MECH 4860 –Engineering Design

Fire Truck Cab Entryway Improvements Final Design Report
Fort Garry Fire Trucks
Team #9

December 1st, 2014

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December 1, 2014

Dear Dr. Labossiere:

We herewith submit Team #9's final design report entitled "Fire Truck Cab Entryway Improvements Final Design Report." This document is submitted for the final evaluation of our Mechanical Engineering capstone project.

This report presents our design for a pneumatically actuated, automatically deploying step system, utilized to integrate an ergonomic full width interior floor into an emergency response vehicle produced by our client Fort Garry Fire Trucks.

Also included are preliminary finite element analysis results requested by the client to determine whether this same vehicle meets the roof loading requirements for commercial vehicles established by the European Union.

Sincerely,

Rhys Werdermann, Martin Long, Chee Him Cheung, and Youssef Amin

Enclosed: Fire Truck Cab Entryway Improvements Final Design Report

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EXECUTIVE SUMMARY

Our team has partnered with Fort Garry Fire Trucks (FGFT) to solve an issue facing their current emergency response vehicle design. Currently in their Crown cab design, the interior floor partially overhangs the entrance steps, creating a tripping hazard while entering the crown. Additionally FGFT's competitors offer products which have an interior floor that extends the entire width of the vehicle, placing them at a competitive disadvantage when bidding on contracts.

FGFT has tasked us with modifying their Crown design to implement a full width floor, integrating automatically actuating steps to create an ergonomic entrance when entering and exiting the Crown. Consulting with our client, they emphasized that they desired a creative concept, one which would differentiate them from the competition.

Our final design achieves a full width interior floor, integrating a pair pneumatically actuating sliding steps on either side of the Crown. The actuation is designed to automatically extend the steps when the door is opened past 65°, and to retract the steps when the door is closed past this same point. The steps have been designed to meet the National Fire Protection Association's standards for automotive fire apparatus. The steps are 18" wide, a design consideration to eliminate any interference between the door and step during the actuation process, while maintaining a functional width for entering and exiting the Crown. A uniform rise height of 8-1/4" has been designed between the steps, with a uniform distance of 8" between leading edges of each step when they are deployed. Steel diamond plate is used to construct the tread face to provide a non-slip surface.

Considerations have been made within our design to ensure it fulfills FGFT's manufacturing capabilities, and to utilize materials common to their Crown design. The frame of

each step is constructed of 1-1/2” x 1/8” square 6061 aluminum tubing. 2” x 3/16” square and 2”x3”x3/16” 6061 aluminum tubing is used to construct the subframe used to mount all of our design components into the existing crown frame. Wherever possible, off-the-shelf parts have been used.

The pneumatics within our design are powered by an air storage tank that is charged by the fire truck's air brake system. Each step is actuated by its own pneumatic cylinder, an 8" cylinder for the upper step and a 16" cylinder for the lower step, which are connected in parallel so they actuate in unison. Double-acting pneumatic cylinders are used to provide powered out-strokes and in-strokes during actuation. In the fully extended position, the pneumatic actuators remain pressurized to hold the step firmly in place.

In order to control the pneumatic cylinders, an electrical control system was implemented. This control system consisted of two limit switches to sense the door position, and a third switch to allow the user to depressurize the pneumatic cylinders manually for maintenance. The switches route power to the solenoids of a 4-way pneumatic valve, opening and closing the valve to provide pressurized air to the pneumatic cylinders.

For our design, we had been given a budgetary goal of $1500. Breaking down the cost of all the components in our design, without considering labour costs, the total cost of our design was shown to be $1773.11, an overshoot of 18%. Reviewing our component costs there are no clear areas where cost can be further reduced within our chosen design.

To implement our design, it is recommended that FGFT builds an initial prototype of the system. This prototype is needed to fine tune the dynamic interaction between the slides and pneumatics, by adjusting the air flow within our system to ensure the actuation of the step doesn't hit the door during operation. This prototype will also be used to assess the need for bumpers between the door and steps in the stowed state, and the optimal positioning for the manual depressurization switch.

1 INTRODUCTION

For our MECH 4860 design project, our group has partnered with Fort Garry Fire Trucks to design an actuating step mechanism that will allow them to extend the interior floor of their cab the full width of the vehicle. We have also been asked to analyze their current Crown cab structure to ensure it meets the roof loading requirements for commercial vehicles set out by the European Union.

1.1 Background

Fort Garry Fire Trucks (FGFT) is Canada's largest manufacturer of emergency fire vehicles, providing fire trucks, pumper trucks, water tankers, and other rescue vehicles to fire departments across North America [1]. FGFT is currently looking to expand its market share by modifying their current design to better compete in the North American market and by expanding into the European market.

The initial model that FGFT intends to introduce to the European market, and the model they have asked us to modify for the North American market, is built on a Freightliner chassis (as shown in Figure 1); with a supplementary custom built cab, called a Crown, added behind the Freightliner cab to provide seating for an additional three to four firefighters and to house the controls for different equipment.

Figure 1: Fort Garry Fire Trucks Pumper Tanker with Crown cab [1]

The issues facing the current layout of the Crown are the ergonomics of the entrance steps, and the lack of a full width floor. Currently, when entering the Crown, there is a considerable tripping hazard created by an overhang of the interior floor as shown in Figure 2.

Figure 2: Current entrance step of the Crown

This overhang is neccesitated by the seating arrangement of the Crown (shown in Figure 3); without this floor extension, the two seats on the outside of the Crown would lack support for the feet of the firefighters seated there. Additionally, FGFT's competitors currently produce vehicles with full width interior floors, which places FGFT at a competitive disadvantage when bidding on contracts.

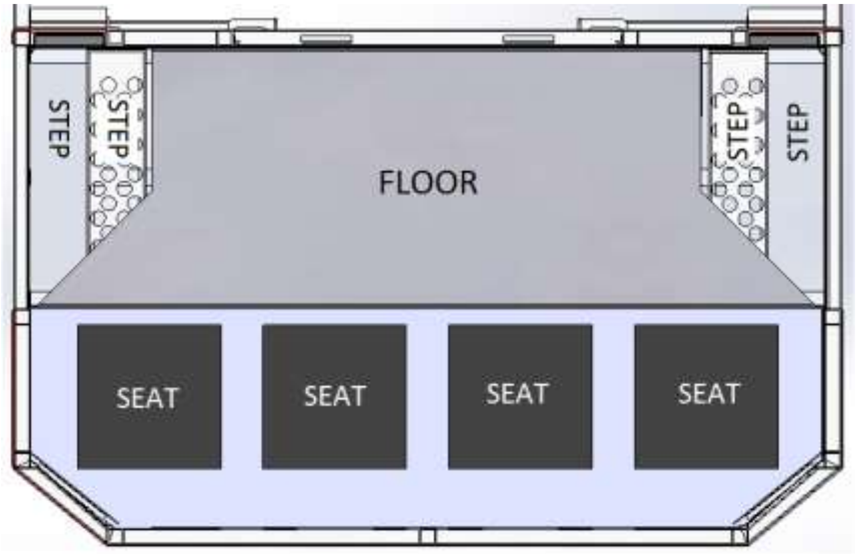

Figure 3: Overhead view of seating arrangement of Crown with current floor configuration

To alleviate these issues, FGFT has tasked us with creating a design concept which extends the interior floor the full width of the Crown and integrates an actuating mechanism which will deploy ergonomic stepping platforms when the door of the Crown is opened.

1.2 Design Requirements

There are some basic requirements for our design as provided by our client. These requirements are stipulated by the National Fire Protection Association (NFPA) - specifically *NFPA 1901: Standard for Automotive Fire Apparatus* [2] which states any step must:

- Support 500 lbs applied to a 5" diameter circle
- Be a minimum of 5" wide and 8" deep
- Be a maximum of 24" from the ground with a maximum of 18" between steps
- Have a non-slip surface

The client has also specified that the step must open and close in conjunction with the door opening and closing and should be as ergonomic as possible; specifically, the step should not be ladder-like.

1.3 Design Constraints

Our design must also fulfill a number of constraints related to space availability, manufacturing capability, and cost.

The major constraint of our design is the space within the Crown that our mechanism may occupy. Our mechanism must fit within the space currently occupied by the fixed steps at the Crown door (shown in Figure 1 and Figure 2). Currently, behind this space is a heater, used to heat the Crown in winter. After consulting with our client, they agreed that the space currently occupied by the heater may also be utilized by our design, as the addition of the full width floor above the heater will cause it to be ineffective in heating the passage compartment. The dimensions of our design space are shown in Figure 4.

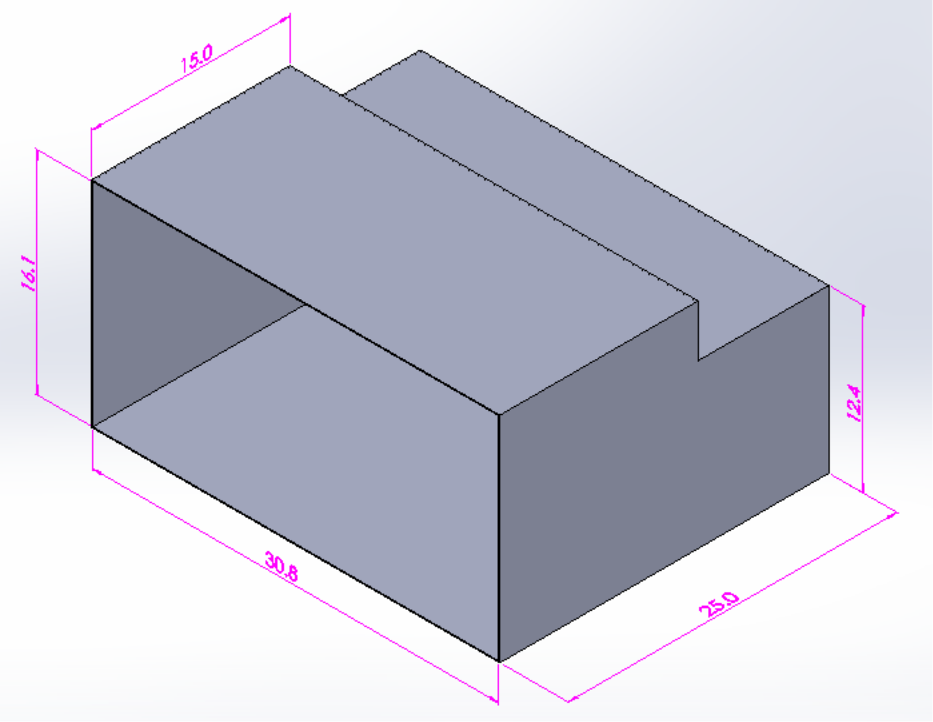

Figure 4: Space allocation within Crown for our mechanism, dimensions shown in inches.

There are also some material and manufacturing constraints imposed due to the manufacturing capabilities of FGFT's facility. The Crown structure is primarily constructed out of aluminum alloys with steel also being used. This precludes our design from being constructed out of composites or plastics. FGFT does have a CNC plasma table; therefore, we can incorporate this into our design to construct more complicated geometry if needed.

Additionally, FGFT has given us a budgetary goal of $1500. This budget includes all materials and components required to implement our design on both sides of the Crown. Labour costs have been omitted.

1.4 Crown Roof Loading Analysis

FGFT is currently looking to expand its market share further into the European market and gave us the additional task of assisting them in ensuring their emergency response vehicles meet the standards and criteria for use in Europe.

Only the Crown needs to be analyzed, as the Freightliner chassis used in the model they asked us to analyze meets European Union commercial vehicle standards. Of prime interest to FGFT is the roof loading standards, subsection 7.4 of Regulation No. 29 of the Economic Commission for Europe of the United Nations, which states that the roof of the Crown must be able to withstand a static load equal to the maximum mass authorized for the front axle of the vehicle up to a maximum of 98kN [3]. This corresponds to a load of 12,500 lbs, or 55.6kN, for the model being analyzed.

We were asked to perform a finite element analysis (FEA) on the Crown design to test whether it will meet this criterion. This analysis factored heavily into the early stages of our project, as it was used to determine the scope of our design content. If the Crown was shown to pass, FGFT is confident their design will meet the other requirements presented in the European standards and did not asked for any supplemental analysis from us. However, if this analysis were to show any deficiencies in their current design, our design task would have been to modify their Crown structure to fix these deficiencies. The results obtained from this analysis demonstrated that the crown will pass the static roof loading requirement, which allowed us to define the scope of our project as outlined. As this analysis of the Crown roof loading does not factor into our actuating step design, the results can be seen in Appendix A: Preliminary FEA Results. Based on the results of this analysis, FGFT intends to perform physical testing to confirm the results.

2 DESIGN CONCEPTS

As the design content of our project could not be defined until the after Crown analysis was performed, a process which was not completed until mid-October, our concept development process needed to be condensed. A full Gantt chart detailing our project development can be found in Appendix D. Additionally, there was a misunderstanding of scope and client need during the initial concept development of our actuating step project, which further condensed the time available for concept development. Our team still developed several ideas to redesign the steps in the Crown with a concept development process focused on two categories: a rotary step and a sliding step.

2.1 Rotary Step

The rotary step concept, seen in Figure 5, has the steps rotate into position as the door opens.

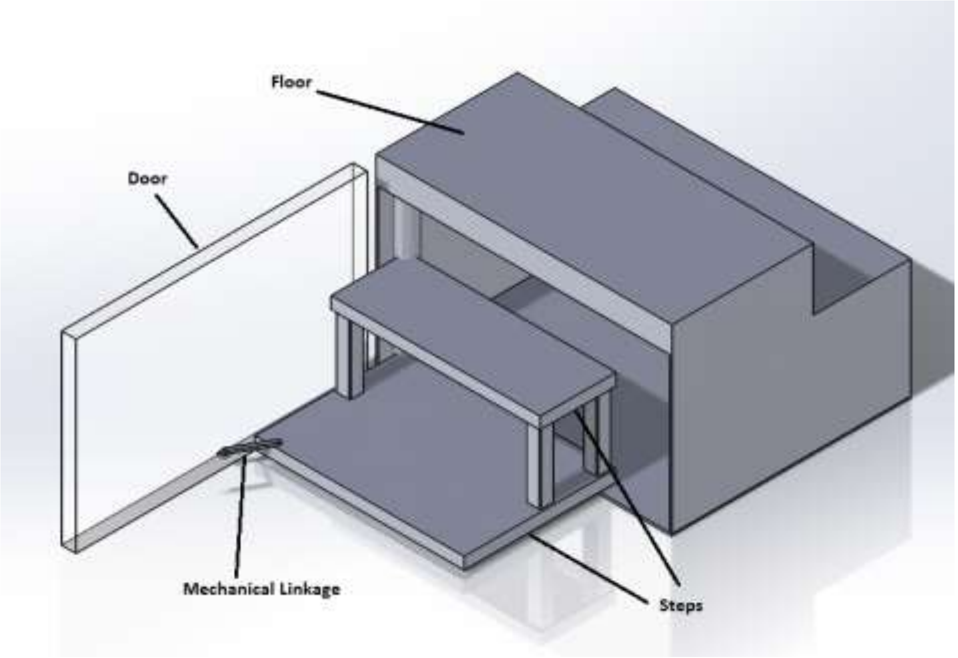

Figure 5: Rotary step design at fully extended position

For this concept, steps are attached to a pivot located inside the Crown near the pivot point of the door. The step assembly can be actuated by a mechanical linkage connecting the door to the step assembly. When the door is opened, the link will pull the steps to the deployed position; when the door is closed, the link will push the steps back into their stowed position. Additionally, a locking mechanism will be used to hold the steps in position while in use. The major limitation of this design is the depth of the allocated space; as this restricts the maximum width of the deployed step, potentially impacting ergonomics and usability.

2.2 Sliding Step

The sliding step concept has the steps move out linearly when door is opened, as shown in Figure 6.

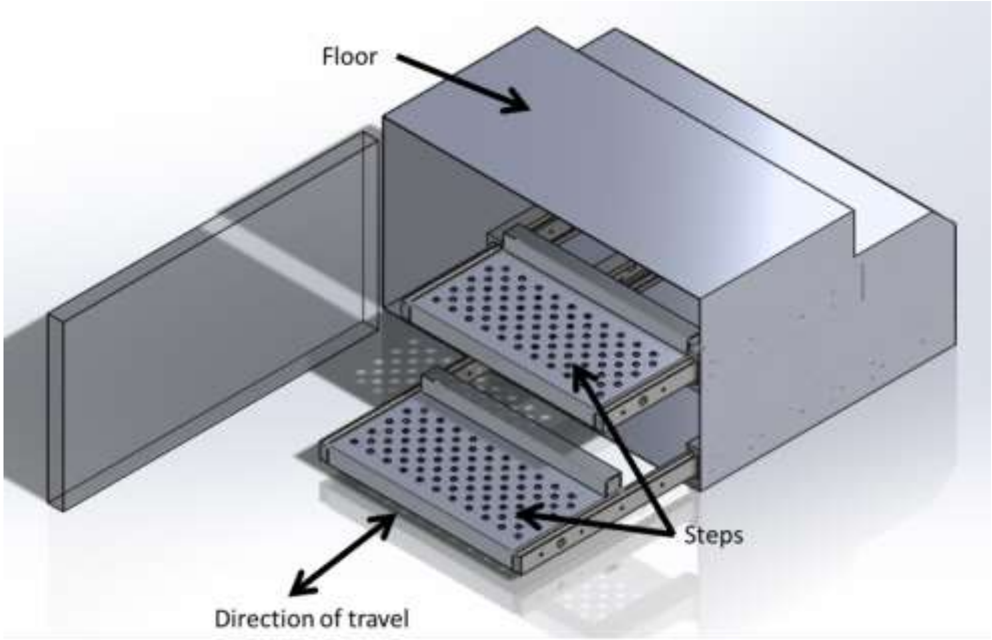

Figure 6: Sliding step design at fully deployed position

The linear motion of the sliding steps mechanism introduced an additional constraint on the width of the steps in order to prevent the steps colliding with the door. This, again, potentially impacts the ergonomics and usability of the step.

With the sliding step, multiple actuation and slide mechanisms were considered. These mechanisms are described below.

2.2.1 Actuation Mechanisms

In order to deploy and retract the steps as the door opens and closes, two actuation mechanisms were considered: pneumatic actuators and mechanical linkages.

2.2.1.1 Pneumatic Actuator

Pneumatic actuation utilizes linear pneumatic actuators, also called pneumatic cylinders, to deploy and retract the steps. Pneumatics was considered over electronic actuators or hydraulics due to the availability of an onboard air source; the pneumatic system can be run as an accessory of the airbrake system on the fire truck. Sensors monitoring the door position are required to control the pneumatic actuators, deploying or retracting the steps as the door opens and closes. Choosing an appropriately-sized pneumatic cylinder during our final design process will provide an actuation mechanism that can rapidly deploy and retract the steps, with valves and flow control being used to tune the speed of the mechanism.

2.2.1.2 Mechanical Linkage

The second actuation mechanism investigated was a mechanical linkage between the door and the steps. However, unlike the mechanical linkage used in the rotary step concept (which merely translated the rotary motion of the door to a rotary motion about a parallel axis), this mechanism would be required to convert the rotary motion of the door to a linear motion of the step. Two mechanical linkage concepts that could be utilized for a linear step were investigated.

The first mechanical linkage design is shown in Figure 7. A rigid arm is used to connect the door and steps. In this configuration, the linkage acts as a two-force member. As such, during opening and closing, an equal amount of force is being directed perpendicular to the step travel at certain points, reducing the efficiency of this mechanism.

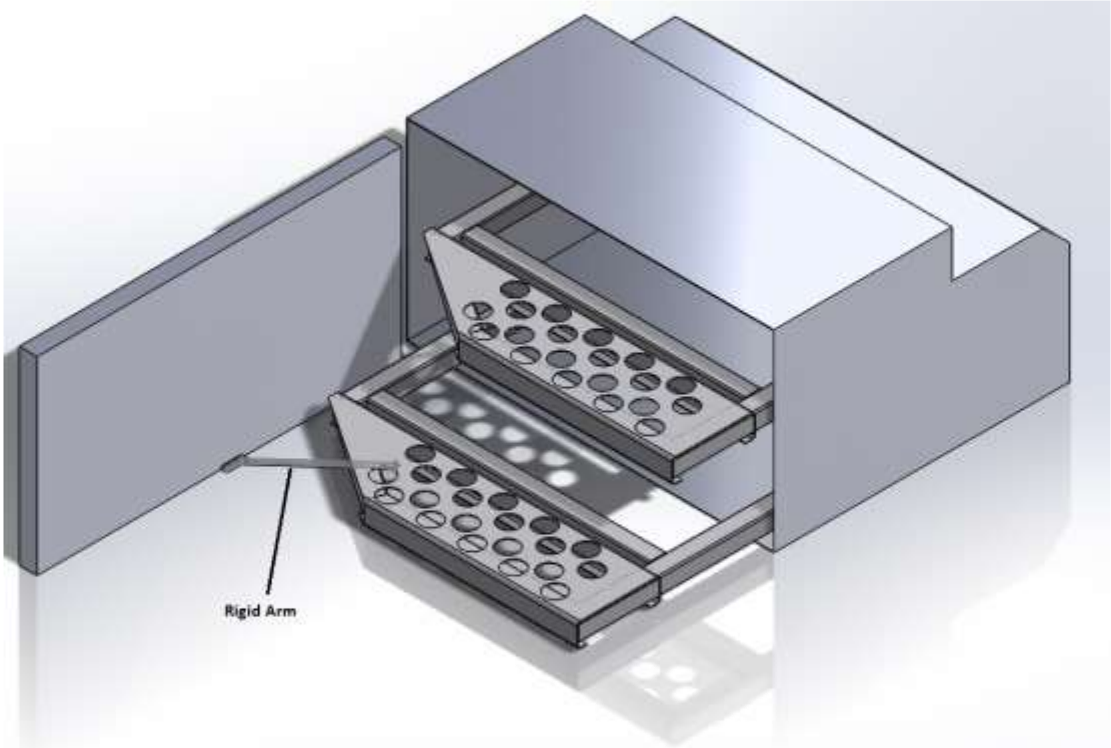

Figure 7: Mechanical linkage with small rigid arm

The second design is shown in Figure 8. In this design, an arm is connected to the door, and a pin provides a connection between the arm and the step. A track is mounted within the Crown. During operation, the pin will move along this track, which shifts the rotary motion of the door into a linear motion. However, this design increases the mechanical complexity as compared to the first design, while suffering from the same efficiency issues.

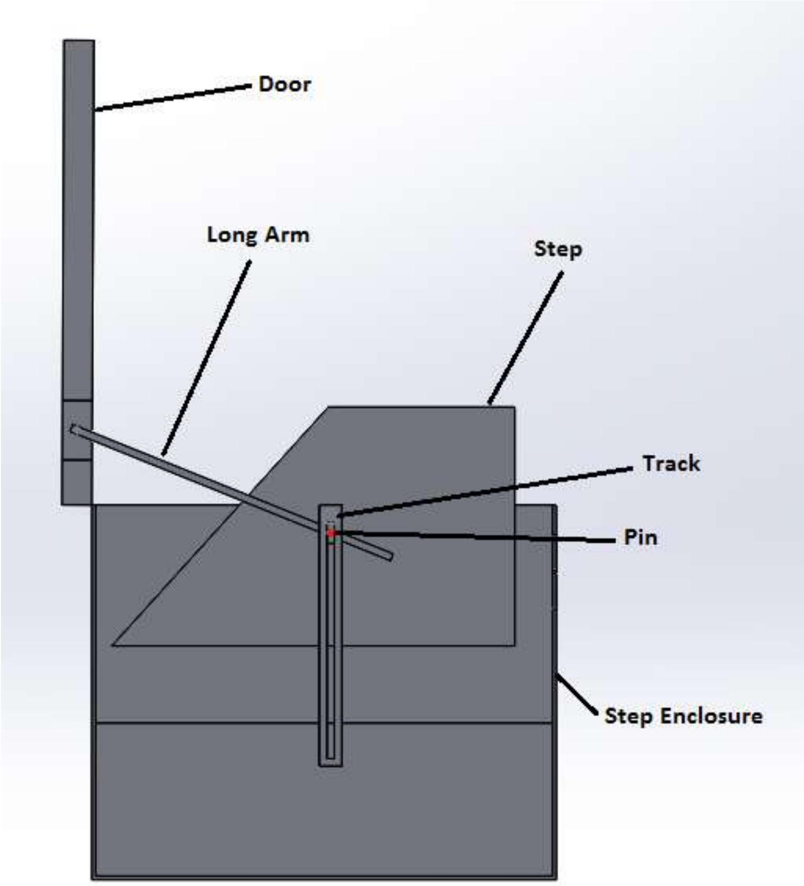

Figure 8: Bottom view for mechanical linkage with long arm (step at extended position)

2.2.2 Slide Mechanism

To facilitate the sliding action of the mechanism, a pair of mechanical tracks (called slides) is required. For our design, the slides need to satisfy several functional requirements. First, they must be of sufficient length to allow the step to extend to an ergonomic position and have a retracted length which neatly fits into the allocated space within the Crown. Second, they must be strong enough to support the weight of a firefighter when the step is fully extended, fulfilling the 500 lb load requirement from the

NFPA standards. Third, friction from the slide needs to be minimized in order to reduce the force required of the actuation mechanism we implement.

At first, a custom-designed option was considered. This would require the design of a fixed track and a wheeled slide. When considering the loading involved when the extended step is supporting 500 lbs, and the dynamic requirements of the slide, it was quickly determined that custom-built slides were infeasible due to our manufacturing and material constraints. Researching commercially produced slides, a number of different manufacturers were found to produce slides which meet all of the requirements of our design. It was decided that utilizing an off-the-shelf product would be the ideal solution for a sliding step mechanism, if it were to be chosen for our final design, with further research required.

2.3 Concept Selection

The selection of the concept with which we chose to move forward was primarily driven by discussions with our client and research of competitor designs. Our client emphasised that they were interested in receiving a creative concept from us that would differentiate them from their competitors. In our meetings with the client, and our independent research, we saw that the competitors utilize rotating step designs. As such, the sliding step concept was chosen for our final design, as it was determined to best satisfy our client’s wants and needs.

For the two possible actuation methods for this design, it was determined that the mechanical linkage had some major drawbacks which precluded it from being an optimal solution. For one, to prevent interference between the door and step during actuation, there must be a considerable gap between the two when they are fully open. This leaves the linkage unguarded, meaning it would be easy for the user to accidentally step on and damage the linkage when egressing the cab. Secondly, the off-the-shelf slides we intend to implement are designed to support vertical loading. As previously mentioned, the mechanical linkage will cause loading perpendicular to the motion of the step when opening and closing, a loading condition for which the commercial slides are not designed. The dynamics of the slides under these loading conditions are unknown, and seizing of the mechanism may occur.

Considering pneumatics, the major drawback is the increased complexity and cost over the mechanical linkage. However, pneumatic cylinders don't exhibit any of the following drawbacks of a mechanical linkage: The pneumatic components can be located inside the Crown, with the cylinder attached below the tread of the step, which eliminates the possibility of the user accidentally damaging the component. Also, pneumatic cylinders operate in a purely linear fashion, which fits the designed loading conditions for the off-the-shelf slides.

Further research was conducted to determine the feasibility of utilizing pneumatics, and it was determined that the controls that would need to be implemented for our application can be fit into our $1500 budget without need for compromise in other areas.

3 FINAL DESIGN

Our design achieves a full width interior floor in the Crown, integrating a set of pneumatically actuated sliding steps which extend and retract in conjunction with the door. Renderings of our design within FGFT's Crown model are shown in Figure 9.

