128.78	112.90	[mm]	Toadstool	
			0.00	112.90	[mm]	Toadstool	
			77.98	56.44	[mm]	Toadstool	interior
			179.58	56.44	[mm]	Toadstool	interior
			271.78	48.87	[mm]	Toadstool	interior
			361.70	38.46	[mm]	Toadstool	interior
			323.39	105.41	[mm]	Toadstool	interior
			323.39	161.16	[mm]	Toadstool	interior
		700-113469-03_A0	0.00	0.00	[mm]	Toadstool	
			169.47	-7.11	[mm]	Toadstool	beneath origin
			354.13	-20.32	[mm]	Toadstool	beneath origin
			415.62	-7.21	[mm]	Toadstool	beneath origin
			387.81	105.41	[mm]	Toadstool	
			387.81	161.16	[mm]	Toadstool	
			415.62	220.29	[mm]	Toadstool	
			335.92	220.29	[mm]	Toadstool	
			231.57	220.29	[mm]	Toadstool	
			258.98	162.43	[mm]	Toadstool	interior?
			258.98	105.28	[mm]	Toadstool	interior?
			128.78	112.90	[mm]	Toadstool	
			0.00	112.90	[mm]	Toadstool	
			77.98	56.44	[mm]	Toadstool	interior
			179.58	56.44	[mm]	Toadstool	interior
			271.78	48.87	[mm]	Toadstool	interior
			361.70	38.46	[mm]	Toadstool	interior
			323.39	105.41	[mm]	Toadstool	interior
			323.39	161.16	[mm]	Toadstool	interior
	Enforcer 4X10G	700-113468-03_A0	0.00	0.00	[mm]	Toadstool	
			169.47	-7.11	[mm]	Toadstool	beneath origin
			354.13	-20.32	[mm]	Toadstool	beneath origin
			415.62	-7.21	[mm]	Toadstool	beneath origin
			387.81	105.41	[mm]	Toadstool	
			387.81	161.16	[mm]	Toadstool	
			415.62	220.29	[mm]	Toadstool	
			335.92	220.29	[mm]	Toadstool	
			231.57	220.29	[mm]	Toadstool	
			258.98	162.43	[mm]	Toadstool	interior?
			258.98	105.28	[mm]	Toadstool	interior?
			128.78	112.90	[mm]	Toadstool	
			0.00	112.90	[mm]	Toadstool	
			77.98	56.44	[mm]	Toadstool	interior
			179.58	56.44	[mm]	Toadstool	interior
			271.78	48.87	[mm]	Toadstool	interior
			361.70	38.46	[mm]	Toadstool	interior
			323.39	105.41	[mm]	Toadstool	interior
			323.39	161.16	[mm]	Toadstool	interior
			0.00	0.00	[mm]	Toadstool	
			169.47	-7.11	[mm]	Toadstool	beneath origin
			354.13	-20.32	[mm]	Toadstool	beneath origin

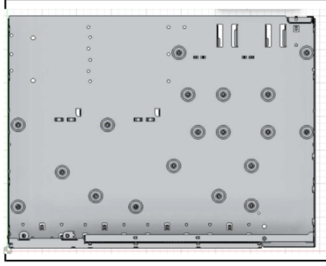


	415.62	-7.21	[mm]	Toadstool	beneath origin
	387.81	105.41	[mm]	Toadstool	
	387.81	161.16	[mm]	Toadstool	
	415.62	220.29	[mm]	Toadstool	
	335.92	220.29	[mm]	Toadstool	
	231.57	220.29	[mm]	Toadstool	
700-113470-03_A0	258.98	162.43	[mm]	Toadstool	interior?
	258.98	105.28	[mm]	Toadstool	interior?
	128.78	112.90	[mm]	Toadstool	
	0.00	112.90	[mm]	Toadstool	
	77.98	56.44	[mm]	Toadstool	interior
	179.58	56.44	[mm]	Toadstool	interior
	271.78	48.87	[mm]	Toadstool	interior
	361.70	38.46	[mm]	Toadstool	interior
	323.39	105.41	[mm]	Toadstool	interior
	323.39	161.16	[mm]	Toadstool	interior

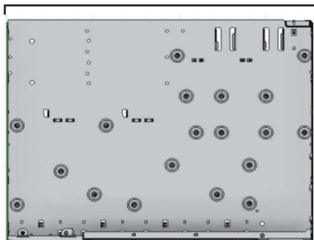


	0.00	0.00	[mm]	Toadstool	
	0.00	121.92	[mm]	Toadstool	
	128.78	121.92	[mm]	Toadstool	
	111.76	15.88	[mm]	Toadstool	
	169.47	0.00	[mm]	Toadstool	
	231.57	229.31	[mm]	Toadstool	
	244.60	167.01	[mm]	Toadstool	
	258.98	111.13	[mm]	Toadstool	
	288.93	15.88	[mm]	Toadstool	
700-115393-03_B1	335.92	1.85	[mm]	Toadstool	
	415.62	229.31	[mm]	Toadstool	
	415.62	111.13	[mm]	Toadstool	
	335.92	60.96	[mm]	Toadstool	interior
	359.87	167.01	[mm]	Toadstool	interior
	359.87	111.13	[mm]	Toadstool	interior
	63.50	51.44	[mm]	Toadstool	interior
	223.95	60.96	[mm]	Toadstool	interior
	295.45	167.01	[mm]	Toadstool	interior
	295.45	111.13	[mm]	Toadstool	interior

Gunner Non-POE

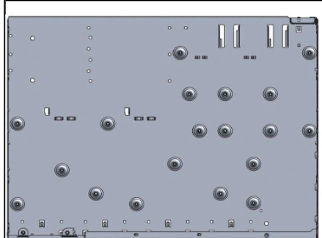


	0.00	0.00	[mm]	Toadstool	
	0.00	121.92	[mm]	Toadstool	
	111.76	15.88	[mm]	Toadstool	
	128.78	121.92	[mm]	Toadstool	
	169.47	0.00	[mm]	Toadstool	
	231.57	229.31	[mm]	Toadstool	
	288.93	15.88	[mm]	Toadstool	
	335.92	1.85	[mm]	Toadstool	
	415.62	229.31	[mm]	Toadstool	
700-115392-03_B1	415.62	111.13	[mm]	Toadstool	
	63.50	51.44	[mm]	Toadstool	interior
	223.95	60.96	[mm]	Toadstool	interior
	244.60	167.01	[mm]	Toadstool	interior
	258.98	111.13	[mm]	Toadstool	interior
	295.45	167.01	[mm]	Toadstool	interior
	295.45	111.13	[mm]	Toadstool	interior
	335.92	60.96	[mm]	Toadstool	interior
	359.87	167.01	[mm]	Toadstool	interior
	359.87	111.13	[mm]	Toadstool	interior

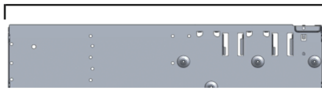


	0.00	0.00	[mm]	toadstool	
	0.00	121.92	[mm]	toadstool	
	111.76	15.88	[mm]	toadstool	
	128.78	121.92	[mm]	toadstool	
	169.46	0.00	[mm]	toadstool	
	231.57	229.31	[mm]	toadstool	
	288.93	15.88	[mm]	toadstool	
	335.92	1.85	[mm]	toadstool	
	415.62	229.31	[mm]	toadstool	
700-114420-03_B1	415.62	111.13	[mm]	toadstool	
	63.50	51.44	[mm]	toadstool	interior
	223.96	60.96	[mm]	toadstool	interior
	244.60	167.01	[mm]	toadstool	interior
	258.98	111.13	[mm]	toadstool	interior
	295.45	167.01	[mm]	toadstool	interior
	295.45	111.13	[mm]	toadstool	interior
	335.92	60.96	[mm]	toadstool	interior
	359.87	111.13	[mm]	toadstool	interior
	359.87	167.01	[mm]	toadstool	interior

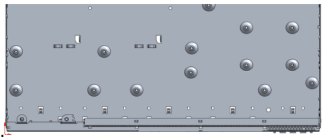
Gunner POE



	0.00	0.00	[mm]	toadstool	
	0.00	121.92	[mm]	toadstool	
	128.78	121.92	[mm]	toadstool	
	111.76	15.88	[mm]	toadstool	
	169.47	0.00	[mm]	toadstool	
	231.57	229.31	[mm]	toadstool	
	244.60	167.01	[mm]	toadstool	
	258.98	111.13	[mm]	toadstool	
	288.93	15.88	[mm]	toadstool	
700-115111-03_B1	335.92	1.85	[mm]	toadstool	
	415.62	229.31	[mm]	toadstool	
	415.62	111.13	[mm]	toadstool	
	335.92	60.96	[mm]	toadstool	interior
	359.87	167.01	[mm]	toadstool	interior
	359.87	111.13	[mm]	toadstool	interior
	63.50	51.44	[mm]	toadstool	interior
	223.95	60.96	[mm]	toadstool	interior
	295.45	167.01	[mm]	toadstool	interior
	295.45	111.13	[mm]	toadstool	interior



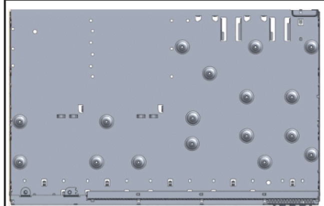
	0	0	[mm]	toadstool	
	0.00	58.42	[mm]	toadstool	
	123.70	58.42	[mm]	toadstool	
	109.47	0.00	[mm]	toadstool	
	169.47	0.00	[mm]	toadstool	
	246.63	63.50	[mm]	toadstool	



700-113465-03_B2

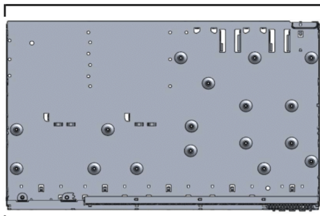
231.57	165.81	[mm]	toadstool	
335.92	165.81	[mm]	toadstool	
349.05	0.00	[mm]	toadstool	
415.62	165.81	[mm]	toadstool	
415.62	10.80	[mm]	toadstool	
245.49	26.67	[mm]	toadstool	interior
270.51	127.76	[mm]	toadstool	interior
323.39	93.98	[mm]	toadstool	interior
323.39	38.10	[mm]	toadstool	interior
387.81	93.98	[mm]	toadstool	interior
387.81	38.10	[mm]	toadstool	interior

Vore Classic Non-POE



700-113673-03_A0

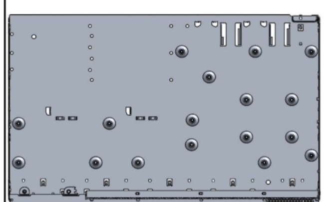
0.00	0.00	[mm]	toadstool	
0.00	58.42	[mm]	toadstool	
123.70	58.42	[mm]	toadstool	
109.47	0.00	[mm]	toadstool	
169.47	0.00	[mm]	toadstool	
246.63	63.50	[mm]	toadstool	
231.57	165.81	[mm]	toadstool	
335.92	165.81	[mm]	toadstool	
349.05	0.00	[mm]	toadstool	
415.62	165.81	[mm]	toadstool	
415.62	10.80	[mm]	toadstool	
245.49	26.67	[mm]	toadstool	interior
270.51	127.76	[mm]	toadstool	interior
323.39	93.98	[mm]	toadstool	interior
323.39	38.10	[mm]	toadstool	interior
387.81	93.98	[mm]	toadstool	interior
387.81	38.10	[mm]	toadstool	interior



700-113466-03_A0

0.00	0.00	[mm]	toadstool	
0.00	58.42	[mm]	toadstool	
128.78	58.42	[mm]	toadstool	
109.47	0.00	[mm]	toadstool	
169.47	0.00	[mm]	toadstool	
246.63	63.50	[mm]	toadstool	
231.57	165.81	[mm]	toadstool	
335.92	165.81	[mm]	toadstool	
349.05	0.00	[mm]	toadstool	
415.62	165.81	[mm]	toadstool	
415.62	10.80	[mm]	toadstool	
245.49	26.67	[mm]	toadstool	interior
270.51	127.76	[mm]	toadstool	interior
323.39	93.98	[mm]	toadstool	interior
323.39	38.10	[mm]	toadstool	interior
387.81	93.98	[mm]	toadstool	interior
387.81	38.10	[mm]	toadstool	interior

Vore Classic POE



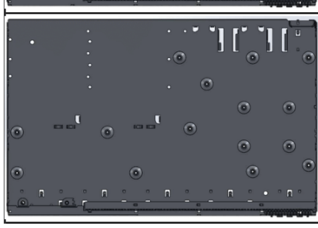
700-113674-03_B2

0.00	0.00	[mm]	toadstool	
0.00	58.42	[mm]	toadstool	
128.78	58.42	[mm]	toadstool	
109.47	0.00	[mm]	toadstool	
169.47	0.00	[mm]	toadstool	
246.63	63.50	[mm]	toadstool	
231.57	165.81	[mm]	toadstool	
335.92	165.81	[mm]	toadstool	
349.05	0.00	[mm]	toadstool	
415.62	165.81	[mm]	toadstool	
415.62	10.80	[mm]	toadstool	
245.49	26.67	[mm]	toadstool	interior
270.51	127.76	[mm]	toadstool	interior
323.39	93.98	[mm]	toadstool	interior
323.39	38.10	[mm]	toadstool	interior
387.81	93.98	[mm]	toadstool	interior
387.81	38.10	[mm]	toadstool	interior

700-122030-01_02

0	0	[mm]	toadstool	
169.47	0.00	[mm]	toadstool	
335.92	1.85	[mm]	toadstool	
415.62	10.80	[mm]	toadstool	
128.72	58.42	[mm]	toadstool	
0.00	58.42	[mm]	toadstool	
231.57	165.81	[mm]	toadstool	
335.92	165.81	[mm]	toadstool	
415.62	165.81	[mm]	toadstool	
387.81	38.10	[mm]	toadstool	interior
323.39	38.10	[mm]	toadstool	interior
246.63	63.50	[mm]	toadstool	interior
323.39	93.98	[mm]	toadstool	interior
387.81	93.98	[mm]	toadstool	interior
270.51	127.71	[mm]	toadstool	interior

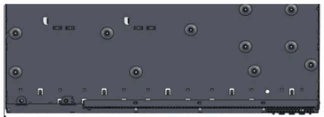
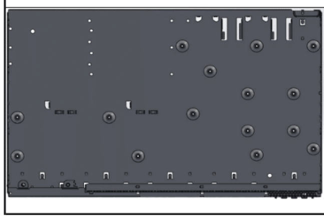
Vore CR Non-POE



700-122032-01_03

0.00	0.00	[mm]	toadstool	
169.47	0.00	[mm]	toadstool	
335.92	1.85	[mm]	toadstool	
415.62	10.80	[mm]	toadstool	
128.72	58.42	[mm]	toadstool	
0.00	58.42	[mm]	toadstool	
231.57	165.81	[mm]	toadstool	
335.92	165.81	[mm]	toadstool	
415.62	165.81	[mm]	toadstool	
387.81	38.10	[mm]	toadstool	interior
323.39	38.10	[mm]	toadstool	interior
246.63	63.50	[mm]	toadstool	interior
323.39	93.98	[mm]	toadstool	interior
387.81	93.98	[mm]	toadstool	interior
270.51	127.71	[mm]	toadstool	interior

0	0	[mm]	toadstool
169.47	0.00	[mm]	toadstool
335.91	1.85	[mm]	toadstool
415.62	10.80	[mm]	toadstool
128.78	58.42	[mm]	toadstool
0.00	58.42	[mm]	toadstool

			231.57	165.81	[mm]	toadstool	
		700-118668-01_07	335.92	165.81	[mm]	toadstool	
			415.62	165.81	[mm]	toadstool	
			387.81	38.10	[mm]	toadstool	interior
			323.39	38.10	[mm]	toadstool	interior
			246.63	63.50	[mm]	toadstool	interior
			323.39	93.98	[mm]	toadstool	interior
			387.81	93.98	[mm]	toadstool	interior
			270.51	127.76	[mm]	toadstool	interior
	Vore CR POE		0.00	0.00	[mm]	toadstool	
			169.47	0.00	[mm]	toadstool	
			335.91	1.85	[mm]	toadstool	
			415.62	10.80	[mm]	toadstool	
			128.78	58.42	[mm]	toadstool	
			0.00	58.42	[mm]	toadstool	
			231.57	165.81	[mm]	toadstool	
		700-122031-01_05	335.92	165.81	[mm]	toadstool	
			415.62	165.81	[mm]	toadstool	
			387.81	38.10	[mm]	toadstool	interior
			323.39	38.10	[mm]	toadstool	interior
			246.63	63.50	[mm]	toadstool	interior
			323.39	93.98	[mm]	toadstool	interior
			387.81	93.98	[mm]	toadstool	interior
			270.51	127.76	[mm]	toadstool	interior

Appendix E: Quake Chassis Standardization

Quake Chassis Standardization

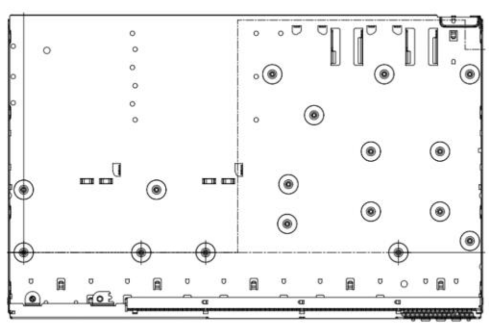
Cisco 1RU Cal Poly Senior Project

Prototype 4

1

Background

Our Senior Project aims to standardize Quake chassis hole locations. This document will serve as the official standardization documentation and sorts Quake chassis by their depth. We have used image overlays to attempt to create a guide for optimal hole locations of new chassis.



