2017

Raytheon Cable Stability

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Raytheon

Team 22: Stable Cable
Sponsor: Raytheon

Team Members:
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Faculty Advisors :Professor Bahram Nassersharif

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Abstract

Stable Cable has been tasked by Raytheon to create a universal, modular, vibration resistant cable management system. This design report highlights the steps taken to research, conceptualize, evaluate, and construct a working version of our product. This cable management system must be seismic zone 4 compliant and provide a serviceable solution in a small footprint. To evaluate our product's ability to perform Stable Cable completed a cost analysis, as well running various computer simulations on CAD,Computer Aided Design, models. An prototype was also assembled to provide real world vision into the size of the product and was load and vibrationally tested. The goal of product is create an easily manufactured cable management solution that can be applied to Raytheon projects in the future.

The concept prototype was created after extensive market research in the fall semester and consisted of three main parts, two vertical and one horizontal piece. Both parts attached using the Electronic Industries Alliance, EIA, standard rack specifications. The vertical pieces are an L shape with repeating slotted elliptical holes. The horizontal piece is a U-shaped bracket with repeating semi-circles holes across its face. Three-dimensional CAD models were drawn using Solidworks and tested using simulation software in Abaqus. A cost analysis was also created to find how expensive the manufacturing costs would be and still be a competitive price.

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EIA-Electronic Industries Alliance
CAD-Computer aided design
URI-University of Rhode Island
PPM-Parts Per Million
NEBS- Network Equipment Building System

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1 Introduction

Raytheon was first established on July 7th 1922 in Cambridge, Massachusetts making it one of the first technology start-ups in the nation. Raytheon got its revolutionary breakthrough by innovating how a nation communicated. Their development of the S gas rectifier eliminated batteries and allowed radios to be powered through a socket in the wall. Raytheon further developed and began its growth into the company it is today when it began doing research on radar systems for the military around World War II. Today Raytheon has built a company that is a global technological leader that specializes in national defense, homeland security and other government markets. Their goal to provide trusted "state-of-the-art electronics, mission systems integration and other capabilities in the areas of sensing; effects; and command, control, communications and intelligence systems, as well as cybersecurity and a broad range of mission support services" is how Stable Cable was provided the opportunity innovate cable management.

A cable management system is essentially any system that creates an organized routing of cables such as power, Ethernet, etc. Raytheon has presented Stable Cable with the problem definition to "create a universal solution that is an improved method for cable management within electronic cabinet enclosure". Within Raytheon's scope of work cabinets are used inside of their test bays all the way up to dedicated rooms on ships and ground based shelters. Routing cable is always a challenge based on the allowable space, structurals loads and bending that may occur. Fiber optics are also making it increasingly hard due to their allowable bending radius despite their increase in performance..

More particular cable management systems are a necessity in data cabinets where up to forty-two shelves for hardware are available. Each shelf or 1U is 1.75 inches and can contain equipment such as data storage, power distribution, servers and switches. Equipment in 1U can contain up to forty wires, therefore it is necessary to have a vertical component to feed the wires to a desired height and a horizontal component to feed them into the equipment. Fastening of these components will be done using EIA 310 standard rack dimensions. Figure 1 below shows the dimensions of a standard EIA 310 rack. Cabinet dimensions vary but through research it is expected that 2-3 inches will be available to the left and right of the data rack and 6 inches from the rack to the closing door. Additionally these components will also have to be seismic zone 4 compliant, which prevents damage from loading and bending during the constant vibration force of an earthquake.

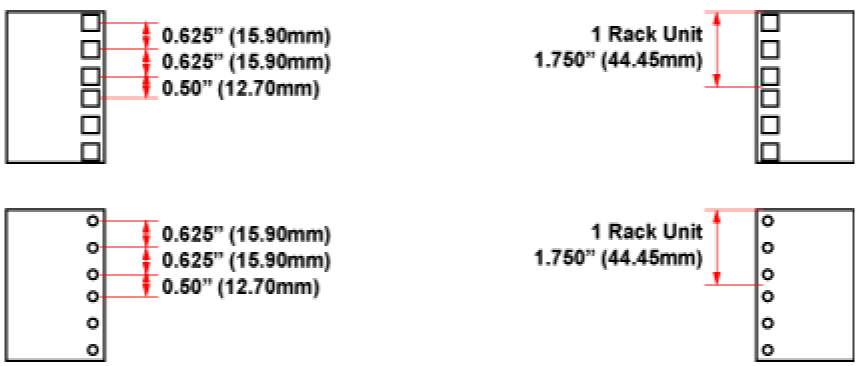


Figure 1: Standard EIA 310 Rack

Once the mass of cables have reached their designated cabinet proper distribution to their correct U is achieved through vertical organization or a vertical component. Generally this component is a plastic or metal piece mounted the length of a rail flange. This component protrudes outward towards the door and has forty-two holes, slots, or some form of geometry to promote organization along its face. Its design allows wire to be fed up or down until it has reached the desired U, then fed horizontally. This particular component must be able to handle any stress to loading based on the weight of the wires especially if vibrational force is experienced.

When wires have reached the proper U it is then the job of the horizontal component to direct the wire to it's proper equipment. Some of the concerns for horizontal components are service loop, bending radius, load concentration, connector allowance and open concept. Service loop is leaving an adequate amount of wire for better serviceability, such as in the case of rewiring. Bending radius is the maximum radius a wire can have and function properly. Power wires bending radius' are fairly small where fiber-optics require a larger bend radius. Load concentration should focused off the connector to reduce any chance of damage to the connection. Connector allowance is also a major issue because the holes on which the wires rest must fit the diameter of the cable but must also allow for the connector to fit through them. Slotted holes are ideal for no restrictions in diameter but lack rigid organization, where closed holes provide better rigid organization but are restricted to the diameter of the holes. The last major concern for horizontal components is its open concept. Open concepts provide more sufficient air flow, and the ability to select and reroute wire with ease.

While many products by competitive companies are made of plastic, based on our structural needs metal is the only choice. Any holes used for feeding wires would normally create a risk of fraying wires, but with use of metal this will be exasperated. That is why the use grommets through our design will help reduce any damage to the wire.

Fastening methods vary across the competitive market based on the dimensional needs. Some companies designs offer designs which simply use face plates to create a restricted space for the wire. This is typically more expensive and creates a lack of airflow and large footprint. Whereas fastening methods such as reusable/ single use zip ties, or velcro straps to fasten the wire. This method is typically cheaper, provides better airflow, but can increase installation time.

With the help of CAD software Solidworks and simulation software Abaqus Stable Cable will be able to prove our concepts ability to perform. All components will be drawn using the 3D CAD Solidworks to their exact dimensions. This will provide 2D dimensions that can be used to create prototypes and final designs in the future. Also these 3D models can be imported into Abaqus simulation software to check for static loads due to cables as well as forces created by vibrations. These simulations will provide tangible data as to why Stable Cables product has the ability to perform. CAD drawings can be found in the appendix and simulations can be found in the Engineering Analysis of this report.

Before the end of the fall semester a prototype was constructed to the exact dimension but not of the desired material. This prototype was strictly created to bring real world vision into the product. Seeing how dimensions translate to the real world and how the prototype satisfies mock routing is the final denominator going forward for a successful product.

Following the specifications of our product and with the goal set in our problem definition we set out to create a solid reliable solution for Raytheon. Our product will contain two vertical pieces and up to 42 horizontal pieces that's structural integrity can handles all stresses brought about. These components will take up a small footprint,promote serviceability and airflow as well as sufficient wire distribution inside of data cabinets. Standard EIA 310 Rack dimensions will make this product universal and our different depth horizontals pieces with create a modular solution for Raytheon. Finally it's simplicity will create a more manufacturable product in terms of cost and time.

Project Planning

Project planning with the computer software microsoft project was an excellent resource to effectively approach the solution to our problem definition. Stable Cable's project plan is depicted in appendix. Utilizing this software Stable Cable was able keep a detailed record of team, sponsor and design review meetings, as well as presentations and other important assignment dates. It is also through microsoft project that Stable Cable was able to see the progress made in research, CAD Drawings and simulation testing. This organizational tool is an instrumental process in meeting deadlines for a successful product. Ultimately the project plan broke down into several periods research, concept generation, preliminary designs.

Communication was a mutual goal for Stable Cable, and the team concluded that if communication by phone, email and face to face was frequent a solid product could be achieved. Stable Cable aimed to have at least two meetings a week with frequent contact to provide organization for individual work. Time in team meetings was spent researching, brainstorming, and submitting weekly progress reports. Communication with the team's sponsor Raytheon resulted in three face to face meetings throughout the fall semester. It was during these meetings that the design specifications were determined and reliable constructive criticism was given.

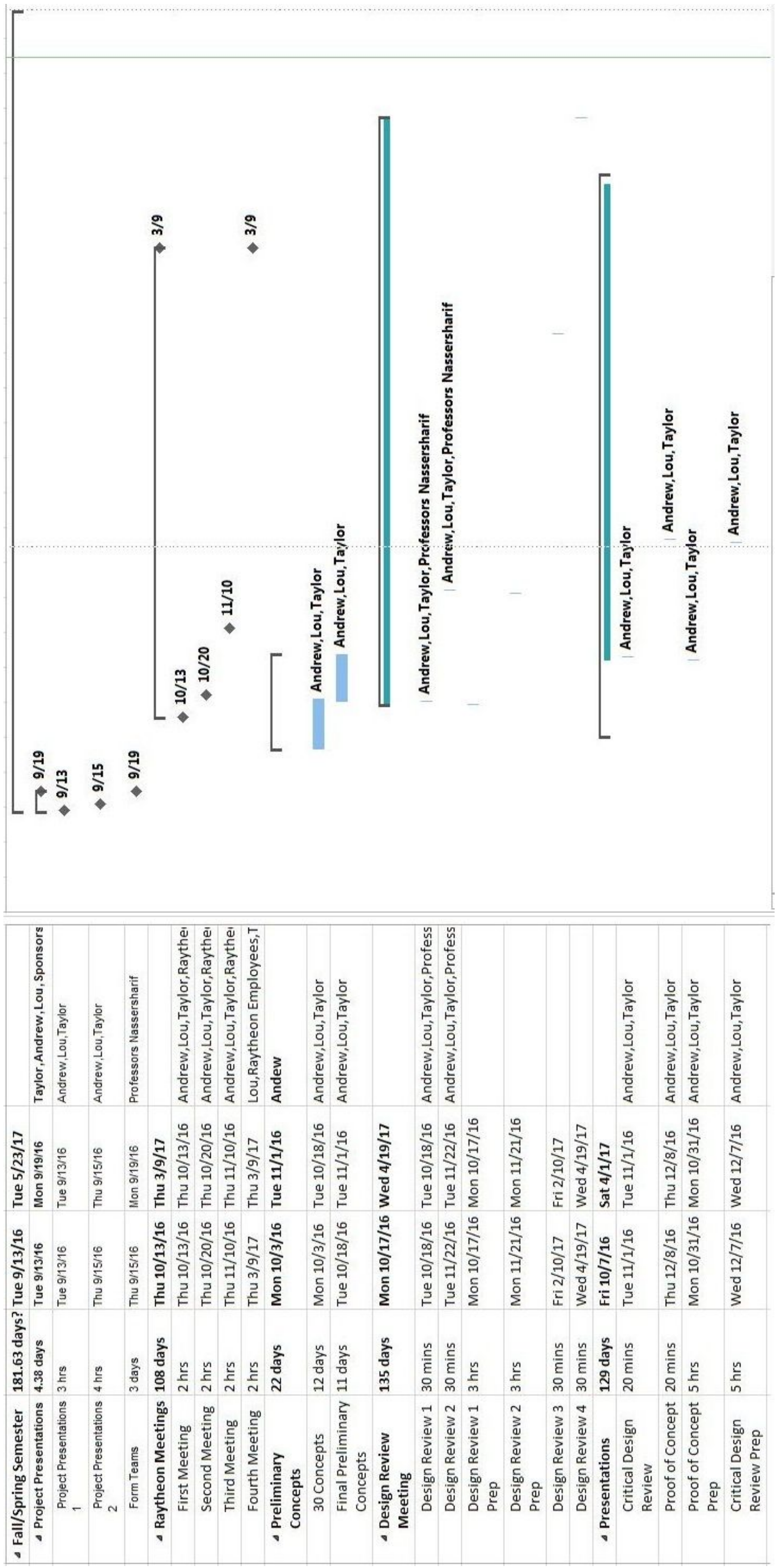
The layout of microsoft project is also an effective way of showing progress in a team's goal. By setting start and finish dates for any product research, development,or analysis visual evidence of the team's progress. Recording the team's binder and sakai upkeep was also straightforward as dates clearly displayed the last date updated. Initially finish dates are set a few days before their required due date to insure completion, however these dates were adjusted as many of these were demanding timeframes.

In the research phase of the team's semester the entire focus was widespread research of the topic. In this period general knowledge of all the components that are used in a data center, as well as regulations and code were documented. Once a solid understanding of the topic was attained market research was conducted. Market research gave Stable Cable a better understanding of how typically solutions are approached in cable management and why. Finally patent searches were conducted by all team members in order to avoid patent infringement.Patent Searches conducted by Stable Cable can be found in the patent search portion of this report.

In the second period of the fall semester the main focus was concept generation. From the research compiled by the team, concepts solutions were brainstormed individually, as a team and with our sponsor Raytheon. Individually members of Stable Cable created thirty concepts each. Originally concepts were hand sketched, but were replaced with CAD models once many concepts were eliminated. Proactive discussion and CAD models were essential in exposing errors in possible concepts as well as highlighting positives.

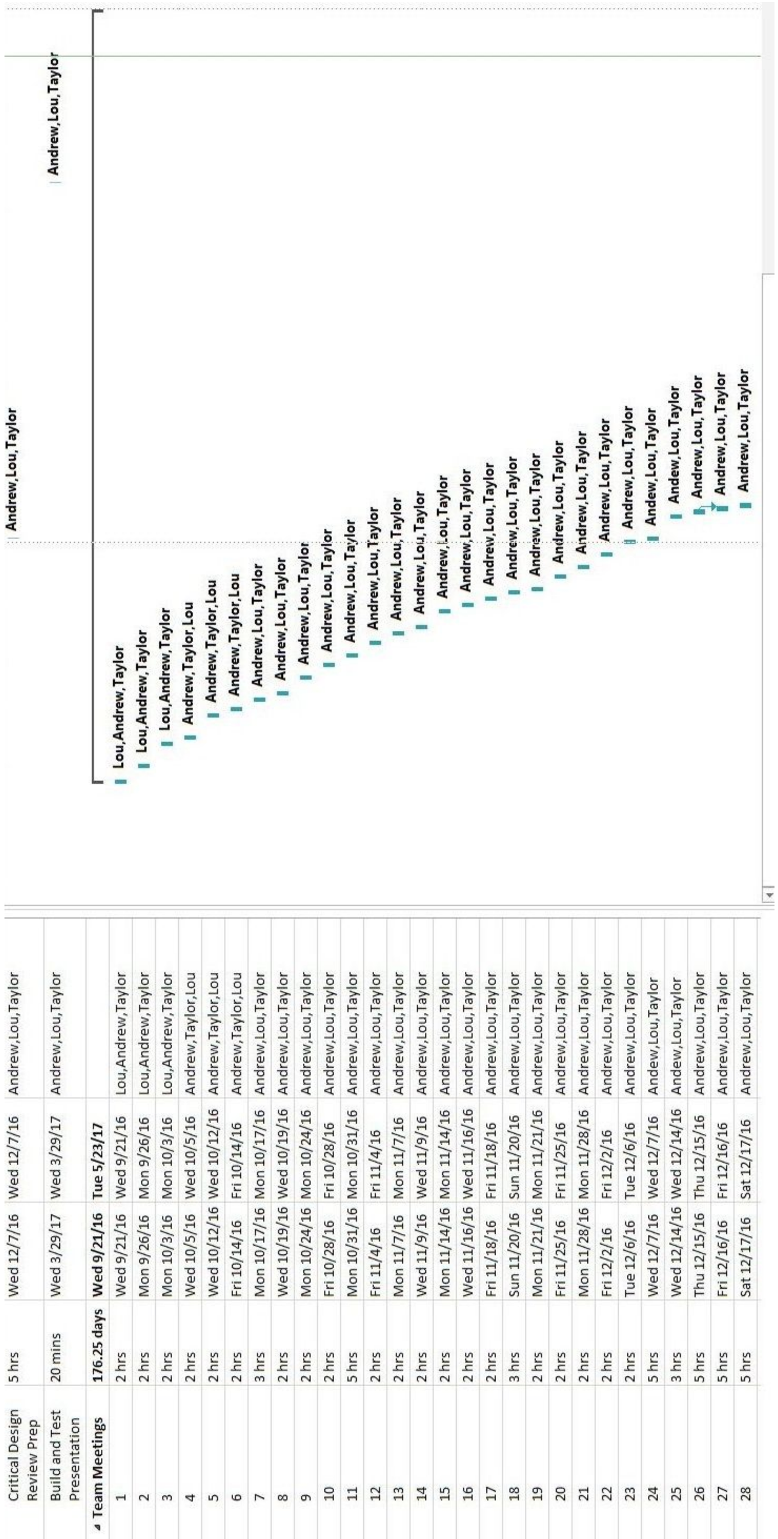
In the final period of the fall semester the goal of the team was complete a proven preliminary design. Through discussion and the QFD, Stable Cable came to a conclusion on how many components and what features should be incorporated. Stable Cable's final preliminary concept was then put under static loading and vibrational force simulation testing. Dimensions were revised from these results to improve the concept's durability and manufacturability. Once this preliminary design had passed structurally and was calculated to be cost effective, statistical evidence was documented. Refer to the the table of contents to find the engineering analysis and financial analysis of this report . The final step of this semester was to create a scale prototype. Assembled out cheaper materials, a model was then built to exact dimensions in order to gain tangible evidence that final preliminary design concept dimensions were realistic. After several dimension refinements a scale size prototype solidified feasibility.

In the second semester of our capstone project, Stable Cable began purchasing materials and creating a fully working prototype. Stable Cable utilized a Computer Numerical Controlled (CNC) milling machine to cut our CAD models out of Aluminum 6061. CAD models and simulations continued to be performed throughout the semester with up to date dimensions for our models due to design changes. Once models had passed simulation testing and were physically created through CNC milling and bending Stable Cable tested these products for failure during Static and Vibrational loading. On April 28th 2017 Stable Cable participated in a Design Showcase, allowing Raytheon and outside companies to see our final design. From there a Final Design Report was written. Finalized CAD drawings and procedure for manufacturing were included as well a dimensions for each component and a bill of materials. Frequently updating and setting demanding target dates in our project plan with ultimately position Stable Cable for a successful product.



Fall/Spring Semester	181.63 days?	Tue 9/13/16	Tue 5/23/17	
Project Presentations	4.38 days	Tue 9/13/16	Mon 9/19/16	Taylor,Andrew,Lou,Sponsors
Project Presentations 1	3 hrs	Tue 9/13/16	Tue 9/13/16	Andrew,Lou,Taylor
Project Presentations 2	4 hrs	Thu 9/15/16	Thu 9/15/16	Andrew,Lou,Taylor
Form Teams	3 days	Thu 9/15/16	Mon 9/19/16	Professors Nassersharif
Raytheon Meetings	108 days	Thu 10/13/16	Thu 3/9/17	
First Meeting	2 hrs	Thu 10/13/16	Thu 10/13/16	Andrew,Lou,Taylor,Raythe
Second Meeting	2 hrs	Thu 10/20/16	Thu 10/20/16	Andrew,Lou,Taylor,Raythe
Third Meeting	2 hrs	Thu 11/10/16	Thu 11/10/16	Andrew,Lou,Taylor,Raythe
Fourth Meeting	2 hrs	Thu 3/9/17	Thu 3/9/17	Lou,Raytheon Employees,T
Preliminary Concepts	22 days	Mon 10/3/16	Tue 11/1/16	Andew
30 Concepts	12 days	Mon 10/3/16	Tue 10/18/16	Andrew,Lou,Taylor
Final Preliminary Concepts	11 days	Tue 10/18/16	Tue 11/1/16	Andrew,Lou,Taylor
Design Review Meeting	135 days	Mon 10/17/16	Wed 4/19/17	
Design Review 1	30 mins	Tue 10/18/16	Tue 10/18/16	Andrew,Lou,Taylor,Profess
Design Review 2	30 mins	Tue 11/22/16	Tue 11/22/16	Andrew,Lou,Taylor,Profess
Design Review 1 Prep	3 hrs	Mon 10/17/16	Mon 10/17/16	
Design Review 2 Prep	3 hrs	Mon 11/21/16	Mon 11/21/16	
Design Review 3	30 mins	Fri 2/10/17	Fri 2/10/17	
Design Review 4	30 mins	Wed 4/19/17	Wed 4/19/17	
Presentations	129 days	Fri 10/7/16	Sat 4/1/17	
Critical Design Review	20 mins	Tue 11/1/16	Tue 11/1/16	Andrew,Lou,Taylor
Proof of Concept	20 mins	Thu 12/8/16	Thu 12/8/16	Andrew,Lou,Taylor
Proof of Concept Prep	5 hrs	Mon 10/31/16	Mon 10/31/16	Andrew,Lou,Taylor
Critical Design Review Prep	5 hrs	Wed 12/7/16	Wed 12/7/16	Andrew,Lou,Taylor

Chart 1 : Project Plan pt.1



Critical Design Review Prep	5 hrs	Wed 12/7/16	Wed 12/7/16	Andrew,Lou,Taylor
Build and Test Presentation	20 mins	Wed 3/29/17	Wed 3/29/17	Andrew,Lou,Taylor
Team Meetings	**176.25 days**	**Wed 9/21/16**	**Tue 5/23/17**	
1	2 hrs	Wed 9/21/16	Wed 9/21/16	Lou,Andrew,Taylor
2	2 hrs	Mon 9/26/16	Mon 9/26/16	Lou,Andrew,Taylor
3	2 hrs	Mon 10/3/16	Mon 10/3/16	Lou,Andrew,Taylor
4	2 hrs	Wed 10/5/16	Wed 10/5/16	Andrew,Taylor,Lou
5	2 hrs	Wed 10/12/16	Wed 10/12/16	Andrew,Taylor,Lou
6	2 hrs	Fri 10/14/16	Fri 10/14/16	Andrew,Taylor,Lou
7	3 hrs	Mon 10/17/16	Mon 10/17/16	Andrew,Lou,Taylor
8	2 hrs	Wed 10/19/16	Wed 10/19/16	Andrew,Lou,Taylor
9	2 hrs	Mon 10/24/16	Mon 10/24/16	Andrew,Lou,Taylor
10	2 hrs	Fri 10/28/16	Fri 10/28/16	Andrew,Lou,Taylor
11	5 hrs	Mon 10/31/16	Mon 10/31/16	Andrew,Lou,Taylor
12	2 hrs	Fri 11/4/16	Fri 11/4/16	Andrew,Lou,Taylor
13	2 hrs	Mon 11/7/16	Mon 11/7/16	Andrew,Lou,Taylor
14	2 hrs	Wed 11/9/16	Wed 11/9/16	Andrew,Lou,Taylor
15	2 hrs	Mon 11/14/16	Mon 11/14/16	Andrew,Lou,Taylor
16	2 hrs	Wed 11/16/16	Wed 11/16/16	Andrew,Lou,Taylor
17	2 hrs	Fri 11/18/16	Fri 11/18/16	Andrew,Lou,Taylor
18	3 hrs	Sun 11/20/16	Sun 11/20/16	Andrew,Lou,Taylor
19	2 hrs	Mon 11/21/16	Mon 11/21/16	Andrew,Lou,Taylor
20	2 hrs	Fri 11/25/16	Fri 11/25/16	Andrew,Lou,Taylor
21	2 hrs	Mon 11/28/16	Mon 11/28/16	Andrew,Lou,Taylor
22	2 hrs	Fri 12/2/16	Fri 12/2/16	Andrew,Lou,Taylor
23	2 hrs	Tue 12/6/16	Tue 12/6/16	Andrew,Lou,Taylor
24	5 hrs	Wed 12/7/16	Wed 12/7/16	Andew,Lou,Taylor
25	3 hrs	Wed 12/14/16	Wed 12/14/16	Andew,Lou,Taylor
26	5 hrs	Thu 12/15/16	Thu 12/15/16	Andrew,Lou,Taylor
27	5 hrs	Fri 12/16/16	Fri 12/16/16	Andrew,Lou,Taylor
28	5 hrs	Sat 12/17/16	Sat 12/17/16	Andrew,Lou,Taylor

Chart 1 : Project Plan pt.2

28	5 hrs	Sat 12/17/16	Sat 12/17/16	Andrew,Lou,Taylor
29	8 hrs	Sun 12/18/16	Sun 12/18/16	Andrew,Lou,Taylor
30	5 hrs	Mon 12/19/16	Mon 12/19/16	Andrew,Lou,Taylor
31	2 hrs	Mon 1/30/17	Mon 1/30/17	Andrew,Lou,Taylor
32	0.25 days	Wed 2/1/17	Wed 2/1/17	Andrew,Lou,Taylor
33	0.25 days	Fri 2/3/17	Fri 2/3/17	Andrew,Lou,Taylor
34	0.25 days	Mon 2/6/17	Mon 2/6/17	Andrew,Lou,Taylor
35	0.25 days	Thu 2/9/17	Thu 2/9/17	Andrew,Lou,Taylor
36	0.25 days	Tue 2/14/17	Tue 2/14/17	Andrew,Lou,Taylor
37	0.25 days	Thu 2/16/17	Thu 2/16/17	Andrew,Lou,Taylor
38	0.25 days	Mon 2/20/17	Mon 2/20/17	Andrew,Lou,Taylor
39	0.25 days	Wed 2/22/17	Wed 2/22/17	Andrew,Lou,Taylor
40	0.25 days	Tue 2/28/17	Tue 2/28/17	Andrew,Lou,Taylor
41	0.25 days	Fri 3/10/17	Fri 3/10/17	Andrew,Lou,Taylor
42	0.25 days	Mon 3/13/17	Mon 3/13/17	Andrew,Lou,Taylor
43	0.25 days	Wed 3/15/17	Wed 3/15/17	Andrew,Lou,Taylor
44	0.25 days	Mon 3/20/17	Mon 3/20/17	Andrew,Lou,Taylor
45	0.25 days	Wed 3/22/17	Wed 3/22/17	Andrew,Lou,Taylor
46	0.25 days	Mon 3/27/17	Mon 3/27/17	Andrew,Lou,Taylor
47	0.25 days	Thu 3/30/17	Thu 3/30/17	Andrew,Lou,Taylor
48	0.25 days	Mon 4/3/17	Mon 4/3/17	Andrew,Lou,Taylor
49	0.25 days	Fri 4/7/17	Fri 4/7/17	Andrew,Lou,Taylor
50	0.25 days	Tue 4/11/17	Tue 4/11/17	Andrew,Lou,Taylor
51	0.25 days	Fri 4/14/17	Fri 4/14/17	Andrew,Lou,Taylor
52	0.25 days	Mon 4/17/17	Mon 4/17/17	Andrew,Lou,Taylor
53	0.25 days	Thu 4/20/17	Thu 4/20/17	Andrew,Lou,Taylor
54	0.25 days	Tue 5/23/17	Tue 5/23/17	Andrew,Lou,Taylor
55	0.25 days	Thu 4/27/17	Thu 4/27/17	Andrew,Lou,Taylor
Research	**55 days?**	**Mon 10/3/16**	**Fri 12/16/16**	**Andrew,Lou,Taylor**
General Data Center knowledge	55 days?	Mon 10/3/16	Fri 12/16/16	Andrew,Lou,Taylor
Telecordia Code	13 days?	Thu 10/13/16	Mon 10/31/16	Andrew,Lou,Taylor

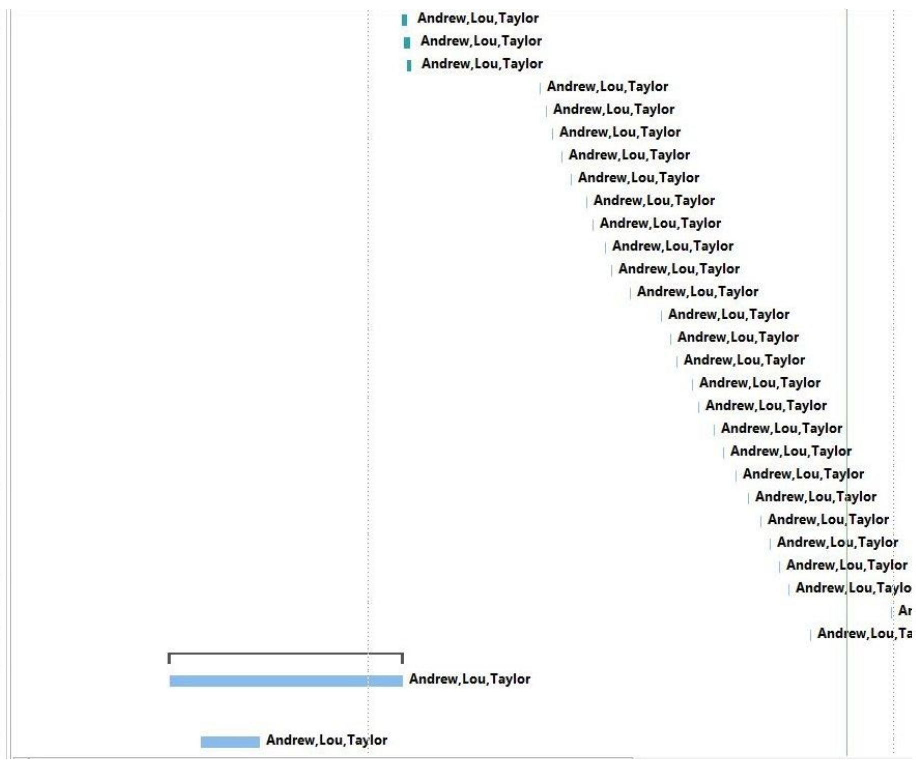


Chart 1 : Project Plan pt.3

Telecordia Code	13 days?	Thu 10/13/16	Mon 10/31/16	Andrew,Lou,Taylor
EIA Standards	21 days?	Mon 10/3/16	Mon 10/31/16	Andrew,Lou,Taylor
Design Specs	26 days?	Fri 10/7/16	Fri 11/11/16	Andrew,Lou,Taylor
Manufacturing Processes to Produce Parts	**13 days?**	**Wed 11/30/16**	**Fri 12/16/16**	
Cost	13 days?	Wed 11/30/16	Fri 12/16/16	Andrew
Machining	13 days?	Wed 11/30/16	Fri 12/16/16	Andrew
Materials	13 days?	Wed 11/30/16	Fri 12/16/16	Andrew
Advantages/Disadva	**54 days?**	**Tue 10/4/16**	**Fri 12/16/16**	
Servicability	43 days?	Wed 10/19/16	Fri 12/16/16	Lou,Andrew,Taylor
Air Flow	43 days?	Wed 10/19/16	Fri 12/16/16	Lou,Andrew,Taylor
Modular	43 days?	Wed 10/19/16	Fri 12/16/16	Lou,Andrew,Taylor
Durability	43 days?	Wed 10/19/16	Fri 12/16/16	Lou,Andrew,Taylor
Patents	54 days?	Tue 10/4/16	Fri 12/16/16	Lou,Andrew,Taylor
Time of Installation	43 days?	Wed 10/19/16	Fri 12/16/16	Lou,Andrew,Taylor
Amoun of Components	1 day?	Fri 12/16/16	Fri 12/16/16	Lou,Andrew,Taylor
CAD Drawings	**139 days?**	**Thu 10/20/16**	**Fri 4/28/17**	
Concepts	22 days?	Thu 10/20/16	Fri 11/18/16	Taylor
Final Prelim Vertical	21 days?	Fri 11/18/16	Fri 12/16/16	Taylor
Final Prelim Horizontal	21 days?	Fri 11/18/16	Fri 12/16/16	Taylor
Final Horizontal	54 days?	Wed 2/1/17	Mon 4/17/17	Taylor
Final Vertical	54 days?	Wed 2/1/17	Mon 4/17/17	Taylor
3 piece vertical	4 days?	Wed 4/12/17	Mon 4/17/17	Taylor
3 piece Horizontal	4 days?	Wed 4/12/17	Mon 4/17/17	Taylor
Redesign Horizontal	10 days?	Mon 4/17/17	Fri 4/28/17	Taylor
Redesign Vertical	10 days?	Mon 4/17/17	Fri 4/28/17	Taylor
Engineering Analysis	**139 days?**	**Thu 10/20/16**	**Fri 4/28/17**	

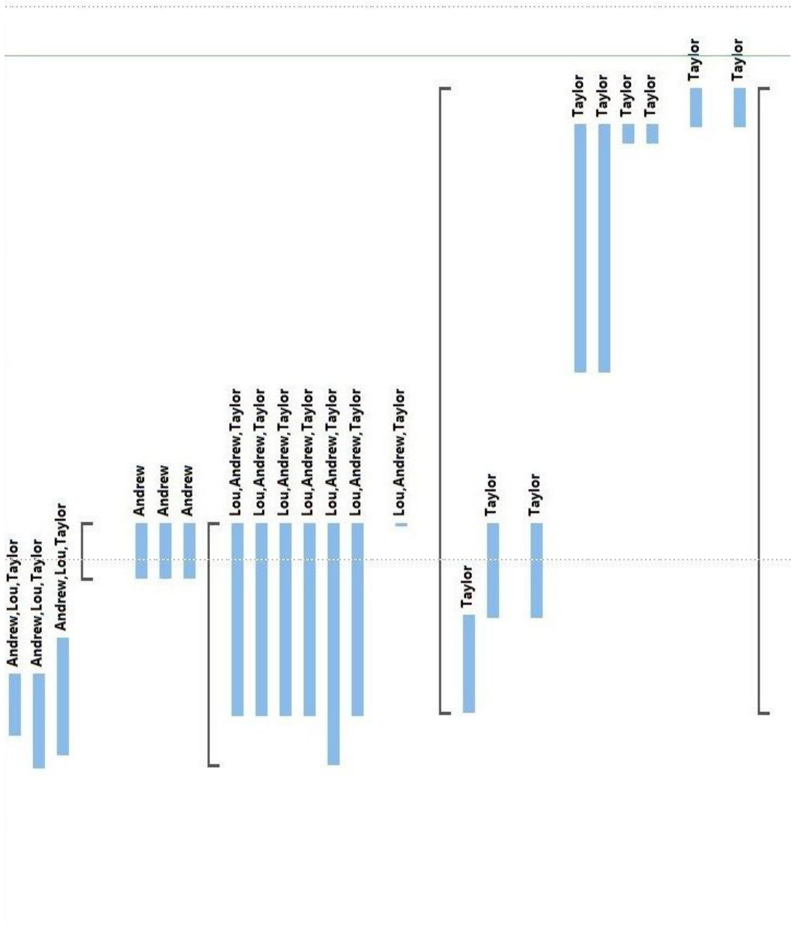
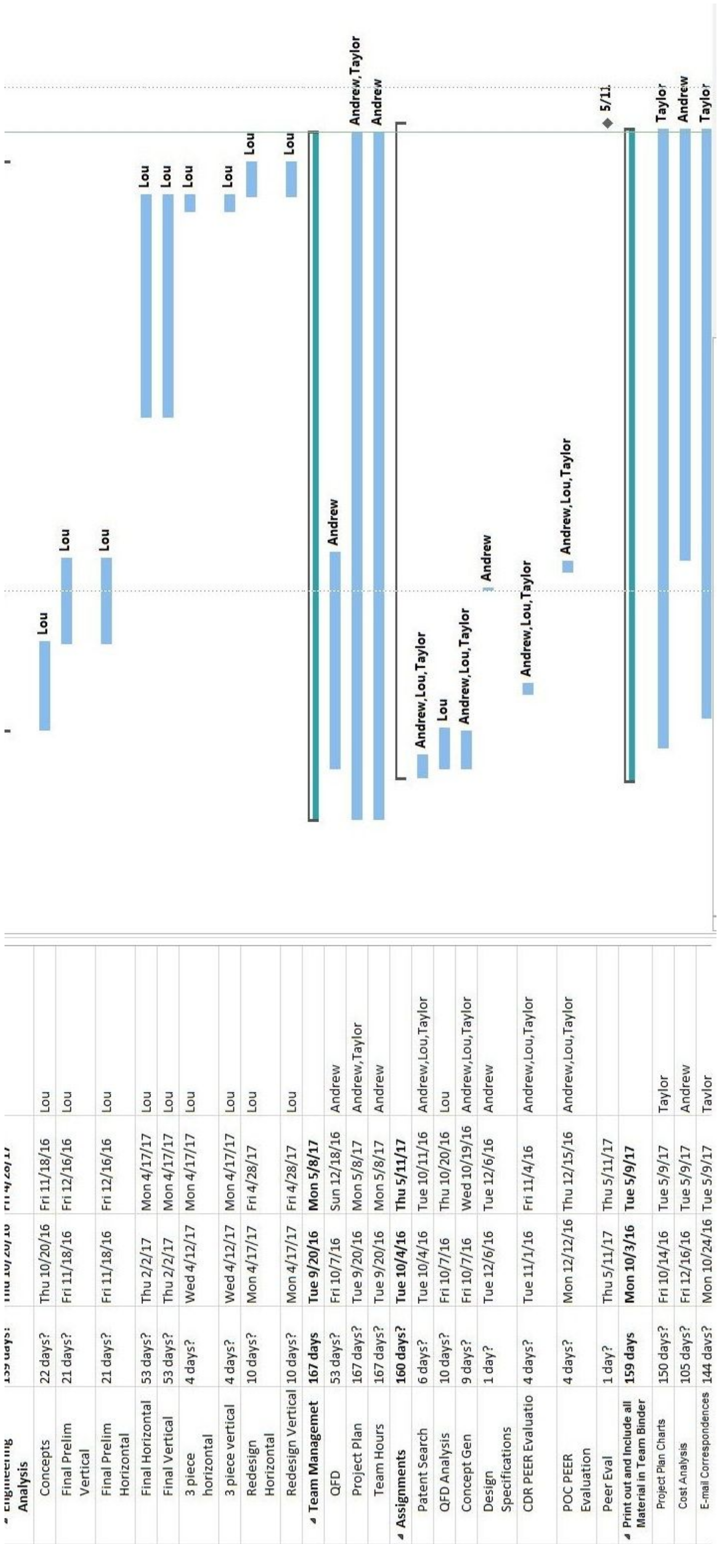
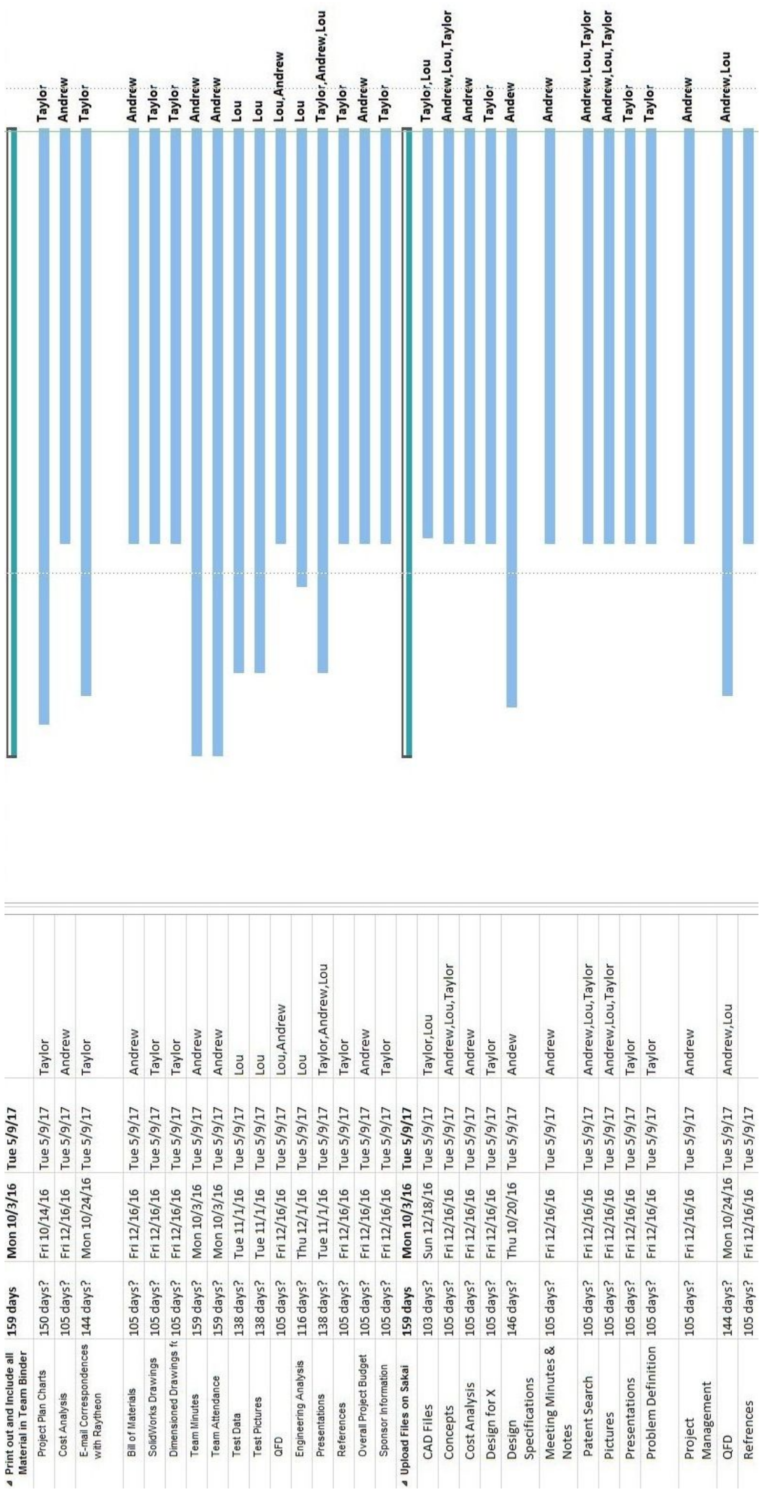


