Cisco Rackmount Bracket Optimization

Final Report

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Statement of Disclaimer

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Table of Contents

Statement of Disclaimer 2

List of Tables 5

List of Figures 6

Executive Summary 8

Introduction 9

Background and Needs 9

Problem Statement 9

Requirements 9

Objectives and Constraints 10

Management Plan 10

Background 10

Existing Products 10

Design Development Process 12

Ideation/Preliminary Design Concepts 12

Final Design Process 17

Redefined Project Focus 17

Early Design Approach 17

Design Analysis 18

Standard Analysis 18

Finite Element Analysis 27

Early Design Recommendations 34

Final Design Details 35

Four-Hole Open Window Bracket 36

Hybrid Slot Open Window 36

Product Realization 37
Design Verification 38
Instron Pull Test 38
Motivation 38
Setup 38
Results 41
Discussion 42
Hanging Chassis Test 43
Motivation 43
Setup 44
Results 46
Discussion 48
Conclusions and Recommendations 51
References 52
Appendix A: Project Schedule 52
Appendix B: Final Drawings (attached) 53
Appendix C: List of vendors 53

List of Tables

Table 1: Relevant Engineering Requirements 9
Table 2: Ventilation Area and Displacement for Concept Brackets 16
Table 3: Resulting reaction forces for given weight and depth 21
Table 4: Parametric Study Results 24
Table 5: FEA Simulation Material Properties for 1018 cold rolled Steel 28

List of Figures

Figure 1: Standard Rackmount Hole Spacing as defined by EIA–310–E (Courtesy: www.server-racks.com/eia-310.html) 10
Figure 2: Early analysis of existing bracket hole-patterns 12
Figure 3: Internal look at spacers below main circuit board 13
Figure 4: Notches found in circuit boards to allow for screw protrusion 13
Figure 5: Ventilation Design Concepts 14
Figure 6: FEA displacement study for open and cross member ventilation designs 15
Figure 7: Ventilation Area vs. Displacement for Concept Brackets 16
Figure 8: Early conceptual mounting hole designs (From top left clockwise) – slotted, outer scalloped, inner scalloped, fully scalloped 18
Figure 9: Overall System for Hand Calculations 19
Figure 10: Original FBD 20
Figure 11: Simplified FBD 20
Figure 12: Base bracket for simulations 22
Figure 13: Bracket Boundary Conditions 23
Figure 14: FEA Results for Vent Size Variations 25
Figure 15: FEA Results for Vent Spacing Variations 26
Figure 16: FEA Results for Thickness Variations 26
Figure 17: SolidWorks assembly 27
Figure 18: Simplified Bracket 27
Figure 19: Rack and fastener 28
Figure 20: Chassis and fastener model 28
Figure 21: Symmetry and encastre boundary conditions applied to the assembly. 29
Figure 22: Detail of contact definition between flat head machine screw and bracket (Left). Contact between rack mounting face and bracket (Right). 29
Figure 23: Flat head machine screw bolt loading applied to cross section of bolt (Left), and tractive load applied at end of chassis (Right). 30
Figure 24: Mesh convergence study performed on displacement and Von Mises shear stress at 2 separate points on the bracket for a seed size ranging from 0.6 to 0.075. 31
Figure 25: Bracket with 0.15 in mesh seed after performing convergence study. 31

Figure 26: Von Mises shear stress plot for bracket subjected to worst case loading conditions. . 32
Figure 27: Displacement plot of bracket under worst case loading conditions. 33
Figure 28: Chassis stress plot under worst case loading conditions. Maximum stress occurs on the screw shaft and is near the yielding point of 1018 cold rolled steel. 33
Figure 29: Standard 4-hole design recommendation 34
Figure 30: Scalloped hole design recommendation 34
Figure 31: Four-Hole Open Window Bracket 35
Figure 32: Hybrid Slot Open Window 36
Figure 33: Scallop DFM Foxconn 37
Figure 34: Pull Test Apparatus 38
Figure 35: Scalloped Test Bracket 39
Figure 36: Bracket Pairs with Spacer Block 39
Figure 37: Thick "Chassis" Plate 40
Figure 38: Assembled Pull Test Apparatus 40
Figure 39: Slotted Pull Test Results 41
Figure 40: Scalloped Pull Test Results 41
Figure 41: 4-Hole Pull Test Results 42
Figure 42: Sheared Screws from 4-Hole Test 42
Figure 43: Destroyed Ribs from Pull Test 43
Figure 44: Detent from Sliding in Pull Test 43
Figure 45: Schematic for Test Setup 44
Figure 46: Physical Setup and Measurement Device 44
Figure 47: Deflection Measurement Method 45
Figure 48: Open Window of Installed Bracket 46
Figure 49: Front View of Installed Chassis 46
Figure 50: Deflection Trend for Increasing Weight 48
Figure 51: Angular Change Trend with Increasing Weight 48
Figure 52: Max Deflection During Testing 49
Figure 53: Flange Deflection 49
Figure 54: Side-Wall Deflection 50
Figure 55: Bracket Shifting 50

Executive Summary

Cisco Systems has asked us to design a solution to a problem that the company has had for some time: consolidate all the mounting patterns for their 1RU rackmount products as much as possible. This lack of consolidation has led to logistical issues and end-user misuse. The original plans included a single bracket for legacy products and a single bracket with a single hole pattern, for use with future products. Later discussions have caused the legacy product bracket to be shelved, with the focus of this report mainly on the future products bracket. FEA analysis, real-world bend testing, and pull testing were used to determine the main features of the bracket, while DFM analysis at the prototyper was utilized to determine the hole pattern for the final bracket. After much deliberation, two mounting patterns, a four-hole pattern and a hybrid hole-slot pattern, have been designed as our recommended designs. Additionally, the testing procedures mentioned in this report are to be utilized in a way that a whitepaper should be read.

Introduction

Background and Needs

Cisco Systems, Incorporated is a multinational Fortune 500 corporation focused on communications and computer networking. Headquartered in San Jose, California, the company produces routing systems, teleconference solutions, servers, network authentication systems, and other networking and communications solutions. Many of their products are mounted on racks in datacenters. Racks have a standard spacing of 1.75 inches between holes, and each set of holes represents one rackmount unit, known as 1RU. Due to many historical events, Cisco has over 80 1RU chassis, each with various mounting patterns. As a result, there are nearly one-thousand brackets for the 1RU families. Our team has been tasked to consolidate the various brackets into the smallest amount possible for legacy products, as well as for a next-generation 1RU chassis. The most optimal design would be able to accommodate every chassis with a single bracket.

Problem Statement

As mentioned above, due to various historical reasons, Cisco has over 1000 brackets for 1RU chassis. This causes problems for Cisco and end-users, such as installing screws in ventilation holes. To make matters worse, most divisions inside Cisco choose to make a new mounting pattern instead of working with an existing mounting pattern. Because of this, our goal is to develop a new universal mounting pattern for a next-generation chassis, with the promise that the new mounting pattern will propagate across the various divisions at Cisco that use 1RU chassis.

Requirements

Table 1: Relevant Engineering Requirements

Parameter Description	Requirement or Target	Tolerance	Risk
Material	CR Steel		
Height	44.45 mm	max	L
Nominal Load	30 lbs	max	M
Peak Load (SF = 1.3?)	40 lbs?	max	H
Manufacturing Method	Stamping		L
Rack Hole Spacing (see figure1.)	.625”-.625”-.5”		M
Earthquake Loading	5 g-Zone 4 (GR-63)		M
Deflection	TBD		L
Fastener Shear Load	TBD		M

Objectives and Constraints

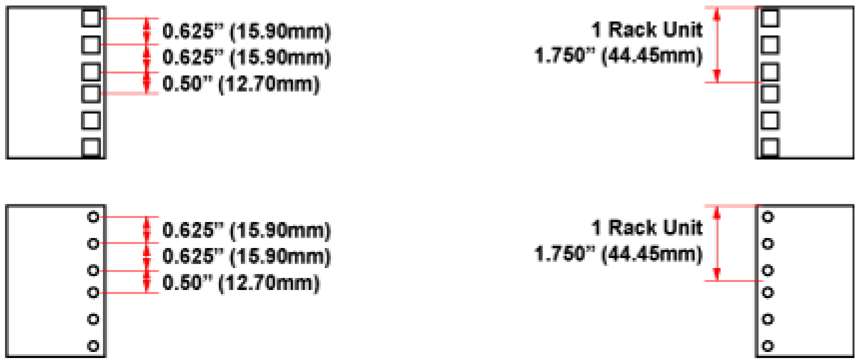


Figure 1: Standard Rackmount Hole Spacing as defined by EIA–310–E (Courtesy: www.server-racks.com/eia-310.html)

After reading through the standards documents such as GR-63, and from previous information gathered from Cisco team members, we were able to get a general target for our engineering requirements. For example, initial information from Cisco specified that chassis can weigh up to 30+ lbs. Also, the GR-63 document specifies the worst case scenario vibration test for earthquake safety at 2 Hz for 5 g's and 50 Hz for 1.6g's. Safety is always a high priority, and all targets directly related to safety will get more conservative targets. In addition, the brackets will undergo mechanical design verification testing as well as earthquake simulation. More objectives and engineering targets will be added as development continues.

Management Plan

In order to successfully complete this project in a timely matter, various tasks have been divided amongst the team members. All team members are required to gather information pertinent to the project and their assigned tasks as well as document their progress. Michael will be handling communication with Cisco. He will also be managing the testing portion of this project because he has internship experience working in a test lab with rackmount units. Edwin has experience with Microsoft Project and will be tracking the overall progress of the project. Garrett will be responsible for handling the budget as well as ordering prototyping materials because he has experience managing/ordering club supplies. In addition to managing the budget, Garrett will be in charge of the FEA simulations because he has taken the M.E. Finite Element Analysis course. Garrett is a team technician at the machine shop and Edwin is an SAE assistant lead, they will be splitting the prototype fabrication responsibilities.

Background

Existing Products

As a starting point, we went to Cisco's website to investigate their product families that would be within the scope of the optimization project. We searched through product overview pages and technical specifications sheets. To supplement the online information, we also obtained a box of some sample materials from Cisco to look at the common brackets and chassis. With the hardware, we sorted out the chassis and their matching brackets. The sample of hardware began to provide us insight on the types of material we would be working with, and some of the bracket designs that need to be unified. In addition to the material supplied by Cisco, members of the Cal Poly IT staff and Computer Engineering faculty allowed us to tour the labs and data centers on Cal Poly's campus. From the tours, we learned how the units are mounted to the rack both properly and improperly. For example, some of the chassis were mounted with an arbitrary bracket that did not match the hole-pattern, and the screws were fastened into ventilation holes. It is evident that there is a need for a unified bracket in order to prevent logistical nightmares for the manufacturers as well as misuse by the end user.

In our initial research, we found that the common standard for a rack is the four-post rack with 19 inch wide nominal spacing between the hole-centers. Vertically, the holes repeat a spacing pattern every 1.75 inches; the repeating spacing between holes is 5/8th inches, 5/8th inches, and ½ inches. In addition to the four-post racks, it is common to have a two-post rack which is called a Telco rack. The Telco rack follows the same hole-spacing pattern vertically and horizontally. For the specific brackets, we expect specifications for static, dynamic, and fatigue loading. From our group's previous experience in the area, we know that there will be shock and vibration specifications to be met for the brackets.

A number of additional bracket designs by other companies have tried to tackle similar problems. We located a variety of patents that investigated different methods of accommodating for multiple configurations. For example, Dell designed a rotatable bracket and rail kit with sliding brackets that can adjust for different dimensions depending on the chassis. From these types of attempts, we will brainstorm our own design ideas to find the optimal solution to unifying the brackets.

To complement our own findings, Cisco has provided us with several specification documents. These documents define the constraints our designs have to fall under. These documents are Verizon's procedures for testing, ETS-300-119, and EIA-310-E. The Verizon testing procedures document mentions several NEBS requirements, NEBS standing for "Network Equipment Building Systems." These requirements include GR-63, which define thermal, noise, earthquake prevention, size, and fire prevention requirements; GR-1089, defining electrical safety requirements, and GR-78, of which we currently have no information on. The document also defines the specific method needed to test the equipment. ETS-300-119 defines chassis size, rack spacing, temperature limits, and maximum loads. EIA-310-E discusses rack sizing. These documents assisted us during the preliminary design process.

Design Development Process

Ideation/Preliminary Design Concepts

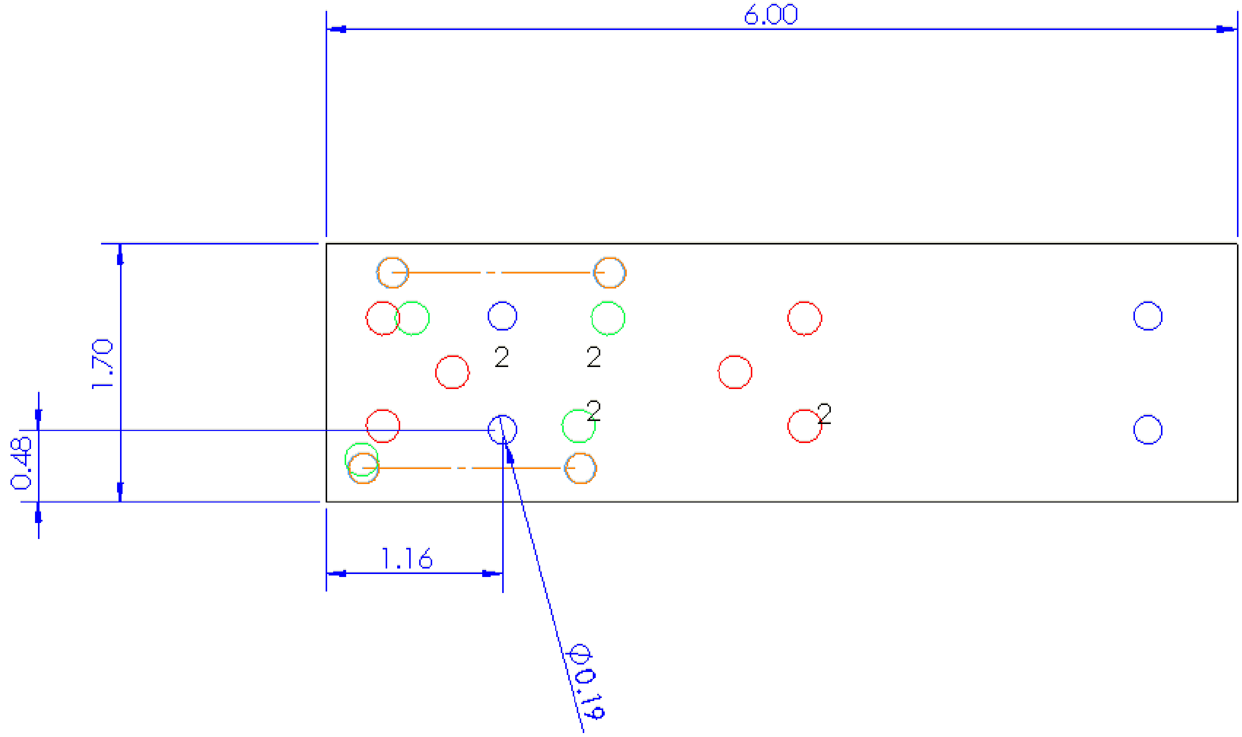


Figure 2: Early analysis of existing bracket hole-patterns

Our ideation process started by placing the hole-patterns of the brackets we currently had in possession, into a single sketch on CAD. This resulted in Figure 2, and showed us the scope of the problem. Holes do not line up as easily, even if the patterns appeared to be the same. In addition, the dimples used for alignment and some load bearing were not incorporated into this drawing. From the analysis of current hole-patterns, we decided that it was best to split the design project into two parallel paths: the consolidation of existing brackets and the creation of a new, universal bracket.

One path will focus on the legacy brackets, and developing a minimum amount of brackets to accommodate for the various hole-patterns and the structural loads expected with those products. At this time, Cisco team members have informed us that there are around one thousand 1RU brackets that Cisco is responsible for. Due to the constraints of being a student project, the scope for handling these legacy brackets is being significantly narrowed to a much more manageable amount. Cisco is considering the option of limiting the consolidation design to the top 20 brackets ranked by volume of production. Until a final list of brackets is decided on, our project will focus on the design of the next generation bracket.

The other path, designing a universal bracket for the next generation chassis, is primarily concerned with creating a bracket that will be versatile in mounting options as well as the loading conditions it can support. Looking at the material we already had, we decided that the best starting point would be with the largest bracket that Cisco provided us with; this bracket will already be closest to meeting the engineering specifications for strength. Furthermore, a simple and symmetric hole-pattern was decided on in order to prevent possible issues with the other mounting options such as mid-mounting and rear-mounting. Before setting the dimensions for the holes' positions, we investigated the internal components of different chassis to see if the screws would be interfering with any of the internal circuitry or other electrical components. Looking inside some of the chassis, we found that there is a spacing that lifts the main circuit board off of the base of the chassis. (Figure 3) As a result, we found that, in general, moving the holes towards the midline (lengthwise) of the bracket would prevent possible conflicts.

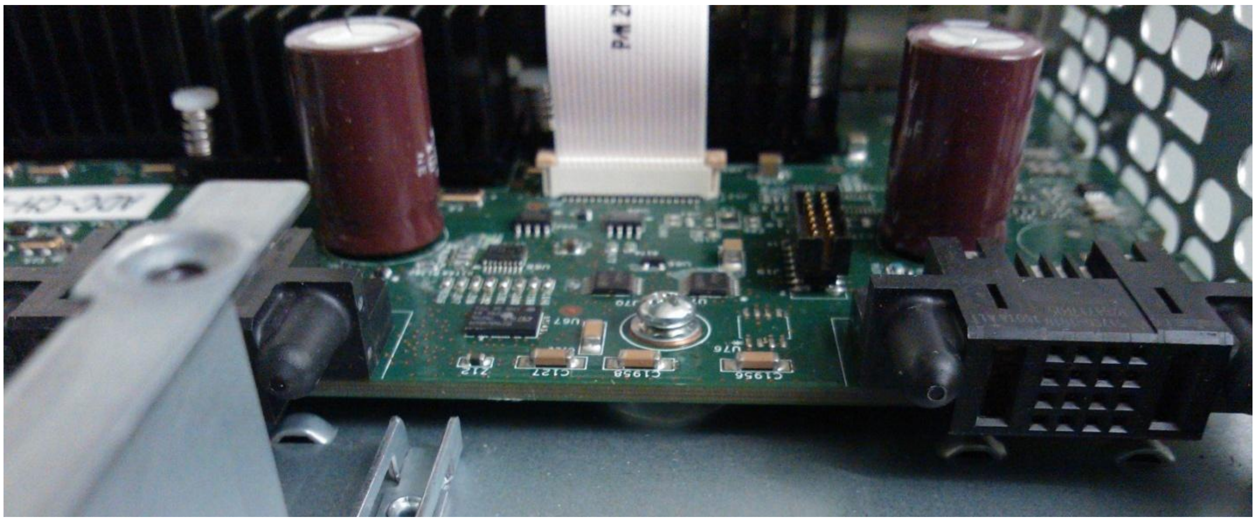


Figure 3: Internal look at spacers below main circuit board

Also, despite best efforts to avoid interference between the hardware, we discovered cases where components other than the bracket and fasteners were modified. For example, Figure 4 demonstrates a notch in one of the boards to allow for the screw to protrude into its plane.