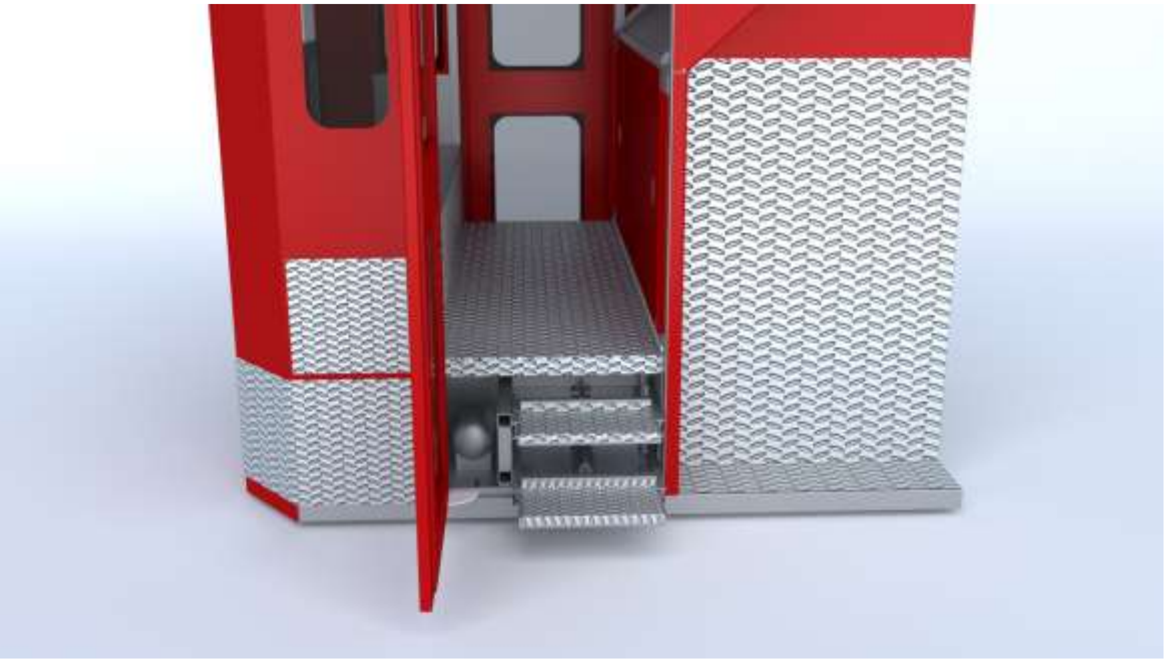

Figure 9: Render of our final actuating step design in the deployed position

The actuation is designed to extend the steps when the door is opened past 65° and to retract the steps when the door is closed past this same point. The width of the step, 18", has been designed to eliminate any interference between the door and step during the actuation process, while maintaining a functional width for entering and exiting the Crown. Figure 10 shows a diagram of the ergonomic factors of our design.

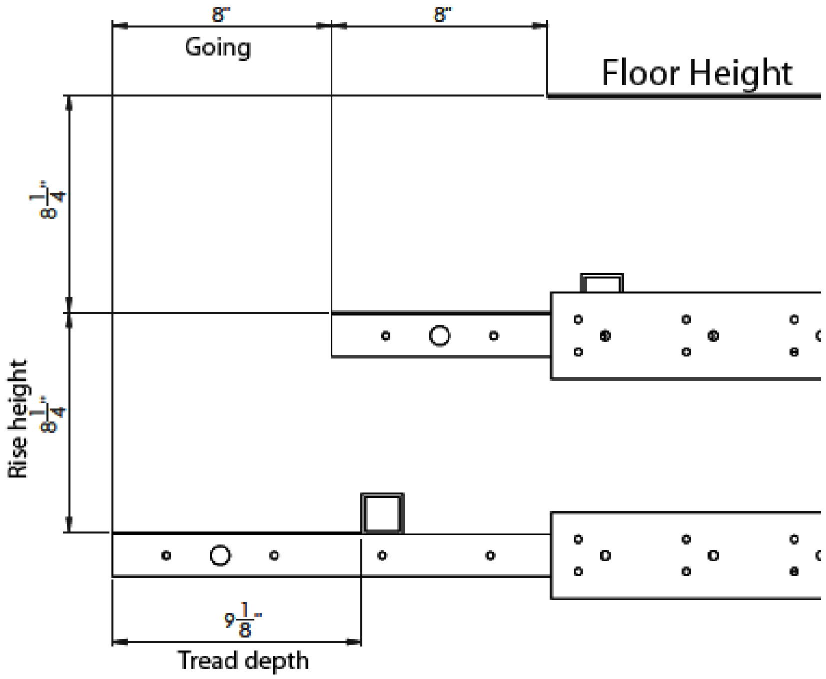

Figure 10: Measurements of extended step position

From this, we see our step design has a rise height of 8-1/4", tread depth of 9-1/8", and going of 8". The tread of each step is constructed out of stainless steel diamond plate to provide a non-slip surface.

The pneumatics within our design are powered by an air storage tank that is charged by the fire truck's air brake system. Each step is actuated by its own pneumatic cylinder, an 8" cylinder for the upper step and a 16" cylinder for the lower step, which are connected in parallel so they actuate in unison. Double-acting pneumatic cylinders are used to provide powered out-strokes and in-strokes. In the fully extended position, the pneumatic actuators remain pressurized to hold the step firmly in place.

Considerations were made in our design to address functionality if mechanical failure or loss of electrical power occurs. If stuck in the retracted position, our design will still function as a ladder, impacting ergonomics during egress but still being functional.

The pneumatic control valve we selected has a default exhausted position. This means that if power is lost, pressure in the cylinders is vented; so, the step can be manually retracted. This design consideration eliminates the chance of the step being stuck in a deployed position, which would prevent the door from being closed. A power disconnect switch is also included in our design, giving the user control to exhaust the cylinders if the step needs to be manually extended or retracted or to perform maintenance.

Further details of the individual design components, including selection criteria and analysis, are detailed in the following sections.

3.1 Tread Design

The tread of our design is formed by a welded tube structure, constructed out of 1-1/2"x1/8" square 6061 aluminum tubing, and a formed piece of 1/8" stainless steel diamond plate which is riveted to the frame. The tread design is shown in Figure 11. This tread has a tread depth of 9-1/8" and a width of 18". Mounting holes are provided along the sides of the tread to fasten it to the slides. To accommodate the pneumatic cylinder which will be paired to this component, the rear tube is offset above the rest of the frame, allowing the pneumatic cylinder to be positioned in parallel with the centreline of the step. A mounting tab to fasten the clevis of the pneumatic cylinder is provided on the front tube of the step frame.

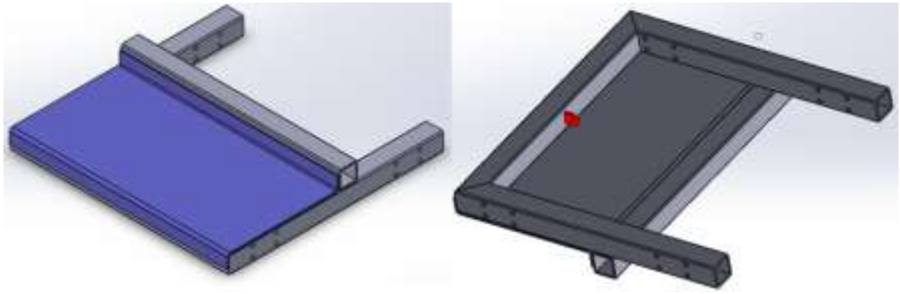

Figure 11: Tread design

To meet the design requirements, the tread is designed to support a load of 500lb. To test this, FEA was performed on the tread. For this analysis, the sides of the tread (where it is bolted to the slides) were set as fixtures, and a 500 lb load was applied to a 5" diameter circle on the face of the tread. A stress plot of this simulation is shown in Figure 12.

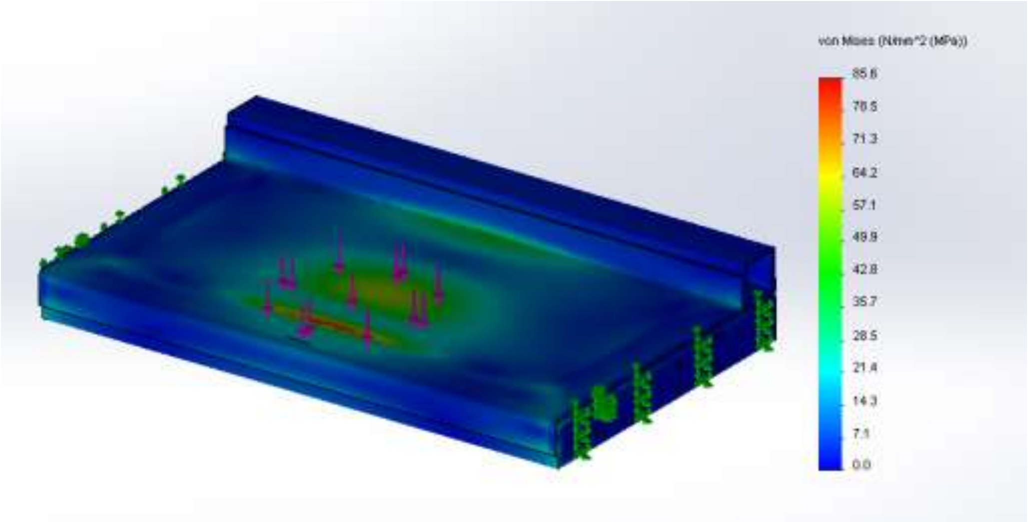

Figure 12: Stress plot of tread structure with 500 lb load applied

From this plot, we see a peak stress of 85.6MPa in the steel tread face; this is much less than the 220MPa yield strength of the stainless steel plate. Deflections in the plate were demonstrated to be less than 0.5 mm. Notable stress concentrations in this analysis were seen in the areas of contact between the tube structure and plate, which would be unexpected in a riveted connection between the two. As such, the tube structure was analysed separately resulting in the stress plot shown in Figure 13.

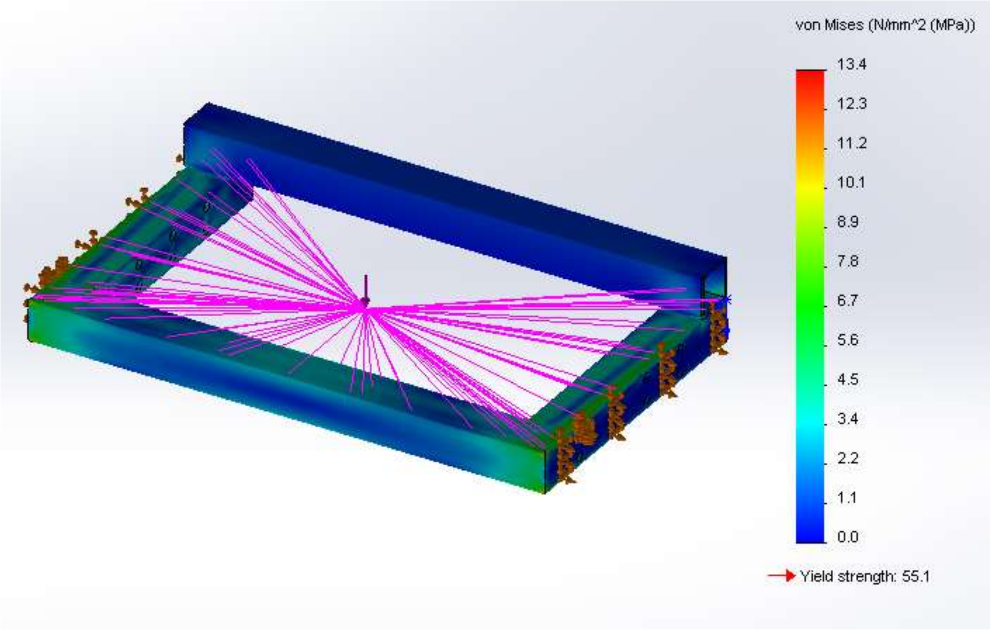

Figure 13: Stress plot of aluminum tread frame subjected to 500 lb remote load.

For this analysis, the same fixture conditions were used, with the 500 lb load now distributed along the top faces of the aluminum tubes using a remote load application point analogous to the user stepping on the tread face. From this plot, we see a maximum stress of 13.4MPa - less than the 55.1MPa yield strength of the 6061 tubes. This analysis demonstrates that our step meets the loading criteria of our design.

Engineered drawings of this component can be found in Appendix C.

3.2 Slide

In selecting an off-the-shelf slide, four criteria were considered: maximum allowable load, extension length, retracted length, and cost. The chosen slides needed a designed capacity of at least 500 lb applied at a point near full extension. They need extension lengths capable of reaching the designed distance for the deployed steps, which are 8” and 16” for upper and lower step respectively, while maintaining retracted lengths that fit into the allocated space in the Crown. The cost of the chosen slide is a major consideration, as eight slides are required in total.

Slides from the GSF Sliding Systems DTS 60 series, pictured in Figure 14, were chosen for our final design. These slides were chosen as they meet all of our requirements while having an economical price that fits into our budget.

Figure 14: GSF Sliding Systems DTS 60 series telescopic slides. [4]

These slides are a two section telescopic slides, milled out of C45E+C steel. The I-beam structure of the middle slide component gives this product high strength while maintaining a compact profile. Additionally, this product is considered excellent for applications experiencing dynamic loading (which describes our application well) and are designed to be shock and vibration resistant.

The loading rating for these slides is based on a distributed load at the centre of the slide. As our load is concentrated at approximately 3/4 of the length of the slide, it was determined the rated load for these slides of 900-1000 lbs would be sufficient. A summary of the properties of the selected slides is shown in TABLE I. Full technical specifications for this product can be found in Appendix B.

TABLE I: PROPERTIES FOR SELECTED SLIDE [4] [5]

Part Number	**4015.DTS060.0250**	**4015.DTS060.0450**
Installation (retracted) length	9.84"	17.72"
Extension length (in)	9.84"	17.72"
Load per pair of slides (lbs)	904 lbs	970 lbs

3.3 Pneumatics

A pneumatic actuating system consists of three main components: the air compressor, the compressed air tank, and the air cylinder. The first component is the compressor, providing the high pressured air needed to operate the system. In our project, our system is run as an accessory of the vehicle's air brake system, which provides our pressure source. The second component is the compressed air tank, which is used to store the compressed air. This results in greater volumetric flow rates and, thus, greater piston speeds; it also allows our design to operate when the vehicle's engine is not running. The team has chosen a one gallon tank to store the pressurized air. The final component is the pneumatic cylinder, the requirements of which are described in the following section.

3.3.1 Cylinder Requirements

In order to operate the sliding step in the final design, two pneumatic cylinders are utilized: one for the lower sliding step and a second for the upper sliding step, as shown in Figure 15.

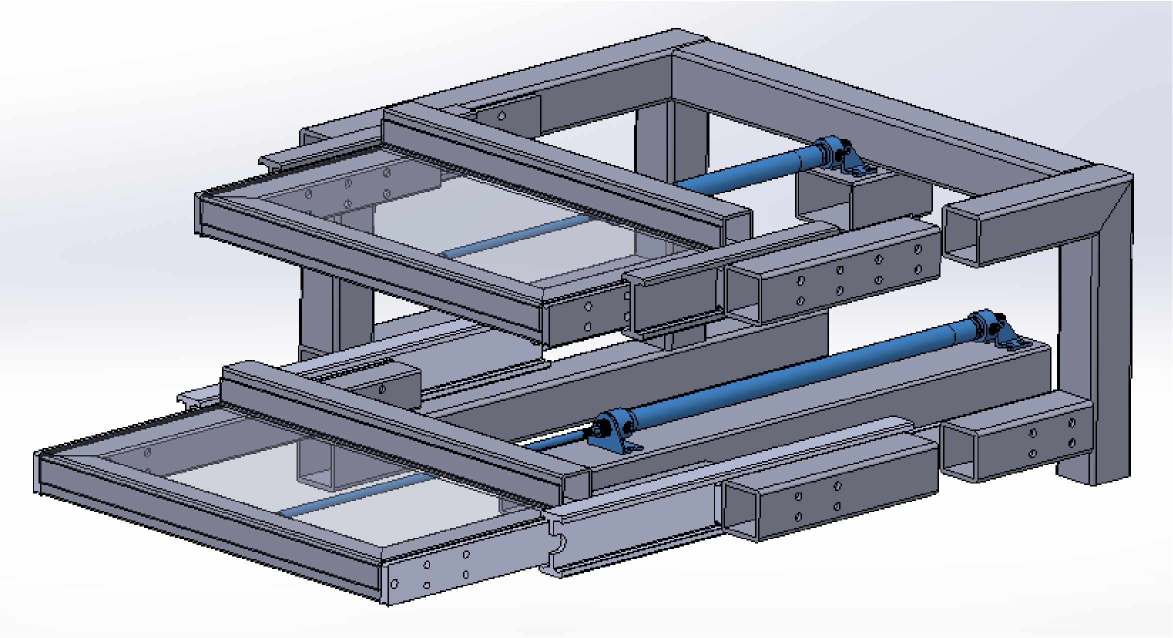

Figure 15: The configuration of the two cylinders, highlighted in blue, required for the upper and lower sliding step

In order to ensure the sliding steps function as intended, the pneumatic cylinders must meet five constraints: They must be double acting, have appropriate stroke lengths, operate in low temperatures, have an outside diameter which fits in our space constraints, and operate under an appropriate pressure. Double acting cylinders will be used, as they allow for forward movement of the steps when the Crown door opens and backward movement of the steps when the Crown door closes. To meet the design requirements, the stroke length of the cylinder attached to the lower tread must be 16”, and the stroke length of the cylinder attached to the upper tread must be 8”. To fit within our space constraints, specifically to nest underneath the step frame, the cylinders must have an outside diameter less than 1-1/4”. Lastly, the operating pressure of the two cylinders must be within 80 - 150 psi.

Cylinders from the McMaster Carr switch-ready stainless steel air cylinder product line were chosen, as they meet all the preceding constraints. The smaller cylinder of our design is shown in Figure 16.

Figure 16: The Small Cylinder of 8” Stroke Length [6]

A summary of the properties of the selected pneumatic cylinders is shown in TABLE II. Full technical specifications can be found in Appendix B.

TABLE II: PROPERTIES FOR PNEUMATIC CYLINDERS

Part Number	**4952K229**	**4952K251**
Bore Size	3/4"	3/4"
Stroke Length	8"	16"
Retracted Length	13-1/8"	21-18"
Outside Diameter	1-1/8"	1-1/8"
Minimum Operating Temperature	-30°C	-30°C

To control the air flow going in and out of the cylinders, an air flow control valve is used. An air flow control valve is a device that reduces the flow rate of the air, consequently reducing the extension and retraction speed of the pneumatic cylinder.

3.3.2 Cylinder location

Both air cylinders are located in the allocated space below the interior floor of the crown, nested underneath and behind the tread in the retracted position, as shown in Figure 17. The cylinders are centred behind each step to provide even force between the paired slides during actuation. Furthermore, the location of the two cylinders provides easy access to perform maintenance on the cylinders.

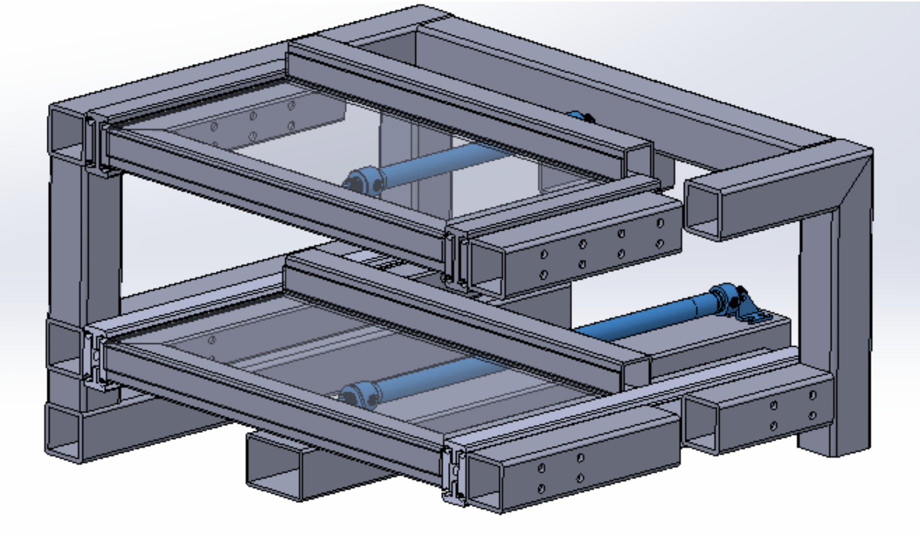

Figure 17: Location of the pneumatic cylinder. Cylinders are highlighted blue. Tread face has been hidden to better illustrate cylinder position.

3.3.3 Cylinder Mounting Components

The choice of mounting style can improve the pneumatic cylinder performance by avoiding misalignment between the cylinder rod and the axis of step travel and preventing buckling of the cylinders [7]. The team has chosen rear pivot mounts for both the small and large cylinders, as shown in Figure 18, utilizing the pivot brackets designed for the McMaster Carr product line. On the longer cylinder, an additional foot bracket is added at the front end of the cylinder. This is added to reduce the length of the unsupported cylinder at full extension in order to reduce buckling loads. Technical specifications of these mounting components can be found in Appendix B.

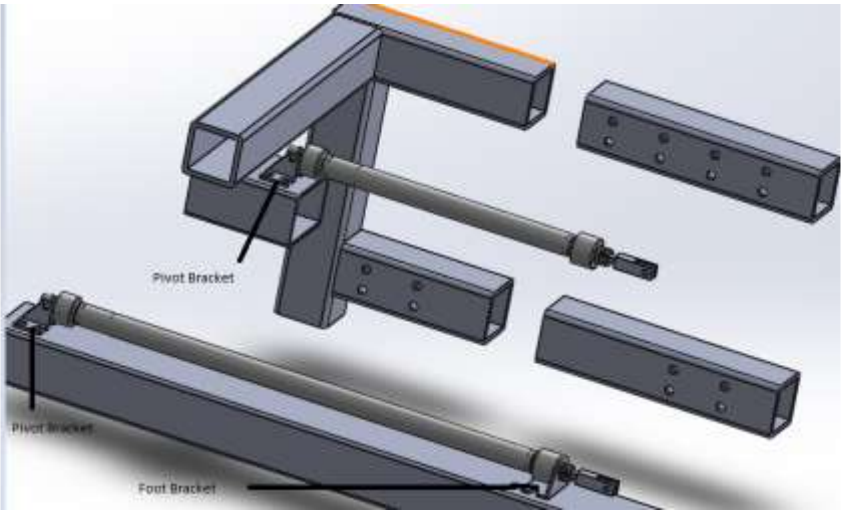

Figure 18: Small And Large Cylinders Mounted to Pivot Bracket and Large Cylinder Mounted To Foot Bracket

3.3.4 Cylinder Maintenance

The selected cylinders are non-repairable, meaning that these parts need to be replaced as a unit if they fail. Repairable pneumatic cylinders were also researched, however the cost difference between the two option made non-repairable cylinders the preferable option. The piston seals and rod seal of the chosen cylinders are made of nitrile rubber, which has a high wear resistance; this in turn, increases the life span of the cylinder [8].

3.4 Mounting

To mount and support the different components of our design, additions to the frame of the Crown must be made. After determining the geometry of the design and selecting the different components that will be utilized; a subframe was created to connect all the components together, which was then integrated into the existing Crown frame. Figure 19 shows how this frame fits into the existing frame.

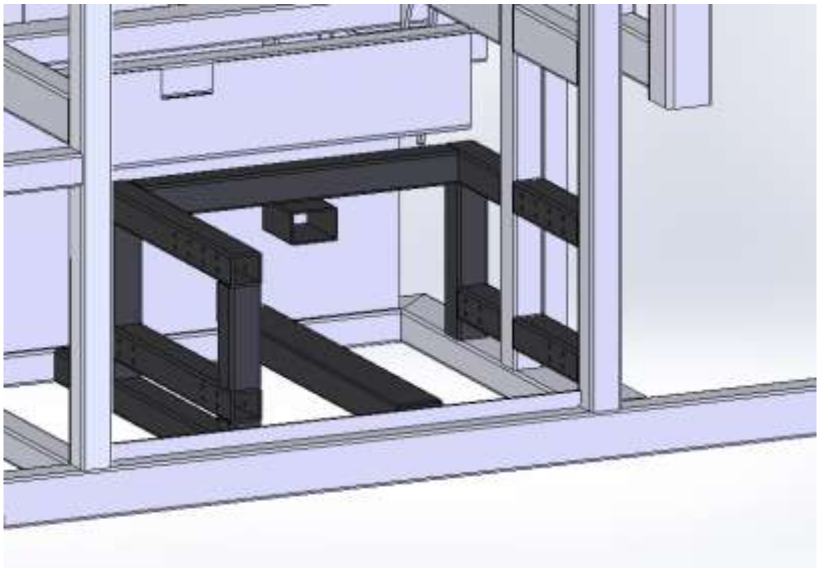

Figure 19: Subframe addition to support design components. Dark grey components are new frame members which will be added to the existing Crown frame.

The subframe is constructed using material and manufacturing operations consistent with the rest of the Crown frame. The subframe contains mounting surfaces for the slides and pneumatics. To ensure it is robust enough to support the loading from our design, FEA was performed. A plot of the stresses observed in the structure when subjected to load analogous to 500 lbs on each step is shown in Figure 20.

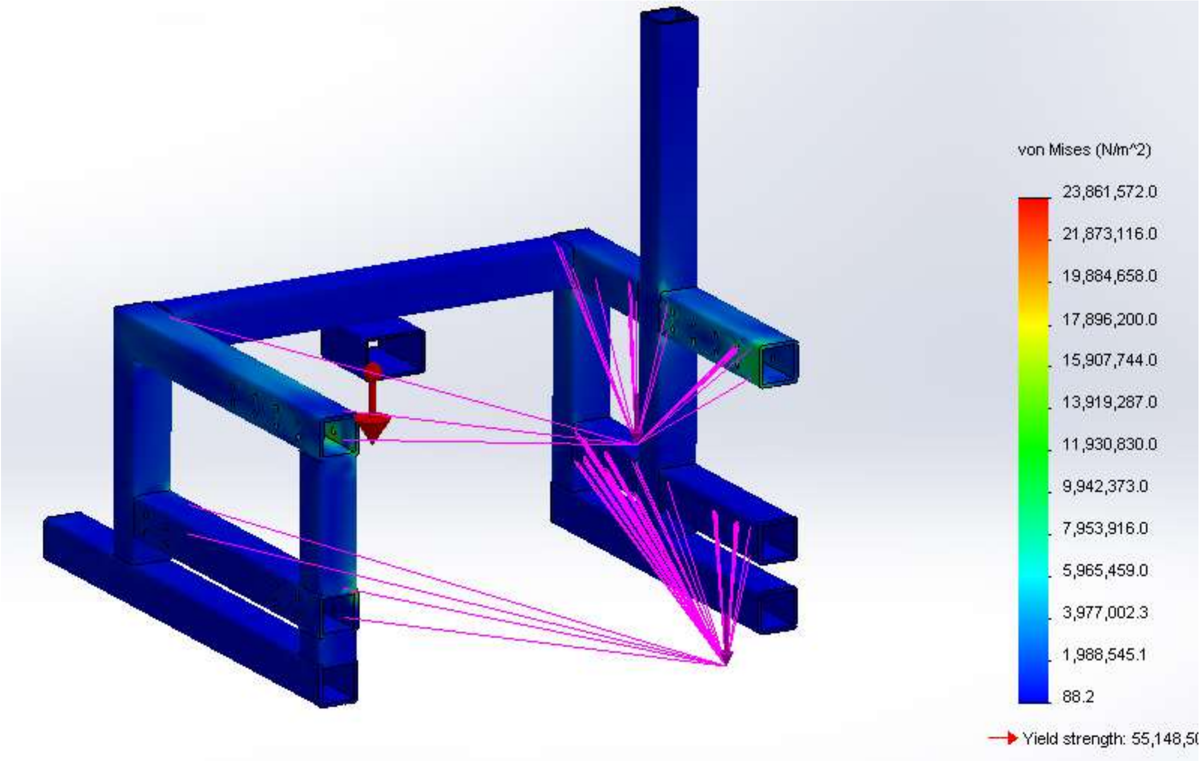

Figure 20: Stress plot of subframe subjected to 500 lb loading on each step.