2

Instructions

1. Review the following pages
2. Complete the attached survey to provide feedback
   [Survey Link]

Schedule for Prototype Rounds		
To maximize the MATLAB 30 day free trial we will follow this schedule to get four protototype feedback rounds		
Cisco Team	**Cal Poly**	**# of Days Used**
Monday, April 26 to Friday, April 30	Saturday, May 1 to Sunday, May 2	7 of 30
Monday, May 3 to Friday, May 7	Saturday, May 8 to Sunday, May 9	14 of 30
Monday, May 10 to Friday, May 14	Saturday, May 15 to Sunday, May 16	21 of 30
Monday, May 17 to Friday, May 21	Saturday, May 22 to Sunday, May 23	28 of 30

13.6” Depth vs. 11.2” Depth Chassis

Chassis were classified based on differences in their Y-value. Dimensions below are in the form (X,Y).

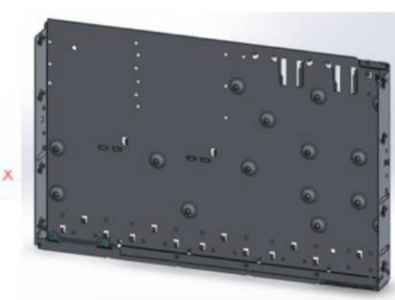


Figure 29. 13.6” Depth Chassis 700-113467-03_A0 from Enforcer 2X25G subfamily

Dimensions: 17.4” x 13.6”

Includes: Enforcer, Gunner, Hornet

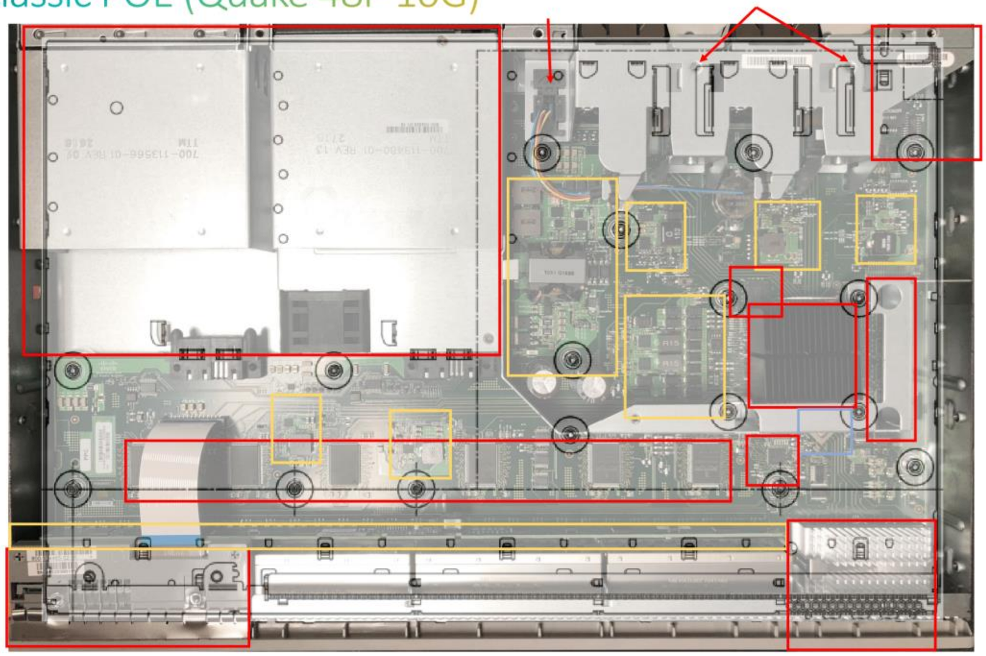
Figure 30. 11.2” Depth Chassis 700-122030-01_02 from Vore CR Non-POE subfamily

Dimensions: 17.4” x 11.2”

Includes: Vore Classic, Vore CR

Vore Classic POE (Quake 48P 10G)

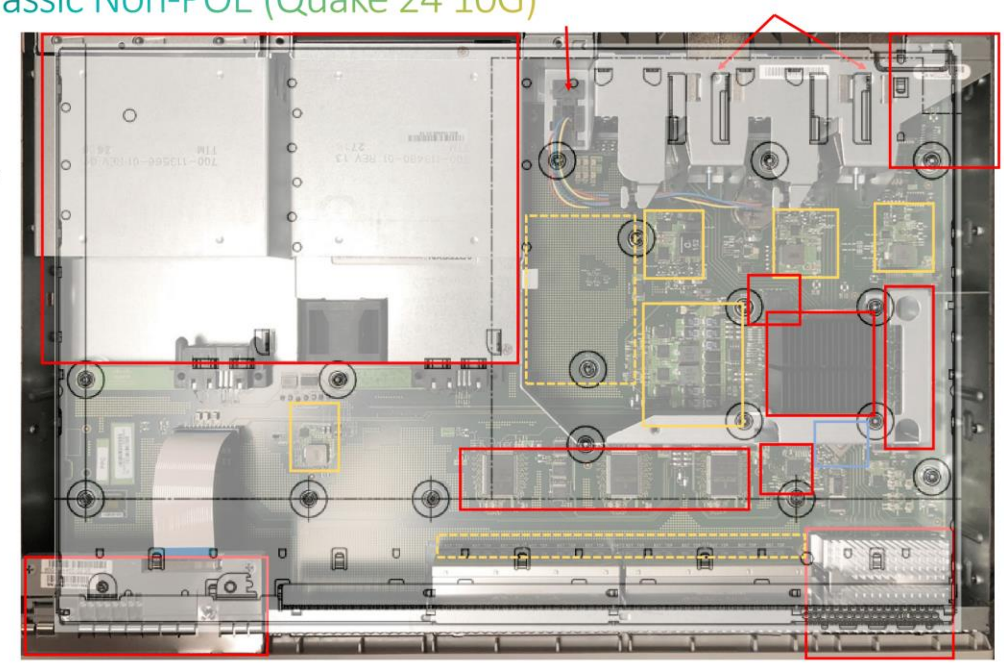
Block Diagram of hardware layout on a motherboard



5

Vore Classic Non-POE (Quake 24 10G)

Block Diagram of hardware layout on a motherboard

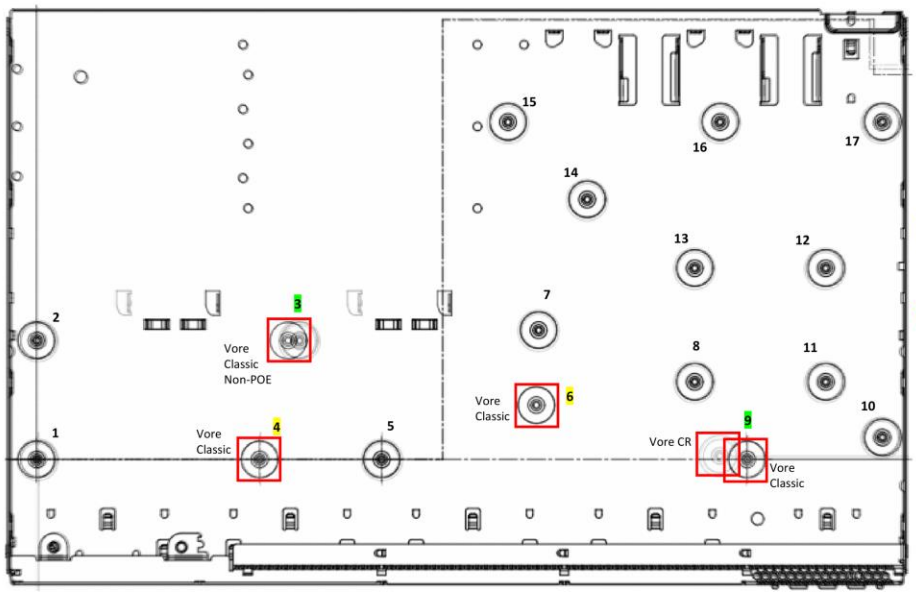


6

11.2” Depth Chassis Standardization (Vore Classic and Vore CR)

Coordinates (mm)

1. (0,0)
2. (0,58)
3. (124,58)
   (129,58)
4. (109,0)
5. (169,0)
6. (245,27)
7. (247,64)
8. (323,38)
9. (336,2)
   (349,0)
10. (416,11)
11. (388,38)
12. (388,94)
13. (323,94)
14. (271,128)
15. (232,166)
16. (336,166)
17. (416,166)

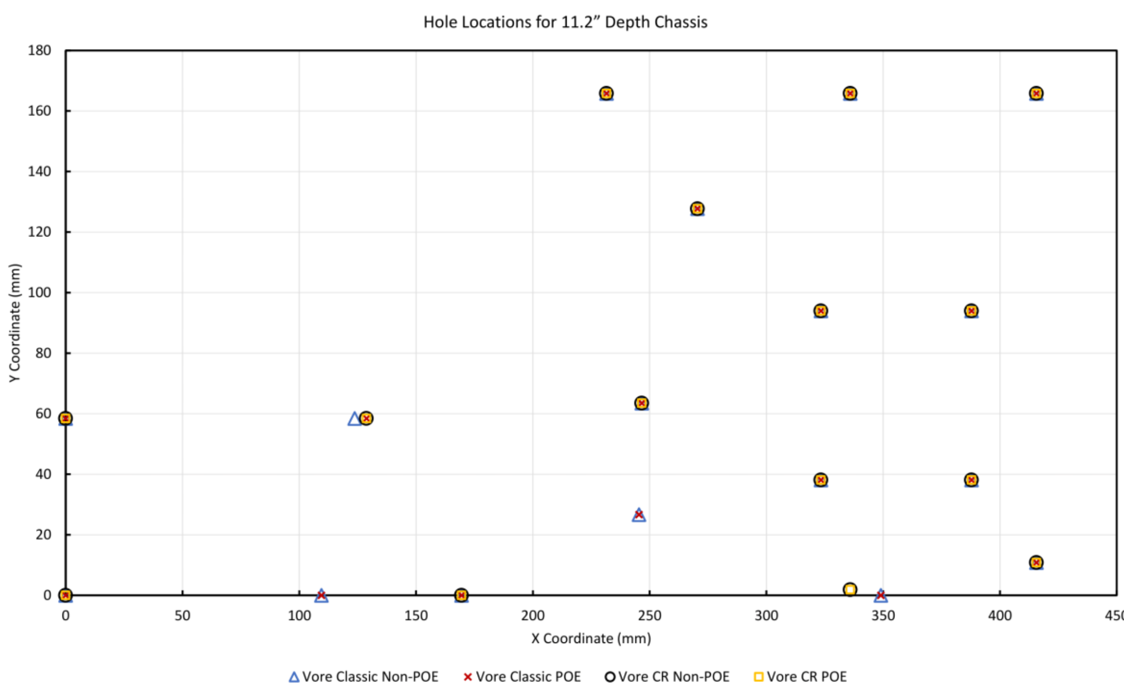


-Each number indicates a region

::: Location limited to specific chassis

::: All chassis in a region but not directly overlapping

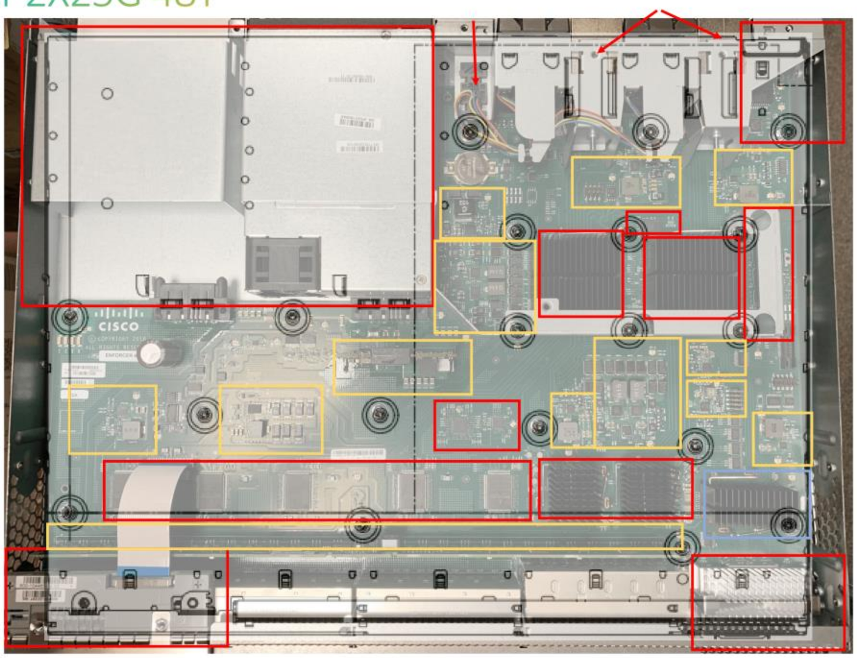
7



8

Enforcer 2X25G 48Y

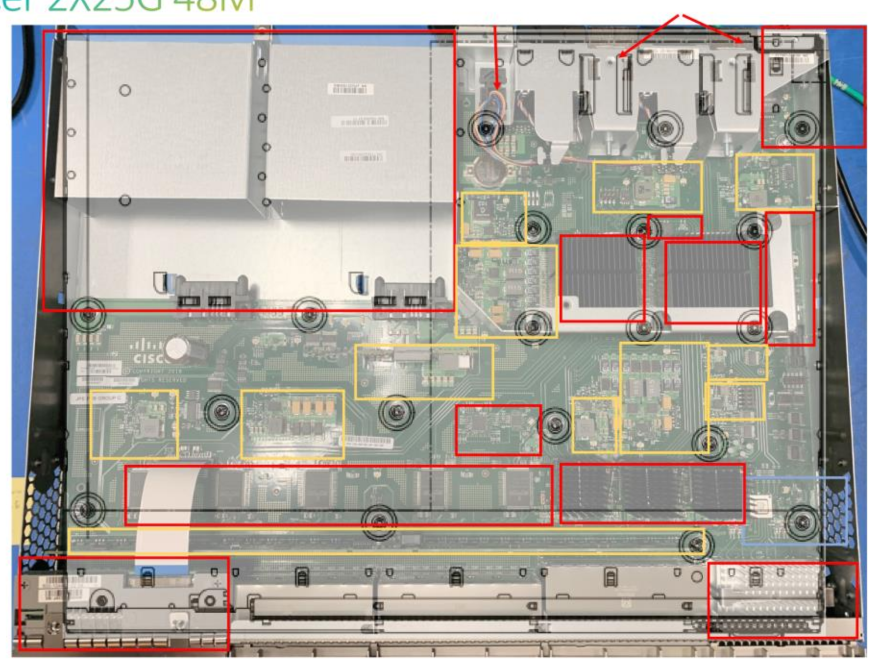
Block Diagram of hardware layout on a motherboard