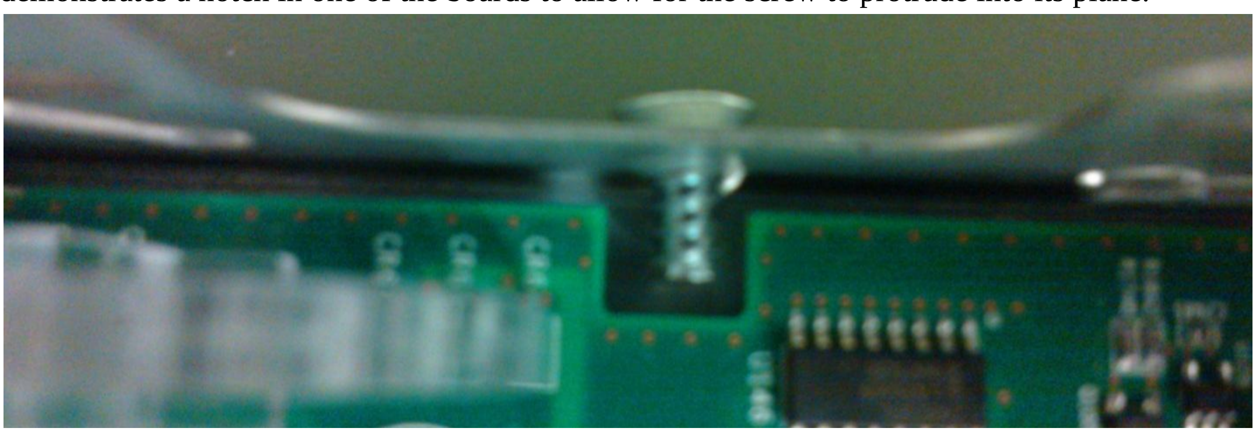


Figure 4: Notches found in circuit boards to allow for screw protrusion

Although the notch solution has been done, we intend to avoid having interferences between the mechanical and electrical components to truly allow for a universal chassis and bracket that give more design freedom to the components going inside the box. We will continue to investigate the specific placement of the holes for the bracket both vertically and horizontally to optimize our solution.

In addition to the placement of the holes, we are concerned with the ventilation allowed through the sides of the chassis that could be blocked by the bracket. Starting with the most ventilation area with open “windows”, we continued to brainstorm a variety of different ventilation patterns.

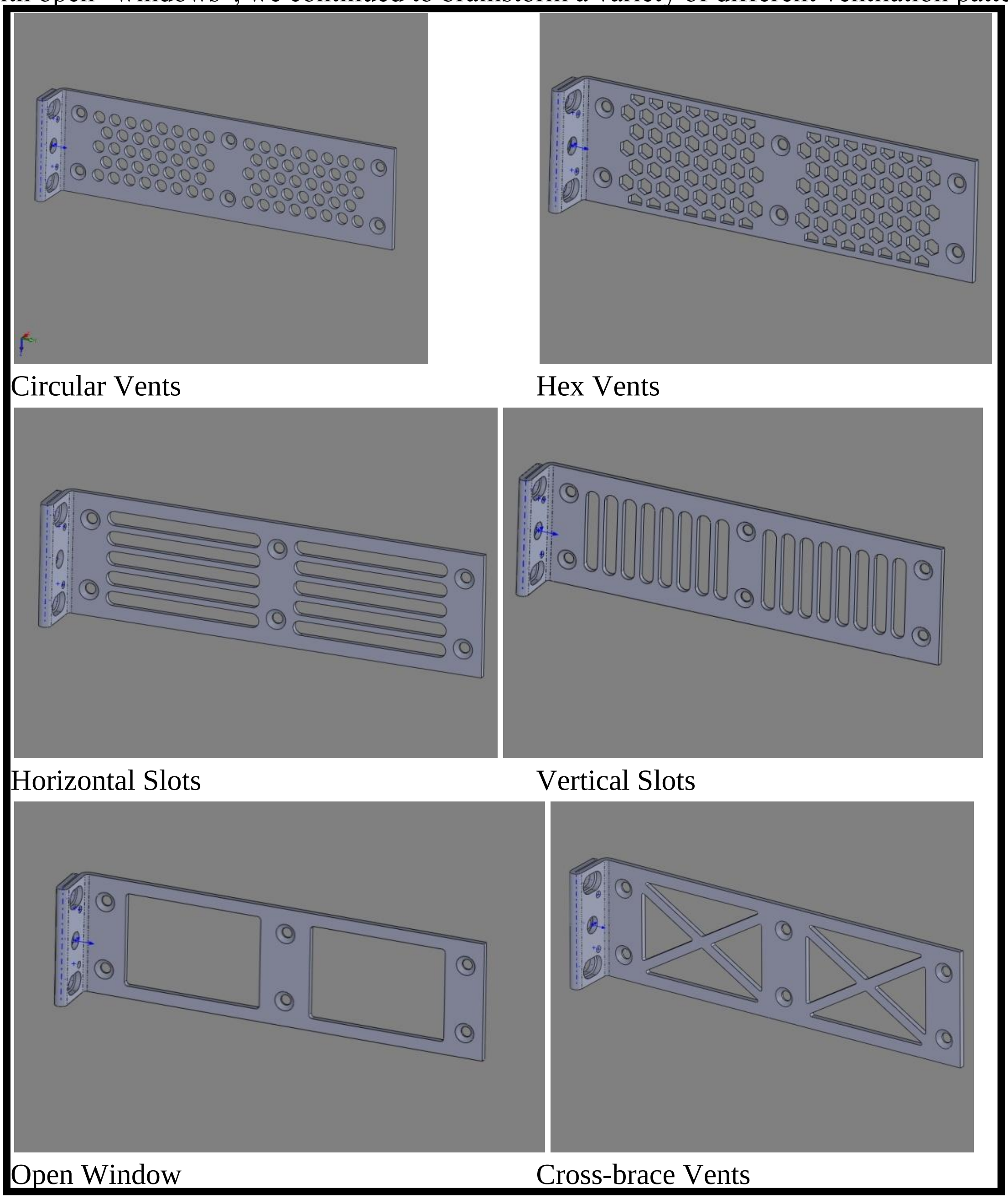


Figure 5: Ventilation Design Concepts

In order to get a simple evaluation on the various designs, we performed rudimentary FEA through a simulation in SolidWorks. This study assumed a worst-case scenario of only two screws securing the brackets at the bottom left and upper right corners. The brackets were fixed at the flange and constrained from twisting out of the plane. From simple statics, and the predefined maximum loading of four times the weight (approximately 30 lbs) applied at the end of the chassis (measured 21 inches), we calculated resultant forces of 170lbs and 230lbs respectively for the lower left and upper right holes. We tabulated the ventilation (open) area and corresponding deflection from each case in Table 1 and plotted the trend in Figure 7.

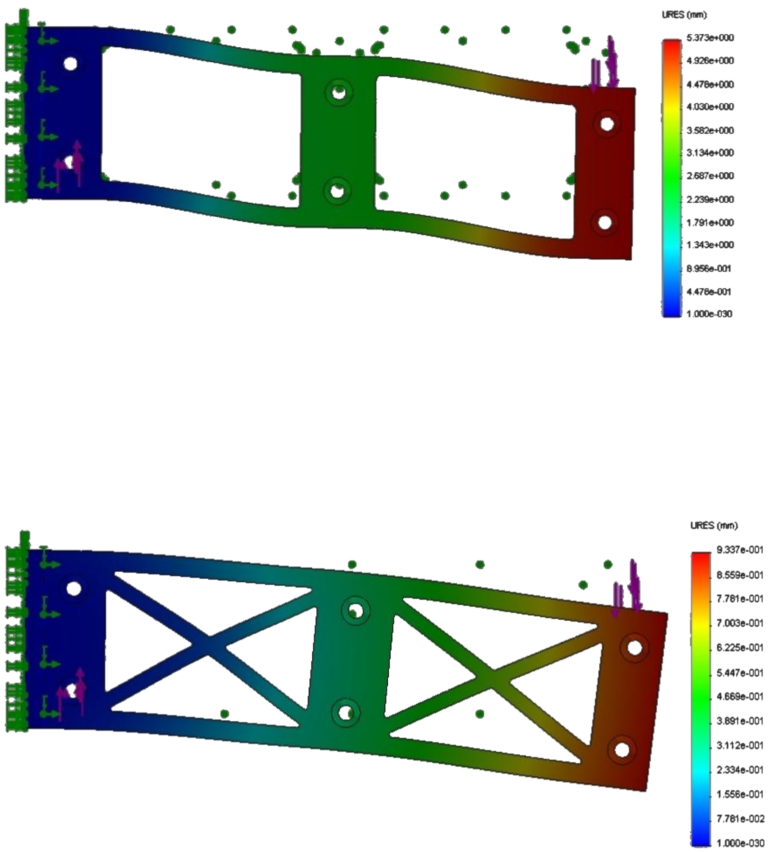


Figure 6: FEA displacement study for open and cross member ventilation designs

Table 2: Ventilation Area and Displacement for Concept Brackets

Bracket Vent Pattern	Ventilation Area (in^2)	Displacement (mm)
Open	5.762	5.319
Cross Members	4.251	0.926
Vertical Slots	4.015	1.900
Horizontal Slots	4.655	4.253
Hex 4Hole	4.033	1.005
Hex Vents	3.658	0.980
Dual Vertical Slots	3.366	1.022
Circular Vents	2.754	0.671

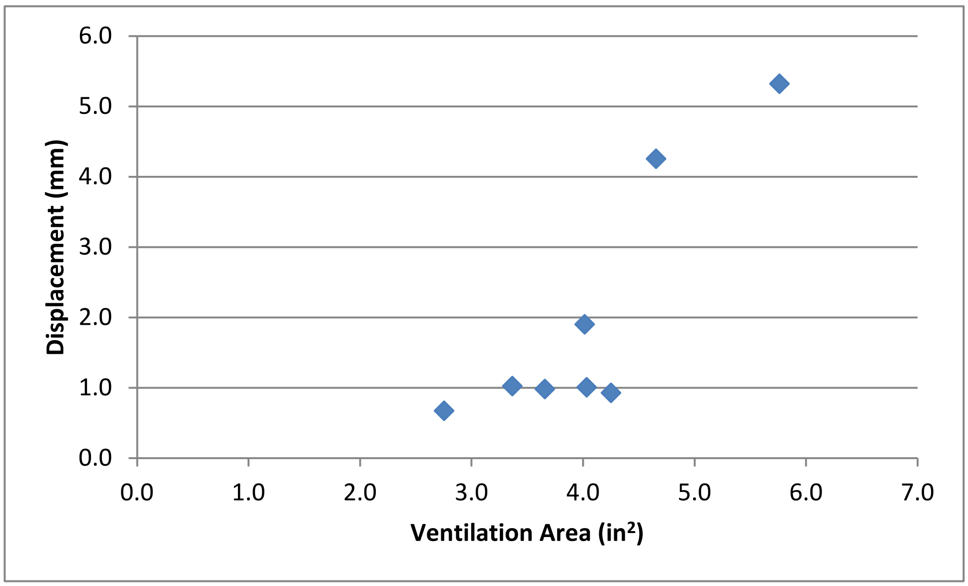


Figure 7: Ventilation Area vs. Displacement for Concept Brackets

The general trend from our study showed that increasing the ventilation area generally increases the deflection as well. However, through the use of staggered patterns such as the hex vent pattern, or structural reinforcements like the cross braces, we can obtain a large ventilation area while still limiting the displacement. It is our goal to further improve our concepts by moving farther into the lower right corner of the Ventilation Area vs. Displacement plot. Also, it is important to note that we were not as concerned with the exact values of displacement in this study. Due to simplicity of the simulation ran as well as the specific loading condition mentioned, the specific values of deflection are not completely accurate. From our knowledge in mechanics of materials, however, we know that the trends will remain roughly the same and this study is valuable in allowing us to sort through the early iterations of design concepts. We will conduct more in-depth and detailed analysis on the brackets that performed the best in order to optimize the final solution. More sophisticated analysis will be performed that takes into account multiple loading conditions on the bracket, chassis, fasteners and rack. This analysis will be performed using the Abaqus FEA software program.

Final Design Process

Redefined Project Focus

Upon further discussions with Cisco, the original intent of the project has changed. The universal bracket design for current products has been shelved. The discontinuation of development of the universal bracket is due to the number of hole patterns needed to be supported, as the number ranged up to about 1000 1RU bracket designs. Instead, the focus of the project is now on the design of the next-generation universal 1RU bracket.

Early Design Approach

Feedback from Cisco allowed the development of early brackets. First, the alignment dimples seen in example brackets provided are not common, so the final design can be flat. Next, to help the development of derivative chassis models, it is recommended that hardware be standardized. It is also mentioned that four screw holes are the ideal solution, and that slotted mounting holes be considered. It is also important that the bracket does not slip. From these discussions, early designs were created in CAD.

Among the early approaches, it was agreed that the standard 4-hole design would have a bracket. When it came to the slotted holes, however, the team had concerns about the area of grip the screw would have. As a result, it was agreed that a scalloped hole also be designed in addition to the slotted hole, as the scallops would have more material for additional gripping. The design of the scalloped hole, however, was deadlocked on determining which part of the hole should be scalloped. Consequently, three options were designed: scalloped inner holes, scalloped outer holes, and fully scalloped holes. The results of these discussions are shown in the figure below.

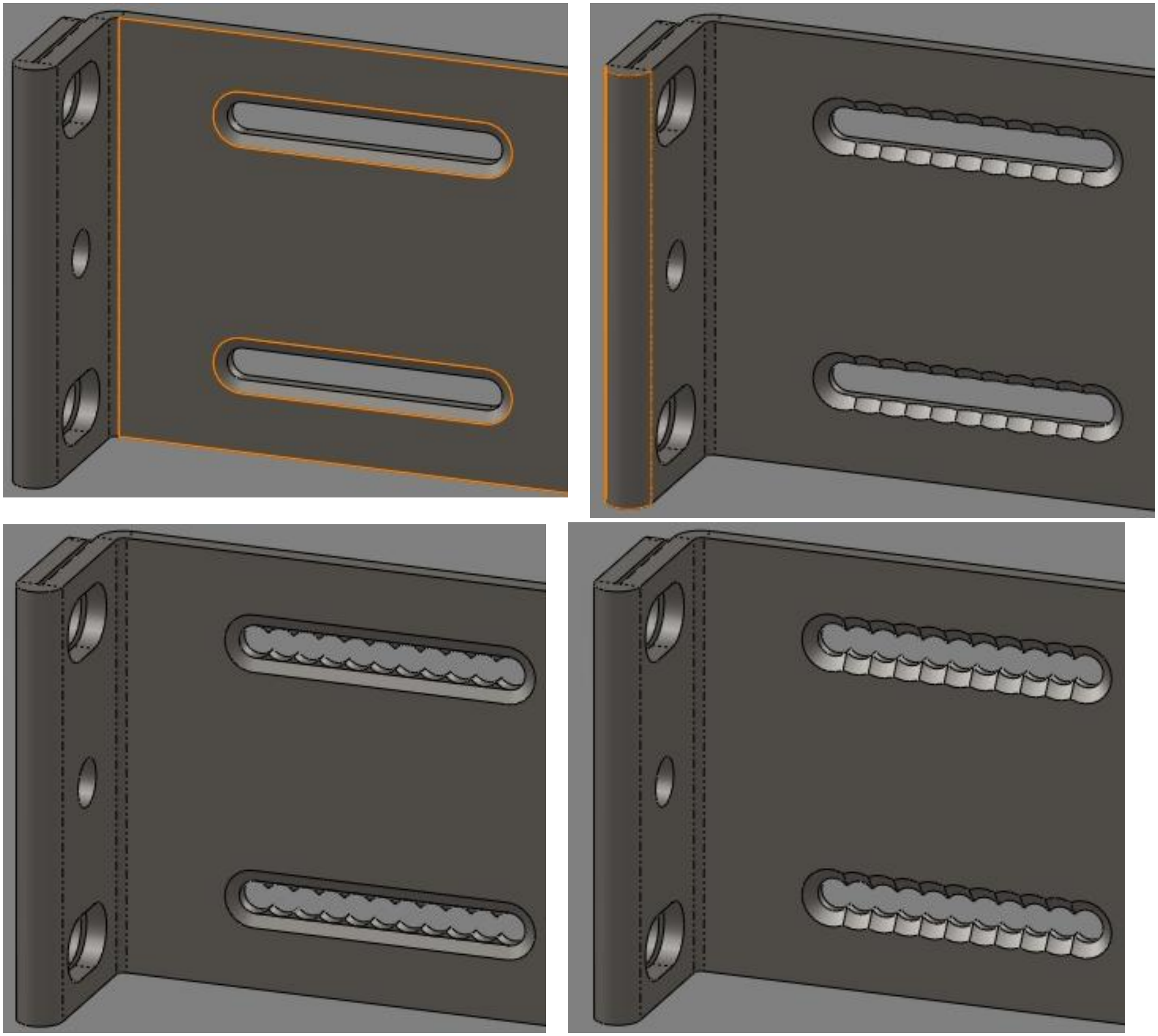


Figure 8: Early conceptual mounting hole designs (From top left clockwise) – slotted, outer scalloped, inner scalloped, fully scalloped

Standard Analysis

Hand Calculations

Before performing any FEA or experimental analysis, we began with hand calculations in order to get a general idea of the order of magnitude that we should be expecting for forces and deflection. With this information, would be able to develop a system of equations that solve for the forces at each screw location in the bracket as a function of the chassis weight and depth. To begin, we assumed the system comprised of a chassis mounted at its front with two symmetrical brackets to a two-post rack. (Figure 9)