Chart 1 : Project Plan pt.4



Engineering Analysis	159 days?	Thu 10/20/16	Fri 4/28/17	
Concepts	22 days?	Thu 10/20/16	Fri 11/18/16	Lou
Final Prelim Vertical	21 days?	Fri 11/18/16	Fri 12/16/16	Lou
Final Prelim Horizontal	21 days?	Fri 11/18/16	Fri 12/16/16	Lou
Final Horizontal	53 days?	Thu 2/2/17	Mon 4/17/17	Lou
Final Vertical	53 days?	Thu 2/2/17	Mon 4/17/17	Lou
3 piece horizontal	4 days?	Wed 4/12/17	Mon 4/17/17	Lou
3 piece vertical	4 days?	Wed 4/12/17	Mon 4/17/17	Lou
Redesign Horizontal	10 days?	Mon 4/17/17	Fri 4/28/17	Lou
Redesign Vertical	10 days?	Mon 4/17/17	Fri 4/28/17	Lou
Team Managemet	**167 days**	**Tue 9/20/16**	**Mon 5/8/17**	
QFD	53 days?	Fri 10/7/16	Sun 12/18/16	Andrew
Project Plan	167 days?	Tue 9/20/16	Mon 5/8/17	Andrew,Taylor
Team Hours	167 days?	Tue 9/20/16	Mon 5/8/17	Andrew
Assignments	**160 days?**	**Tue 10/4/16**	**Thu 5/11/17**	
Patent Search	6 days?	Tue 10/4/16	Tue 10/11/16	Andrew,Lou,Taylor
QFD Analysis	10 days?	Fri 10/7/16	Thu 10/20/16	Lou
Concept Gen	9 days?	Fri 10/7/16	Wed 10/19/16	Andrew,Lou,Taylor
Design Specifications	1 day?	Tue 12/6/16	Tue 12/6/16	Andrew
CDR PEER Evaluatio	4 days?	Tue 11/1/16	Fri 11/4/16	Andrew,Lou,Taylor
POC PEER Evaluation	4 days?	Mon 12/12/16	Thu 12/15/16	Andrew,Lou,Taylor
Peer Eval	1 day?	Thu 5/11/17	Thu 5/11/17	
Print out and Include all Material in Team Binder	**159 days**	**Mon 10/3/16**	**Tue 5/9/17**	
Project Plan Charts	150 days?	Fri 10/14/16	Tue 5/9/17	Taylor
Cost Analysis	105 days?	Fri 12/16/16	Tue 5/9/17	Andrew
E-mail Correspondences	144 days?	Mon 10/24/16	Tue 5/9/17	Taylor

Chart 1 : Project Plan pt.5



Print out and Include all Material in Team Binder	**159 days**	**Mon 10/3/16**	**Tue 5/9/17**	
Project Plan Charts	150 days?	Fri 10/14/16	Tue 5/9/17	Taylor
Cost Analysis	105 days?	Fri 12/16/16	Tue 5/9/17	Andrew
E-mail Correspondences with Raytheon	144 days?	Mon 10/24/16	Tue 5/9/17	Taylor
Bill of Materials	105 days?	Fri 12/16/16	Tue 5/9/17	Andrew
SolidWorks Drawings	105 days?	Fri 12/16/16	Tue 5/9/17	Taylor
Dimensioned Drawings fc	105 days?	Fri 12/16/16	Tue 5/9/17	Taylor
Team Minutes	159 days?	Mon 10/3/16	Tue 5/9/17	Andrew
Team Attendance	159 days?	Mon 10/3/16	Tue 5/9/17	Andrew
Test Data	138 days?	Tue 11/1/16	Tue 5/9/17	Lou
Test Pictures	138 days?	Tue 11/1/16	Tue 5/9/17	Lou
QFD	105 days?	Fri 12/16/16	Tue 5/9/17	Lou,Andrew
Engineering Analysis	116 days?	Thu 12/1/16	Tue 5/9/17	Lou
Presentations	138 days?	Tue 11/1/16	Tue 5/9/17	Taylor,Andrew,Lou
References	105 days?	Fri 12/16/16	Tue 5/9/17	Taylor
Overall Project Budget	105 days?	Fri 12/16/16	Tue 5/9/17	Andrew
Sponsor Information	105 days?	Fri 12/16/16	Tue 5/9/17	Taylor
Upload Files on Sakai	**159 days**	**Mon 10/3/16**	**Tue 5/9/17**	
CAD Files	103 days?	Sun 12/18/16	Tue 5/9/17	Taylor,Lou
Concepts	105 days?	Fri 12/16/16	Tue 5/9/17	Andrew,Lou,Taylor
Cost Analysis	105 days?	Fri 12/16/16	Tue 5/9/17	Andrew
Design for X	105 days?	Fri 12/16/16	Tue 5/9/17	Taylor
Design Specifications	146 days?	Thu 10/20/16	Tue 5/9/17	Andew
Meeting Minutes & Notes	105 days?	Fri 12/16/16	Tue 5/9/17	Andrew
Patent Search	105 days?	Fri 12/16/16	Tue 5/9/17	Andrew,Lou,Taylor
Pictures	105 days?	Fri 12/16/16	Tue 5/9/17	Andrew,Lou,Taylor
Presentations	105 days?	Fri 12/16/16	Tue 5/9/17	Taylor
Problem Definition	105 days?	Fri 12/16/16	Tue 5/9/17	Taylor
Project Management	105 days?	Fri 12/16/16	Tue 5/9/17	Andrew
QFD	144 days?	Mon 10/24/16	Tue 5/9/17	Andrew,Lou
Refrences	105 days?	Fri 12/16/16	Tue 5/9/17	

Figure : Project Plan pt.6

Financial Analysis

Projected:

The budget for this project was provided by Raytheon at a total of 3000$. This total was to be split between two teams, so for the cable management prototype a total of 1500$ was allotted.

The time spent working on this project must be factored into the overall cost analysis. The time spent by the team was broken into 4 major sections. These sections include meetings, research and design, assignments including presentations and prototype work. For the purposes of this project it was determined that the members of Stable Cable would be earning 15$/hr. This value comes from the typical pay of an engineering intern currently in school. It was also decided that hours spent with professionals, including Raytheon employees and professors at the university would be earning on average of 35$/hr.

During the first semester the team met twice a week before or after class hours for an average of an hour and a half per meeting. During these meetings work was delegated, ideas and concepts were discussed and assignments were completed. The team also had 3 meetings with the sponsor Raytheon where the problem statement was defined, ideas and concepts were examined and feedback was given and recorded. These meetings lasted between 1.5 to 2 hours. Finally, there were two meetings with Professor Nassersharif in which the team notebooks and binder were assessed. Each meeting lasted between 20 and 30 minutes. Altogether these meetings took a total of 35 hours. Each member of the team was responsible for researching and designing for 30 concepts and checking the concepts against current patents. Once the rough version of the final design was decided on, all 3 members were responsible for research and redesign of the concept. In total each member spent an average of 4-5 hours per week on research and design for a total of 120 hours. Throughout the project a number of assignments had to be completed at certain deadlines and this took on average 3 hours of the team's time per week. The presentations took the team on average 5 hours each to complete. This comes to a total of 40 hours. This comes to a total of 20 hours spent on assignments. The final segment of time was spent on creating the physical proof of concept and the associated presentations. The total time spent on the physical concept, between purchasing materials and fabrication, was an estimated 15 hours. The total man hours dedicated to the project was 215 hours.

For the second semester, the team had a slightly different work schedule. The first difference was that work related to our project was now done during class hours. This meant the team would work on design, test and redesign for 6 hours a week along with once a week out of class for 2 hours. This is a total of 8 hours a week. On top of this the team met with Raytheon once a month for one hour each time, and twice with Professor Nassersharif for a total of one hour. So for 12 weeks the team spent an estimated 100 hours working on this design project. Finally the team spent an estimated 12 hours preparing and giving presentations along with participation in the Design Showcase. This brings the total time spent on the project to 321 hours.

Below is a breakdown of the man hours and their dollar equivalent.

Table 1: Man hours and labor costs

Human Resources	Team members (15 $/Hr)	Professionals (35 $/Hr)	Total ($)
Meetings	34	9	825
Research and Design	115	5	1900
Assignments + Prese	52	0	780
Prototype	106	0	1590
		Total Labor Projected ($)	$5,095

When considering the final design that the team chose to go forward with producing, a few cost related decisions had to be made. Primarily in terms of manufacture and what the best option for fabricating the part was. The team opted to use a CNC machine for the physical prototype. To estimate the cost of this process on a large scale a cost estimating tool from custompart.net was used. For this updated cost estimation, the team used the redesigned version of the product. This reduced the horizontal portion to one long part instead of 3 separate pieces.

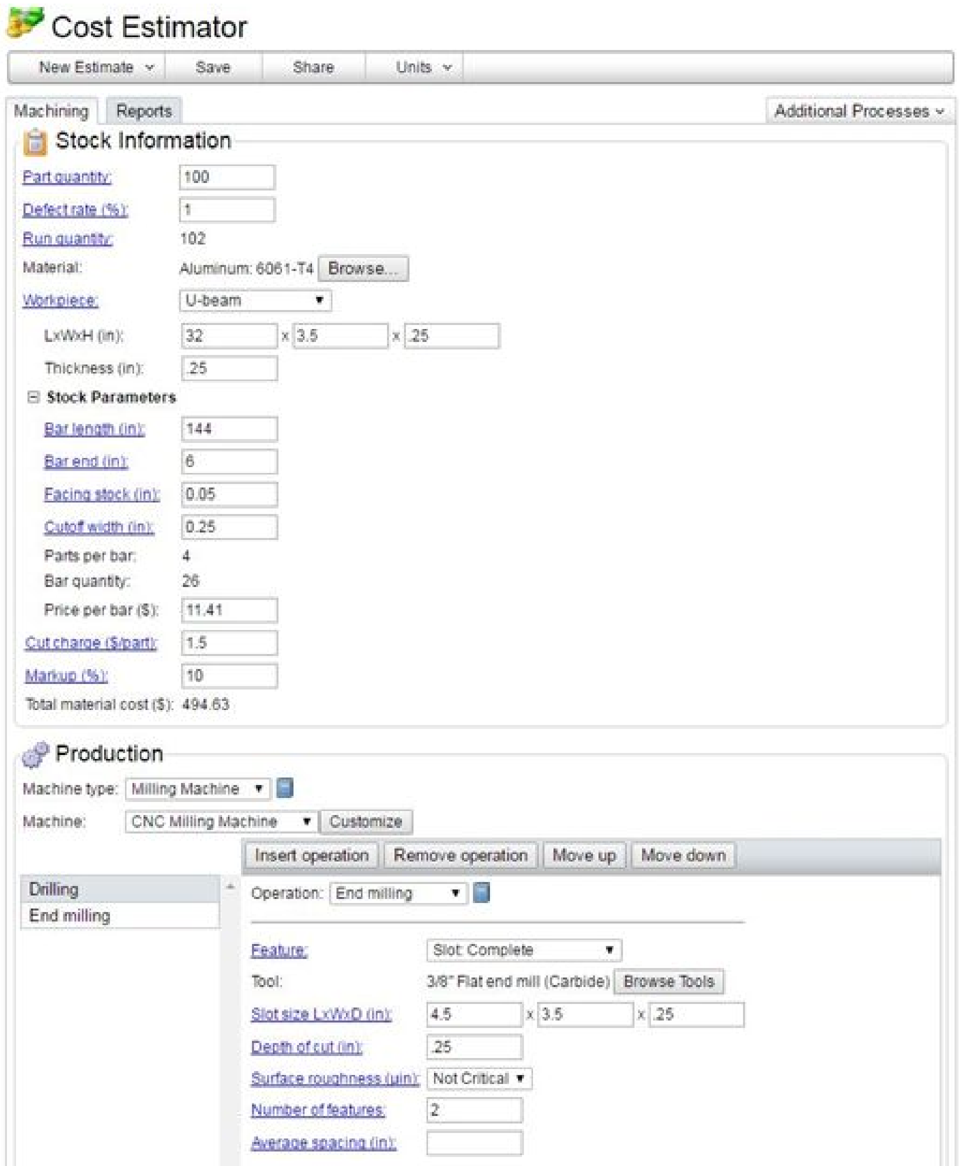
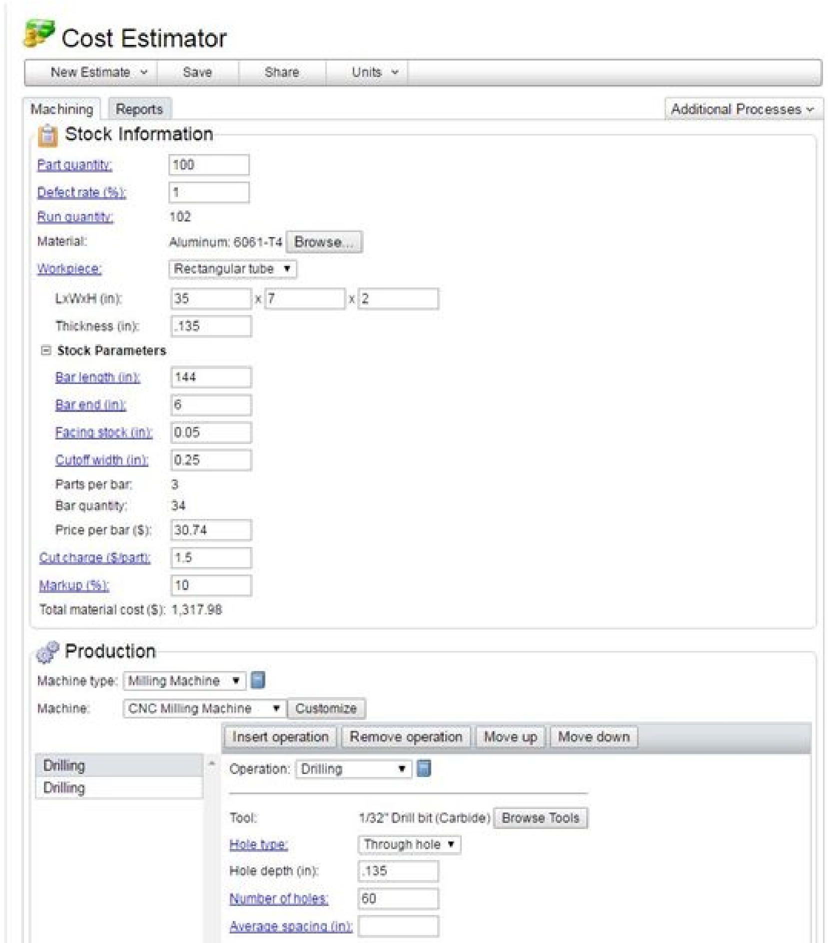


Figure 2: Material and Production cost (Horizontal)

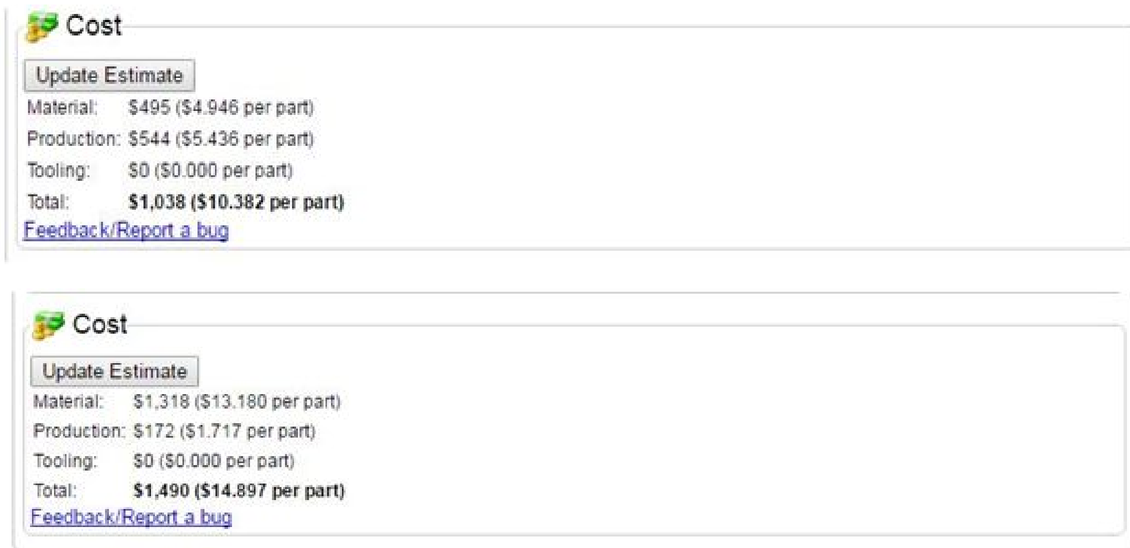
Figure(2) is a layout of the material and production operations necessary for the horizontal component of the design. It includes the drilling and milling operations used to create the face and side profiles. The recommended tool used to cut aluminum was a flat end carbide tool. The estimator uses this information to estimate the speed and overall cost of these operations. It also takes into consideration a defect rate of 1% and a markup of 10% to pay the manufacturing facility and its employees.



Figure(3): Material and Production cost (Vertical)

Figure (3) is a breakdown of the vertical piece. Each horizontal unit requires two vertical pieces of identical but mirrored dimensions. Since the both vertical pieces need the same holes on opposite ends of the bar, it is possible to machine the pieces from one rectangular tube then cut it directly down the vertical centerline to create the two necessary units for each side of the rack. The above figure includes the same markup and defect rate as the previous figure except now the cuts and sizing is for the vertical piece.

The following figure represents the total cost of material and production for the horizontal and vertical pieces prior to the addition of the Sorbothane coating.



Figure(4): Total Cost of Production (Horizontal and Vertical)

The final stage of production includes the Sorbothane coating that is designed to dampen vibration effects and the recommended adhesive used to attach the material to metal surfaces. These values are under the assumption that the heating of the Sorbothane prior to shaping is a negligible cost. The screws that will be used to mount the product to the EIA-310 racks and their accompanying screws are sold in packages of 100. This value was multiplied by 8 because the horizontal and vertical pieces of the design require 4 screws each.

Table 2: Cost of individual material

Extra Material	Cost $/ 100 units
Sorbothane	$3,468.00
3M #80 Adhesive	28
10-32 Screw (100 pk.)	$32.00
10-32 Nut (100 pk.)	62$
Total Cost $ (100 Units)	$3,528.00

In summation, the total cost of producing 100 units is $6,057.00 or $60.57 per unit.

Raytheon was not able to provide the team with any specific information regarding the amount of money normally spent on their current cable management systems. On top of this they also expressed that the products they use always vary in cost and quantity due to the nature of the work they do. To analyze return on investment the best option was to compare our products total projected cost against some of the leading competitors that in the field that Raytheon recommended to us. Since there are no current products that are sold as a modular package like Stable Cable's design, it was necessary to put together a package from competitor's catalogs that closely replicate the performance and range of our prototype. Stable Cable's design allows for interchanging of pieces within the cabinet so sizing for most of the competitor's vertical solutions ran twice the length of our design. To account for this the total cost of one Stable Cable package was doubled to be comparable to the competition.

Table 3:Competitors Comparison

Competitor Comparison	Stable Cable	Panduit	APC Cabinets
Cost for 100 Units	$ 12,114.00	$ 10,250.00	$ 13,700.00
Savings per 100 Units	X	$ (1,864.00)	$ 1,586.00

As seen above, the Stable Cable solution falls right in between the two major competitors that Raytheon could use. This is acceptable for the solution because there is a major difference in material and in turn, durability, between the solutions. The competitor's products came in ABS plastics as opposed to our 6061 Aluminum. As discussed in the engineering analysis section of this report, the Aluminum Alloy provides a much higher factor of safety and much more durability than the competing products. This was a major design specification that Raytheon requested we focus on as opposed to just lowering overall cost.

Prototype Build:

The final prototype produced by the team was made from Aluminum 60-61 and was CNC machined in two separate pieces. The actual material cost that the team spent is detailed in the table below. The cost included below represents all the materials that were used in the manufacturing process whether they incurred a direct cost or not. It also includes all of the materials purchased that were used in the original prototype attempts.

Table 4: Material costs per unit

Financial Analysis (prototype)			
Materials Bought	Vendor	Quantity	Unit Price
Plasti DIP Can (651ML)	Ace Hardware	1	$13.99
3/16 x 2 6061 Aluminum Flat 4"	Metals Depot	1	$12.88
.100 Thick 6061-T6 Aluminum sheet 1x4	Metals Depot	1	$74.96
Bolts	Home Depot	1 pkg.	$4.25
Labor - Metal bending, CNC, Sanding	Team 22	N/A	$0.00
EIA-310 Rack	URI	1	$0.00
		Total	$106.08
		Budget	$1,500.00
		Remaining	$1,393.92

The price to create one fully functioning prototype was considerably lower than the projected numbers for a few obvious reasons. The labor cost came to a total of 0$ since our team were the only ones working on the prototype itself. The CNC machine and other necessary tools were provided free of charge by the University. The above analysis also considers all materials purchased by the group to eventually reach one successful prototype, however, only portions of each purchase were actually used in the final design. These items are included and described in the table below.

Table 5: Final Prototype Cost

Material	Cost	qty	Total
PlastiDip can (651 Ml)	13.99	1	13.99
3/16" x 2 6061 Aluminum Flat 4'	12.88	1	12.88
Bolts	4.25	1 Pkg.	4.25
		Total ($)	31.12

Going forward, there are many things the team considered in terms of cost considerations. The most obvious adjustment for future work would be in terms of the mass production. Metal stamping and punching would be a much more profitable and cost effective method of producing these units in bulk. For the purpose of this project, the initial tooling cost of this method was clearly out of the question, but this would most likely be the production method. There was also an initial design that included the horizontal plate being made of 3 separate pieces. This idea was quickly scrapped due to the increased cycle time of splitting the part into 3 sections. There was also a direct reduced cost due to reducing the number of bolts per unit from 8 to 4.

PATENT SEARCH

During the research period of the fall semester Stable Cable pursued any insight into cable management systems.While it is important to gain general knowledge, research into the market is ultimately the best way to conceptualize solutions. Looking into common cable management products, Stable Cable found positives and negatives to different approaches. Patent Searches were critical during

the conceptualizing phase for a research and legal reasons. Patent Searching allows you to directly observe similar products which can lead to the incorporation of elements into design. These searches also prevent any patent infringement which is a serious legal offense.

Patent Number: US6809258B1
Patent Name: Apparatus for cable routing management
Patent Date: February 24th 2003
Competitors: Johnathan Engineering Solutions, Neat Patch
Patent Description: An apparatus for managing the routing of a cable inter-coupling two components in an installation is disclosed. The apparatus has a drawer for storing a portion of the cable and a drawer for cross-connecting the cable, which is connected to one component, with another cable, which is connected to the other component. The apparatus can be used with optical and electrical cables.

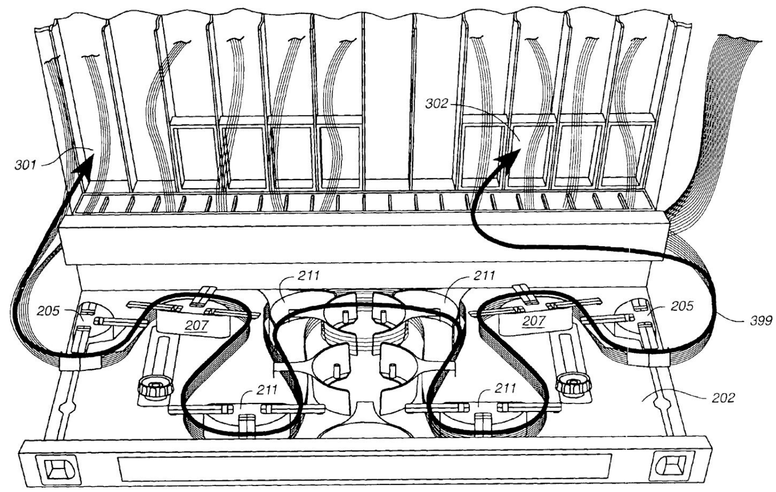


FIG._3B

Figure(5): Cable routing apparatus - Jonathan Engineering

Publication Number :US 7973242 B2

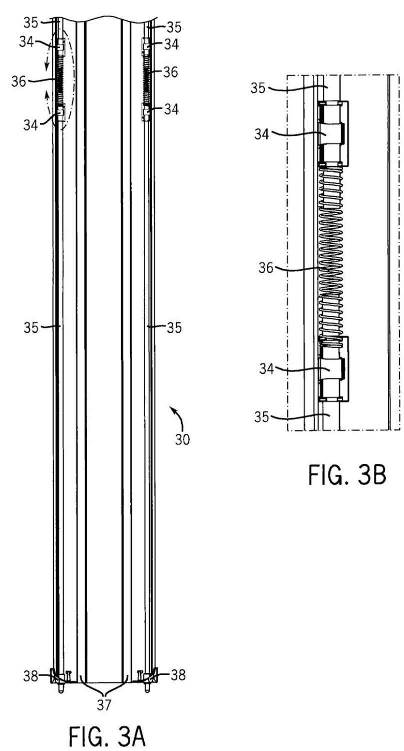
Publication title: Vertical Cable Manager

Publication date: July 5th, 2011

Company: Hoffman Enclosures, Inc

This cable management component was designed for the routing of cables vertically within a data rack. The component shown in figure below consists of trough with two sets of protruding fingers. Arrow-shaped heads on these fingers create retaining geometry for cables as well as enhance serviceability. There are 42 finger slots for the 42U standard in data rack height.On the other side of this component 5 U shaped bracket contain cables until they can be fed through one of the circular access holes. A removable door can also be placed over both sides of the trough for a cleaner more contained system. This component is attached to the side of an EIA 310 rack it is mounted using bolts to side face of the frame.

All of the patents above had elements that were incorporated into our final design. Observing the patents of the components above, Stable Cable was able to see benefits like serviceability, solid organization, and manufacturability. However with more demanding durability and space concerns , they concluded different materials and manufacturing would be needed, as well as a component with a small footprint.



Figure(6): Vertical cable manager - Hoffman Enclosures

Patent Number: US D463253 S1

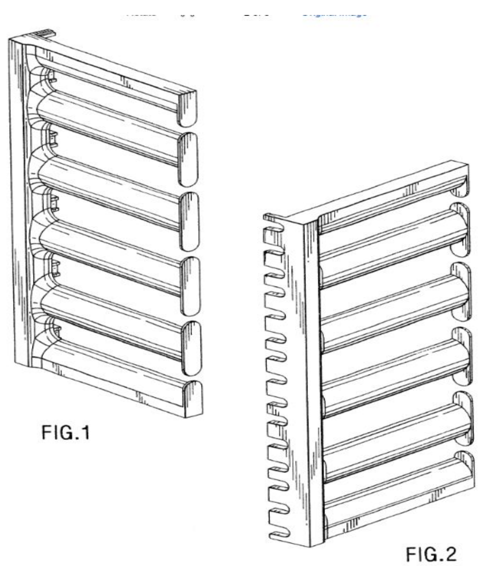
Paten Name: Vertical Cable Manager

Patent Date: Sep 24, 2002

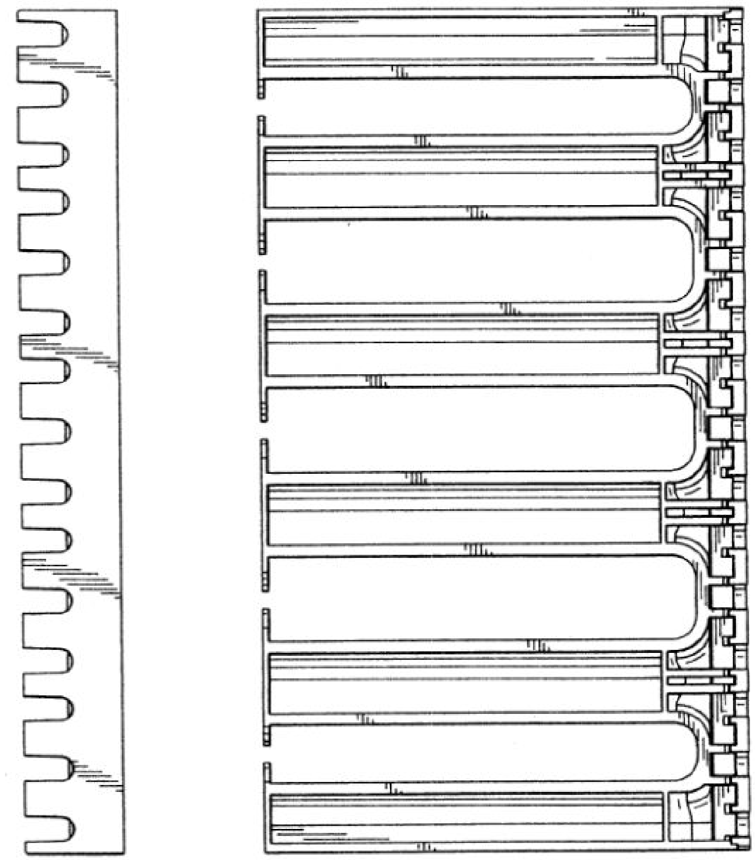
Competitor: Panduit Corp.

Patent Description: A cable manager is disclosed. The cable manager includes a backbone, a plurality of finger sections connected to the backbone to form a vertical cable channel, and a first pair of horizontal rails connected to the top end of the backbone and a second pair of horizontal rails connected to the bottom end of the backbone. The cable manager also includes a first cross brace connected to the first pair of horizontal rails and a second cross brace connected to the second pair of horizontal rails. Each cross brace includes a mounting surface having a plurality of guide surfaces and an alignment aid protruding from the mounting surface and extending beyond a horizontal axis extending between the guide surfaces.

The figures below show front and side views along with angled views of the apparatus as presented in the patent file.



Figure(7): Angled view - Panduit vertical cable manager



Figure(8): Side and front view- Panduit vertical manager

Evaluation of Competition:

An important step in the preliminary design phase of the project was to evaluate competitor's products to learn the pros and cons of what already existed. The field of cable management is very broad and due to this there were many existing competitors with a variety of proven solutions. Raytheon provided a short list of companies that they had commonly used before. From this list the team chose 2 companies that offered similar functioning products to compare and contrast the benefits of each. The two companies of focus are Panduit® and APC Cabinets®. Both of these companies offer vertical and horizontal components of similar function and are designed to fit standard EIA-310 racks.

Panduit® was founded in 1955 and is headquartered in Tinley Park, Illinois. This company creates a variety of products related to electronic cabinet enclosures and their associated accessories. A major division of Panduit® is their cable management sector. They offer a wide variety of solutions that combine horizontal and vertical components, the major difference being that they only offer products made from either ABS plastic or PVC. Below is a figure of the CWMPV3318 Vertical Manager and its specifications.

Figure(9): Panduit vertical part

Product Type	In-Cabinet Vertical Manager - Front Only
CE Compliant	No
Color	Black
Depth (In.)	3.00
Depth (mm)	76.2
Height (In.)	32
Height (mm)	813
Length (In.)	3.27
Length (mm)	83.1
Material	PVC
No. of Rack Spaces	18
Rack System Width (In.)	19.23
Width (In.)	3.25
Width (mm)	82.5
RoHS Compliancy Status	Compliant
Min. Order Qty.	1.0000

Figure(10): Panduit vertical specification chart

This model was chosen for evaluation because it is rated for 18 U and is the most comparable to the Stable Cable design for 20 U. It is made of PVC and ranges in price from $80 - $90 for just this component. The CE compliance mentioned in the specifications chart is only applicable in Europe and is not a necessity for cable management products. Both the Stable Cable and this Panduit design are RoHS compliant and are capable of managing any sized cable used in an EIA-310 Rack. This model is extremely interchangeable with the Stable Cable design if being applied in a standard data storage room that is not under any space constraints or loading expectations. A few problems arise when being applied in a cabinet with limited space, for instance, in the hull of a naval ship. The primary concern is with the edges of the rungs that would be holding the larger groupings of cables as they run up the sides of the cabinet. The thin, rough edges of those rungs leave the cables very susceptible to fraying when vibrations are applied to the cabinet. As the cabinet vibrates, the cables are tied to these rungs to take the loading force away from the connectors. Due to this, all of the vibrations will be felt in the same location on the cables over long periods of time. This constant vibration can eventually cause fraying that will damage the cords where they rest on the rungs. In the Stable Cable design the rungs will be curved and covered in Sorbothane. The vibration damping effects of this material would elongate the fraying of these thus saving Raytheon money on cable casings.

The horizontal component from Panduit® that was found most comparable was the NCMHF2 Horizontal Cable Manager. This component was chosen due to its similarity in function and size. Both the Stable Cable design and the below component are rated for 2U, are RoHS compliant and are capable of managing 38999-STD Mil-Spec cables. Raytheon expressed that they used these cables most frequently.

Figure (11): Panduit Horizontal Manager

Color	Black
No. of Rack Spaces	2
Rack System Width (In.)	19.0
Material	ABS
CE Compliant	No
Width (In.)	3.74
Width (mm)	95.10
Height (In.)	3.47
Height (mm)	88.14
Depth (In.)	3.74
Depth (mm)	95
Length (In.)	19.00
Length (mm)	482.59
RoHS Compliancy Status	Compliant since June 1, 2006
Min. Order Qty.	1.0000

Figure (12): Panduit horizontal manager specification chart

This horizontal managing component is made of ABS plastic and functions similarly to the Stable Cable design. These units can be found for sale at a price between \$50 and \$75. A major difference between the two is the central slot on the front face of the unit. The above design features two separate holes, which minimizes the amount of cables that can be fed out the front and up or down the rack. The Stable Cable design is one large opening that allows for a larger amount of cables to be fed in this direction if the bend radius requirements dictate as such. The other concern once again lies with the hard edges the cables would be resting on with this application. Fraying can be of major concern when the cabinet is under vibrating forces and there is no material in place to help deter that.

The second competitor that was evaluated was APC® by Schneider Electric. APC® was acquired by Schneider Electric in 2007 and was combined with MCE UPS Systems to create Schneider Electric's new Electrical and Cooling Service Unit.

The vertical solution being analyzed is the NetShelter SX 750mm Wide 42U Vertical Cable Manager. Unfortunately APC does not offer a vertical component closer in size to the Stable Cable solution so the price range is different as this unit runs in the range of $250. To match the capabilities of this unit, 2 vertical units of the Stable Cable design would need to be purchased. In function and application this is a very similar solution to the previous Panduit component and the one designed by the team.

Figure (13): APC vertical manager

Physical

Maximum Height	70.0inches (1778mm , 177.8cm)
Maximum Width	3.8inches (97mm , 9.7cm)
Maximum Depth	6.3inches (160mm , 16.0cm)
Net Weight	9.0lbs. (4.09kg)
Shipping weight	10.8lbs. (4.91kg)
Shipping Height	8.0inches (203mm , 20.3cm)
Shipping Width	6.5inches (165mm , 16.5cm)
Shipping Depth	43.0inches (1092mm , 109.2cm)
Color	Black

Figure (14): APC vertical part specification chart

This unit features a similar vertical design with a rung for cable support at every U in the cabinet. This solution opts to minimize material in the face perpendicular to the cabinet face to maximize the amount of cables that can be fed through each rung. Where the stability of the extra material in the previous competitor's solution makes it unlikely that a rung would break, this solution is less reliable under high vibration forces. This solution is made of ABS plastic which, as shown in the engineering analysis section of this report, has a much smaller factor of safety than the 60161 Aluminum alloy used by Stable Cable. The rungs on which the cables sit are not as harshly cut as the Panduit solution and actually feature a slightly convex face to rest on. Each U is supported by twin rungs as in the Panduit solution and this is an area that the Stable Cable solution is lacking. The twin rungs allow for a wider variety of options when fastening the cables, more separation of the bundles allows for easier access while installing and removing the cables. This improvement, however, is at the expense of putting a cap on available space on the sides of the cabinet. The design with one set of rungs allows for the maximum amount of space between the rack and the wall of the enclosure. The two rung system limits that space to the channel between the rungs. In the case that there is very minimal space between the rack and enclosure the Stable Cable design is also favorable because there is no minimum requirement while the other options are limited by the width of the back face on the component.

Figure (15): APC horizontal manager

This horizontal component is the AR8426A Horizontal Cable Organizer and is made of an undisclosed steel alloy. The average sale price for this unit is $50. Like the other two designs discussed, this unit is rated for 2U and is RoHS compliant. This component offers similar left to right and top to bottom cable managing as the other designs except with a major disadvantage. Both the Stable Cable and Panduit designs allow for the horizontal component to be mounted directly over rack space occupied by a blade, this design requires space either below or above the blade to be available for use. In a congested cabinet, companies do not always have the luxury of leaving a U of space between each blade. With the APC design companies would lose up to half of the functioning cabinet space. This unit offers a high ease of manufacturing along with durability and ease of use, but does not offer the versatility of the Stable Cable design.

Specifications Definition

While meeting with Raytheon for the first time, the goal was to narrow down and specify the project scope. Due to regulations regarding national defense contracts that Raytheon currently holds, the members of Stable Cable where not permitted to see any of the actual cabinets or cable management systems they were using. With limited specifics, the team had to turn to a few basic guidelines that had to be met. The primary requirement was that the solution had to fit an EIA-310 rack. This is a universally used data rack and designing to its parameters would ensure that the product would fit any of Raytheon's existing enclosures.