9

Enforcer 2X25G 48M

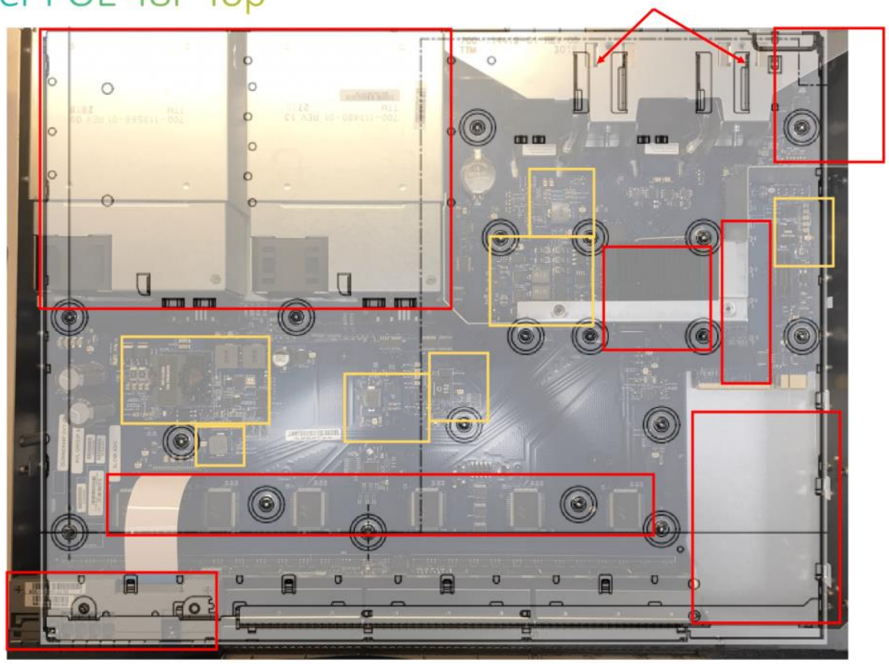
Block Diagram of hardware layout on a motherboard



10

Gunner POE 48P Top

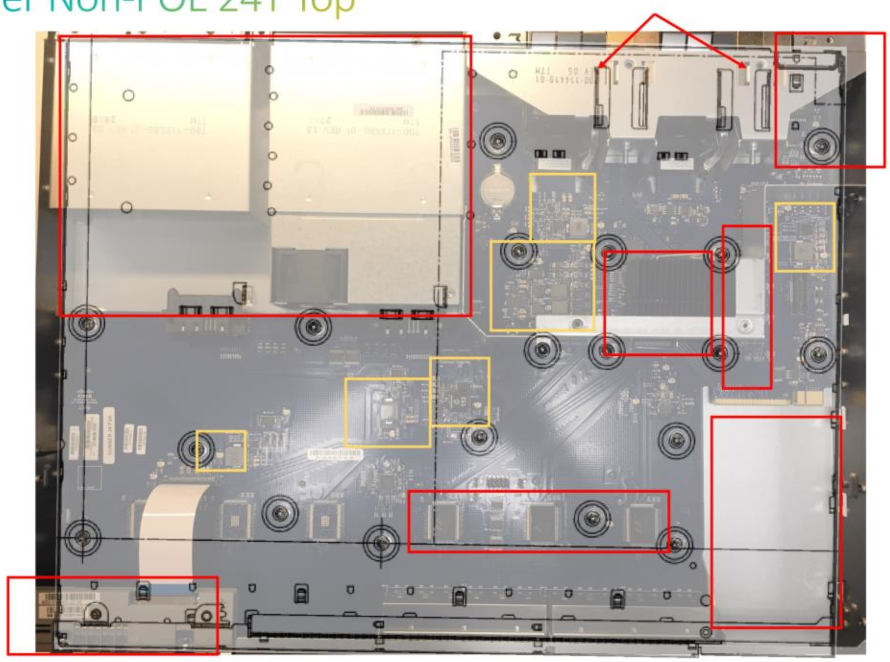
Block Diagram of hardware layout on a motherboard



11

Gunner Non-POE 24T Top

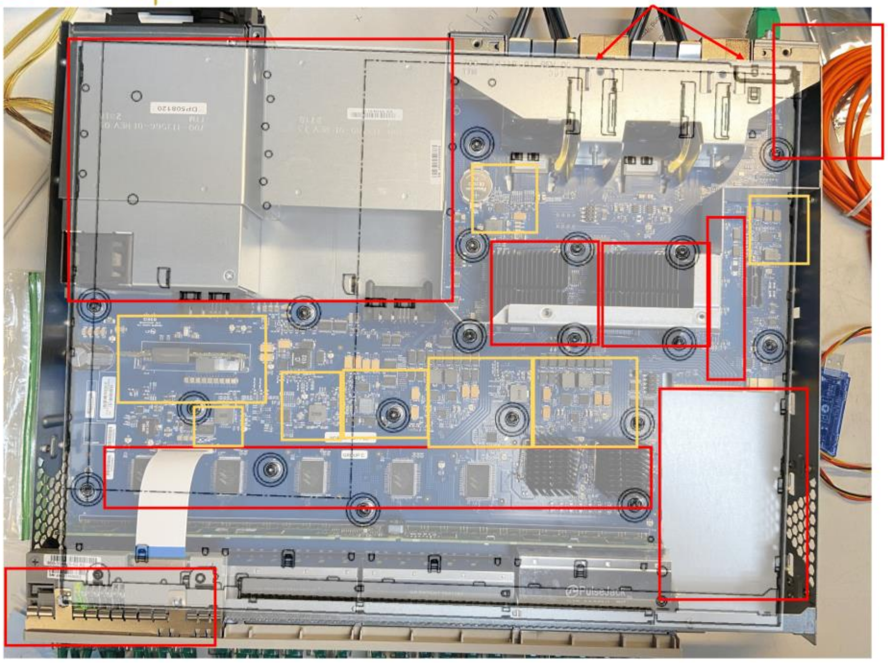
Block Diagram of hardware layout on a motherboard



12

Hornet 48P Top

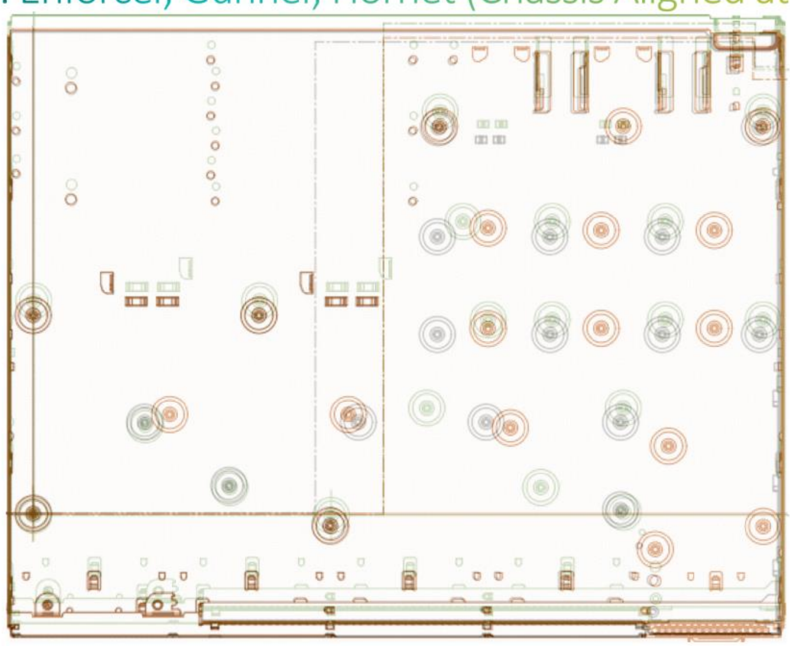
Block Diagram of hardware layout on a motherboard



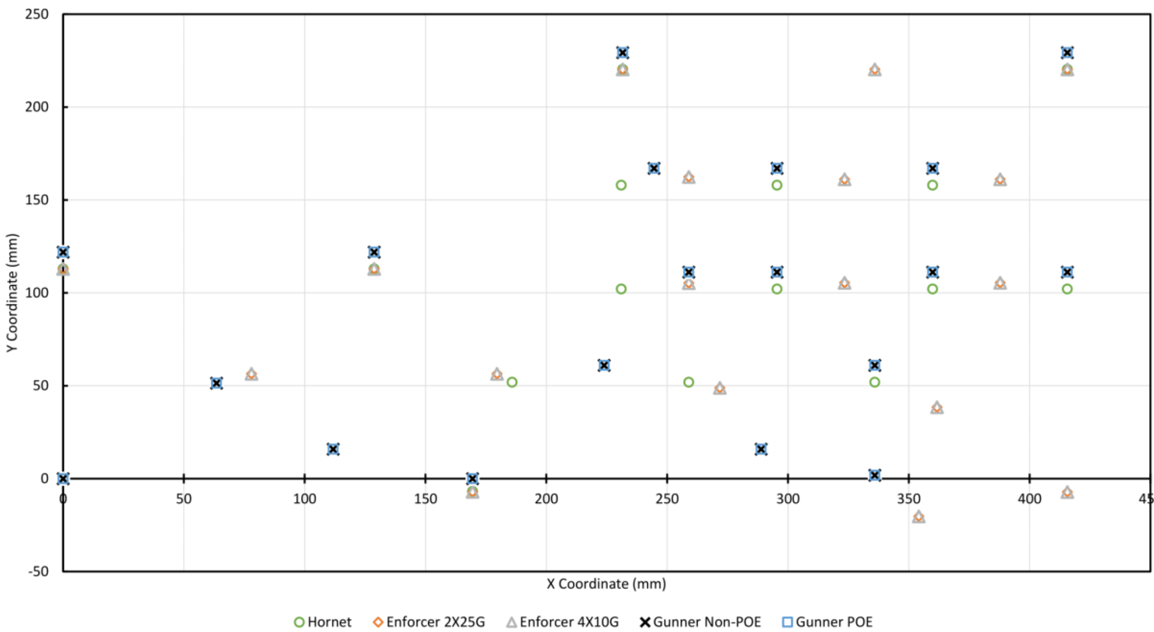
13

13.6" Depth: Enforcer, Gunner, Hornet (Chassis Aligned at Origin)

Orange = Enforcer
Green = Gunner
Black = Hornet



14

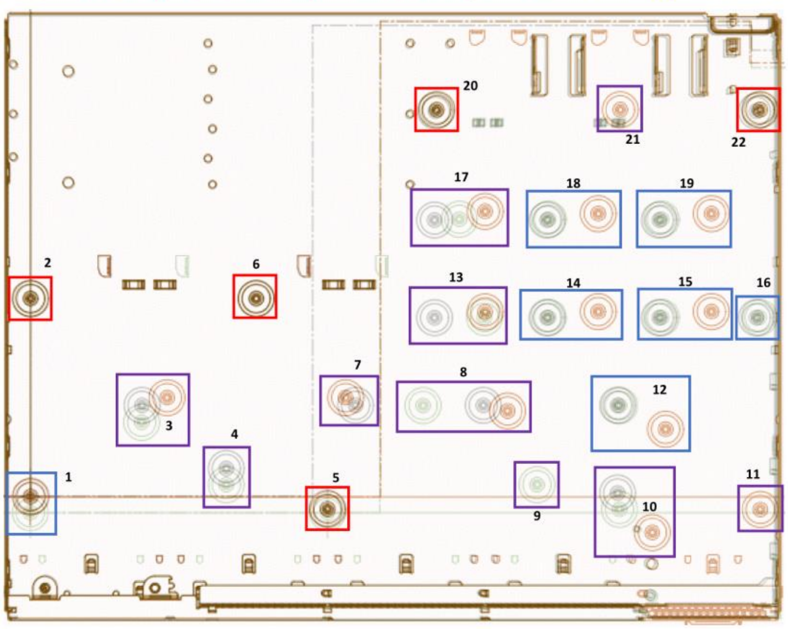


15

13.6” Depth: Enforcer, Gunner, Hornet (Chassis Aligned at Corners)

Coordinates (mm)

1. (0,0) (0,0) (0,-9.00)
2. (0,112.90)
3. (65.50,51.94) (77.98,66.54) (63.50,42.44)
4. (111.76,15.88) (111.76,6.88)
5. (169.47,-6.86)
6. (128.78,112.90)
7. (185.85,51.94) (179.58,56.44)
8. (258.93,51.94) (271.78,48.87) (223.96,51.96)
9. (288.93,6.88)
10. (335.92,1.85) (354.13,-20.32) (335.92,-7.15)
11. (415.62,-7.21)
12. (335.92,51.94) (361.70,38.46) (335.92,51.96)
13. (231.04,102.11) (258.98,105.28) (258.98,102.13)
14. (295.45,102.11) (323.39,105.41) (295.45,102.11)
15. (359.87,102.11) (387.81,105.41) (359.87,102.11)
16. (415.62,102.11) (415.62,102.11)
17. (231.04,157.99) (258.98,162.43) (244.60,158.01)
18. (295.45,157.99) (323.39,161.16) (295.45,157.99)
19. (359.87,157.99) (387.81,161.16) (359.87,157.99)
20. (231.57,220.29)
21. (335.92,220.29)
22. (415.62,220.29)



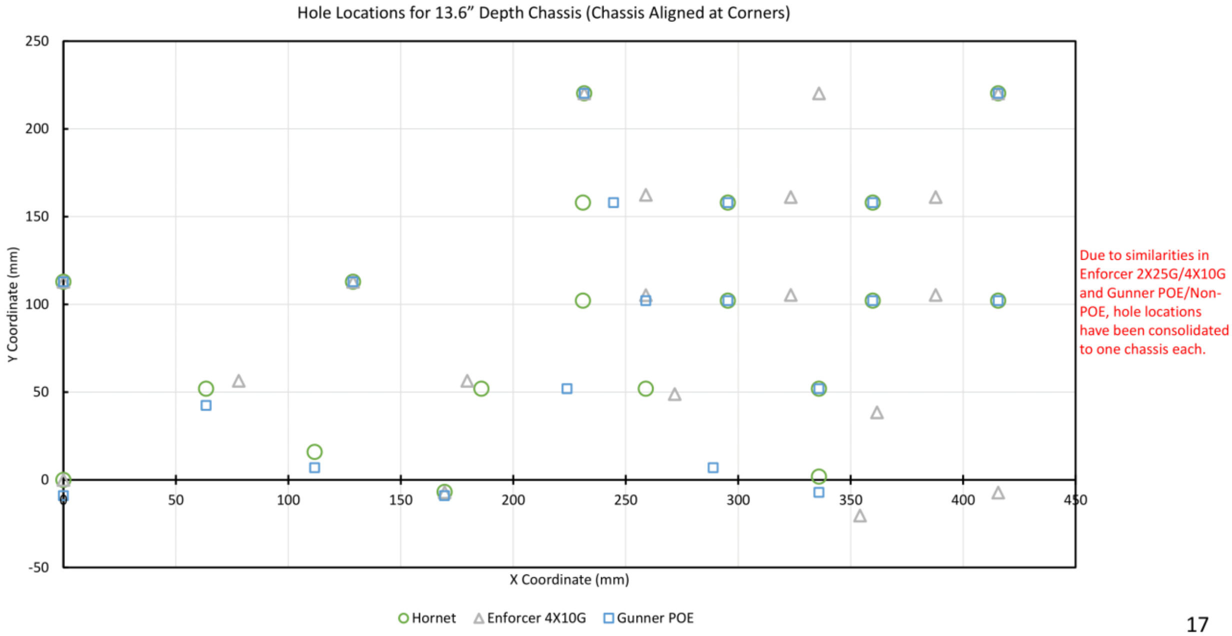
Orange = Enforcer
Green = Gunner
Black = Hornet