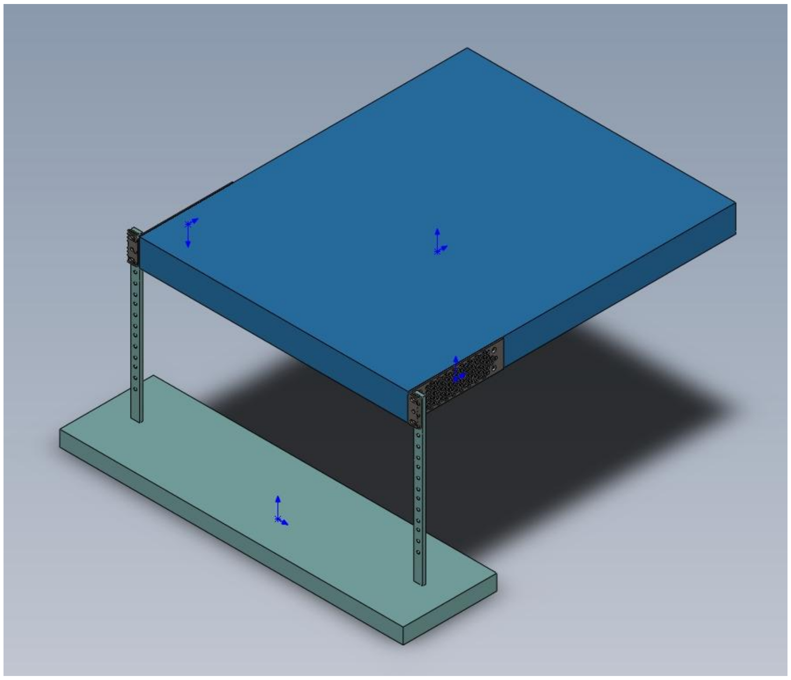


Figure 9: Overall System for Hand Calculations

Analyzing the chassis, we resolved the weight to a force-couple system at the front edge and included point reaction forces at each of the four main screw locations (Figure 10). From Newton's Second law and basic statics analysis, we formulated a system of three equations, but found that we had eight unknowns — a statically indeterminate problem. In order to make this problem solvable by hand, it was necessary to make some extra assumptions. Due to the symmetry of the bracket geometry and external loading, it was reasonable to assume that the magnitude of the force at locations A and C were equal. Similarly, the magnitudes of the force at locations B and D were equal. Also, due to the symmetry of the bracket, we were able to assume that the reaction forces in the x-direction for A and B could be combined into a single force acting along the axis between A and B. This force would be shared equally between screws at A and B. In our model, there are two brackets mounted symmetrically on the left and right side of the chassis; as a result, the forces would be shared equally between the two brackets. Finally, because the FBD was drawn for the chassis, the reaction forces on the bracket will be equal in magnitude, but opposite in direction. The final simplified FBD is shown in Figure 11.

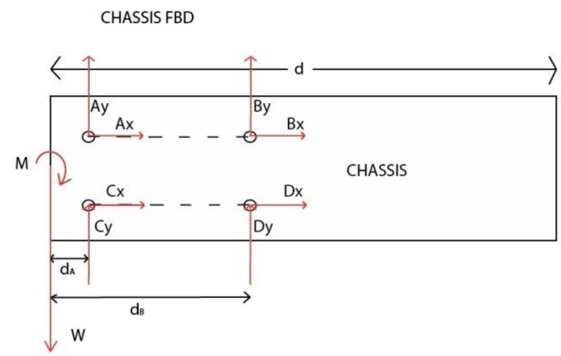


Figure 10: Original FBD

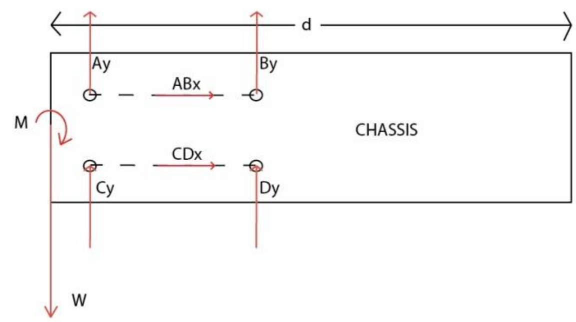


Figure 11: Simplified FBD

Using basic statics and from Newton's Second Law we were able to solve for the simplified forces:

$$\sum F_y = 0$$

$$A_y + B_y + C_y + D_y - W = 0$$

$$\sum F_y = 0$$

$$A_x + B_x + C_x + D_x = 0$$

$$\sum M_o = 0$$

$$A_y \cdot d_A + B_y \cdot d_B + C_y \cdot d_C + D_y \cdot d_D - M = 0$$

$$4A_y + 4B_y = W \qquad (1)$$

$$AB_x + CD_x = 0 \qquad (2)$$

$$2A_y(d_A + d_C) + 2B_y(d_B + d_D) = M \quad (3)$$

Now with the geometry of the bracket and equations (1), (2), and (3), we could solve for the reaction forces at each screw depending on the chassis weight and depth. Using a sample of 14 chassis from Cisco, we solved a parametric table using Engineering Equation Solver (EES) (Table 2)

Table 3: Resulting reaction forces for given weight and depth

Ay (lbf)	By (lbf)	Cy (lbf)	Dy (lbf)	Abx (lbf)	CDx (lbf)
-41.59	59.59	41.59	59.59	0	0
-37.24	57.24	37.24	57.24	0	0
-24.21	37.21	24.21	37.21	0	0
-12.73	23.73	12.73	23.73	0	0
-17.27	28.27	17.27	28.27	0	0
-7.833	15.83	7.833	15.83	0	0
-25.87	39.87	25.87	39.87	0	0
-53.37	72.37	53.37	72.37	0	0
-46.23	62.73	46.23	62.73	0	0
-33.62	45.62	33.62	45.62	0	0
-54.88	76.38	54.88	76.38	0	0
-23.39	37.89	23.39	37.89	0	0
-28.78	43.78	28.78	43.78	0	0
-24.67	40.67	24.67	40.67	0	0

From these results, we noted that the reaction forces in the x-axis completely cancelled out. Furthermore, as we expected, the majority of the forces will point downward and contribute to some deflection. This analysis is an oversimplification for real world simulations, but is a good start to get loading conditions for preliminary FEA using SolidWorks.

In addition to the reaction force hand calculations, we performed simplified beam bending calculations to get an idea of what magnitude of deflections that the bracket may experience. We resolving worst-case load (4xW @ end of chassis) to the end of the bracket, and modeled the bracket as a cantilever beam with a moment and point load applied at the end. Using super position and beam deflection equations from Shigley's mechanical design text, we obtained:

$$y_{max} = -\frac{Wl^3}{3EI} - \frac{Ml^2}{2EI} \quad (4)$$

From our SolidWorks model, using a typical cross section in the middle of the bracket (to include vent holes), we found the area moment of inertia, I = 0.09 in4.

For steel, $E = 30x10^6$ psi

Length of bracket, l = 6 in

W = 43 lbs (4xW of heaviest chassis split evenly between 2 brackets)

M = 645 in-lb_f (resolving weight from back of chassis to end of bracket)

Plugging in values to equation (4), we get the maximum deflection, $y_{max} = -0.00545$ in. Similar to the reaction force hand calculations, this estimate is conservative because beam equation doesn't take into account full effect of the staggered ventilation holes. From this value, we expect a relatively small deflection in Abaqus — on the order of 0.001 to 0.100 inches.

Preliminary Stress Analysis – SolidWorks

With some basic loading conditions and general expectations for deflection results, we began the computer analysis with less complex FEA software that is built into SolidWorks. With the studies in SolidWorks, it was our goal to discover general trends in parameter variations and justify choices for design features on the bracket. We began the simulations working with a bracket that contained all of the base dimensions for each feature that we planned to vary (Figure 12)

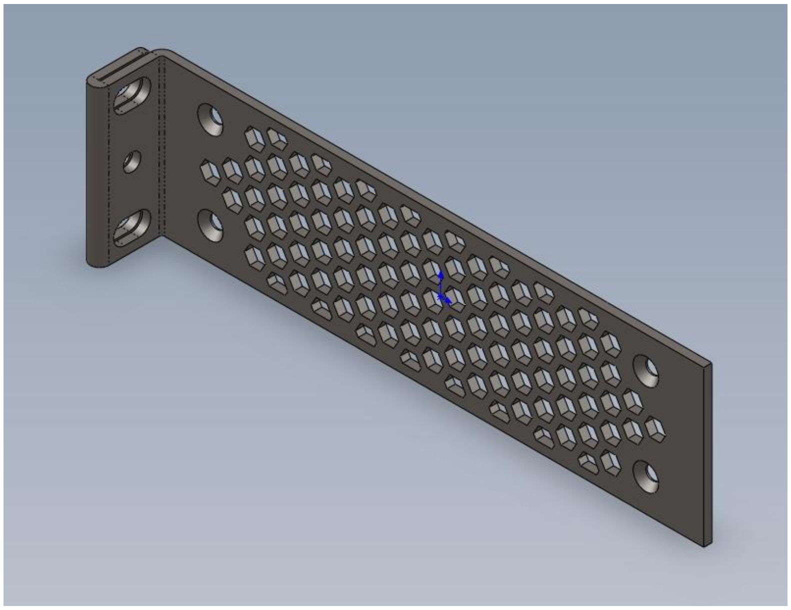


Figure 12: Base bracket for simulations

From this bracket, sets of revised models were created that modified one feature at a time. The features chosen for modification included the vent-hole size, vent spacing, and material thickness—it also should be noted here that after reviewing the design, an important parameter that required further investigation is the bend radius at the flange of the bracket.

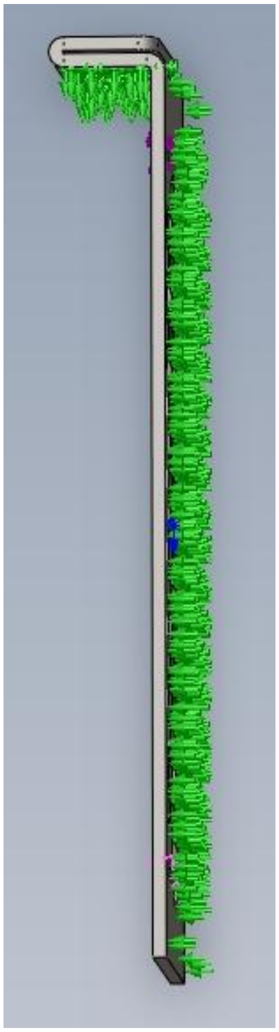


Figure 13: Bracket Boundary Conditions

Within SolidWorks, we needed to set up boundary conditions that would be consistent for every simulation (Figure 13). First, the mesh was generated with average size elements to provide acceptable results, but also increase the speed of running the simulation. The inside flange face was fixed in space to simulate being screwed into the "rigid" rack. Also, the back face of the bracket was assigned a "roller" boundary so that translation was only allowed within the vertical plane as if it was attached to the chassis. Finally, point loads generated from the hand calculations were applied at each screw location. Our overall results are summarized in Table 3 below:

Table 4: Parametric Study Results

Model	Characteristic Dimension	Max Displacement (mm)	Max Stress (N/m2)
Base	0.2	0.849	5.35E+08
	0.08	0.849	5.35E+08
	13	0.849	5.35E+08
vents1	0.225	0.77	3.60E+08
vents2	0.25	1.11	7.30E+08
vents3	0.275	1.02E+00	5.54E+08
smallvents1	0.175	0.826	3.94E+08
smallvents2	0.15	0.773	4.46E+08
smallvents3	0.125	0.731	4.06E+08
thickness1	15	0.574	3.97E+08
thickness2	14	0.511	3.38E+08
thickness3	12	0.73	4.44E+08
thickness4	11	0.639	4.08E+08
spacing1	0.04	1.25	6.24E+08
spacing2	0.06	1.03	5.03E+08
spacing3	0.1	0.801	4.04E+08
spacing4	0.12	0.696	3.58E+08
spacing5	0.14	0.714	3.93E+08
spacing6	0.16	0.669	3.80E+08

Overall, the simulations showed the highest stress concentrations to be along the edges near the vent-hole patterns, and the max deflection out at the end of the bracket. Taking a closer look at each parameter, we were able to discover some general trends. First, looking at the vent sizes (Figure 14), we found that there was a decrease in maximum deflection with smaller vents. However, due to the slight changes in vent pattern for each vent size, the stress did not correlate strongly with vent size. If the resulting vent pattern had more vents closer to the brackets edge, the stresses were generally higher. Similarly, by increasing the spacing between vents, the displacement also decreased. Vent spacing showed a stronger correlation to the stress concentrations (Figure 15); larger vent spacing resulted in less stress in the bracket. Furthermore, looking at the graph, we noted that the changes in displacement and stress began to level off at vent spacing of 0.1 inches. While smaller vents and larger spacing between vents decreased the deflection and stress values, ventilation area would also be sacrificed. Finally, the thickness of the bracket had interesting results. As we expected, the thicker brackets decreased the maximum deflection and stress values (Figure 16). However, the 14 and 15 gauge sheet metal (thinner) resulted in interesting geometry with the countersink. From the different geometry, the loads could not be applied in the same way and could be considered outliers. Finally, given the allowable clearance between the chassis and rack, 13-gauge is the practical maximum for this application.