From this plot we can see that the 500 lb load is supported by this subframe while maintaining a factor of safety greater than two.

Engineered drawings of this component can be found in Appendix C.

3.5 Control System

As the steps are to be deployed automatically as the door opens, a system is required to control the flow of air to the pneumatic cylinders in order to deploy and retract the steps at the proper times. The following section details the design process and final design of the control system for the automatic steps.

The control system was designed by first evaluating the desired behaviour of the system, identifying the necessary inputs and outputs of the system and their relationships to each other. With this done, a hardware system was then designed to detect the required inputs and translate them into the corresponding outputs.

3.5.1 Desired Behaviour

When the door opens, the steps are to deploy; however, if the steps deploy too early, they will hit the door - forcing it open. Thus, in order to avoid that situation, the steps should not begin to deploy until the door has opened enough that it will not interfere with the fully deployed steps. Similarly, when closing the door, the steps should begin to retract to their stowed position before the door hits them. When the door is fully closed, the pneumatic cylinders should be depressurized to limit air leaks in the system. Finally, in order to allow for maintenance; the user should have the ability to move the steps freely, at their discretion, regardless of the current door position.

3.5.2 System Inputs and Outputs

From the above behaviour, three inputs can be identified: The first is whether the door will interfere with the fully deployed steps; this corresponds with an opening angle of approximately 60°. A small buffer will be added and, thus, the point along the door's arc at which the steps will deploy or retract is 65° (henceforth referred to as the "deploy/retract point"). The second input detects whether or not the door is completely closed, and the third input allows the user to manually depressurize the system.

Furthermore, these inputs lead to four possible states: The first is the stowed state. The system is in the stowed state when the door is completely closed. In this state, the pressure in the pneumatic cylinders is exhausted, and the steps are only held in place by the door and the back of the slides. The second state is the deployed state, active when the door is opened beyond the deploy/retract point. In the deployed state, pressure is applied to the back of the pneumatic cylinders while the front is exhausted, deploying the steps; and, once deployed, holding the steps in place. The third state is retracted. The system is in the retracted state when the door is between the deploy/retract point and the fully closed point. While in the retracted state, pressure is applied to the front of the pneumatic cylinders while the back is exhausted, pulling the steps back to their fully retracted position and holding them there so that the steps do not collide with the door. The final state is the maintenance state in which the pneumatic cylinders are depressurized at the user's discretion regardless of the door position. This allows the steps to move freely, simplifying maintenance. Of these four possible states, the stowed and maintenance states both result in the pneumatic cylinders being depressurized; thus, these two states can be considered a single output which can be the result of multiple possible input conditions.

3.5.3 Implementation

In order to control the double acting pneumatic cylinders and put them into the required three distinct states (deployed, retracted, and maintenance/stowed); a 4-way, 3-position, double solenoid, center exhausted valve was selected. Such a valve will put the system in the deployed state when solenoid 1 is energized, the retracted state when solenoid 2 is energized, and the stowed/maintenance state when neither solenoid is energized.

The specific model selected was a NITRA Pneumatics AVS-513E1-24D, as it met the specific needs of this system (with the exception of poor cold weather performance, as the valve is only rated to -5°C [9]). There are valves with lower minimum operating temperatures that fit the needs of this system; however, these options were significantly more expensive, costing several hundred dollars more. Detailed specifications of the NITRA Pneumatics AVS-513E1-24D can be found in Appendix B.

To energize the proper solenoid, three switches are used to detect the inputs detailed in section 3.4.2. One switch senses when the door reaches the deploy/retract point (switch 1), sending current to solenoid 1 when the door is opened beyond 65° and to solenoid 2 when the door is opened at an angle less than 65°. A second switch senses when the door is fully closed (switch 2), at which point it opens the circuit cutting power to the solenoids. The third switch is used to manually put the system into the maintenance state (switch 3), again, by opening the circuit. The two limit switches used to sense door position (switches 1 and 2) are both single pole double throw (SPDT). A normally closed, single pole single throw (SPST) switch could be used for switch 2; however, as the price difference between SPST and SPDT switches is negligible, it would be more advantageous to simplify the production and maintenance of the system by having switches 1 and 2 utilize the same model of SPDT switch. Switch 3 is a SPST rocker switch, allowing the user to quickly and easily put the system into the maintenance state. These three switches are wired in series as seen in Figure 21. The specific switches chosen were C&K Components ASKHF3T04AC for switches 1 and 2, and an Arcolectric C1500WABB-B for switch 3. Detailed specifications for both switches can be found in Appendix B.

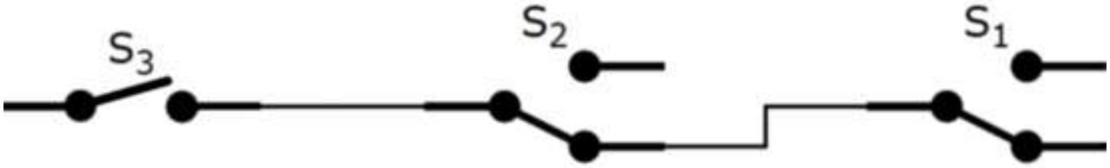

Figure 21 : Circuit diagram for the step control system

3.5.4 Switch Positioning

Switch 1 is mounted to the floor of the step enclosure, 4" back from the forward edge of the door frame and ¼" in from the doorsill. A plate (Figure 22) is attached to the inside of the door 1.5" from the bottom and flush with the front edge of the door. The plate is a quarter circle with a radius of 4" and extends out horizontally from the door. When the door is closed, the plate depresses switch 1, routing power to solenoid 2. When the door is opened beyond the deploy/retract point, the switch is uncovered, re-routing power to solenoid 1 and setting the system to the deployed state.

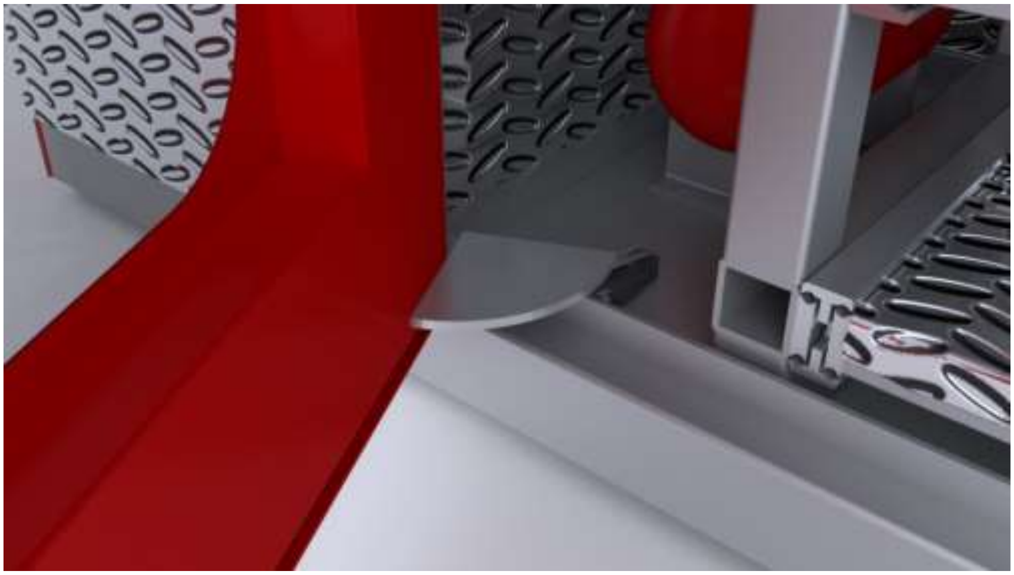

Figure 22: Sensor Plate

Switch 2 is mounted to the inside of the doorframe between the two steps (Figure 23). In this position, the switch will only be depressed (opening the circuit) when the door is in the fully closed position.

Figure 23: Switch 2 positioning

The exact positioning of switch 3 is relatively unimportant as the only requirement is that it is accessible to the user. The team determined that the most convenient place would be just inside the door, about 2’ above the floor of the Crown, as the user could easily reach this position from both inside and outside of the Crown.

3.5.5 Control System Overview

The double acting pneumatic cylinders are controlled by a 4-way, 3-position, double solenoid, center exhausted valve (NITRA Pneumatics AVS-513E1-24D). This valve is, in turn, triggered by three switches wired in series. Switch 1 flips when the door opens beyond the deploy/retract point, switch 2 opens when the door is fully closed, and switch 3 is toggled by the user. Figure 24 shows a diagram of the control system in the maintenance state.

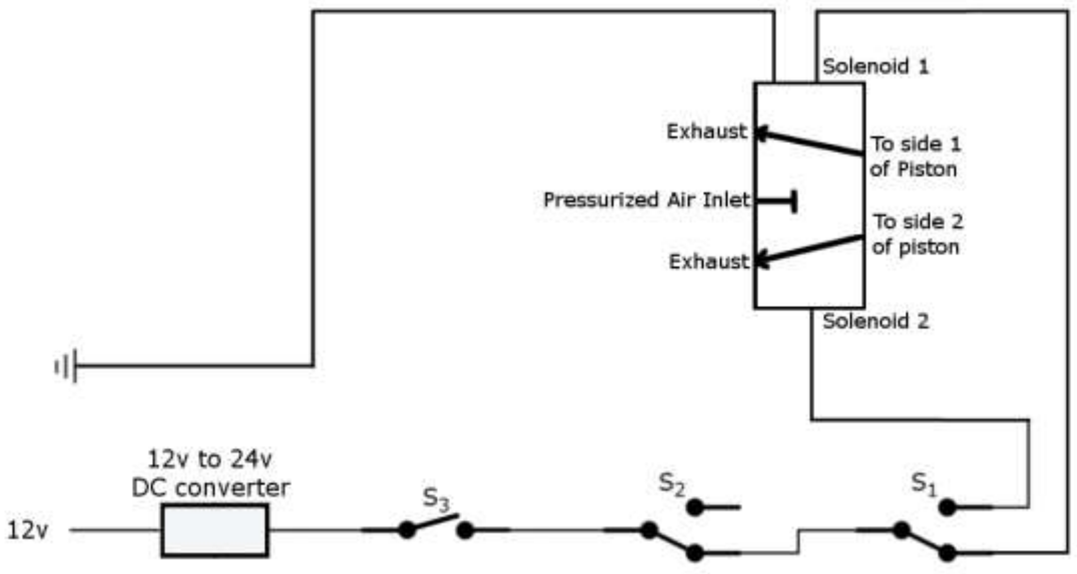

Figure 24: Control system diagram

3.6 Cost Breakdown

To determine the total cost of our design, it has been broken down to the component level in TABLE III. This table has been subdivided into three categories to demonstrate the cost distribution; raw materials, pneumatics, and slides.

TABLE III: COST BREAKDOWN OF FINAL DESIGN

Part Description	Part Number	QTY	Cost Per unit ($)	Total Cost($)	Reference
Raw Materials					
1-1/2" x 1/8" wall 6061 Aluminum Square Tube	-	22 ft.	1.65/ft	36.30	[10]
2" x 3/16" wall 6061 Aluminum Square Tube	-	24 ft.	3.60/ft	86.40	[10]
3” x 2” x 1/8” wall 6061 Aluminum Rectangle Tube	-	5 ft.	5.99/ft	29.95	[10]
Stainless Steel Diamond Plate	-	6 sqft	6.42/sqft	38.42	[10]
			Subtotal	**$191.17**	
Pneumatics					
Air Flow Control Valve - 1/8” NPT Female x 1/8” NPT Female	62005K613	2	24.47	48.94	[11]
Air Hose 1/8" ID	451029	12 ft.	0.42/ft.	5.04	[12]
Air Hose Connector 1/8” Pipe to 1/8” Hose Fitting, Pack of 10	11924-1-PKG	2 packs	8.12/pack	16.24	[13]
Coupler Plug ¼” NPT to 1/8” NPT	G4978023	2	0.77/Plug	1.54	[14]
Horizontal Pressure Tank, 1 Gallon Capacity, 6" Diameter x 11" Long	9888K9	1	202.02	202.02	[15]
Pivot Bracket with Pin for 3/4" Bore	4952K675	4	4.48	17.92	[16]
Foot Bracket for 3/4" Bore Cylinder	WWG5THP1	2	2.97	5.94	[17]
Rod Clevis with Pin for 3/4" Bore Cylinder	G0385043	4	6.07	24.28	[18]

Air cylinder 8" stroke ¾ bore	4952K229	2	57.36	114.72	[6]
Air cylinder 16" stoke ¾ bore	4952K251	2	76.10	152.20	[19]
Valve 4-way 3-position pneumatic valve	AVS-513E1-24D	2	42.00	84.00	[20]
Switch snap SPDT switch	CKN9948-ND	4	5.32	21.28	[21]
SPST rocker switch	1091-1161-ND	2	4.14	8.28	[22]
12v DC-24v DC converter	811-1584-5-ND	1	15.84	15.84	[23]
			Subtotal	**$718.24**	
Sliding Rails					
DTS-60 Heavy Duty Slide Length of 9.84"	4015.DTS060.0250	4	87.73	350.92	[5]
DTS-60 Extreme Duty Slide Length 17.72"	4015.DTS060.0450	4	128.22	512.88	[4]
			Subtotal	**$863.80**	
Total				**$1773.11**	

From this, we see that our design has gone over our budgetary goal of $1500 by 18%. Looking at the subsection costs in the table, we see that the slides are the most costly components, accounting for 48% of our final cost. From our research of other slide options when determining the optimal slide for our design, the chosen DTS-60 slides were considerably less expensive than other suitable options, almost half the cost of the other options. As such, it is unlikely that the cost of the slides can be reduced much more. If this design is to be implemented widely in FGFT's production, it may be possible to get a bulk discount greater than the current 10 percent bulk discount factored into our cost analysis. Reviewing the cost of other components within our system, it is unlikely overall cost can be reduced further without modifying the functionality of our design.

4 RECOMMENDATIONS

An initial prototype of our design will be required before implementing it into FGFT production. This prototype is needed to fine tune the dynamics of the slides and pneumatics; as certain mechanical properties, such as the efficiencies of the slides and the linear speed of the entire mechanism, are unknown or cannot be calculated to a sufficient degree of accuracy.

To tune the speed of the mechanism as a whole, the air flow regulating valve will be adjusted to ensure the actuation of the step doesn't hit the door during operation. The need for a damper on the door to limit the closing speed will also be further assessed during this test.

When the step is retracted and the door is closed, the system is depressurized. This means, depending on the inherent friction provided by the pneumatic cylinder and slides, that the step may shift around and hit the door when the vehicle turns. If it is noted that the step is moved easily when depressurized, bumpers will be added to either the door or the step to prevent potential damaging impacts between the two components. In this situation it may also be necessary to add a mechanical means to fix the steps in the ladder failsafe mode.

Physical testing will also help to determine the optimal position for the depressurization switch, ensuring it is adequately accessible when the user is standing inside or outside of the Crown.

5 CONCLUSION

FGFT tasked us with improving the entryway ergonomics of their Crown cab design, by extending the interior floor the full width of the Crown, and implementing automatically actuating steps.

Our final design achieves a full width interior floor, integrating a pair pneumatically actuating sliding steps on either side of the Crown. The actuation is designed to automatically extend the steps when the door is opened past 65°, and to retract the steps when the door is closed past this same point. The steps have been designed to meet the National Fire Protection Association's standards for automotive fire apparatus. The steps are 18" wide, a design consideration to eliminate any interference between the door and step during the actuation process, while maintaining a functional width for entering and exiting the Crown. A uniform rise height of 8-1/4" has been designed between the steps, with a uniform distance of 8" between leading edges of each step when they are deployed. Steel diamond plate is used to construct the tread face to provide a non-slip surface.

The pneumatics within our design are powered by an air storage tank that is charged by the fire truck's air brake system. Each step is actuated by its own pneumatic cylinder, an 8" cylinder for the upper step and a 16" cylinder for the lower step, which are connected in parallel so they actuate in unison. Double-acting pneumatic cylinders are used to provide powered out-strokes and in-strokes during actuation. In the fully extended position, the pneumatic actuators remain pressurized to hold the step firmly in place.

In order to control the pneumatic cylinders, an electrical control system was implemented. This control system consistes of two limit switches to sense the door position, and a third switch to allow the user to depressurize the pneumatic cylinders manually for maintenance. The switches route power to the solenoids of a 4-way pneumatic valve, opening and closing the valve to provide pressurized air to the pneumatic cylinders.

Our design has been demonstrated to fulfill all of the requirements and constraints imposed on our project. However, our final design has exceeded out budgetary goal of $1500, with our cost coming in at a total of $1773.11, an overshoot of 18%. Further analysis of our costs has shown that this figure cannot be reduced without altering design functionality.

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A.1 Introduction

Fort Garry Fire Trucks (FGFT) is Canada's largest manufacturer of emergency fire vehicles, providing fire trucks, pumper trucks, water tankers, and other rescue vehicles to fire departments across North America [1]. FGFT are currently looking to expand their market share further, and have tasked us with assisting them in ensuring their emergency response vehicles meet the standards and criteria for use in Europe.

The initial model that FGFT intends to introduce to the European market is built on a Freightliner chassis, as shown in Figure 1, with a supplementary custom built cab, called a Crown, added behind the Freightliner cab to provide seating for an additional three to four firefighters and to house the controls for different equipment. As the Freightliner chassis already meets European Union commercial vehicle standards, only the Crown needs to be analyzed.

Figure 1: Fort Garry Fire Trucks Pumper Tanker with Crown Cab [1]

Of prime interest to FGFT is the roof loading standards, subsection 7.4 of Regulation No 29 of the Economic Commission for Europe of the United Nations, which states that the roof of the Crown must be able to withstand a static load equal to the maximum mass authorized for the front axle of the vehicle, up to a maximum of 98kN [2]. This corresponds to a load of 12,500lbs, or 55.6kN, for the model being analyzed. We have been asked to perform a finite element analysis (FEA) on the Crown design to test whether it will meet this criterion. If the Crown is shown to pass, FGFT is confident their design will meet the other requirements presented in the European standards, and have not asked for any supplemental analysis.

Depending on the results of the FEA, there were two paths forward for the design portion of this project. If the Crown failed to meet the roof loading standards, we were to modify the design to meet all loading requirements as outlined in the European Union standards for commercial vehicles. We would also be looking for ways to optimize the design with regard to material, labour, and manufacturing costs. If the Crown was shown to meet the roof loading standards, FGFT invited us to consult on design improvements for the Crown.

A.2 Preliminary SolidWorks Analysis

To perform the FEA requirements, FGFT provided us with their SolidWorks model of the Crown, shown in Figure 2. This model included the full tube structure of the Crown, exterior panelling, trim, and walkways. As such, significant refinement of the model was required; so, it would be suitable for usage with our analytical software. To facilitate this refinement process, preliminary analysis was performed using SolidWorks Simulation; as this made it easier to move between the modelling environment and the simulation environment.

Figure 2: Provided SolidWorks model of Crown

We began the refinement process by suppressing all non-structural assembly components, paring the model down to the tube frame. Some suppressed components may influence the structural integrity of the Crown, such as the exterior panelling; but we chose to work on the initial assumption that if the stripped down tube frame passes the loading standards, the assembled Crown will also pass. The pared down model is shown in Figure 3.

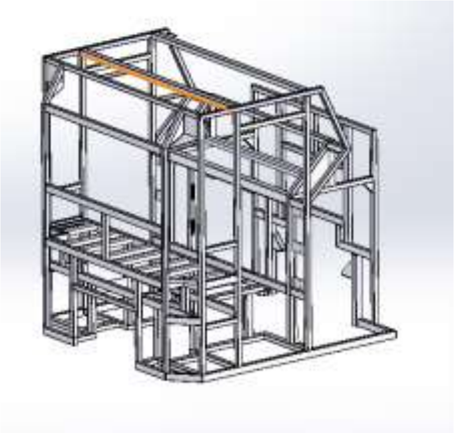

Figure 3: Pared down Crown model. Non-structural components have been suppressed.

To accommodate meshing, further refinement of the model was still required. To do this, we next removed all fillets and chamfers on the model parts. This was an extensive process as there were 176 different components, all modeled with filleted edges. To organize this process, each subassembly of the Crown model was refined individually. This allowed us to work on a smaller scale, ensuring all mating relations were maintained locally, and made it easier to identify any component interferences or modelling discontinuities. An example of one of the simplified subassemblies is shown in Figure 4.

Figure 4: Refined subassembly. All extraneous modelling features have been suppressed. Component interferences have been resolved.

Once the refinement process had been performed on the 16 subassemblies, they were compiled into a new assembly to limit the number of suppressed components associated with the FEA assembly file. We were now able to trial our numerical solution.

A.2.1 Material Properties

For our initial runs, where only the tube frame was used, 6061 aluminum alloy was set as the material for all components. This material has a yield strength of 55 MPa and a Young's modulus of 69 GPa. 5052-O aluminum alloy, with a yield strength of 90 MPa and

Young's modulus of 70 GPa, will be used for any exterior paneling. Carbon steel, with a yield strength of 220 MPa and Young's modulus of 210 GPa will be used for any floor surfaces.

A.2.2 Component Connections

To simulate the welded connections present in the physical construction of the Crown, our simulation uses rigid bonded connections at all component interfaces.

A.2.3 Fixtures

To approximate the physical loading conditions, our model is constrained by fixed geometry at the 6 points on the Crown where it is mounted to the Freightliner chassis. These fixture points can be seen in Figure 5.

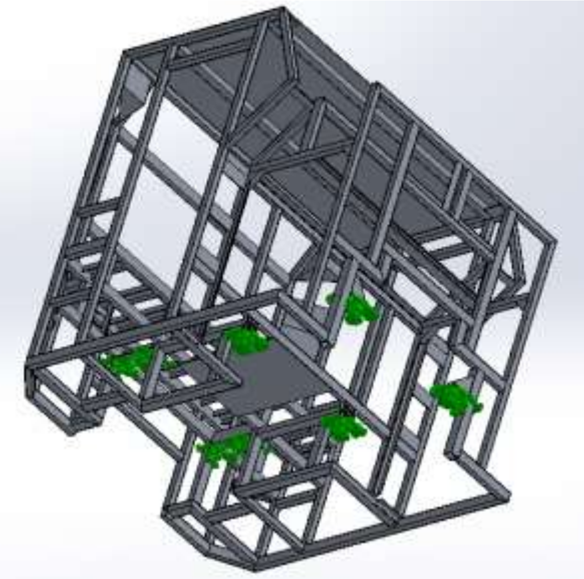

Figure 5: Under view of Crown, showing fixed geometry. Green arrows indicate locations of fixtures, corresponding to the six points where the Crown attaches to the Freightliner chassis

A.2.4 Loading Conditions

For our analysis, we needed to apply an evenly distributed 12,500 lb load to the roof of the Crown. To accommodate this in our model, a plate of 5052-O aluminum was modeled and rigidly bonded to the top of the structure, which can also be seen in Figure 6 in section A.2.5. A distributed mass of 12,500 lbs was applied to this plate, and gravitational force was added to the simulation.

A.2.5 Mesh Structure

Due to the size and complexity of the model, SolidWorks Simulation standard mesh settings failed to create appropriate global mesh values. As such, custom mesh properties were established using a curvature based mesh. To ensure convergence of results, iterative mesh settings were used, refining our mesh model from a maximum element size of 4.5" to 1.6" in incremental runs. Figure 6 shows one of the iterative mesh steps.

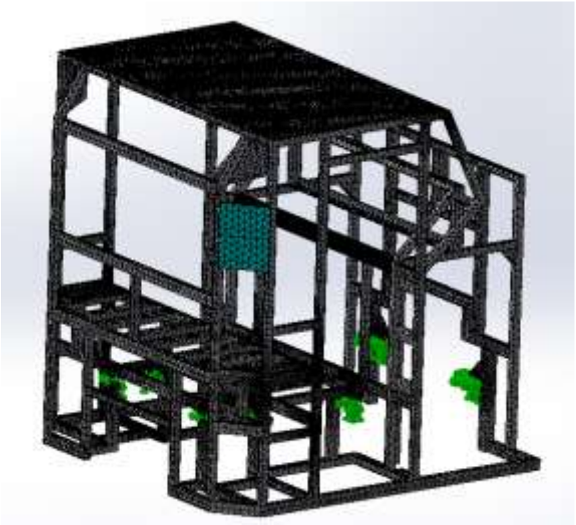

Figure 6: Highly refined mesh structure of Crown

A.2.6 Preliminary Results

For our initial model configuration, consisting solely of the tube frame, our results showed a maximum equivalent stress of approximately 45.9 MPa, less than the 55 MPa yield strength of the 6061 aluminum alloy. Figure 7 shows the convergence plot for this configuration demonstrating the convergence of analytical results as the mesh is refined.

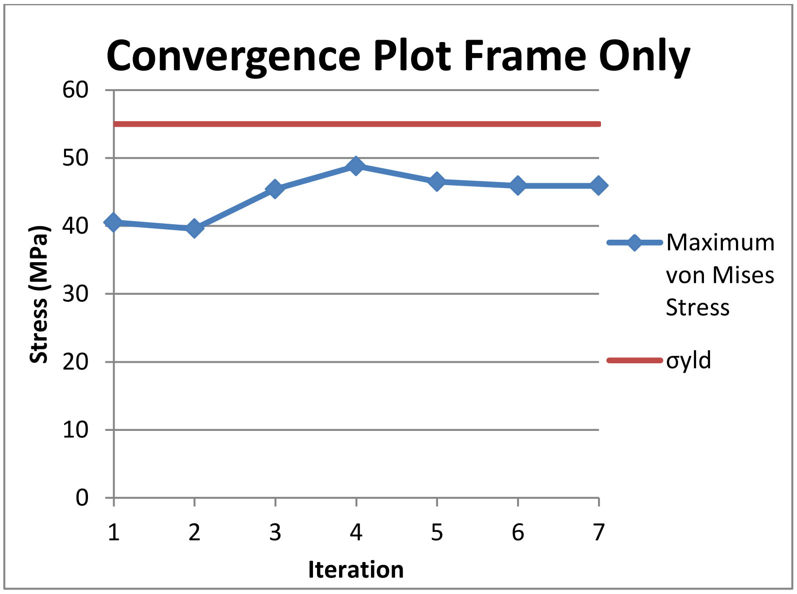

Figure 7: Convergence plot for initial FEA run with the tube frame only. The maximum von Mises stress is shown to converge to a value of 45.9 MPa, less than the 55 MPa yield strength of the material.

This demonstrates that the tube structure is sufficient to support the load without yielding; however, a higher factor of safety is desirable. It is expected that the exterior panelling of the Crown will enhance structural integrity, as it is of considerable grade and is welded directly to the tube frame. To determine where to include the exterior paneling in our simulation model, we looked at where in the structure the highest stresses are foundand where the largest displacements are seen. Figure 8 shows the stress effects across the Crown, and Figure 9 shows the resultant displacements of the Crown when subjected to the load. Note: The results are scaled to better illustrate deformation to a scale of 234:1.