Common hole among all chassis

Common hole region for 2 chassis

No common chassis

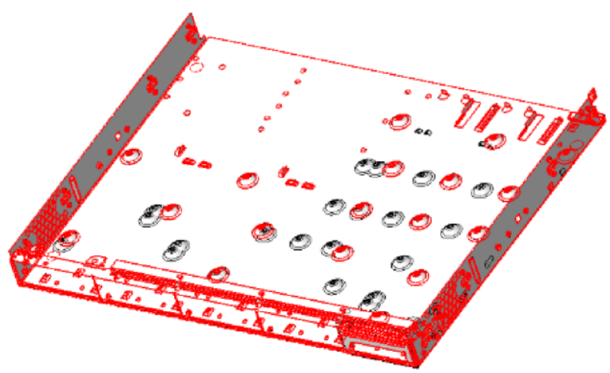
16



13.6” Depth: Enforcer, Gunner, Hornet - Chassis Aligned at Corners

- Gunner chassis was developed first
  - Gunner PCB supports 1G speed and only one CPU required
- Enforcer and Hornet are multi-Gig boxes, require more bandwidth, therefore require a different PCBA layout.
  - This board has more PHYs and two main CPUs
- Due to the new board layout requirement for Enforcer and Hornet, new sets of chassis holes are required
  - This results in Gunner having a slightly different origin (0,-9.00)

Enforcer (highlighted), Gunner and Hornet superimposed – Toad Stools are at different locations



Appendix F: MATLAB Script Max Density Hole Locator

Compare tooling to existing designs

```
clc
clear all
opts1 = spreadsheetImportOptions("NumVariables", 2);
opts2 = spreadsheetImportOptions("NumVariables", 2);

%Specify sheet and range for spreadsheets
opts1.Sheet = "Sheet1"; %different sheet per tooling?
opts2.Sheet = "Sheet1";
opts1.DataRange = "A1:B5";  %Change accordingly
opts2.DataRange = "A1:B553";

% Specify column names and types
opts1.VariableNames = ["VarName1", "VarName2"];
opts2.VariableNames = ["VarName1", "VarName2"];
opts1.VariableTypes = ["double", "double"];
opts2.VariableTypes = ["double", "double"];

% Import the data
ToolingHoleLocations = readtable("Tooling Hole Locations.xls",
 opts1, "UseExcel", false)
ChassisHoleLocations = readtable("Chassis Hole Locations.xls",
 opts2, "UseExcel", false)
n=0;
a=1;
ii=1;
increment= 1; % XX size of jumps between locating points
Matrix_1= table2array(ToolingHoleLocations)
Matrix_2 = table2array(ChassisHoleLocations)
Minimum_Distance= 2; %XX distance from reference point acceptable

out1=[];
out2=[];
%compare tooling hole locations to chassis hole locations
for k=1:size(Matrix_1,1)     %runs through tooling holes
    for i= 1:size(Matrix_1,1) % going through each input point
        if sqrt((Matrix_1(k,1)-Matrix_2(i,1))^2+(Matrix_1(k,2)-
Matrix_2(i,2))^2) <= Minimum_Distance     %matches similar holes
            n=n+1;
            i+i+1;
            out2 = [out2; n, Matrix_2(i,1), Matrix_2(i,2)]  %output
 for chassis
        else
            n=n+0;
        end
            out1 = [out1; n, Matrix_1(k,1),Matrix_1(k,2)]   %output
 for tooling

    Density = [n, Matrix_2(k,1),Matrix_2(k,2)]
    end



end


figure(1)
scatter(Matrix_2(:,1),Matrix_2(:,2),'o','r')
hold on
scatter(out1(:,2),out1(:,3),'filled','d','blue')
```

Appendix G: Second MATLAB Script

Table of Contents


```
clc
clear all
```

Inputs:

```
Minimum_Distance= 2; %[mm]if hole location coordinates are also in
 [mm] units change accordingly to excel input units

% Compare tooling to Existing Designs
```

Sheet 2

```
opts1 = spreadsheetImportOptions("NumVariables", 2); %callout for the
 spreadsheet
opts2 = spreadsheetImportOptions("NumVariables", 2);

%Specify sheet and range for spreadsheets
opts1.Sheet = "Sheet2"; %different sheet per chassis
opts2.Sheet = "Tooling";
opts1.DataRange = "A1:B20";  %Data selection
opts2.DataRange = "A1:B20";

% Specify column names and types
opts1.VariableNames = ["VarName1", "VarName2"];
opts2.VariableNames = ["VarName1", "VarName2"];
opts1.VariableTypes = ["double", "double"];
opts2.VariableTypes = ["double", "double"];

% Import the data
ToolingHoleLocations = readtable("Chassis Hole Locations Test.xlsx",
 opts2, "UseExcel", false);
ChassisHoleLocations = readtable("Chassis Hole Locations Test.xlsx",
 opts1, "UseExcel", false);
n=0;
a=1;
ii=1;
increment= 1; % XX size of jumps between locating points [mm]
Matrix_1= table2array(ToolingHoleLocations); %Creating matrix for
 tooling data set
```

```
Matrix_2 = table2array(ChassisHoleLocations); %Creating matrix for
 chassis data set

out1=[]; %output matrix

for k=1:size(Matrix_1,1)    %runs through tooling holes
    for i= 1:size(Matrix_1,1) % going through each input point
        if sqrt((Matrix_1(k,1)-Matrix_2(i,1))^2+(Matrix_1(k,2)-
Matrix_2(i,2))^2) <= Minimum_Distance    %matches similar holes
            n=n+1;
            i+i+1;
        else
            n=n+0;
        end

    end
    out1 = [out1; n, Matrix_2(k,1),Matrix_2(k,2)] ;  %output for
 chassis
    Density = [n, Matrix_2(k,1),Matrix_2(k,2)] ;  %density output
    n = 0;
end

Sheet2 = sum(out1(:,1)) %number of holes that are within minimum
 distance [mm] from tooling
```

Sheet2 =

17

Sheet 3

```
opts1 = spreadsheetImportOptions("NumVariables", 2); %callout for the
 spreadsheet
opts2 = spreadsheetImportOptions("NumVariables", 2);

%Specify sheet and range for spreadsheets
opts1.Sheet = "Sheet3"; %different sheet per chassis
opts2.Sheet = "Tooling";
opts1.DataRange = "A1:B20";  %Data selection
opts2.DataRange = "A1:B20";

% Specify column names and types
opts1.VariableNames = ["VarName1", "VarName2"];
opts2.VariableNames = ["VarName1", "VarName2"];
opts1.VariableTypes = ["double", "double"];
opts2.VariableTypes = ["double", "double"];

% Import the data
ToolingHoleLocations = readtable("Chassis Hole Locations Test.xlsx",
 opts2, "UseExcel", false);
```

```
ChassisHoleLocations = readtable("Chassis Hole Locations Test.xlsx",
 opts1, "UseExcel", false);
n=0;
a=1;
ii=1;
increment= 1; % XX size of jumps between locating points [mm]
Matrix_1= table2array(ToolingHoleLocations); %Creating matrix for
 tooling data set
Matrix_2 = table2array(ChassisHoleLocations); %Creating matrix for
 chassis data set

out1=[]; %output matrix

for k=1:size(Matrix_1,1)     %runs through tooling holes
    for i= 1:size(Matrix_1,1) % going through each input point
        if sqrt((Matrix_1(k,1)-Matrix_2(i,1))^2+(Matrix_1(k,2)-
Matrix_2(i,2))^2) <= Minimum_Distance     %matches similar holes
            n=n+1;
            i+i+1;
        else
            n=n+0;
        end

    end
    out1 = [out1; n, Matrix_2(k,1),Matrix_2(k,2)] ;  %output for
 chassis
    Density = [n, Matrix_2(k,1),Matrix_2(k,2)] ;  %density output
    n = 0;
end

Sheet3 = sum(out1(:,1)) %number of holes that are within minimum
 distance [mm] from tooling


Sheet3 =

    14
```

Sheet 4

```
opts1 = spreadsheetImportOptions("NumVariables", 2); %callout for the
 spreadsheet
opts2 = spreadsheetImportOptions("NumVariables", 2);

%Specify sheet and range for spreadsheets
opts1.Sheet = "Sheet4"; %different sheet per chassis
opts2.Sheet = "Tooling";
opts1.DataRange = "A1:B20";  %Data selection
opts2.DataRange = "A1:B20";

% Specify column names and types
opts1.VariableNames = ["VarName1", "VarName2"];
```

```
opts2.VariableNames = ["VarName1", "VarName2"];
opts1.VariableTypes = ["double", "double"];
opts2.VariableTypes = ["double", "double"];

% Import the data
ToolingHoleLocations = readtable("Chassis Hole Locations Test.xlsx",
 opts2, "UseExcel", false);
ChassisHoleLocations = readtable("Chassis Hole Locations Test.xlsx",
 opts1, "UseExcel", false);
n=0;
a=1;
ii=1;
increment= 1; % XX size of jumps between locating points [mm]
Matrix_1= table2array(ToolingHoleLocations); %Creating matrix for
 tooling data set
Matrix_2 = table2array(ChassisHoleLocations); %Creating matrix for
 chassis data set

out1=[]; %output matrix

for k=1:size(Matrix_1,1)     %runs through tooling holes
    for i= 1:size(Matrix_1,1) % going through each input point
        if sqrt((Matrix_1(k,1)-Matrix_2(i,1))^2+(Matrix_1(k,2)-
Matrix_2(i,2))^2) <= Minimum_Distance    %matches similar holes
            n=n+1;
            i+i+1;
        else
            n=n+0;
        end

    end
    out1 = [out1; n, Matrix_2(k,1),Matrix_2(k,2)] ;  %output for
 chassis
    Density = [n, Matrix_2(k,1),Matrix_2(k,2)] ;  %density output
    n = 0;
end

Sheet4 = sum(out1(:,1)) %number of holes that are within minimum
 distance [mm] from tooling


Sheet4 =

    14
```

Sheet 5

```
opts1 = spreadsheetImportOptions("NumVariables", 2); %callout for the
 spreadsheet
opts2 = spreadsheetImportOptions("NumVariables", 2);

%Specify sheet and range for spreadsheets
```

```
opts1.Sheet = "Sheet5"; %different sheet per chassis
opts2.Sheet = "Tooling";
opts1.DataRange = "A1:B20";  %Data selection
opts2.DataRange = "A1:B20";

% Specify column names and types
opts1.VariableNames = ["VarName1", "VarName2"];
opts2.VariableNames = ["VarName1", "VarName2"];
opts1.VariableTypes = ["double", "double"];
opts2.VariableTypes = ["double", "double"];

% Import the data
ToolingHoleLocations = readtable("Chassis Hole Locations Test.xlsx",
 opts2, "UseExcel", false);
ChassisHoleLocations = readtable("Chassis Hole Locations Test.xlsx",
 opts1, "UseExcel", false);
n=0;
a=1;
ii=1;
increment= 1; % XX size of jumps between locating points [mm]
Matrix_1= table2array(ToolingHoleLocations); %Creating matrix for
 tooling data set
Matrix_2 = table2array(ChassisHoleLocations); %Creating matrix for
 chassis data set

out1=[]; %output matrix

for k=1:size(Matrix_1,1)     %runs through tooling holes
    for i= 1:size(Matrix_1,1) % going through each input point
        if sqrt((Matrix_1(k,1)-Matrix_2(i,1))^2+(Matrix_1(k,2)-
Matrix_2(i,2))^2) <= Minimum_Distance     %matches similar holes
            n=n+1;
            i+i+1;
        else
            n=n+0;
        end

    end
    out1 = [out1; n, Matrix_2(k,1),Matrix_2(k,2)] ;  %output for
 chassis
    Density = [n, Matrix_2(k,1),Matrix_2(k,2)] ;  %density output
    n = 0;
end

Sheet5 = sum(out1(:,1)) %number of holes that are within minimum
 distance [mm] from tooling


Sheet5 =

    14
```

Sheet 6

```
opts1 = spreadsheetImportOptions("NumVariables", 2); %callout for the
 spreadsheet
opts2 = spreadsheetImportOptions("NumVariables", 2);

%Specify sheet and range for spreadsheets
opts1.Sheet = "Sheet6"; %different sheet per chassis
opts2.Sheet = "Tooling";
opts1.DataRange = "A1:B20";  %Data selection
opts2.DataRange = "A1:B20";

% Specify column names and types
opts1.VariableNames = ["VarName1", "VarName2"];
opts2.VariableNames = ["VarName1", "VarName2"];
opts1.VariableTypes = ["double", "double"];
opts2.VariableTypes = ["double", "double"];

% Import the data
ToolingHoleLocations = readtable("Chassis Hole Locations Test.xlsx",
 opts2, "UseExcel", false);
ChassisHoleLocations = readtable("Chassis Hole Locations Test.xlsx",
 opts1, "UseExcel", false);
n=0;
a=1;
ii=1;
increment= 1; % XX size of jumps between locating points [mm]
Matrix_1= table2array(ToolingHoleLocations); %Creating matrix for
 tooling data set
Matrix_2 = table2array(ChassisHoleLocations); %Creating matrix for
 chassis data set

out1=[]; %output matrix

for k=1:size(Matrix_1,1)    %runs through tooling holes
    for i= 1:size(Matrix_1,1) % going through each input point
        if sqrt((Matrix_1(k,1)-Matrix_2(i,1))^2+(Matrix_1(k,2)-
Matrix_2(i,2))^2) <= Minimum_Distance    %matches similar holes
            n=n+1;
            i+i+1;
        else
            n=n+0;
        end

    end
    out1 = [out1; n, Matrix_2(k,1),Matrix_2(k,2)] ;  %output for
 chassis
    Density = [n, Matrix_2(k,1),Matrix_2(k,2)] ;  %density output
    n = 0;
end

Sheet6 = sum(out1(:,1)) %number of holes that are within minimum
 distance [mm] from tooling
```



```
vars =
 {'Matrix_1' 'Matrix_2' 'out' 'n' 'i' 'k' 'Density' 'opts1' 'opts2' 'increment' 'i
 all unecessary variables from workspace
clear(vars{:});


Sheet6 =

    14
```

Published with MATLAB® R2021a

Appendix H: MATLAB Script User Manual

MATLAB Testing V4 (May 17- May 21)

Schedule for Prototype Rounds		
To maximize the MATLAB 30 day free trial we will follow this schedule to get four prototype feedback rounds		
Cisco Team	**Cal Poly**	**# of Days Used**
Monday, April 26 to Friday, April 30	Saturday, May 1 to Sunday, May 2	7 of 30
Monday, May 3 to Friday, May 7	Saturday, May 8 to Sunday, May 9	14 of 30
Monday, May 10 to Friday, May 14	Saturday, May 15 to Sunday, May 16	21 of 30
Monday, May 17 to Friday, May 21	Saturday, May 22 to Sunday, May 23	28 of 30

Purpose of MATLAB Tool

The goal of this project is to create a tool to help Cisco place mounting locations for future chassis designs. We want to standardize mounting hole locations so that instead of having a different tool for each chassis, each tool will create multiple chassis or new chassis can utilize previous tooling. In order to standardize mounting hole locations, our goal is to compare a new set of mounting hole locations to previous sets of tooling hole locations. By ranking which tooling hole locations match the closest to the new set of hole locations, designers can visualize which tooling set they could potentially copy for their new chassis design.