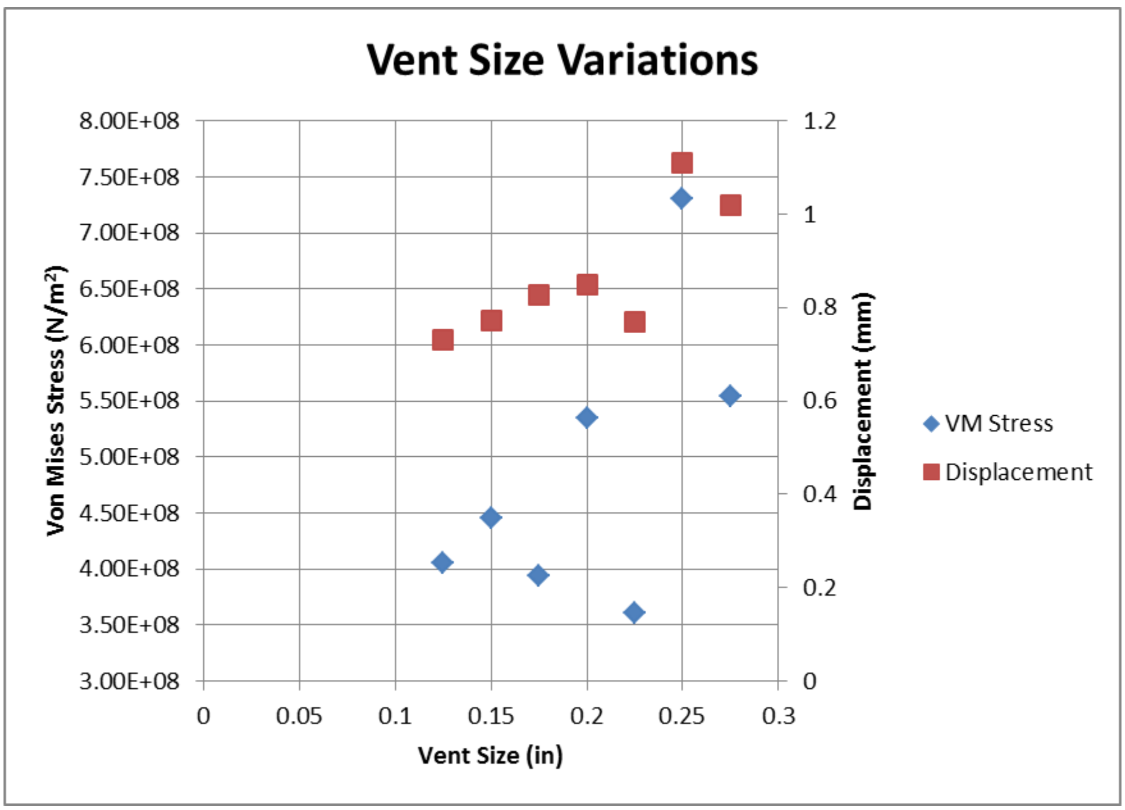


Figure 14: FEA Results for Vent Size Variations

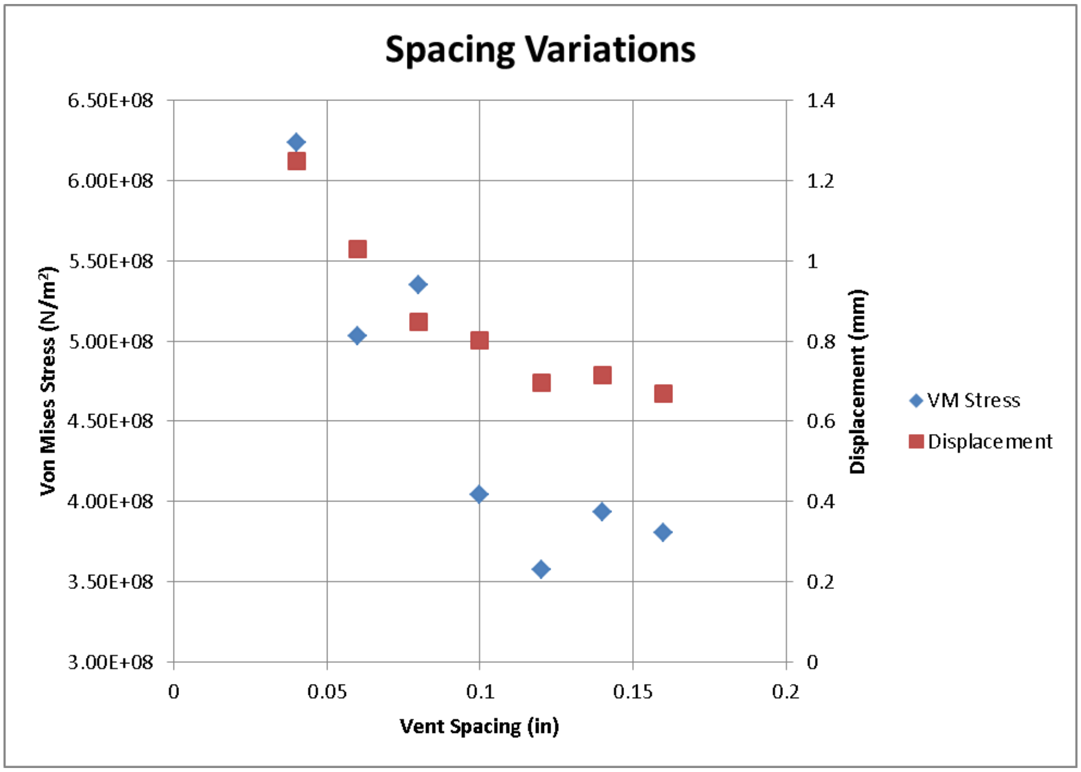


Figure 15: FEA Results for Vent Spacing Variations

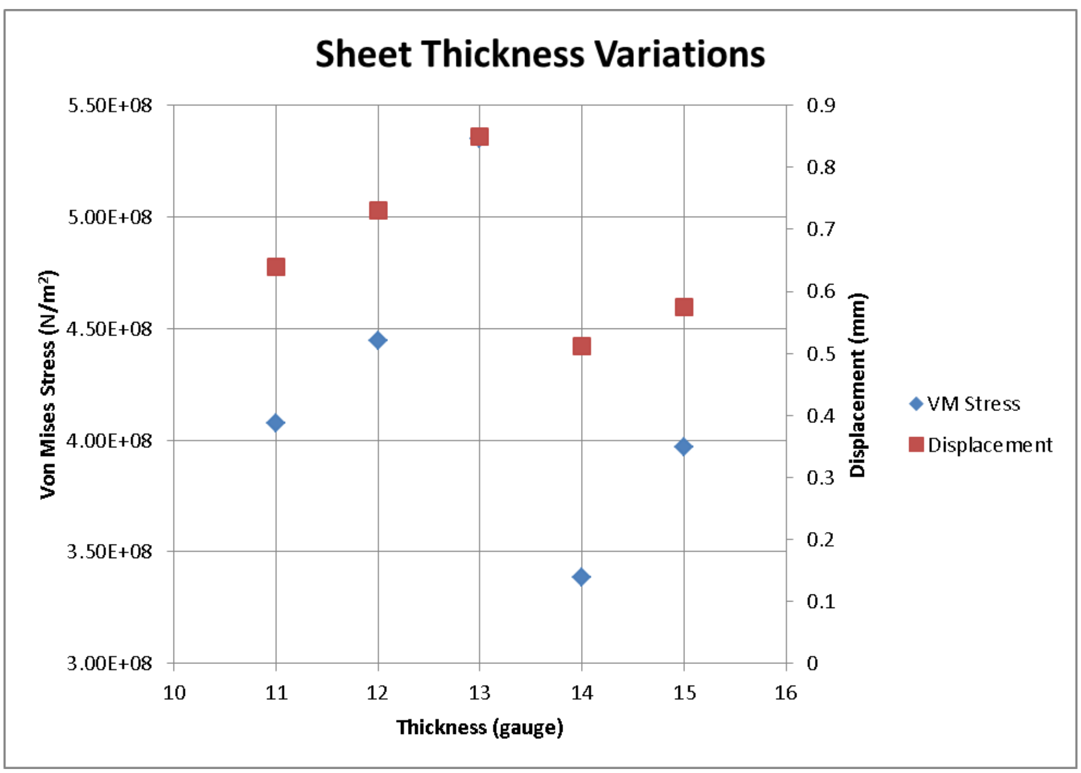


Figure 16: FEA Results for Thickness Variations

Finite Element Analysis

A detailed finite element analysis was performed on the standard 4-hole bracket with the staggered hex vent pattern under the worst case static loading conditions. Simplified models of the bracket, chassis, rack, and fasteners were created and assembled in Solidworks, and then imported into Abaqus as a stp file. All pieces were appropriately attached together using a combination of tie constraints and surface to surface contact. A convergence study was performed and determined and appropriate element seed size of 0.1 in. Bolt forces were applied at each fastener and a traction load was applied to the end of the chassis to simulate the loading conditions. With this initial model it was determined that the bracket vent pattern plays a very minimal role in supporting the chassis. It was found that the bracket bend was the critical point for the design. Under the worst case loading condition of four times the chassis weight applied at the end of the chassis it was determined that the bracket would yield at the bend. With this finding, further analysis is being performed that will more closely examine the effects that bend radius and the vent pattern have on the overall stress in the bracket.

Model Development

The Rackmount system has five crucial parts that were modeled in ABAQUS. A model of these parts can be seen in figure 17 to the right.

- Bracket (Grey)
- Chassis & 6-32 Machine Screws (Green)
- Rack & 10-32 Pan Head Machine Screws (Blue)

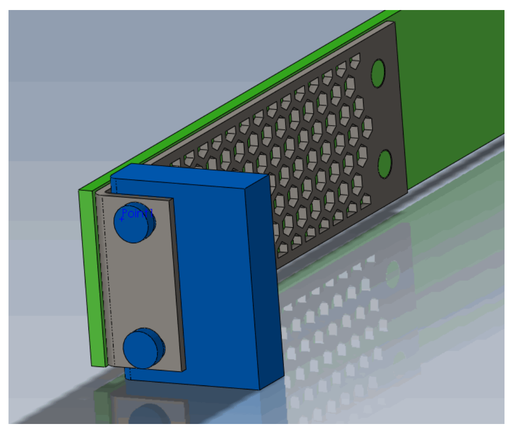


Figure 17: SolidWorks assembly

Only the structural components were considered for this model. Any unnecessary features were excluded from the solid models to speed up simulation time. Non-structural fillets and the cable management mount hole were excluded on the bracket. The model of the bracket can be seen in figure 18.

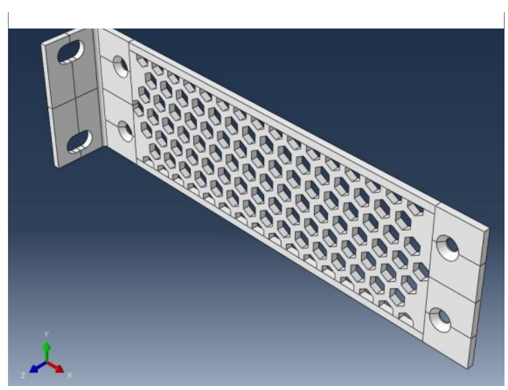


Figure 18: Simplified Bracket

To simplify the analysis the 6-32 and 10-32 fasteners were modeled as part of the chassis and rack, respectively. The chassis was modeled as a simple beam with dimensions of 21x1.75x0.15 in. The flat head machine screw dimensions were obtained from McMaster-Carr parts drawing files. Detail of the flat head machine screw and chassis part can be found in figure 19. The same method was used to model the rack and pan head screws. The rack/pan head machine screw part can be found in figure 20.

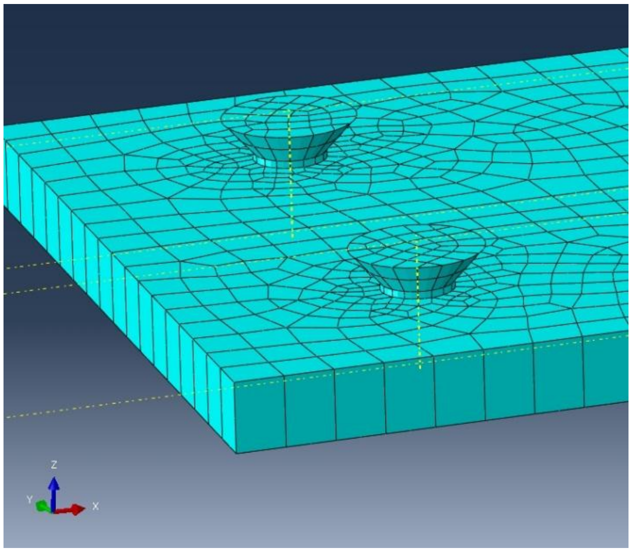


Figure 20: Chassis and fastener model

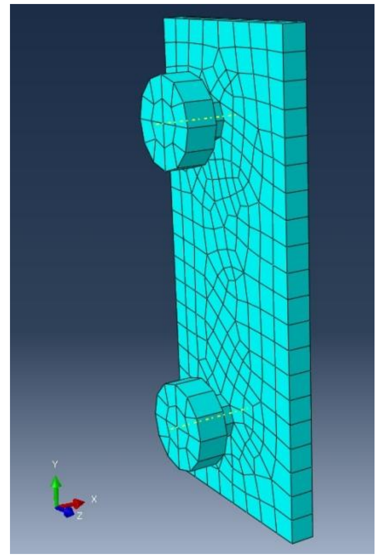


Figure 19: Rack and fastener er

Material Properties:

Each part was given an elastic definition and a density of 1018 cold rolled steel. Material properties used for this model can be found in Table 4. Material property units had to match the model base length units of inches. The tensile strength of the material was not used in the FE model, but used to judge the results of the simulation.

Table 5: FEA Simulation Material Properties for 1018 cold rolled Steel

Property	Value	Unit
Density	0.26	lb/in^3
Young's Modulus	30×10^6	psi
Poisson's Ratio	0.5	-
Tensile Strength	85×10^6	psi

Boundary Conditions:

A total of two boundary conditions were applied to this model. The rack was fixed using the encastre (U1, U2, U3, UR1, UR2, UR3 = 0) boundary condition on its top, right, and bottom faces in order to simulate the rest of the rack. Symmetry (U3, UR1, UR2 = 0) was applied to the inner face of the chassis in order to simplify the analysis process. It was assumed that the bracket loading would be symmetric and therefor it was only necessary to model half of the assembly. The end load was divided by 2 to account for the symmetry. Figure 21 shows the applied boundary conditions.

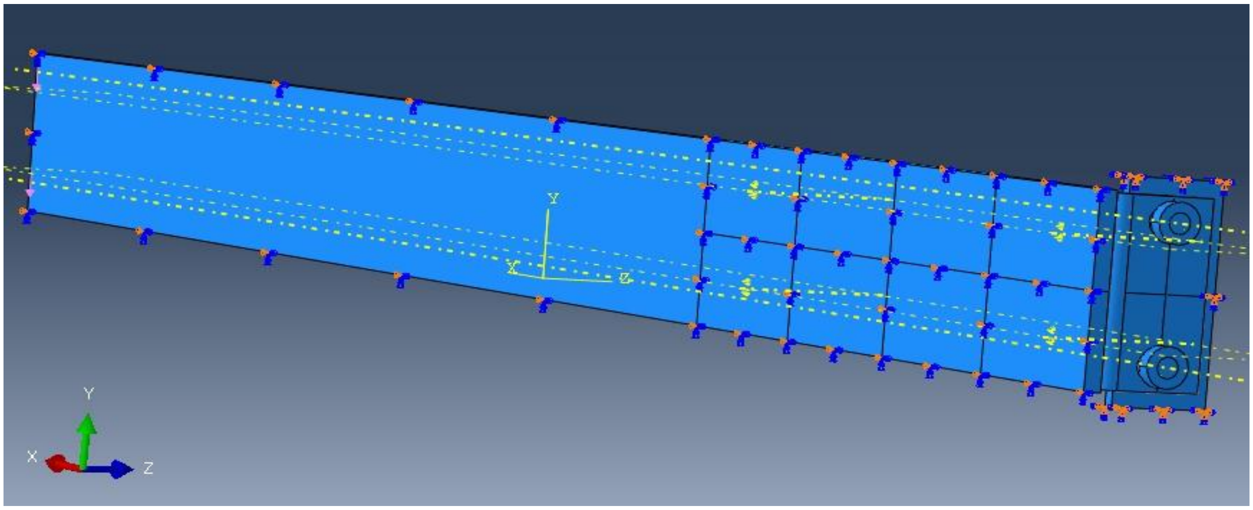
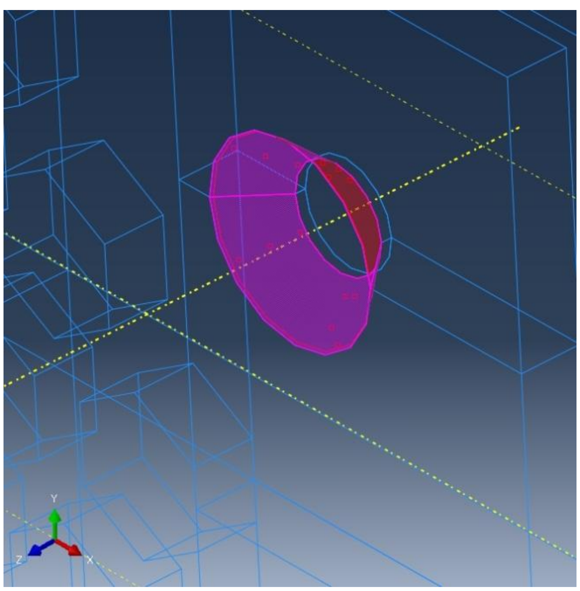


Figure 21: Symmetry and encastre boundary conditions applied to the assembly.

Interactions:

All individual interactions were modeled with a standard surface to surface contact formulation. Each interaction was assigned individually. Contact was defined between the chassis, bracket, rack, flat head machine screws and the pan head machine screws. A friction coefficient of 0.5 was used for friction between steel and zinc-plated steel. The bracket was defined as the slave surface for all surface to surface contact interactions. Figure 22 below illustrate two surface to surface contacts used in the model.



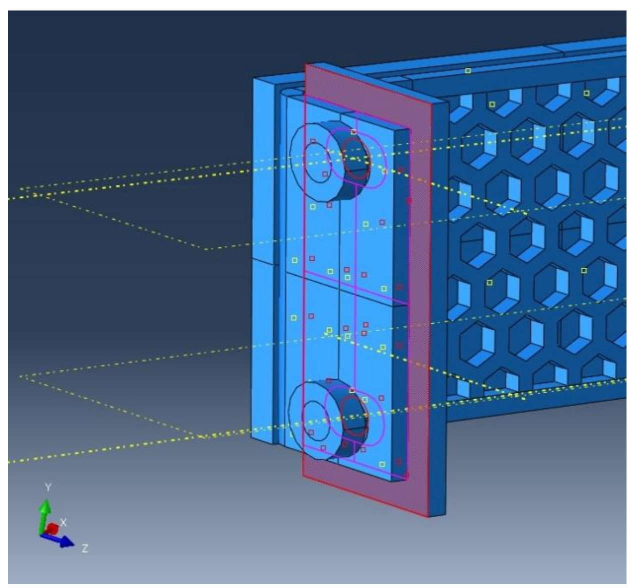


Figure 22: Detail of contact definition between flat head machine screw and bracket (Left). Contact between rack mounting face and bracket (Right).

Loading Conditions:

Three different loads were applied to the assembly; the loads consisted of bolt preloads applied to both the flat head machine screws and the pan head machine screws (Figure 23L), as well as a tractive load applied at the end of the chassis (Figure 23R) that simulates the worst case loading condition. Bolt loads of 320 lb_f and 820 lb_f were applied to the 6-32 and 10-32 fasteners respectively. Bolt loads are based on a Spaenaur industrial fasteners data sheet for grade 2 steel bolts. The tractive load required to simulate the load was 164 psi.

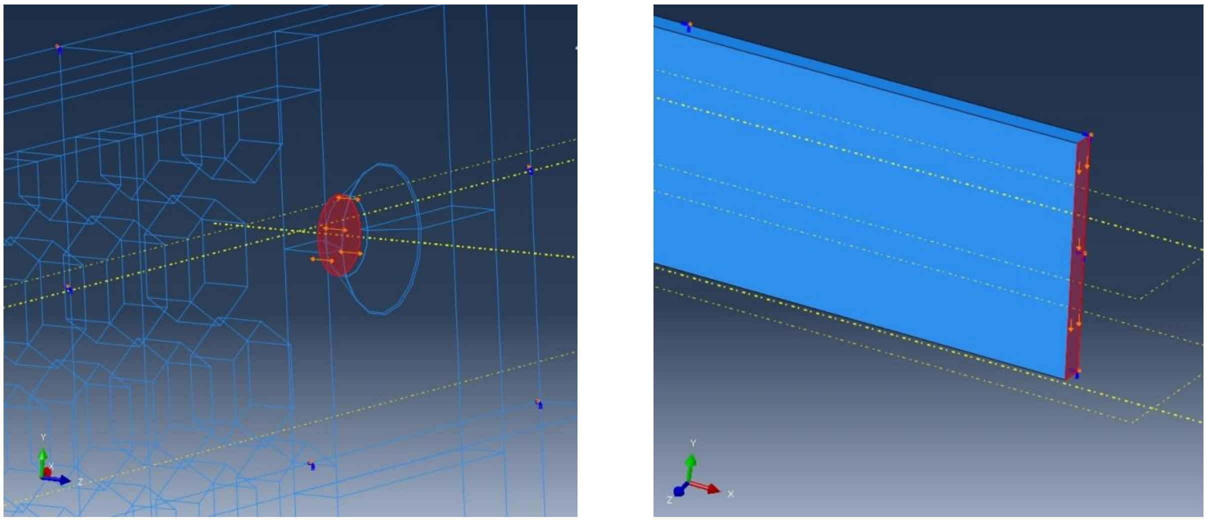


Figure 23: Flat head machine screw bolt loading applied to cross section of bolt (Left), and tractive load applied at end of chassis (Right).

Mesh Development:

Each part was meshed with standard quadratic hexahedral elements (C3D20). A hex dominated mesh was specified, and a combination of structured and swept meshing techniques was used. A convergence study was performed on mesh seed sizes ranging from 0.6 to 0.05 inches. The displacement was measured at the end of the bracket and the Von Mises shear stress was measured near the bracket bend. These values were plotted in Excel (Figure 24). and it was determined that a seed size of 0.15 inches was acceptable for the simulation. In addition to the global seed size of 0.15, edge seeds of 0.05 were used around the countersink locations as well as on the flat head machine screws. Detail of the bracket mesh can be seen in figure 25.