Table 6: Dimensions of EIA-30 rack

EIA-310 Rack Dimensions	
Height	73.5 in.
Width	19 in.
Depth	34 in.

The other dimensions that needed to be considered based on the EIA-310 rack where the spacing and size of the threaded holes that ran the entire height of the rack. These are used to mount the blades and any subsequent cable management systems needed. Every rack is broken up into a measurement called a U. A U represents 1.75" in height and is the typical height of one data blade. A standard EIA-310 rack has a height of 42 U. The pattern for the placement of the threaded holes is repeated for each U. Each U has 3 holes with specific distances between each other. Those dimensions are described in the below table.

Table 7: Dimensions of EI-30 rail

EIA-310 Rack Railing Dimensions	
Thread size	10-32"
Space between hole 1 & 2	5/8"
Space between hole 2 & 3	5/8"
Space between hole 3 & 1	1/2"

Another major specification was the design's ability to handle different bend radius requirements for different types of fiber optic cables. Designing to these requirements proved difficult because it is unknown which type of cable will be in use at any given time. To account for this, Stable Cable chose to provide a range of arm lengths for the horizontal manager. This allows the worker to use a different size manager for each blade. If each blade has its own manager, any bend radius requirement can be met throughout the cabinet. The following table provided by www.datatrend.com, lays out the minimum bend radius requirements of a variety of commonly used fiber optic cables.

Cable Type	Minimum Bend Radius	During Installation
Installation	4 x OD	-
4-pair, screened	8 x OD	-
Multi-pair copper UTP	10 x OD	-
Premise distribution fiber (1- 4-F)	25 mm (1 in)	50 mm (2 in)
Premise distribution fiber (5+ F)	10 x OD	20 x OD
Indoor/outdoor fiber (1- 12-F)	10 x OD	20 x OD
Indoor/outdoor fiber (12+-F)	10 x OD	20 x OD
OSP optical fiber	10 x OD	20 x OD

Figure (15): Datatrend Fiber optic bend radius chart

The final major requirement was the number of cables and their associated load that the Stable Cable design could handle. Under high vibration forces the load of the cables could wear down and break a poorly designed component, so designing for an extreme amount of cables and weight would ensure a universally functioning product. To quantify this, the weight of all the common cables mentioned by Raytheon were multiplied by 40 to simulate a fully loaded data board and the associated weight of its cables. Along with the load, the diameter of the connector on the cables had to be addressed to ensure that the central hole in the horizontal manager was large enough for it to pass in and out without issue.

Table 8: Weight of cables and connectors

Cable weight and connector size	Weight * 40 cables (lb.)	Connector Diameter (in.)
38999-Mil spec (steel)	11.025	1.4
38999-mil spec (aluminum)	9.075	1.4
CAT 6-A	8	0.5
Fiber Optic (optical)	2	0.4

Conceptual Design

After extensive research into cable management systems, data centers racks and equipment, Stable Cable began conceptualizing possible solutions. During this phase of the design we started very broad and explored a plethora of different solutions. Stable Cable started by brainstorming ideas that involved buss bars, simple machined parts, and even different wire bundling solutions. The focus at the start of these concepts was to stimulate better airflow and organize as best as possible the cables entering the cabinet.

Through communication with our sponsor Raytheon and our problem definition we were able to switch our focus to finding a concept that was more manufacturable, durable and space efficient. While airflow and organization were still very important in our overall design eliminating concepts based on that failed these focus's helped narrow down our selection until final concept could be selected. It is also important to note that many of these concepts were blended into the final concept as there were many positives that could be taken from early concept generation.

Taylor Fortier's Concepts

1) Thin metal sheet with extruded holes for feeding wire and grooves for stability of wire.

   Analysis: Military Spec cables would have connector diameters to big for the extruded holes.
2) Horizontal 1U Component making short connections, cables fed vertically will be attached to the side ports.

Analysis: A horizontal buss bar would be expensive and timely to manufacture. Attaching cables to the sides would lead to just another location for possible failure.

3) Vertical component making short power connections to desired U.
Analysis: a vertical power buss bar would be expensive and timely to manufacture. Also it would be a large footprint in relation to the amount of space available.
4) Scissor grip style clip that can be attached easily.
Analysis: Creating a scissor clip that would be able to handle static and vibrational forces yet flexible enough to be able to insert wires would be very challenging. Also this wouldn't be a cost effective since binding solutions is a relatively low cost allocation in our design.
5) Horizontal tray with adjustable clamps for cable organization. Cable will be fed from clamps to their destination.

   Analysis: Easily manufacturable and cost effective. Clamps will be able to handle any amount of wires and still have good rigidity.
6) EMI Suppressive Polymer coated trays. Separate wiring chambers and suppressive coat will prevent interference and all cable types can be ran up the same side.

   Analysis:

7) Multiple face cable feeder. Two parallel plates have extruded holes through them. The first face has three large holes then second face has individual holes for each cable.Plastic grommets to prevent cable fray.

   Analysis: The two facs allows cables to meet bending radius requirements. Open and simple concept promotes airflow and a small footprint. Extruded holes will not fit Military Specification cable connectors however.

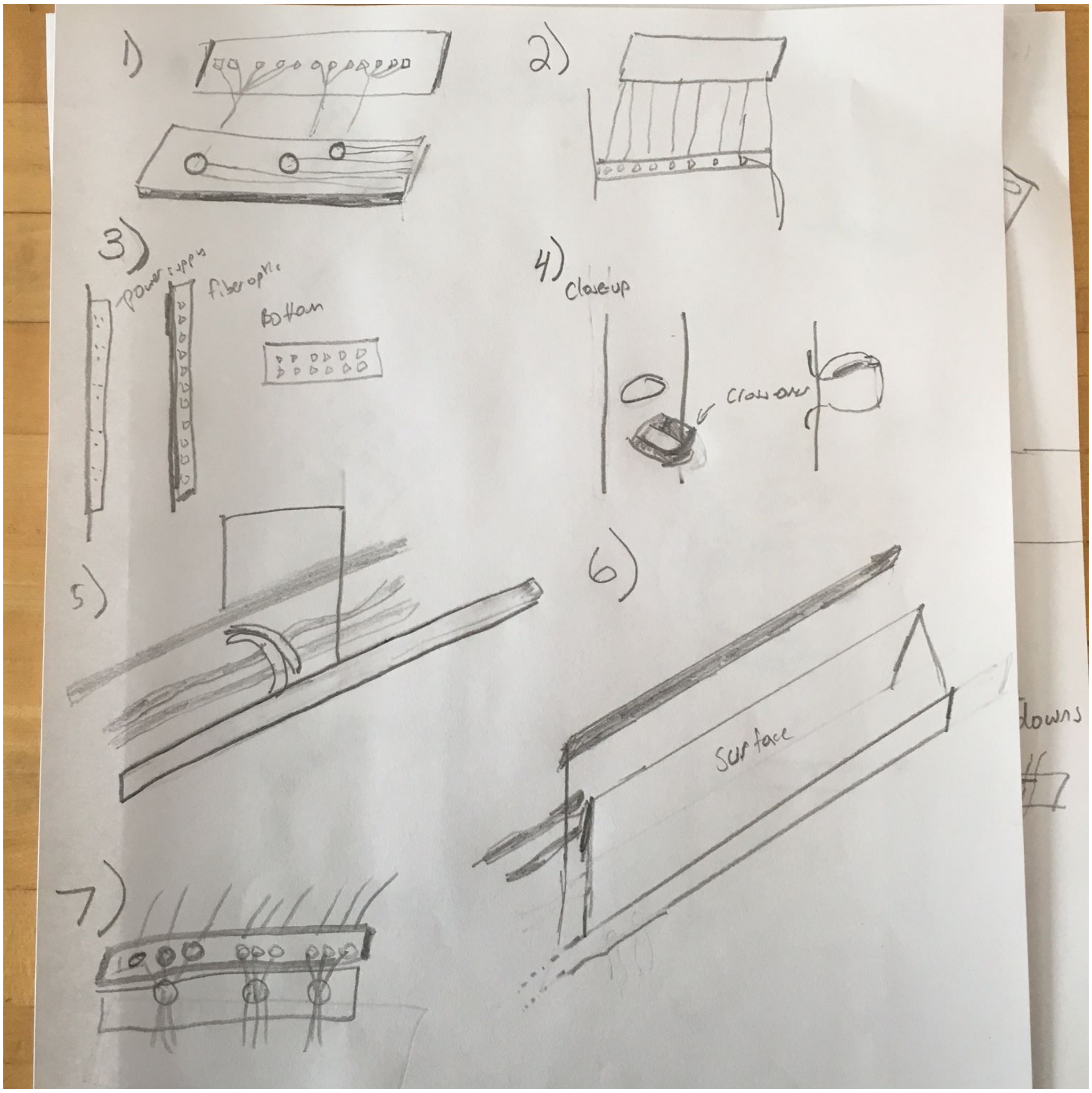


Figure (16): Taylor concepts pt. 1

8) Rectangular Sheet with extruded access holes. Could have different or many of the same size holes. Plastic grommets to prevent cable fray.
   Analysis: Useful in separating cables for serviceability yet organizing a large cable mass. Issues arise with the Military Specification Cable connector diameter.

9) Horizontal 1U Component consisting of 4 protruding faces. Each face will have slotted cable holes,the slot form a triangular shaped structure with the centermost cable slot at the tip. Rubber/Plastic grommet grip the wire based on compression

Analysis: Design would allow for the maximum amount of cables and meet bending radius requirements. Some possible problems may be vibrations causing rubber plastic holding grommets to be less effective, and grommets must be strong enough to grip but not harm the cable.

10) Multiple face rectangular sheet with extruded access holes. Has different faces each having a certain amount of same size holes.The amount of holes can increase/decreases based on wiring needs. Plastic grommets to prevent cable fray.

Analysis: Useful in separating cables for serviceability yet organizing a large cable mass. Issues arise with the Military Specification Cable connector diameter.

11) Grooved Roller Pin on slidable 1U faceplate. Cable are fed around roller pins. Smaller faceplate and slider bearing can move creating tension at various length service loops.

Analysis: Open concept promotes airflow and serviceability. Possibility of different service loop lengths also make it service friendly. Having a lot of parts this concept creates more points for possible failure and manufacturing cost and timeliness issues.

12) Bendable rail cable supporter. Metal Rail with cable sized grooves secured by rubber. Able to bend and conform to desired service loop and feed shape.

Analysis: This concept has almost no footprint and is very serviceable. A possible issue is the rail to be able to bend but not fail during vibration forces.

13) Horizontal 1U component with cable securing pins. Faceplate has 90 degrees of rotation which goes from parallel to the floor to perpendicular.

Analysis: Space , manufacturing and airflow efficient. Rotation secured through thumb screw.

14)Vertical component with side flanges to contain cable in desired U. Coated with rubber to prevent cable fraying.

Analysis: Very simple yet effective concept which translate to manufacturing benefits.

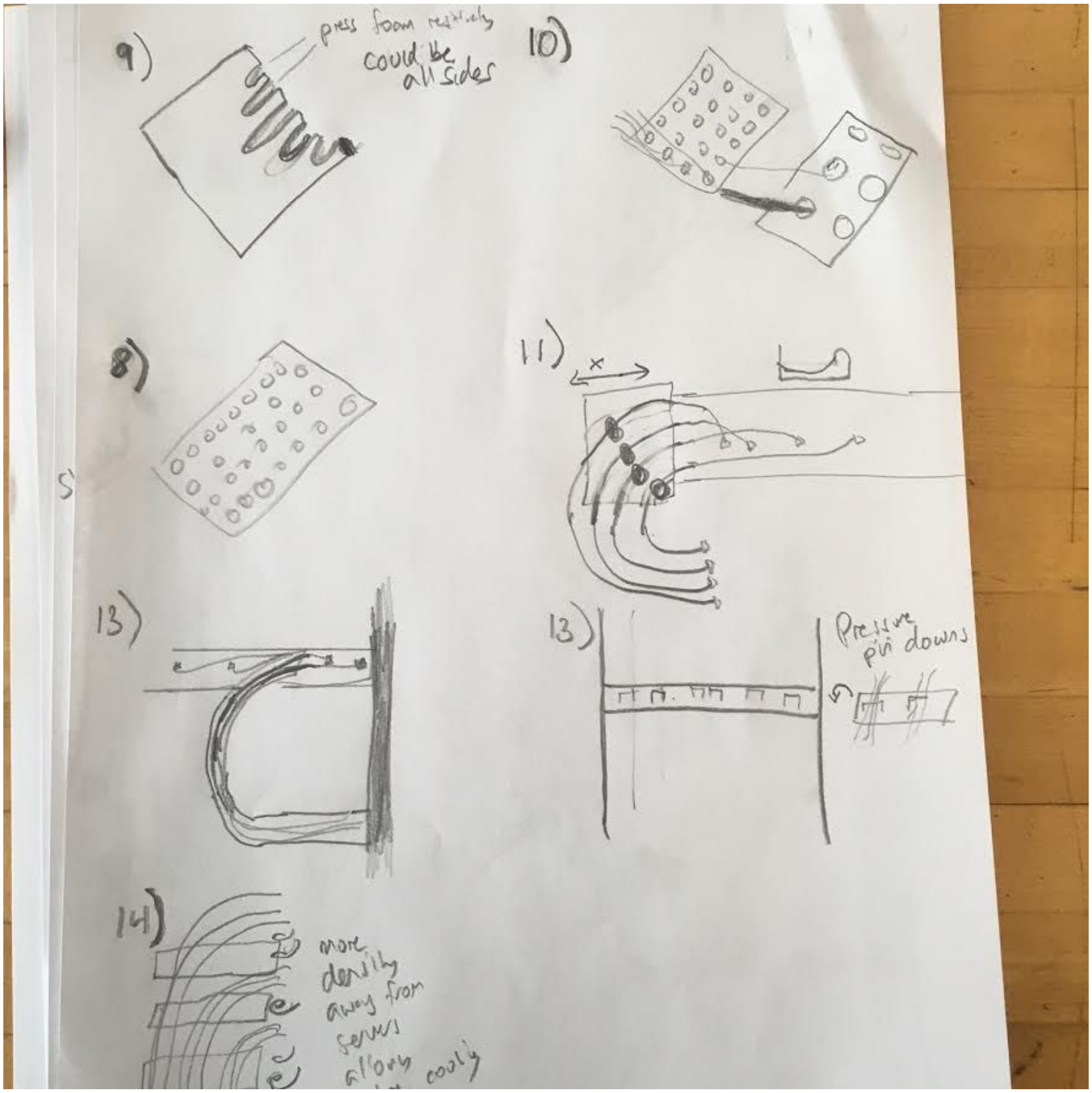


Figure (17): Taylor concepts pt. 2

15) Panel Separators. Adjustable sheet to isolate hot and cold aisles.

Analysis: Creates material barrier where equipment is not present to isolate hot and cold aisles.

16) Diagonal grommet rack. Rigid face plate covering several Us with extruded slots and securing rubber grommets.

Analysis: This concept is simple and cost effective to manufacture. Rigid and provides service loop. Some concerns are design may not be that universal for all equipment.

17) Side rail with EMI coated walls. Several coated compartments for various combinations of wires to be fed without interference.

Analysis: This concepts ability to run cable without interference is advantageous for serviceability. Having several different compartments could raise space and manufacturing issues.

18) Snap close cable grouper piece. Plast or metal hinged piece that can hold of various diameters that hold a mass of cables together.

Analysis: Small, cost effective piece can be used anywhere from feeding cables into the cabinet to an addition of a horizontal piece.

19) Clamping side rail wire sorter. Adjusts based on diameter of cable mass, and provides support for cable loads vertically.

Analysis: Versatility and simplicity of manufacturing are positives. Also takes up a small footprint and could be used in cohesion with vertical components.

20) Horizontal 1U component composed of a single rod with clamping clips.

Analysis: This concept is a simple and cost effective solution. However the diameter of the rod may have to be larger than expected to support load.

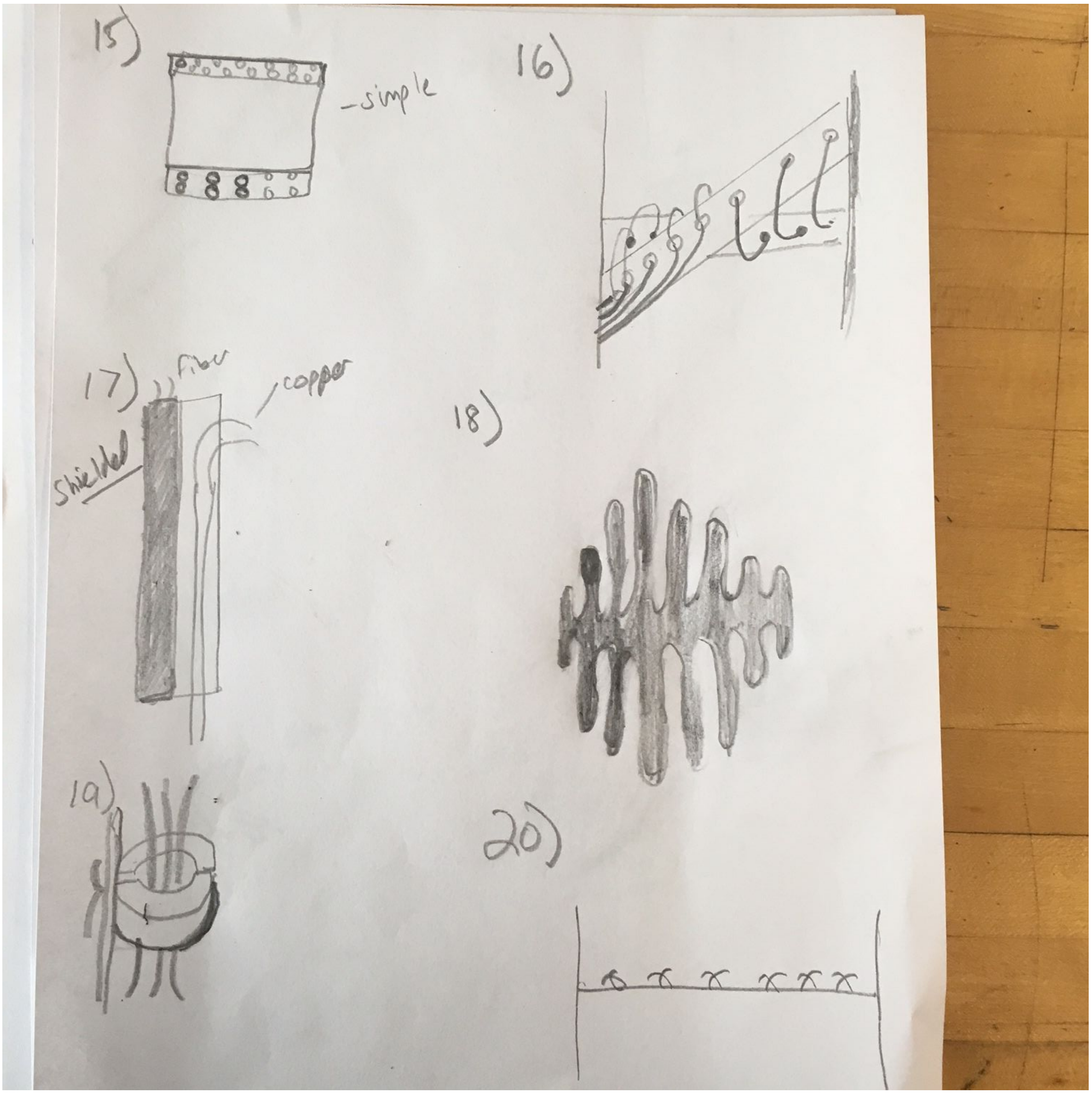


Figure (18): Taylor concepts pt. 3

21) Horizontal 1U component composed of a rod with wire size grooves. Very manufacturable and very small footprint.

Analysis: Extremely simple and manufacturable. Some possible problems may be vibrations causing rubber plastic holding grommets to be less effective, and grommets must be strong enough to grip but not harm the cable.

22) Rectangular faces with fiberoptic female connectors, placed along every U in the cabinet.

Analysis: Promotes serviceability and airflow however is not easily manufactured, cost effective and has many points of possible failure.

23) Slide out Vertical Component. Component is on a rail slide allowing for a more accessible vertical component.

Analysis: Vertical component with enhanced serviceability. Downfalls include increased manufacturing costs, point of failure and limited space.

24) Blank Flat panel with adjustable pins. Pins create service loop tension between different Us.

Analysis: Concept is not cost effective and may not be necessary on all projects.

25) Small single cable support. Cable support that mold fits one cable and can be modular based on the amount of cables in a U.

Analysis: Promotes airflow and serviceability with an easily manufacturable design. Cost effectiveness may change if loads are too high for small parts.

26) Sinusoidal angled cable aligner. This 1U horizontal component has slotted holes with rubber that follow the shape of a sinusoidal graph.

Analysis: Small and effective use of space. Simple design makes it structurally reliable and efficient in organizing many cables.

27) Horizontal 1U component with inward or outwards faceplate creating a triangle shape. Slotted holes with rubber grommets secure the cables.

Analysis: Small and effective use of space. Simple design makes it structurally reliable and efficient in organizing many cables.

28) Side Rail service loop restrainer. This concept mount along the side rails and secures cable service loop with restraining pins.

Analysis: Footprint of this concept is small enough to work alongside a vertical component. It's goal to create service loop increases serviceability and it's small simple footprint is a positive for manufacturability.

29) Rugged Bendable Spine. Chain like conduit provides rugged protection and will allow for proper bend radius.

Analysis: Would provide cable organization into and out of the cabinet. This component however is not a necessity and not cost effective.

30) Add a station Plate Isolator. Modular face plate addition for organization of service loop in wires. Pins are used to keep tension in cables but forfeiting a usable U.

Analysis: This concept is simple, however may create manufacturing issues and may not be necessary in all instances.

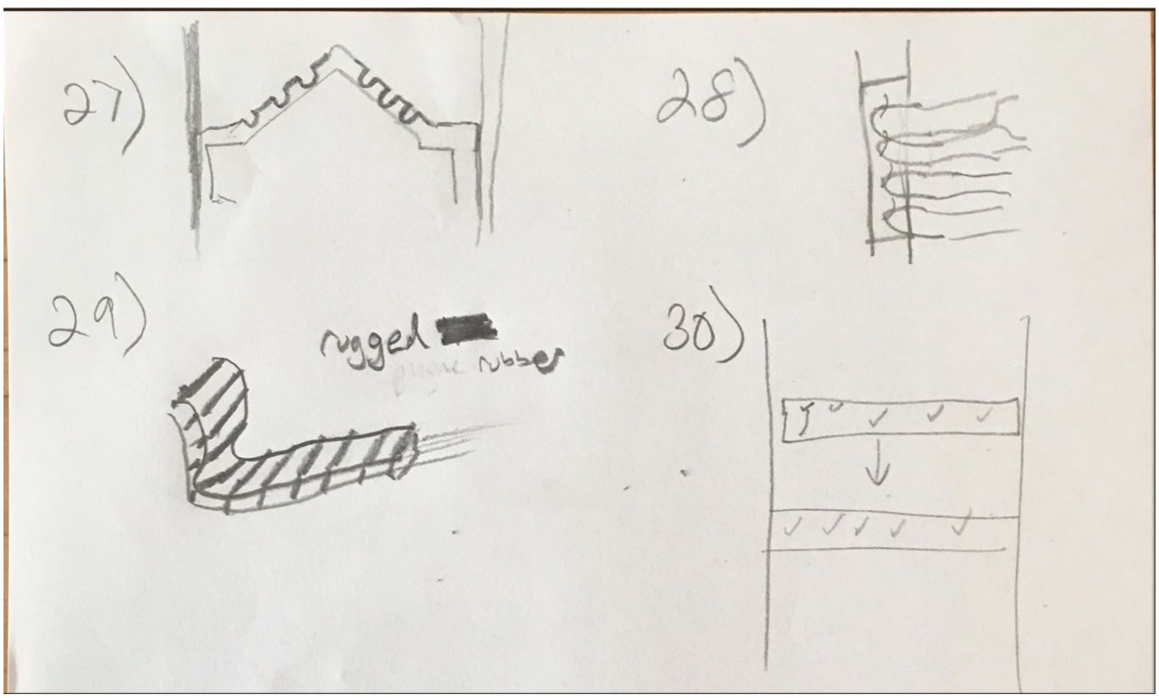


Figure (19): Taylor concepts pt. 4

Andrew Moreno's Concepts:

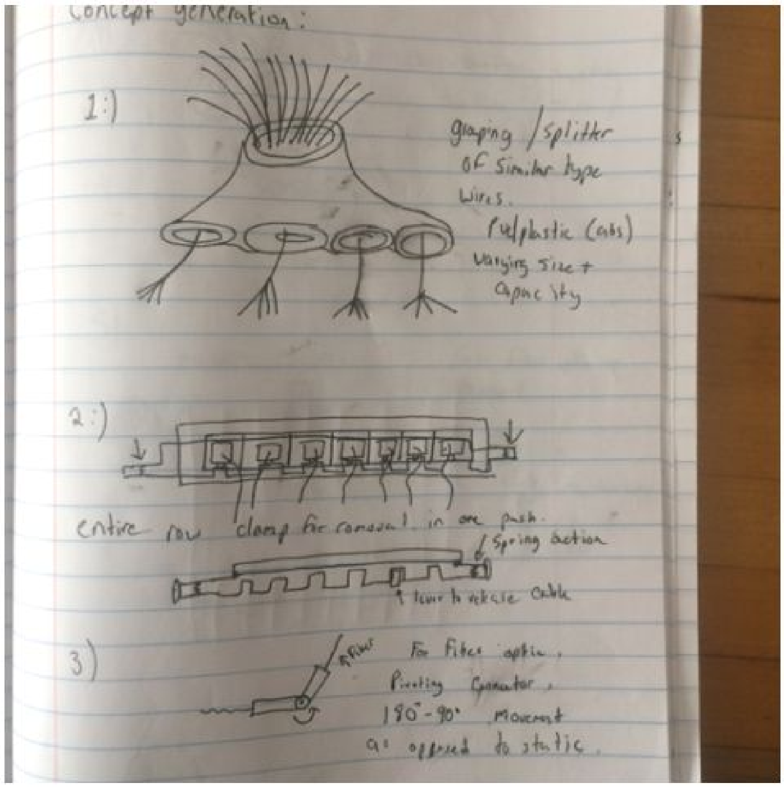


Figure (20): Andrew concepts pt. 1

1.) ABS Plastic / other plastic router, groups similar types of wires and separates them into groupings corresponding to their position on the blade. 1 unit per U in cabinet. Not cost effective enough for function.

2.) Plastic Clip with spring action lever that runs length of blade. Sits on top lip of blade and when pushed down, releases levers of all cables plugged in and allows for the entire row to be removed without disorganizing. High difficulty of manufacturing.

3.) Metallic tube with pivot arm for 90 – 180 degree motion for fiber optic cables with bend radius concerns. Locks in place at max bend radius. Difficulty in install and removal.

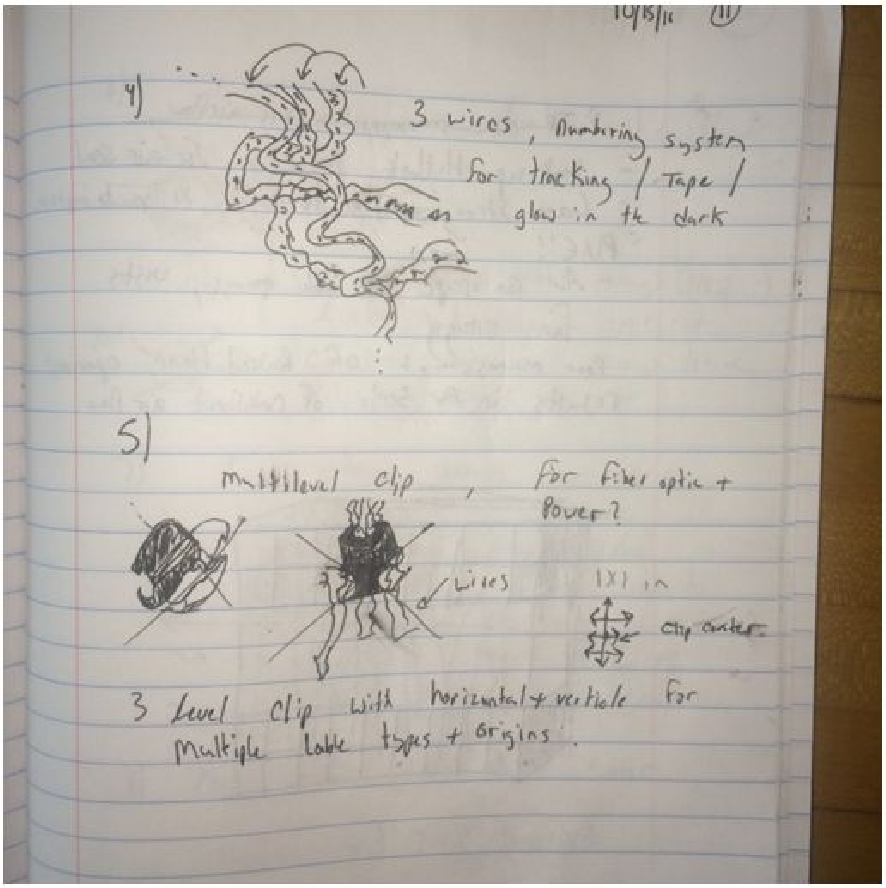


Figure (21): Andrew concepts pt. 2

4.) Neon light sticker system for each row of cables. Numbers run down cord to easily identify the cable to its port housing. Ideally numbers could be printed directly onto cable instead of sticker application. Similar patents exist.

5.) 3 – Level clip with each level being capable of holding a central cord and one on each side. Attachable to other 3 level clips to adjust for need. Difficulty in application.

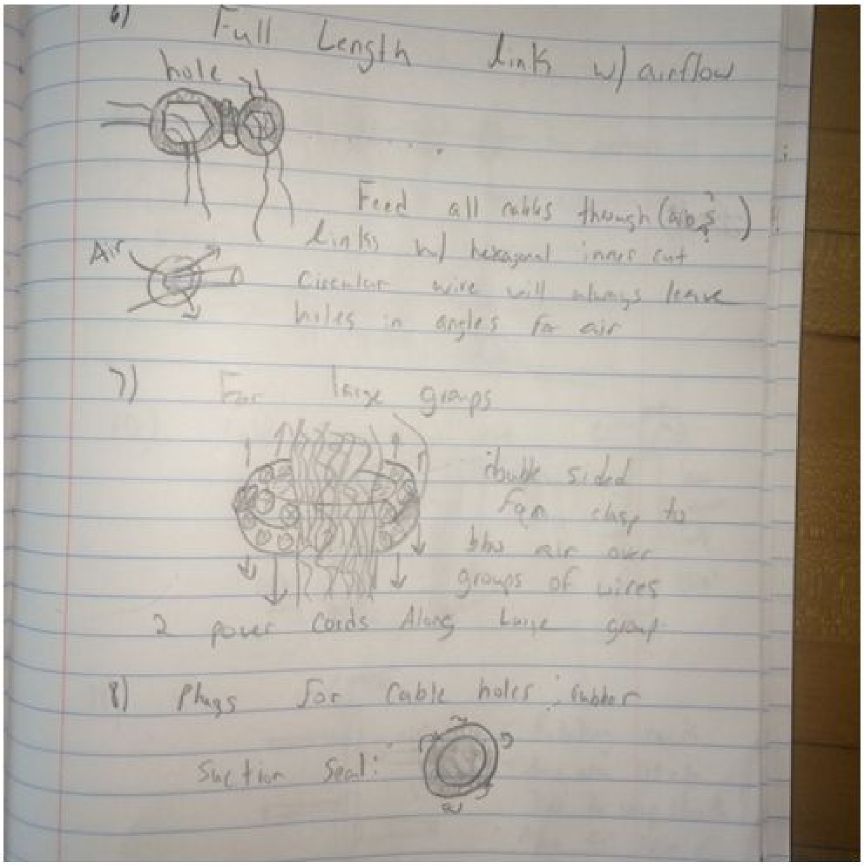


Figure (22): Andrew concepts pt. 3

6.) Metal link system with 1 cm Diameter for hollowed out pin between each link to improve airflow through mass of cables. Difficulty removing and installing.

7.) Large sized ring of small blade fans that clip around denser/ hotter sections of cables to add cooling element while grouping cables. No way to power/ useless.

8.) Rubber plug that has suction like motion for capping empty cable ports that release air, improves air cooling efficiency. Doesn't involve scope of project.

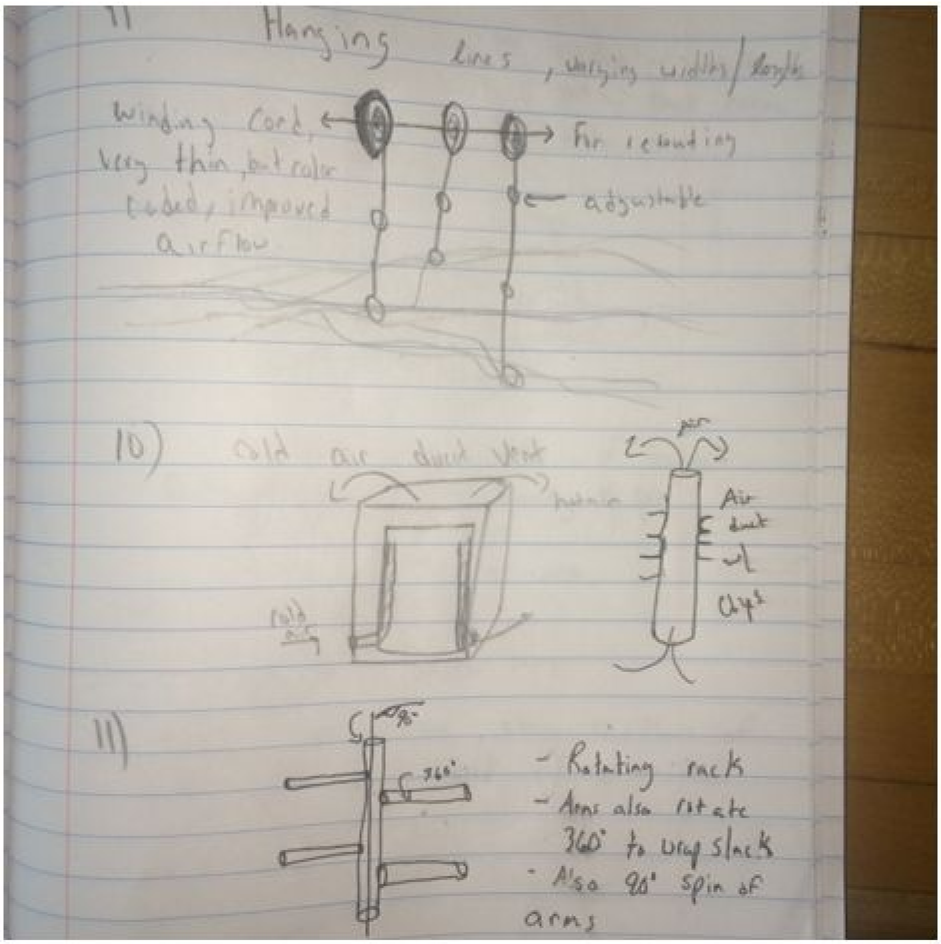


Figure (23): Andrew concepts pt. 4

9.) Hanging spools of wire with rings at varying heights to group each blade / power source wiring separately. Slack can be wrapped around tops or rings so then can be pulled up and down. Not enough space in cabinets.

10.) Small tubing running under cabinet from cold air aisle towards the back of the cabinet to help cooling in the back of cabinet near hot aisle. Not in scope of project.

11.) Centrally mounted rack which rotates its' arms 90 degrees from flush with the boards too directly pointed out. Arms themselves spin 360 degrees freely to wrap cords for slack. Free spin allows cords to be unwound quickly for access and spun open for other needed access. Not enough room for rotation.

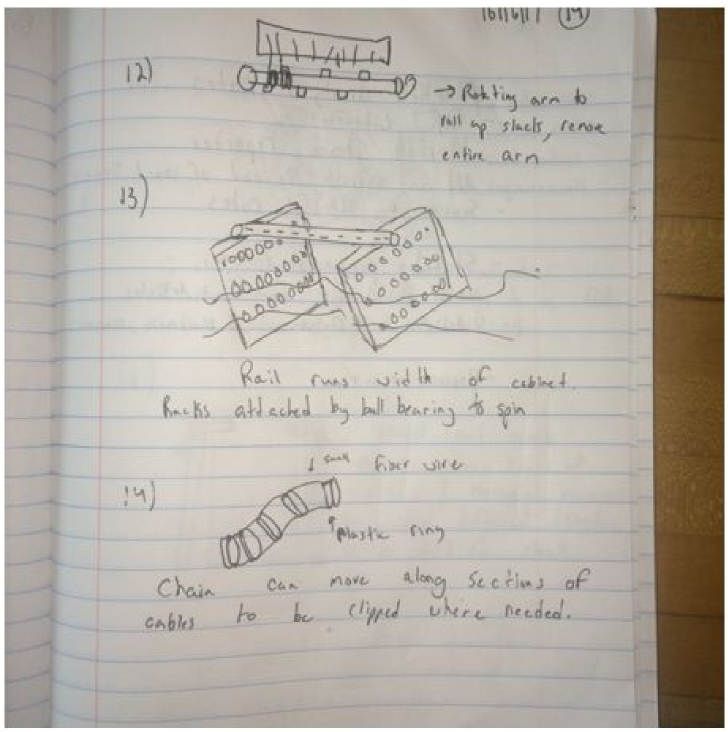


Figure (24): Andrew concepts pt. 5

12.) Offset clips on rotating arm, vertical or horizontal application. Helps keep slack organized and readily available. Mounted to bottom or side wall of cabinets. Not versatile enough.

13.) Pivoting Grate style rack that has opening for each wire, hole size can vary. Can pivot from flat against the wall of cabinet to 90 degrees to face employee working on boards. Numbered to make identifying cables easier. No stability/ durability.

14.) Aluminum Link system with thin fiber holding links together. Lightweight and capable of moving along entire length of wires. Ideal for groups of 10 fiber optic wires or less. No more useful than zip-ties.