Our MATLAB tool does this by comparing each input hole location to an input set of tooling hole locations. Figure 1 below gives an example of how this works.

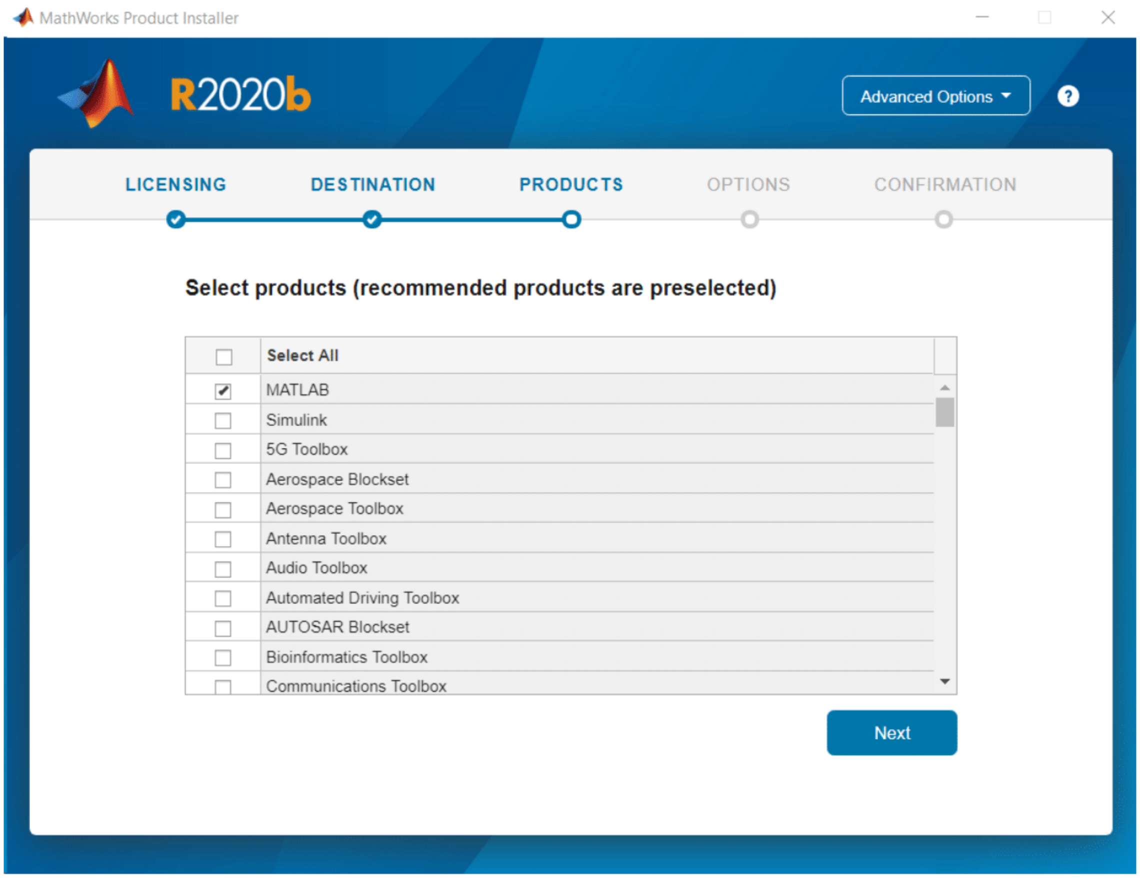
Figure 1: Tooling Ranking Example

The inputs Cisco can specify are the coordinates for the set of hole locations they want compared and the "capture radius" for those hole locations. If a tooling hole location is within that "capture radius" then it will increase the ranking. Therefore Figure 1 shows that Tool A has a ranking of 2 and Tool B has a ranking of 1. This means Tool A is ranked higher than Tool B. In addition, the radius is denoted by the *Minimum_Distance* variable.

MATLAB Testing Procedure

By following the steps of instruction and using the MATLAB tool, our goal is to help Cisco engineers understand how to use our tool and to also receive feedback to improve our tool for Cisco's needs.

*When using the MATLAB installer, be sure to only check MATLAB to reduce the download time. An example of this can be seen below.

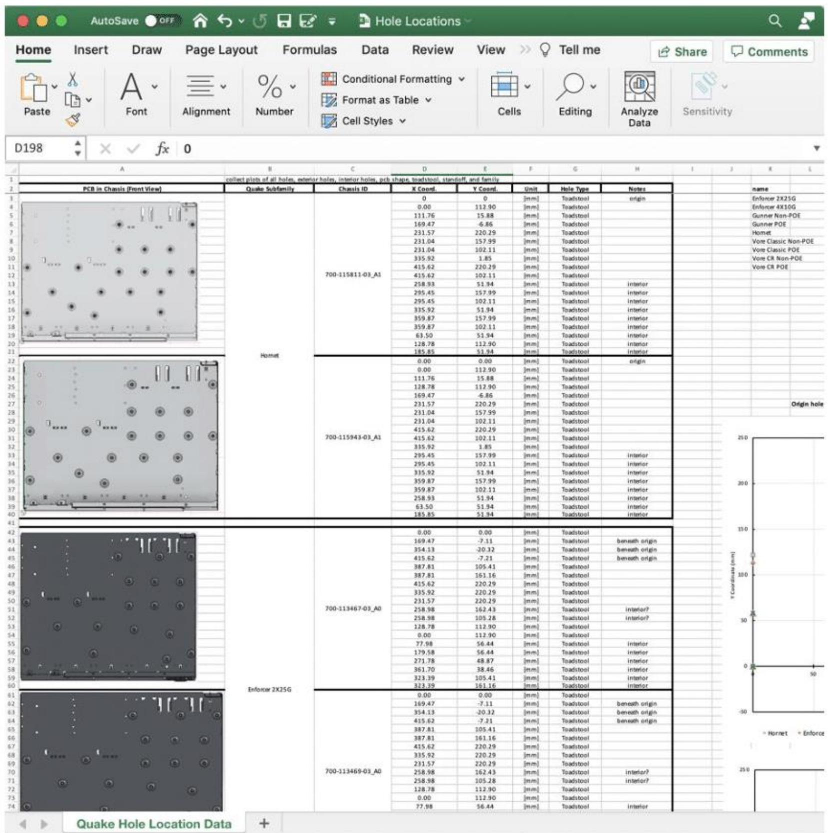


Instructional Video Link is also provided here: https://youtu.be/_id_1cllrww

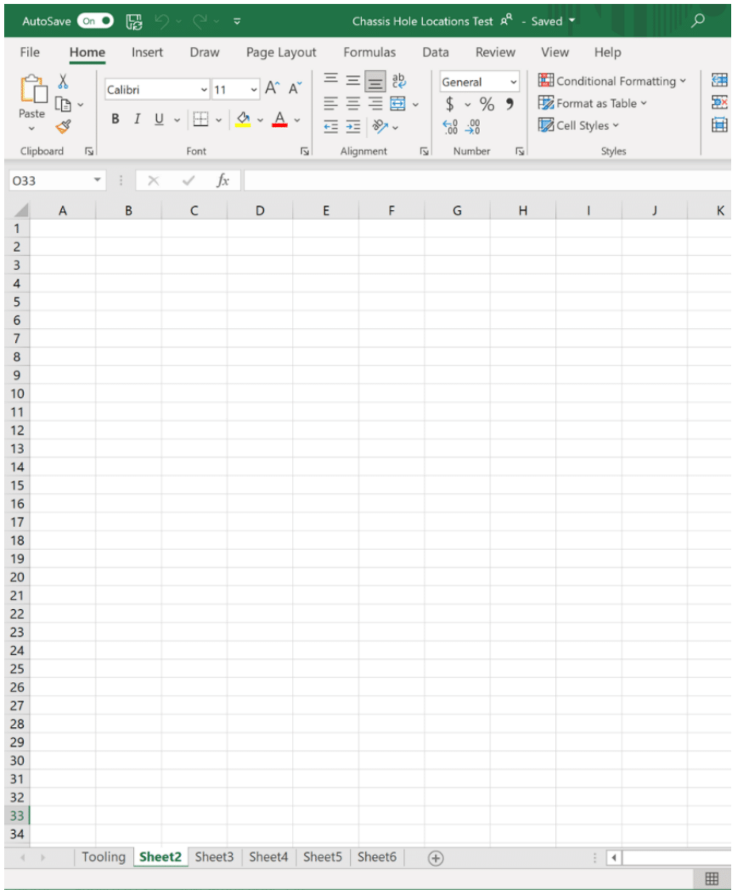
Step 0: Delete all files from previous package before downloading new package.

Step 1: Open excel file “Hole locations.xlsx” and click on Sheet “Quake Hole Location Data” within the excel file.

***These will be used as our inputs for the tool.**

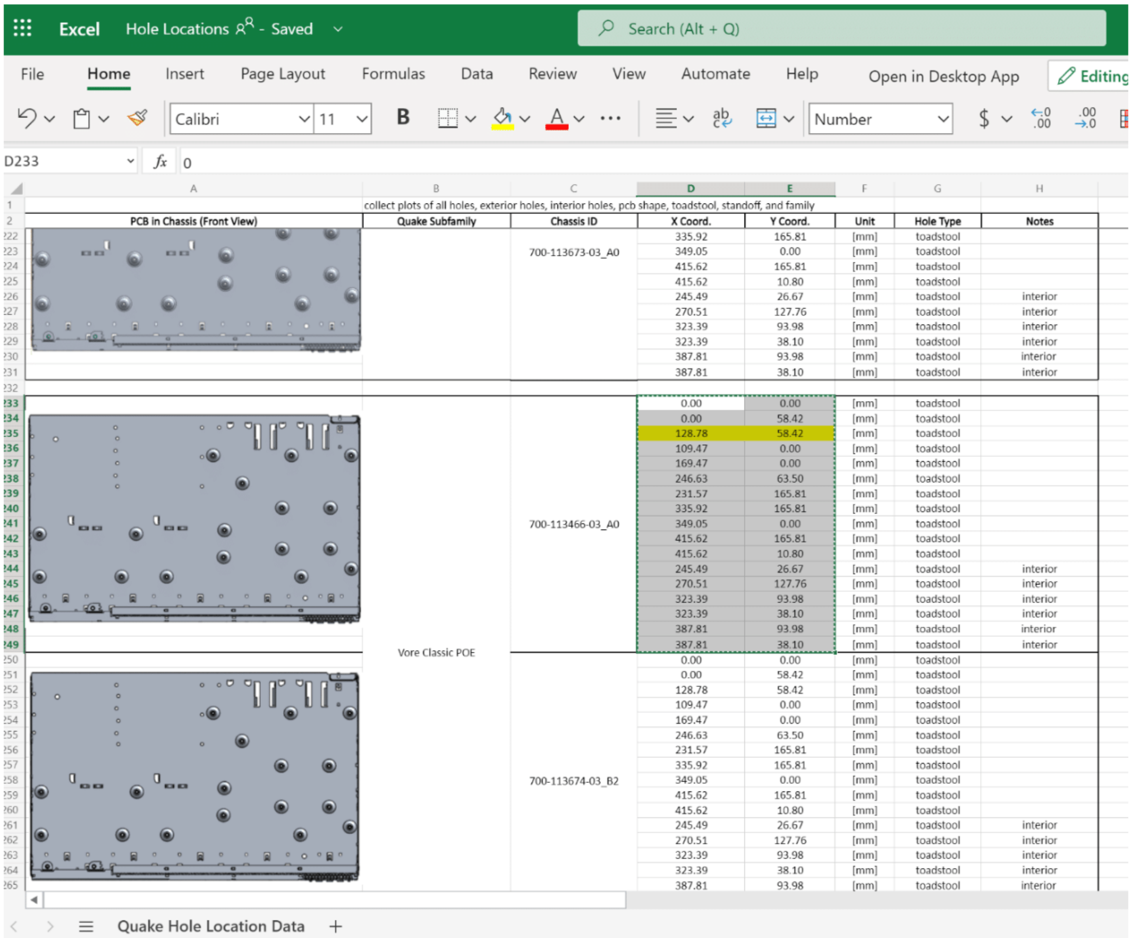


Step 2: Open excel file “Chassis Hole Locations Test.xlsx” (MATLAB will reference this file for inputs)



Step 3: Copy chassis ID: 700-113466-03_A0 coordinates D233:E249 from excel file “Hole locations.xlsx” sheet “Quake Hole Location Data”

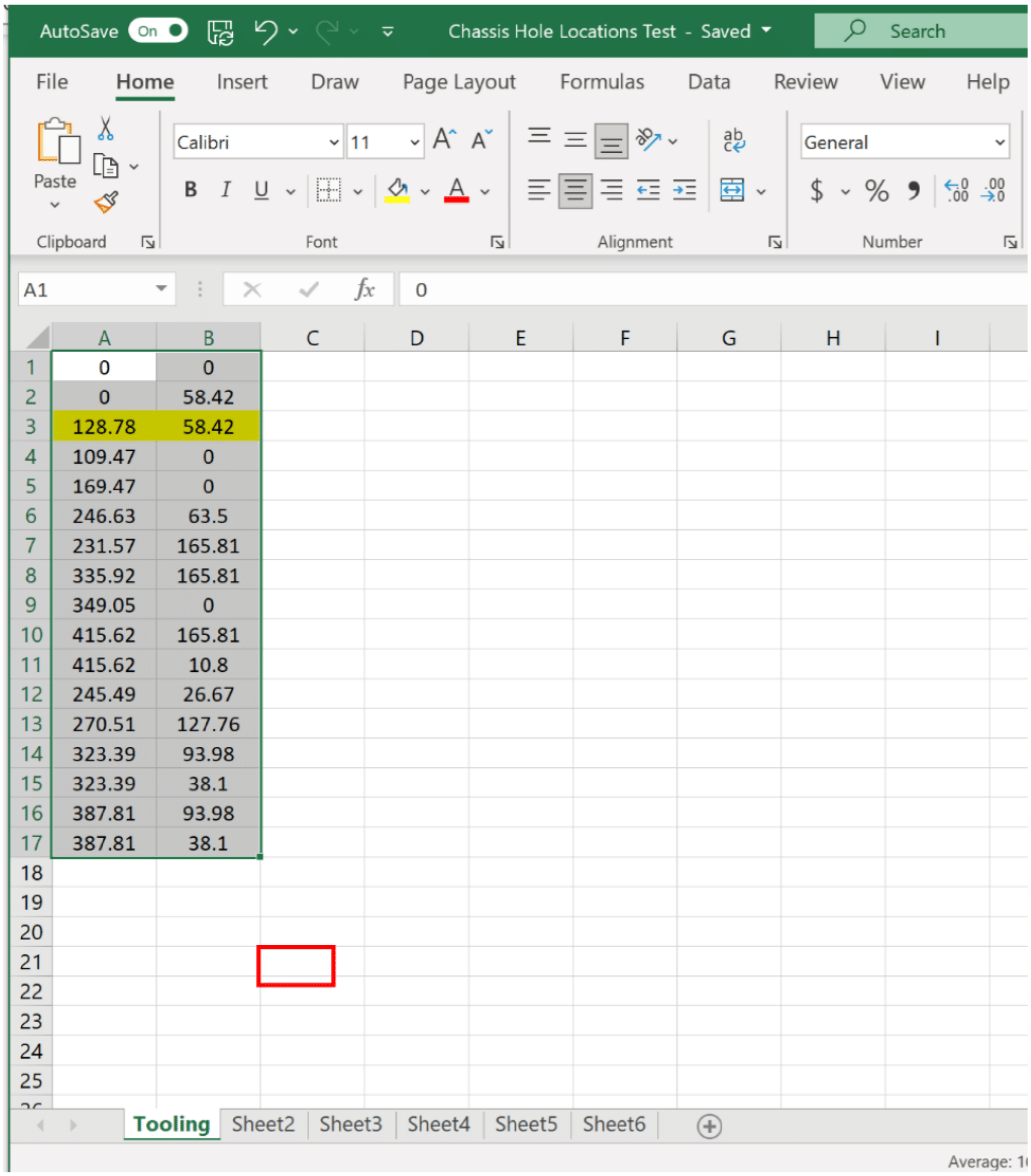
*Coordinates not in “Chassis Hole Locations.xlsx” will not be read by MATLAB script.