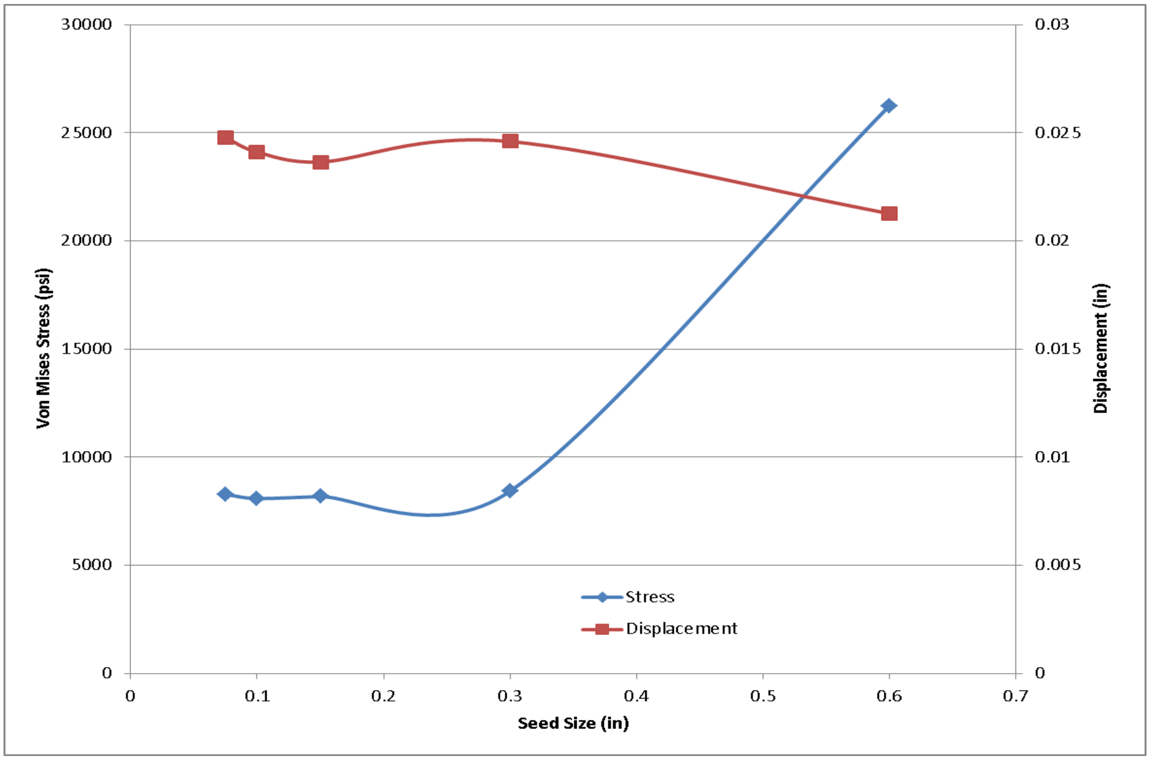


Figure 24: Mesh convergence study performed on displacement and Von Mises shear stress at 2 separate points on the bracket for a seed size ranging from 0.6 to 0.075.

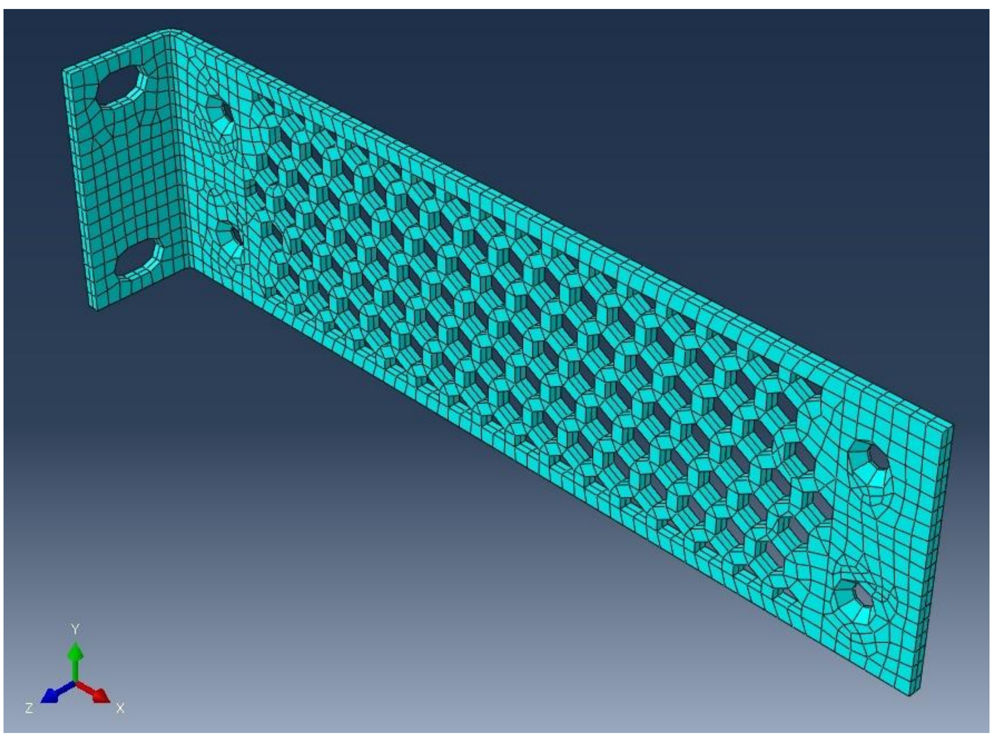


Figure 25: Bracket with 0.15 in mesh seed after performing convergence study.

Results:

Under the worst case static loading conditions of four times the weight applied at the end of the chassis, the simulation resulted in a maximum Von Mises shear stress of 239500 psi at the inner bend radius. This maximum stress is well above the yield strength of 66000 psi and tensile strength of 85,000 psi indicating that the bracket will not only yield, but it will also fail. Preliminary results of this simulation are shown in figure 26. The initial assumption that the bracket would yield around the vents proved to be incorrect. It was determined that this is because the chassis is essentially rigid which drastically increases the stiffness of the assembly and therefore all the stress is transferred to the bend. This finding means that the bracket vent pattern can be simplified or eliminated. In addition to changing the vent pattern, more analysis will be performed to investigate the effects different bend radii have on the maximum stress in the bracket. Maximum displacement at the end of the bracket was found to be 0.024 inches, as shown in the displacement plot (figure 27). Figure 28 shows the stress plot of on the chassis with the maximum stress of 65,000 psi occurring at the screw shank. The simplified screw model does not take into account the thread dimensions on the bolt meaning that the shaft of the screw would actually be smaller than that in the model. With the yield stress and simulated stress so close in the screws, more analysis needs to be performed on the fasteners.

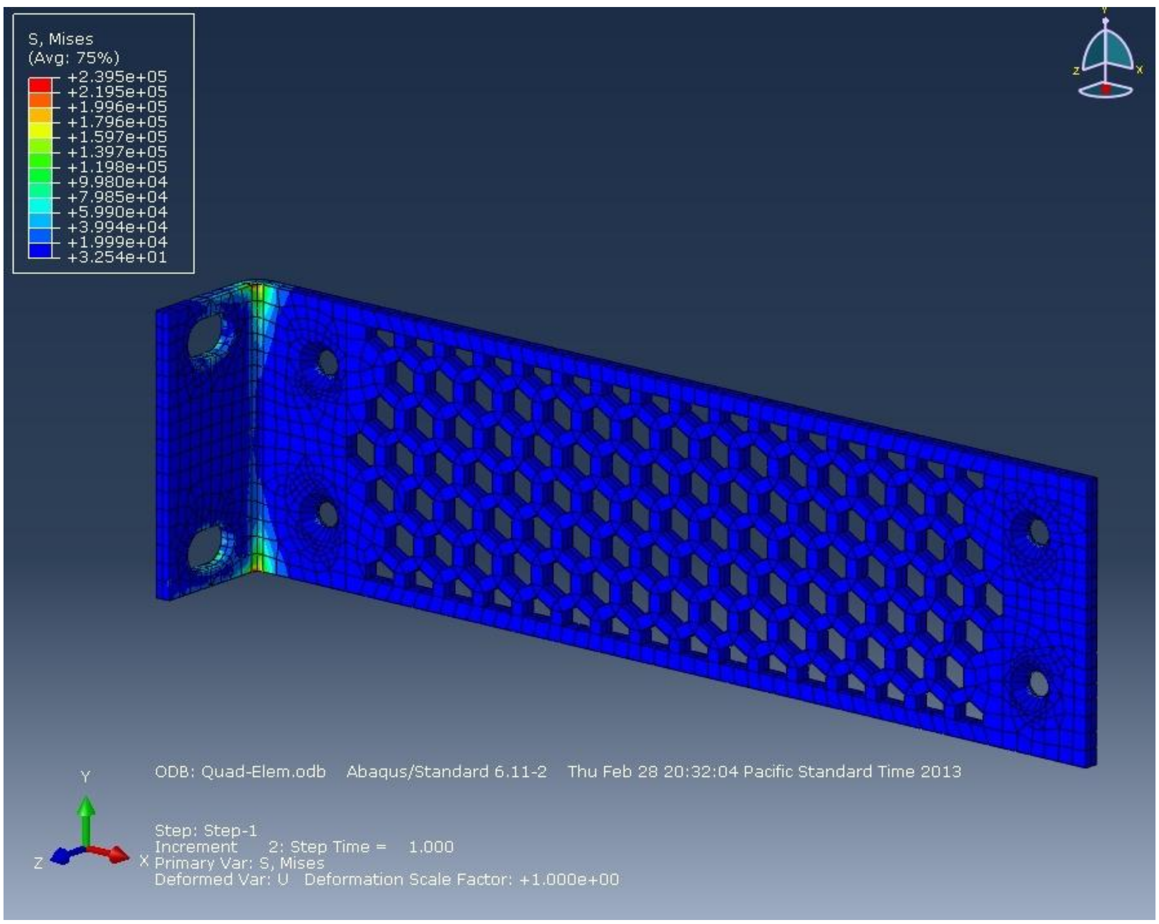


Figure 26: Von Mises shear stress plot for bracket subjected to worst case loading conditions.

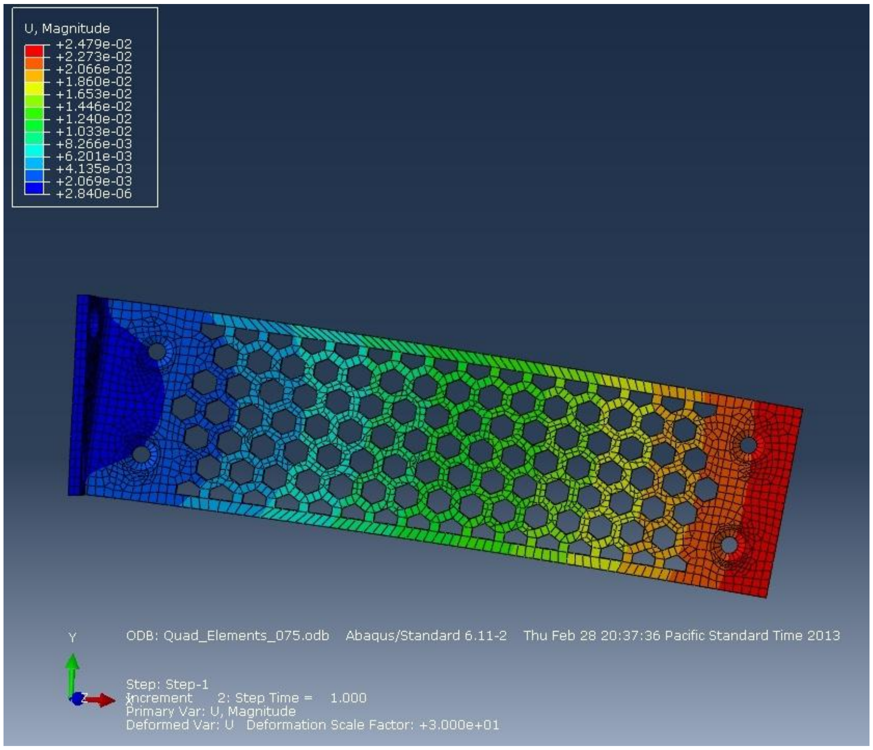


Figure 27: Displacement plot of bracket under worst case loading conditions.

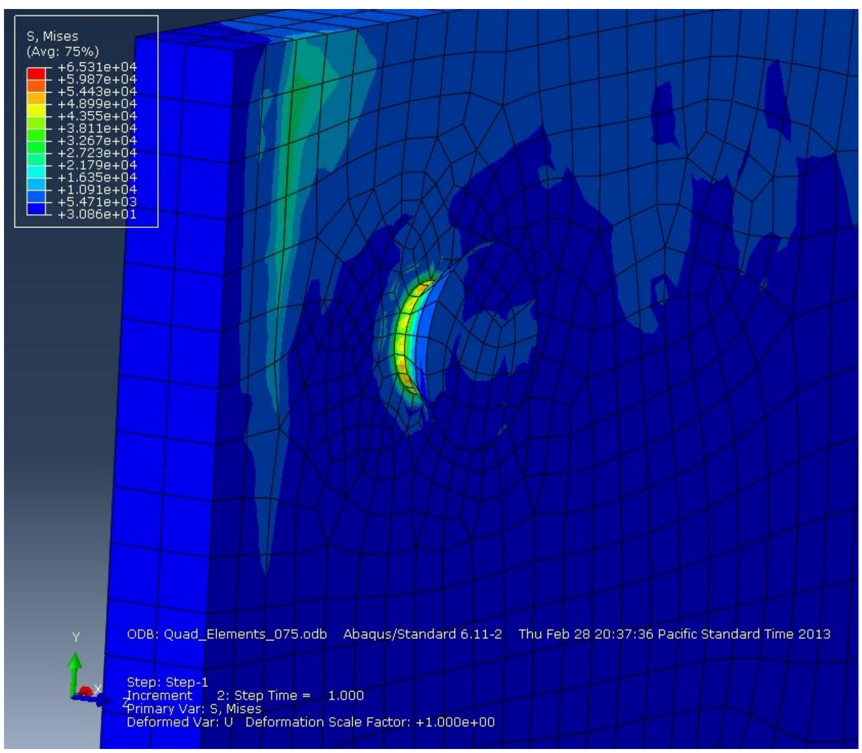


Figure 28: Chassis stress plot under worst case loading conditions. Maximum stress occurs on the screw shaft and is near the yielding point of 1018 cold rolled steel.

Early Design Recommendations

From our testing results, we chose the best options for the final design. It was decided that due to the poor results from the pull test in comparison to the other options, the slotted hole was disqualified. There are two brackets, both with a 0.20-inch hex hole and 0.10-inch hole-to-hole spacing. The brackets would be made of 0.09-inch sheet steel and have a double-bend rack connection. The vent-hole pattern is similar to a design Cisco is currently using. Both design options are shown in the figures below.

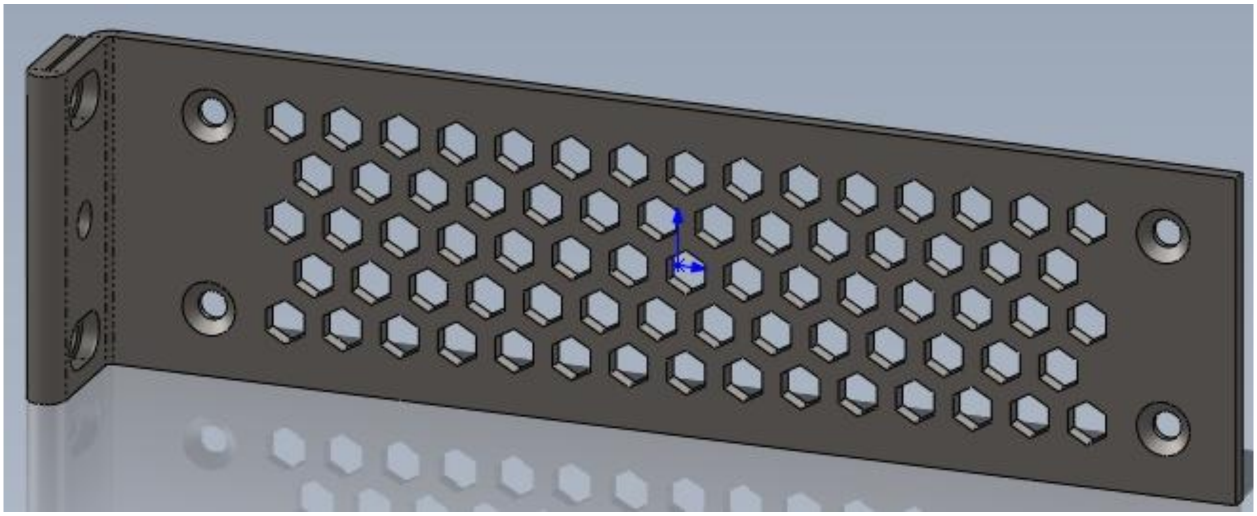


Figure 29: Standard 4-hole design recommendation

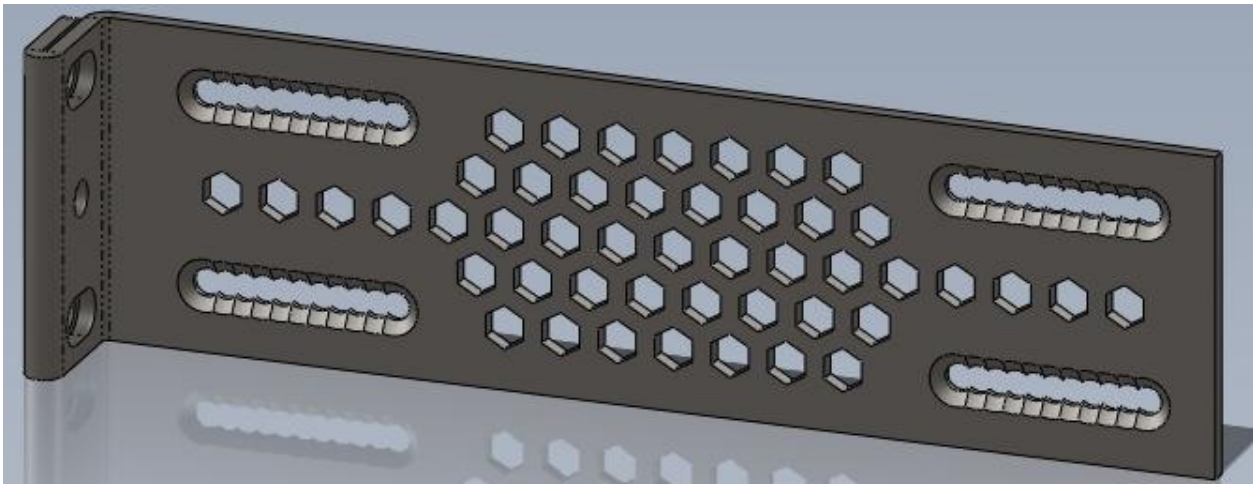


Figure 30: Scalloped hole design recommendation

From the discussions with Cisco and observations done during analysis, additional considerations can be factored. First, FEA testing showed that most, if not all, of the stress is placed on the bracket bend. Consequently, a bend radius has not been defined. Additionally, this means that the vent patterns could be of any type, any shape, and any size, as the integrity of the bracket will not change significantly. Additional FEA showed that with an open window design, deflection and stress did not change much at all.