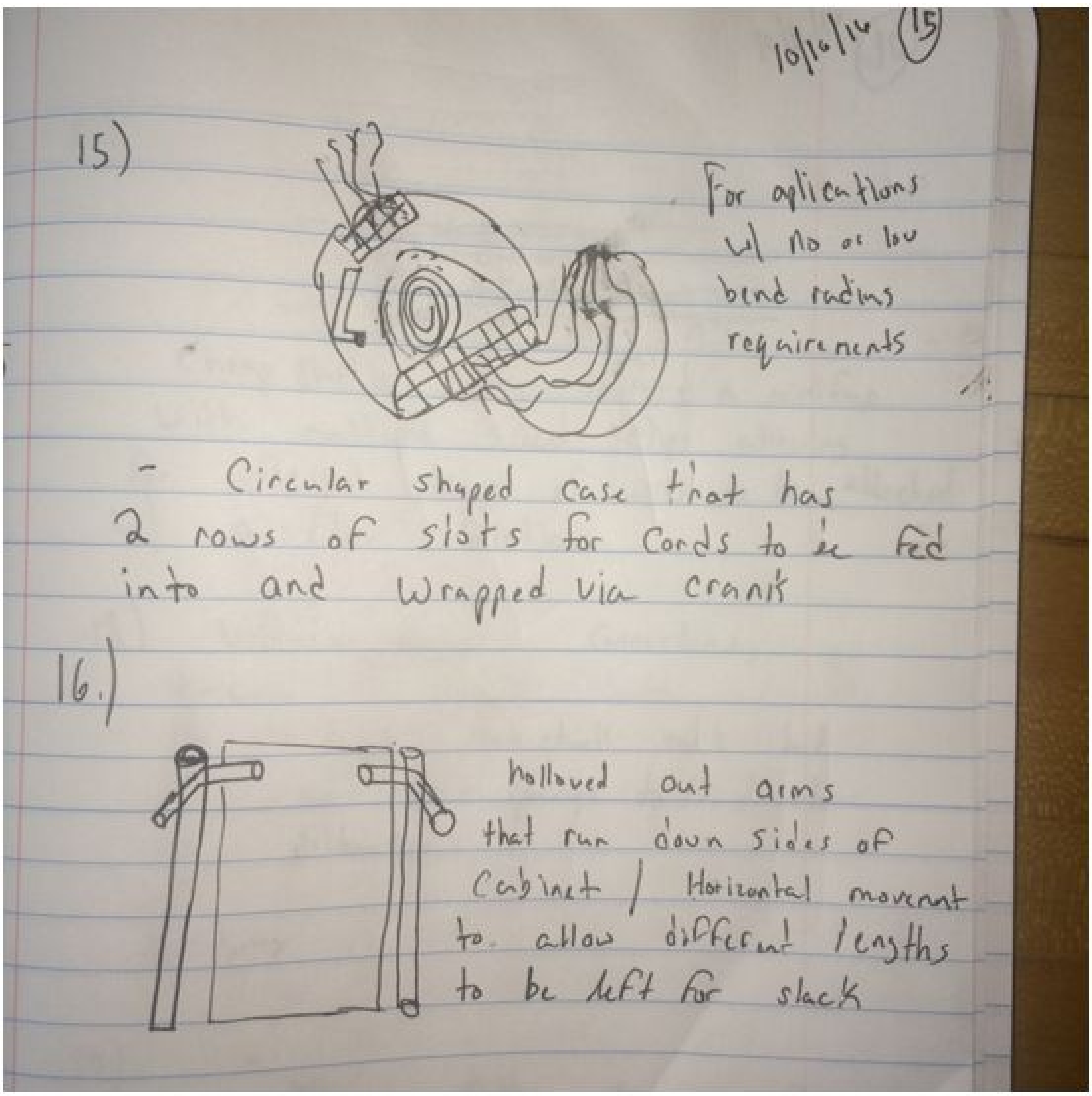


Figure (25): Andrew concepts pt. 6

15.) Spool that sits either flush with the roof of cabinet or hangs down with openings leading towards front exit of cabinet. For cables with no difficult bend radius requirements. Handle to wrap all cords in one motion. No space or need for this application.

16.) Thick, hollowed out ABS plastic tubing running down outside of cabinet with openings to inside of cabinet running down it. Cables feed in through holes and are grouped into larger tube which protects cables that were previously exposed on outside of cabinet. Not in scope of project

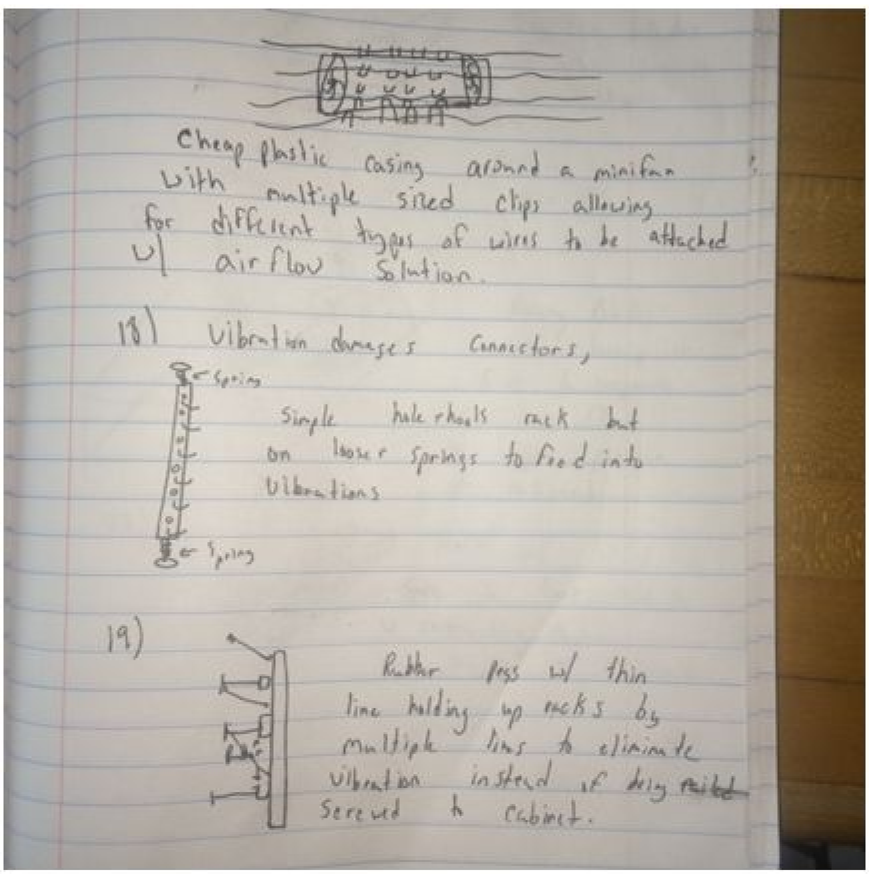


Figure (26): Andrew concepts pt. 7

17.) Similar to previous idea except clips sit on outside rim of free spinning arm with core of arm being a fan. Could improve cooling and gets rid of wasted space inside diameter of rotating arm. Not durable.

18.) Side mounted, metallic rack, attached to springs on top and bottom to help alleviate vibration to the connector by absorbing it in the cable. Springs make installation complicated.

19.) Rubber stoppers against the face of metallic rack mounted to the cabinet wall that could also assist in vibration depletion. Rubber concept applied in final design.

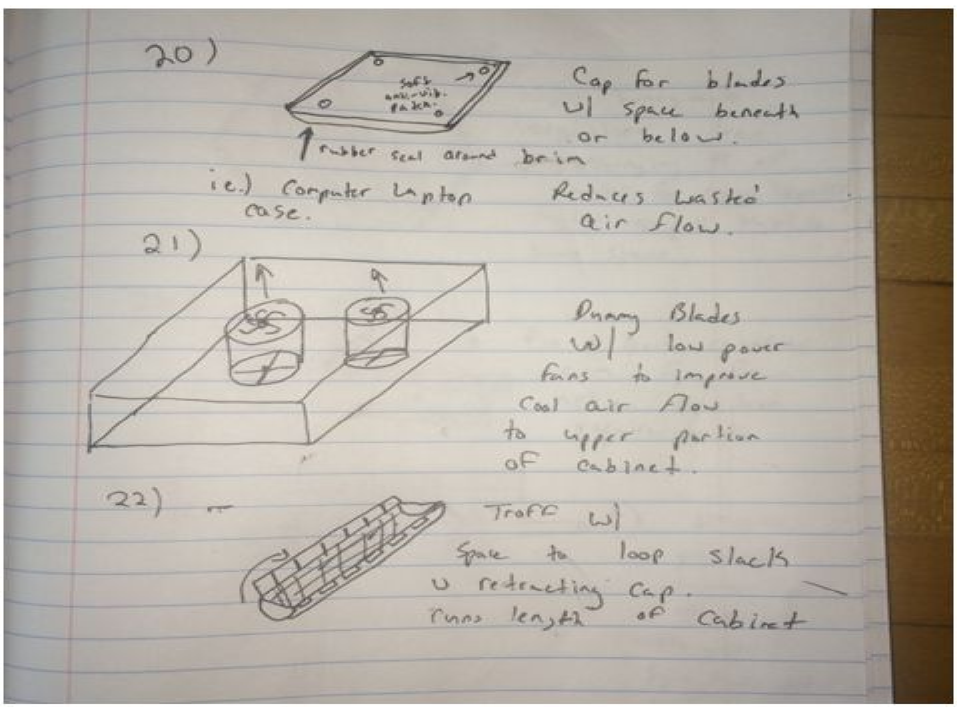


Figure (27): Andrew concepts pt. 8

20.) Laptop case style cap for top or bottom of boards with not boards above or beneath them. This reduces free airflow that helps cooling efficiency. Not in scope of project.

21.) Dummy Blade with spaced out fans for mid-cabinet cooling. Same style power source as blade. Very open ventilation on top and bottom. Not in scope of project.

22.) Cable trough space to fit slack. Runs length of blade with separate opening for each set of cables. Similar shape used in final project.

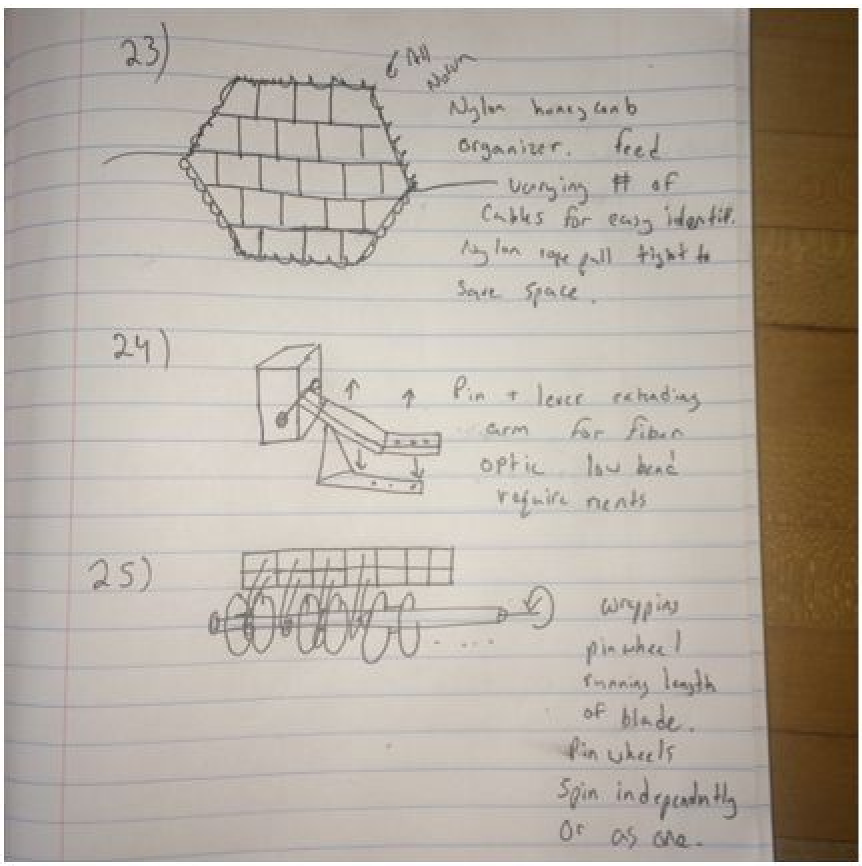


Figure (28): Andrew concepts pt. 9

23.) Nylon honeycomb style clasp/wrapping. Separate hole for each cable that can be tightened by pulling on nylon string. Keeps cords separate but grouped together. Not an improvement on current zip ties.

24.) Pin and arm hanging from top of cabinet. Lever can extend down as far as halfway down cabinet to hold fiber optic cables at 180 degree angle when they have a difficult bend radius to work with. Complex manufacturing and installation.

25.) Spinning arm that can slide up and down 2 U worth of units with a separate pinwheel that spins freely to wrap each type of cable as needed. Not an improvement in organization.

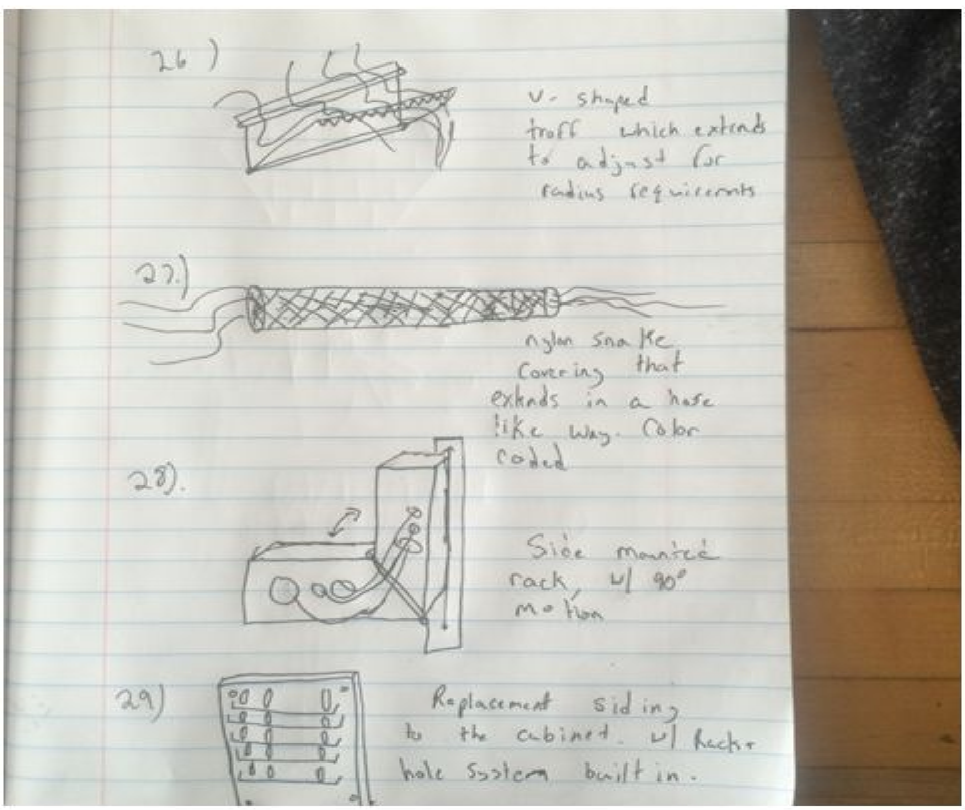


Figure (29): Andrew concepts pt 10

26.) V- Shaped trough that extends on a pivot to adjust with different radius requirements. 1 unit per U or 2 per U if multiple types of cables are needed. Similar shape used in final project.

27.) Nylon "snakeskin" type of wrapping that is color coded to group cables easily. Easily removable and flexible to any bend radius. Not an improvement on current products.

28.) L shaped cube mounted to edges of cabinets that can house slack as well as pivot to allow more access to the cables. Does not meet space requirements.

29.) Replacement cabinet wall , with built in rack and hole system to hold up cords. Same material as cabinet. Not in scope of project.

30.) ZIP TIES!

Louis Maroun's Concepts:

Louis Maroun

30 Idea Concepts

1u = 1.75"

1. Molded plastic piece that attaches to back of server. Allows wires to be neatly run with enough slack to remove unit. There are grooved slots that the wires will attach to. The height of the unit will be 1 u tall and span the width of the entire server.

2. Plastic piece that attaches to the side of the cabinets. The wires run through and attach to individual slots. The height of this piece will be 7u, so 6 pieces will be needed for a 42u cabinet. The pieces will be able to easily stack and attach to one another.

3. A universal power source that runs the entire length of the cabinet. Every other port will be a three way 208V, and a 3 way 220V respectively. This power strip will be able to be reset remotely. There will be different circuits within the strip, so individual circuits can be reset. This power strip will be on the opposite wall as the data cables so there will be no electrical interference.

4. A column of 90 degree fiber optic connector that allow the cables to be run strait down from the top of the cabinet, then strait to the back of the server. These connectors will sit in a rubber housing to isolate the connection from vibrations. There will be a connector every other u height. These columns will be mounted to the side of the cabinet with rubber insulators.

5. An arm with a hinge that attaches to the back of the cabinet. The wires will run neatly through the arm and have enough slack for adequate movement. The arm will be slightly spring loaded so that its resting position is close to an equilateral triangle. This is to allow for better air flow. This system cannot be used with fiber optic cables because it will exceed the bend radius of the cable.

6. A multi-cable distributor to use for server-to-server connections. There will be one input panel and many outputs for 'x' number of cables. The output ports will span the length of the cabinet. All the input/ output ports will be numerically labeled for easy installation.

7. A comb like piece that organizes individual wires. The piece snaps together around a group of wires, to ensure they all stay properly aligned. The comb shape piece will attach to the cabinet wall.

8. A wire organizer for many cables to be neatly dispersed to each individual server. Inside the organizer are many passageways that are numbered at both the inlet and outlet portion of the organizer. The height of this piece will be 1 u tall. It will attach to both side walls of the cabinet, sitting in the same orientation as the server.

9. A system of enclosed tubes that is responsible for running bundles of cables down the cabinet to the correct server height. The inlets and outlets will be numbered sequentially starting from the bottom of the cabinet. These tubes will mount to the side wall of the cabinet.

10. A central input board where most of the incoming wires will connect. There will be multiple outputs for every input, and the ratio of outlets to inlets will vary depending on the how many servers use a given data cable. The vertical and horizontal positions will be denoted on the input board. This system will mount directly to the rear wall of the cabinet.

11. A series of different sized straps that run the entire height of the cabinet. The biggest being at the bottom. From the bottom, they will slowly decrease in diameter. Each strap will be numbered to denote the vertical position in the cabinet. This will allow the cables to run straight up the cabinet, make a 90 degree bend, then run straight to the server.

12. A spiral housing that runs vertically up the cabinet. The housing will enclose the data cables and the walls will be slotted for air flow. There are fins on the inside of the spiral to promote effective natural convection to cool the cabinet. There will be exit points for the cables every 3 u's.

13. A rectangular housing that will bolt to the floor using existing the pre-existing mounting points of the cabinet. The walls in this housing are grooved with pre-installed wire ties to secure the data cables. The walls of the housing will be slotted.

14. An enclosed, 2-piece tube structure with one input and many outputs for the cables to snake through. The cables will be temporarily secured using wire ties, until all the wires are run, then the installer can attach the other half of the tube. At the cable entrance, there will be a fan pushing air into the tubes.

15. A column of rigid, pre-bent tube that fiber optics cables are run through. This rigid bend will be at the optimal angle, which will ensure that the cable will function properly. The column of these tubes will be attached to one side of the cabinet wall. This will take the guess work out of installing fiber optic cables.

16. A series of many movable support arms that guide each cable to the correct server. These arms will attach to a main structure. This main structure will then mount to the side of the cabinet wall. Each arm will be numbered with by vertical and horizontal position inside the cabinet.

17. A system of comb like piece that keep the wires separated, but very close. Each slot in this piece will be numbered to keep the orientation of the cables consistent.

Each server will require its own system. The system will be attached to the side of the cabinet wall, but allowed to move slightly.

18. A fan assembly that mounts to the top of the cabinet that has a large pass through for the data cables to run past. This assembly will have one electrical input and many outputs, each output on its own circuit, which can be remotely reset. The fan will run off the electricity provided by the central power input.

19. A series of metal hooks that attach to both the cabinet ceiling and rear of the server. The wires will be supported by these hooks. The hooks will promote gentle bends of the wires.

20. A plastic piece that is grooves and has pre-installed cable ties. This plastic piece will attach to the side of the cabinet walls using heavy duty Velcro. This will allow the Velcro to separate before putting stress on the cables when removing a server.

21. A series of metal rods that attach to the cabinet ceiling. Each metal rod will be a different length to accommodate different server heights. The data cables will attach to the rods using heavy duty Velcro.

22. A very low-profile fan assembly that attaches to the top of the rear wall of the cabinet. This fan will be powered by a 208V 3-way power source, a very common power rating used for many servers. This fan will push cold air into the back of the server to help cool the system. .

23. A series of hard plastic rectangular boxes with slots in them to allow for airflow. These boxes will run from the rear of the cabinet to the rear of the server, providing the cables with support. One unit will be needed for each server.

24. A mesh weave that runs vertically through the back of the cabinet. The cables will snake down through the weave and then run out to the rear of the server. This weave will attach to the back of the cabinet with rubber bushings to prevent vibrations.

25. A series of spools in which the data cables runs down into, wraps around the spool, then run to the back of the server. There will be a spool for every server in the cabinet. The slack in the cable will allow easy removal of the server.

26. Metal rods that bolt to the floor of the cabinet. The rods will slotted every 4 inches, and be different lengths. Data cables will be attached using cable ties through the slotted rod.

27. Multiple ducts that attach to the ceiling of the cabinet, extending down. One central fan will blow air into the ducts to evenly cool the cabinet. This fan will be powered by a 208V 3-way power source.

28. A series of metal racks that the cables can weave through. The cables will run straight down the back of the cabinet and then cross over to the servers using the racks as support. The cables will be attached using cable ties.

29. A grid of metal hooks that is attached to the ceiling of the cabinet. This hooks will allow the cables to droop freely down to the back of the server and will take much of the load of the cable off of the connector.

30. A row of 90 degree fiber optic connectors that span horizontally across the cabinet. This will allow the fiber optic cables to run strain down the cabinet, then

directly to the server. There can be multiple rows of these depending on how many fiber optic cables are being used. The connectors will sit in a rubber housing to isolate them from vibration.

QFD

Using a Quality Function Deployment, or QFD, makes it easier to convert what the customer's demands are to engineering design specifics. By using a method called the house of quality, one can better analyze and assess the engineering specifications. The house of quality allows an engineer to analyze the problem and possible solution step by step. This process includes identifying the customer's requirement, and assign numerical importance to each. The most important requirements will have the greatest weight in the final decision of a solution. From there, one must evaluate the current competition to understand how the customer's requirements are or are not being met. From there, the engineer creates a list of engineering specifications and correlates theses to the customer's requirements. The engineer also correlates these specifications with one another. The difficulty of accomplishing these design specifications are then ranked numerically. After filling out all this information, the engineer can then pursue what they think is the best possible solution for the customer.

A trade-off analysis between the three concepts was also used when deciding the solution to Raytheon's problem. Consideration of strength, durability, and universal use were the driving factors, while cost and airflow in the cabinet had less of an impact on the final decision. An analysis of the competition's current products was also performed. This analysis indicated what specifications were currently being met, and which were not. By using these analyses, Stable Cable was able to choose a solution to Raytheon's data cabinets' cable management problem.

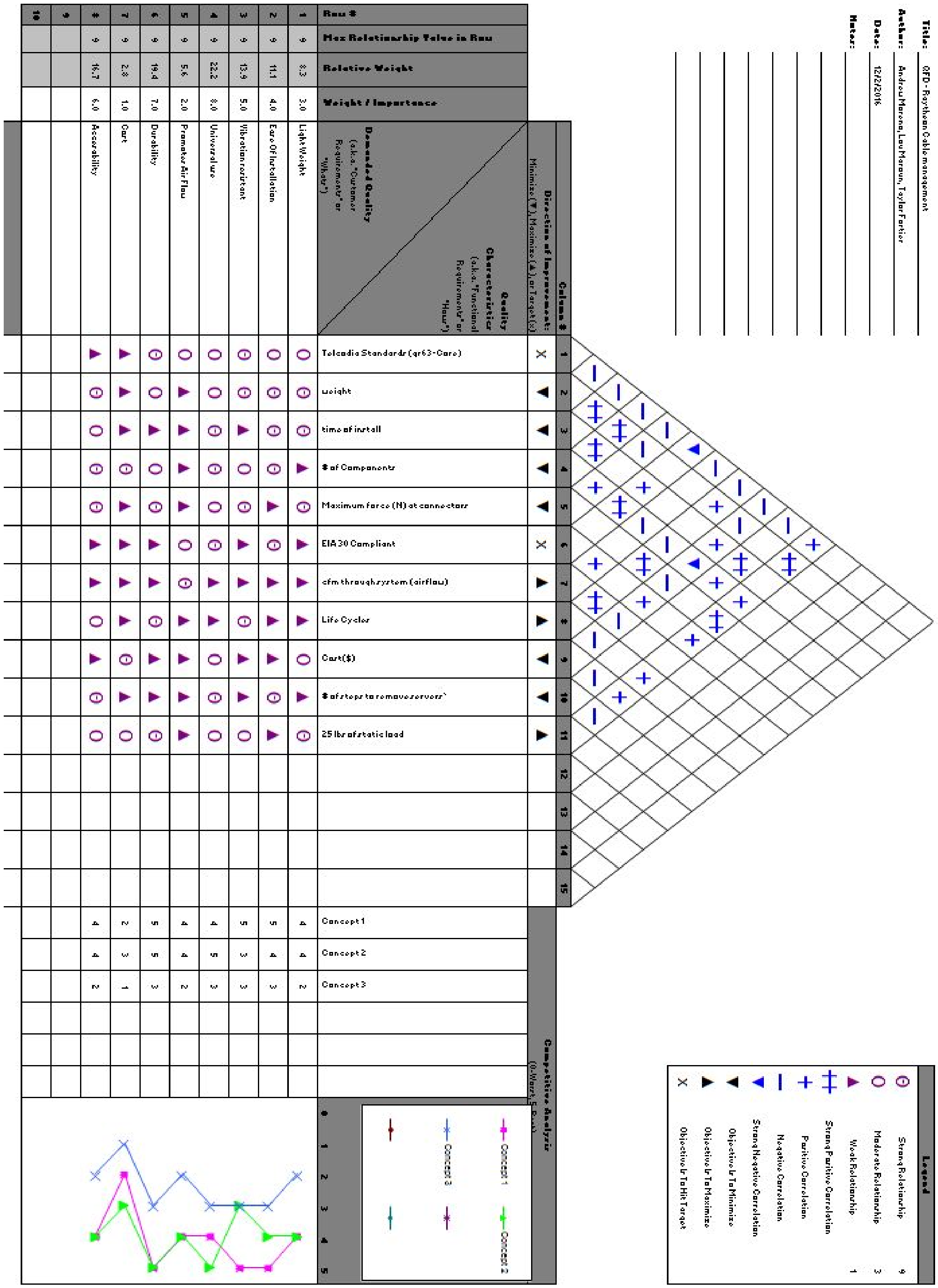


Figure (30): QFD house of quality

Demanded Quality

When Raytheon, presented their problem of cable management, they also had a list of requirements that needed to be met by the solution. It was made clear that the product Stable Cable needed to produce was meant for 'Defense Applications,' meaning that it would be used in extremely tough environments. Most data centers are located in very controlled atmospheres; the data cabinets are stationary and do not fluctuate in temperature. Being on a defense submarine of ship, the environment of Raytheon's data center is cruel. These data cabinets experience vibrations, flexing motions, change in temperature, and a corrosive environment.

The most driving requirement was the need of a universal fit product that could be grabbed off the shelf and easily installed into almost any data cabinet. Raytheon uses a cabinet with industry-standard dimensions; the product must fit these dimensions. The industry-standard rail system in data cabinets is characterized as EIA-30. The dimensions of these rails include the width, height, and hole spacing.

Because the cabinets are used for defense applications, the durability of the cable management system is a high concern. The product that is needed must be able to perform in harsh conditions without possibility of failing due to the importance of the application. The lifespan of the product must exceed the life of the cabinet. The product must create a maintenance-friendly situation if something were to go wrong with a server or management system. This will allow a technician to fix an issue in a time efficient way, reducing down-time and operation cost.

Raytheon designs their cabinets to withstand seismic zone 4 conditions, forcing the cable management system to be able to endure these conditions as well. The cable management product will experience dynamic movement as well as strong vibrations. These forces must be accounted for in choosing an appropriate solution. Any solution that is rendered will be tested using simulation software to ensure that it can withstand these forces. The vibration also poses another problem of resonance in the product; the product must withstand its own natural frequency vibrations. Raytheon also expressed the need for a lightweight product. Since there will be many data cabinets on the vessel, many management systems will be needed. Weight is a large factor on a defense vessel, forcing the product to be light. This will also improve the vibration resistance of the product.

It was made clear that any type of plastic solution was not possible; metal was the only material that Raytheon wanted the product to be made out of. The metal must not be corrosive due to the fact that the product will spend most of its working life on the open ocean in a salty environment. The cost of the product was not a great issue, which expanded our list of possible materials.

Competitive Analysis

It is important to research what current products are offering to consumers. The features of these products are then compared to the requirements of the customer. There is no product currently on the market that caters to defense applications, forcing Stable Cable to compare standard management systems to Raytheon's requirements. The largest companies that were assessed were Panduit, Johnathan Engineering, Neat Patch, and Schroff. Each of the competitor's products were related to the given requirements and given a number from 0 to 5 as to how well they accommodated these requirements. Because these products were not meant for defense applications, they were all deemed insufficient solutions. By researching the competitor's products, our team gained knowledge about how these systems are designed and installed. This knowledge helped in rendering potential concepts.

Functional Requirements

In this section of the house of quality the engineering specifications are listed. These specifics put the customer's requirements into measurable parameters. Each of Raytheon's requirements were broken down into testable specifications. These specifications were then compared to the requirements given by Raytheon. The specification and requirement were rated based on how closely they were correlated. If there was a weak coloration, it was given a 1 in the matrix, a moderate coloration received a 3, and a strong coloration received a 9. The difficulty of each design specification is then rated on a scale from 0 to 10, 0 being the easiest to accomplish.

The weight of the product is an easily measurable variable, measured in kilograms. If the weight of the product was low, then fewer problems would arise. Because of this we wanted to minimize the overall weight of the product. A lower weight makes the product easier to install, more vibration resistant, and easier to maintain. It could also reduce the amount of material needed to produce it, driving the cost down. Keeping the weight down while maintaining the strength is a difficult requirement to meet.

The time of installation was addressed in this section as well, measured in hours. Installation time should be minimized. By minimizing the installation time, Raytheon will spend less in payroll for a worker to mount the system, creating a more efficient work flow. The initial installation time will also be a judge of how long maintenance will take to complete. It is not outrageously difficult to accomplish the installation time low for the product.

Minimizing the number of components correlates with many of Raytheon's requirements. The number of components should be minimized. If there are fewer components, the product will be easier to install, make it more universal, cheaper, and easier to maintain. The fewer components, the lower the installation and maintenance times are. Having fewer components will force each component to be more universal. The fewer components also drive cost down, there will be less parts required, which correlates to less shelf time and space. This task is manageable to accomplish because there are only three planes in which the wires travel on, therefore only three directions will need to be accounted for.

It is important to take the weight of the delicate connector of the cables. The force that the connector experiences is measured in Newton's. My minimizing this force, the life of the cable will be prolonged. The vibrations and motions of the cabinet will not affect the cables as much if this force is minimized. It will be difficult to reduce the force on the connectors due to the fact that there are many wires that need to be accommodated.

It is important that the product follows the industry-standard EAI-30 rail system. These dimensions can be easily researched. This will allow the installation time to be reduced due to the fact that it is widely used and technicians are already trained to work on these rails. By following these dimensions, the product will also be more universal. It is not hard to create a product that follows these dimensions. First the mounting parameters are set, and then the product will be shaped around it, ensuring a proper fitment.

The airflow to the cabinet is important for proper cooling of the servers. There is a lot of heat generated from these cabinets from the large amount of power that is delivered to the servers. The airflow is measured in CFM's or Cubic Feet per Minute. By increasing the airflow inside the cabinet, the internal temperature will be decreased. By decreasing the temperature inside the cabinet, all the components will have a longer working life. This task will be easily accomplished because neatly running wires automatically promotes good airflow.

The longevity of the cable management system is important and needs to be maximized. The fatigue strength of the product will need to be considered. The number of loading and unloading cycles will be used to measure this quantity. By increasing the life cycles of the product, the durability will be increased. This will be difficult to accomplish due to the need of being lightweight. If weight was not an issue then a thicker component could be used, which creates a stronger product.

The cost of the cable management system can easily be quantified in a dollar amount. The cost depends on many variables including production, material, and working life to name a few. Raytheon expressed that cost was not a large issue when considering a solution to their problem, making this a very easy parameter to meet.

Trade-Off Analysis

A trade-off analysis was performed using a table to compare each concept to the design specifications that needed to be met. The data from in the table was from the competitor analysis section of the house of quality. The ranking that each product received was then multiplied by its relative importance level. The total score of each concept was added up and compared. After performing this analysis, concept 1 and 2 were chosen be used, while the third concept was not implemented. Concept 1 best met all the requirements that were given by Raytheon. This concept is for the horizontal positions of the wires. Concept 2 also met the design requirements sufficiently. Concept 2 organizes the vertical positions of the cables. The data showed that using these two concepts in conjunction would be the best way to solve Raytheon's cable management problem.

Table 9: Weight comparison of concepts

Concept	Lightweight	Ease of Install	Vibration Resistant	Universal use	Airflow	Durability	Cost	Accessibility
Concept 1	4	5	5	5	4	5	2	4
Concept 2	4	4	3	5	4	5	3	4
Concept 3	2	3	3	3	2	3	1	2

Table 10: Adjusted weight comparison of concepts

Concept	Lightweight	Ease of Install	Vibration Resistant	Universal use	Airflow	Durability	Cost	Accessibility	Total
Concept 1	12	20	25	40	8	35	2	24	**166**
Concept 2	12	16	15	40	8	35	3	24	**153**
Concept 3	6	12	15	24	4	21	1	12	**95**

Design for X

Design for Universal

As in cable management systems that already exist how a component is incorporated into a data rack directly affects its ability to be used universally within any data rack. The standard rack used in the mark is built EIA 310 dimensions. Rail flanges on the left and right of a rack will have 42U rack height and each you will be 1.75 inches tall. Three holes are extruded in 1U, the holes are .625 inches apart and there is .5 inches between the U directly above or below it. These holes are ⅜ an inch and can be square or circular. EIA racks are 19 inches wide and and the holes are 18.312” apart center to center. Fitting these dimensions for vertical and horizontal component designs would provide universal attachment to data racks however space within a data cabinets is limited. To create a more universal product Stable Cable reduced the footprint of each component. Through research there were were many designs which utilized troughs in their vertical components. Data cabinets typically have around 6 inches of clearance between the attaching face of the EIA rack and the door as well as 3 inches clearance to the right or left of the respective rack flange. Stable cable chose to go with an L shaped flange that provided vertical organization that limit would be any space to the left or right of the EIA rack flange. In their horizontal components Stable Cable will provide various different lengths for equipment inset into the rack, these length will provide a wider range of uses. The holes created on the vertical component utilizes a slot so that wire of any diameter can be used. This concept is also used in the horizontal component were extruded semi circles contain various cable wire diameters and are not restricted in terms of connector diameter. It is also necessary for components used in electrical or electronic product to be RoHS compliant. This means that the following materials can not exceed a certain value of PPM per product, those materials are Lead, Mercury, Cadmium, Hexavalent Chromium, Polybrominated

Biphenyls,Polybrominated Diphenyl Ethers, Bis(2-Ethylhexyl) phthalate, Benzyl butyl phthalate ,Dibutyl phthalate, Diisobutyl phthalate. The PPM allowance of the materials mentioned can be found in the RoHS Regulations document, Stable Cables material choice does not include any of the above materials. Following EIA standards and creating a small footprint Stable cable was able to create a universal and modular set of components.

Design for Serviceability

The goal of any cable management system is improve the serviceability of a data rack. Managing cables in such a way that a technician can easily locate a particular cable is done in general by bundling similar cables together then isolating them close to their termination destination. The vertical component does this well by routing up to 40 cables into 1U through the geometry of the holes. Wire tie slits and industrial reusable wire ties are placed along the face te to secure cables until they have reached their desired rack height.

In the horizontal component design there are 20 different semicircles holes extruded to contain several cables based on their size before they reach their termination destination. Using semi-circles that fit all diameter possibilities allow for different hardware to be accommodated and cables are secured using individually but reusable instrustrial wire tires. When installing these components for the first time or removing components all it takes is the removal of several bolts. Horizontal components are secured in two locations on both rack flanges and the vertical components are secured over a number of connections. Vertical components are attached to both rail flanges first and individual horizontal components are added on top of the vertical components. This method of installation allows both the vertical and horizontal components to share a securing bolt. It is through these element considerations that Stable Cable created a product that can be installed quickly and efficiently organizes the cables for service.

Design for Manufacturability

Many times intricate designs can be used to organize cables within a data rack because the material choice. Stable Cable's durability needs meant that some sort of metal would need to be used which unlike plastic can not be injection molded. This meant that the designs chosen must be simple enough that machining is feasible. While manufacturing our prototypes the only process available to us was the CNC milling machine. While this gives us very accurate dimensioning, in industry this would be very time consuming and expensive. Also hand bending the material after milling proved to be very hard since a brake press was not available, because of this the dimensions were not as true as our CAD models. Stable Cable realized that having the metal stamped into shape, would structurally help the component as one piece component is more sturdy, as well as be more cost effective . The vertical component will have the proper holes dimensions cut into the metal, the EIA rack dimension will be pierced out of the sheet and then it will be bent into an L. The horizontal component similarity will have the mounting holes pierced out through a sheet metal stamp press process before it is stamped into a U shaped bracket. This simple approach reduces machining costs and layover of product but also is more cost effective due to a reduced amount of material.

Design for Cost

To compete in a market flooded with cable organizational tools, Stable Cable knew they had to be more cost effective to ultimately reduce the cost for the consumer. Through market research it was found that injection molding was the most popular method for creating cable organization solutions, and more sturdy vibration resistant solutions were made of metal. What this meant for Stable Cable was that to compete in this market we needed to ultimately be priced somewhere in between the two material choices. In the financial section of this report the competitor's price breakdown can be seen. Injection molding is rather cheap and whereas solutions marketed as vibrational resistant solutions were rather expensive, so Stable Cable had about a 60 dollar window between the two material choices. Aluminium 6061-T6 is fairly cheap despite its strength so this was Stable Cable's material choice. Then we tried to make manufacturing related decisions during the design process. That meant eliminating complex shapes, extra material, labor costs and ultimately anything that did not provide a significant advantage and warranted spending more money. The final product created by Stable Cable is a simple yet strong solution that came in slightly above the injection molding solutions and significantly above the vibrational resistant solutions.

Design for Durability

Designing for durability was the ultimate goal for Stable Cable during the fall semester. Once research into cable management systems had developed Stable Cable began researching into Telcordia GR-63. Telcordia GR-63 is a set of standards in data centers that provides a set of rules for certifying data racks. These standards include subjecting components to waves of force equivalent to 8.3 Richter Scale Earthquakes. Telcordia Standards dictate that the components be subjected to low-level sine sweeps between 1- 50 hz and then the component is subjected to waveform VERTEQII up to 50 hz. As displayed in the Enginnery Analysis section components were subjected to the more demanding waveform test with increased frequency of 500 hz to insure the component would not fail under any circumstances. As the semester progressed our sponsor informed us that load testing our prototypes at 10x gravity at an average of 10 lbs per 1U would be sufficient for testing for frequency loading. Once the simulations were successful our group statically loaded our prototypes and used Team VIBCO's vibrator to confirm our products durability during vibrational loading. One element that was introduced to help durability during conception was reducing the weight of the component. Reducing the weight would ultimately reduce the mass which contributes directly to the forces felt by the component. The oscillations felt by the component push and pull the component in different directions. Reducing the mass reduces the force or gravity and ultimately reducing oscillating forces forces Finding the stress and displacement caused by these powerful waves gave Stable Cable numerical evidence to prove its structural integrity.

Project Specific Details & Analysis

The target market Stable Cable's cable management system caters to is any data center large or small throughout the United States. The product is strong enough to handle all seismic zones contained in the U.S. making it desirable in especially in zone 4 where these conditions are at the worst. The Stable Cable product also caters to defense applications, making Raytheon and Electric Boat possible purchasers. As of 2015, there are over 3 million data centers in the United States. Each data center, depending on the size, will need some type of cable management system installed in their cabinets. The number of data centers keeps increasing, creating a market demand.