Row	PCB in Chassis (Front View)	Quake Subfamily	Chassis ID	X Coord.	Y Coord.	Unit	Hole Type	Notes
222				335.92	165.81	[mm]	toadstool	
223			700-113673-03_A0	349.05	0.00	[mm]	toadstool	
224				415.62	165.81	[mm]	toadstool	
225				415.62	10.80	[mm]	toadstool	
226				245.49	26.67	[mm]	toadstool	interior
227				270.51	127.76	[mm]	toadstool	interior
228				323.39	93.98	[mm]	toadstool	interior
229				323.39	38.10	[mm]	toadstool	interior
230				387.81	93.98	[mm]	toadstool	interior
231				387.81	38.10	[mm]	toadstool	interior
232								
233				0.00	0.00	[mm]	toadstool	
234				0.00	58.42	[mm]	toadstool	
235				128.78	58.42	[mm]	toadstool	
236				109.47	0.00	[mm]	toadstool	
237				169.47	0.00	[mm]	toadstool	
238				246.63	63.50	[mm]	toadstool	
239				231.57	165.81	[mm]	toadstool	
240				335.92	165.81	[mm]	toadstool	
241			700-113466-03_A0	349.05	0.00	[mm]	toadstool	
242				415.62	165.81	[mm]	toadstool	
243				415.62	10.80	[mm]	toadstool	
244				245.49	26.67	[mm]	toadstool	interior
245				270.51	127.76	[mm]	toadstool	interior
246				323.39	93.98	[mm]	toadstool	interior
247				323.39	38.10	[mm]	toadstool	interior
248				387.81	93.98	[mm]	toadstool	interior
249				387.81	38.10	[mm]	toadstool	interior
250		Vore Classic POE		0.00	0.00	[mm]	toadstool	
251				0.00	58.42	[mm]	toadstool	
252				128.78	58.42	[mm]	toadstool	
253				109.47	0.00	[mm]	toadstool	
254				169.47	0.00	[mm]	toadstool	
255				246.63	63.50	[mm]	toadstool	
256				231.57	165.81	[mm]	toadstool	
257				335.92	165.81	[mm]	toadstool	
258			700-113674-03_B2	349.05	0.00	[mm]	toadstool	
259				415.62	165.81	[mm]	toadstool	
260				415.62	10.80	[mm]	toadstool	
261				245.49	26.67	[mm]	toadstool	interior
262				270.51	127.76	[mm]	toadstool	interior
263				323.39	93.98	[mm]	toadstool	interior
264				323.39	38.10	[mm]	toadstool	interior
265				387.81	93.98	[mm]	toadstool	interior

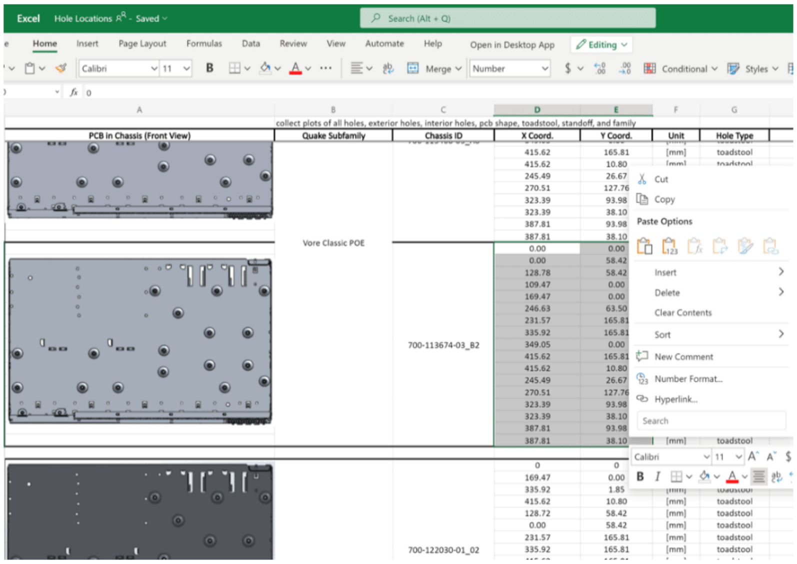
Step 4: Paste the following coordinates into the top left of the “Tooling” sheet of the “Cha Locations.xls” file.

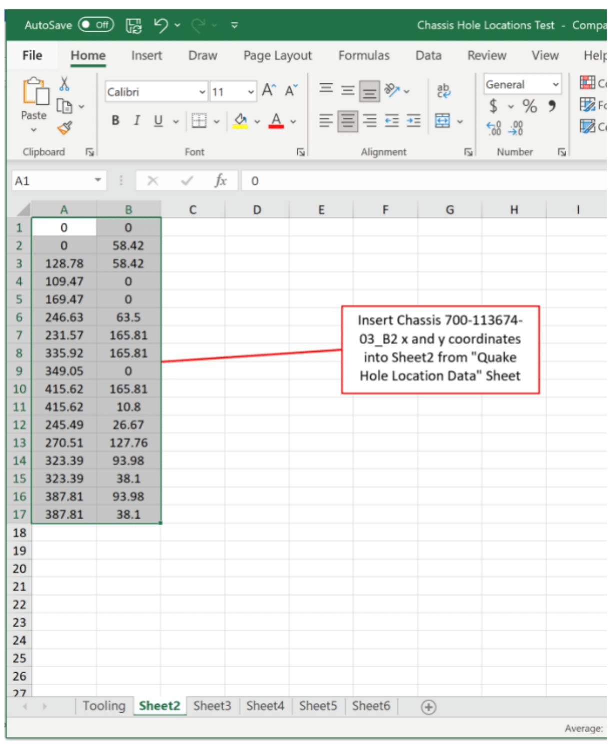
*MATLAB will use this set as the reference tool to compare with other sets of coordinates fro Sheet3, etc.



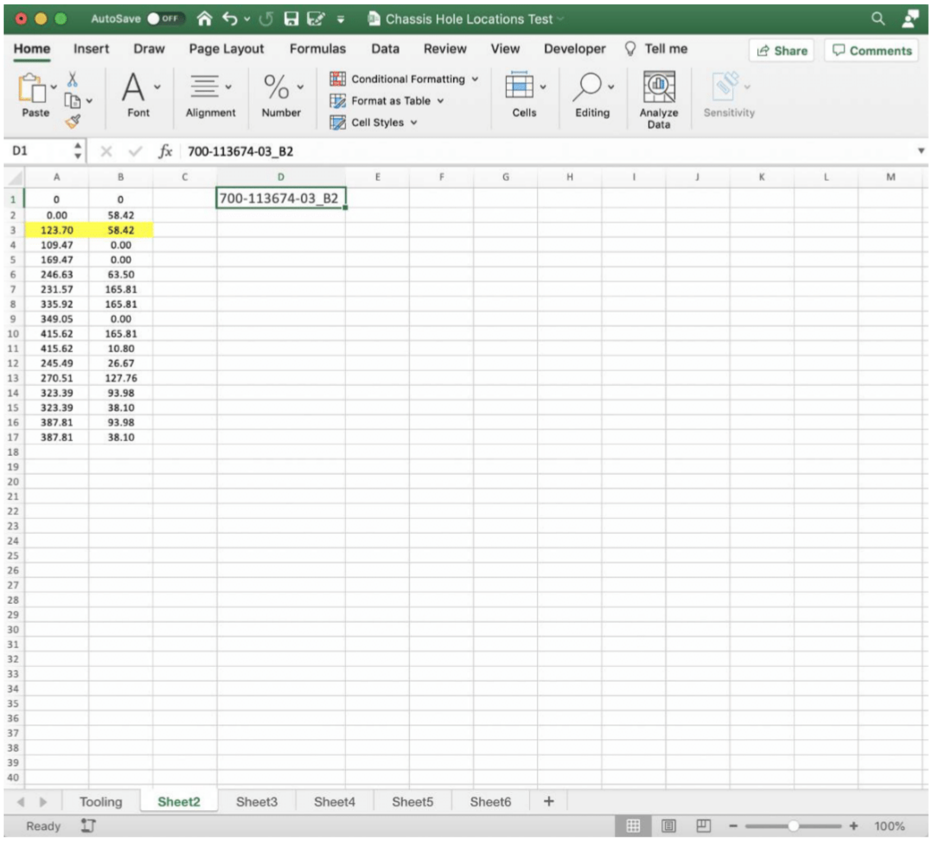
Step 5: Copy and paste the chassis ID: 700-113674-03_B2 hole coordinates (copy D250:E266) from the "Hole locations.xls" file. Paste X-coordinates into column A and Y-coordinates into column B in "Sheet2" of the "Chassis Hole Locations Test.xlsx" file.

***It is important that the data is pasted in the top left corner of each sheet.**





Step 6: Copy and paste chassis ID to cell D1 of Sheet2. (This will make the outputs easier to reference)

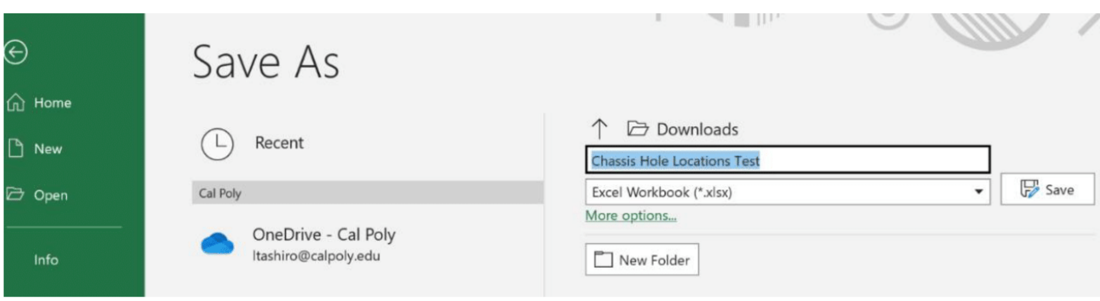


Step 7: Repeat steps 5 and 6 for the following chassis:

- For chassis ID: 700-122030-01_02 copy D268:E282 into Sheet3
- For chassis ID: 700-122032-01_03 copy D283:E297 into Sheet4
- For chassis ID: 700-118668-01_07 copy D299:E313 into Sheet5
- For chassis ID: 700-122031-01_05 copy D314:E328 into Sheet6

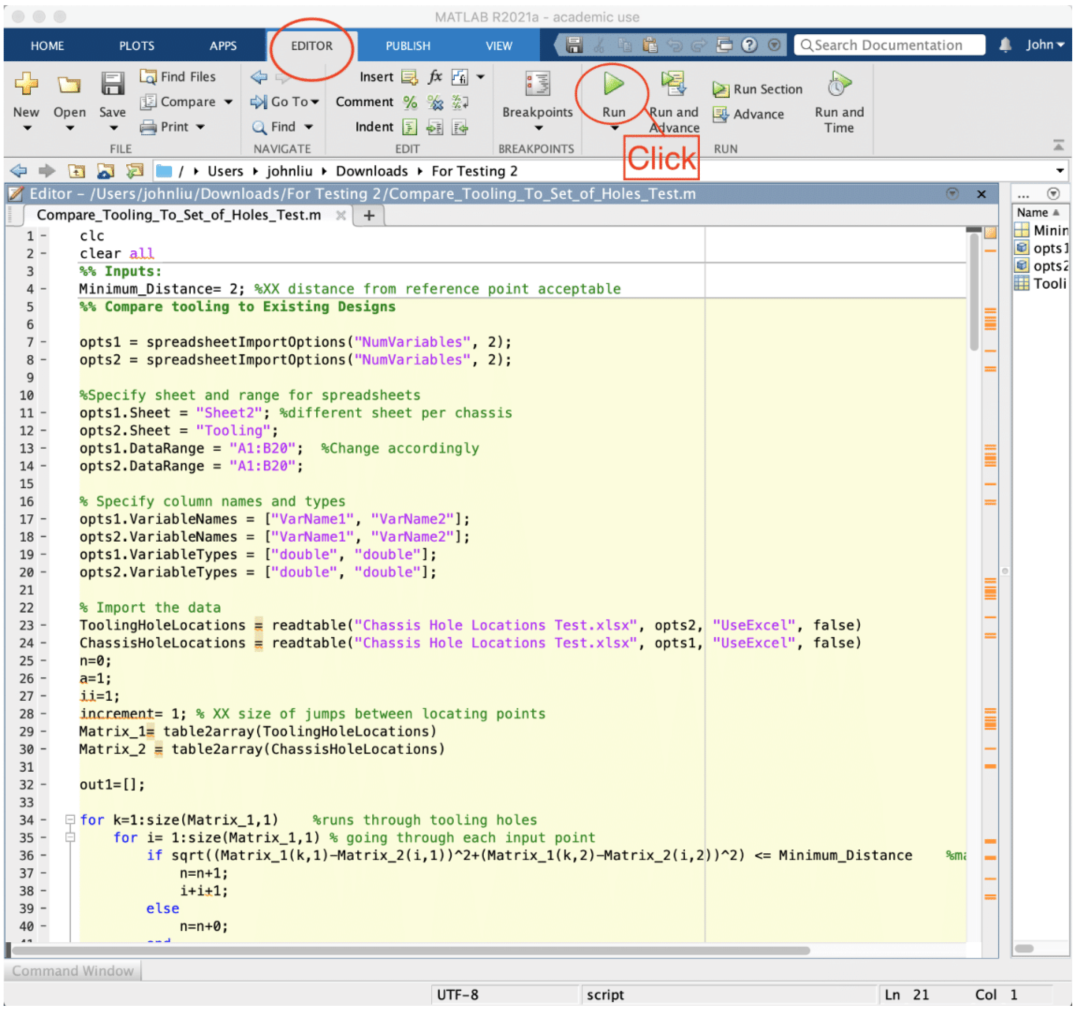
*If more than 5 chassis are being compared to the reference tooling, refer to page 10.

Step 8: Save excel file "Chassis Hole Locations.xlsx" so MATLAB will use updated inputs. Close the file after saving it.

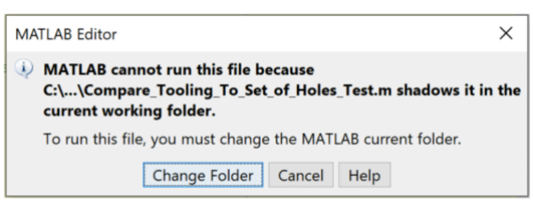


Step 9: Open the MATLAB file "Compare_Tooling_To_Set_of_Holes_TestV4.m" and check you are in the Editor tab before clicking the green arrow to run the code.

*Outputs should show in the command window at the bottom if the code is running successfully.