Later discussions with Cisco alluded to the fact that scalloped holes have possible issues with manufacturing. A hybrid design was suggested, with the front holes being standard holes, and the back holes being slots. This would allow a fixed position, but also the ability to place the back mounting holes in different positions to accommodate other design constraints. The possible issue with this design is the fact that the chassis designer could also change the vertical spacing in addition to the horizontal position. This would still need to be investigated.

The original pull test was redone with more precisely machined components for better alignment for the holes. Also, the data acquisition system for the Instron pull tester was functioning properly so that we could obtain data for each pull test.

In addition, a study was performed in Abaqus to determine the effect of the bend radius on the stress and deflection of the bracket. As we expected, the larger bend radius values reduced the stress. Unfortunately, the physical dimensions of the clearance between the chassis and rack limited us practically to a radius equal to half of the bracket thickness.

Final Design Details

Through hand calculations, FEA model simulations, mechanical testing, and manufacturer's recommendations we finalized two main designs: standard four-hole, open window bracket, and hybrid slot, open window bracket.

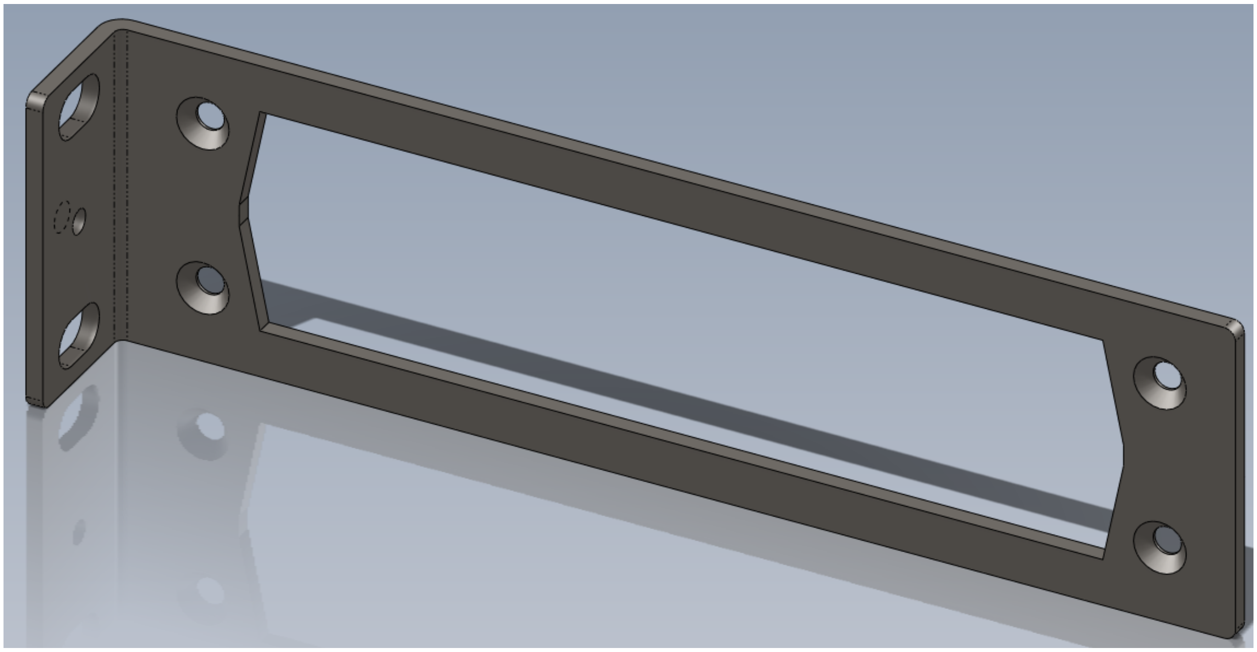


Figure 31: Four-Hole Open Window Bracket

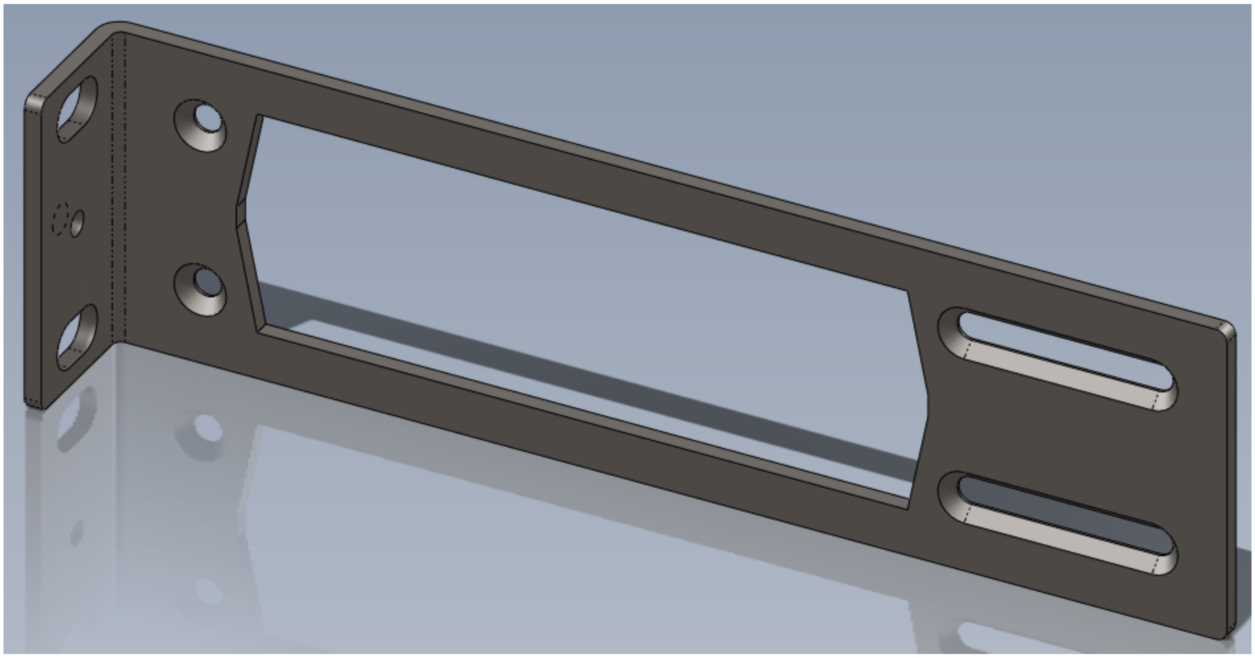


Figure 32: Hybrid Slot Open Window

Note: The full detail drawings of these parts can be seen in Appendix B. While there were originally three designs going into the final stage, the scalloped hole design was rejected by manufacturers because of difficult features to make.

Four-Hole Open Window Bracket

This design was constantly a front runner in all of the various forms of analysis and testing. Despite its simplicity, it out-performed the other brackets in pull-testing, bend-testing, and other FEA simulations. Similar to the other designs, it has a bend radius of half the plate thickness, 90 thousands thickness, and the same overall height and length dimensions. Unique features to this bracket include its simple four-hole pattern for maximum strength when clamping to the chassis. Furthermore, the ventilation area in this bracket is significantly larger due to the wide spacing between holes longitudinally. As a result, there is more versatility in the options of vent patterns that a mating chassis could have.

Hybrid Slot Open Window

In order to offer a wider variety of hole configurations that work with this bracket, it was designed to have a set of two slots for the back screws. The slotted design alone doesn't provide significant support for external forces in the longitudinal direction. Removing two of the slots and replacing them with holes in the front allows for the same freedom in hole spacing layouts, while also adding a considerable amount of strength. Unfortunately, a limit in the design of both brackets is the lack of adjustability in the vertical direction; hole-patterns will need to be matched up vertically with the bracket.

Product Realization

The manufacturing of final prototypes was completed by Foxconn though Cisco due to the need for precision and other methods not available at the Cal Poly machine shop such as plating. When the final designs were chosen, we sent the detail drawings to Cisco and Foxconn designers for a Design for Manufacturing (DFM) review. From the manufacturing for the pull test, we expected that Foxconn should have no problem with the countersunk holes and slots. However, the scalloped holes had been very challenging to manufacture. In our experience, as the holes were drilled, the drill bits would bend and try to enter the previously drilled hole. This left a lot of burs that needed to be cleaned by hand and slight misalignment of the hole spacing. Not surprisingly, Foxconn encountered similar issues and recommended that the scalloped design be abandoned. For mass production, the features of the plate would be stamped rather than machining. Brackets that are in full production for a company like Cisco can be produced in the thousands each day. Requiring a special machining feature would slow the entire productivity down and increase costs. Therefore, the scalloped design was dropped from the final designs, and we stuck with more easily manufacturable geometries.

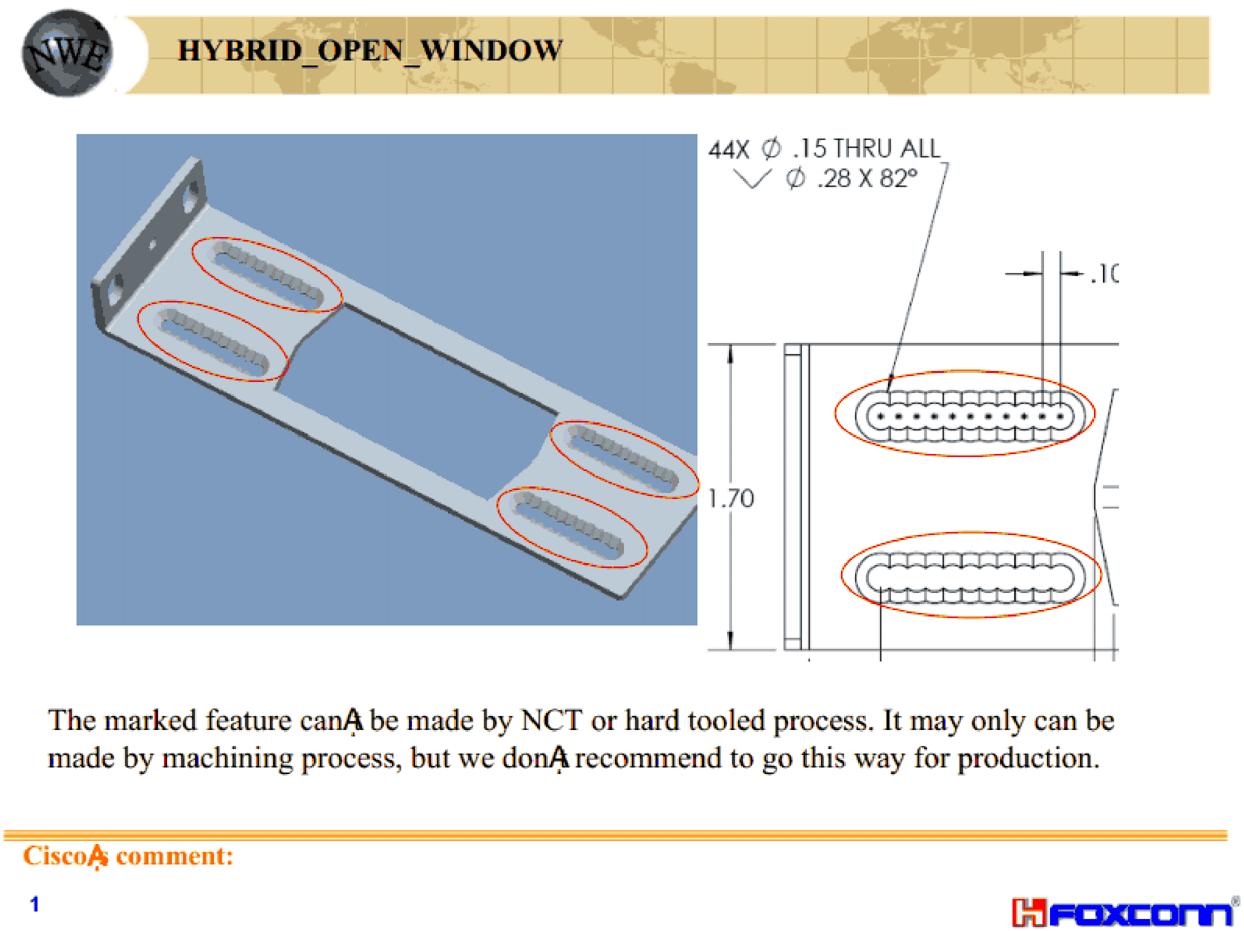


Figure 33: Scallop DFM Foxconn

Design Verification

Instron Pull Test

Motivation

During meetings with the Cisco team, we undertook a sub-project of investigating the feasibility of using slots in our bracket design. After spending time researching, and not finding very much reliable data, we decided that it would be a good opportunity to perform an experiment to get our own data. Our objective was to perform a pull test in order to find the maximum shear load that the brackets could withstand along the longitudinal axis. With this data we would be able to determine if the bracket would maintain a firm grip on the chassis during normal loading, as well as extreme conditions during an earthquake.

Setup

In Figure 29, our idea for the test apparatus is shown. We simplified the brackets by using the same basic size as our design, but only included the different hole designs (standard, slot, and scallop). Furthermore, by using a much thicket plate between the two brackets, we could assume it to be rigid which left the hole designs as the only significant factors in the test.

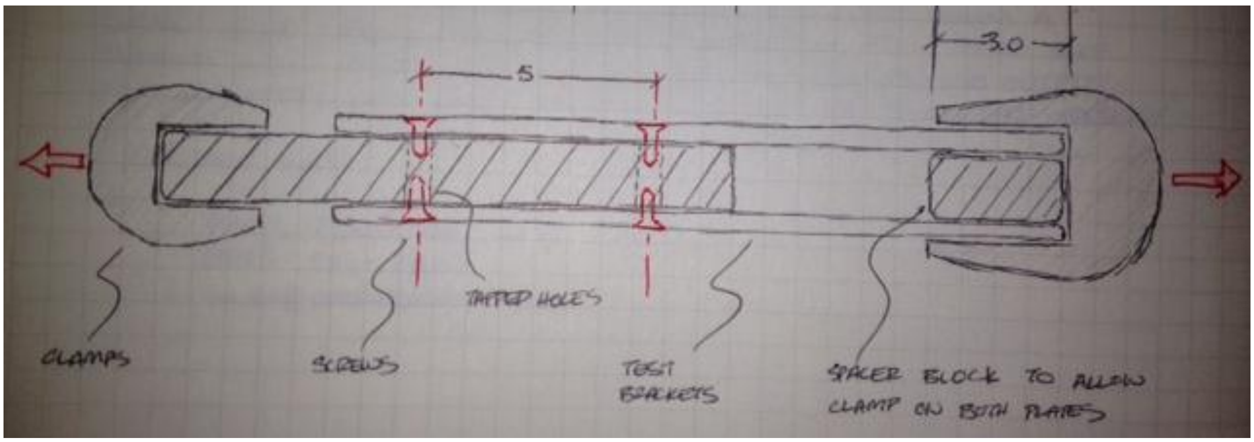


Figure 34: Pull Test Apparatus

To manufacture the test brackets, we used a CNC machine on campus in order to get precise locations and details for the brackets. Manufacturing the standard 4-hole and slotted countersunk brackets presented no problems. However, while drilling holes for the scalloped bracket, we encountered a considerable amount of tool flex, and had sharp burrs remaining (Figure 30).

Figure 35: Scalloped Test Bracket

After all of the test brackets were made, we welded the identical pairs together by attaching a spacer block. This would evenly distribute the load between the two brackets and provide a place for the pull-test machine to grab. Next, we cut out a thick steel plate to simulate the chassis, and drilled and tapped a set of holes for each bracket.

Figure 36: Bracket Pairs with Spacer Block

Figure 37: Thick "Chassis" Plate

The test brackets were assembled with the thick plate using #6 machine screws. One of the screws on each side was not able to be screwed down all of the way due to a slight alignment issue of the tapped holes (Figure 33).

Figure 38: Assembled Pull Test Apparatus

Finally, everything was ready to be placed into the Instron Pull Tester. The top and bottom of the apparatus were tightly clamped by the machine and the tensile load was set to zero. Slowly, the machine ramped up the force while we monitored the tensile load and displacement of the brackets relative to the thick steel plate.