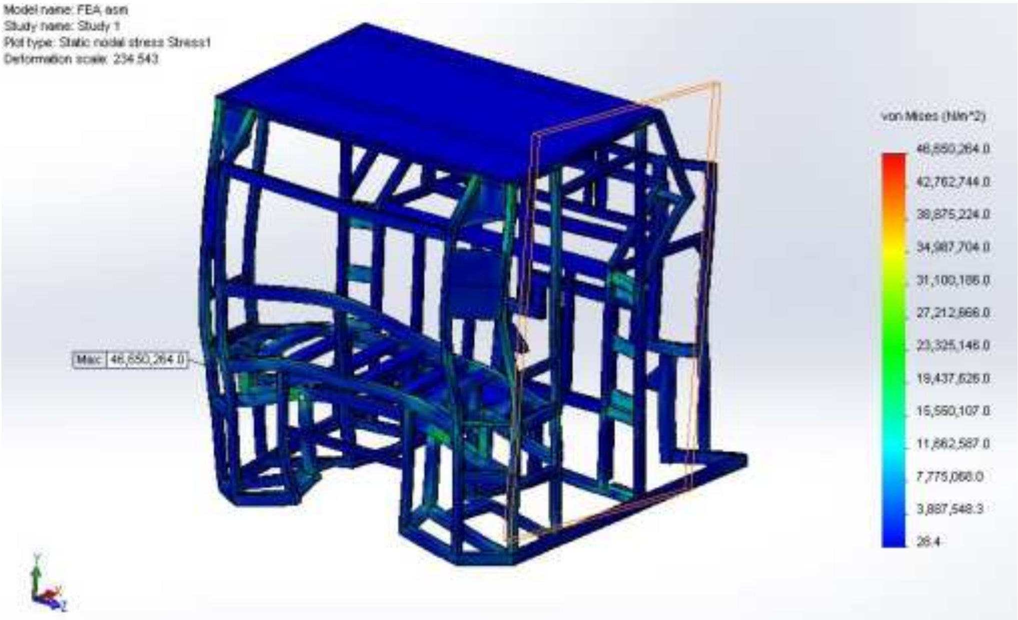

Figure 8: Stress Plot for frame only simulation. The maximum effective stress of the simulation is highlighted.

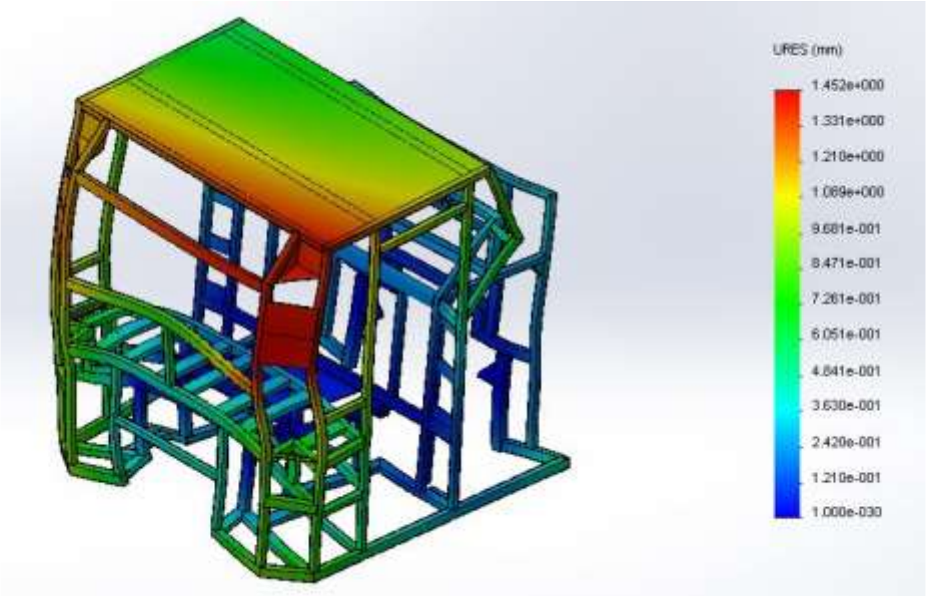

Figure 9: Resultant displacement plot for the frame only simulation.

From these figures, we see the highest stresses are concentrated near the forward frame mounting points, with considerable deformation seen in the members in this area of the Crown (shown in more detail in Figure 10). To account for this, the front exterior panel of the Crown was added into the model as was the interior floor of the Crown. This updated model is seen in Figure 11.

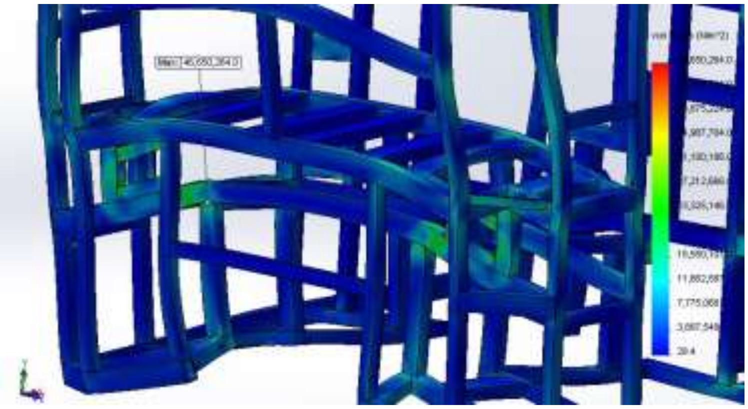

Figure 10: Stress plot of frame only simulation, cropped to illustrate stress concentrations seen near the forward mounts of the Crown.

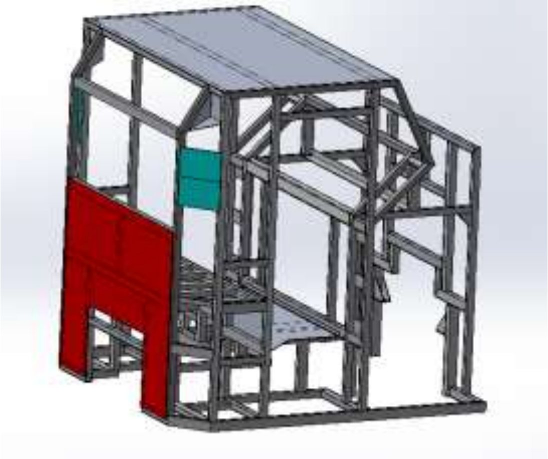

Figure 11: Revised Crown simulation model. The front exterior panel and interior floor panel have been unsuppressed

From this model we attained new results. We now see a maximum equivalent stress of approximately 27.0 MPa, again less than the 55 MPa yield strength of the 6061 aluminum alloy. Figure 12 shows the convergence plot for this configuration, demonstrating the convergence of analytical results as the mesh is refined.

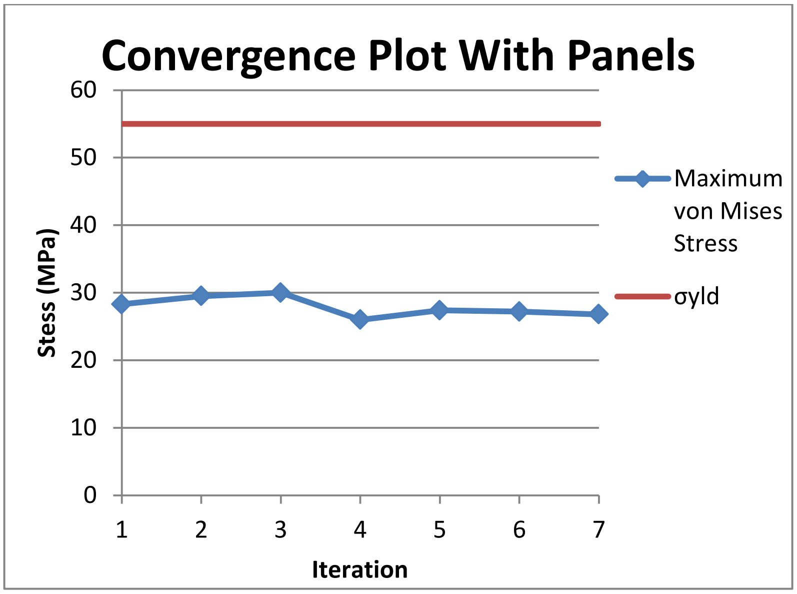

Figure 12: Convergence plot for model with added panelling. Here we see the maximum von Mises stress converges to 27.0 MPa

This is an improvement on the previous run; as we've now attained a factor of safety of 2.07, suggesting our assumption that the panelling has a structural effect was correct. We can likely improve this result further by incorporating all the exterior panelling. Effective stresses and resultant displacement in the current model configuration can be seen in Figure 13 and Figure 14, respectively. These plots have a deformation scale of 432:1 to make the resultant displacements easier to visualize.

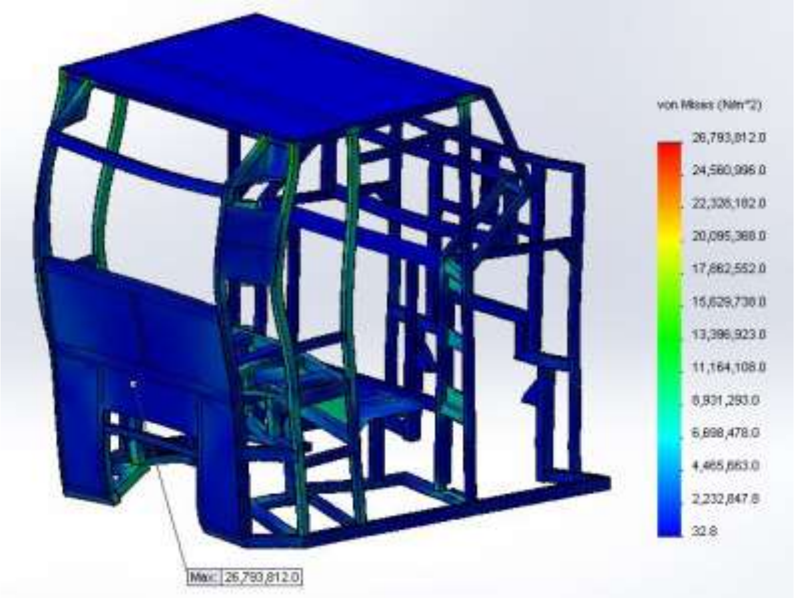

Figure 13: Stress plot of model with added panelling. Maximum stress is again seen in the front Crown mounts.

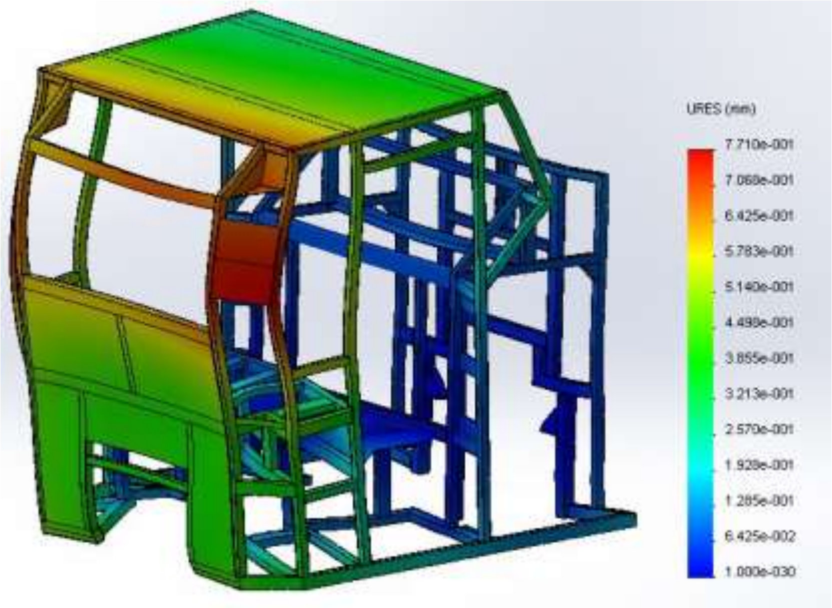

Figure 14: Resultant displacement plot of model with added panelling.

From these graphics we again see stress concentrations near the forward frame mounts of the Crown. In general, we see that stress levels throughout the Crown fall within acceptable values, and deformations are very minimal.

A.2.7 Preliminary SolidWorks Conclusions

From these preliminary results we can make a decision regarding the direction of our project, as the results suggest the Crown passes the loading test. These simulations will be rerun using ANSYS to get confirmation of our results now that we have shown our refined model produces replicable results.

A.3 ANSYS Confirmation

Issues were encountered when using ANSYS with our model. The license available to us to perform our analysis was a teaching license, which imposes a node limit on the mesh geometry. This license limitation prevented us from performing full analysis with this software, as the node limit was reached before convergent results could be attained.

By observing trends, the initial ANSYS performed before the node limit was reached can provide a degree of confirmation to our SolidWorks results. Figure 15, Figure 16, and Figure 17 present the results from our ANSYS simulations. Note that symmetry conditions were used to reduce the node count of the mesh, and as a result only one half of the frame is presented in these plots. These simulations were run under identical conditions as on SolidWorks.

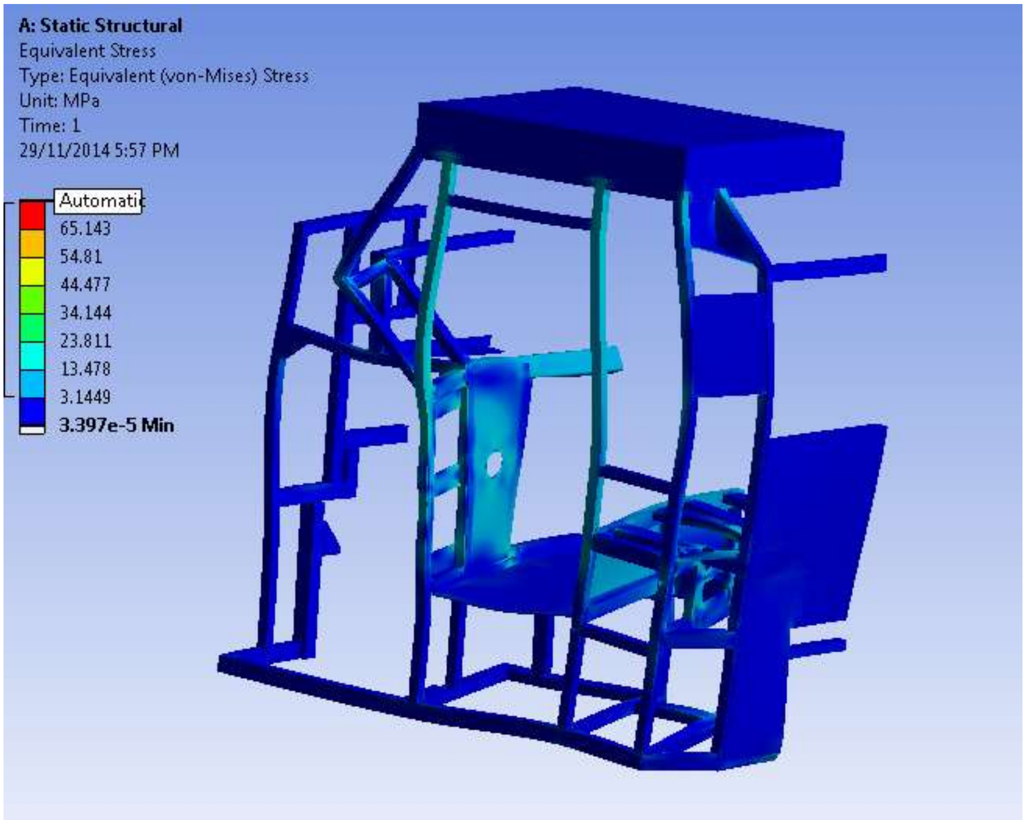

Figure 15: Stress plot of Crown frame using ANSYS

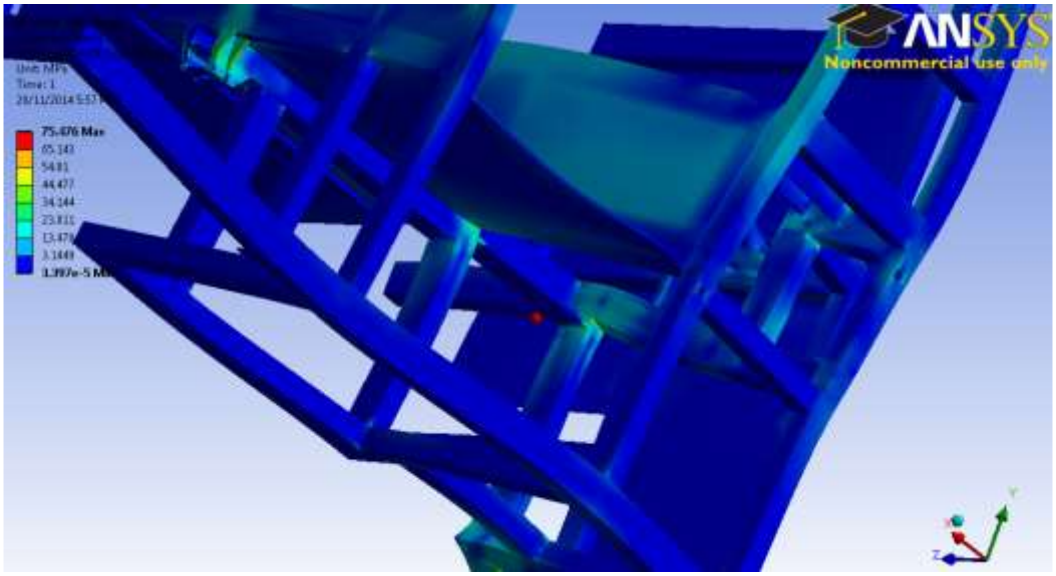

Figure 16: Stress plot from ANSYS. Notable stress concentrations are seen in Crown mounting locations.

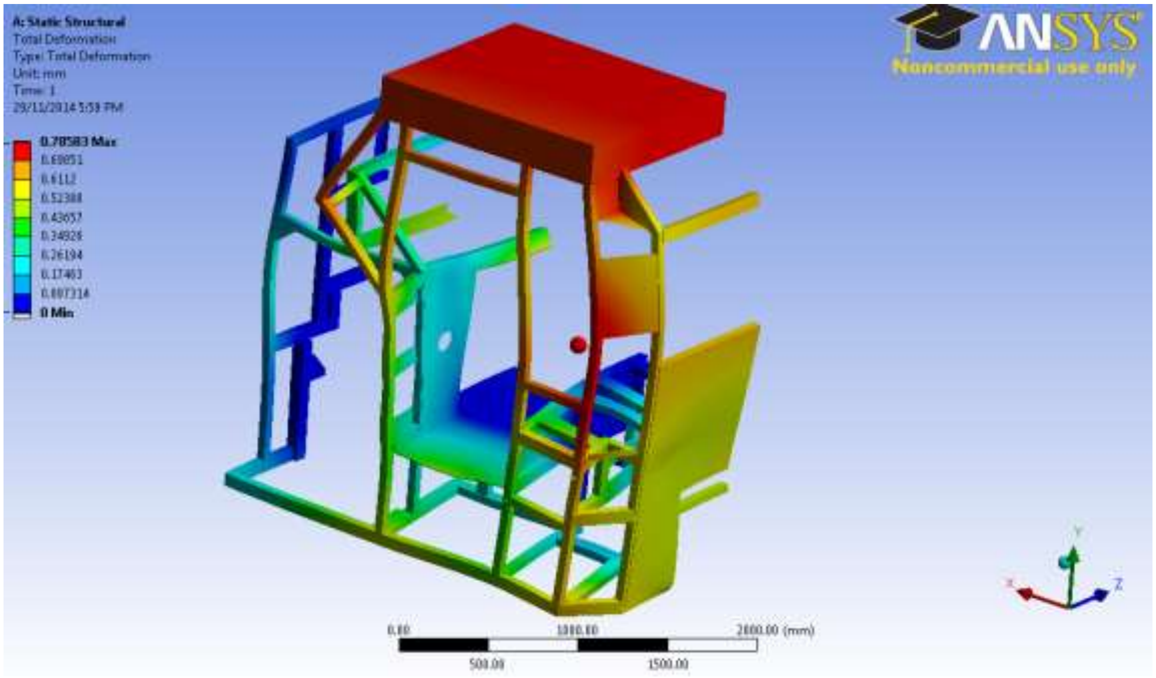

Figure 17: Resultant displacement plot of Crown from using ANSYS

From these plots we note that the trends in the stress and deformation conform to the results we obtained in SolidWorks. We note that the highest stresses experienced in the structure are seen in the mounting points between the Crown and chassis. Regarding deformation, the overall deformed shape seen is similar to the deformation seen in SolidWorks. While we don't have numerical confirmation of results, these observed trends between the two software packages used are of positive note.

A.4 Loading Limit Simulations

After the submission of our initial SolidWorks results, our client requested further simulations. They asked us to incrementally increase the load applied to the roof by 2000lbs, until the results indicate a factor of safety less than 1.65. To do this we used the simulation configuration established in section A.2, adjusting the magnitude of the distributed load.

To streamline the process of running multiple simulations, an intermediate mesh size which demonstrated convergent results in our previous trials at 12,500lbs, was used to run single simulations at 14,500lbs, 16,500lbs, and 18,500 lbs. A summary of these intial simulations is presented in TABLE I.

TABLE I: SUMMARY OF INTIAL INCREMENTAL LOADING SIMULATIONS

Load Applied	Peak Stress Observed	Factor of Safety
14,500lbs	29.2MPa	1.88
16,500lbs	33.0MPa	1.67
18,500lbs	36.7MPa	1.50

From this table we see that the 16,500lbs simulation produced an indicated factor of safety nearest 1.65. However, as noted earlier, some components of the structure have been excluded from our model. As such, it is possible that the 18,500lbs load could attain a suitable factor of safety if additional exterior panelling were included in the simulation to increase the rigidity of the structure. To determine where additional rigidity could be beneficial, we look to the stress plots attained from our simulation. These plots, as well as a resultant displacement plot, are shown in Figure 18 through Figure 21.