The main focus of Stable Cable's product was to cater to the needs of defense applications. Products in defense applications must be able to endure extreme conditions. The forces the product must withstand are constant dynamic motion, vibrations of seismic zone 4 areas, and a corrosive atmosphere. Raytheon currently does not have a universal product that they can use when running cables inside their data cabinets; this is because no company offers a product strong enough for their use. Instead, a custom system must be designed for each cabinet, increasing labor and material costs. By providing Raytheon and other defense companies with a universal solution would save them both time and money. It is estimated that Raytheon alone produces 1000 data cabinets per year, most of these cabinet require more than one cable management component. Assuming that the average number of cable management components inside a data cabinet is five, it can be concluded that Raytheon will require 5000 components annually. Stable Cable's management system cannot offer a solution to all these applications however. If Stable Cable's product can cater to 70% of the cabinets, then Raytheon alone will require 3,500 components annually.

Stable cable will use the marketing strategy of being the toughest universal cable management system on the market. This will especially appeal to the large number of data centers in California, which is a seismic zone 4 area. The number of data centers is constantly growing, creating a demand for cable management systems country wide. In 2015, over one million new data cabinets were sold by the leading brands in the market. These brands include HP, Dell, IBM, and others. Estimating that the average cabinet will require 5 cable management components creates a need for five million components annually. If stable cable could vend to 5% of the market, the total number of units sold would be 250,000 units.

A survey could be performed to ask heads of data centers questions to give information about cable management needs. These questions would help determine the market price of Stable Cable's units, as well as how appealing they are to consumers. Possible questions could include:

Does a stronger cable management system make it more appealing than what is currently on the market?

Would you be willing to pay more for a cable management system that is much stronger than the competition?

What would be the maximum cost per unit you would pay for each vertical and horizontal component?

Detailed Product Design

Stable Cable produced a two piece solution to Raytheon's cable management problem. One piece is responsible for the horizontal running of the wires, while the other is for the vertical running of wires. Each product has been tested and confirmed that it has met all the requirements that Raytheon has provided. These requirements include a product that is lightweight, reliable, accessible, can be universally used in most data cabinets, and strong enough to withstand a defense application setting. When choosing a final design, all these criteria were considered. These requirements shaped the initial concepts into a final design.

The products that are to be created must follow the industry-standard dimensions for data cabinet mounting rails. By following these dimensions, the products are able to be applied in many applications. The industry-standard rails are named EIA-30, a guideline that not only the data cabinets follow, but also the servers inside. The rails are the mounting points for all servers; therefore an additional mounting point for the cable management system was deemed unnecessary. The vertical distance between servers is measured in a unit denoted as ‘u’. One u is 1.75 inches of vertical displacement on the rail. Most servers are 1 to 2 u’s in height, forcing the horizontal component of the cable management to have the same height. The mounting holes for an EIA-30 rack follow a repetitive, vertical pattern throughout the length of the cabinet. For every u distance down the rail, there are a set of 3 mounting holes. The distance from the upper edge of the top hole to the lower edge of the bottom hole is 1.75”. From center to center, these two holes measure a distance of 1.25”. The mounting hole between the upper and lower is 0.625” center to center from each hole. The dimensions of these sets do not change, however between each u height; the sets are spaced closer to one another. Between two sets of mounting holes, the vertical distance from center to center of the holes reduces from 0.625” to 0.5”. By doing this the cabinet can be more tightly packed with servers and other components. Because of this, it is essential to create the horizontal cable management piece with a height of 1.75”. The horizontal width of the mounting points for EIA-310 racks is 18.31 inches from center to center, with an uncertainty of 0.06 inches. These mounting points are either square or circular holes. The square mounting holes measure 0.38”x.038” and the diameter of the circular mounting holes is 0.279”. The circular holes are threaded with a #12-24 or #10-32 thread pattern.

The products that were tested by Stable Cable catered to the rack system with square mounting holes. The loading analysis showed that the mounting points of the products did not experience a high stress, therefore it can be concluded that the products will perform the same way with either square or circular mounting points.

The material that was chosen for both the horizontal and vertical components of the cable management system is Aluminum Alloy 6061-T6. This material was chosen because its properties satisfy the needs of Raytheon. Al6061-T6 is relatively inexpensive, easily machined, and resists corrosion. Its mechanical properties also coincide with the requirements of Raytheon. This alloy is strong enough to handle the weight of the cables, as well as handle the dynamic movement that the data cabinets will experience in defense applications. Because the cables will be moving and vibrating constantly, the cable wear must be considered. Have a cable moving on bare metal makes it susceptible to wear and fraying. To account for this, all cable-component interfaces of each component will be covered in plasti-dip, an inexpensive, rubber-like material. Not only will this material provide protection against wear to the cables, but will also absorb vibration energy. Absorbing the vibrational energy that is experienced in defense applications will prolong the life of the cables and connectors. This is especially important when dealing with fiber optic cables because they are more fragile than other cables. The CAD drawing can be viewed in the Appendix, Figures 39 and 40/

Horizontal Component

When designing a horizontal component, the dimensions of the EIA-310 rack were considered. All mounting points for this piece follow these dimensions. For the piece to be used universally, it must follow these guidelines and also be able to handle a large number of cables. Raytheon uses some servers in their data cabinets that connect to 40 wires. These wires are not just standard Ethernet cables, but also include fiber optic cables as well as power supply cables. These cables are heavier than standard consumer cables; therefore the piece must be strong enough to support them. After using Solidworks and Abaqus to perform stress analysis, the optimal thickness of the component was chosen to be 0.15”. This thickness provides enough support for the load and vibrations that will be experience, and also keep the piece lightweight. The size of the connector plugs for these wires must also be considered. Some connectors have a diameter of over an inch, making it more difficult to run them. To accommodate for the larger diameter connects, the top layer of the horizontal piece does not require the cable to be snaked through an opening; instead it can be laid on top and guided through a grove. The top layer is designated for cables with large diameter connectors. The bottom layer of the horizontal piece is designated for cables with smaller connectors. These cables will be snaked through the middle of the piece, increasing the capacity of wires the piece can handle. To secure the wires to the cable management piece, wire ties will be used. The horizontal piece has many mounting points for these cable ties to ensure the cables are mounted securely to it. The cables are guided using slots that are covered in Sorbothane to reduce wear and vibration. Fiber optic cables cannot be sharply bent when being run through a cabinet because they use light to transmit data. The bending radius of fiber optic cables is a function of the diameter of the cable. The bending radius is usually 4 times the diameter of the cable itself. To accommodate this, the mounting points for the cables are spaced far enough away to gently bend the cable into position during installation.

Vertical Component

The cable will be guided down the cabinet by a vertical component with a comb like structure. This vertical component will be attached to the cabinets using the EIA-30 rails, making it easy to install for the technician. The length of this component measures 42u. The quantity of this component depends on the size of the cabinet. Data cabinets can range up to 42u, which equates to just over 6 feet. By making shorter lengths of this component, the installation time will be lessened. The installation technician will not need to make cuts of do any customization to the product to make it fit; instead it will just be a bolt-on application. The wires will be run tangent to the component down the length of the cabinet and be attached using wire ties. Slots for these wire ties are machined into this piece to ensure the security of the cables. Every surface that the cables contact the piece will be coated in Sorbothane to offer protection against wear and vibration. The thickness of this vertical component will be 0.15”, the same as the horizontal piece to simplify the manufacturing process.

Engineering Analysis

Raytheon requires a cable management system that can withstand the harsh environment presented in a defense application. To ensure that Stable Cable's cable management system can withstand these conditions, computer analyses were performed. The focus of the analysis was static loading of each component. Reactions to vibrations were also tested and observed. Raytheon required a product that can withstand seismic zone 4 conditions. An object in seismic zone 4 conditions will experiences an acceleration of 100% of gravity. Therefore each fully loaded component must be able to handle and oscillating force of 100 Hertz. The resonance of each component was also observed when it experiences its natural frequency vibration.

Horizontal Component

Each component of the cable management system will be subject to static loading. To approximate the force that will be experienced by each piece, simple calculations were used. The weight of a data cable can range from .1 to .2 pounds for a three foot section of wire, including the connector. Multiplying this weight by 40, the maximum number of wires that can be supported by the horizontal component gave a total weight of 8 pounds. This force is distributed along the surfaces of the top and bottom rows of cable grooves. The cross-sectional area of this surface was then calculated and found to be 13.96 square inches. The pressure that is experienced by these surfaces can then be calculated by dividing the total weight by the cross sectional area. The distributed pressure along the surface was found to be 0.573 pounds per square inch. The following equations those used to calculate this data.

$$\boldsymbol{W} = 40cables \times .2lb = \boldsymbol{8lb}$$

Equation 1

$$A_{support} = .6in * 16.7in = 10.02in^2$$ Equation 2

$$10.02in^2 * 2\ levels = 20.04in^2$$ Equation 3

$$A_{cable\ ties} = .4 \times .38 = .152in^2$$ Equation 4

$$.152in^2 * 40\ cable\ ties = 6.08in^2$$ Equation 5

$$A_{total} = A_{support} - A_{cable\ ties}$$ Equation 6

$$\boldsymbol{A_{total}} = 20.04in^2 - 6.08in^2 = \mathbf{13.96in^2}$$ Equation 7

$$\boldsymbol{P} = \frac{F}{A} = \frac{8lb}{13.96in^2} = \mathbf{.573}\frac{\boldsymbol{lb}}{\boldsymbol{in^2}}$$ Equation 8

The boundary conditions that were used to secure the horizontal component were then implemented. The mounting holes inside surfaces were restrained from any motion in the X-Y-Z planes and were also restrained from rotating in any plane. Doing this replicated the use of a bolt to attach the component to the rails of a data cabinet, giving the most accurate results. The mechanical properties of Aluminum 6061-T4 were then applied to the component. This data was preloaded into the Solidworks database and simply had to be selected. The test was also run with ABS plastic to compare Stable Cable's product to what is currently on the market. Finally an analytical mesh was applied to the component. The mesh quality was very fine to ensure the most accurate results. The mesh consisted of 86,463 nodes which separated the part into 48,426 elements to be analyzed.

The first test ran was on the horizontal component made from ABS plastic. Under the calculated load of 0.573 pounds per square inch, the factor of safety was only 1.163, with a maximum deflection of 2.254mm. This factor of safety and displacement are unacceptable for use in defense application. After continuing the analysis with larger and larger loads, the breaking point of the piece was found to be 2.5 pounds per square inch.

The analysis was then performed on the component using Aluminum 6061-T4. The first test load was the calculated 0.573 pounds per square inch. Under this load, the part performed much better than the ABS. The factor of safety increased to 20.53 and the maximum displacement was .0978 mm. The maximum displacement occurs at the midpoint of the component, but is almost negligible at this loading. These statistics of static loading are acceptable for use in a defense application. The testing then continued with increasing loads until the component failed. The critical load was 12 pounds per square inch, a 20 times larger load than what the component will experience under normal conditions. Under this high load, the maximum displacement was found to be 2.05mm at the center point of the piece

Figure (31): Solidworks generated property chart

The Solidworks software showed the stress concentration areas, which is useful during redesign. The highest stress occurred at the middle and outermost cable grooves. These areas are the first to fail and could be redesigned to be stronger if needed. The inside corners of the connecting arms also experienced higher stress than the rest of the component. All stresses are in the acceptable range; however the design can be changed to strengthen all these areas.

The component was then transferred into Abaqus to compare the results with Solidworks. The same loading, material, and boundary conditions in Solidworks were used in Abaqus. The analytical mesh was changed to a 10-Node Quadratic Tetrahedron for a more accurate result. When loading the part to 0.573 pounds per square inch in Abaqus, the results came out to be very similar to the results given by Solidworks with only a 6.5% discrepancy. The factor of safety was reported to be a satisfactory 19.

After performing the static load tests, vibration analysis was then observed using Abaqus. The unloaded component was fixed at the same surfaces, and meshed with the same 10-Node Quadratic Tetrahedron as the static loading. The frequency of vibrations that the component experienced was observed at ranged from 0 to 500 Hertz. During the analysis, the resonance of the material was accounted for. The analysis showed that at the 500 Hertz, the maximum vertical displacement of the component was .473 inches, and there was an acceptable amount of resonance at the component's natural frequency.

After redesigning the horizontal component, the same load and vibration tests were performed in the same manor as the original design. These test included the static loading of 100 pounds evenly distributed over the top surface of the horizontal component. As expected, the component held up very similarly to the original design. The 100 pounds of static load was to simulate a 10 pound static load undergoing 10 g's of force. The 10 g's of force is equivalent to a normal shock while being used in a defence application. All three arm lengths of 3, 5, and 7 inches were testing using the SolidWorks simulation feature. The maximum stresses experienced by the 3, 5, and 7 inch components were 224.8, 285.6, and 306.8 N/mm^2, respectively.The maximum displacements under full load were found to be 2.731, 1.146, and 4.174 mm for the 3, 5, and 7inch arms respectively. These theoretical numbers were found to be acceptable values, therefore manufacturing of the redesigned components could be initiated.

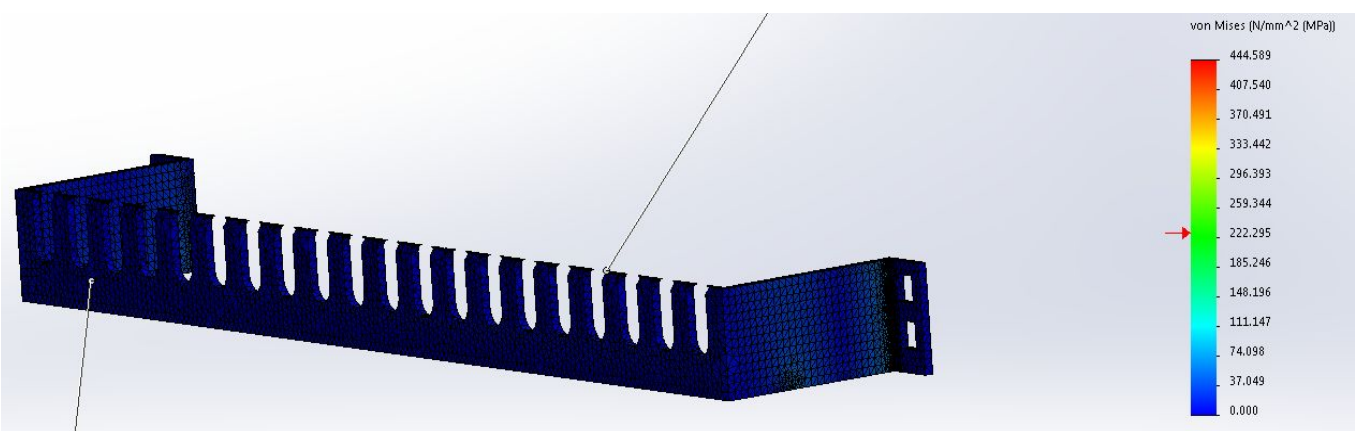


Figure (32): Von misses stress - Horizontal (3 inch arms)

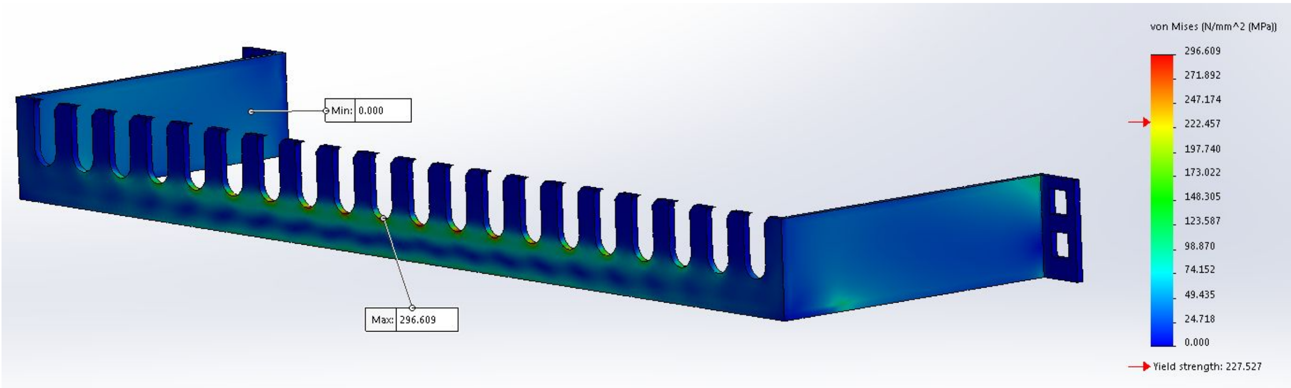


Figure (33): Von misses stress - Horizontal (5 inch arms)

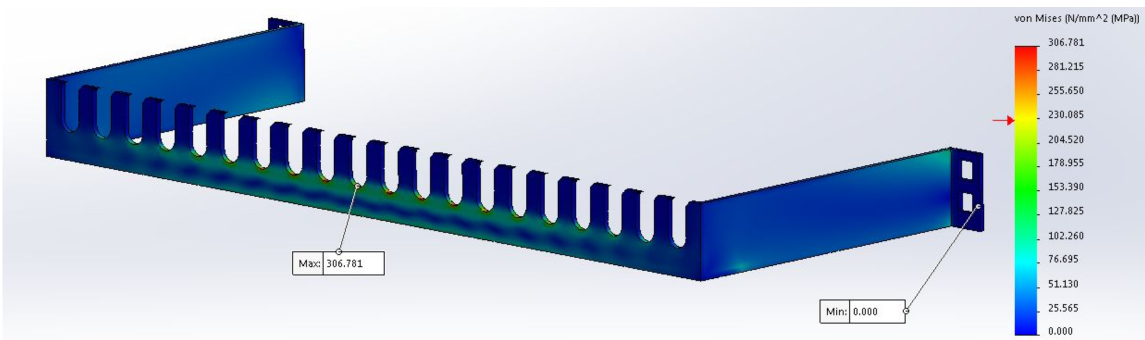


Figure (34): Von misses stress - Horizontal (7 inch arms)

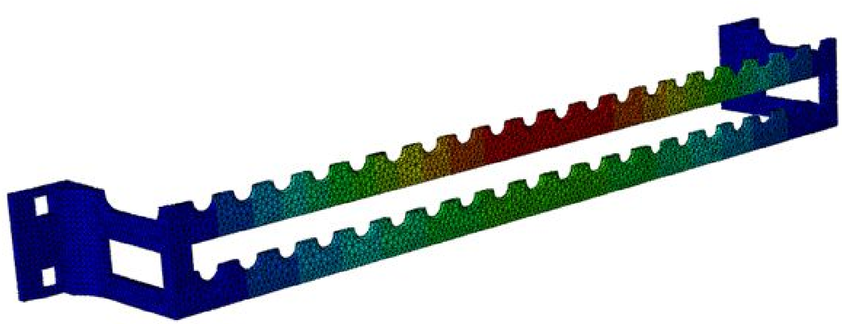


Figure (35): Stress from 500 Hz Vibration

Vertical Component

The testing of the vertical component of the cable management system included both static loads and vibrational effects. The length of the component that was tested is 42u. To calculate the force that will be exerted on this component, a few assumptions were made. The assumptions are each cable weighing an average of 2 pounds, and that this vertical component will hold 500 cables. This equates to a distributed load of 1000

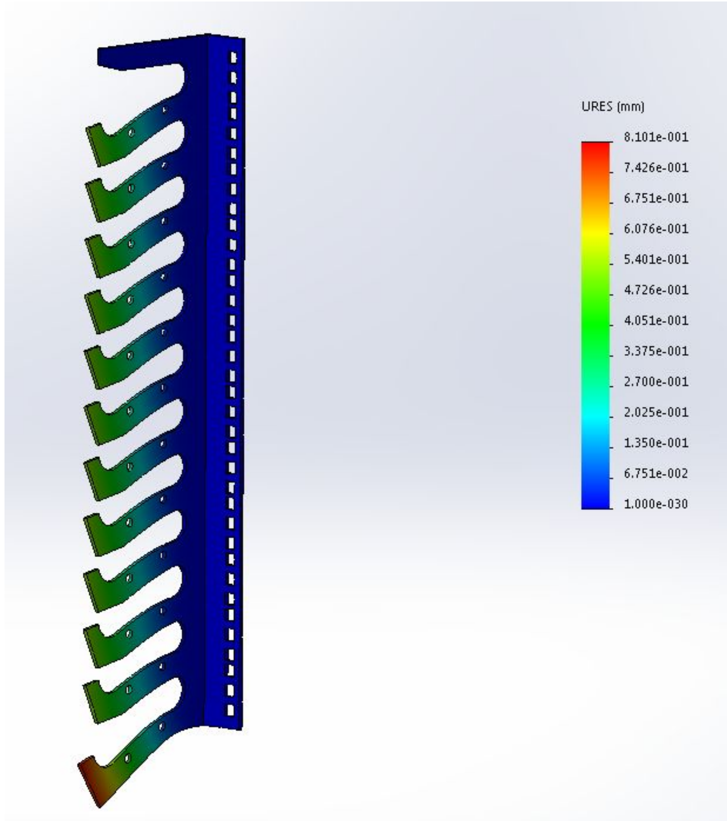
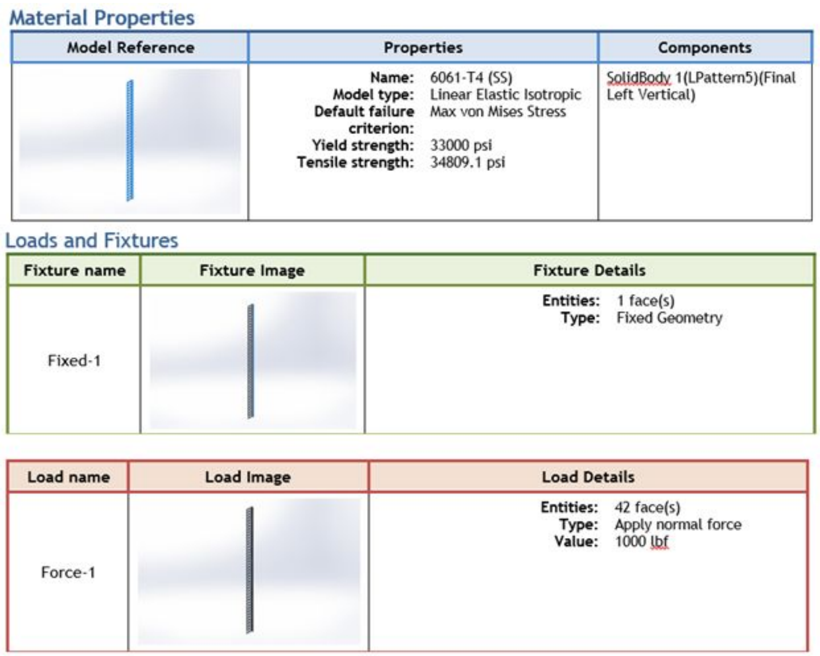


Figure (36): Von Mises Stress - Vertical

pounds throughout the piece. This load was implemented using a many concentrated forces being applied to the top surface of each rung throughout the component. A fixture was added to the surface that meets the rail. This fixture prevented motion and rotation in all three planes, simulating it being bolted to the EIA-30 rail. The material Aluminum 6061-T4 was then applied to the piece. An analytical mesh was then applied to the component. The mesh quality was very fine to obtain the most accurate results. A total of 91168 nodes were used to create 42733 elements to be analyzed.

The Solidworks simulation reported that the factor of safety for this component under a 1000-pound load was 11.4, a very comfortable level. It was also reported that the



Material Properties

Model Reference	Properties	Components
	Name: 6061-T4 (SS) Model type: Linear Elastic Isotropic Default failure criterion: Max von Mises Stress Yield strength: 33000 psi Tensile strength: 34809.1 psi	SolidBody 1(LPattern5)(Final Left Vertical)

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		Entities: 1 face(s) Type: Fixed Geometry

Load name	Load Image	Load Details
Force-1		Entities: 42 face(s) Type: Apply normal force Value: 1000 lbf

Figure (37): Solidworks generated property chart - Vertical

maximum vertical displacement of the rungs under the loading is 0.0017 inches. This piece performed as expected, it stayed virtually unreformed under static loading. To perform the vibration analysis, the horizontal component was loaded into Abaqus. The fixtures and loading, and material remained the same as the Solidworks simulation. The analytical meshing was changed to a very fine 10-Node Quadratic Tetrahedron mesh. The vibration analysis was performed from 0 to 500 Hertz. Abaqus reported that the maximum displacement of the component under vibrations of 500 Hertz to be .45 inches.

It was also reported that the component did not experience any resonating vibrations when exposed to its natural frequency.

Simulations with Bolt Assembly

Knowing that we were going to fabricate our designs with a 3 piece assembly due to our limited manufacturing capabilities, tests were done for the the each of the different lengths. First we wanted to make sure that our 7 inch original design was capable of handling the loads, this of course is the length most vulnerable to loads due to the toque the loads create. Once again based on Raytheon's requested we tested the designs to handle loads of 100 lbs static which is 10 lbs of cables amplified by 10 g's. When this test was done to the 7 inch Original Design we saw max deflections distances of 1.02 mm, and max stresses of 180.417 N/mm^2 at the center. This was deemed an acceptable deflection distance as well as a acceptable max stress since the yield strength is 620.422 N/mm^2. Images from the Solidworks Simulations can be seen in the figures blank and blank below.

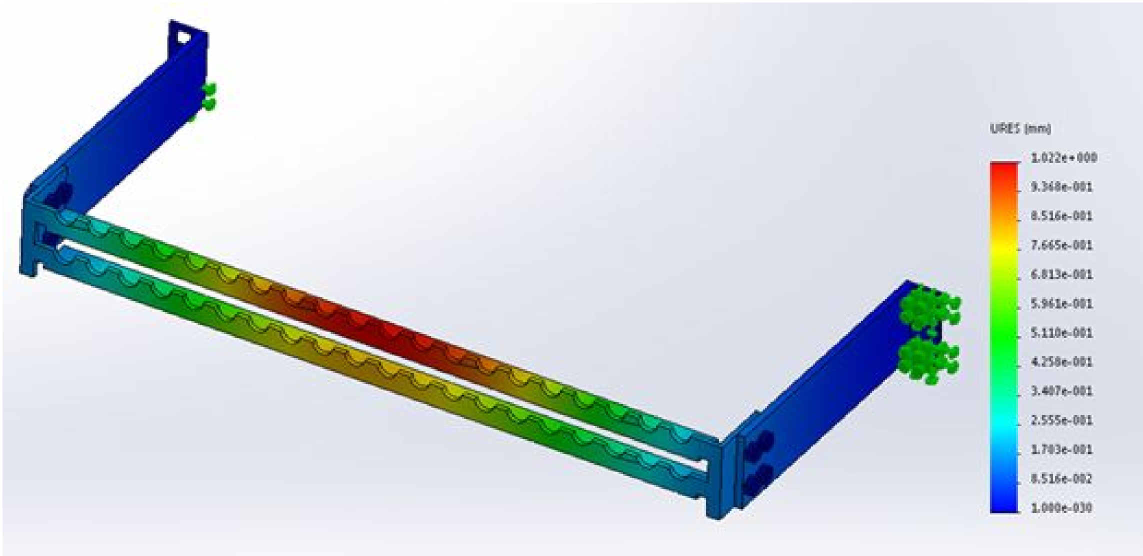


Figure (38) : 7 inch Original Design Displacement Results

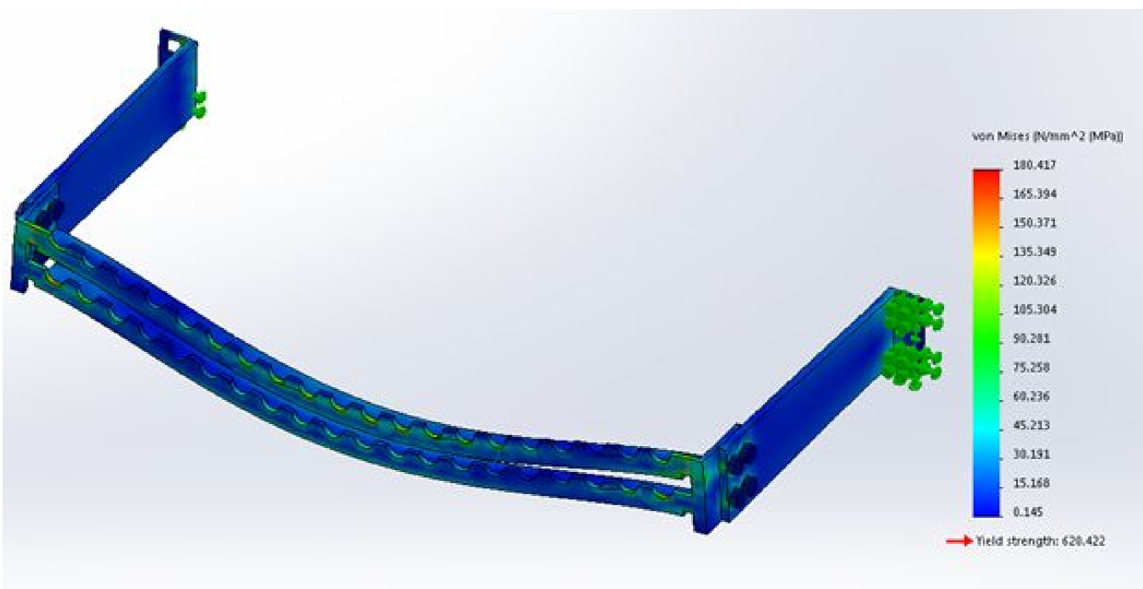


Figure (39) : 7 inch Original Design Stress Results

Next we proceed to test all of the redesigns starting with the 3-inch 3-piece assembly. Here the 3-inch redesign experienced max deflection of 2.731 mm and max stresses 2.248x10^8 N/m^2. These were also deemed acceptable as the yield strength is 2.75x10^8 N/m^2. Images from these simulations can be seen in the figures blank and blank below.

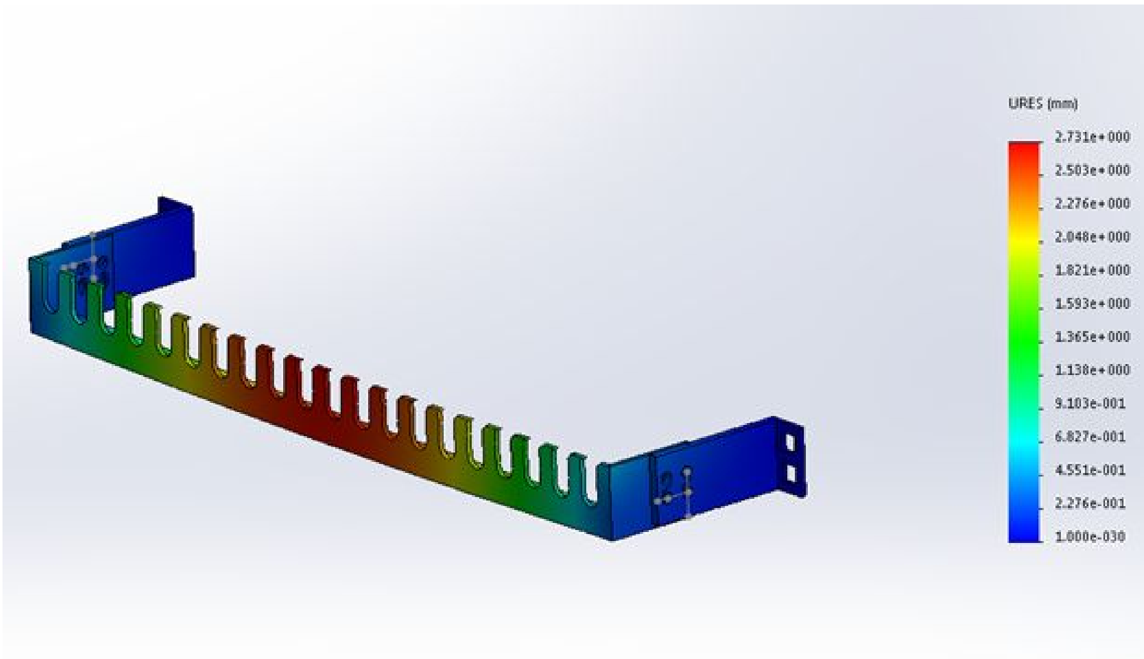


Figure (40) : 3 inch Redesign Displacement Results

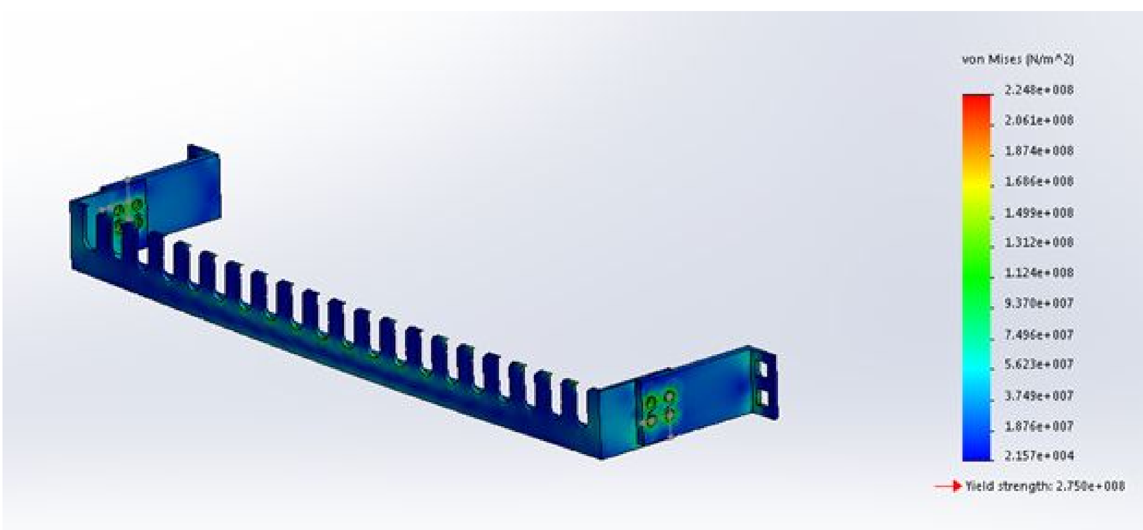


Figure (41): 3 inch Redesign Stress Results

For the 5-inch redesign max deflections values of 1.146 mm were seen as well as max stresses of 2.356×10^8 N/m^2. Once again these were deemed acceptable as the yield strength of 6.204×10^8 N/m^2 was not reached. Simulation images for these tests can be seen in figures blank and blank below.

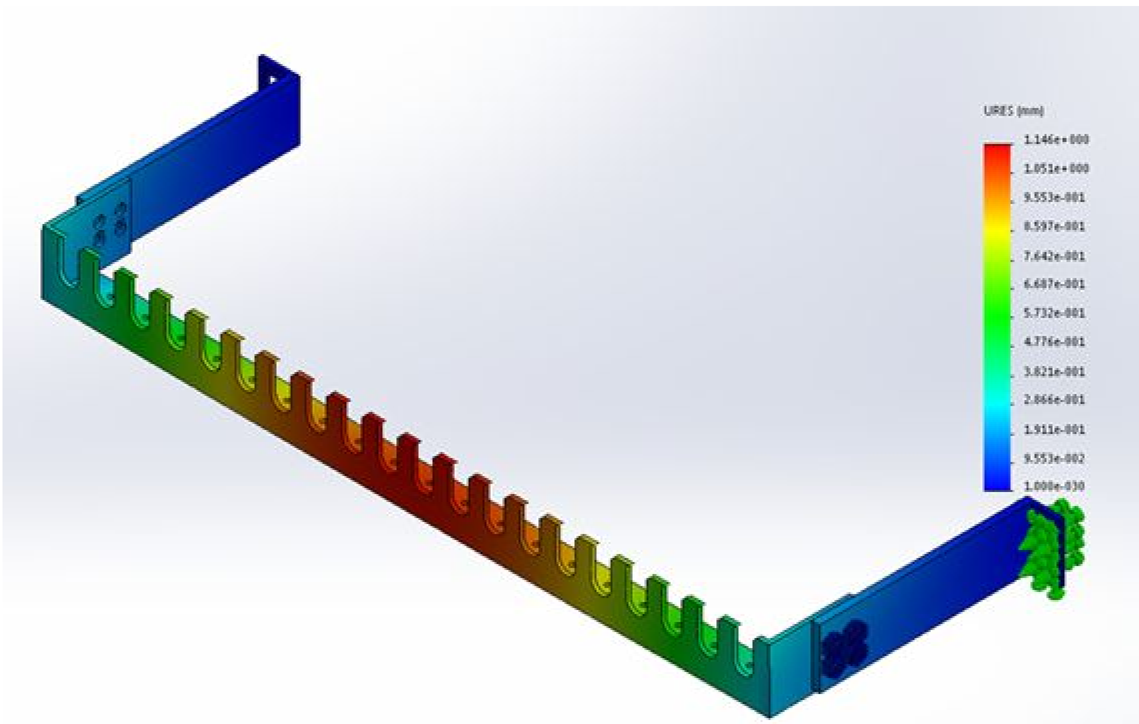


Figure (42): 5 inch Redesign Displacement Results

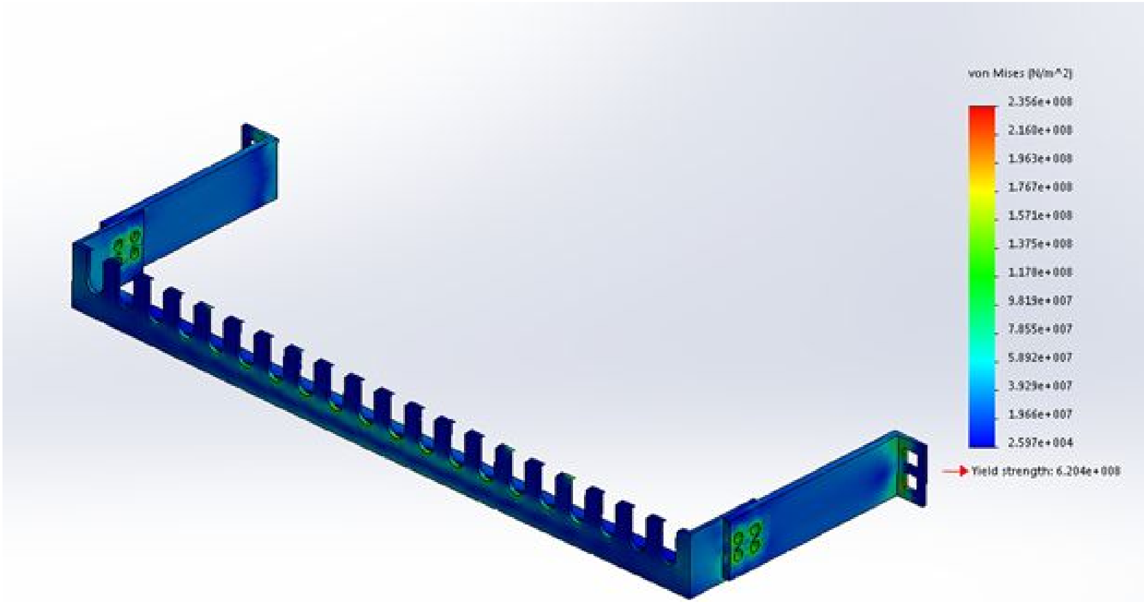


Figure (43): 5 inch Redesign Stress Results

Finally, we tested the 7-inch 3-piece assembly which we knew would take the most stress due to torque. Here the max deflection was 4.174 mm and the max stress was 2.9642×10^8 N/m^2. These results were seen as acceptable but not favorable. Since the max stress was more than the yield strength there was some concern however upon inspection we noticed that the max stress was experienced not at the center but where the securing bolts would be placed. We found this acceptable because when attached to the EIA rack with bolts, the forces would be better distributed around the surface area of the bolt and nut, taking the force away from this area. The images for these simulations can be seen in figures blank and blank below.