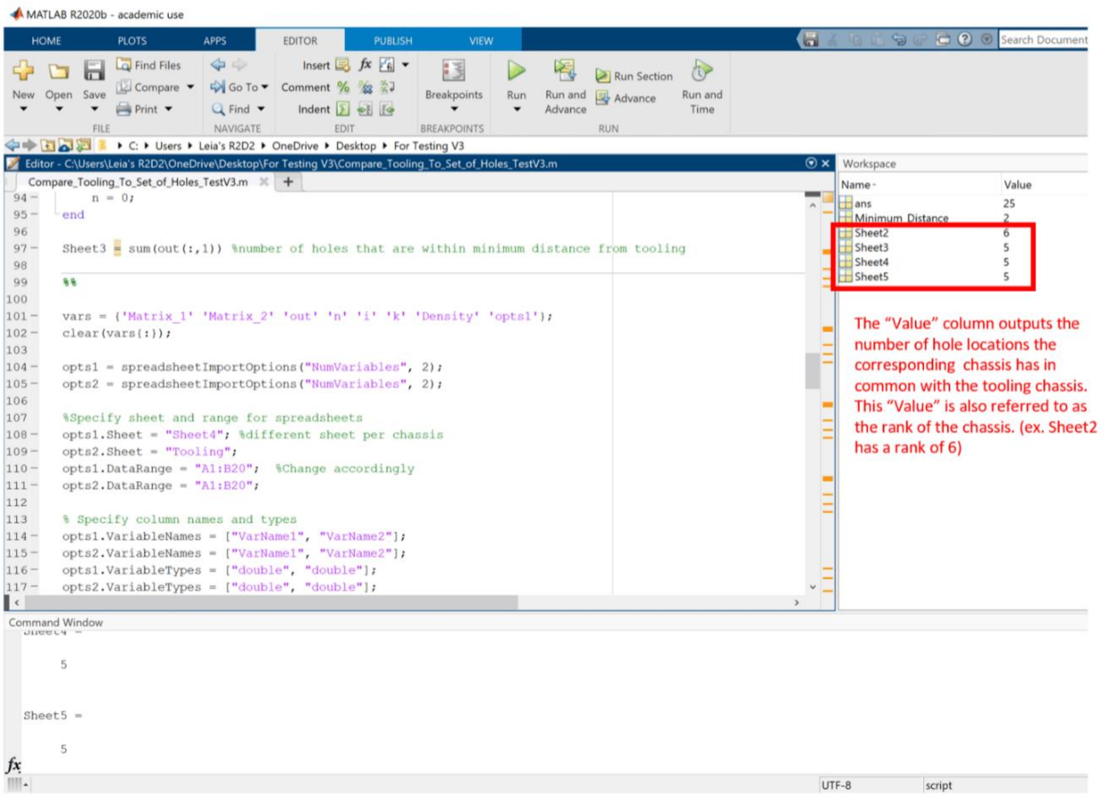


If this window pops up, click "Change Folder."

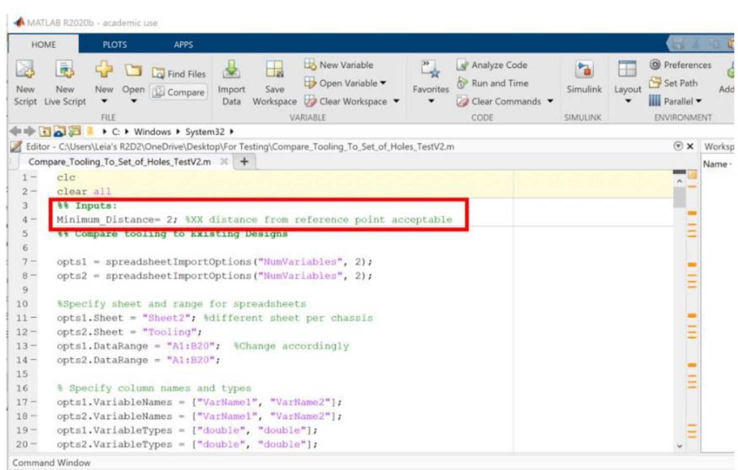


Step 10: Each sheet's rank will be displayed in the workspace (right side in MATLAB in the value column). You will need these values to complete the survey.

*Note that a *better* chassis is indicated by a larger number in the workspace.



*The *Minimum_Distance* variable can be modified in MATLAB to change the size of the capture radius [mm].



Step 11: Fill out Google Survey for feedback!

Survey Link

To compare more than 5 chassis to the tooling chassis here are the instructions:

Step 1: Copy lines 195:246 from the MATLAB code and paste them directly underneath line 247.

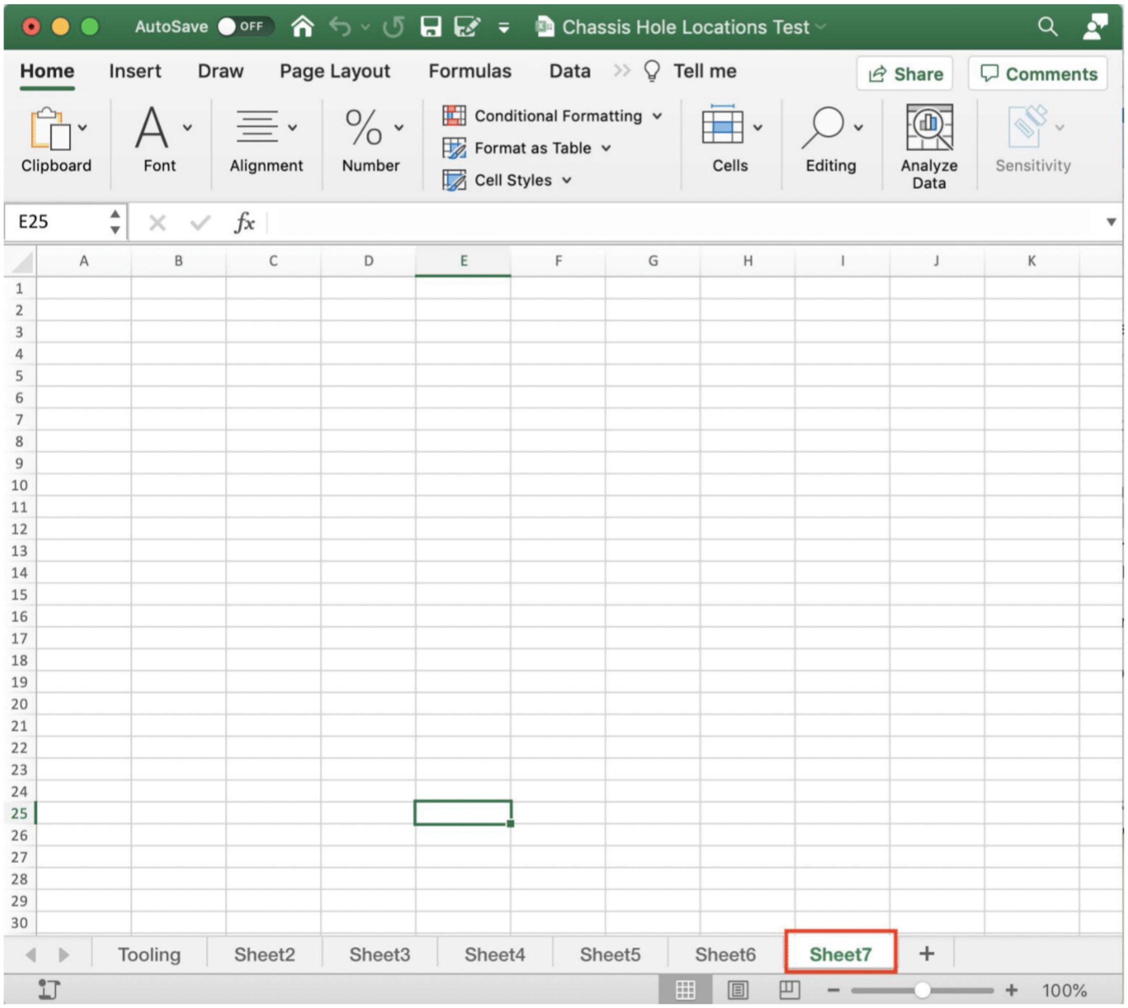
```
193
194     Sheet5 = sum(out(:,1)) %number of holes that are within minimum distance from tooling
195     %% Sheet 6
196
197     vars = {'Matrix_1' 'Matrix_2' 'out' 'n' 'i' 'k' 'Density' 'opts1'};
198     clear(vars{:});
199
200     opts1 = spreadsheetImportOptions("NumVariables", 2);
201     opts2 = spreadsheetImportOptions("NumVariables", 2);
202
203     %Specify sheet and range for spreadsheets
204     opts1.Sheet = "Sheet6"; %different sheet per chassis
205     opts2.Sheet = "Tooling";
206     opts1.DataRange = "A1:B20";  %Change accordingly
207     opts2.DataRange = "A1:B20";
208
209     % Specify column names and types
210     opts1.VariableNames = ["VarName1", "VarName2"];
211     opts2.VariableNames = ["VarName1", "VarName2"];
212     opts1.VariableTypes = ["double", "double"];
213     opts2.VariableTypes = ["double", "double"];
214
215     % Import the data
216     ToolingHoleLocations = readtable("Chassis Hole Locations Test.xlsx", opts2, "UseExcel",
217     ChassisHoleLocations = readtable("Chassis Hole Locations Test.xlsx", opts1, "UseExcel",
218     n=0;
219     a=1;
220     ii=1;
221     increment= 1; % XX size of jumps between locating points
222     Matrix_1 = table2array(ToolingHoleLocations);
223     Matrix_2 = table2array(ChassisHoleLocations);
224     out=[];
225
226     for k=1:size(Matrix_1,1)    %runs through tooling holes
227         for i= 1:size(Matrix_1,1) % going through each input point
228             if sqrt((Matrix_1(k,1)-Matrix_2(i,1))^2+(Matrix_1(k,2)-Matrix_2(i,2))^2) <= Mini
229                 n=n+1;
230                 i+i+1;
231             else
232                 n=n+0;
233             end
234
235         end
236         out = [out; n, Matrix_2(k,1),Matrix_2(k,2)] ;  %output for chassis
```

Step 2: Change “Sheet 6” to “Sheet 7” in highlighted areas

***This will let MATLAB reference a different sheet in “Chassis Hole Locations Test.xlsx” named “Sheet7”**

```
clear(vars{:});
%% Sheet 7

vars = {'Matrix_1' 'Matrix_2' 'out' 'n' 'i' 'k' 'Density' 'opts1'};
clear(vars{:});

opts1 = spreadsheetImportOptions("NumVariables", 2);
opts2 = spreadsheetImportOptions("NumVariables", 2);

%Specify sheet and range for spreadsheets
opts1.Sheet = "Sheet7"; %different sheet per chassis
opts2.Sheet = "Tooling";
opts1.DataRange = "A1:B20";  %Change accordingly
opts2.DataRange = "A1:B20";

% Specify column names and types
opts1.VariableNames = ["VarName1", "VarName2"];
opts2.VariableNames = ["VarName1", "VarName2"];
opts1.VariableTypes = ["double", "double"];
opts2.VariableTypes = ["double", "double"];

% Import the data
ToolingHoleLocations = readtable("Chassis Hole Locations Test.xlsx", opts2, "UseExcel",
ChassisHoleLocations = readtable("Chassis Hole Locations Test.xlsx", opts1, "UseExcel",
n=0;
a=1;
ii=1;
increment= 1; % XX size of jumps between locating points
Matrix_1 = table2array(ToolingHoleLocations);
Matrix_2 = table2array(ChassisHoleLocations);
out=[];

for k=1:size(Matrix_1,1)    %runs through tooling holes
    for i= 1:size(Matrix_1,1) % going through each input point
        if sqrt((Matrix_1(k,1)-Matrix_2(i,1))^2+(Matrix_1(k,2)-Matrix_2(i,2))^2) <= Min
            n=n+1;
            i+i+1;
        else
            n=n+0;
        end

    end
    out = [out; n, Matrix_2(k,1),Matrix_2(k,2)] ;  %output for chassis
    Density = [n, Matrix_2(k,1),Matrix_2(k,2)] ;
    Density = [n, Matrix_2(k,1),Matrix_2(k,2)] ;
    n = 0;
end



Sheet7 = sum(out(:,1)) %number of holes that are within minimum distance from tooling

vars = {'Matrix_1' 'Matrix_2' 'out' 'n' 'i' 'k' 'Density' 'opts1' 'opts2' 'increment' 'i
clear(vars{:});
```

Step 3: Create an additional sheet in "Chassis Hole Locations Test.xlsx" and name it "Sheet7"



Note: Insert coordinates in the same format as other sheets
(column A = X-coordinate, column B = Y-coordinate)

Step 4: Refer to the original instructions starting from **Step 7/8.**

Appendix I: DVP&R

DVP&R - Design Verification Plan (& Report)

Project: 1RU Chassis Standardization - F15 | Sponsor: Cisco | Edit Date: 5/6/2021

Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING Start date	TIMING Finish date	Numerical Results	Notes on Testing
	TEST PLAN									**TEST RESULTS**	
1	Team testing on MATLAB tool before sending out for Cisco testing.	All team members will individually run MATLAB test and compare results	N/A	If all members end up with the same results	MATLAB (possible to get done with a 30 day free trial),a PDF viewer, and access to the internet.	N/A	Each member will test MATLAB code and write down the results for each sheet# output.	4/23/2021	4/25/2021	Results are shown in the instructional video: https://youtu.be/_id_1cllrww	All members were able to run MATLAB code succesfully and get the same results.
2	MATLAB and standardization document survey (zip file via email)	Users will use MATLAB and our pdf version of the standardization document to guage how effective our material is in standardizing new chassis hole locations	N/A	Fully filled out survey with no lingering questions.	MATLAB (possible to get done with a 30 day free trial),a PDF viewer, and access to the internet.	N/A	As a team we will make sure that the survey material is continusously updated and reach out each week to the Cisco Engineers.	4/26/2021	5/23/2021	Survey Results: https://docs.google.com/forms/d/1Fzh5MFavlWnym4NMU09OVoJK3dsdnhJn7HZlz5itxUc/edit#responses	Initial approach aimed at 5-10 Cisco engineers
3	MATLAB and standardization document survey (1-on-1 session)	Users will use MATLAB and our pdf version of the standardization document alongside the team to most accurately start them off	N/A	Fully filled out survey with no lingering questions.	MATLAB (possible to get done with a 30 day free trial),a PDF viewer, and access to the internet.	N/A	As a team we will make sure that the survey material is continuously updated and reach out each week to the Cisco Engineers.	4/26/2021	5/23/2021	Survey Results: https://docs.google.com/forms/d/1Fzh5MFavlWnym4NMU09OVoJK3dsdnhJn7HZlz5itxUc/edit#responses	Already done with Peter Wu and Rob G.
4	Self Test on MATLAB tool after final week	We will test our software again after our 4 iterations to see if it has gone in the direction we were anticipating	N/A	If we feel that is has developed enough over the 4 weeks and shows value to Cisco.	MATLAB (possible to get done with a 30 day free trial),a PDF viewer, and access to the internet.	N/A	Each member will run through the survey in its entirety and iterate based on feedback	5/23/2021	6/3/2021	Simple vote across the team where each person decides whether or not they felt that the material has properly developed over the 4 iterations.	useful to make sure that we are happy with the final product

Appendix J: Google Form Survey

Cisco 1RU Senior Project Team Survey

We are attempting to assess how well we are doing at providing material that Cisco can utilize.

For any questions that include the "other" option, please include an explanation of any issue you may have encountered.

Please provide your email so we can track your feedback over the four prototype rounds. *

Short answer text

Who are you? *

- Cisco Employee
- Student
- Professor

Please select Prototype # *

- Prototype 1
- Prototype 2
- Prototype 3
- Prototype 4

Standardization Documentation

Review the Quake Chassis Standardization PDF

Do the proposed methods of standardization agree with what Cisco is currently doing during chassis manufacturing? *

- 5 - Great
- 4 - Good
- 3 - Neutral
- 2 - Bad
- 1 - Poor
- N/A
- Other...

Is the document aesthetically pleasing? *

- 5 - Great
- 4 - Good
- 3 - Neutral
- 2 - Bad
- 1 - Poor
- Other...

Is the document coherent and easy to read? *

- 5 - Great
- 4 - Good
- 3 - Neutral
- 2 - Bad
- 1 - Poor
- Other...