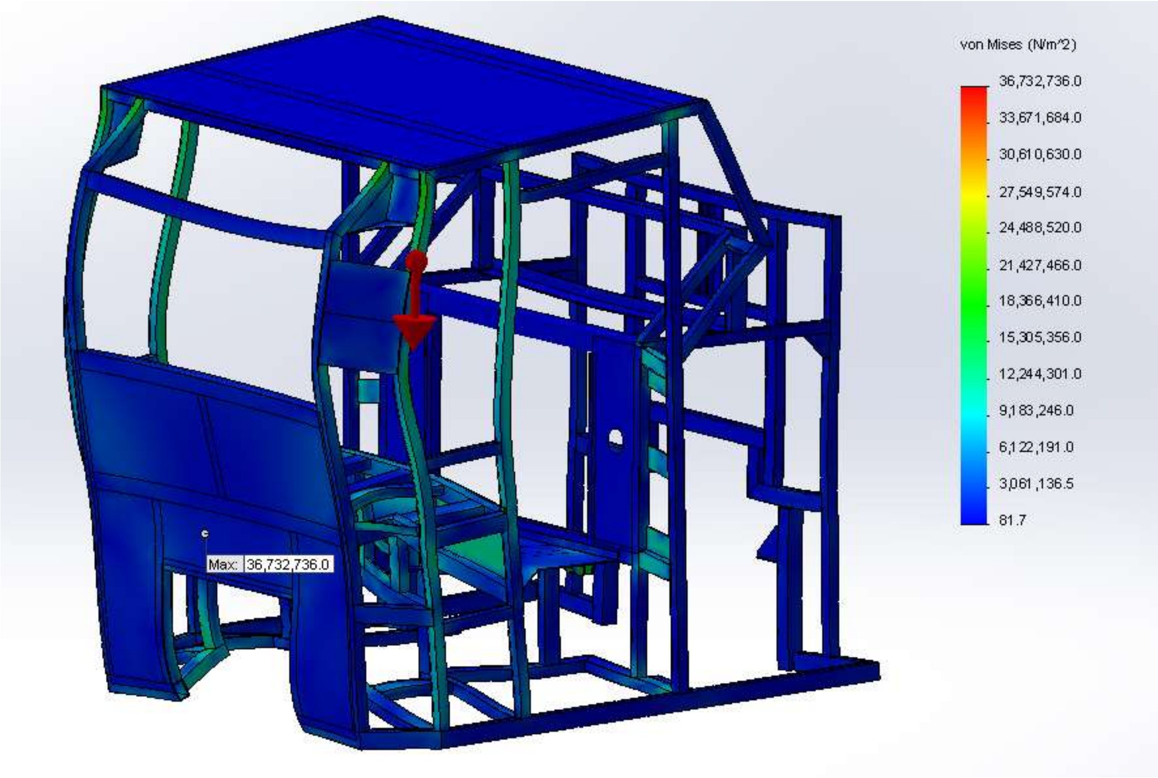

Figure 18: Stress plot of Crown under load of 18,500lbs

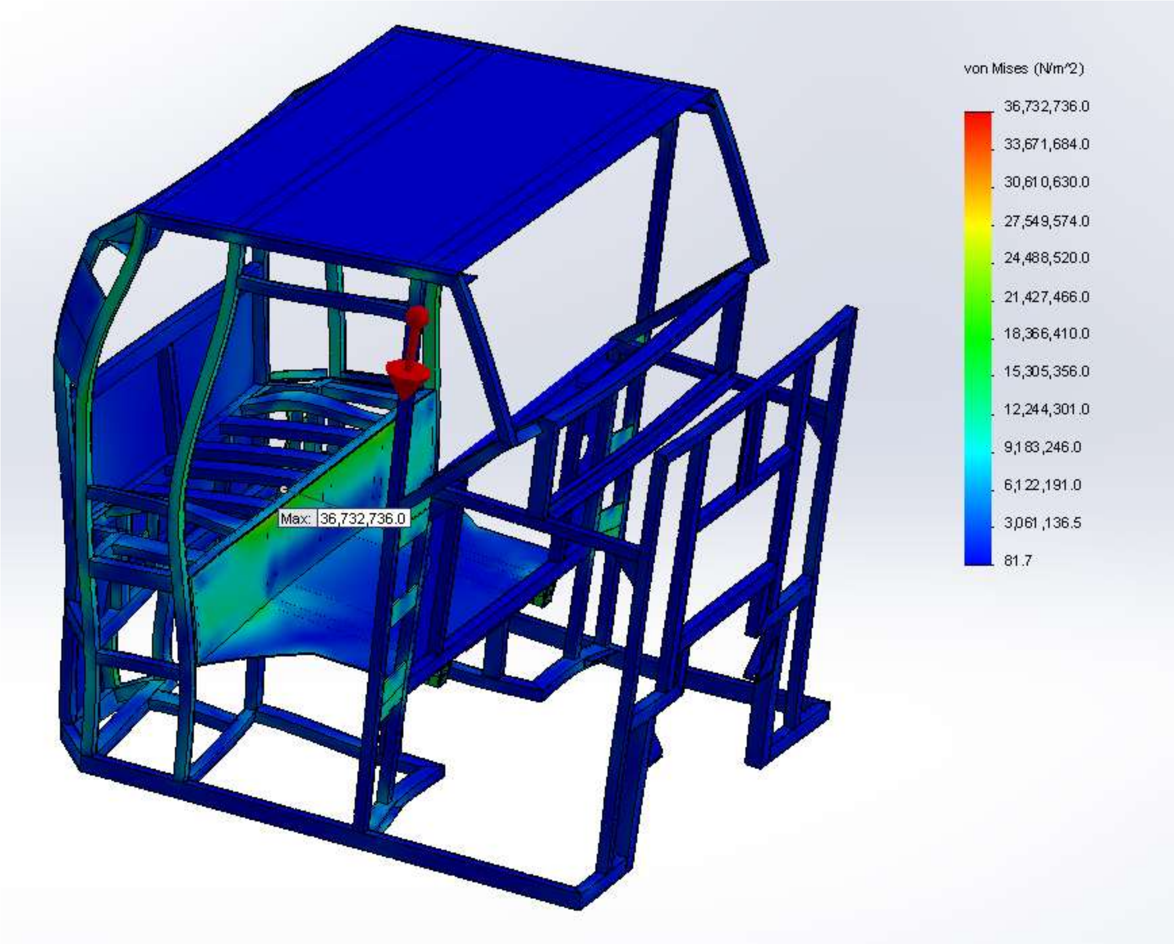

Figure 19: Stress plot of Crown under load of 18,500lbs

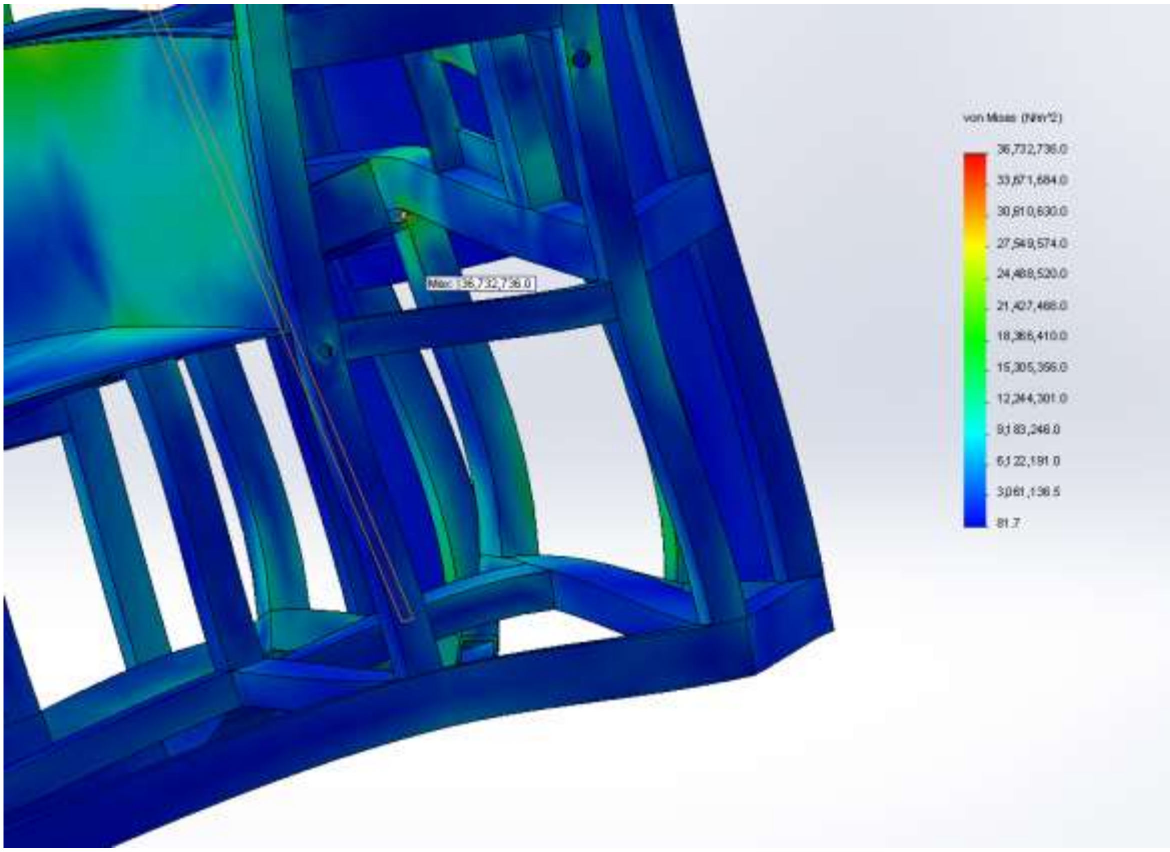

Figure 20: Stress plot of Crown under load of 18,500lbs

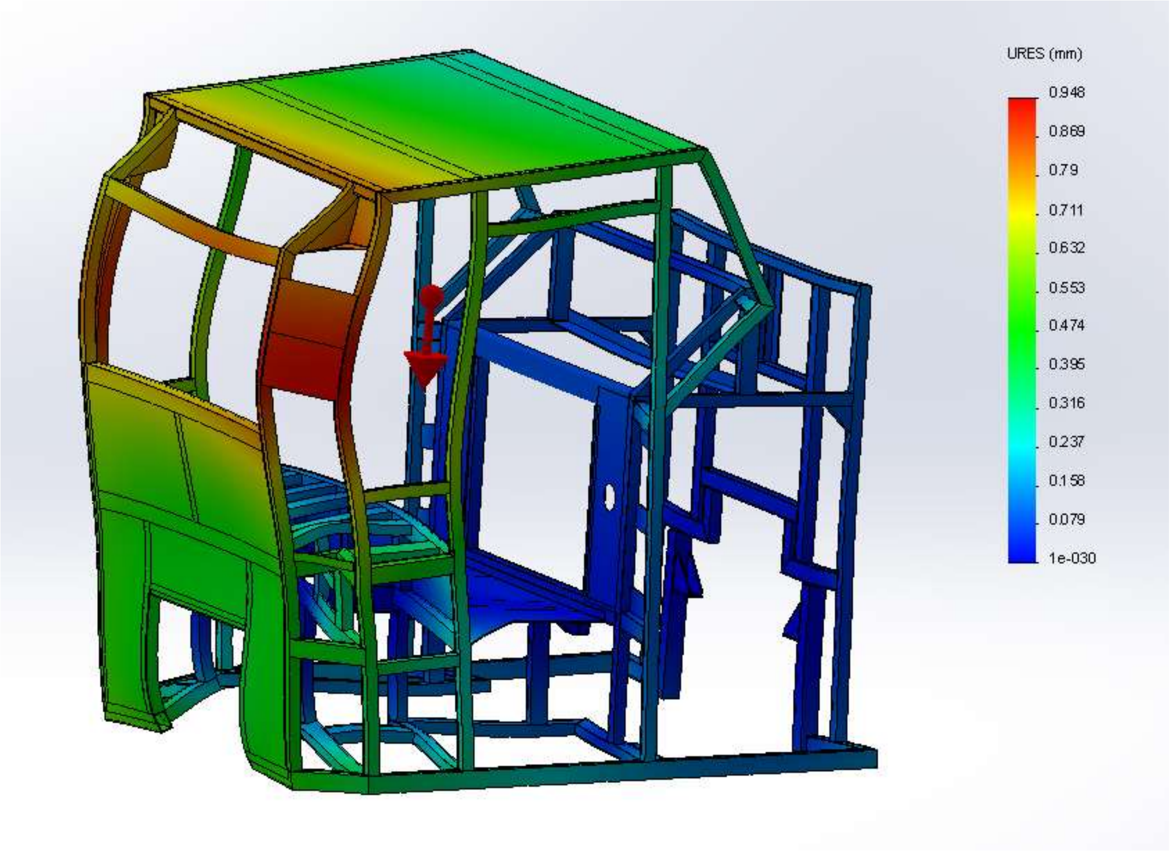

Figure 21: Resultant displacement plot of Crown under load of 18,500lbs

From these plots we see that the highest stress concentrations are seen in the mounting points between the Crown and the chassis. Also, the deflections seen within our model are less than 1mm. As such, it is unlikely that including additional exterior panelling in our simulation will lower stress levels seen, as deflections are minimal, and the stress concentrations are seen in areas where the additional rigidity provided by these components will have little influence. As such, it was decided that further investigation into the factor of safety achieved at loading of 18,500lbs is not needed.

To conclude our analysis of the Crown structure, a convergence test was performed with loading of 16,500lbs to ensure the results achieved for this scenario are proper. To do this, iterative simulations with increasing mesh refinement levels were run. A convergence plot for these simulations is shown in

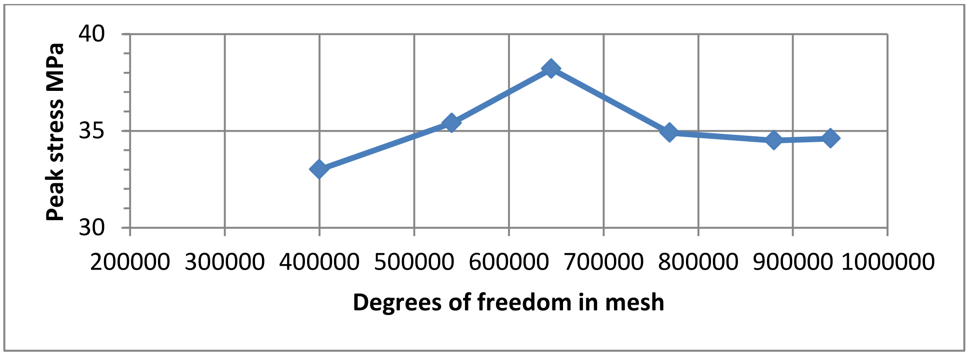

Figure 22: Convergence plot for loading of 16,500lbs

From this plot we see the peak stress to converge to a value of 34.6MPa. This correlates to a factor of safety of 1.60, less than the desired limit of 1.65. From this we can state that the Crown will fail to achieve the desired factor of safety when the load is incremented to 16,500lbs

A.5 Conclusions

Our results indicate that FGFT's Crown cab structure will support a static roof loading of 12,500lbs in accordance with the European Union standards for commercial vehicles. This loading indicated a factor of safety of 2.07.

Attempts were made to use ANSYS to confirm the results obtained through SolidWorks, but issues were encountered due to limitations imposed on the license available to us as students of the University of Manitoba. However initial simulations performed using ANSYS before node limitations were reached demonstrated similar deformation characteristics and areas of stress concentration as seen in our SolidWorks results.

Further simulations were performed, incrementing the load in steps of 2000lbs, to determine the loading limit of the Crown structure before the factor of safety observed dropped below 1.65. Our results indicated that at a loading of 16,500lbs, the factor of safety in the Crown will drop to 1.60. Alternatively, it can be stated that 14,500lbs is the largest load that can be safely applied to the Crown roof while maintaining a factor of safety of 1.65.

WORKS CITED

[1] "Fort Garry Fire Trucks," Fort Garry Fire Trucks Ltd., [Online]. Available: http://www.fgft.com/. [Accessed September 2014].

[2] "Regulation No 29 of the Economic Commision for Europe of the United Nations (UN/ECE) - Uniform provisions concerning the approval of vehicles with regard to the protection of the occupants of the cab of a commerical vehicle," *Official Journal of the European Union,* vol. 304, pp. 304/21-304/46, 2010.

APPENDIX B: PRODUCT DETAILS

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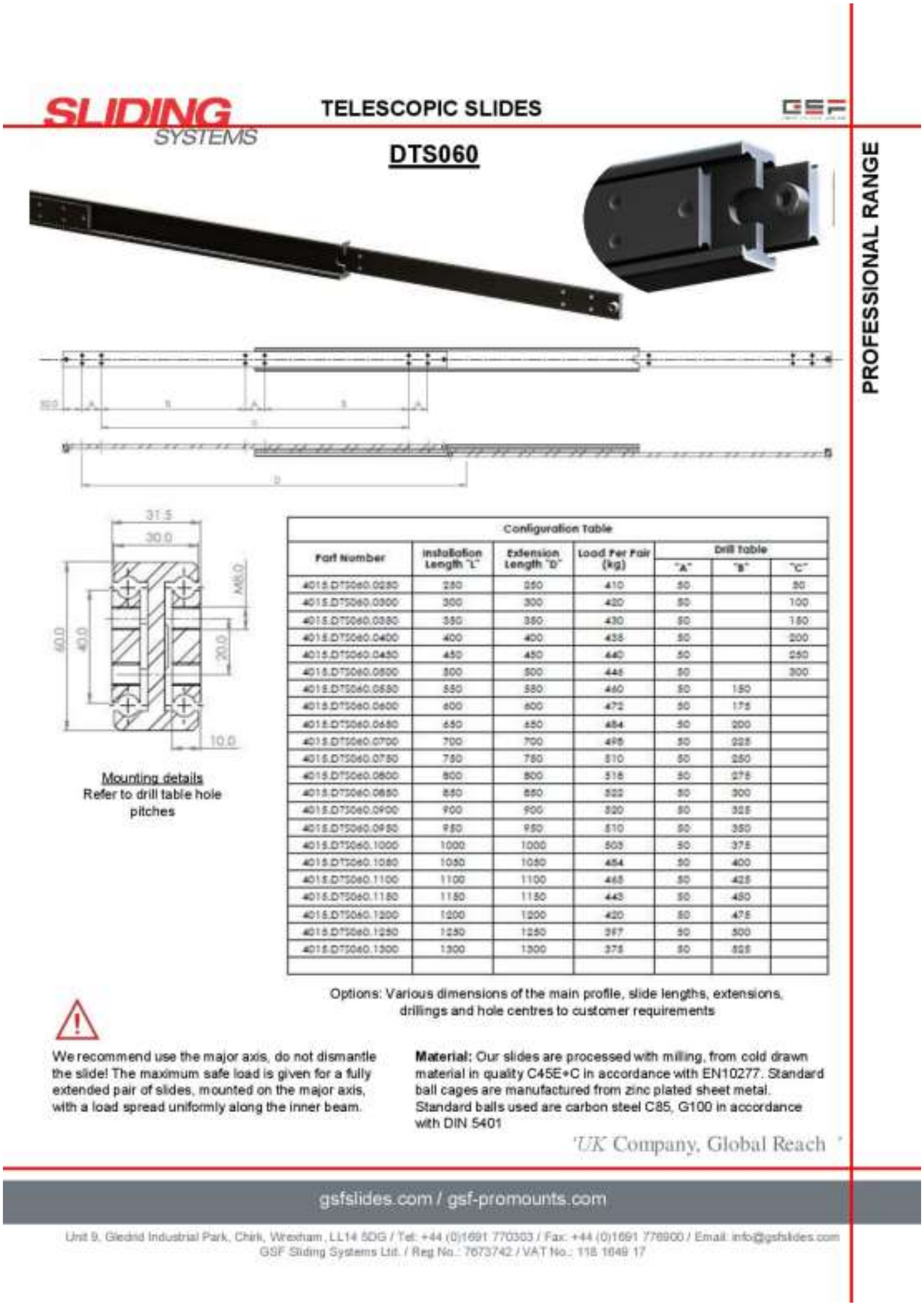
B.1 Introduction

In this appendix, relevant product details for the final design components are presented. These details are presented as excepts of relevant manufacturer product manuals and brochures. The following components are included in this appendix:

- Slide specification from the GSF Sliding Systems DTS 60 series [1].
- Pneumatic cylinder specification from McMaster Carr switch-ready stainless steel air cylinder product line [2].
- Control valve specification from NITRA Pneumatics AVS-5 series [3].
- SPDT switch specification from C&K Components general purpose snap-acting switches A series [4].
- Rocker switch specification from Arcolectric 1500 Standard & 1300 High Inrush Switches series [5].

B.2 Slides Specification



TELESCOPIC SLIDES

DTS060

Mounting details
Refer to drill table hole pitches

Configuration Table						
Part Number	Installation Length "L"	Extension Length "D"	Load Per Pair (kg)	Drill Table		
				"A"	"B"	"C"
4015.DTS060.0250	250	250	410	50		50
4015.DTS060.0300	300	300	420	50		100
4015.DTS060.0350	350	350	430	50		150
4015.DTS060.0400	400	400	435	50		200
4015.DTS060.0450	450	450	440	50		250
4015.DTS060.0500	500	500	446	50		300
4015.DTS060.0550	550	550	460	50	150	
4015.DTS060.0600	600	600	472	50	175	
4015.DTS060.0650	650	650	484	50	200	
4015.DTS060.0700	700	700	496	50	225	
4015.DTS060.0750	750	750	510	50	250	
4015.DTS060.0800	800	800	516	50	275	
4015.DTS060.0850	850	850	522	50	300	
4015.DTS060.0900	900	900	520	50	325	
4015.DTS060.0950	950	950	510	50	350	
4015.DTS060.1000	1000	1000	503	50	375	
4015.DTS060.1050	1050	1050	484	50	400	
4015.DTS060.1100	1100	1100	465	50	425	
4015.DTS060.1150	1150	1150	443	50	450	
4015.DTS060.1200	1200	1200	420	50	475	
4015.DTS060.1250	1250	1250	397	50	500	
4015.DTS060.1300	1300	1300	375	50	525	

Options: Various dimensions of the main profile, slide lengths, extensions, drillings and hole centres to customer requirements

We recommend use the major axis, do not dismantle the slide! The maximum safe load is given for a fully extended pair of slides, mounted on the major axis, with a load spread uniformly along the inner beam.

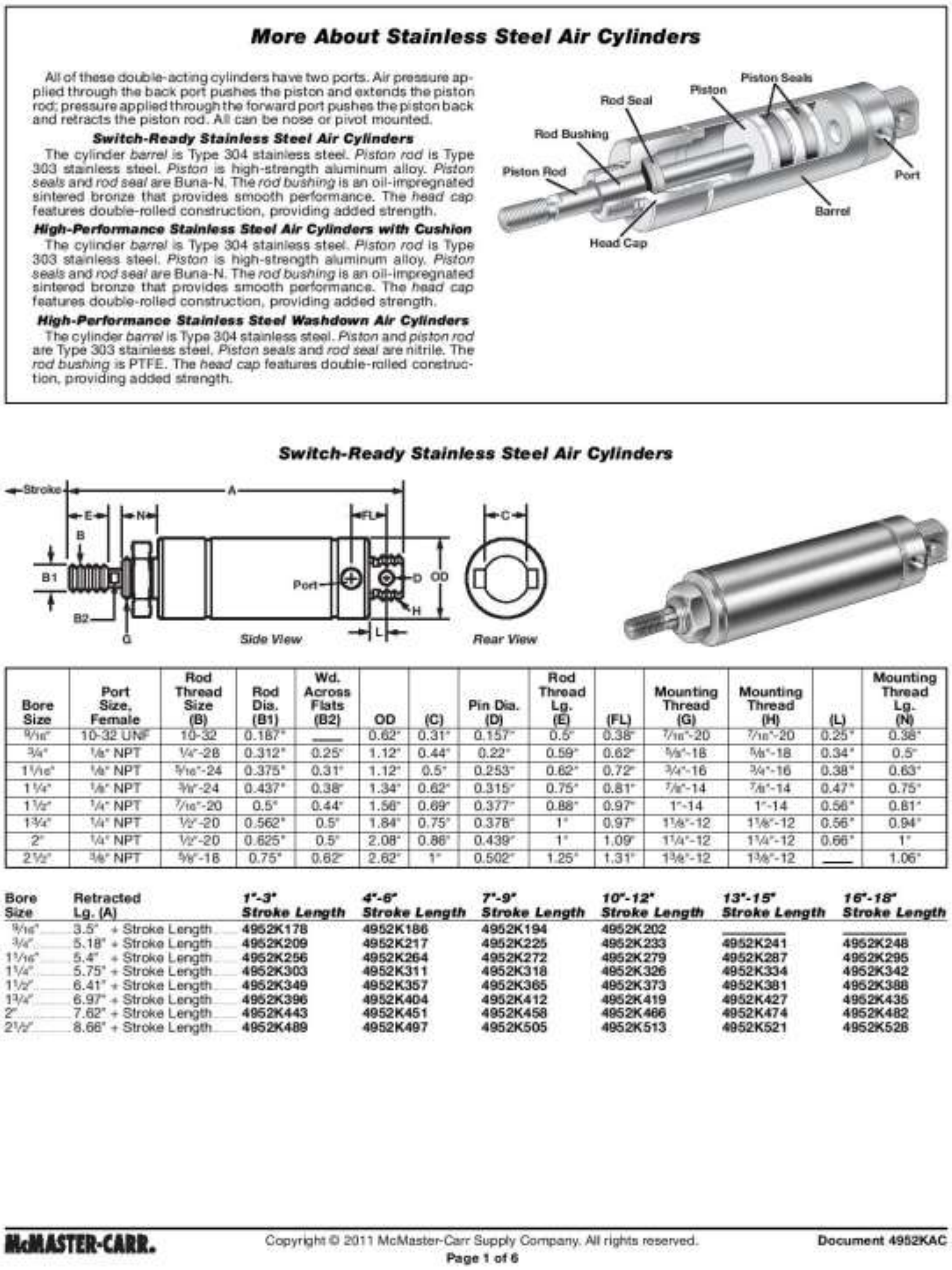
Material: Our slides are processed with milling, from cold drawn material in quality C45E+C in accordance with EN10277. Standard ball cages are manufactured from zinc plated sheet metal. Standard balls used are carbon steel C85, G100 in accordance with DIN 5401

'*UK* Company, Global Reach '

gsfslides.com / gsf-promounts.com

Unit 9, Gledrid Industrial Park, Chirk, Wrexham, LL14 5DG / Tel: +44 (0)1691 770303 / Fax: +44 (0)1691 776900 / Email: info@gsfslides.com
GSF Sliding Systems Ltd. / Reg No.: 7673742 / VAT No.: 118 1649 17

B.3 Pneumatic cylinders Specification



More About Stainless Steel Air Cylinders

All of these double-acting cylinders have two ports. Air pressure applied through the back port pushes the piston and extends the piston rod; pressure applied through the forward port pushes the piston back and retracts the piston rod. All can be nose or pivot mounted.

Switch-Ready Stainless Steel Air Cylinders

The cylinder *barrel* is Type 304 stainless steel. *Piston rod* is Type 303 stainless steel. *Piston* is high-strength aluminum alloy. *Piston seals* and *rod seal* are Buna-N. The *rod bushing* is an oil-impregnated sintered bronze that provides smooth performance. The *head cap* features double-rolled construction, providing added strength.

High-Performance Stainless Steel Air Cylinders with Cushion

The cylinder *barrel* is Type 304 stainless steel. *Piston rod* is Type 303 stainless steel. *Piston* is high-strength aluminum alloy. *Piston seals* and *rod seal* are Buna-N. The *rod bushing* is an oil-impregnated sintered bronze that provides smooth performance. The *head cap* features double-rolled construction, providing added strength.

High-Performance Stainless Steel Washdown Air Cylinders

The cylinder *barrel* is Type 304 stainless steel. *Piston* and *piston rod* are Type 303 stainless steel. *Piston seals* and *rod seal* are nitrile. The *rod bushing* is PTFE. The *head cap* features double-rolled construction, providing added strength.

Switch-Ready Stainless Steel Air Cylinders

Bore Size	Port Size, Female	Rod Thread Size (B)	Rod Dia. (B1)	Wd. Across Flats (B2)	OD	(C)	Pin Dia. (D)	Rod Thread Lg. (E)	(FL)	Mounting Thread (G)	Mounting Thread (H)	(L)	Mounting Thread Lg. (N)
9/16"	10-32 UNF	10-32	0.187"	—	0.62"	0.31"	0.157"	0.5"	0.38"	7/16"-20	7/16"-20	0.25"	0.38"
3/4"	1/8" NPT	1/4"-28	0.312"	0.25"	1.12"	0.44"	0.22"	0.59"	0.62"	5/8"-18	5/8"-18	0.34"	0.5"
1 1/16"	1/8" NPT	5/16"-24	0.375"	0.31"	1.12"	0.5"	0.253"	0.62"	0.72"	3/4"-16	3/4"-16	0.38"	0.63"
1 1/4"	1/8" NPT	3/8"-24	0.437"	0.38"	1.34"	0.62"	0.315"	0.75"	0.81"	7/8"-14	7/8"-14	0.47"	0.75"
1 1/2"	1/4" NPT	7/16"-20	0.5"	0.44"	1.56"	0.69"	0.377"	0.88"	0.97"	1"-14	1"-14	0.56"	0.81"
1 3/4"	1/4" NPT	1/2"-20	0.562"	0.5"	1.84"	0.75"	0.378"	1"	0.97"	1 1/8"-12	1 1/8"-12	0.56"	0.94"
2"	1/4" NPT	1/2"-20	0.625"	0.5"	2.08"	0.86"	0.439"	1"	1.09"	1 1/4"-12	1 1/4"-12	0.66"	1"
2 1/2"	3/8" NPT	5/8"-18	0.75"	0.62"	2.62"	1"	0.502"	1.25"	1.31"	1 3/8"-12	1 3/8"-12	—	1.06"

Bore Size	Retracted Lg. (A)	***1"-3" Stroke Length***	***4"-6" Stroke Length***	***7"-9" Stroke Length***	***10"-12" Stroke Length***	***13"-15" Stroke Length***	***16"-18" Stroke Length***
9/16"	3.5" + Stroke Length	4952K178	4952K186	4952K194	4952K202	—	—
3/4"	5.18" + Stroke Length	4952K209	4952K217	4952K225	4952K233	4952K241	4952K248
1 1/16"	5.4" + Stroke Length	4952K256	4952K264	4952K272	4952K279	4952K287	4952K295
1 1/4"	5.75" + Stroke Length	4952K303	4952K311	4952K318	4952K326	4952K334	4952K342
1 1/2"	6.41" + Stroke Length	4952K349	4952K357	4952K365	4952K373	4952K381	4952K388
1 3/4"	6.97" + Stroke Length	4952K396	4952K404	4952K412	4952K419	4952K427	4952K435
2"	7.62" + Stroke Length	4952K443	4952K451	4952K458	4952K466	4952K474	4952K482
2 1/2"	8.66" + Stroke Length	4952K489	4952K497	4952K505	4952K513	4952K521	4952K528

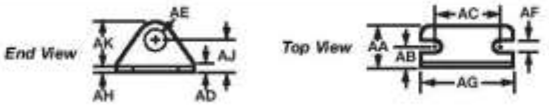
McMASTER-CARR.