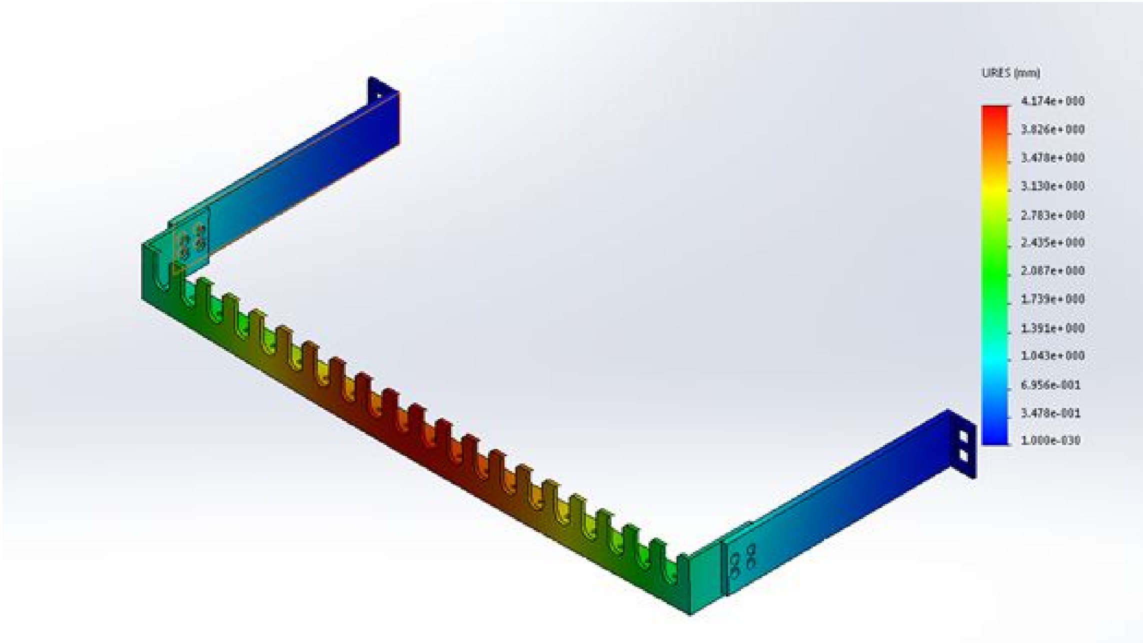


Figure (44): 7 inch Redesign Displacement Results

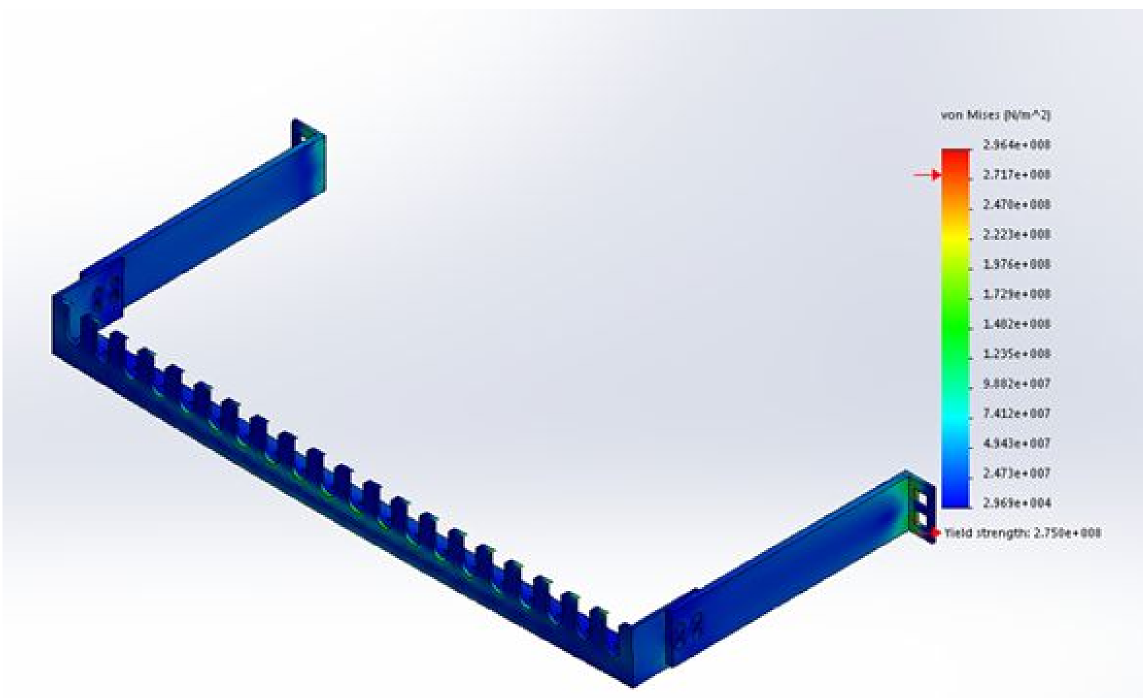


Figure (45): 7 inch Redesign Stress Results

Vertical Component Testing for Raytheon's Standards

For the vertical pieces a load of 100 lbs. was placed on each rung, which was due to each horizontal component take 100 lbs. From testing our original design, we saw a max deflection of .315 mm which was significantly positive feedback. For max stresses we saw 1.189×10^8 N/m^2 which was also significantly positive feedback considering the yield strength was 2.750×10^8 N/m^2. Original vertical design simulations can be seen in the figures blank and blank below.

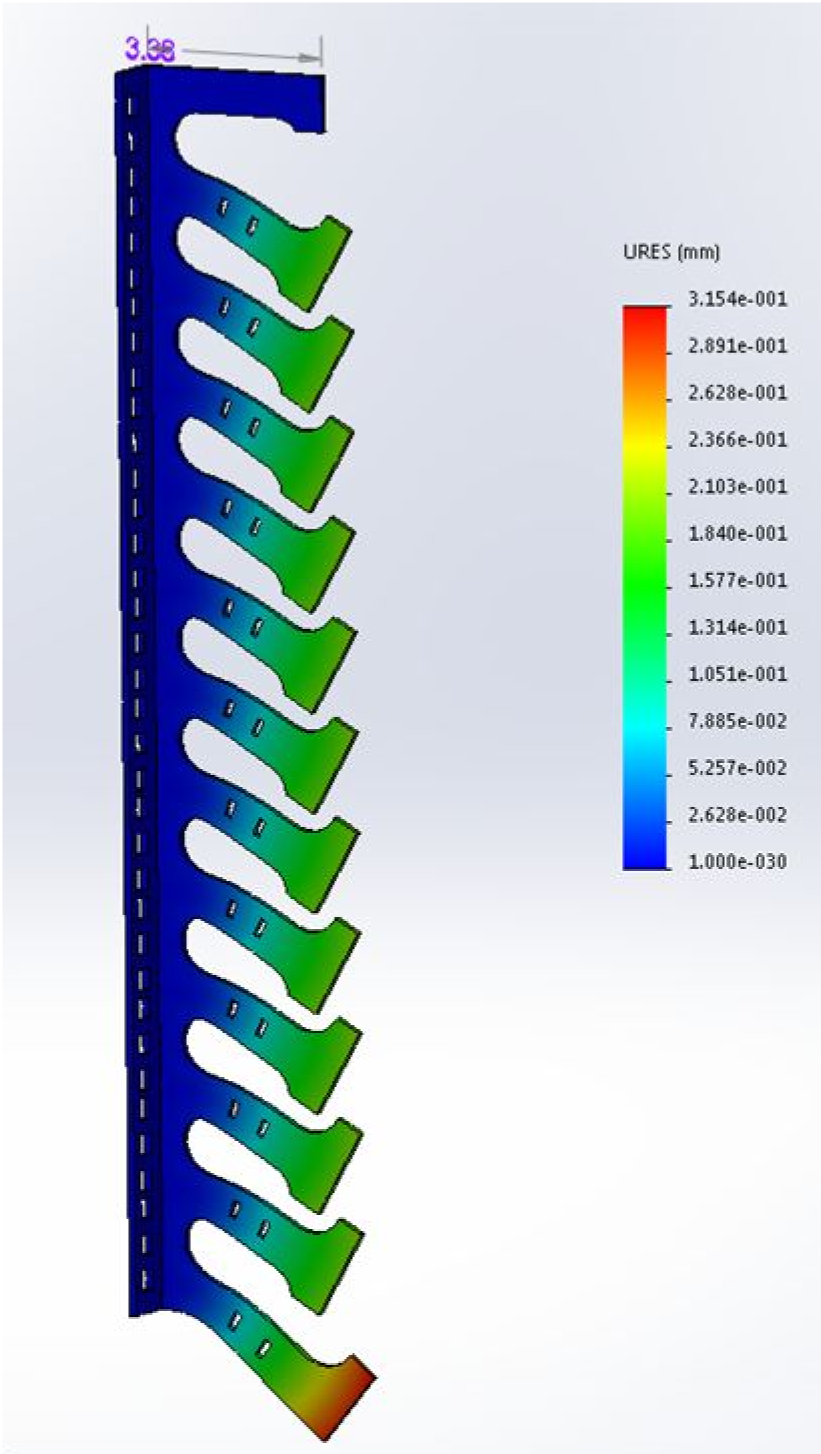


Figure (46) : Original Vertical Displacement Results

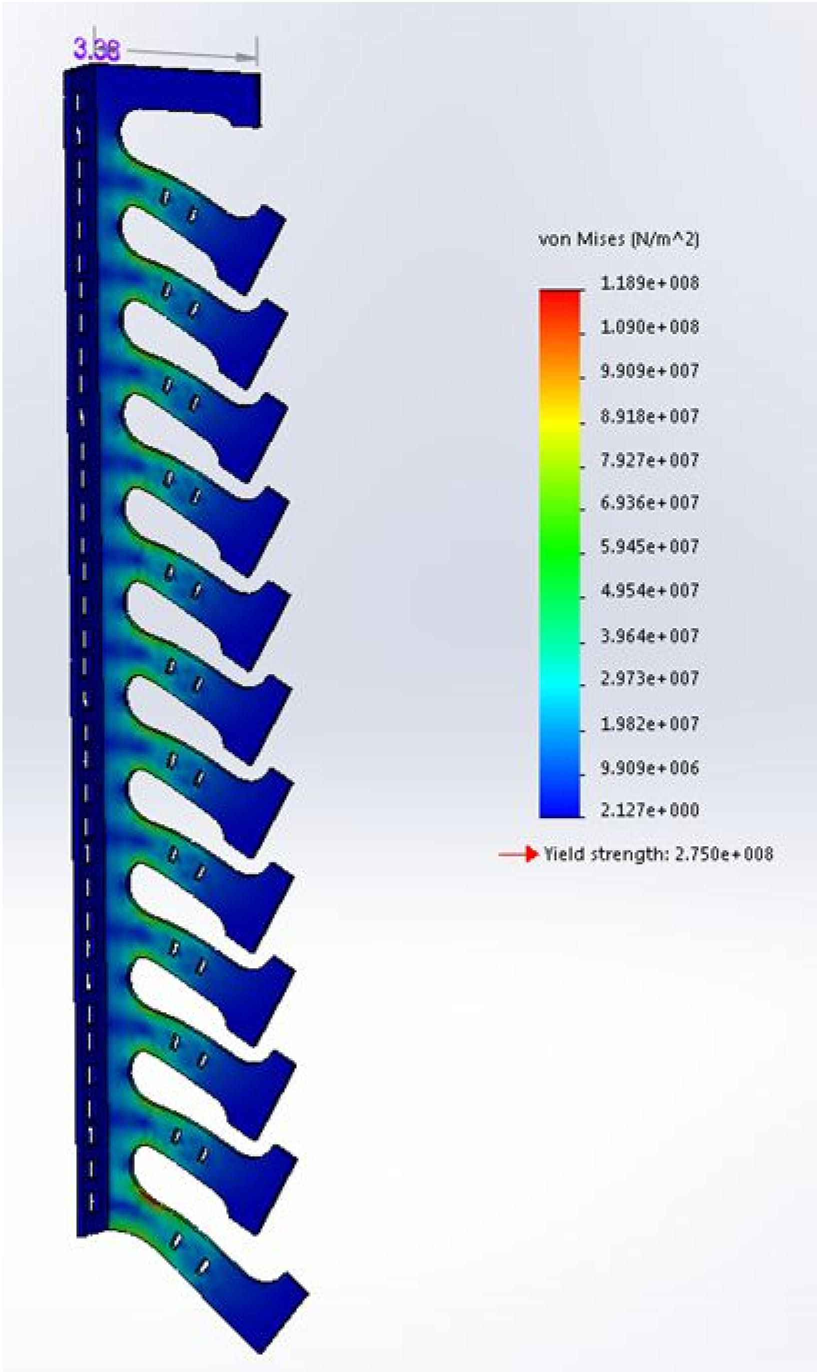


Figure (47): Original Vertical Stress Results

Finally, these tests were replicated on the vertical redesign. These results were also positive as the max deflection was still only .8101 mm and the max stresses that were seen were 1.386×10^8 N/m^2 still below the yield strength of 2.750×10^8 N/m^2. These figures can be seen below.

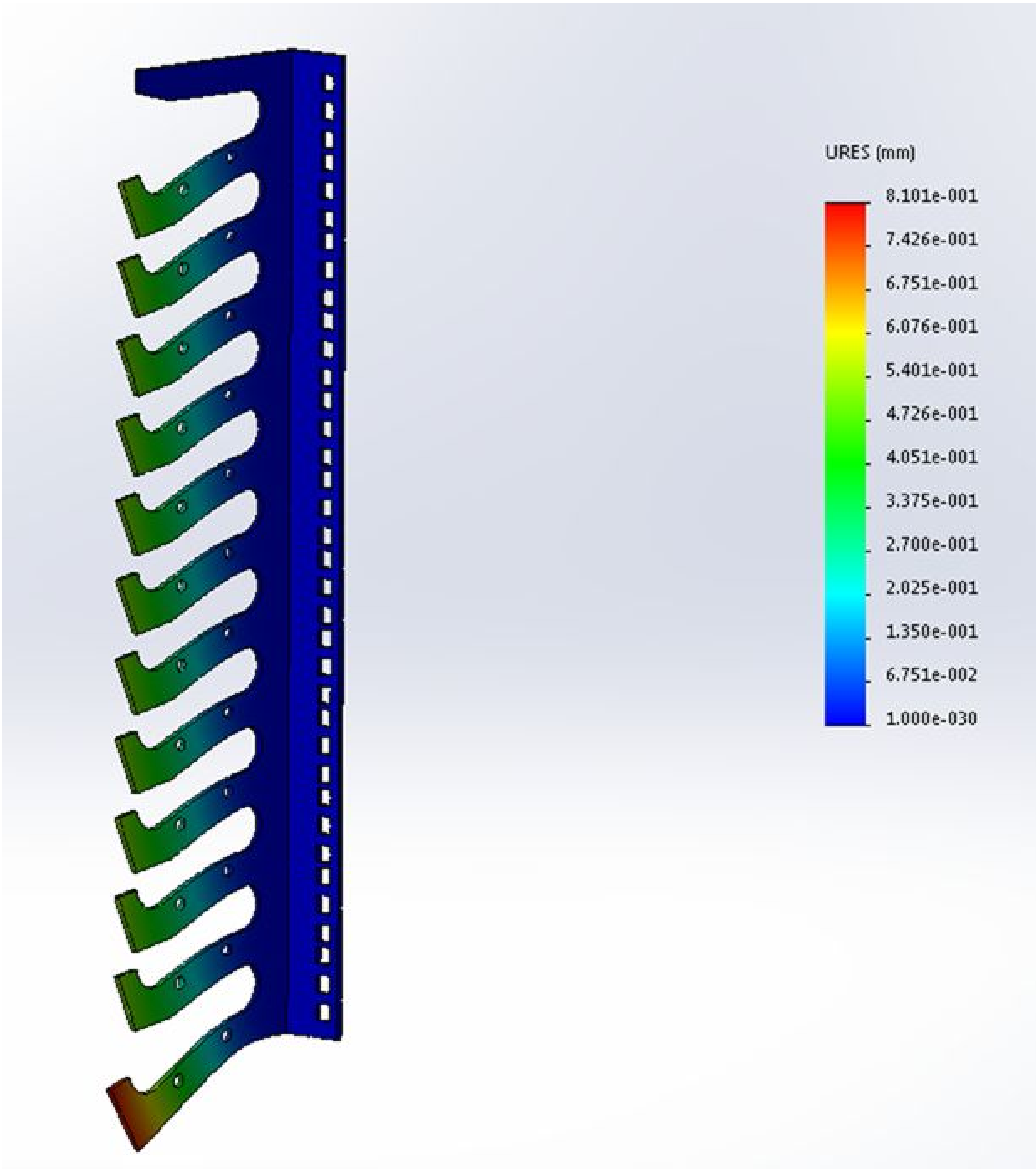


Figure (48): Vertical Redesign Deflection Results

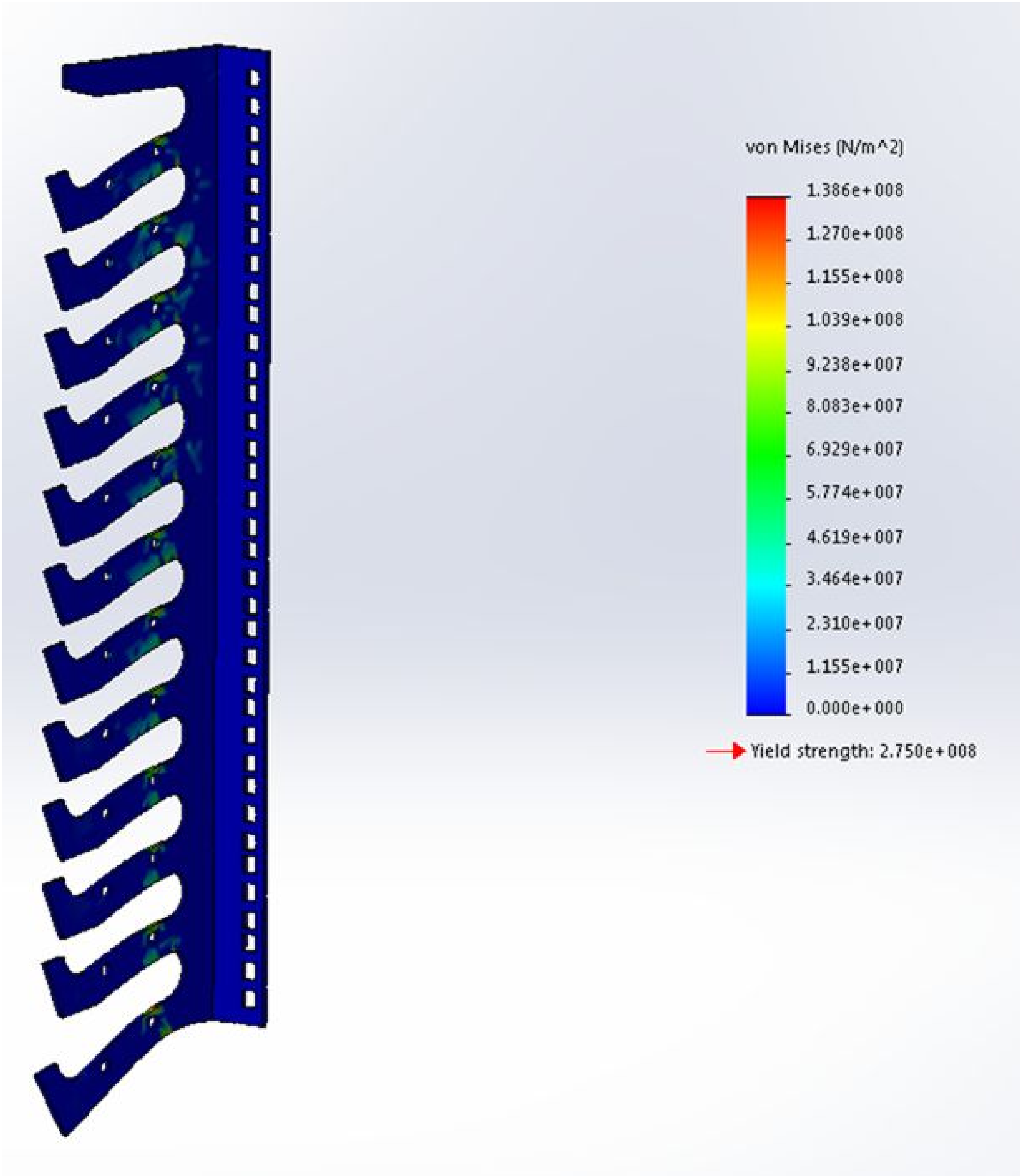


Figure (49): Vertical Redesign Stress Results

Build / Manufacture

The first step to manufacturing the prototype was ordering the proper materials. To order the materials, the team was required to submit order forms to Professor Nassersharif and the teachers' assistant Alex. Once the materials arrived, the team had to convert the SolidWorks drawings into CNC files that the Laguna IX Pro could read. The machine was then set for aluminum cutting and run until the cut was complete.

Once both parts were complete, they were removed from the CNC and sanded. The edges of the material were extremely sharp so sanding in each cable cavity was required by table sander. Once sanded, the two pieces were bent into place. Using a table clamp and rubber mallet, the material was bent into the proper shape. This was originally done by heating with a torch along the bend line, but this tended to damage the material and make it more susceptible to snapping. Once bent into place, the material was dipped in bath of PlastiDip. This was done by wrapping zip ties around two of the cavities and hanging the piece into a bath of the liquid material. Two coats needed to be applied to fully coat the part. Once dried, the unit was assembled onto an EIA-310 Rack that was acquired from the engineering department.

Test Matrix

The original test matrix was incomplete because the initial functionality test was a failure and did not meet Raytheon's standards.

Table 11: Test Matrix 1

Test Matrix (original prototype)				
Test Part	**What to Test?**	**Test Parameters**	**Results**	**Resolutions / comments**
Horizontal Arm	Load	100 lb	Success	
Horizontal Arm	Vibration	x	x	Work with Vibco group to borrow proper vibrator
Horizontal Face	Load (horizontally)	100 lb	Success	
Horizontal Rack(right)	Vibration	x	x	Work with Vibco group to borrow proper vibrator
Horizontal Rack (left)	Vibration	x	x	
Horizontal Bracket(right)	Vibration	x	x	
Horizontal Bracket (left)	Vibration	x	x	
Vertical Part	Load	100 lb	Success	
Vertical Part (horizontal)	load	100 IB	Sucess	
Vertical part (top)	Vibration	x	x	
Vertical part (bottom)	Vibration	x	x	
Horizontal Piece	Function	In Progress	Fail	Re-CNC face with proper cuts
Vertical Piece	Function	In Progress	Fail	Re-CNC face with proper cuts

The second test matrix was able to be completed once the redesign allowed for successful functionality.

Table 12: Test Matrix 2

Test Matrix (Redesign)				
Test Part	**What to Test?**	**Test Parameters**	**Results**	**Resolutions / comments**
Horizontal Arm	Load	100 lb	Success	
Horizontal Arm	Vibration	100 lb	Success	Worked with Vibco group to borrow proper vibrator
Horizontal Face	Load (horizontally)	100 lb	Success	
Horizontal Rack(right)	Vibration	100 lbf	Success	Worked with Vibco group to borrow proper vibrator
Horizontal Rack (left)	Vibration	100 lbf	Success	Worked with Vibco group to borrow proper vibrator
Horizontal Bracket(right)	Vibration	100 lbf	Success	Worked with Vibco group to borrow proper vibrator
Horizontal Bracket (left)	Vibration	100 lbf	Success	Worked with Vibco group to borrow proper vibrator
Vertical Part	Load	100 lb	Success	
Vertical Part (horizontal)	load	100 lb	Success	
Vertical part (top)	Vibration	100 lb	Success	
Vertical part (bottom)	Vibration	100 lb	Success	
Horizontal Piece	Function	40 Cables	Success	New Cable cavity design
Vertical Piece	Function	40 Cables	Success	New Cable cavity design

Redesign

Redesign is the most important element in the fabricating of a quality product. Once all the prior steps in the design process are completed redesign is the step where all unknown problems in a design are corrected. Once our group had created a problem statement, the background research was completed, ideas were brainstormed, solutions were conceptualized then tested using software we were ready to fabricate a prototype.

The first issues that arose for our team during the fabrication process was problems related to the thickness of our metal. At first we had designed the components to be cut from .1875-inch Aluminum 6061, however we found that this metal was too thick to bend. When we tried to bend the horizontal and vertical components' mounting flanges we noticed severe cracking and even fracture. Also are original horizontal component prototype was designed to have two rows of 20 resting holes. What we found was that where the securement holes' flanges were intended to be bent there was not enough material to bend the flange to the CAD dimensions. We also found that having two rows of resting holes did not actually improve the serviceability because the bottom holes were so close to the top that connectors barely fit through them. To correct this, we decided to reduce the number of rows to one and just expand the size of the holes to accommodate the extra wires. We did this by keeping the same radius of .236 inches and extending the extrusion down .7 inches. Then the securement hole flange could be extended to 1 inch to allow for more material to be bent and we did not have the second row of holes to be careful of. With this new design we also anticipated that mounting our horizontal components in every U would be hard because horizontal components would be so close. Now that we had reduced the number of rows we no longer needed our horizontal component face to be 1.75 inches, we reduced it to 1.5 inches to leave more clearance between U's. The reduction of the face size and the expansion of holes we knew could compromise the structural integrity of our component, although the reduced weight would help reduce force due to gravity. Our group proceeded by drawing new CAD models for our three different lengths 3, 5 and 7 inches and reduced the thickness to .1 inches. Taylor drew CAD models as if the component was metal stamped as one piece and also if it was a three-piece assembly. Stable Cable did this to make sure our ideal final design was feasible as well as the final design that we could create using manufacturing process available to us. Both versions of the horizontal component were tested using Solidworks Simulation and the results can be seen in the Engineering Analysis section of this report. After all versions of the horizontal component had successfully passed the load testing, Stable Cable was able to use the CNC milling machine to cut out our horizontal piece. After doing this we successfully able to bend the horizontal mounting flanges and the securement hole flanges. The new design also allowed for easier routing of cables if the component was attached every U.

A new vertical component CAD model with the reduced thickness was also created and successfully bent. Both of the new component successfully passed both a static loading and vibration loading test as can be seen in the Testing portion of this report. After mock wiring over 40 cables to a mock switch in a data rack with both components Stable Cable was satisfied with how both the preformed. Another version of the vertical component was created in Solidworks that utilized the extra 2 inches of space a data cabinet allows. While our vertical component did work sufficiently, Stable Cable decided that adding two inches to the component would allow for easier routing of cables and there was room left in the cabinet to be utilized. Stable Cable Changed extended the elliptical holes an inch and raised the entrance hole .25 inches higher to better contain the wire. This CAD model was also tested using Solidworks Simulation and was sufficient however could not be milled using the CNC due to problems with the CNC available. If more time was available this updated vertical component would have been milled and tested. Stable Cable believes based on the software testing and only slight modifications made to the vertical component that physical loading of the component would have been successful too and ease of installation improved.

Proof Of Concept

To demonstrate that the Stable Cable concept would work, a prototype was constructed. This prototype was made entirely from sheet metal and was fabricated by hand. The Sorbothane was modeled from black electrical tape. The two-piece design was mounted to a mock EIA-310 rack that was also hand fabricated from sheet metal. The team used simple wood screws to mount the prototype to the rack. The prototype was true to scale and was capable of guiding CAT-6A ethernet cables in all 4 necessary directions. It also demonstrated the ability to invert the horizontal portion to fit either the front or the back of any EIA-310 rack and a variety of blade setups that Raytheon may encounter. Since the material was of lesser strength than the design, the force requirements were not met by the prototype. However, the team has no reason to believe that once the correct material is implemented, those force requirements will not only be met but exceeded. Unfortunately, the prototype created was left in the URI machine shop and thrown away by someone before the team could take proper pictures.

Maintenance

Consumer Maintenance

Customers purchasing this product should inspect all ordered parts to check for defects caused by faulty manufacturing or shipping. Visual defects that may cause concern are chipping to the plastic dipped components which would reduce the effectiveness of eliminating wear on wires. Any cracking along the bent portions of the component would greatly increase the chances of fatigue cracking while in use. Consumers should also make sure that the dimensioning of the product is correct to fit the EIA-310 specifications, holes even slightly off could force the product into a position where it cannot properly attach to the data cabinets. Finally, consumers should check for any cracking along the mounting holes or incomplete extrusions due to the piercing process during manufacturing. Cracking at the mounting holes could cause catastrophic failure since most of the loading will focused at these fixed points. Incomplete extrusions will either prevent proper installation or prevent proper functionality of the guide holes.

Once the product has been in use consumers should regularly check for defects as well as proper fastening. Stable Cable's design to withstand amplified loading due to seismic waves should be sufficient at handling these loads however small visual defects that were not observed during original inspection could be exasperated by being installed in these conditions. Checking the fastening frequently will make sure that the product is handling the application loading the way the product was intended to. Loose fastening especially in vibrational loading scenarios could cause loads to fall onto to more centralized parts of the mounting holes or the bolts they rest on. These components may not be sufficient in handling these loads in these scenarios.

Disposal and Recycling

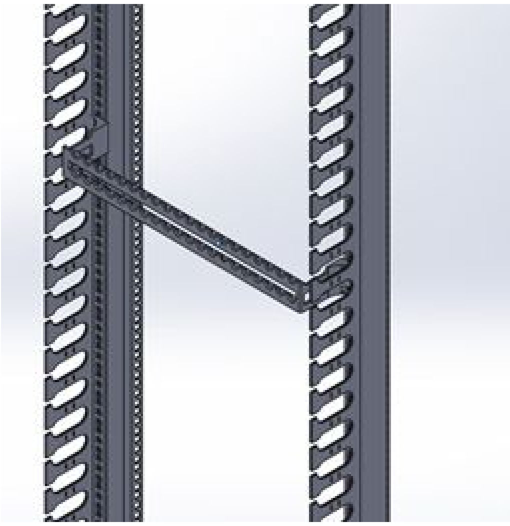
Recycling Stable Cable's product is very easy and can even give costumer's some return on their investment. Our products can be brought to any local Waste Management Scrapyard where the plastic dip coating will be stripped from the Aluminum using a chemical stripper such as Methylene Chloride or Acetone. From here the Aluminum can be recycled and payment for its weight will be distributed. If rusting has occurred on the aluminum, it can be still recycled no matter how extensive the rusting that has taken place is. The plastic dip coating that was removed will be drained of chemicals, heated up to a liquid consistency and be sold for reuse. There are many plastic dip companies that will purchase this recycled plastic for their use in their products marketed as "recycled" plastic dip. Both of these materials are made from non- renewable resources which means they cannot readily be replaced by natural means. It is for this reason that both of these materials be recycled to benefit the environment. Checking with your local government for disposal instructions is highly recommended as the process for recycling these materials may vary depending on your location.

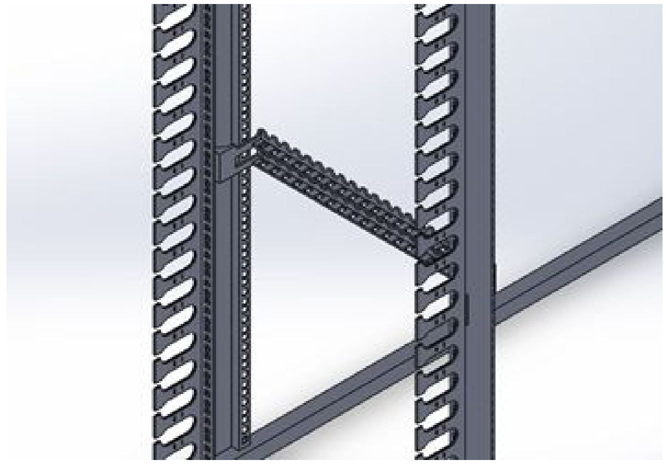
Operation

Stable Cable's design solution functions by conveniently routing the cable along the sides of the Cable Rack and then to your desired U on the data rack. By placing the vertical components on both sides of the data rack and securing the wires using wire tires, the wires become easily serviceable as well as prevent any unwanted movement that could result in disconnection. Once the wire is routed up the vertical piece and reached the desired U, the consumer can route the cable horizontally across the proper rung. The rung's geometry allows for freedom of the wire but still contains the wire to that desired U. Now that the wire has reached the desired U, the consumer can then route the cable through the hole that is most conveniently located to its termination destination. Once the wires in that hole have been connected to their desired locations, the consumer to secure those wire to their corresponding wire tie. The securement of the wire should leave some slack to prevent disconnection during vibrational loading. By securing the wire our product allows for better serviceability and loading to fall on the horizontal piece and not the connector itself.

Installation

Installation of Stable Cable's product is a very quick and intuitive process. While installing your electrical components such as switches and servers you will notice that they are mounted on rails with securing bolts. These securing bolts will also be used to secure the vertical and horizontal components in our solution system. Align the Vertical Component with the side flange you wish to place it on and extend the bolt through both the rail and the vertical piece and secure it tightly to the rack. Make sure that the vertical components mounting holes line up perfectly with EIA-310 mounting holes, as well as make sure there is a vertical rung for every U in your data rack. If a rung is out of place, the consumer has placed the vertical component 1U too low or too high. It is suggested that the vertical component be loosely secured to desired flange before adding the mounting rails for the ease of installation. Next take the desired version of our horizontal component that you wish to use and place it facing inward (all versions) for electrical components inset into the rack or facing outward (3-inch version) for components that are not inset into the rack. Refer to the figure below for the two different orientations that are possible. Once you have placed it where you want the consumer should remove the mounting bolts for that electrical component and use them to secure the vertical component, horizontal component and mounting rails to the data rack. Because you have already secured the vertical component and mountains rails it is suggested the installer does one side of the horizontal component at a time to prevent possible harm to the electrical component on those rails.

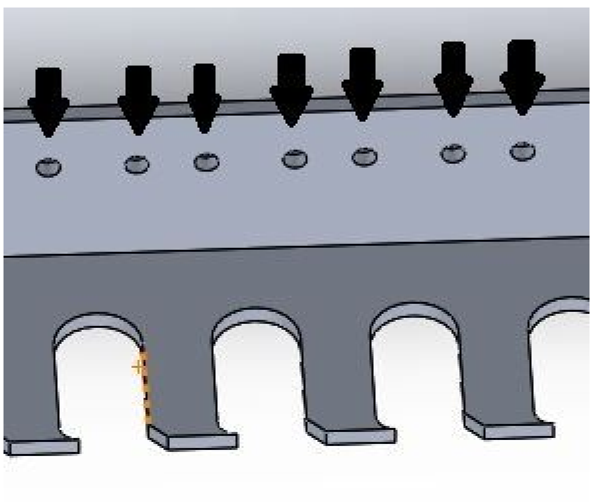


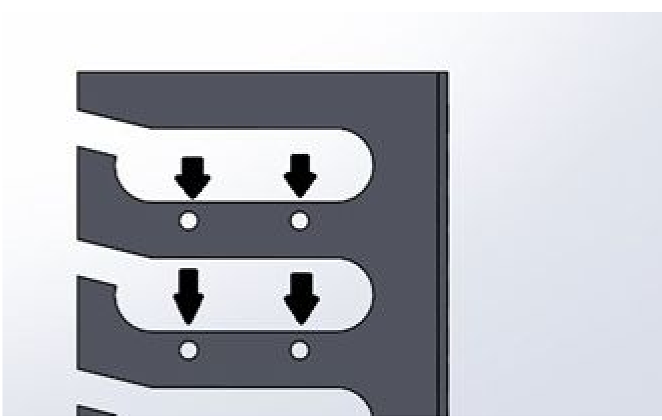


Outward Orientation

Inward Orientation

Once all the mounting rails, vertical and horizontal components are installed tightly you can begin to rout the wires. It is suggested the installer start from the bottom U and work their way up the rack, by doing this the clutter caused by loose wire can be eliminated. Route the wire up the vertical component into the horizontal component and secure it tightly with the designated wire tire. Wires should be fed into holes that are near the location of the termination destination. Wire tires should be wrapped through the extruded holes that corresponding with these holes and fastened to be tight however not tight enough to cause harm to the wire. Also be sure to leave slack between the termination destination and the securement location as well as the vertical component and the securement location. This allows freedom of movement so the connector does not feel the load. Wires can be fastened individually or in groups if they share the same resting hole. Refer to the Figure below for a visual of the wire tie securement holes. Continue to route the wires in the same manner until you have reached the final U. Once all cables have been secured on the horizontal components go back and secure the bulk of wires to the securement holes located on the vertical component. This can be done in groups based on the U they correspond to or done to secure all the wire. Refer to figure blank below for a visual of the securement holes on the vertical piece.





Additional Considerations

Economic Impact

The economical impact of Stable Cable's product will be small, due to the fact that it caters to a very specific group of potential clients. Only those who deal with industrial cable management, with a focus on use in defence applications will consider purchasing this product. This product could also be used in no defence applications since it could be manufactured and sold at current competitors prices. The volume of units sold may have an impact on our competitors' revenue, however there is no current product that is used for defence applications, therefore there will not be a major economic change in the market. Stable cable is the first to cater to the defence application market of cable management.

Environmental Impact

Stable Cable's product is made out of two environmentally benign materials. The first material is aluminum alloy 6061. This material has no harmful effects to humans or the environment in the state in which our product is produced. Since aluminum is non corrosive and does not oxidize, it does not need a harmful coating to be stored on the shelf for long periods of time. Aluminum 6061 can also be reused and recycled which cuts down the waste of manufacturing this product. All clean scrap metal and chips produced from manufacturing can be collected, melted down, and reused for later production. The second material used for this product is Plasti-Dip. This material is used to coat all metal surfaces of the product. Doing this protects the wires from wear or fraying under vibrations and movements in a defence application. Plasti-Dip can be found at any consumer hardware store in the paint section and has a variety of uses and applications. It can be purchased in an aerosol can or as liquid paint used for dipping. Stable cable used the liquid variety to dip the metal in because it produces a thicker, more even coat. This product follows all guidelines and laws for current consumer paint products. At the end of Stable Cable's product's working life, the Plasti-Dip must be peeled off the metal and disposed of properly, following the guidelines provided by their company. Once the Plasti-Dip is removed, the aluminum pieces can be melted down and repurposed.

Societal Impact

Stable Cable produces a product that not many people will use, however cable management is extremely important to those who design data cabinets. Having a cable universal cable management product that will outlast the life of the cabinet puts Stable Cable's products above the competition. Because of this, these cable management products will have a positive societal impact on the community.A one-time purchase of many units can be made by a company to eliminate the need of constantly shopping around for a correct product to fit their unique needs.

Political Impact

There is not a large political impact for the products created by Stable Cable. It is a small product with a relatively small market. It can be said that if Stable cable were to mass produce its products in Rhode Island, it could create local jobs. When opening up a manufacturing company, Stable Cable would be sure to only hire local engineers, as well as recent college graduates. By doing this, Stable Cable could receive government funding and tax write-offs. In turn, this would create a positive political impact by giving the company a positive social image.

Ethical Considerations

Because Stable Cable caters to defence applications, the products must conform to specific specifications and guaranteed not to fail under extreme circumstances. Stable cable's claims must be correct as to assure there are no failures in the field of such a highly sensitive application. Because the applications of the products are so sensitive, Stable Cable must be an ethical company, and not make claims unless they are tested and confirmed.