Results

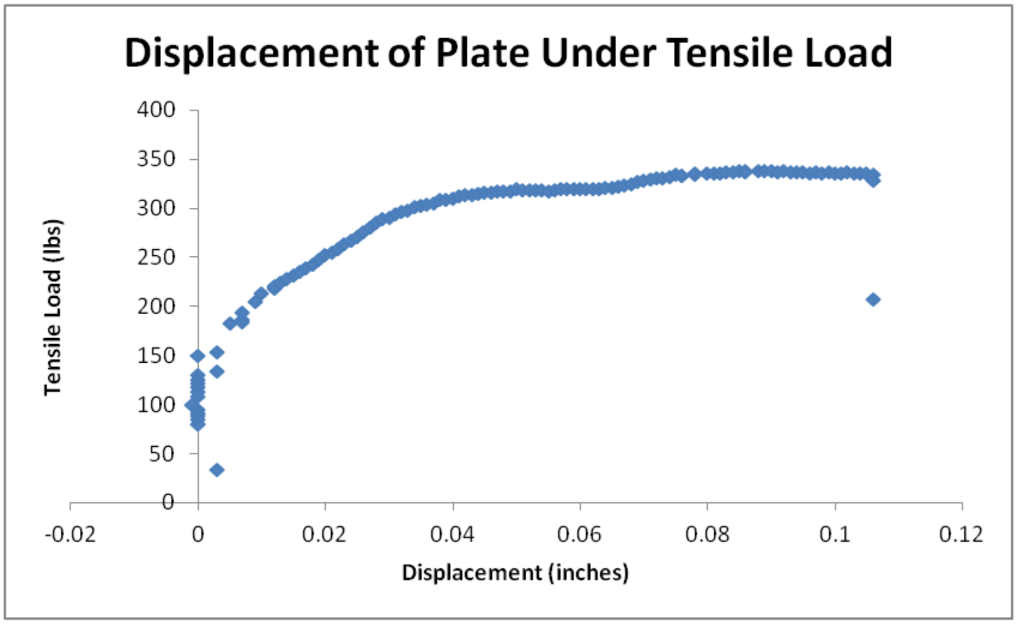


Figure 39: Slotted Pull Test Results

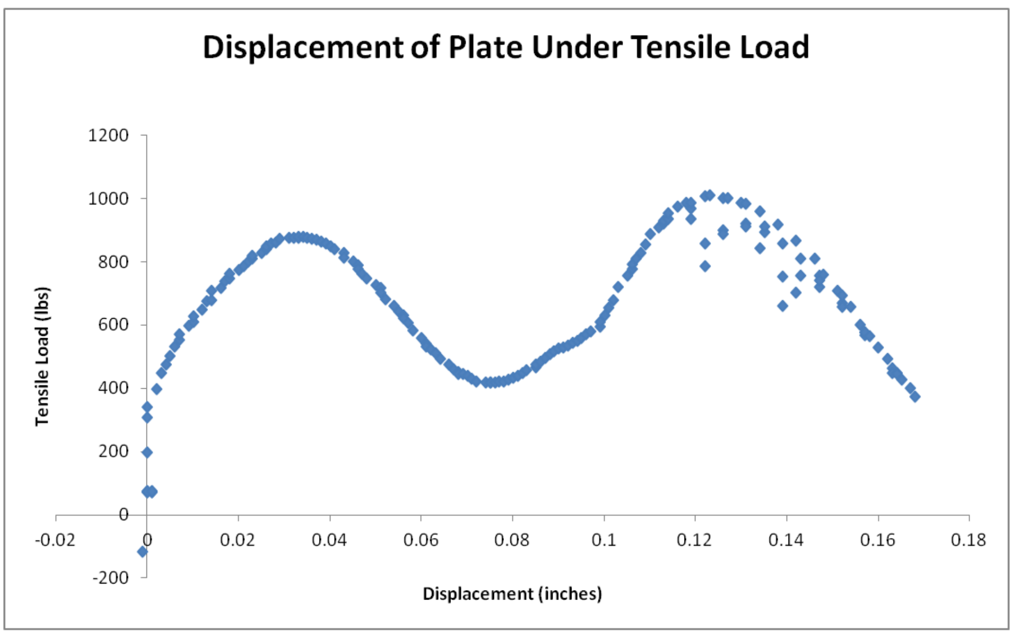


Figure 40: Scalloped Pull Test Results

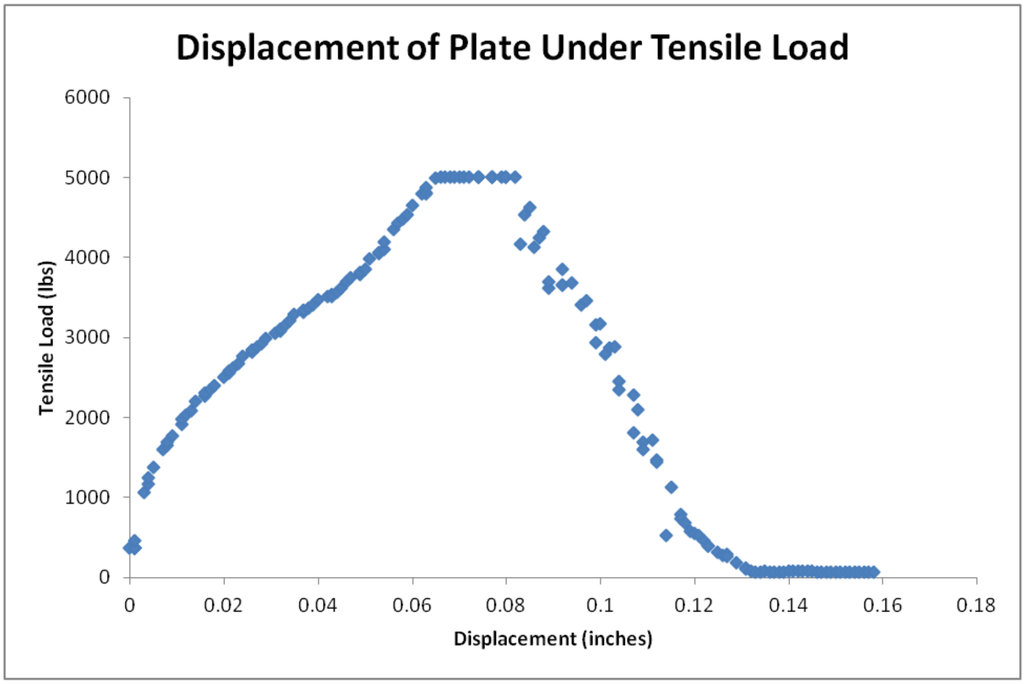


Figure 41: 4-Hole Pull Test Results

Discussion

As we expected, the standard 4-hole bracket survived the longest at a max load of 5000 lbs. As the force reached its maximum, the screws began to bend slightly before the heads completely sheared off, as can be seen in figure 34. Even after the failure, there was little damage that could be seen on the brackets. The scalloped design held up to a maximum tensile load of 1000 lbs, and then cycled periodically between 1000 lbs and 400 lbs. This periodic cycle was due to the "ribs" of each scallop that held the screw in place. As the maximum load was reached, the screw would deform the ribs and pass into the next scallop. This deformation can be seen in figure 35. Lastly, the slotted design was only capable of holding a maximum load of 350 lbs before the screws began to gradually slide along the slot. We previously determined that slipping in any way is not acceptable, therefore the slotted hole design is not recommended as a final solution. While the scalloped and 4-hole performed much better, the manufacturing issues with the scallops demonstrated that the simple 4-hole was the best design for this failure criteria.

Figure 42: Sheared Screws from 4-Hole Test

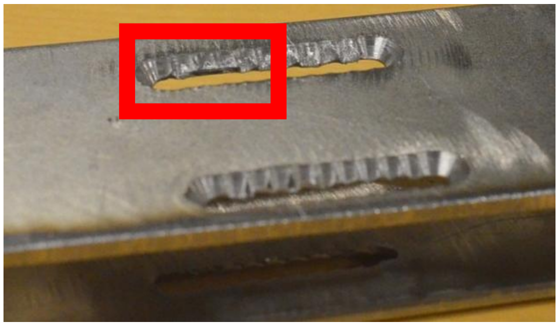


Figure 43: Destroyed Ribs from Pull Test

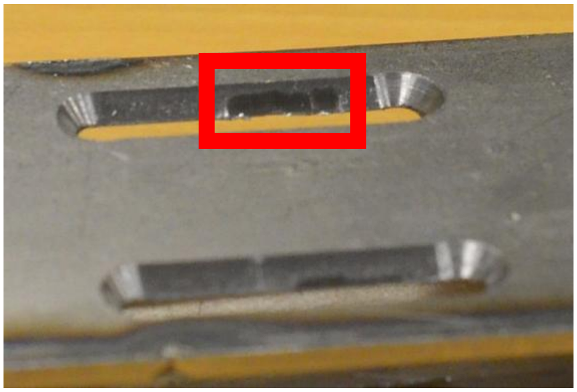


Figure 44: Detent from Sliding in Pull Test

Hanging Chassis Test

Motivation

One of the original design constraints expressed by the Cisco team for static loading conditions was the ability of the bracket to be able to withstand four times the weight of the chassis applied at its end. During FEA, results consistently showed that the brackets were yielding well before the design requirement. Additionally, even at very high loads, almost all of the stress was concentrated in the corner between the flange and base of the bracket—suggesting that the vent pattern geometry was irrelevant to the stress and deflection of the whole bracket. In order to verify the model (or discover a problem), we decided to physically test our prototype as well as one of the thicker brackets previously obtained from the Cisco Team.

Setup

In order to test the design condition, we needed to set up a way to attach various increments of weight at the far end of the chassis.

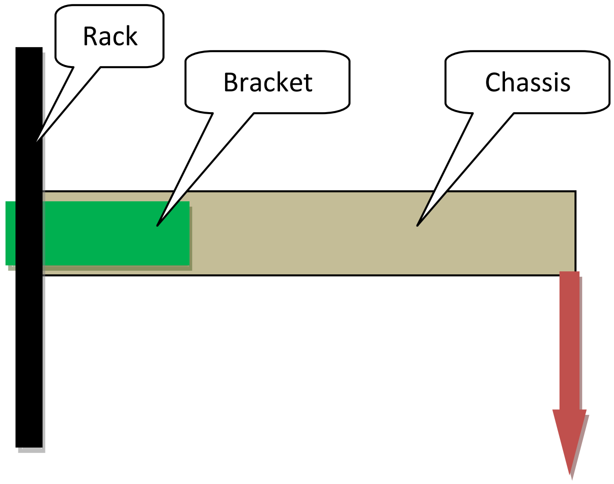


Figure 45: Schematic for Test Setup

Furthermore, it was necessary to have a way of measuring the deflection once it started occurring. In order to accomplish this, we obtained an electronic level that reads out the current angle relative to absolute horizontal. Also, we attached a ruler to the rack and a paperclip to the back of the chassis in order to check the tip deflection linearly.

Figure 46: Physical Setup and Measurement Device

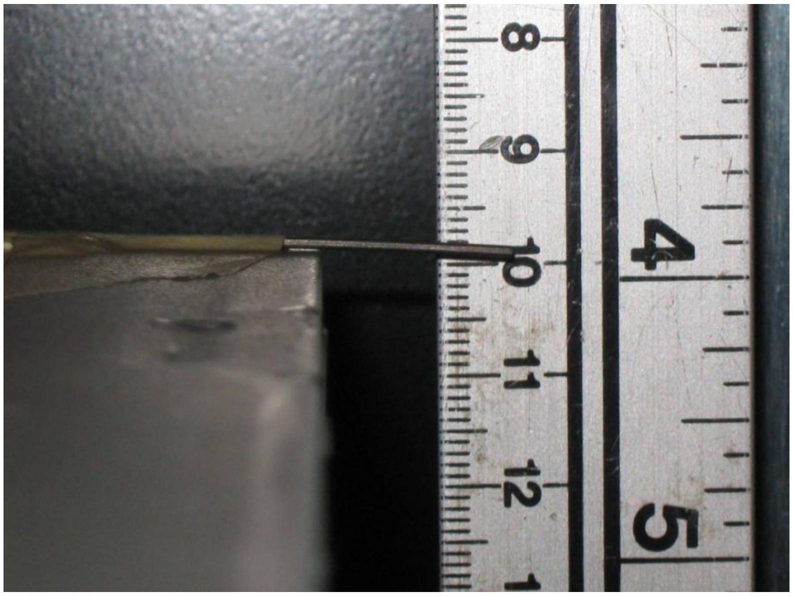


Figure 47: Deflection Measurement Method

For this test, we used the deepest and second heaviest chassis that we had in our possession from Cisco. This chassis came with two sets of 1RU brackets for mounting in a standard rack. These brackets were the thickest measured (0.090") and had no ventilation holes which led us to believe it is the strongest bracket of the samples we had. For the first set of brackets, we made no changes. The second set, however, we milled out a large pocket to simulate the open window design of our prototypes.

Figure 48: Open Window of Installed Bracket

Figure 49: Front View of Installed Chassis

Finally, using a clamp at the end of the chassis and a bag to hold the weight, we proceeded to add weights in 2.5 lbf increments. Our capacity went up to 30 lbf which was well under the design requirement of four times the weight of the 20 lbf chassis. We quickly discovered that in both sets of brackets, deflection and permanent deformation occurred much earlier than we anticipated.

Results

After going up to 30 lb_f for each set of brackets, we tabulated and plotted our data below:

Weight (lbf)	Deflection (cm)				Angle (deg)	
	Solid		Open		Solid	Open
	Nominal	Change	Nominal	Change	Nominal	Nominal
0.0	27.3	0.0	9.9	0.0	1.2	1.6
2.5	27.5	0.2	10.1	0.2	1.3	1.7
5.0	27.6	0.0	10.3	0.0	1.5	2.0
7.5	27.8	0.1	10.6	0.2	1.7	2.4
10.0	28.1	0.3	11.0	0.5	2.0	2.8
12.5	28.2	0.6	11.2	0.9	2.2	3.0
15.0	28.4	0.7	11.5	1.1	2.3	3.4
17.5	28.8	0.9	12.1	1.4	2.7	4.0
20.0	29.1	1.3	12.6	2.0	3.1	4.5
22.5	29.7	1.6	13.3	2.5	3.7	5.2
25.0	30.6	2.2	14.1	3.2	4.6	6.1
27.5	31.7	3.1	15.6	4.0	5.8	7.5
30.0	33.3	4.2	17.0	5.5	7.5	9.0

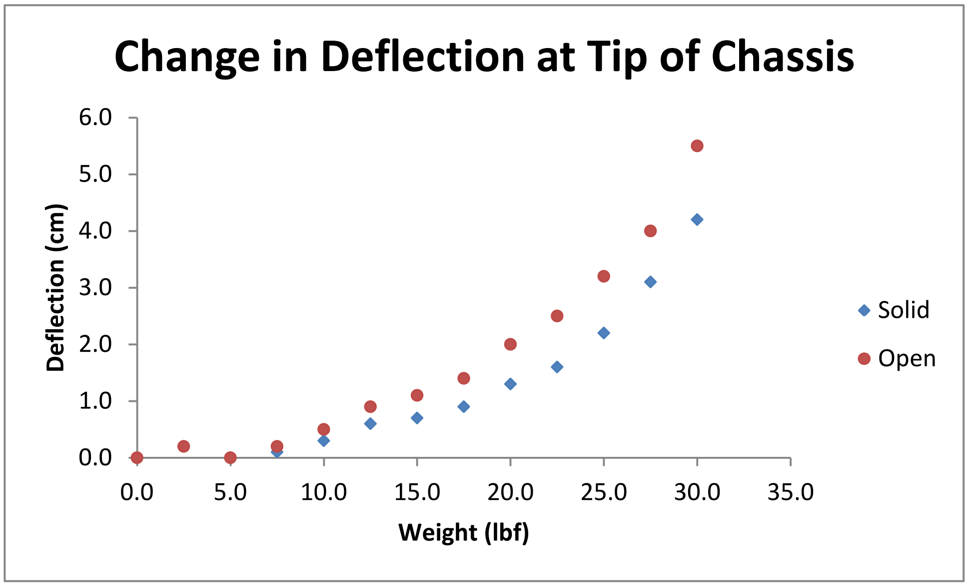


Figure 50: Deflection Trend for Increasing Weight

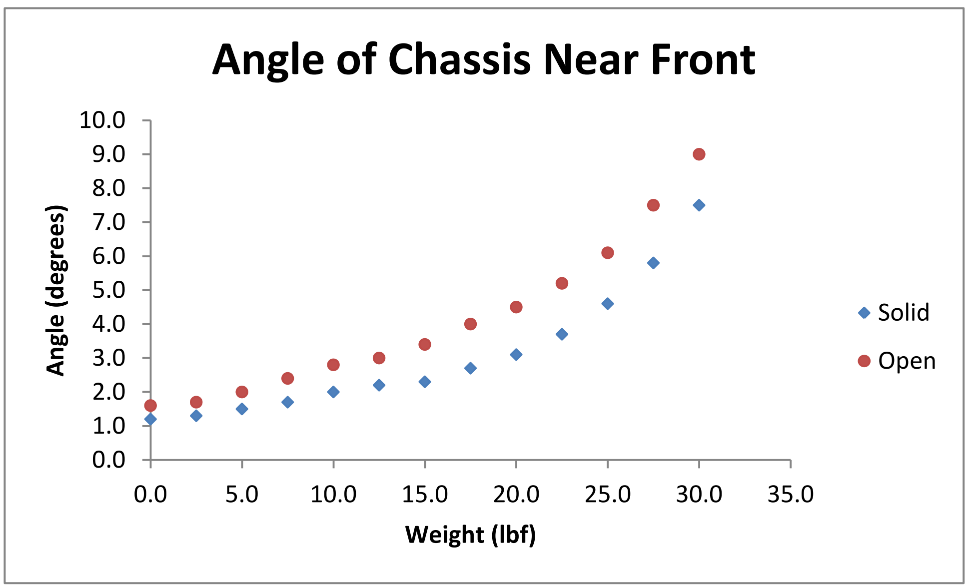


Figure 51: Angular Change Trend with Increasing Weight

Discussion

Although the solid bracket held up better than the open window, the overall deflection of each was not very different from each other. The biggest concern is how early the brackets (and even rack) began to yield. Small, but permanent deformation took place in lighter loads. Furthermore, the deformation increased exponentially starting at around 15 pounds for both brackets. This test confirmed our results in Abaqus studies that the bracket will be yielding much earlier than the original rule of thumb at "4 times the weight of the chassis applied at the end." The brackets used in testing were Cisco brackets designed for the Predator chassis—one of the deepest and heaviest in our possession—but still yielded much earlier than the design criterion. In order to achieve this criterion, further support would be required at the back of the chassis.

Figure 52: Max Deflection During Testing

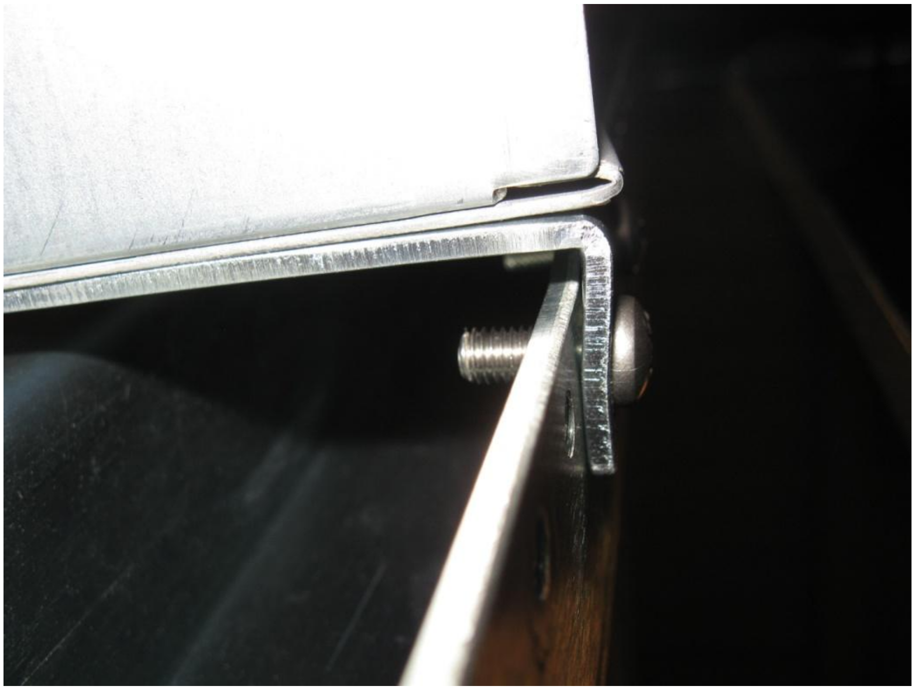


Figure 53: Flange Deflection

We also discovered a few things that weren't being demonstrated by the Abaqus model. First, we noted that despite nearly all of the stress and deflection happening at the flange of the bracket, we still had some deflection happening at the side-walls. This deflection less significant than that of the flange, but was noticeable. In order to minimize the effect, we increased the side-wall thickness in our final design.