Page 1 of 6

Document 4952KAC

Attachments for Switch-Ready Stainless Steel Air Cylinders

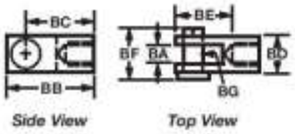
Foot Bracket



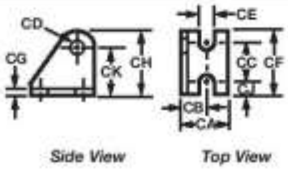
Fits Bore Size	AA	AB	AC	AD	Dia., AE	AF	AG	AH	AJ	AK	
9/16"	0.69"	0.38"	1"	0.12"	0.44"	0.19"	1.38"	0.09"	0.56"	0.74"	**4952K126**
3/4"	1"	0.56"	1.5"	0.25"	0.62"	0.27"	1.88"	0.10"	0.81"	1.26"	**4952K127**
1 1/16"	0.94"	0.53"	1.38"	0.24"	0.75"	0.28"	1.88"	0.12"	0.81"	1.31"	**4952K667**
1 1/4"	1.16"	0.66"	1.56"	0.32"	0.88"	0.28"	2.12"	0.16"	1"	1.59"	**4952K668**
1 1/2"	1.31"	0.75"	1.82"	0.38"	1"	0.28"	2.38"	0.12"	1.12"	1.81"	**4952K669**
1 3/4"	1.44"	0.81"	2.12"	0.38"	1.12"	0.34"	2.75"	0.19"	1.25"	2"	**4952K671**
2"	1.59"	0.91"	2.38"	0.44"	1.25"	0.34"	3"	0.22"	1.38"	2.22"	**4952K672**
2 1/2"	1.88"	1.06"	3"	0.5"	1.38"	0.41"	3.75"	0.25"	1.62"	2.56"	**4952K673**

Rod Clevis with Pin

Fits Bore Size	BA	BB	BC	BD	BE	BF	Dia., BG	
9/16"	0.19"	0.94"	0.75"	0.38"	0.56"	0.56"	0.19"	**4952K101**
3/4"	0.22"	1.44"	1.18"	0.44"	0.75"	0.62"	0.22"	**4952K684**
1 1/16"	0.25"	1.44"	1.19"	0.5"	0.75"	0.69"	0.25"	**4952K685**
1 1/4"	0.31"	1.69"	1.38"	0.62"	0.94"	0.88"	0.31"	**4952K686**
1 1/2"	0.38"	2"	1.62"	0.75"	1.12"	1.03"	0.38"	**4952K687**
1 3/4"	0.38"	2.12"	1.75"	0.75"	1.12"	1.03"	0.38"	**4952K688**
2"	0.44"	2.31"	1.88"	0.88"	1.31"	1.14"	0.44"	**4952K689**
2 1/2"	0.5"	2.75"	2.25"	1"	1.5"	1.38"	0.5"	**4952K112**

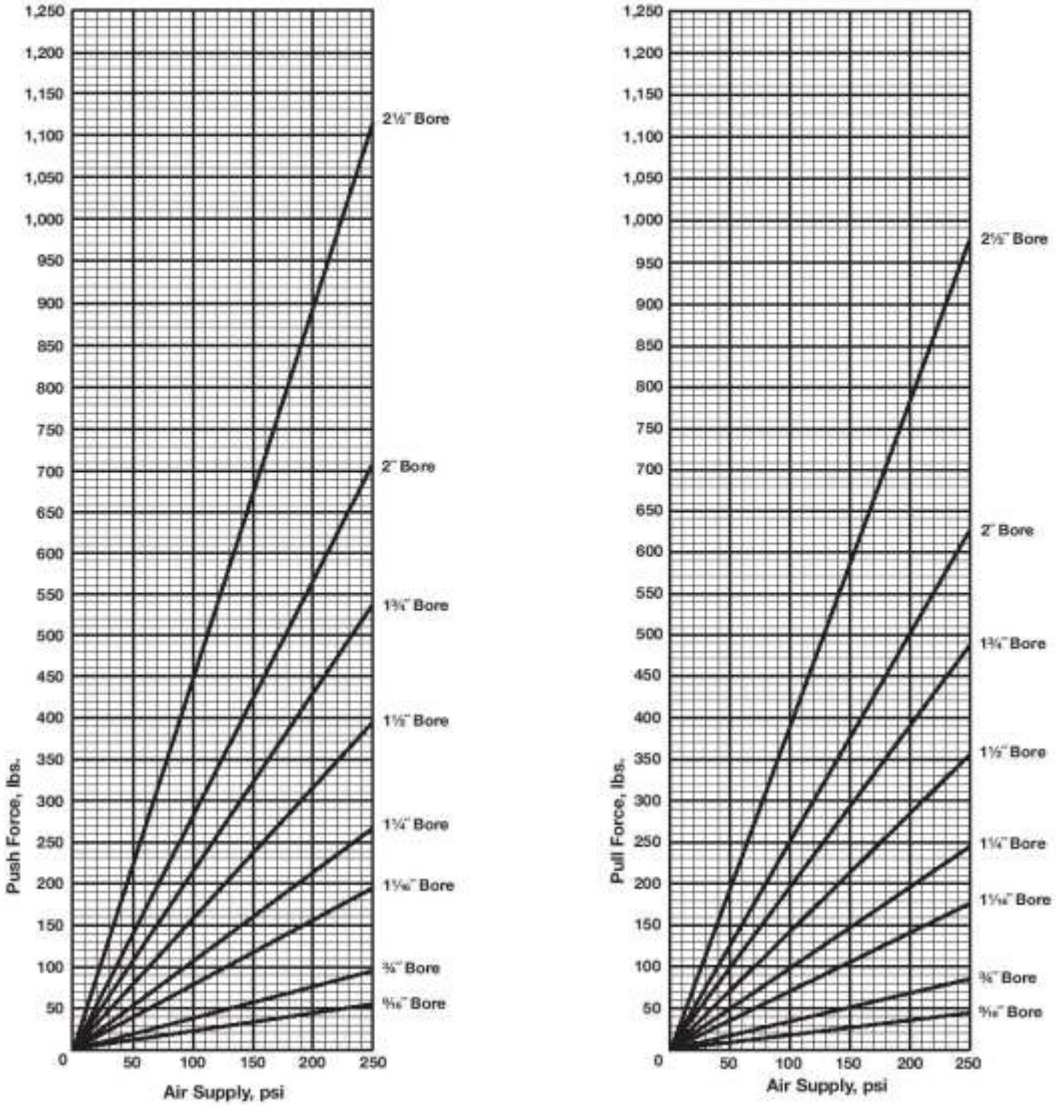


Pivot Bracket with Pin



Fits Bore Size	CA	CB	CC	Dia., CD	CE	CF	CG	CH	CJ	CK	
9/16"	0.5"	0.28"	0.5"	0.16"	0.19"	0.75"	0.06"	0.77"	0.12"	0.56"	**4952K114**
3/4"	0.81"	0.5"	0.56"	0.22"	0.28"	1.06"	0.12"	1.03"	0.25"	0.81"	**4952K675**
1 1/16"	0.81"	0.5"	0.56"	0.25"	0.28"	1.12"	0.12"	1.06"	0.25"	0.81"	**4952K676**
1 1/4"	0.87"	0.56"	0.81"	0.31"	0.28"	1.31"	0.16"	1.31"	0.25"	1"	**4952K677**
1 1/2"	1"	0.62"	1"	0.38"	0.28"	1.5"	0.19"	1.5"	0.25"	1.12"	**4952K678**
1 3/4"	1.12"	0.69"	1"	0.38"	0.34"	1.62"	0.19"	1.62"	0.31"	1.25"	**4952K679**
2"	1.19"	0.75"	1.19"	0.44"	0.34"	1.81"	0.25"	1.81"	0.31"	1.38"	**4952K681**
2 1/2"	1.38"	0.88"	1.38"	0.5"	0.41"	2.14"	0.25"	2.12"	0.38"	1.62"	**4952K682**

Performance Data for Switch-Ready Stainless Steel Air Cylinders



B.4 Valves Specification

Prices as of October 22, 2014. Check Web site for most current prices.

Pneumatic Directional Control Solenoid Valves – AVS-5 Series

NITRA™ pneumatic AVS-5 series directional control solenoid valves are body ported 5-port (4-way) spool valves. Available port sizes are 1/8", 1/4", 3/8" or 1/2" NPT with flow coefficients (Cv) from 0.50 to 2.79. Models are available with single solenoid, spring return or double solenoid 2-position operation. In addition, double solenoid models are available with 3-position, center closed or center exhaust operation. Solenoid coils are available in either 24VDC or 120VAC control voltages. The AVS-5 series can be used in individual valve applications or multiple valves can be field assembled on AM-5 series manifolds simplifying piping connections. AM-5 series manifolds are available in 2, 4, 6 or 8 stations. The DIN style wiring connector includes LED indication of the solenoid coil status.

Stacked solenoids shown mounted an optional manifold

Features

- Body ported, 5-port (4-way) spool valves
- 1/8", 1/4", 3/8" or 1/2" NPT ports
- 2-position, single solenoid normally closed, spring return; 2-position, double solenoid, energize open/energize closed; 3-position, double solenoid center closed or center exhaust
- 24VDC or 120VAC solenoid coils
- DIN style wiring connector with LED indication
- Single valve or multiple manifold mounted valve applications
- Locking manual operator
- 2 year warranty

AVS-5 Series Specifications

Model	AVS-5111-24D	AVS-5111-120A	AVS-5121-24D	AVS-5121-120A	AVS-513C1-24D	AVS-513C1-120A	AVS-513E1-24D	AVS-513E1-120A	AVS-5211-24D	AVS-5211-120A	AVS-5221-24D	AVS-5221-120A	AVS-5212-24D	AVS-5212-120A	AVS-5222-24D	AVS-5222-120A
Price	$18.00	$18.00	$29.00	$29.00	$42.00	$42.00	$42.00	$42.00	$21.00	$21.00	$31.50	$31.50	$21.00	$21.00	$31.50	$31.50
Weight (lb)	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.8	0.8	0.5	0.5	0.8	0.8
Valve Type	5 port 2 position				5 port 3 position				5 port 2 position							
Acting	Internally Piloted															
Diagram	A		B		C		D		A		B		A		B	
Port Size	In/Out/Exhaust=1/8"				In/Out/Exhaust=1/8"				In/Out/Exhaust=1/8"				In/Out=1/4", Exhaust=1/8"			
Orifice Size	12mm² (Cv=0.67)				9mm² (Cv=0.50)				14mm² (Cv=0.78)				16mm² (Cv=0.89)			
Fluid	Air (to be filtered by 40µ filter element)															
Pressure	Working: 20–115 psi, (0.15–0.8 MPa), (1.5–8.0 bar); Proof: 215 psi, (1.48 MPa), (14.8 bar)															
Voltage (VAC @ 50/60 Hz)	24VDC single solenoid	120VAC single solenoid	24VDC double solenoid	120VAC double solenoid	24VDC center closed double solenoid	120VAC center closed double solenoid	24VDC center exhaust double solenoid	120VAC center exhaust double solenoid	24VDC single solenoid	120VAC single solenoid	24VDC double solenoid	120VAC double solenoid	24VDC single solenoid	120VAC single solenoid	24VDC double solenoid	120VAC double solenoid
Power Consumption	DC: 2.5W | AC: 2.5 VA; continuous duty (100% ED)				DC: 3.0W | AC: 3.5 VA; continuous duty (100% ED)											
Max Freq	5 cycles/sec				3 cycles/sec				5 cycles/sec							
Insulation	B class															
Min Response	0.05 sec															
Temperature	-5-60°C (23-140°F)															
Lubrication	Not Required															
Protection	IP65 (DIN40050)															
Connection	9.4 mm DIN Terminal								11mm DIN Terminal							
Body	Aluminum Alloy															
Agency Approvals	Solenoid CE marked; RoHS															

Book 2 (14.1)

ePN-34 Pneumatics 1-800-633-0405

NITRA PNEUMATICS

Pneumatic AVS Directional Control Solenoid Valves – AVS-5 Series

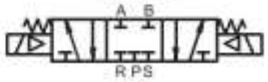
Diagram "A"

2-Pos, Spring Return

Diagram "B"

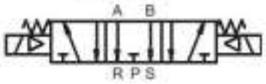
2-Pos, Double Solenoid

Diagram "C"



3-Pos, Closed Center

Diagram "D"



3-Pos, Exhaust Center

AVS-5 Series Specifications

Model	AVS-5312-24D	AVS-5312-120A	AVS-5322-24D	AVS-5322-120A	AVS-5313-24D	AVS-5313-120A	AVS-5323-24D	AVS-5323-120A	AVS-523C1-24D	AVS-523C1-120A	AVS-523E1-24D	AVS-523E1-120A	AVS-523C2-24D	AVS-523C2-120A	AVS-523E2-24D	AVS-523E2-120A
Price	$28.50	$28.50	$40.50	$40.50	$28.50	$28.50	$40.50	$40.50	$54.00	$54.00	$54.00	$54.00	$54.00	$54.00	$54.00	$43.00
Weight (lb)	0.8	0.8	1.0	1.0	0.7	0.7	1.0	1.0	0.9	0.8	0.9	0.9	0.9	0.8	0.9	0.8
Valve Type	5 port 2 position								5 port 3 position							
Acting	Internally Piloted															
Diagram	A		B		A		B		C		D		C		D	
Port Size	In/Out/Exhaust=1/4"				In/Out=3/8", Exhaust=1/4"				In/Out/Exhaust=1/8"				In/Out=1/4", Exhaust=1/8"			
Orifice Size	25mm² (Cv=1.4)				30mm² (Cv=1.68)				12mm² (Cv=0.67)							
Fluid	Air (to be filtered by 40μ filter element)															
Pressure	**Working**: 20–115 psi, (0.15–0.8 MPa), (1.5–8.0 bar); **Proof**: 215 psi, (1.48 MPa), (14.8 bar)															
Voltage (VAC @ 50/60 Hz)	24VDC single solenoid	120VAC single solenoid	24VDC double solenoid	120VAC double solenoid	24VDC single solenoid	120VAC single solenoid	24VDC double solenoid	120VAC double solenoid	24VDC center closed double solenoid	120VAC center closed double solenoid	24VDC center exhaust double solenoid	120VAC center exhaust double solenoid	24VDC center closed double solenoid	120VAC center closed double solenoid	24VDC center exhaust double solenoid	120VAC center exhaust double solenoid
Power Consumption	DC: 3.0W | AC: 3.5 VA; continuous duty (100% ED)															
Max Freq	4 cycles/sec								3 cycles/sec							
Insulation	B class															
Min Response	0.05 sec															
Temperature	-5-60°C (23-140°F)															
Lubrication	Not Required															
Protection	IP65 (DIN40050)															
Connection	11mm DIN Terminal															
Body	Aluminum Alloy															
Agency Approvals	Solenoid CE marked; RoHS															

NITRA PNEUMATICS

Pneumatic AVS Directional Control Solenoid Valves – AVS-5 Series

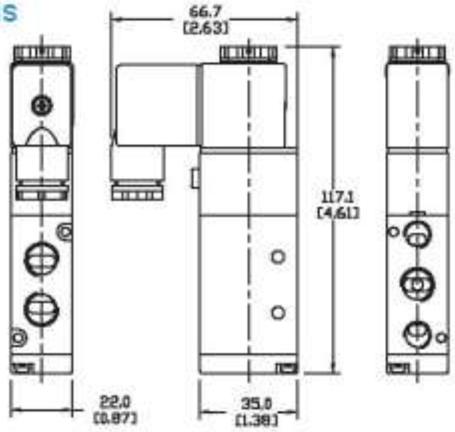
AVS-5 Series Specifications

Model	AVS-533C2-24D	AVS-533C2-120A	AVS-533E2-24D	AVS-533E2-120A	AVS-533C3-24D	AVS-533C3-120A	AVS-533E3-24D	AVS-533E3-120A	AVS-5414-24D	AVS-5414-120A	AVS-5424-24D	AVS-5424-120A	AVS-543C4-24D	AVS-543C4-120A	AVS-543E4-24D	AVS-543E4-120A
Price	$75.00	$75.00	$75.00	$75.00	$75.00	$75.00	$75.00	$75.00	$44.00	$44.00	$56.00	$56.00	$77.00	$77.00	$77.00	$77.00
Weight (lb)	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.3	1.3	1.5	1.5	1.7	1.7	1.7	1.7
Valve Type	5 port 3 position								5 port 2 position				5 port 3 position			
Acting	Internally Piloted															
Diagram	C		D		C		D		A		B		C		D	
Port Size	In/Out/Exhaust=1/4"				In/Out=3/8", Exhaust=1/4"				In/Out/Exhaust=1/2"							
Orifice Size	18mm^2 (Cv=1.0)								50mm^2 (Cv=2.79)				30mm^2 (Cv=1.68)			
Fluid	Air (to be filtered by 40μ filter element)															
Pressure	**Working:** 20-115 psi, (0.15-0.8 MPa), (1.5-8.0 bar); **Proof:** 215 psi, (1.48 MPa), (14.8 bar)															
Voltage (VAC @ 50/60 Hz)	24VDC center closed double solenoid	120VAC center closed double solenoid	24VDC center exhaust double solenoid	120VAC center exhaust double solenoid	24VDC center closed double solenoid	120VAC center closed double solenoid	24VDC center exhaust double solenoid	120VAC center exhaust double solenoid	24VDC single solenoid	120VAC single solenoid	24VDC double solenoid	120VAC double solenoid	24VDC center closed double solenoid	120VAC center closed double solenoid	24VDC center exhaust double solenoid	120VAC center exhaust double solenoid
Power Consumption	DC: 3.0W | AC: 3.5 VA; continuous duty (100% ED)															
Max Freq	3 cycles/sec															
Insulation	B class															
Min Response	0.05 sec															
Temperature	-5-60°C (23-140°F)															
Lubrication	Not Required															
Protection	IP65 (DIN40050)															
Connection	11mm DIN Terminal															
Body	Aluminum Alloy															
Agency Approvals	Solenoid CE marked; RoHS															

Dimensions

mm [inches]

AVS-5111,
AVS-5211,
AVS-5212,
AVS-5312,
AVS-5313,
AVS-5414



DIMENSION TABLE

PART NO.	A	B	C	D
AVS-5111-XXX	117.1 [4.61]	66.7 [2.63]	35.0 [1.38]	22.0 [0.87]
AVS-5211-XXX	117.1 [4.61]	66.7 [2.63]	35.0 [1.38]	22.0 [0.87]
AVS-5212-XXX	117.1 [4.61]	66.7 [2.63]	35.0 [1.38]	22.0 [0.87]
AVS-5312-XXX	134.9 [5.31]	69.2 [2.72]	40.0 [1.57]	27.0 [1.06]
AVS-5313-XXX	134.9 [5.31]	69.2 [2.72]	40.0 [1.57]	27.0 [1.06]
AVS-5414-XXX	168.4 [6.63]	74.0 [2.91]	50.0 [1.57]	34.0 [1.34]

See our website www.AutomationDirect.com for complete Engineering drawings.

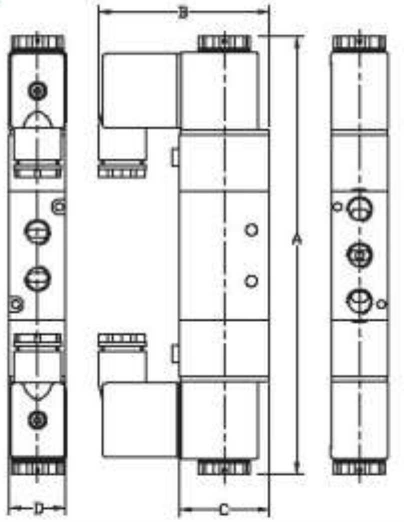
Company Information
Drives
Soft Starters
Motors
Power Transmission
Motion: Servos and Steppers
Motor Controls
Sensors: Proximity
Sensors: Photoelectric
Sensors: Limit Switches
Sensors: Encoders
Sensors: Current
Sensors: Pressure
Sensors: Temperature
Sensors: Level
Sensors: Flow Switches
Pushbuttons and Lights
Stacklights
Signal Devices
Process
Relays and Timers
Pneumatics
Pneumatics: Directional Control Valves
Pneumatics: Cylinders
Pneumatics: Tubing
Pneumatics: Air Fittings
Appendix Book 2
Terms and Conditions

Pneumatic Directional Control Solenoid Valves – AVS-5 Series

Dimensions

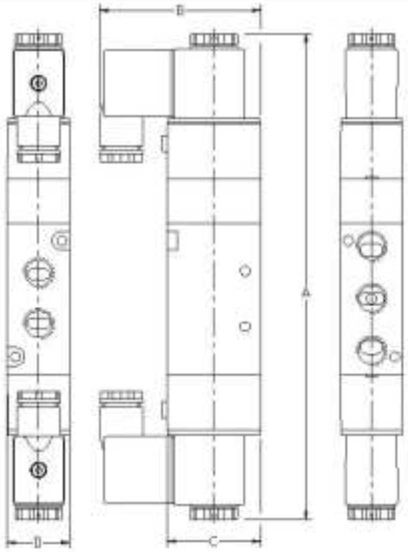
mm [inches]

**AVS-5121,
AVS-5221,
AVS-5222,
AVS-5322,
AVS-5323,
AVS-5424**



PART NO.	A	B	C	D
AVS-5121-XXX	142.4 [5.61]	54.8 [2.16]	27.0 [1.06]	18.0 [0.71]
AVS-5221-XXX	117.1 [4.61]	66.7 [2.63]	35.0 [1.38]	22.0 [0.87]
AVS-5222-XXX	117.1 [4.61]	66.7 [2.63]	35.0 [1.38]	22.0 [0.87]
AVS-5322-XXX	134.9 [5.31]	69.2 [2.72]	40.0 [1.57]	27.0 [1.06]
AVS-5323-XXX	134.9 [5.31]	69.2 [2.72]	40.0 [1.57]	27.0 [1.06]
AVS-5424-XXX	222.8 [8.77]	74.0 [2.91]	50.0 [1.97]	34.0 [1.34]

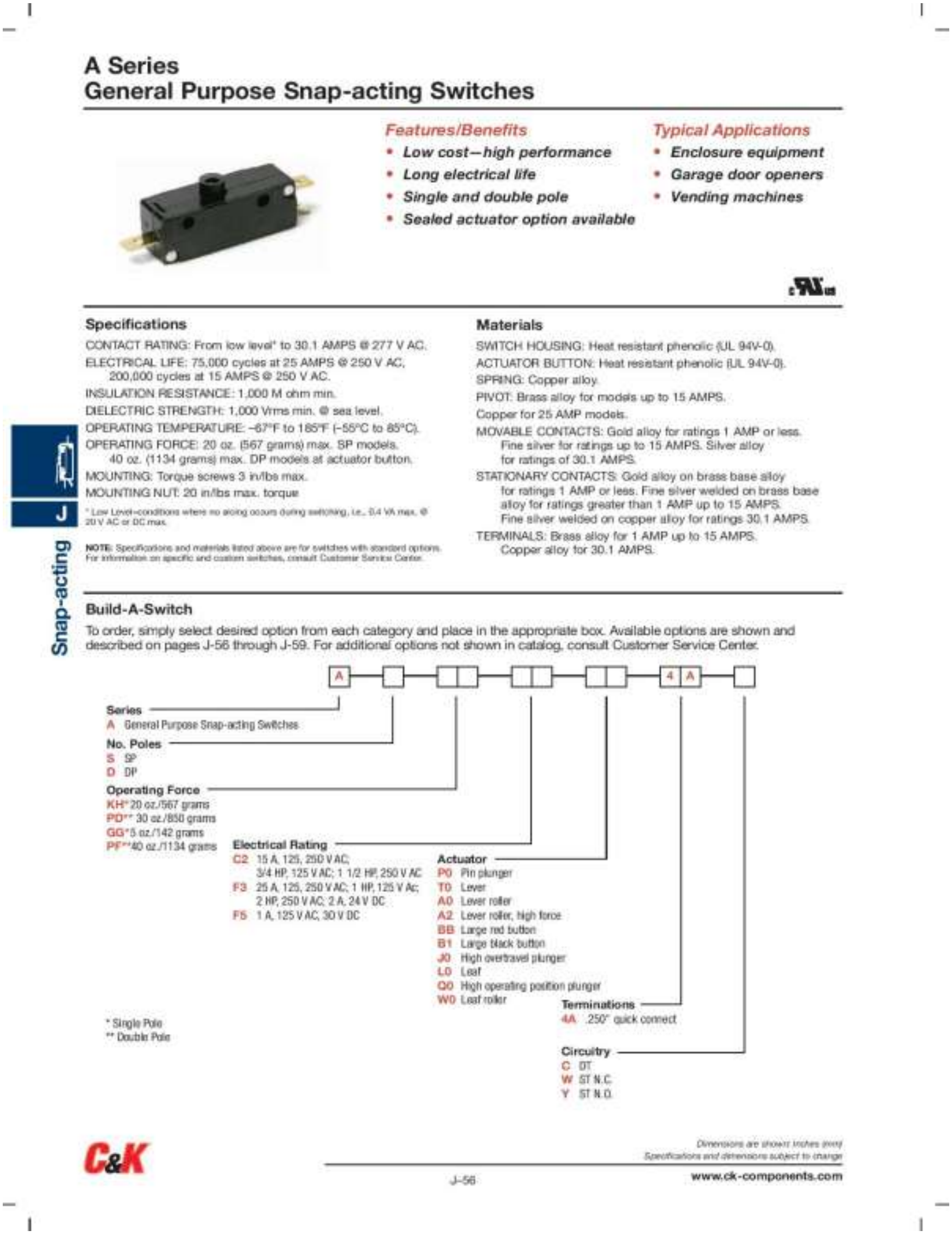
**AVS-513xx,
AVS-523xx,
AVS-533xx,
AVS-543xx**



PART NO.	A	B	C	D
AVS-513XX-XXX	157.4 [6.20]	54.8 [2.16]	26.6 [1.05]	18.0 [0.71]
AVS-523XX-XXX	189.8 [7.47]	66.7 [2.63]	35.0 [1.38]	22.0 [0.87]
AVS-533XX-XXX	208.8 [8.22]	69.2 [2.72]	40.0 [1.57]	27.0 [1.06]
AVS-543XX-XXX	243.8 [9.60]	74.0 [2.91]	50.0 [1.97]	34.0 [1.34]

See our website www.AutomationDirect.com for complete Engineering drawings.

B.5 SPDT Switch Specification



A Series
General Purpose Snap-acting Switches

Features/Benefits

- *Low cost—high performance*
- *Long electrical life*
- *Single and double pole*
- *Sealed actuator option available*

Typical Applications

- *Enclosure equipment*
- *Garage door openers*
- *Vending machines*

J

Snap-acting

Specifications

CONTACT RATING: From low level* to 30.1 AMPS @ 277 V AC.

ELECTRICAL LIFE: 75,000 cycles at 25 AMPS @ 250 V AC, 200,000 cycles at 15 AMPS @ 250 V AC.

INSULATION RESISTANCE: 1,000 M ohm min.

DIELECTRIC STRENGTH: 1,000 Vrms min. @ sea level.

OPERATING TEMPERATURE: –67°F to 185°F (–55°C to 85°C).

OPERATING FORCE: 20 oz. (567 grams) max. SP models. 40 oz. (1134 grams) max. DP models at actuator button.

MOUNTING: Torque screws 3 in/lbs max.

MOUNTING NUT: 20 in/lbs max. torque

* Low Level—conditions where no arcing occurs during switching, i.e., 0.4 VA max. @ 20 V AC or DC max.

NOTE: Specifications and materials listed above are for switches with standard options. For information on specific and custom switches, consult Customer Service Center.

Materials

SWITCH HOUSING: Heat resistant phenolic (UL 94V-0).

ACTUATOR BUTTON: Heat resistant phenolic (UL 94V-0).

SPRING: Copper alloy.

PIVOT: Brass alloy for models up to 15 AMPS.

Copper for 25 AMP models.

MOVABLE CONTACTS: Gold alloy for ratings 1 AMP or less. Fine silver for ratings up to 15 AMPS. Silver alloy for ratings of 30.1 AMPS.

STATIONARY CONTACTS: Gold alloy on brass base alloy for ratings 1 AMP or less. Fine silver welded on brass base alloy for ratings greater than 1 AMP up to 15 AMPS. Fine silver welded on copper alloy for ratings 30.1 AMPS.

TERMINALS: Brass alloy for 1 AMP up to 15 AMPS. Copper alloy for 30.1 AMPS.

Build-A-Switch

To order, simply select desired option from each category and place in the appropriate box. Available options are shown and described on pages J-56 through J-59. For additional options not shown in catalog, consult Customer Service Center.

Series

A	General Purpose Snap-acting Switches

No. Poles

S	SP
D	DP

Operating Force

KH*	20 oz./567 grams
PD**	30 oz./850 grams
GG*	5 oz./142 grams
PF**	40 oz./1134 grams

Electrical Rating

C2	15 A, 125, 250 V AC; 3/4 HP, 125 V AC; 1 1/2 HP, 250 V AC
F3	25 A, 125, 250 V AC; 1 HP, 125 V Ac; 2 HP, 250 V AC; 2 A, 24 V DC
F5	1 A, 125 V AC, 30 V DC

Actuator

P0	Pin plunger
T0	Lever
A0	Lever roller
A2	Lever roller, high force
BB	Large red button
B1	Large black button
J0	High overtravel plunger
L0	Leaf
Q0	High operating position plunger
W0	Leaf roller

Terminations

4A	.250" quick connect

Circuitry

C	DT
W	ST N.C.
Y	ST N.O.