Health, Ergonomics, Safety Considerations

The manufacturing of Stable Cable's products do impose some health risks if not performed correctly. Manufacturing consists of three major parts; cutting, bending, and coating. All three steps of production can cause risk to the person creating the products. Stable Cable used a CNC router to cut a flat sheet of aluminum into the desired shape and dimensions of the design. During the cutting process, the person who is overseeing the operation must wear eye and ear protection, due to the loud noise and shrapnel that is created. After the cutting process is complete, the worker must use thick gloves to handle the material, due to the sharp edges created from the routing process. With ear, eye, and hand protection, the worker must grind all sharp edges to round them out. Once the product is cut out and freed from all sharp edges, it is ready to be bent in a press brake. This poses the risk of pinching a hand or fingers if not done carefully. The final step of production is dipping the piece in Plasti-Dip. This step must be done in a well ventilated area and the worker must wear a mask or respirator to avoid harmful fumes. If all these steps are done correctly, the worker will have no physical harm. At the end of production,the final piece poses no risk of injury or health hazard to the consumer.

Sustainability Considerations

Because Stable Cable's products are made predominantly of metal, the life cycles of the materials of the products are near infinite. Once the Stable Cable products reach the end of their working life, the Plasti-Dip can be stripped from the metal and the metal can be melted down and repurposed for other uses. By doing this, it reduces the carbon footprint left by manufacturing these products. The used Plasti-Dip however cannot be reused, and must be disposed of properly, in accordance to the manufacturer's guidelines. Unfortunately, for now, there is no current way to prevent creating this waste.

Conclusion

After building and testing Stable Cable's design, it was concluded that the products that were manufactured meet or exceeded the project requirement. The original design of the horizontal component was found to be non-manufacturable, therefore a redesign was needed. The second design still met the requirements given by Raytheon, however it was much easier to manufacture than the original. The final product was a modular system that can be used in almost any application. The horizontal component consists of three pieces; the horizontal face and two support arms. These arms come in sizes of three, five, and seven inches. The horizontal piece can be mounted facing either inside or out of a data cabinet, depending on the application. The vertical component consists of one piece, and can also be mounted inside or out of the data cabinet, depending on the application.

By using Aluminum alloy 6061-T4 as the main material, each component of the cable management system is light weight. Weight needed to be reduced for many reasons, first because the overall weight of a defense vessel, either a submarine or ship, should be minimized. Since many components will be needed for a vessel, Raytheon did not want these components to greatly contribute to the overall weight. Keeping the weight of the products low was also important to reduce the vibrations felt by the cables and connectors. As the mass of the component increases, the force of vibrations exerted on the cables increases. By keeping the weight of the product to a minimum optimal point, the vibrations will not greatly affect the cables. The weight of the horizontal component is 0.720 lbs. without the addition of Plasti-Dip.

The Aluminum alloy also provides each component with the necessary strength needed to perform safely in defense applications. Using computer software, and physical testing, each component was stress tested. These tests include both static loading and vibration analysis. These tests were performed by calculating the approximate load of each piece filled to maximum capacity. These loads then needed to be multiplied by ten to simulate the 10 g's of force that these data cabinets can experience in a defence application setting. The analysis showed that the design of the components under the static load had a factor of safety of 20, which is more than sufficient. Because of this high factory of safety, it can be concluded that the components will have a long working life and should not break under normal operating conditions. The vibration analysis proved that when each component is exposed to its natural frequency, the vibrations did not resonate to an unsafe level. The maximum nodal displacement of the horizontal piece was 1.4mm at vibrations slightly higher than those experienced in seismic zone 4 conditions.

Mounting the components to the EIA-310 rails allows them to be easily installed without any further fabrication. A technician can grab a component off the shelf and simply bolt it onto the data cabinet. This will reduce installation time, as well as maintenance time. Using the standard dimensions of the EIA-310 rack will allow the components to be used in many applications. Raytheon wanted a universal solution to their problem which is satisfied by this design aspect. These components will be widely used; however there is no guarantee that the use will be appropriate for all circumstances. A technician that installs the same pieces repetitively will be efficient running cables in data cabinets, cutting down installation time. The organization of the cables provided by the each component will naturally promote good air flow. Each server inside Raytheon's data cabinets requires 7 to 15 kilowatts of power, creating large amounts of heat. Proper airflow inside the cabinet is required to keep the servers and cables cool to prolong the life of all components inside the data cabinet. Raytheon did not require a forced air flow inside the cabinet; keeping the wires neat would provide sufficient airflow through the cabinet.

Stable Cable has provided a solution to Raytheon's cable management problem. The system of cable management that has been designed to meet or exceed all requirements put forth by Raytheon. Physical testing of a prototype has confirmed all assumptions made by computer analysis.

Further Work

Recording important dates into the project plan early helped significantly with the organization and completion of goals. Unfortunately, difficulties with the CNC milling machine prevented Stable Cable from fabricating the final version of our vertical piece. If we had more time we would have proceeded to use the CNC machine to produce this piece from our CAD CNC file. However it is very likely our final design would have been sufficient based on our software simulations as well as the previous vertical piece passing its functionality and physicals test. The final vertical piece and the previous vertical piece had very similar dimensioning with the final version actually having a slightly bigger footprint, the dimensional changes made were only to accommodate more wires and did not drastically change the simulation results. Overall Stable Cable feels we accomplished the necessary fabricating and testing to prove that our design would be an excellent way of organizing cables.

References

[1]"Define: EIA-310." The Server Rack FAQ RSS. Innovative First Incorporated, n.d. Web. 1 Oct. 2016.

[2]"IBM Knowledge Center." IBM Knowledge Center. International Business Themes, n.d. Web. 1 Oct. 2016.

[3]"RoHS Regulations." Government Guidance
Notes 11.527 (2011): 1-38.Www.gov.uk/goverment. Department for Business Innovation & Skills, 1 Feb. 2011. Web. 20 Oct. 2016.

[4]"WaveformData." IRIS: Waveform Data. Nation Science Foundation, n.d. Web. 1 Nov. 2016.

[5]Davis,L. "Electronic Chassis, Racks." How To Specify an Equipment Chassis; Equipment Rack Rail Dimensions.N.p., 2 May 2012. Web.

[6]Dieter,George E. Engineering Design: A Materials and Processing Approach. New York: McGraw-Hill, 1983. Print

[7]Freedman, A. "There Are Now 3 Million Data Centers in the U.S., and Climbing." Mashable.Small Business, 30 Sept. 2014. Web.

[8]Hawking, @datatrend_tech. "IT Solutions, Infrastructure, and IT Optimization Expertise." Datatrend Technologies. N.p., Oct. 2012. Web. 19 Dec. 2016.

[9]Jones,Trent, Jeremy Fink, Marcus Adrian Koukkari, Brian Lynn Mordick, and Inc.
Hoffman Enclosures. "Patent US7973242 - Vertical Cable Manager." Google Patents. Google/ HoffmanEnclosures, n.d. Web. 19 Dec. 2016.

[10]Sherman, R. "AWG Copper Wire Size Table and Data Chart @ 100 Degrees F | Engineers Edge." AWG Copper Wire Size Table and Data Chart @ 100 Degrees F | Engineers Edge. Engineering Edge, 15 Aug. 2001.Web.

[11]Shirer,M. "Worldwide Server Market Revenues Grow 6.1% in the Second Quarter
Bolstered by Strong Demand in the US, According to IDC." Www.idc.com. IDC, 25 Aug. 2015. Web.

[12]Sterling, John. "Manufacturing Cost Estimation." Manufacturing Cost Estimation. N.p., Mar. 2007. Web. 19 Dec.2016.

[13]Telcordia."Earthquake, Office Vibration and Transportation Vibration." NEBS Requirements Physical Protection 3 (2006): 4-21--26. Resheji, 1 Mar. 2006. Web. 1 Nov. 2016.

[14]Young,Joel. "Protecting Data Centers from Seismic Activity." Emcor Enclosure 214.6 (2013): 314. Mission Critical Magazine. Crenlo. Web. 1 Nov. 2016.

Appendix

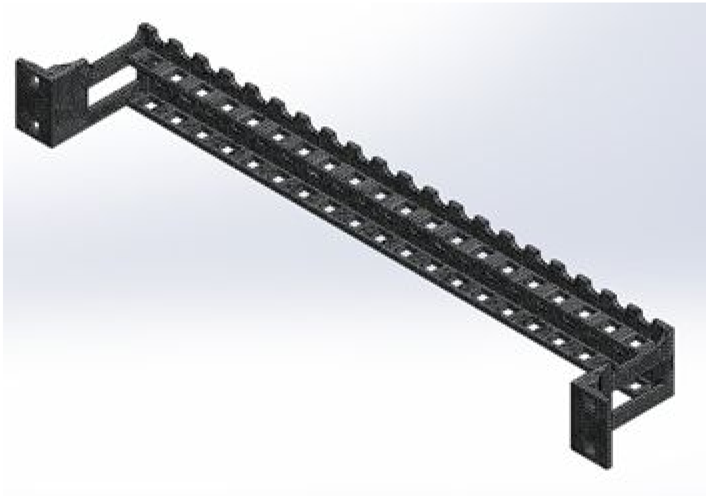


Figure 50: SolidWorks mesh of horizontal component

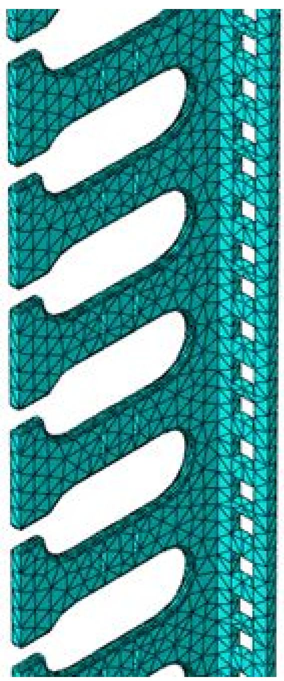


Figure 51: Abaqus mesh of vertical component

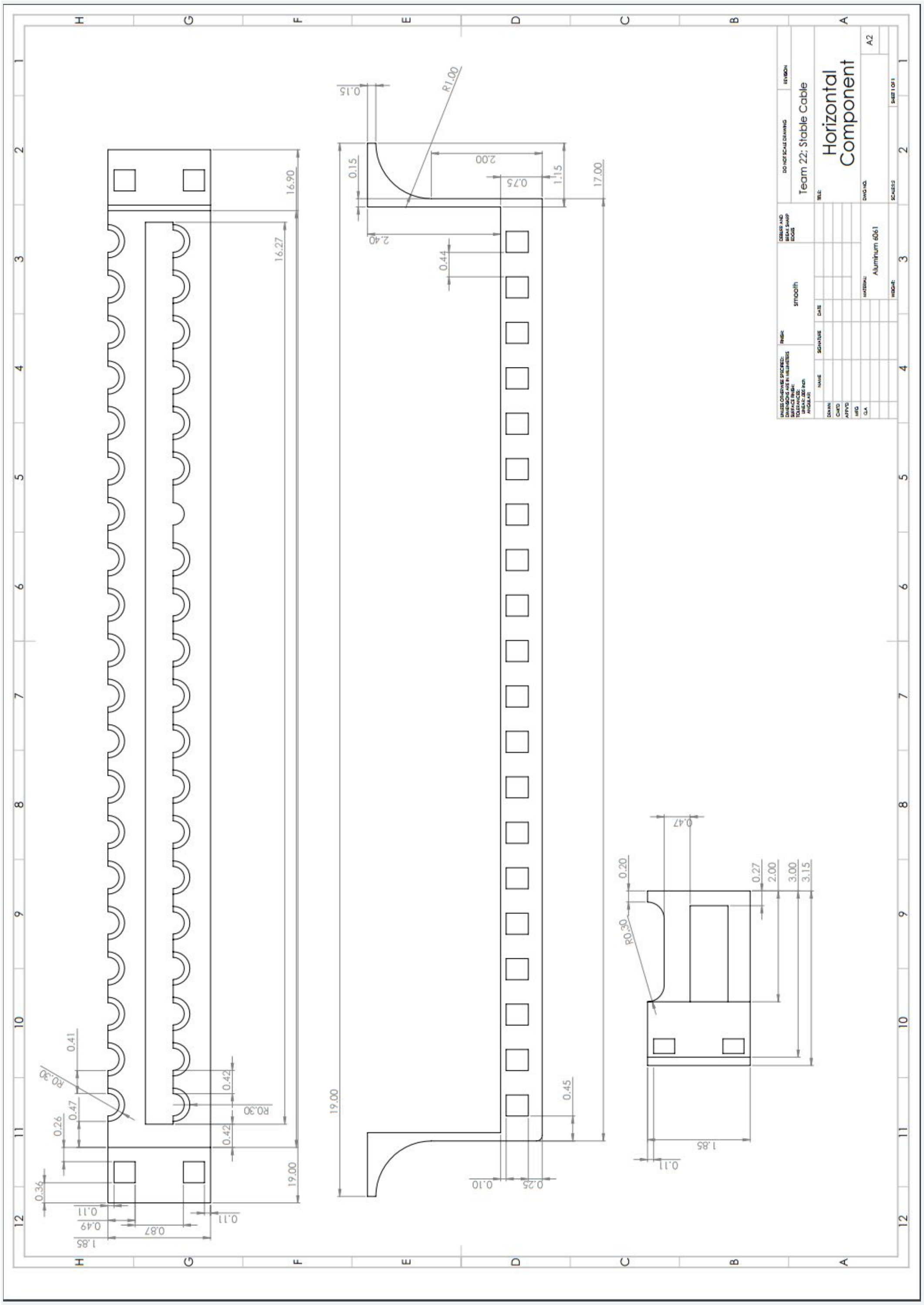


Figure 52: Drawing of horizontal component

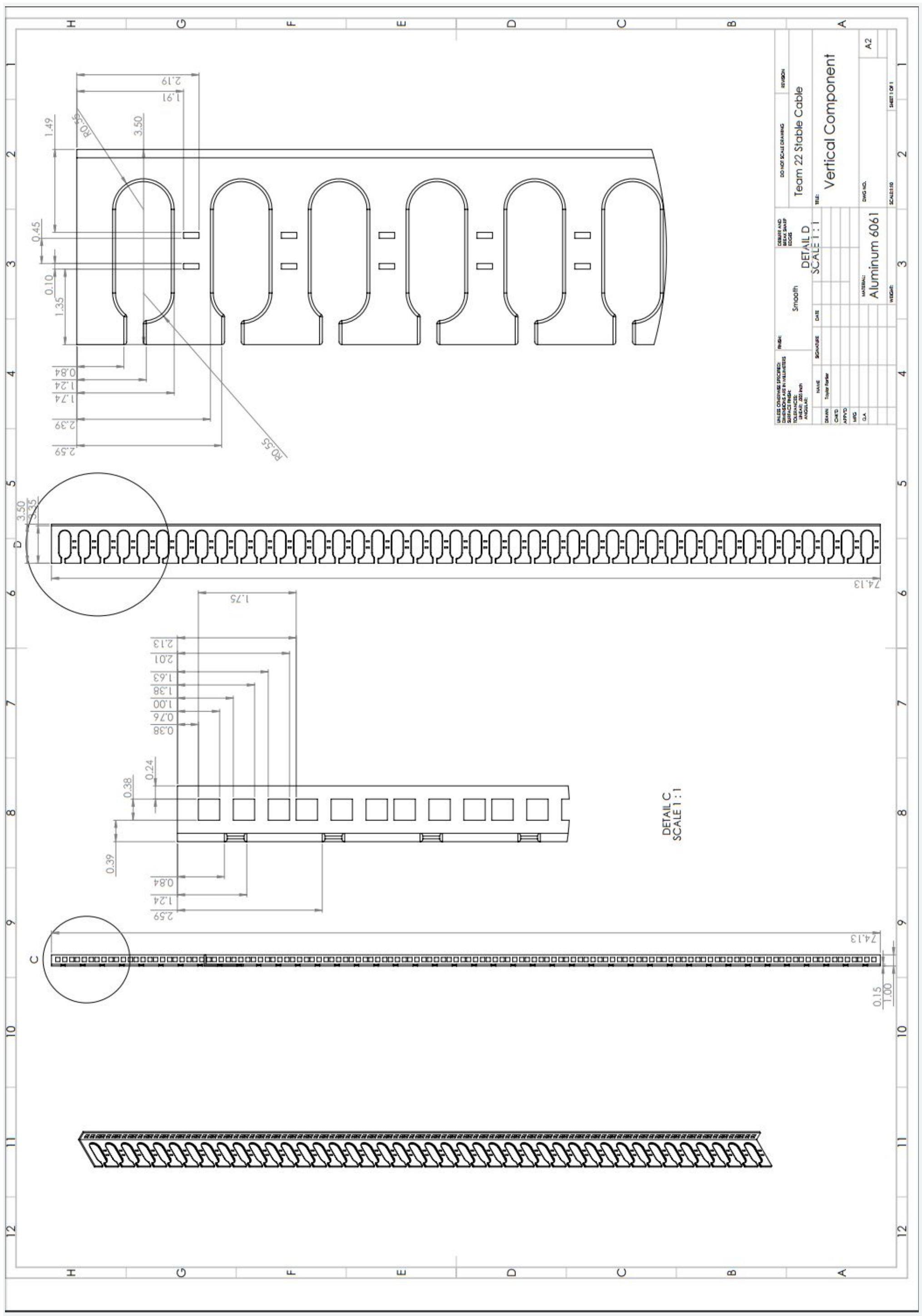

Team 22 Stable Cable
Vertical Component
Aluminum 6061
Smooth
DETAIL D
SCALE 1 : 1
DETAIL C
SCALE 1 : 1
A2

Figure 53: Drawing of vertical component

Figure 54:Assembly of cable management pieces on rack

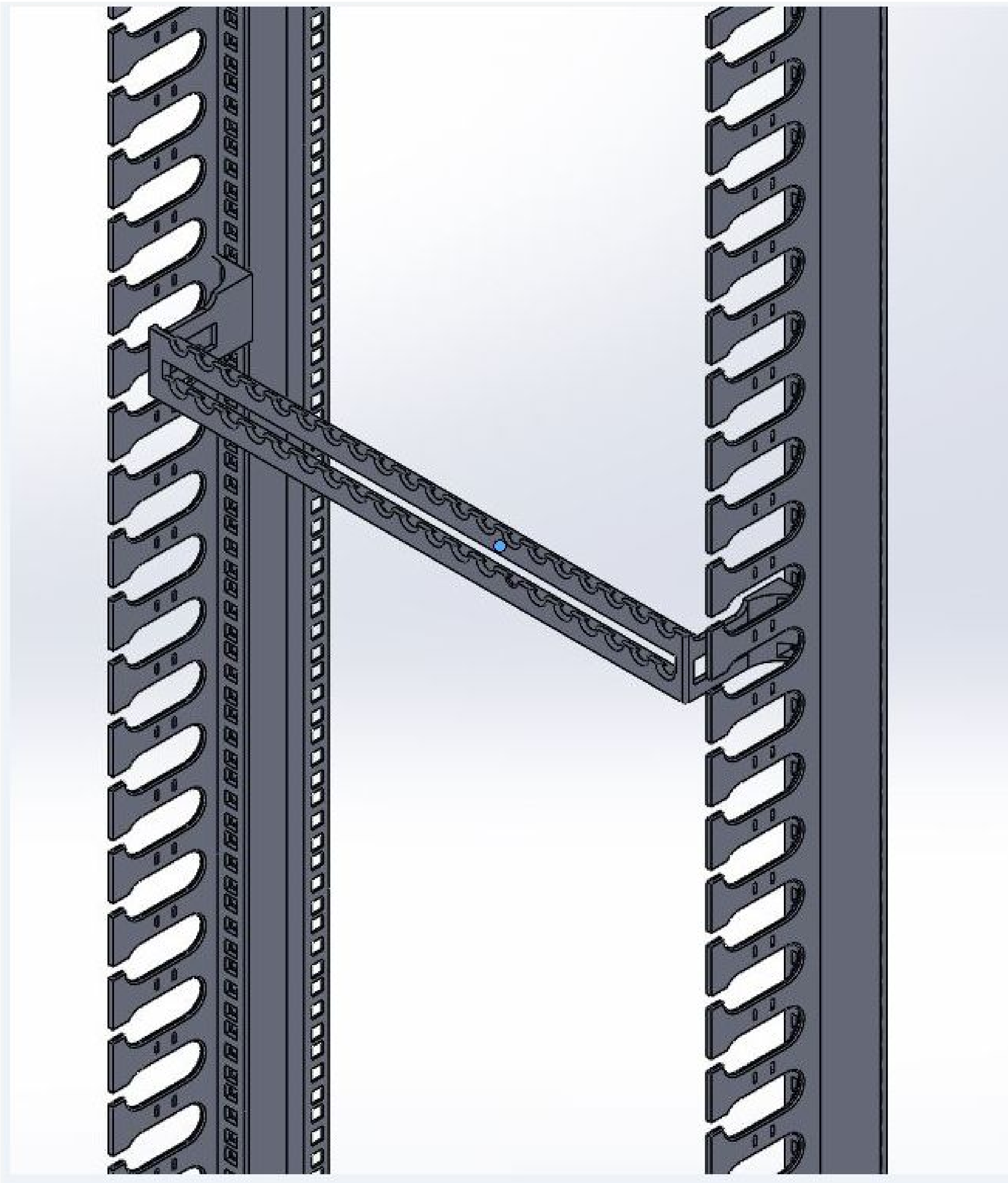
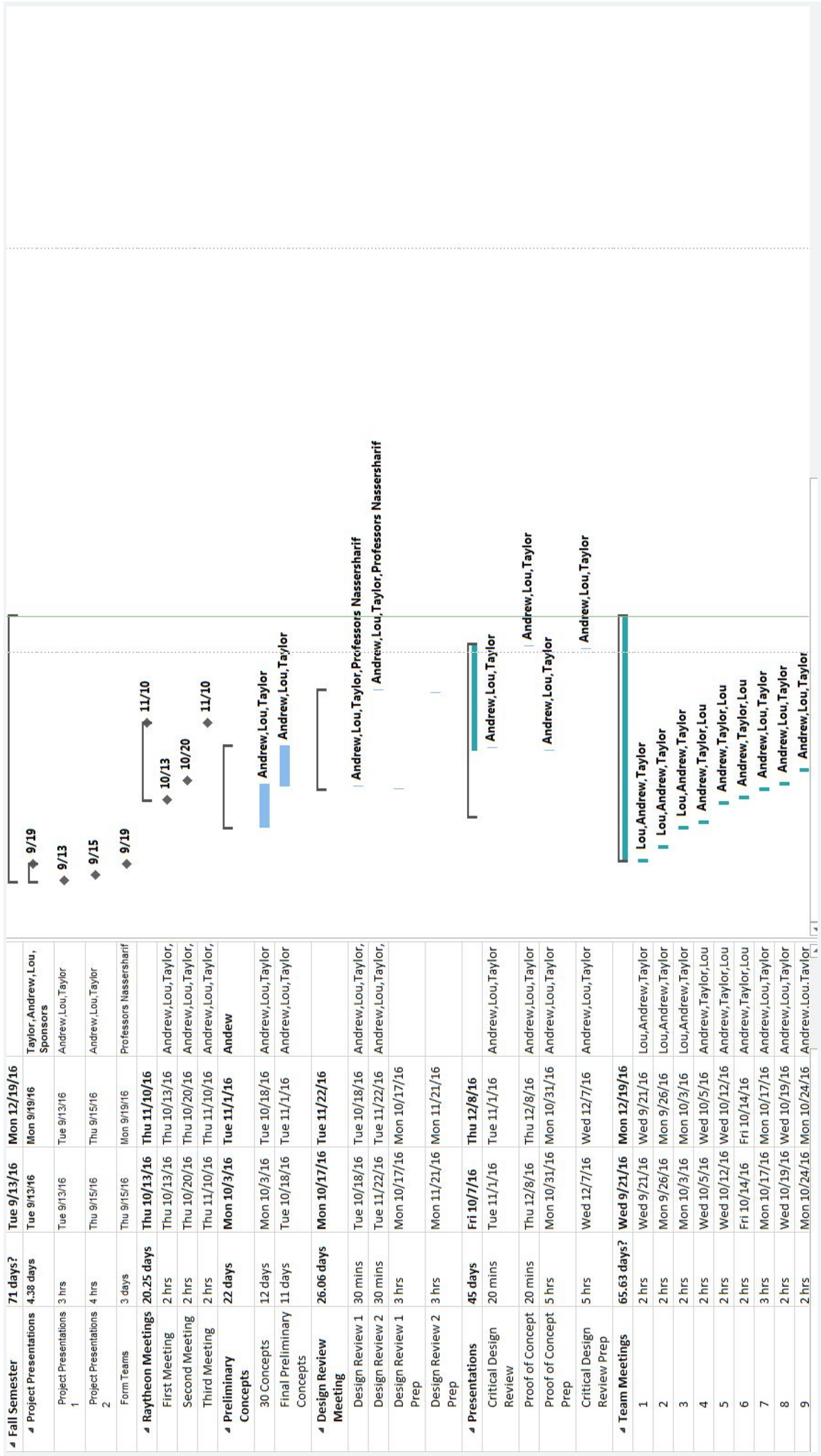
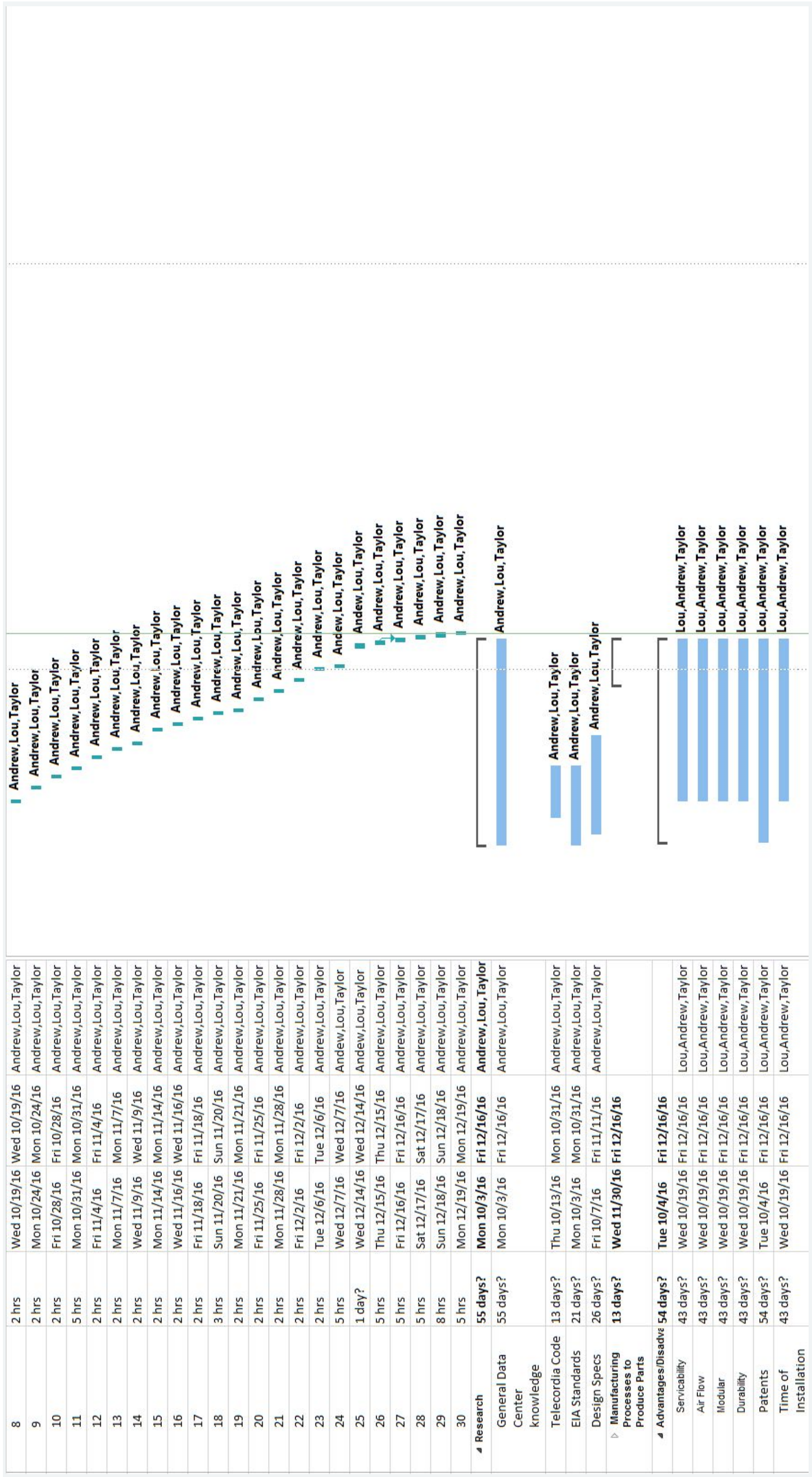


Figure 55: Close up view of Assembly of cable management pieces on rack



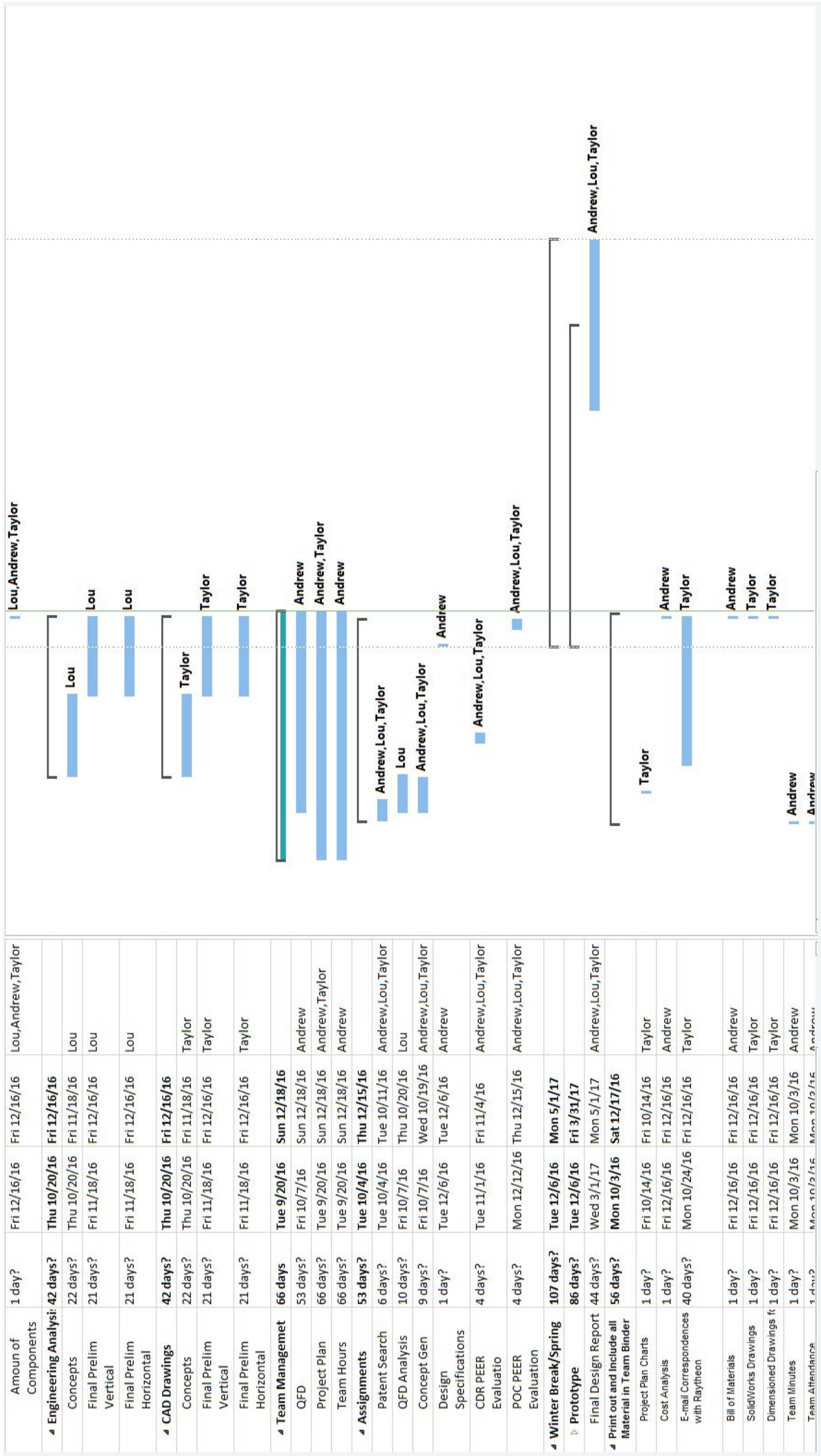
Fall Semester	71 days?	Tue 9/13/16	Mon 12/19/16	
Project Presentations	4.38 days	Tue 9/13/16	Mon 9/19/16	Taylor,Andrew,Lou, Sponsors
Project Presentations 1	3 hrs	Tue 9/13/16	Tue 9/13/16	Andrew,Lou,Taylor
Project Presentations 2	4 hrs	Thu 9/15/16	Thu 9/15/16	Andrew,Lou,Taylor
Form Teams	3 days	Thu 9/15/16	Mon 9/19/16	Professors Nassersharif
Raytheon Meetings	20.25 days	Thu 10/13/16	Thu 11/10/16	
First Meeting	2 hrs	Thu 10/13/16	Thu 10/13/16	Andrew,Lou,Taylor,
Second Meeting	2 hrs	Thu 10/20/16	Thu 10/20/16	Andrew,Lou,Taylor,
Third Meeting	2 hrs	Thu 11/10/16	Thu 11/10/16	Andrew,Lou,Taylor,
Preliminary Concepts	22 days	Mon 10/3/16	Tue 11/1/16	Andew
30 Concepts	12 days	Mon 10/3/16	Tue 10/18/16	Andrew,Lou,Taylor
Final Preliminary Concepts	11 days	Tue 10/18/16	Tue 11/1/16	Andrew,Lou,Taylor
Design Review Meeting	26.06 days	Mon 10/17/16	Tue 11/22/16	
Design Review 1	30 mins	Tue 10/18/16	Tue 10/18/16	Andrew,Lou,Taylor,
Design Review 2	30 mins	Tue 11/22/16	Tue 11/22/16	Andrew,Lou,Taylor,
Design Review 1 Prep	3 hrs	Mon 10/17/16	Mon 10/17/16	
Design Review 2 Prep	3 hrs	Mon 11/21/16	Mon 11/21/16	
Presentations	45 days	Fri 10/7/16	Thu 12/8/16	
Critical Design Review	20 mins	Tue 11/1/16	Tue 11/1/16	Andrew,Lou,Taylor
Proof of Concept	20 mins	Thu 12/8/16	Thu 12/8/16	Andrew,Lou,Taylor
Proof of Concept Prep	5 hrs	Mon 10/31/16	Mon 10/31/16	Andrew,Lou,Taylor
Critical Design Review Prep	5 hrs	Wed 12/7/16	Wed 12/7/16	Andrew,Lou,Taylor
Team Meetings	65.63 days?	Wed 9/21/16	Mon 12/19/16	
1	2 hrs	Wed 9/21/16	Wed 9/21/16	Lou,Andrew,Taylor
2	2 hrs	Mon 9/26/16	Mon 9/26/16	Lou,Andrew,Taylor
3	2 hrs	Mon 10/3/16	Mon 10/3/16	Lou,Andrew,Taylor
4	2 hrs	Wed 10/5/16	Wed 10/5/16	Andrew,Taylor,Lou
5	2 hrs	Wed 10/12/16	Wed 10/12/16	Andrew,Taylor,Lou
6	2 hrs	Fri 10/14/16	Fri 10/14/16	Andrew,Taylor,Lou
7	3 hrs	Mon 10/17/16	Mon 10/17/16	Andrew,Lou,Taylor
8	2 hrs	Wed 10/19/16	Wed 10/19/16	Andrew,Lou,Taylor
9	2 hrs	Mon 10/24/16	Mon 10/24/16	Andrew,Lou,Taylor