Is there any other feedback that you would like to give in regard to our Standardization PDF? *

Long answer text

MATLAB script/Software approach

This software stores previous and future hole locations to accelerate process flow. Please complete after finishing the MATLAB test procedure.

Is the purpose of the tool clear? *

- 4- Very clear
- 3- Makes sense but have some questions
- 2- Kind of makes sense and have some questions
- 1- Doesn't make sense at all

Is the procedure for the MATLAB tool easy to follow along? *

- 4 -Very easy to follow
- 3 - Some complications
- 2 - Many complications
- 1 - Very difficult to follow
- Other...

Is it easy to understand the outputs from the code? *

- ◯ 4- Easy to understand
- ◯ 3- Kind of easy to understand
- ◯ 2- Kind of hard to understand
- ◯ 1- I don't understand

Were you able to add new data into the excel file "Chassis Hole Location Test.xlsx"? *

- ◯ Yes
- ◯ No
- ◯ Other...

Did you get an error when running the script? *

- ◯ Yes
- ◯ No

What was the error?

Short answer text

List the ranking of the sheets you got from using the MATLAB tool (refer to step 10 in the procedure) *

Short answer text

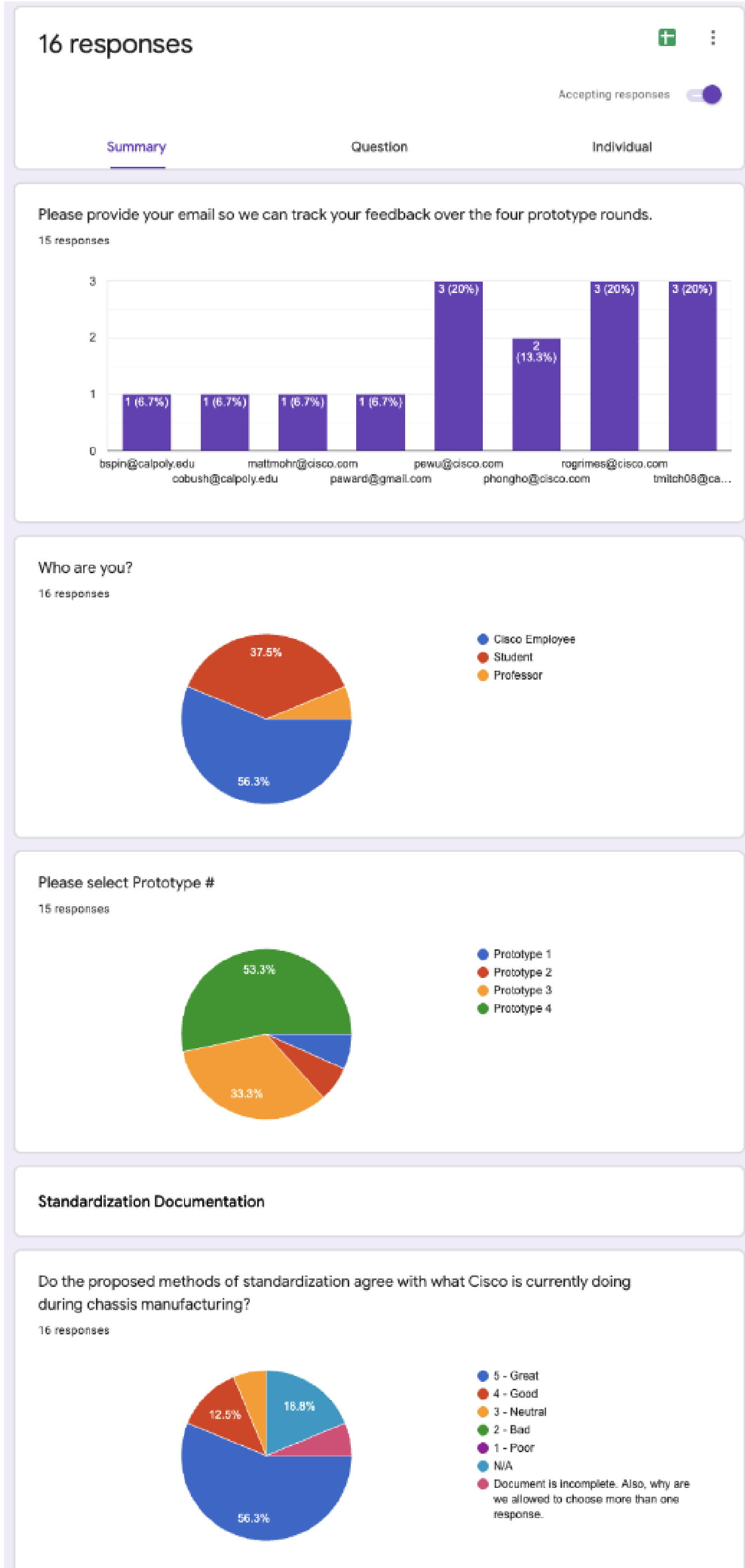
Do you have any feedback for the instructions? *

Long answer text

Do you have any feedback for the tool functionality? *

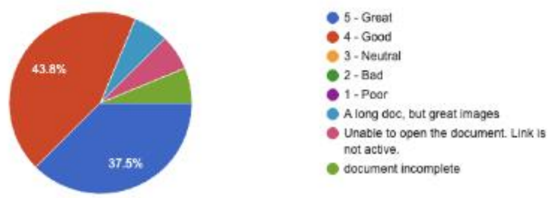
Long answer text

Appendix K: Google Form Survey Results



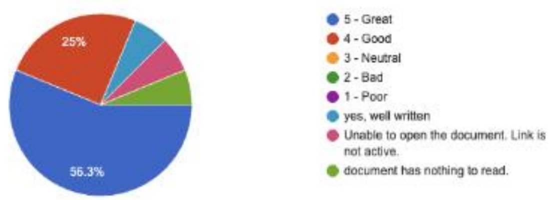
Is the document aesthetically pleasing?

16 responses



Is the document coherent and easy to read?

16 responses



Is there any other feedback that you would like to give in regard to our Standardization PDF?

16 responses

No, I think it is fairly complete.

Good data, good images, maybe less red boxes to make it more clear what I am looking for

Titles text forma and images scaling/position cosmetic can be improved.

Page 4, replace "tall" next to Fig. 29 with 13.6" depth"and "short" next to Figure 30 with 11.2" depth

No

Great documentation!

I would describe exactly how you are supposed to list the ranking of the sheets. Do I list the values? Or do I list the sheets from highest to lowest value?

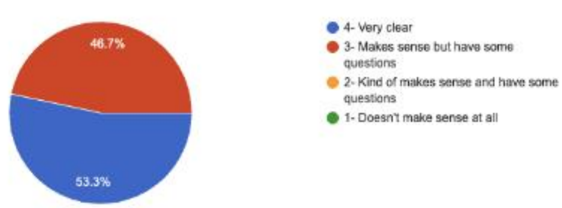
Looks good

Can the coordinates values be automated for new designs?

MATLAB script/Software approach

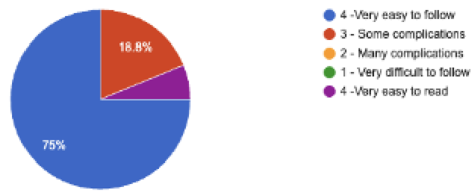
Is the purpose of the tool clear?

15 responses



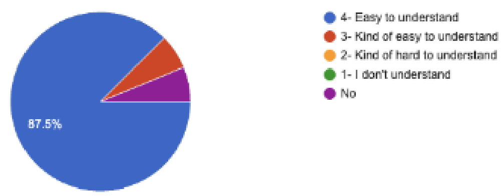
Is the procedure for the MATLAB tool easy to follow along?

16 responses



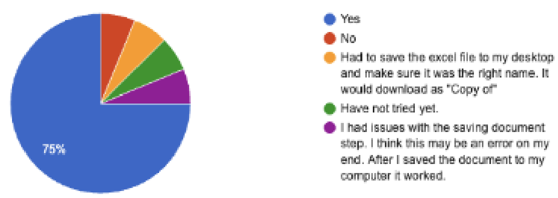
Is it easy to understand the outputs from the code?

16 responses



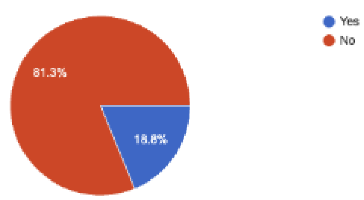
Were you able to add new data into the excel file "Chassis Hole Location Test.xlsx"?

16 responses



Did you get an error when running the script?

16 responses



What was the error?

4 responses

N/a

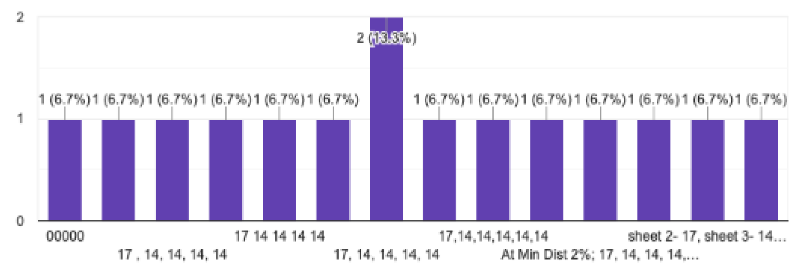
NA

Folder location issue, need to point to the correct folder where files are stored

Add to path error where I had to save to my computer. The "change folder" and "add to path" options did not fix the problem

List the ranking of the sheets you got from using the MATLAB tool (refer to step 10 in the procedure)

15 responses



Do you have any feedback for the instructions?

16 responses

Explain the % Min Distance clearer.

No, very well done

Suggesting location to place HT part-numbers associating with Sheet 2 - Sheet 6 data

a bit more explanation about what output numbers mean as discussed in the meeting

Yeah this long

Easy to follow process

I would describe exactly how you are supposed to list the ranking of the sheets. Do I list the values? Or do I list the sheets from highest to lowest value?

Good and clear instructions

No

Do you have any feedback for the tool functionality?

15 responses

No

Using the same names for the spreadsheets can be confusing. I made sure to change the names of the old versions before running the latest.

No, very clean code, nice simple outputs

Tool works well. Great job!

add in a section where 2mm hole to hole input can be changed and it is not a constant value

Excellent product

Nope, good job!

Works well!

No feedback on the tool but need to know how the coordinates are generated.

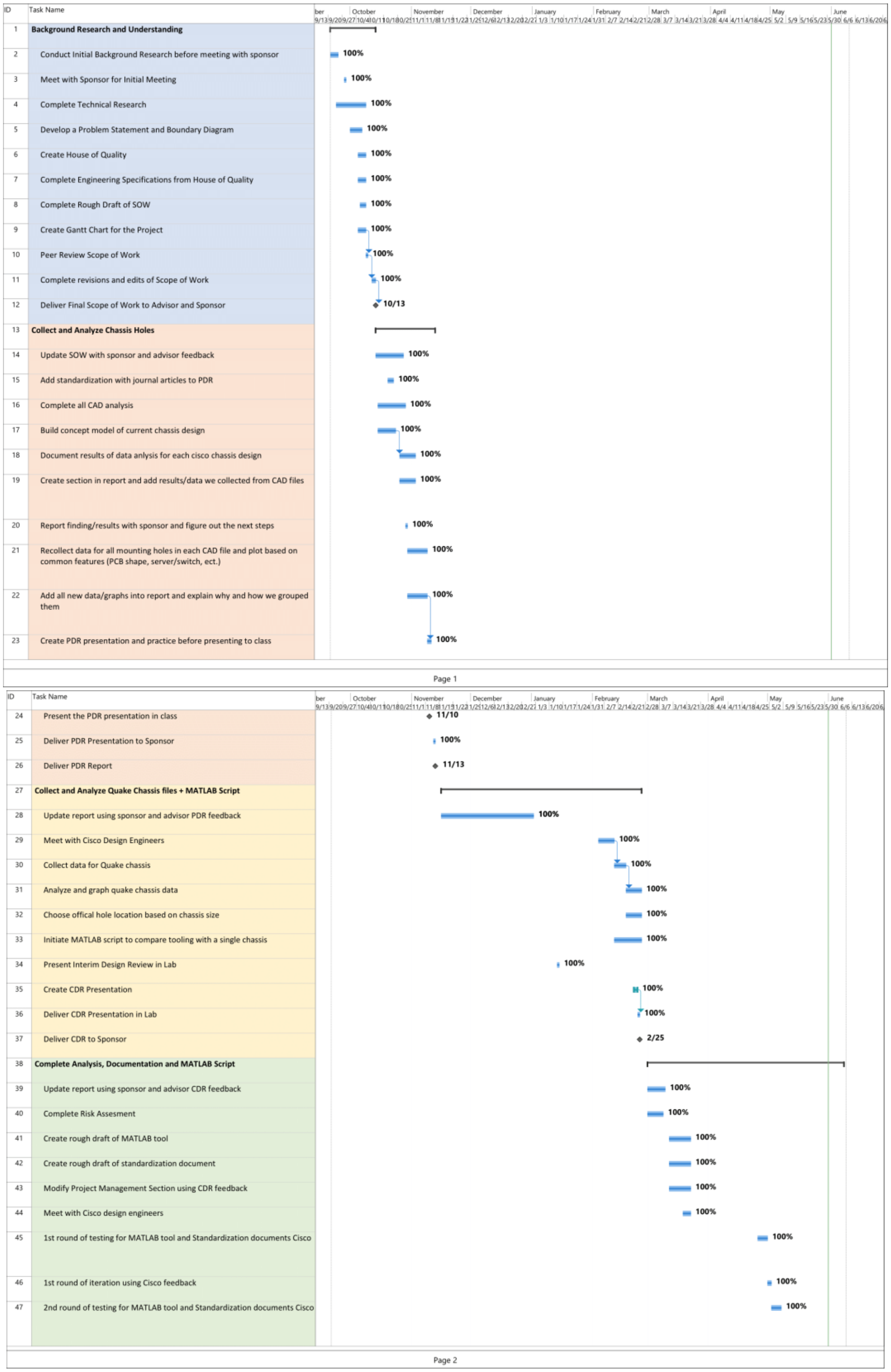
Appendix L: Design Hazard Checklist

PDR Design Hazard Checklist **F15 Cisco 1RU Chassis Standardization**

Y	N	
	×	1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
	×	2. Can any part of the design undergo high accelerations/decelerations?
	×	3. Will the system have any large moving masses or large forces?
	×	4. Will the system produce a projectile?
	×	5. Would it be possible for the system to fall under gravity creating injury?
	×	6. Will a user be exposed to overhanging weights as part of the design?
	×	7. Will the system have any sharp edges?
	×	8. Will any part of the electrical systems not be grounded?
	×	9. Will there be any large batteries or electrical voltage in the system above 40 V?
	×	10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
	×	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
	×	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
	×	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
	×	14. Can the system generate high levels of noise?
	×	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
	×	16. Is it possible for the system to be used in an unsafe manner?
	×	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any "Y" responses, on the reverse side add:
(1) a complete description of the hazard,
(2) the corrective action(s) you plan to take to protect the user, and
(3) a date by which the planned actions will be completed.

Appendix M: Gantt Chart



ID	Task Name	ber · October · November · December · January · February · March · April · May · June
48	2nd round of iteration using Cisco feedback	100%
49	3rd round of testing for MATLAB tool and Standardization documents Cisco	100%
50	3rd round of iteration using Cisco feedback	100%
51	1st round of testing for MATLAB tool and Standardization documents Cisco	100%
52	4th round of iteration using Cisco feedback and complete MATLAB tool and Standardization documents	100%
53	Create Senior Design Project Poster/Final Presentation	100%
54	Conduct Poster Peer Review	100%
55	Complete Rough Draft of FDR	100%
56	Finish Preparing for Expo and Print Poster	100%
57	Complete FDR Reprt Revisions	100%
58	Deliver FDR to Advisor and Sponsor	6/9