* Single Pole
** Double Pole

C&K

Dimensions are shown: Inches (mm)
Specifications and dimensions subject to change

J-56

www.ck-components.com

A Series
General Purpose Snap-acting Switches

ACTUATOR

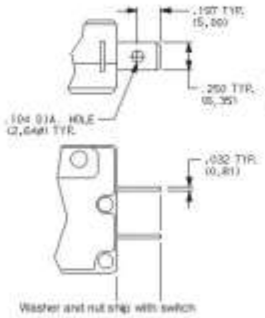
SWITCH CHARACTERISTICS

OPTION CODE	MAXIMUM OPERATING FORCE (OZ./GRAMS)				MINIMUM RELEASE FORCE (OZ./GRAMS)				MAXIMUM PRETRAVEL				MINIMUM OVERTRAVEL			
	GG S.P.	KH S.P.	PD D.P.	PF D.P.	GG S.P.	KH S.P.	PD D.P.	PF D.P.	GG S.P.	KH S.P.	PD D.P.	PF D.P.	GG S.P.	KH S.P.	PD D.P.	PF D.P.
A0	1.5 42.5	4 113	6 170	10 283	0.3 8.5	0.5 14	1 28		.312 (7.92)				312 (7.92)		.187 (4.75)	
A2	1.5 42.5	4 113	6 170	10 283	0.4 11	0.5 14	1 28		.25 (6.4)				.14 (5.6)			
B1	8 227	20 567	30 850	40 1134	1 28	3 85	6 170		.050 (1.27)				050 (1.27)			
B8	8 227	20 567	30 850	40 1134	1 28	3 85	6 170		.050 (1.27)				.050 (1.27)			
J0	5 142	20 567	30 850	40 1134	1 28	3 85	6 170		.050 (1.27)				.187 (4.75)			
L0	3 85	12 340	18 510	22 624	0.5 14	1 28	2 56.7		.281 (7.14)				062 (1.57)			
P0	8 227	20 567	30 850	40 1134	1 28	3 85	6 170		.050 (1.27)				.050 (1.27)			
Q0	5 142	20 567	30 850	40 1134	1 28	3 85	6 170		.050 (1.27)				.050 (1.27)			
T0	1.5 42.5	4 113	6 170	10 283	0.3 8.5	0.5 14	1 28		.312 (7.92)				.187 (4.75)			
W0	3 85	12 340	18 510	22 624	0.5 14	1 28	2 56.7		.281 (7.14)				.062 (1.57)			

NOTE: For basic switch operating forces, see page J-57.

TERMINATIONS

4A .250" QUICK CONNECT



NOTE: Terminals can be supplied at various angles. Other terminal styles can be supplied for special applications. Consult Customer Service Center for special requirements.

CIRCUITRY

C DT (Double Throw, Normally Open & Normally Closed)
W ST N.C. (Single Throw, Normally Closed)
Y ST N.O. (Single Throw, Normally Open)

NOTE: To select number of poles, see NO. POLES section, page J-56

Third Angle Projection

Dimensions are shown: Inches (mm)
Specifications and dimensions subject to change

ACTUATOR

OPTION CODE	FIG.	DIM. A	Operating Position DIM. B	DIM. C	DIM. D	DIM. E	DIM. F
P0	1	.50 (12,7)	.285 ± .030 (7,24 ± 0,76)	–	–	–	–
A0	3	1.38 (35,1)	.718 ± .062 (18,24 ± 1,57)	.375 dia. (9,530)	.50 (12,7)	.50 (12,7)	–
A2	4	1.25 (31,8)	.718 ± .062 (18,24 ± 1,57)	.375 dia. (9,530)	.50 (12,7)	–	–
B1	6	1.50 (38,1)	.40 ± 0.1 (10,2 ± 2.54)	.98 dia. (24,90)	–	–	–
BB	6	1.50 (38,1)	.40 ± 0.1 (10,2 ± 2.54)	.98 dia. (24,90)	–	–	–
J0	5	.50 (12,7)	.810 ± .030 (20,6 ± 0,8)	.38 (9,7)	.25 dia. (6,40)	–	–
L0	2	1.62 (41,1)	.312 ± .062 (7,92 ± 1,57)	.50 (12,7)	–	–	–
Q0	5	.50 (12,7)	.670 ± .030 (17,02 ± 0,76)	.38 (9,6)	.25 dia. (6,40)	–	–
T0	7	1.50 (38,1)	.318 ± .062 (8,08 ± 1,57)	.50 (12,7)	.50 (12,7)	–	–
W0	8	1.50 (38,1)	.801 ± .062 (20,34 ± 1,57)	.375 dia. (9,530)	.50 (12,7)	–	–

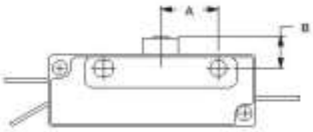


FIG. 1
High Overtravel Plunger

NOTE: The "H0" high overtravel plunger option provides .100 (2,54) min. overtravel and longer mechanical life (1,000,000 operations typical).

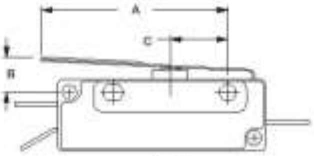


FIG. 2
Leaf

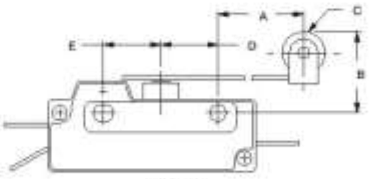


FIG. 3
Lever Roller

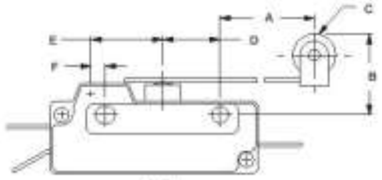


FIG. 4
Lever roller (High Force)

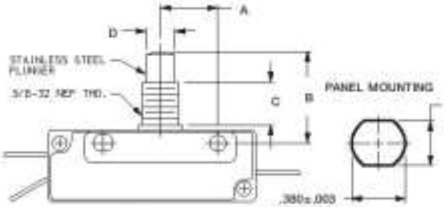


FIG. 5
High Overtravel Plunger

Torque 20 in/lbs max. (Nut)

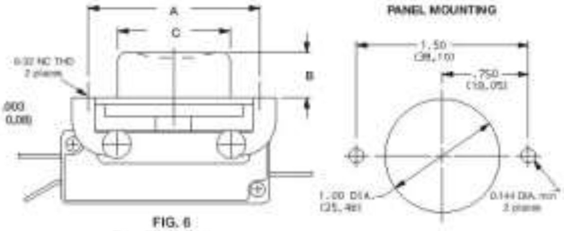
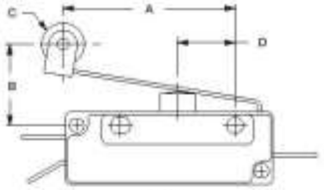


FIG. 6
B1 – Black Button
BB – Red Button



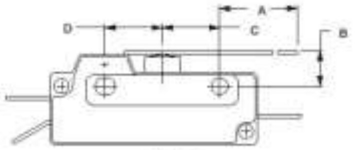


FIG. 7
Lever

FIG. 8
Leaf Roller

Third Angle Projection

Dimensions are shown: Inch (mm)
Specifications and dimensions subject to change

J

Snap-acting

C&K

A Series
General Purpose Snap-acting Switches

OPERATING FORCE

OPTION CODE	NO. POLES	BASIC SWITCH OPERATING FORCE (OZ./GRAMS)
KH	SP	20 567
PD	DP	30 850
GG	SP	5 142
PF	DP	40 1134

NOTE: Operating force varies with actuator, see ACTUATOR option section.

ELECTRICAL RATING

OPTION CODE	CONTACT MATERIAL		ELECTRICAL RATING
	MOVABLE CONTACT	STATIONARY CONTACT	
C2	Fine silver.	Fine silver welded on brass base alloy.	15 AMPS @ 125 & 250 V AC; 3/4 HP @ 125 V AC; 1-1/2 HP @ 250 V AC.
F3	Silver alloy.	Silver welded on copper base alloy.	25 AMPS @ 125 & 250 V AC; 1 HP @ 125 V AC; 2 HP @ 250 V AC; 2 AMPS @ 24 V DC.
F5	Gold alloy.	Gold alloy on brass base alloy.	From low level* to 1 AMP @ 125 V AC; 30 V DC.

* Note: See Technical Data section of this catalog for RoHS compliant and compatible definition and specifications.

All models cRUus with all options.

Contact Customer Service Center for availability and delivery of nonstandard ratings.

* Low Level-conditions where no arcing occurs during switching.

i.e., 0.4 VA max. @ 20 V AC or DC max.

AVAILABLE COMBINATIONS

ELECTRICAL RATING	OPERATING FORCE (OZ./GRAMS)			
	GG 5 142	KH 20 567	PD 30 850	PF 40 1134
C2	•	•	•	•
F3	X	•	•	•
F5	•	•	•	•

• AVAILABLE
X NOT AVAILABLE

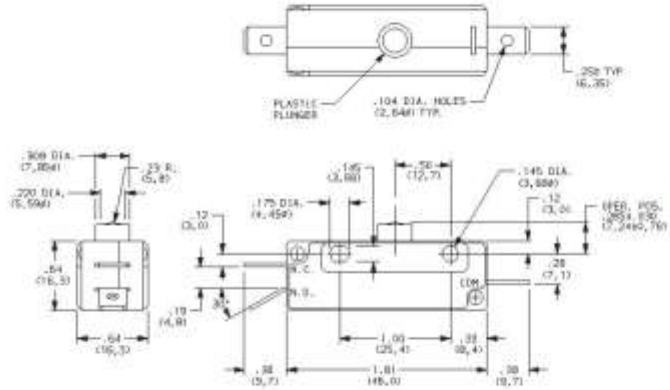
A Series
General Purpose Snap-acting Switches

SERIES ■ ▪ ▪▪ ▪▪ ▪▪ ▪▪ ▪

A GENERAL PURPOSE SNAP-ACTING SWITCHES

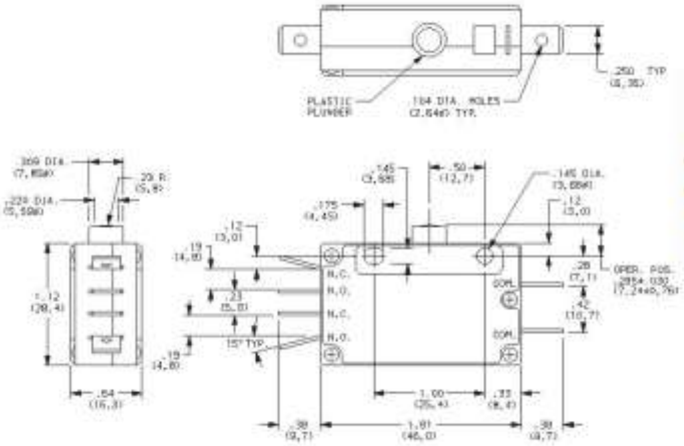
NO. POLES ▪ ■ ▪▪ ▪▪ ▪▪ ▪▪ ▪

S SINGLE POLE SWITCH



Mounting holes will accept pins or screws of .139 dia. (3,53) max., on 1.000 (25,40) centers.

D DOUBLE POLE SWITCH



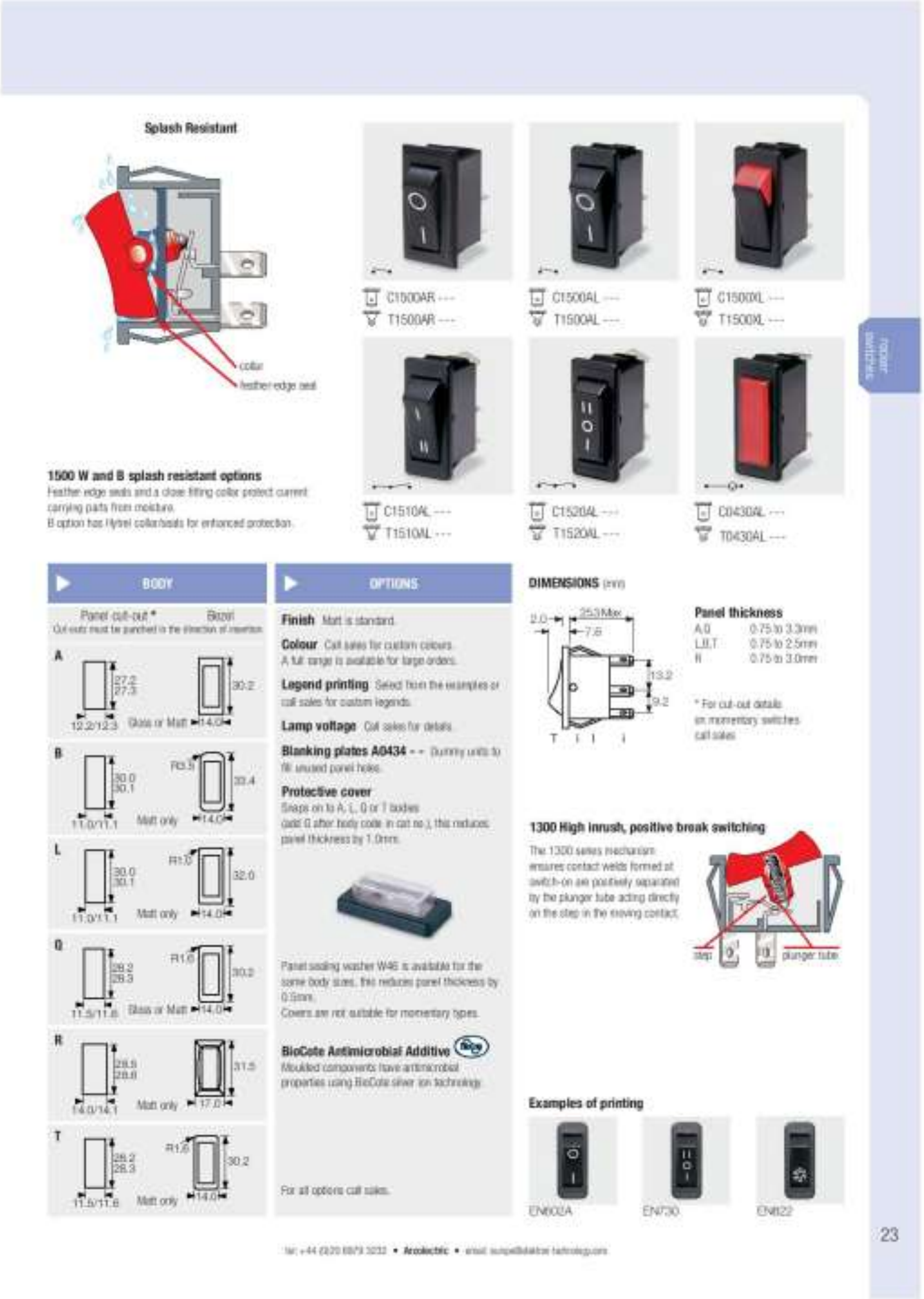
Mounting holes will accept pins or screws of .139 dia. (3,53) max., on 1.000 (25,40) centers.

NOTE: To select switching function, see CIRCUITRY section, page J-59.

Third Angle Projection

Dimensions are shown: Inch (mm)
Specifications and dimensions subject to change

B.6 Rocker Switch Specification



Splash Resistant

1500 W and B splash resistant options
Feather edge seals and a close fitting collar protect current carrying parts from moisture.
B option has Hytrel collar/seals for enhanced protection.

C1500AR ---
T1500AR ---

C1500AL ---
T1500AL ---

C1500XL ---
T1500XL ---

C1510AL ---
T1510AL ---

C1520AL ---
T1520AL ---

C0430AL ---
T0430AL ---

BODY

Panel cut-out * Bezel
Cut-outs must be punched in the direction of insertion

OPTIONS

Finish Matt is standard.

Colour Call sales for custom colours.
A full range is available for large orders.

Legend printing Select from the examples or call sales for custom legends.

Lamp voltage Call sales for details.

Blanking plates A0434 - - Dummy units to fill unused panel holes.

Protective cover
Snaps on to A, L, Q or T bodies
(add G after body code in cat no.), this reduces panel thickness by 1.0mm.

Panel sealing washer W46 is available for the same body sizes, this reduces panel thickness by 0.5mm.
Covers are not suitable for momentary types.

BioCote Antimicrobial Additive
Moulded components have antimicrobial properties using BioCote silver ion technology.

For all options call sales.

DIMENSIONS (mm)

Panel thickness

A,Q	0.75 to 3.3mm
L,B,T	0.75 to 2.5mm
R	0.75 to 3.0mm

* For cut-out details on momentary switches call sales.

1300 High inrush, positive break switching
The 1300 series mechanism ensures contact welds formed at switch-on are positively separated by the plunger tube acting directly on the step in the moving contact.

Examples of printing

EN602A EN730 EN822

23

tel: +44 (0)20 8879 3232 • Arcolectric • email: [illegible]

1500 Standard & 1300 High Inrush Switches 150A to EN61058-1 and 16A 250Vac

- Standard rocker switch
- Non-illuminated
- 1300 high inrush current
- Choice of switching circuits including 3 position
- Choice of bezel styles
- Choice of panel cut outs
- Matching indicator
- Single pole
- Splash resistant option
- BioCote antimicrobial option
- Panel cut out 'A' style: 27.3 x 12.3mm

Approvals and specifications

	1500 Series 16(4)A 250Vac T125
	UL CSA 16A Non Ind 250Vac, (2 posn) 250Vac 1hp, 125Vac 1/2hp, (3 posn) 250Vac 1/2hp, 125Vac 1/4hp UL 10A 14Vdc 'T' (1500 and 1510 only) UL 85°C, file E45221, CSA file LR10990
In house test	10A 24Vdc — Indicative rating only
	1300 series 16(6)A 250Vac T125 5E4 (50,000 Ops.) 150A Inrush to EN61058-1
	UL CSA 20A 250Vac 1hp, 125Vac 1/2hp UL 85°C, file E45221, CSA file LR10990
In house test	20A 24Vdc — Indicative rating only
	BioCote antimicrobial additive. Independently verified to ISO22196:2007.

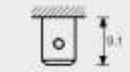
3mm contact gap except if marked µ.
Technical data on pages 4 & 5 (switches), 6 (indicators).

C 1300 A L--- B

TERMINAL FUNCTION ROCKER BODY PRINT, COLOUR, VOLTAGE ETC BioCote

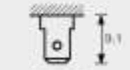
TERMINAL

C



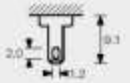
6.3 x 0.8

H



4.8 x 0.8*

K

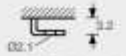


2.8 x 0.8*

T

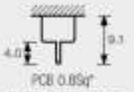
Solder

U



Right angle 'T' solder terminal

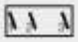
X



PCB 0.8Sq*
*N/A for 1300 series

FUNCTION

Approvals & ratings vary with function
ON OFF Switches - ON when pressed over terminal 1

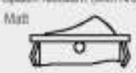


Standard 1500	High Inrush 1300		
	[illegible]	ON - OFF	
1501 [illegible]		ON - OFF (momentary ON)	
1502 [illegible]		ON - OFF (momentary OFF)	
1510 µ [illegible]		ON - ON	
1511 µ [illegible]		ON - ON (momentary 1 side)	
1520 µ [illegible]		ON - OFF - ON	
1521 µ [illegible]		ON - OFF - ON (momentary 1 side)	
1522 µ [illegible]		ON - OFF - ON (momentary 2 sides)	
0430 [illegible]		Indicator Technical data on page 6	

ROCKER

A Softline Matt

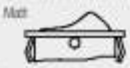
B Splash resistant (with Arcshield) Matt



H Slotted (for custom Adaptors) not momentary

V Curved Matt or gloss

W Splash resistant (with Arcshield) Matt



X Two colour Matt
ON - OFF only (not momentary)

F Flat lens Gloss (0430 only)

A Softline lens Matt (0430 only) as F but with raised profile

Works Cited

[1] The Sliding System, "Product DTS-60," The Sliding System, 2014. [Online]. Available: http://www.gsf-slides.co.uk/en/products/slide-selector-results-details.asp?productid=433&productname=15%2E6032+DTS-60+%28370-550kg%29+Extreme+Duty. [Accessed 21 Nov. 2014].

[2] McMaster Carr, "Switch-Ready Stainless Steel Air Cylinders," McMaster Carr, [Online]. Available: http://www.mcmaster.com/#standard-air-cylinders/=ukheci. [Accessed 12 November 2014].

[3] NITRA Pneumatics, "Pneumatic Directional Control Solenoid Valves – AVS-5 Series," 22 October 2014. [Online]. Available: http://www.automationdirect.com/static/specs/nitradirectionsolenoidavs5.pdf. [Accessed 15 November 2014].

[4] C&K Component, "General Purpose Snap-acting Switches Product Detail," C&K Component, 2014. [Online]. Available: http://www.ck-components.com/a/snap-acting,10542,en.html. [Accessed 28 Nov. 2014].

[5] Arcolectric, "1500 Standard & 1300 High Inrush Switches," Arcolectric, [Online]. Available: http://www.arcolectric.com/1500_1300.html. [Accessed 28 Nov. 2014].

APPENDIX C: ENGINEERED DRAWINGS

TABLE OF CONTENTS

C.1 INTRODUCTION……………………………………………………………C-2

C.2 STEP TREAD………………………………………………………………C-2

C.2.1 Upper Step Frame……………………………………………………C-3

C.2.2 Lower Step Frame……………………………………………………C-4

C.2.3 Tread Plate…………………………………………………………C-5

C.3 SUBFRAME ADDITION ………………………………………………C-6

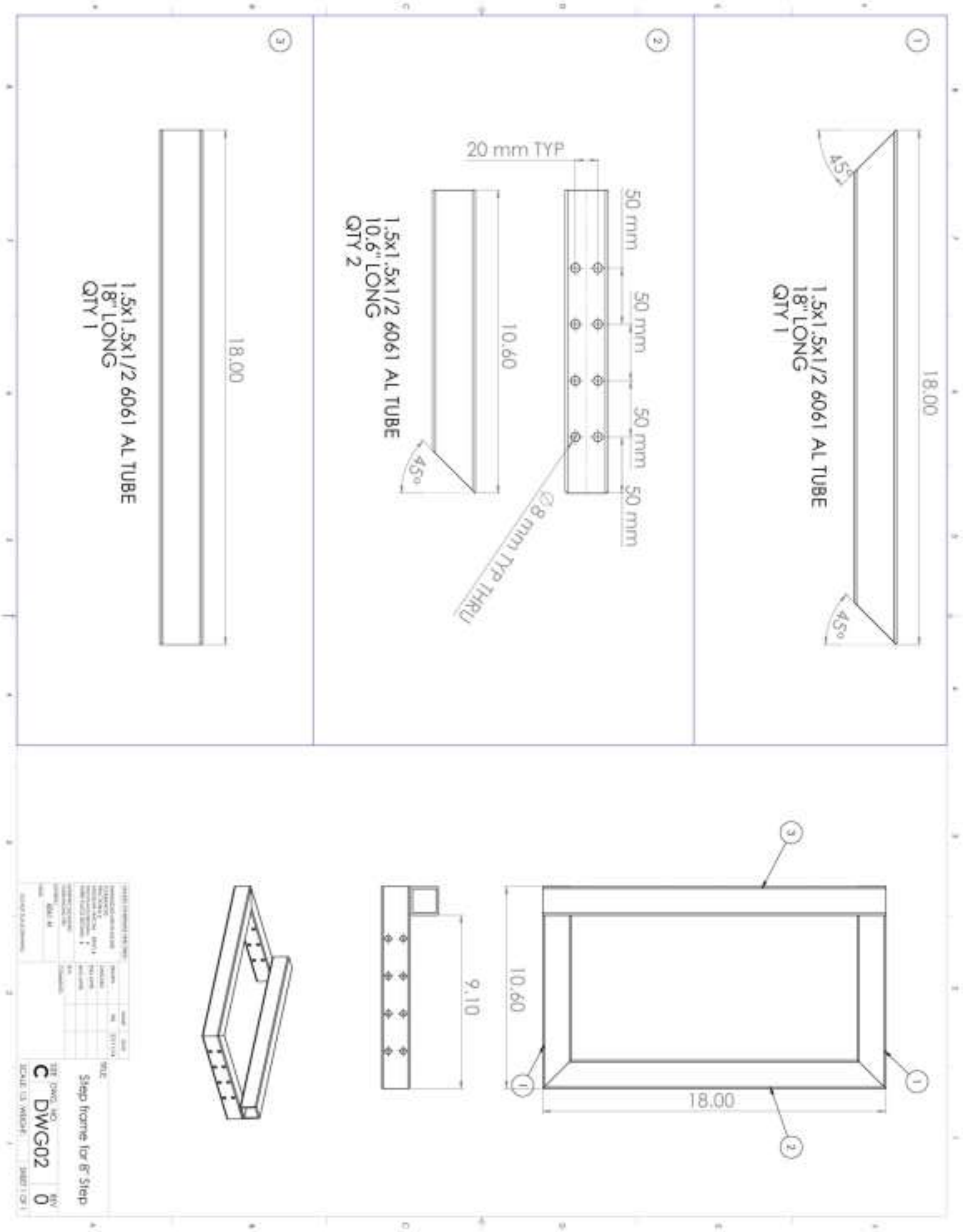
C.1 Introduction

For the components of our design intended to be produced at Fort Garry Fire Trucks (FGFT) manufacturing facility, engineered drawings have been produced. These components include the upper and lower steps, and the subframe addition to the Crown required to mount all of our system components to.

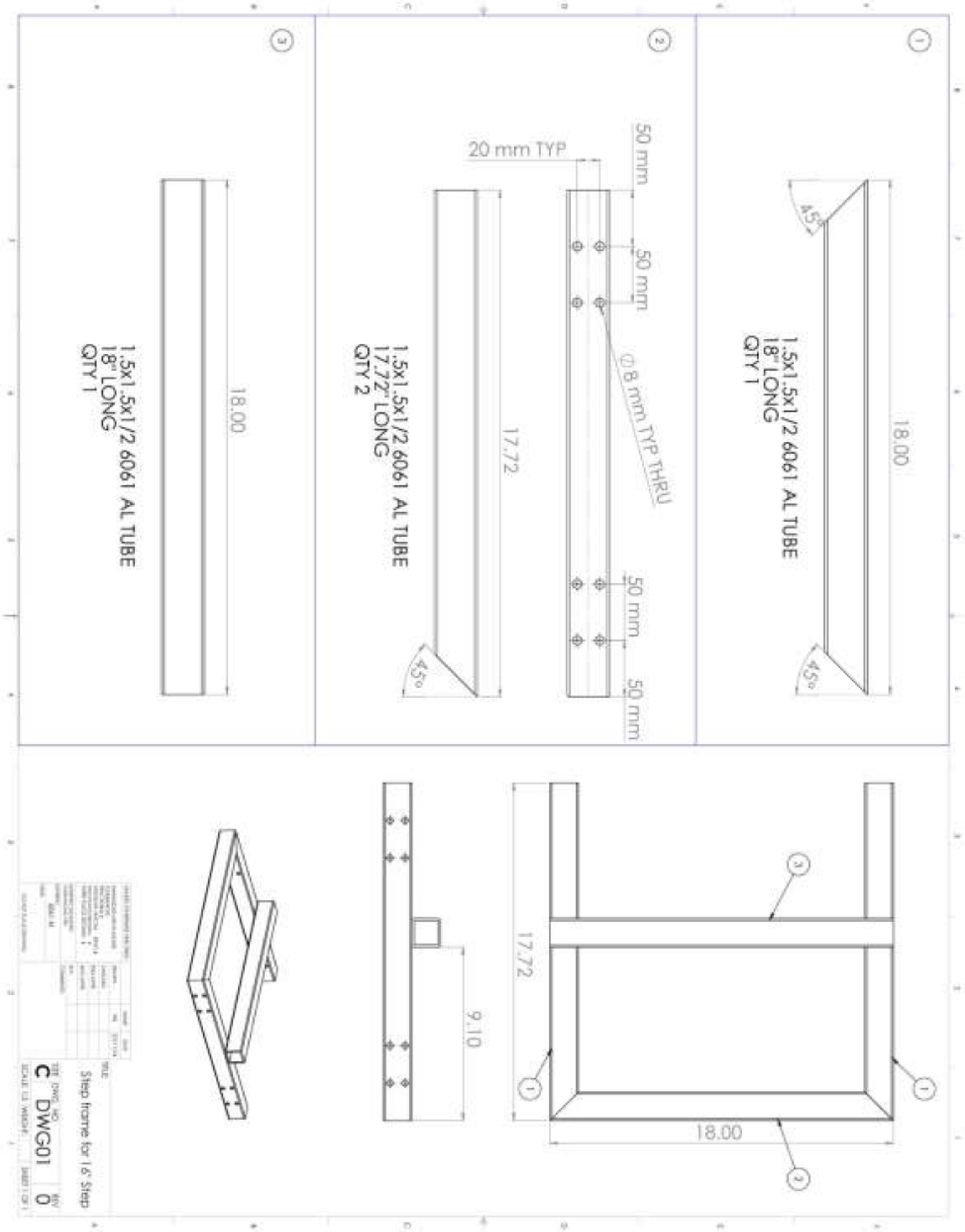
C.2 Step Tread

The upper and lower steps of our design will be produced in FGFT's facility, using materials common to their production line. On the following pages are engineered drawings for the frame of the upper and lower step, and the tread plate.