Figure 56: Project Plan

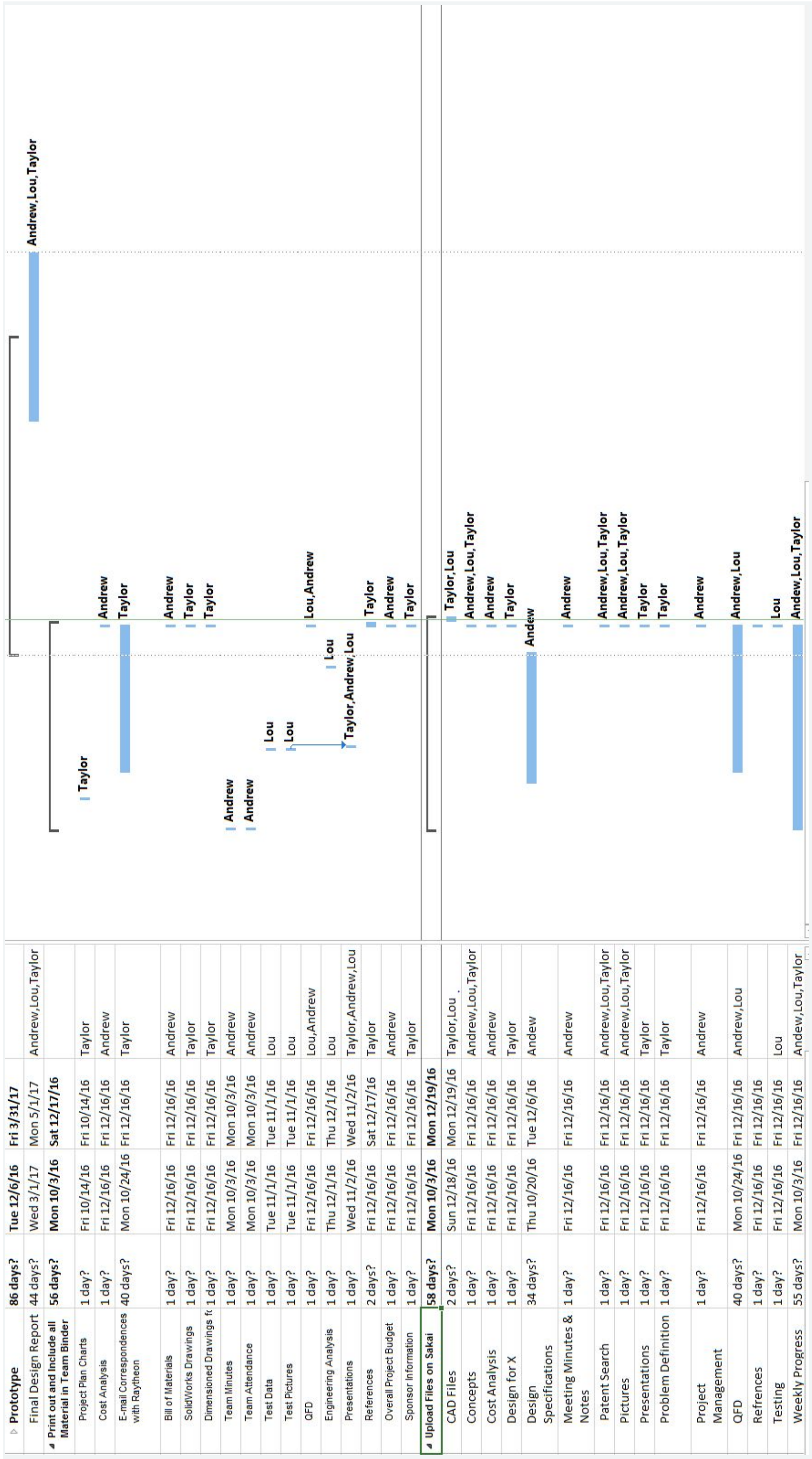


8		2 hrs	Wed 10/19/16	Wed 10/19/16	Andrew,Lou,Taylor
9		2 hrs	Mon 10/24/16	Mon 10/24/16	Andrew,Lou,Taylor
10		2 hrs	Fri 10/28/16	Fri 10/28/16	Andrew,Lou,Taylor
11		5 hrs	Mon 10/31/16	Mon 10/31/16	Andrew,Lou,Taylor
12		2 hrs	Fri 11/4/16	Fri 11/4/16	Andrew,Lou,Taylor
13		2 hrs	Mon 11/7/16	Mon 11/7/16	Andrew,Lou,Taylor
14		2 hrs	Wed 11/9/16	Wed 11/9/16	Andrew,Lou,Taylor
15		2 hrs	Mon 11/14/16	Mon 11/14/16	Andrew,Lou,Taylor
16		2 hrs	Wed 11/16/16	Wed 11/16/16	Andrew,Lou,Taylor
17		2 hrs	Fri 11/18/16	Fri 11/18/16	Andrew,Lou,Taylor
18		3 hrs	Sun 11/20/16	Sun 11/20/16	Andrew,Lou,Taylor
19		2 hrs	Mon 11/21/16	Mon 11/21/16	Andrew,Lou,Taylor
20		2 hrs	Fri 11/25/16	Fri 11/25/16	Andrew,Lou,Taylor
21		2 hrs	Mon 11/28/16	Mon 11/28/16	Andrew,Lou,Taylor
22		2 hrs	Fri 12/2/16	Fri 12/2/16	Andrew,Lou,Taylor
23		2 hrs	Tue 12/6/16	Tue 12/6/16	Andrew,Lou,Taylor
24		5 hrs	Wed 12/7/16	Wed 12/7/16	Andew,Lou,Taylor
25		1 day?	Wed 12/14/16	Wed 12/14/16	Andrew,Lou,Taylor
26		5 hrs	Thu 12/15/16	Thu 12/15/16	Andrew,Lou,Taylor
27		5 hrs	Fri 12/16/16	Fri 12/16/16	Andrew,Lou,Taylor
28		5 hrs	Sat 12/17/16	Sat 12/17/16	Andrew,Lou,Taylor
29		8 hrs	Sun 12/18/16	Sun 12/18/16	Andrew,Lou,Taylor
30		5 hrs	Mon 12/19/16	Mon 12/19/16	Andrew,Lou,Taylor
	Research	**55 days?**	**Mon 10/3/16**	**Fri 12/16/16**	**Andrew,Lou,Taylor**
	General Data Center knowledge	55 days?	Mon 10/3/16	Fri 12/16/16	Andrew,Lou,Taylor
	Telecordia Code	13 days?	Thu 10/13/16	Mon 10/31/16	Andrew,Lou,Taylor
	EIA Standards	21 days?	Mon 10/3/16	Mon 10/31/16	Andrew,Lou,Taylor
	Design Specs	26 days?	Fri 10/7/16	Fri 11/11/16	Andrew,Lou,Taylor
	Manufacturing Processes to Produce Parts	**13 days?**	**Wed 11/30/16**	**Fri 12/16/16**	
	Advantages/Disadva	**54 days?**	**Tue 10/4/16**	**Fri 12/16/16**	
	Servicability	43 days?	Wed 10/19/16	Fri 12/16/16	Lou,Andrew,Taylor
	Air Flow	43 days?	Wed 10/19/16	Fri 12/16/16	Lou,Andrew,Taylor
	Modular	43 days?	Wed 10/19/16	Fri 12/16/16	Lou,Andrew,Taylor
	Durability	43 days?	Wed 10/19/16	Fri 12/16/16	Lou,Andrew,Taylor
	Patents	54 days?	Tue 10/4/16	Fri 12/16/16	Lou,Andrew,Taylor
	Time of Installation	43 days?	Wed 10/19/16	Fri 12/16/16	Lou,Andrew,Taylor

Figure 57: Project Plan Extended



Project Plan 58: Project Plan Extend pt 2



Prototype	86 days?	Tue 12/6/16	Fri 3/31/17	
Final Design Report	44 days?	Wed 3/1/17	Mon 5/1/17	Andrew,Lou,Taylor
Print out and Include all Material in Team Binder	56 days?	Mon 10/3/16	Sat 12/17/16	
Project Plan Charts	1 day?	Fri 10/14/16	Fri 10/14/16	Taylor
Cost Analysis	1 day?	Fri 12/16/16	Fri 12/16/16	Andrew
E-mail Correspondences with Raytheon	40 days?	Mon 10/24/16	Fri 12/16/16	Taylor
Bill of Materials	1 day?	Fri 12/16/16	Fri 12/16/16	Andrew
SolidWorks Drawings	1 day?	Fri 12/16/16	Fri 12/16/16	Taylor
Dimensioned Drawings fc	1 day?	Fri 12/16/16	Fri 12/16/16	Taylor
Team Minutes	1 day?	Mon 10/3/16	Mon 10/3/16	Andrew
Team Attendance	1 day?	Mon 10/3/16	Mon 10/3/16	Andrew
Test Data	1 day?	Tue 11/1/16	Tue 11/1/16	Lou
Test Pictures	1 day?	Tue 11/1/16	Tue 11/1/16	Lou
QFD	1 day?	Fri 12/16/16	Fri 12/16/16	Lou,Andrew
Engineering Analysis	1 day?	Thu 12/1/16	Thu 12/1/16	Lou
Presentations	1 day?	Wed 11/2/16	Wed 11/2/16	Taylor,Andrew,Lou
References	2 days?	Fri 12/16/16	Sat 12/17/16	Taylor
Overall Project Budget	1 day?	Fri 12/16/16	Fri 12/16/16	Andrew
Sponsor Information	1 day?	Fri 12/16/16	Fri 12/16/16	Taylor
Upload Files on Sakai	58 days?	Mon 10/3/16	Mon 12/19/16	
CAD Files	2 days?	Sun 12/18/16	Mon 12/19/16	Taylor,Lou
Concepts	1 day?	Fri 12/16/16	Fri 12/16/16	Andrew,Lou,Taylor
Cost Analysis	1 day?	Fri 12/16/16	Fri 12/16/16	Andrew
Design for X	1 day?	Fri 12/16/16	Fri 12/16/16	Taylor
Design Specifications	34 days?	Thu 10/20/16	Tue 12/6/16	Andew
Meeting Minutes & Notes	1 day?	Fri 12/16/16	Fri 12/16/16	Andrew
Patent Search	1 day?	Fri 12/16/16	Fri 12/16/16	Andrew,Lou,Taylor
Pictures	1 day?	Fri 12/16/16	Fri 12/16/16	Andrew,Lou,Taylor
Presentations	1 day?	Fri 12/16/16	Fri 12/16/16	Taylor
Problem Definition	1 day?	Fri 12/16/16	Fri 12/16/16	Taylor
Project Management	1 day?	Fri 12/16/16	Fri 12/16/16	Andrew
QFD	40 days?	Mon 10/24/16	Fri 12/16/16	Andrew,Lou
Refrences	1 day?	Fri 12/16/16	Fri 12/16/16	
Testing	1 day?	Fri 12/16/16	Fri 12/16/16	Lou
Weekly Progress	55 days?	Mon 10/3/16	Fri 12/16/16	Andew,Lou,Taylor

Figure 59: Project Plan Extended Part 3

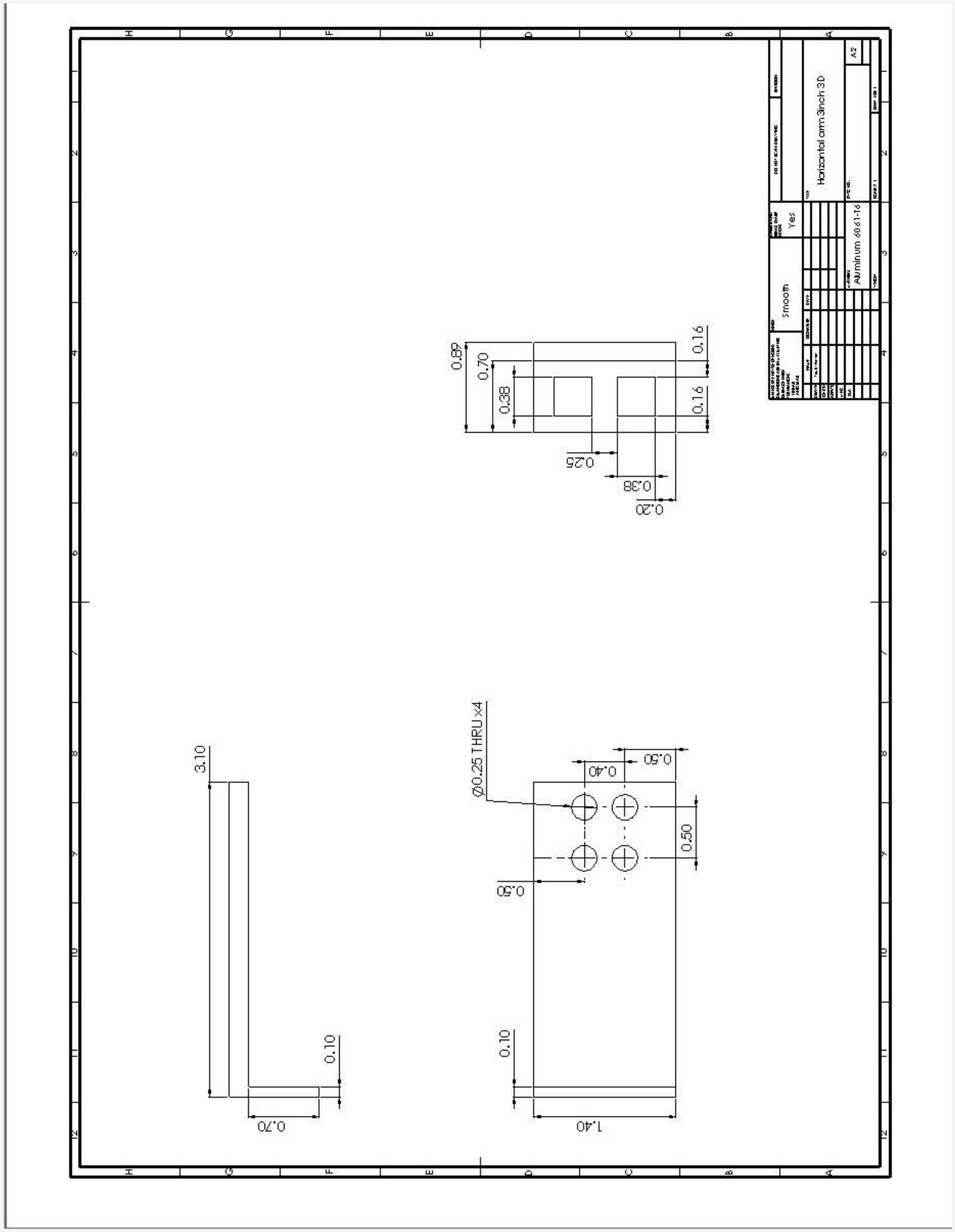


Figure : 3 inch Horizontal Arms

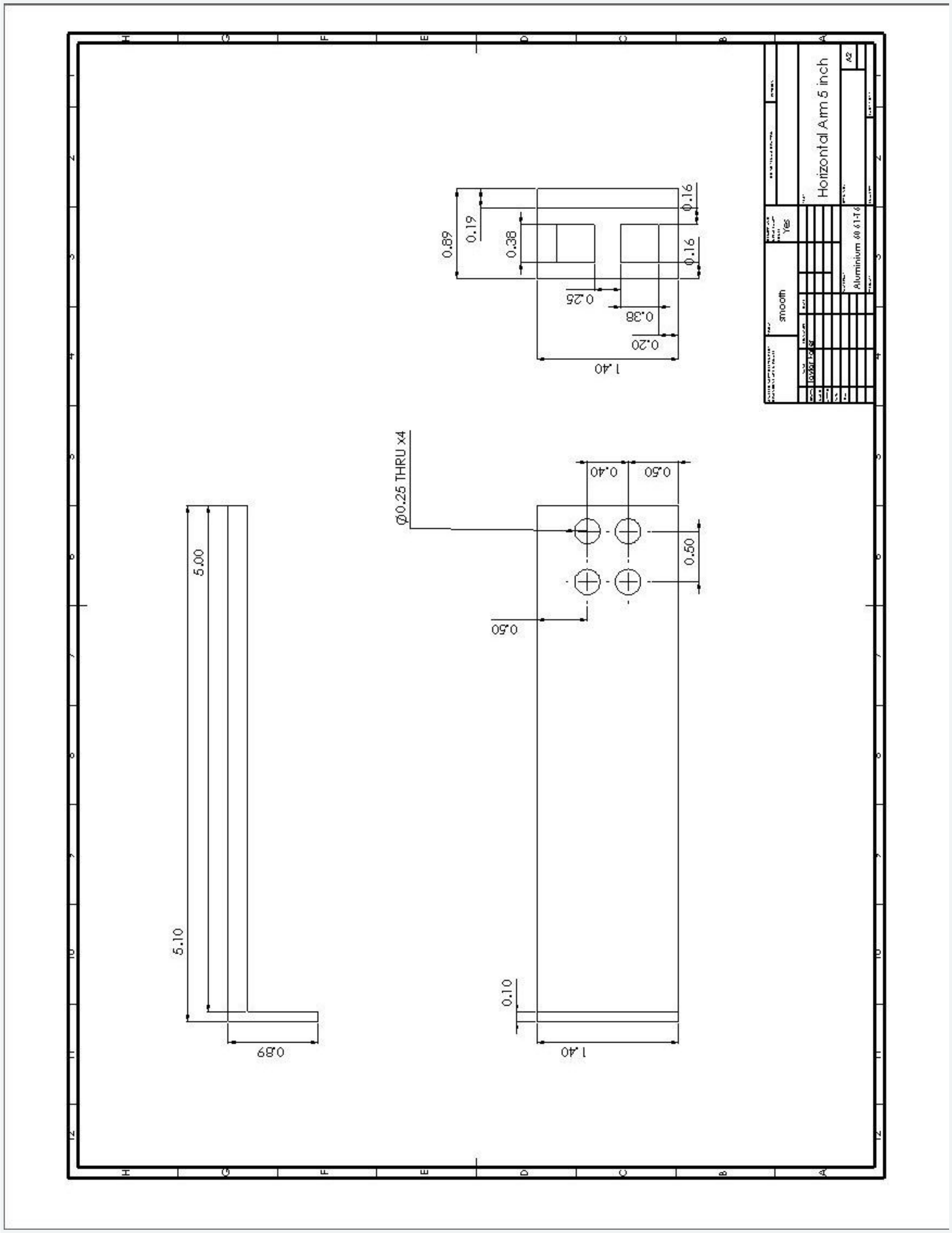


Figure : 5 inch Horiztonal Arms

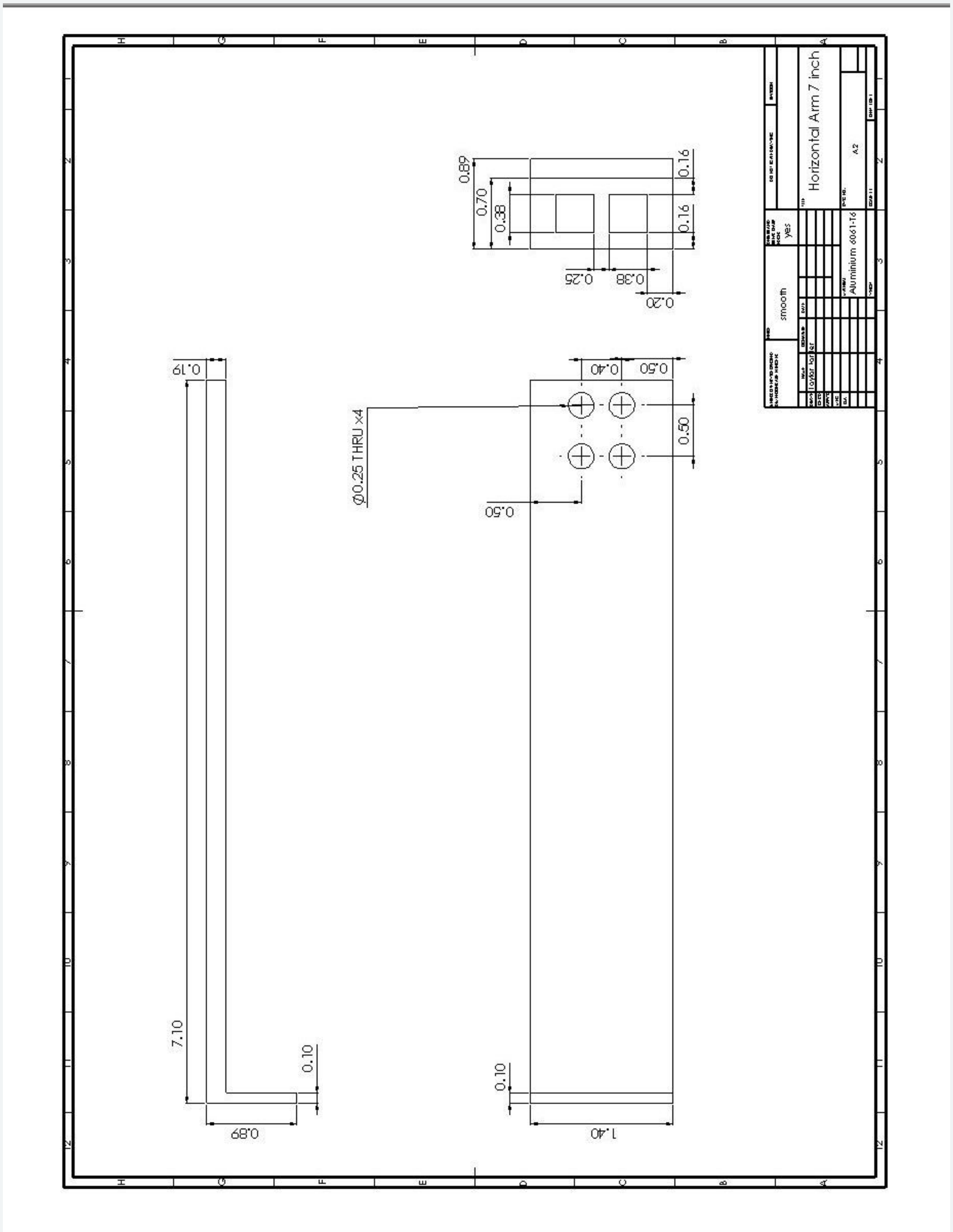


Figure : 7 inch Horizontal Arm

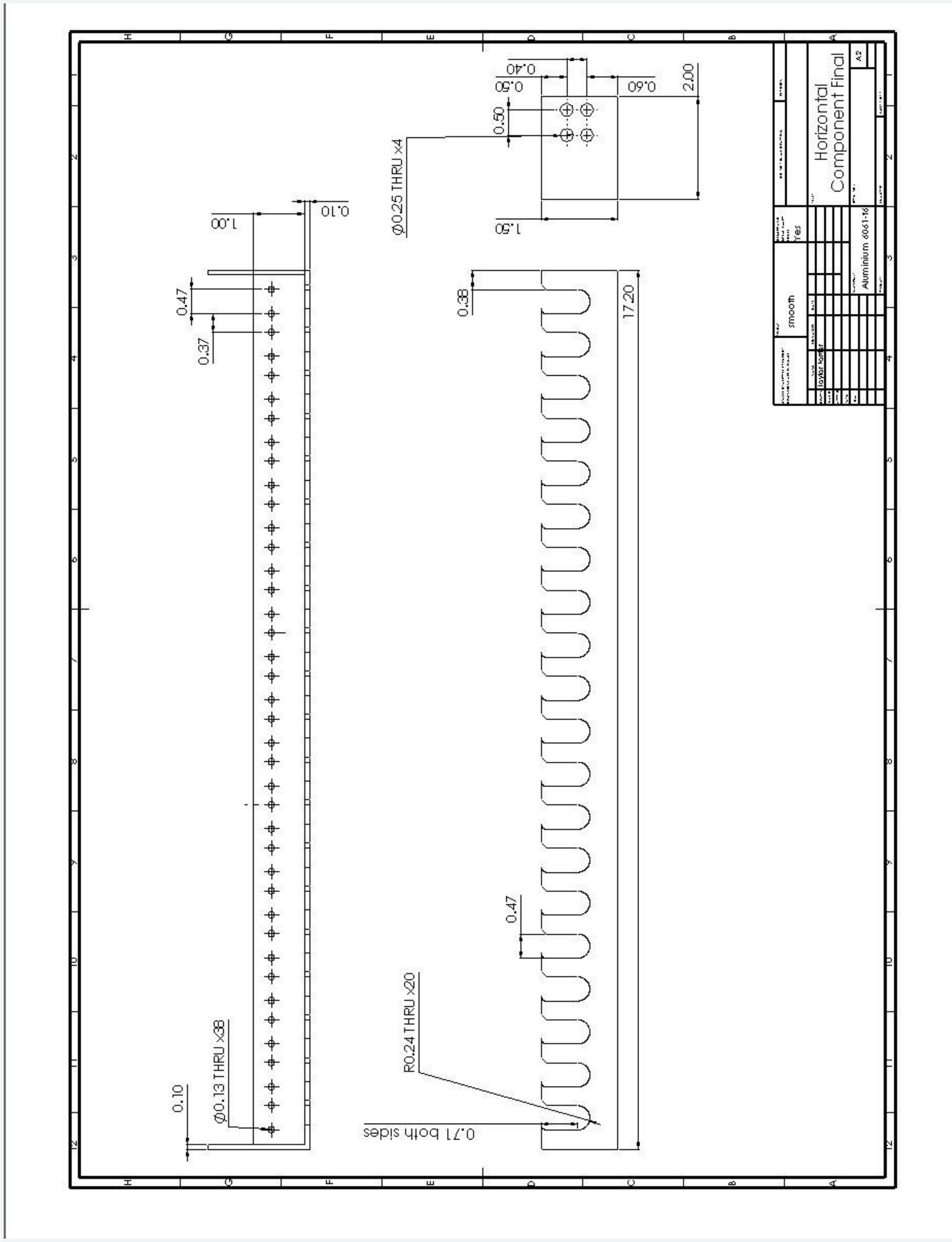


Figure : Horizontal Face for 3-Piece Assembly

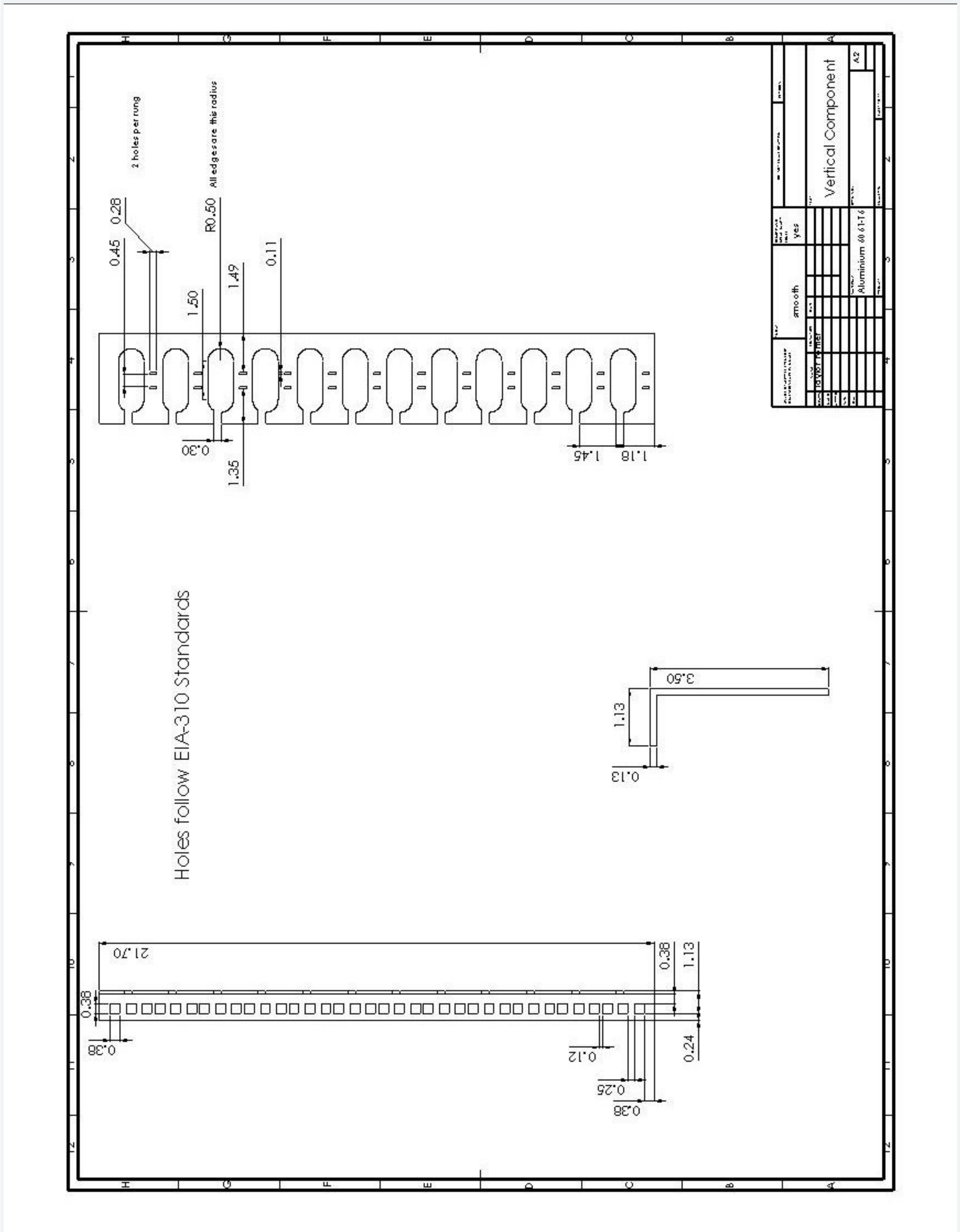


Figure : Vertical Component

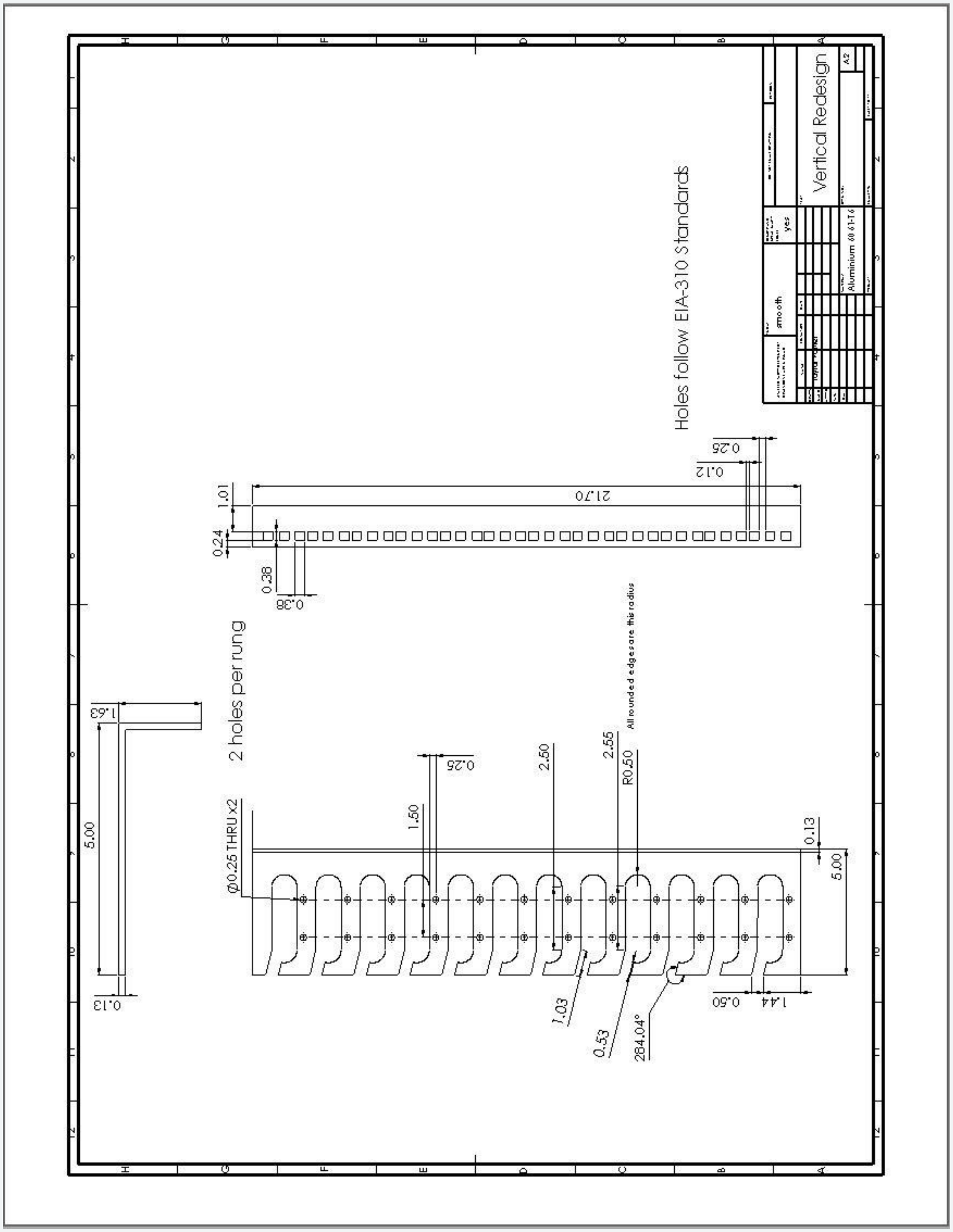
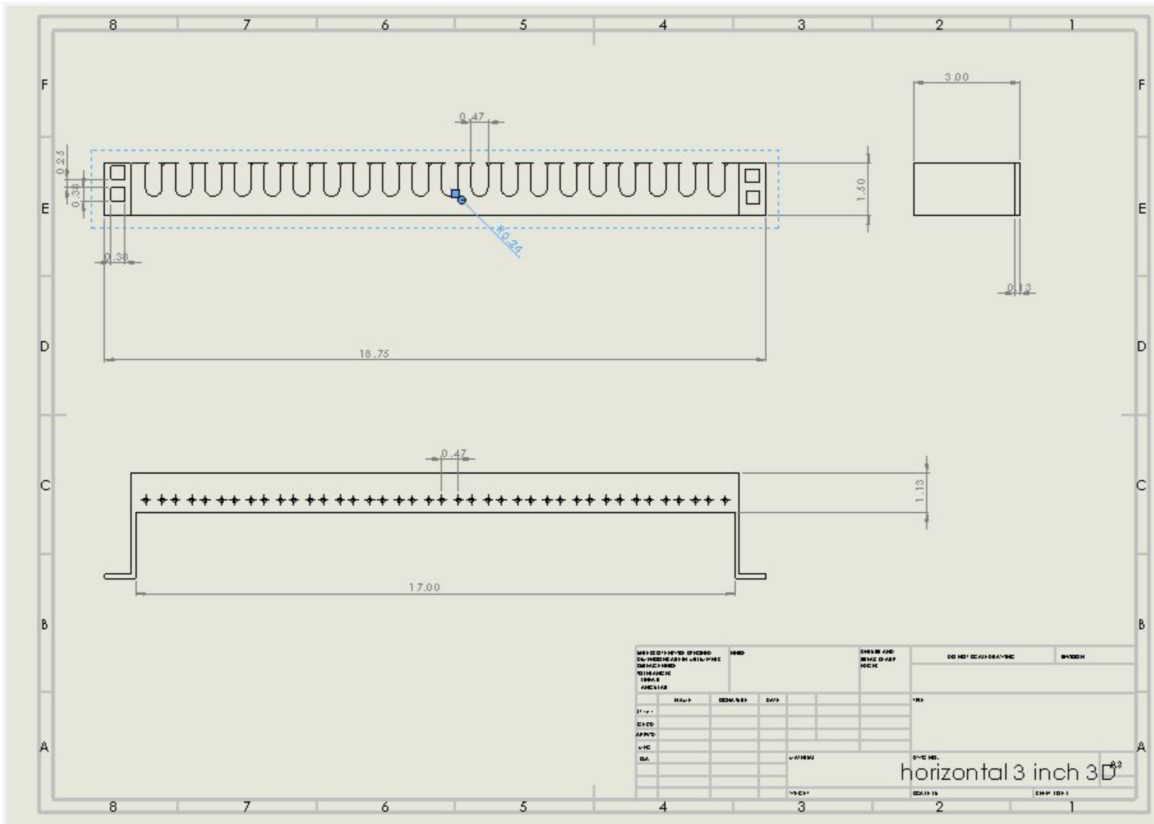
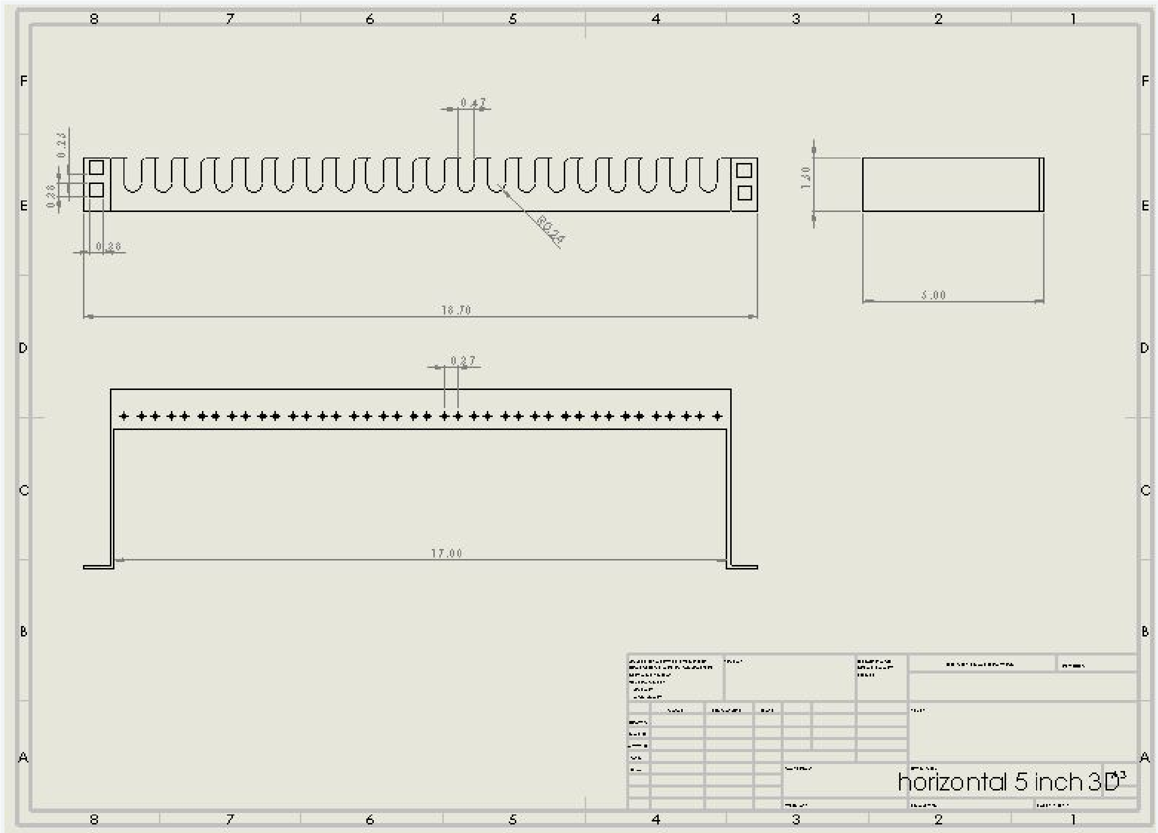
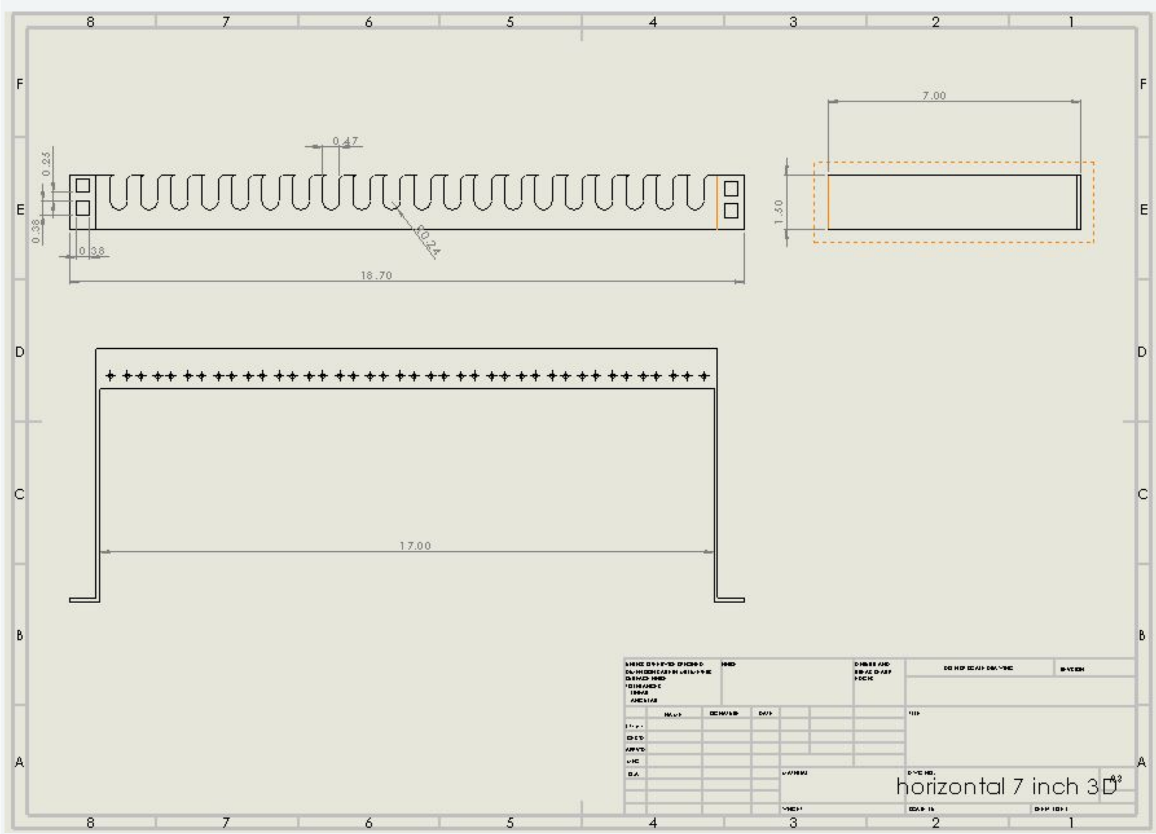


Figure: Vertical Component Redesign


0.47
0.25
0.38
0.38
0.38
1.50
R0.24
18.75
3.00
0.13
0.47
1.13
17.00
horizontal 3 inch 3D


0.47
0.23
0.28
0.28
R0.24
18.70
1.50
5.00
0.27
17.00
horizontal 5 inch 3D


7.00
0.47
0.25
0.38
0.38
R0.24
18.70
1.50
17.00
horizontal 7 inch 3D