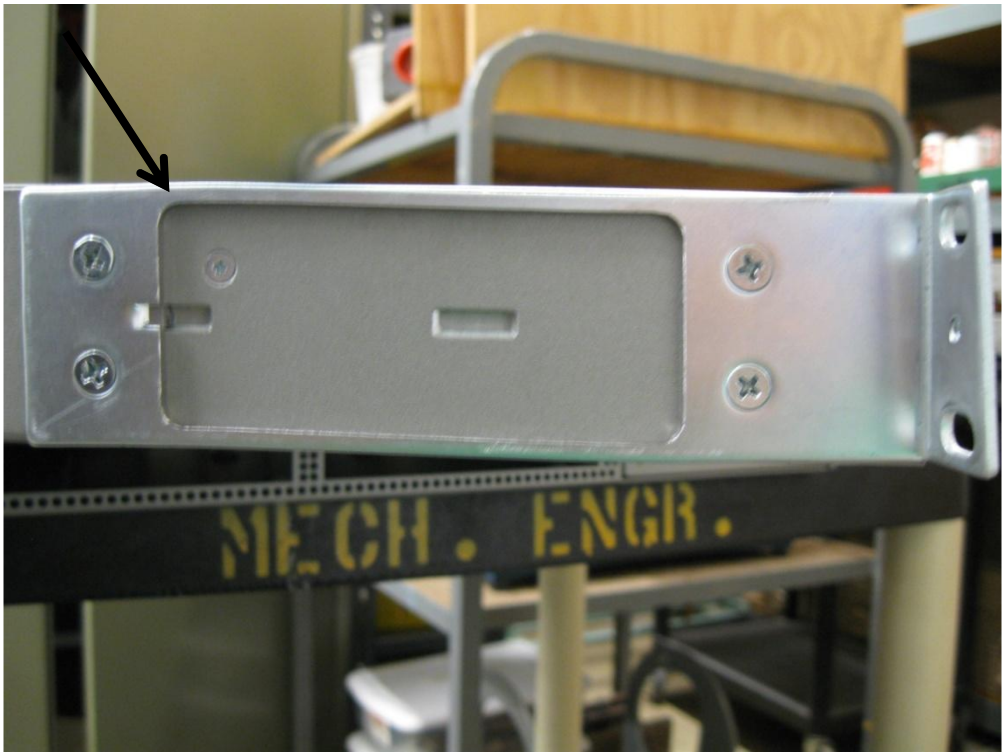


Figure 54: Side-Wall Deflection

Furthermore, despite being locked in with four screws, the holes in the bracket and chassis became misaligned as the chassis deflected. Our pull test showed that the 4-hole screw pattern will work for up to 5000 lbf, but there was still a small amount of movement that might interfere with reinstalling the screws later.

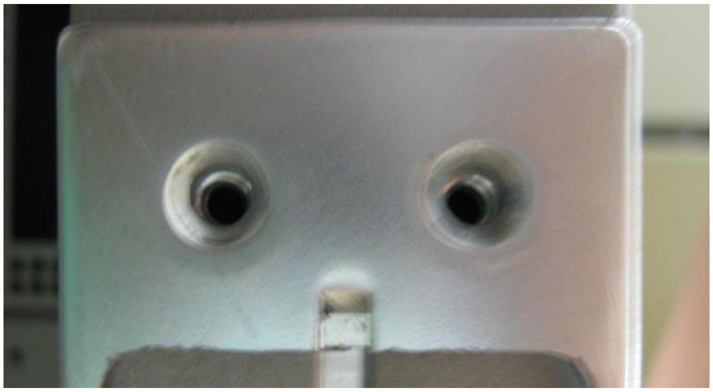


Figure 55: Bracket Shifting

Conclusions and Recommendations

After several months, many discussions with Cisco, and several issues and observations that set us back a few times, we are able to conclude a solution to Cisco's problem. As mentioned earlier, the first of the two original project goals could not be completed due to logistical issues. Instead, it is best to move forward and develop on a new bracket that should be mandated for all future Cisco 1RU products, which is the focus of the project. After going through several CAD designs, hours of FEA analysis, and several tests, we are able to provide Cisco with at least two suggestions to build on. Either one will work, but both have their own specific advantages. The four-hole pattern is better suited for strength, while the hybrid option is better suited for mounting flexibility. Even with this in mind, real-world bend testing shows that deeper/heavier chassis would benefit from reinforcement if they are to be mounted onto a four-post rack.

Additionally, the testing and analysis procedures are more detailed than what Cisco usually does. Discussions with Cisco mentioned that this report should also be a whitepaper. It is suggested that testing teams read over this report, as it was later discovered that our testing and analysis procedures exceeded the level Cisco normally does such work. This occurred twice during the project period.

We recommend that overall, one of the two final suggested brackets be the basis for a new, corporate-wide hole pattern that will not be replaced in the short term.

References

Budynas, Richard G. and Keith J. Nisbett. *Shigley's Mechanical Engineering Design*. 9th ed. McGraw Hill Companies, Inc. 2011. Print

Cisco. 2013. Web 2013

"Documentation." *3ds.com/products/simulia/support/documentation/*. Dassault Systems. Web. 2013.

Appendix A: Project Schedule

Task Name	Duration	Start	Finish	Predecessors
Cal Poly Senior Project: Cisco Product Development	**255 days**	**Tue 9/25/12**	**Fri 6/7/13**	
Project Start	0 days	Tue 9/25/12	Tue 9/25/12	
Research/Information Gathering	30 days	Tue 10/9/12	Thu 11/8/12	
Initial Project Proposal	**23 days**	**Tue 10/9/12**	**Thu 11/1/12**	
Initial Conference Call	0 days	Thu 10/25/12	Thu 10/25/12	
Project Definition	7 days	Thu 10/25/12	Thu 11/1/12	5
Preliminary Design Review	**35 days**	**Fri 11/2/12**	**Fri 12/7/12**	**4**
Ideation	0 days	Tue 11/6/12	Tue 11/6/12	
Concept Model	2 days	Tue 11/6/12	Thu 11/8/12	8
Preliminary Design Review Class Presentation	0 days	Thu 11/8/12	Thu 11/8/12	8,9
Conceptual Design Report	27 days	Thu 11/8/12	Wed 12/5/12	3
Preliminary Design Review Cisco Presentation	0 days	Fri 12/7/12	Fri 12/7/12	
Design	**91 days**	**Tue 1/8/13**	**Tue 4/9/13**	**7**
Refine Proposal	0 days	Tue 1/8/13	Tue 1/8/13	12
Mechanical Analysis	51 days	Tue 1/8/13	Thu 2/28/13	
FEA Optimization	51 days	Tue 1/8/13	Thu 2/28/13	
Preliminary Technical Drawings	44 days	Tue 1/15/13	Thu 2/28/13	
Preliminary CAD Models	44 days	Tue 1/15/13	Thu 2/28/13	
Preliminary Testing	0 days	Tue 2/26/13	Tue 2/26/13	
Critical Design Review	**7 days**	**Fri 2/22/13**	**Fri 3/1/13**	**15,16,19**
Prepare Report	4 days	Mon 2/25/13	Fri 3/1/13	
Practice CDR Presentation	2 days	Tue 2/26/13	Thu 2/28/13	
CDR Preparation	1 day	Thu 2/28/13	Fri 3/1/13	22
Final CDR Presentation	0 days	Fri 3/1/13	Fri 3/1/13	23
Design Finalization	**39 days**	**Fri 3/1/13**	**Tue 4/9/13**	**24**
Incorporate Recommendations	31 days	Fri 3/1/13	Mon 4/1/13	24
Final CAD Models	8 days	Mon 4/1/13	Tue 4/9/13	26

Technical Drawings	8 days	Mon 4/1/13	Tue 4/9/13	26
Bill of Materials	8 days	Mon 4/1/13	Tue 4/9/13	24
Manufacturing and Testing Plan	**8 days**	**Mon 4/1/13**	**Tue 4/9/13**	**24**
Structural Testing	8 days	Mon 4/1/13	Tue 4/9/13	24
Safety Testing	8 days	Mon 4/1/13	Tue 4/9/13	24
Lab Test Reports	8 days	Mon 4/1/13	Tue 4/9/13	24
Manufacturing Plan	8 days	Mon 4/1/13	Tue 4/9/13	24
~~Presentation~~	~~0 days~~	~~Thu 3/7/13~~	~~Thu 3/7/13~~	~~31,32,33,34~~
Ethics Class Module	**30 days**	**Tue 2/12/13**	**Thu 3/14/13**	
Individual Ethics Memo	14 days	Tue 2/12/13	Tue 2/26/13	
Ethics Case Study Presentation	30 days	Tue 2/12/13	Thu 3/14/13	
Project Update Report	**43 days**	**Thu 3/7/13**	**Fri 4/19/13**	
End of Quarter Report to McFarland (Summary of Quarter's Design Review)	4 days	Thu 3/7/13	Mon 3/11/13	
Project Update Report to Cisco	10 days	Tue 4/9/13	Fri 4/19/13	13,40
Manufacturing (Preliminary)	**38 days**	**Tue 4/2/13**	**Fri 5/10/13**	**13**
Manufacturing (outsourced)	7 days	Tue 4/9/13	Tue 4/16/13	
Testing (outsourced)	22 days	Tue 4/16/13	Wed 5/8/13	43SF
Assembly (in-house)	0 days	Fri 5/10/13	Fri 5/10/13	43,44
Project Demonstration	0 days	Thu 5/23/13	Thu 5/23/13	42
Senior Project Expo	0 days	Thu 5/30/13	Thu 5/30/13	46
Final Report	**150 days**	**Tue 1/8/13**	**Fri 6/7/13**	**4**
Compile Report	149 days	Tue 1/8/13	Thu 6/6/13	
Report to McFarland	0 days	Fri 6/7/13	Fri 6/7/13	49
Report to Cisco	0 days	Fri 6/7/13	Fri 6/7/13	49
Library Notice/Form	0 days	Fri 6/7/13	Fri 6/7/13	49
Project End	**0 days**	**Fri 6/7/13**	**Fri 6/7/13**	**48,47**

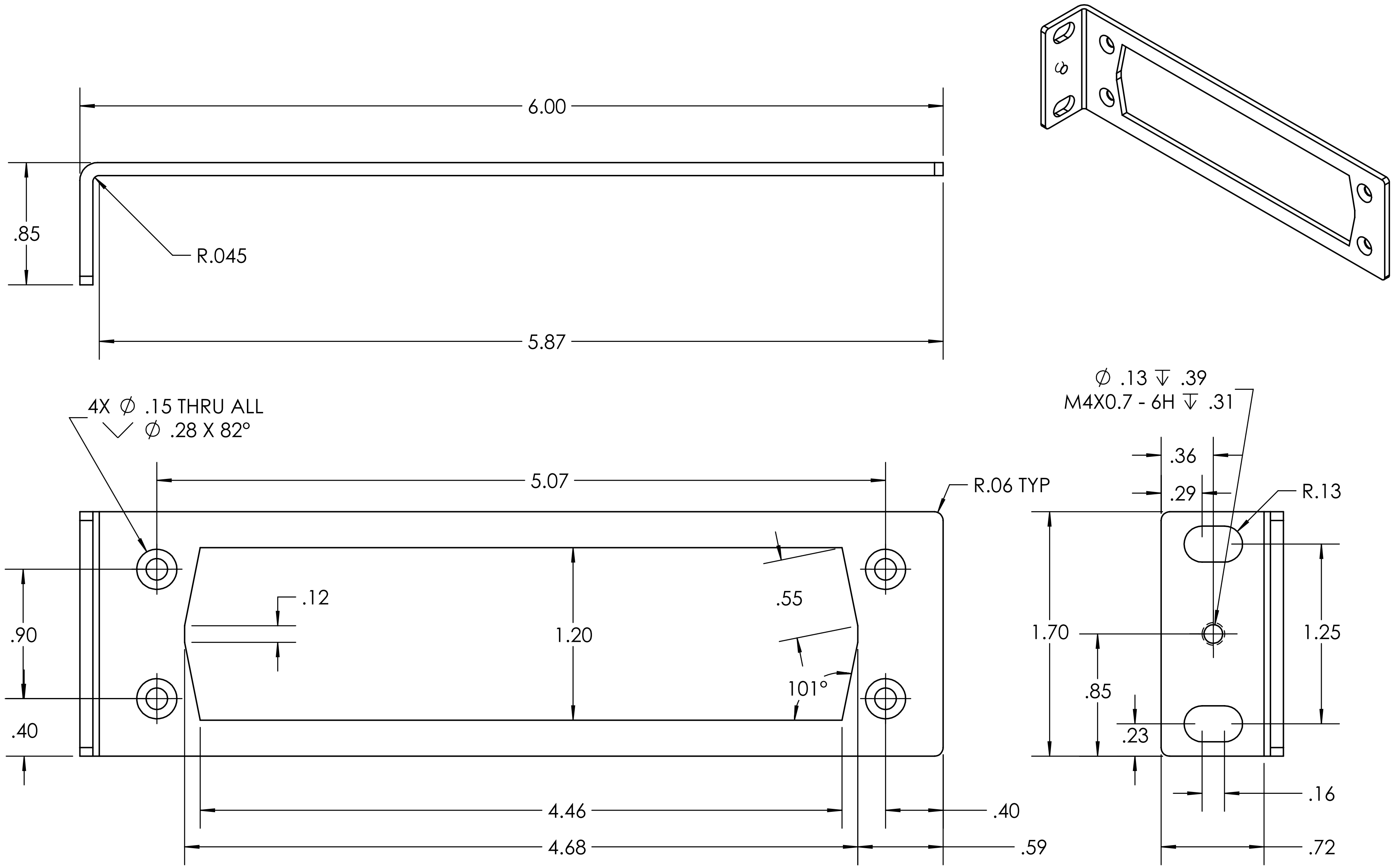
Appendix B: Final Drawings (attached)

Appendix C: List of vendors

Cisco Systems, San Jose, CA

Foxconn, San Jose, CA; China

McMaster-Carr, Los Angeles, CA

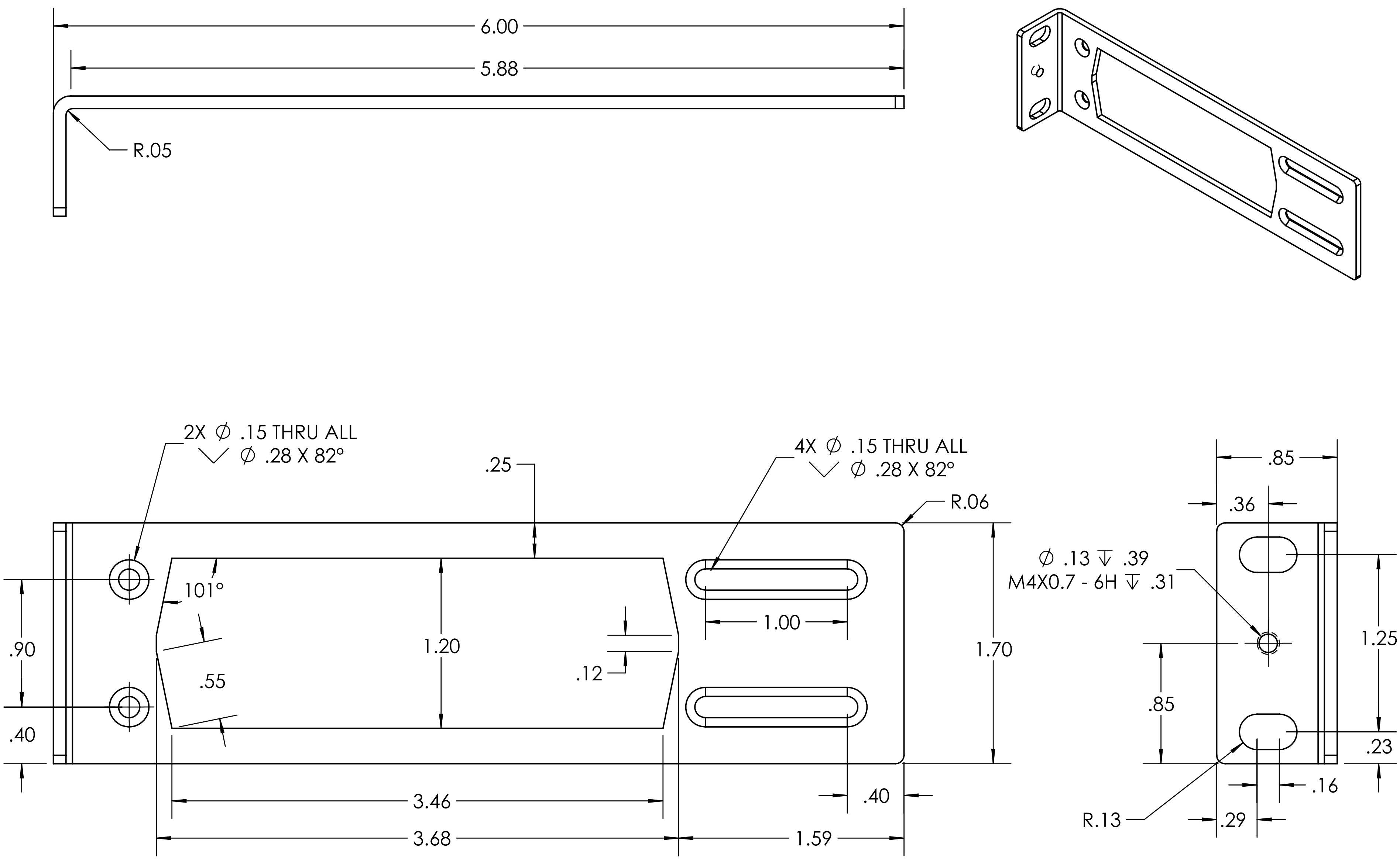


ME430 Spring 2013

Mechanical Engineering CAL POLY

SCALE: 1:1	PART:
UNITS: INCHES	MATERIAL: 0.09"/13GA CRS
TOLERANCE: ±0.01/±0.005/±1°	DATE: 5/3/2013
DWG #:	

5 4 3 2 1



ME430 Spring 2013

Mechanical Engineering CAL POLY

SCALE: 1:1	PART:
UNITS: INCHES	MATERIAL: 0.09"/13GA CRS
TOLERANCE: ±0.01/±0.005/±1°	DATE: 5/3/2013
DWG #:	

5 4 3 2 1