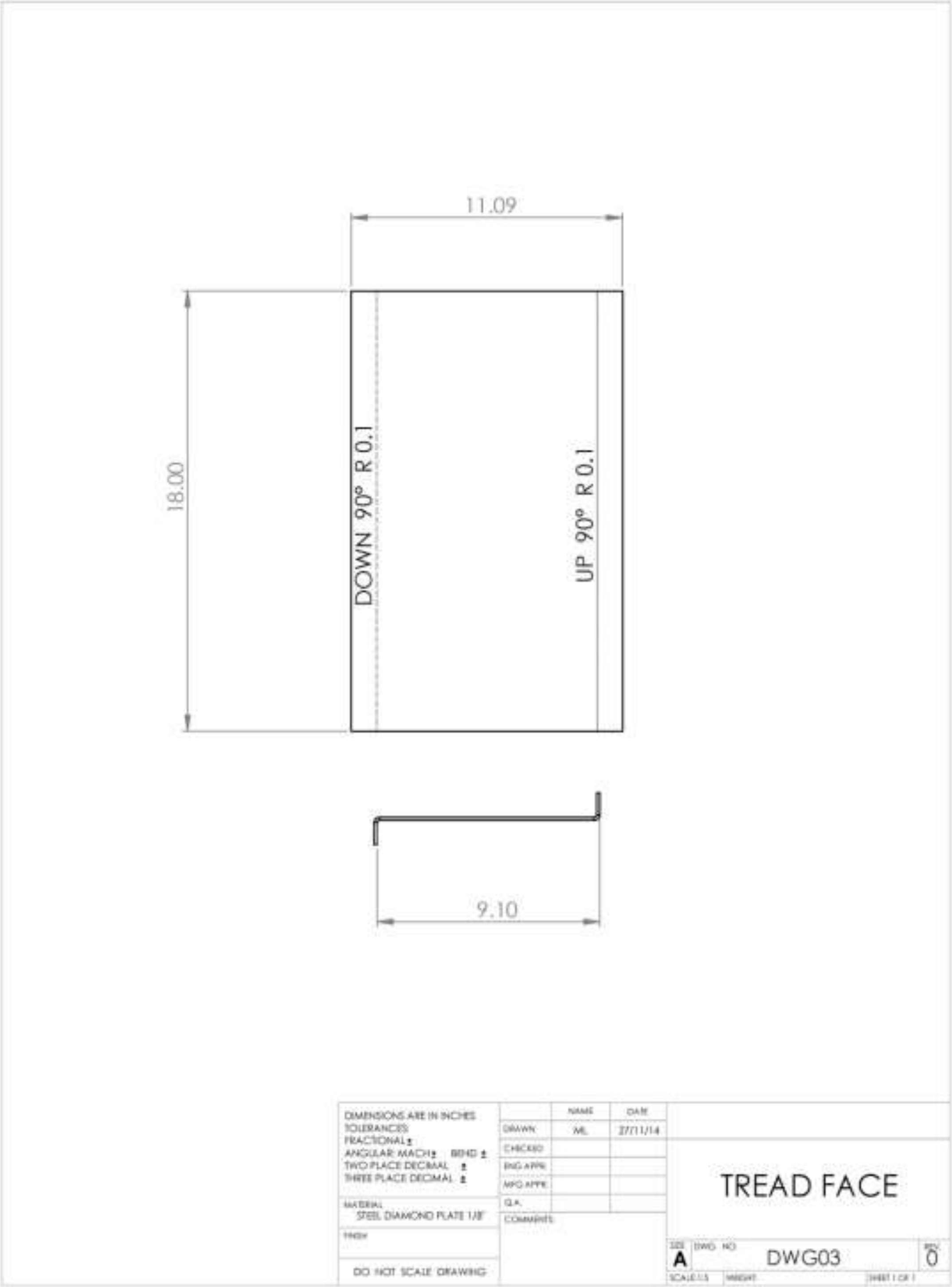
C.2.1 Upper Step Frame



C.2.2 Lower Step Frame

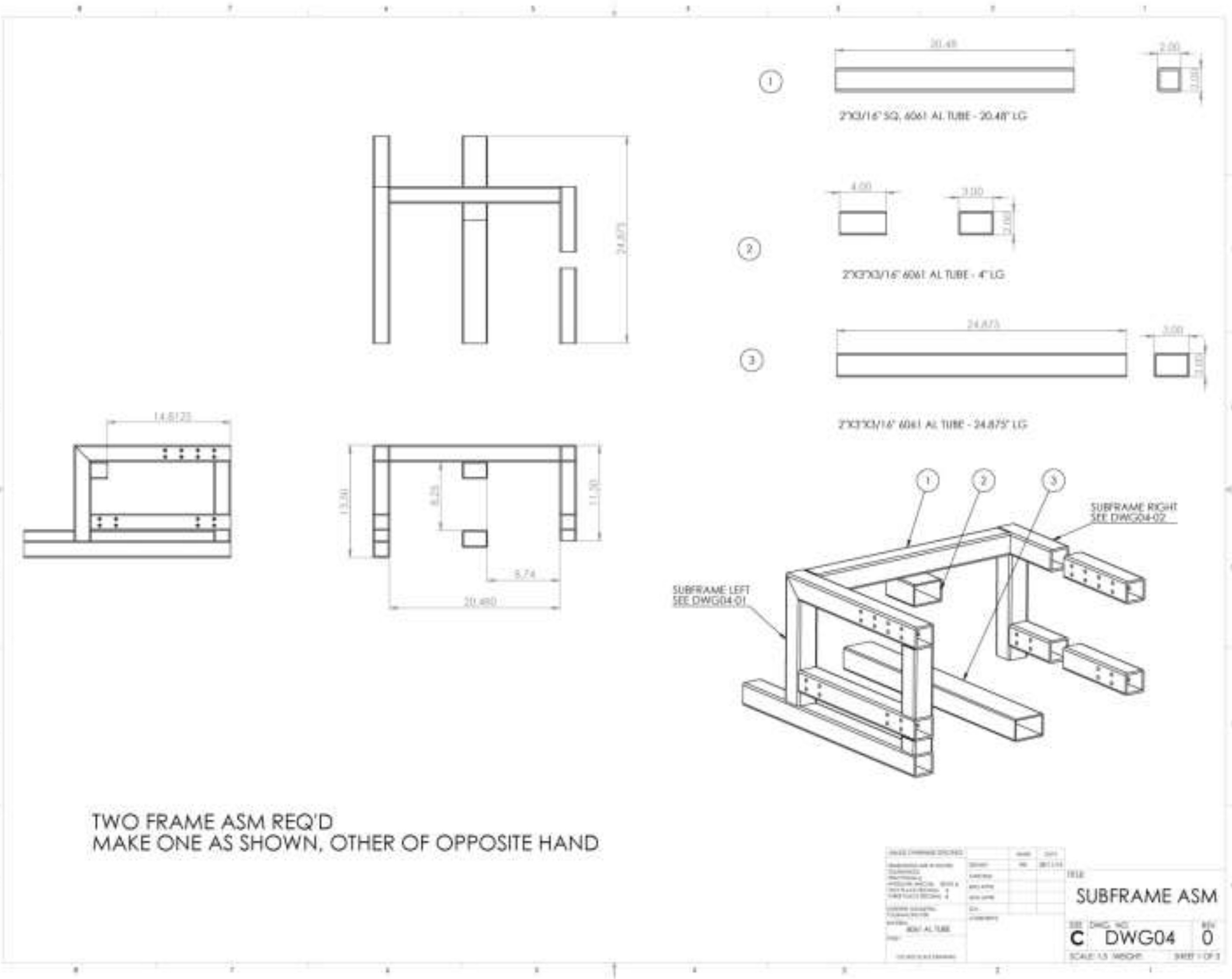


C.2.3 Tread Plate

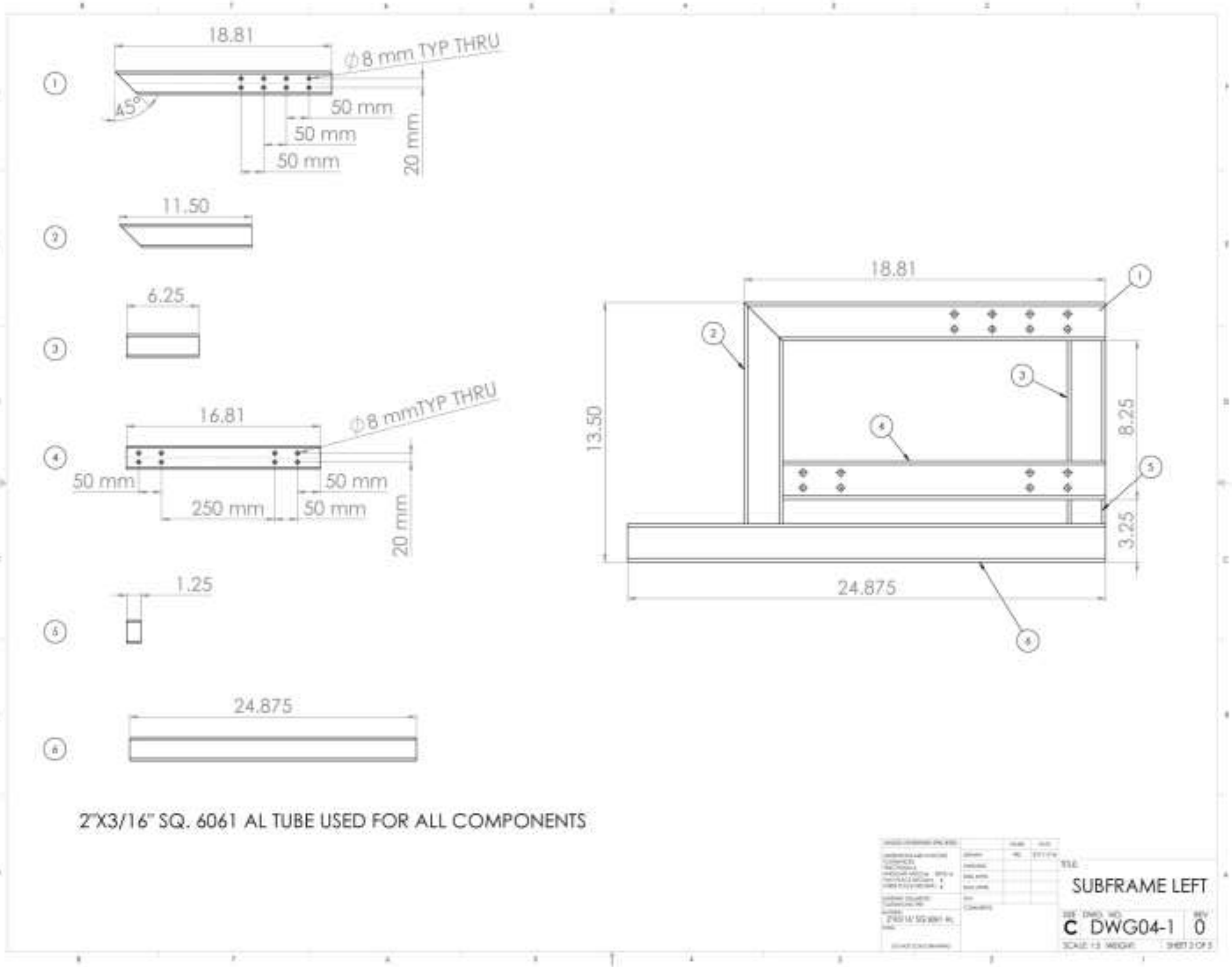


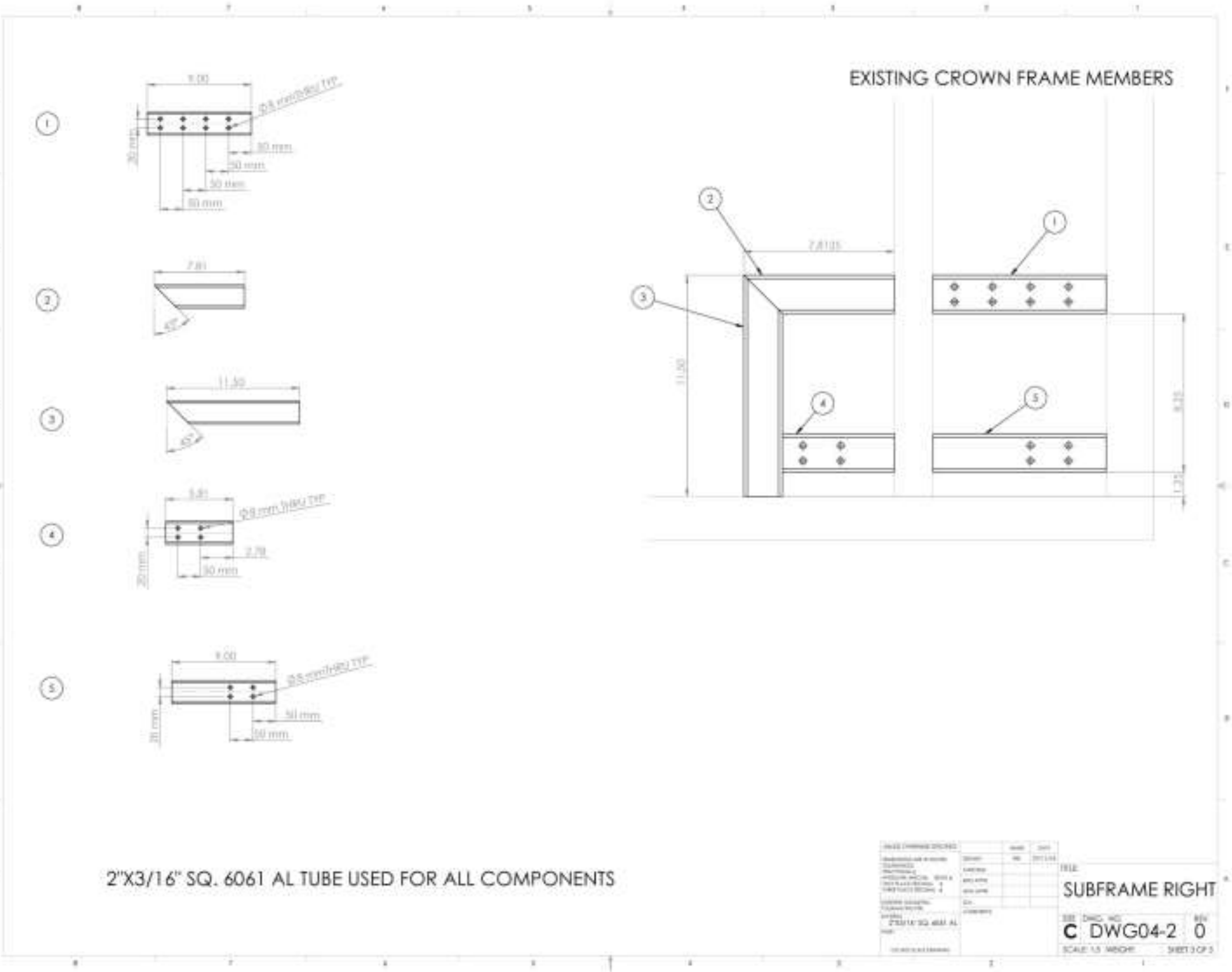
C.3 Subframe Addition

For the subframe addition to the Crown frame, an assembly drawing and two subassembly drawing has been produced. These three drawings are included in the following pages.



①
2"X3/16" SQ. 6061 AL TUBE - 20.48" LG
20.48
2.00
2.00
②
2"X3"X3/16" 6061 AL TUBE - 4" LG
4.00
3.00
2.00
③
2"X3"X3/16" 6061 AL TUBE - 24.875" LG
24.875
3.00
2.00
24.875
14.8125
13.50
8.25
11.50
8.74
20.480
SUBFRAME RIGHT SEE DWG04-02
SUBFRAME LEFT SEE DWG04-01
TWO FRAME ASM REQ'D
MAKE ONE AS SHOWN, OTHER OF OPPOSITE HAND
6061 AL TUBE
TITLE:
SUBFRAME ASM
SIZE
C
DWG. NO.
DWG04
REV
0
SCALE: 1:5
WEIGHT:
SHEET 1 OF 3


①
18.81
⌀8 mm TYP THRU
45°
50 mm
50 mm
50 mm
20 mm
②
11.50
③
6.25
④
16.81
⌀8 mmTYP THRU
50 mm
250 mm
50 mm
50 mm
20 mm
⑤
1.25
⑥
24.875
18.81
13.50
8.25
3.25
24.875
①
②
③
④
⑤
⑥
2"X3/16" SQ. 6061 AL TUBE USED FOR ALL COMPONENTS
TITLE:
SUBFRAME LEFT
SIZE DWG. NO.
C DWG04-1
REV
0
SCALE: 1:5 WEIGHT:
SHEET 2 OF 5



2"X3/16" SQ. 6061 AL TUBE USED FOR ALL COMPONENTS

TITLE:

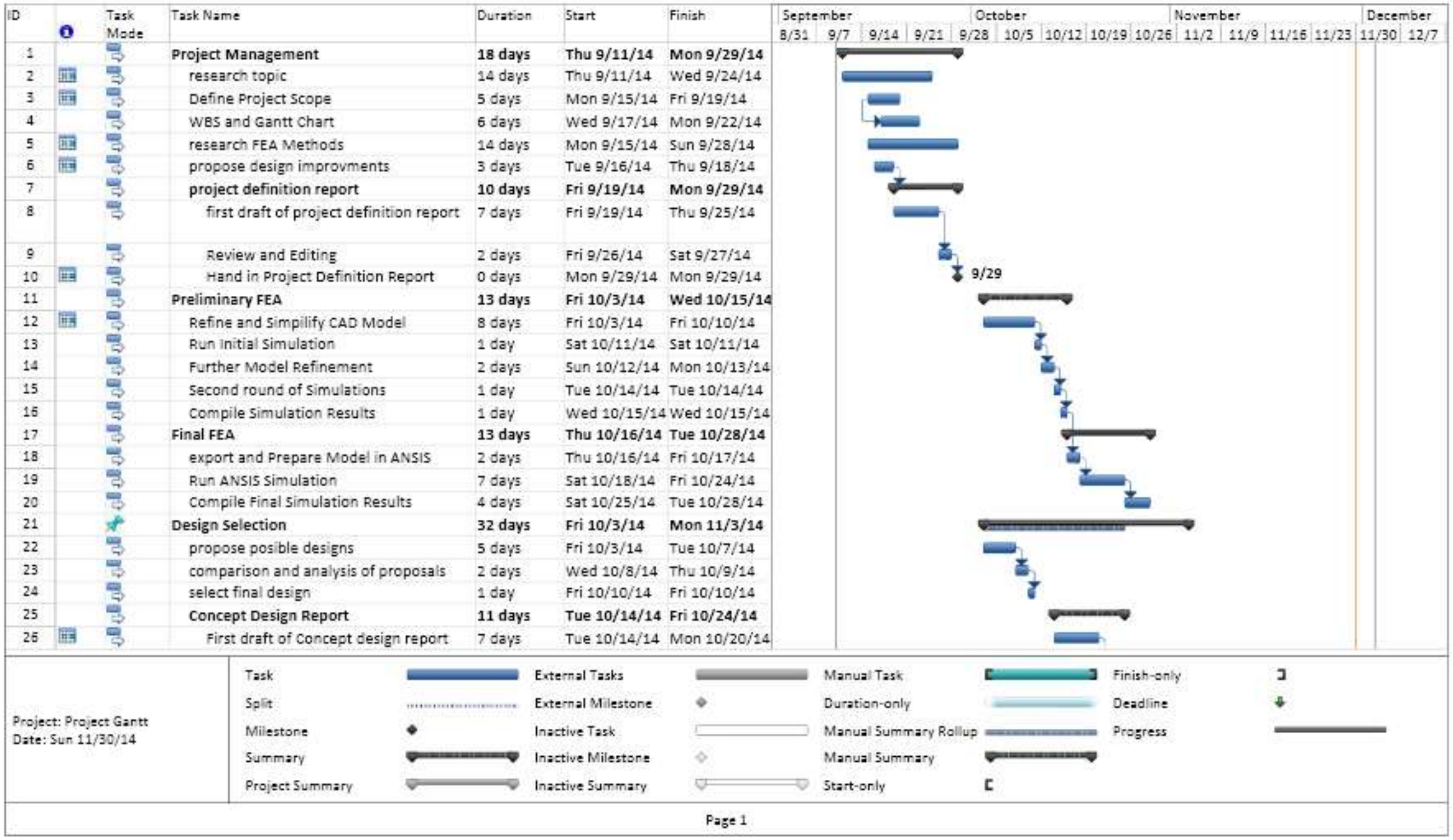
SUBFRAME RIGHT

SIZE C DWG. NO. DWG04-2 REV 0

SCALE: 1:5 WEIGHT: SHEET 3 OF 5

APPENDIX D: GANTT CHART

A Gantt chart detailing our project schedule can be found below.



ID	Task Name	Duration	Start	Finish
1	**Project Management**	**18 days**	**Thu 9/11/14**	**Mon 9/29/14**
2	research topic	14 days	Thu 9/11/14	Wed 9/24/14
3	Define Project Scope	5 days	Mon 9/15/14	Fri 9/19/14
4	WBS and Gantt Chart	6 days	Wed 9/17/14	Mon 9/22/14
5	research FEA Methods	14 days	Mon 9/15/14	Sun 9/28/14
6	propose design improvments	3 days	Tue 9/16/14	Thu 9/18/14
7	**project definition report**	**10 days**	**Fri 9/19/14**	**Mon 9/29/14**
8	first draft of project definition report	7 days	Fri 9/19/14	Thu 9/25/14
9	Review and Editing	2 days	Fri 9/26/14	Sat 9/27/14
10	Hand in Project Definition Report	0 days	Mon 9/29/14	Mon 9/29/14
11	**Preliminary FEA**	**13 days**	**Fri 10/3/14**	**Wed 10/15/14**
12	Refine and Simpilify CAD Model	8 days	Fri 10/3/14	Fri 10/10/14
13	Run Initial Simulation	1 day	Sat 10/11/14	Sat 10/11/14
14	Further Model Refinement	2 days	Sun 10/12/14	Mon 10/13/14
15	Second round of Simulations	1 day	Tue 10/14/14	Tue 10/14/14
16	Compile Simulation Results	1 day	Wed 10/15/14	Wed 10/15/14
17	**Final FEA**	**13 days**	**Thu 10/16/14**	**Tue 10/28/14**
18	export and Prepare Model in ANSIS	2 days	Thu 10/16/14	Fri 10/17/14
19	Run ANSIS Simulation	7 days	Sat 10/18/14	Fri 10/24/14
20	Compile Final Simulation Results	4 days	Sat 10/25/14	Tue 10/28/14
21	**Design Selection**	**32 days**	**Fri 10/3/14**	**Mon 11/3/14**
22	propose posible designs	5 days	Fri 10/3/14	Tue 10/7/14
23	comparison and analysis of proposals	2 days	Wed 10/8/14	Thu 10/9/14
24	select final design	1 day	Fri 10/10/14	Fri 10/10/14
25	**Concept Design Report**	**11 days**	**Tue 10/14/14**	**Fri 10/24/14**
26	First draft of Concept design report	7 days	Tue 10/14/14	Mon 10/20/14

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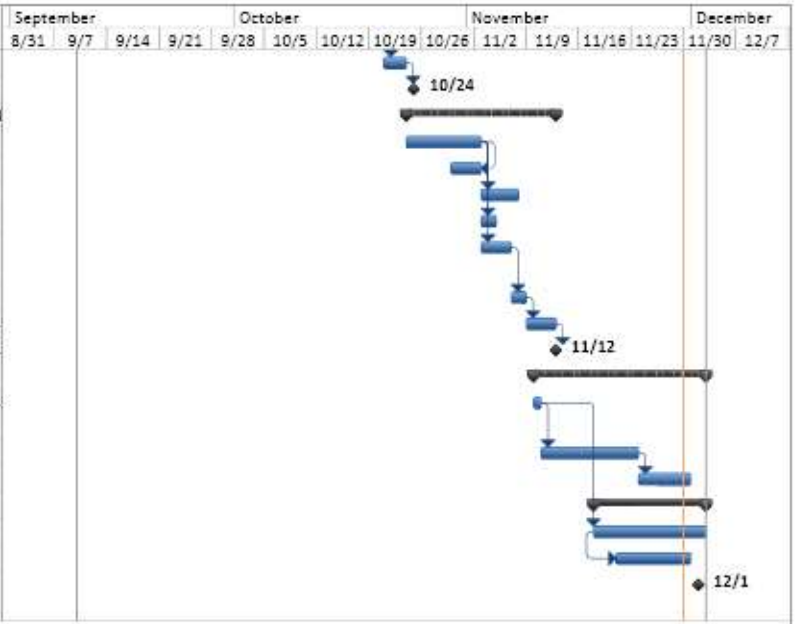
ID	ℹ	Task Mode	Task Name	Duration	Start	Finish
27			review and editing	3 days	Tue 10/21/14	Thu 10/23/14
28	▦		Hand in Concept design report	0 days	Fri 10/24/14	Fri 10/24/14
29			**Design development**	**20 days**	**Fri 10/24/14**	**Wed 11/12/14**
30	▦		Preliminary Step Mechanism Design	10 days	Fri 10/24/14	Sun 11/2/14
31			CAD Modeling	4 days	Thu 10/30/14	Sun 11/2/14
32			Slide Sourcing	5 days	Mon 11/3/14	Fri 11/7/14
33			Actuator Sourcing	2 days	Mon 11/3/14	Tue 11/4/14
34			Integration of stepsystem into Crown Design	4 days	Mon 11/3/14	Thu 11/6/14
35			Crown Floor redesign	2 days	Fri 11/7/14	Sat 11/8/14
36			Refine Design	4 days	Sun 11/9/14	Wed 11/12/14
37			Final Design	0 days	Wed 11/12/14	Wed 11/12/14
38			**Final Reports**	**23 days**	**Mon 11/10/14**	**Tue 12/2/14**
39	▦		Identify how our design improves existing product	1 day	Mon 11/10/14	Mon 11/10/14
40	▦		Final written report	13 days	Tue 11/11/14	Sun 11/23/14
41			review and editing	7 days	Mon 11/24/14	Sun 11/30/14
42			**Oral report**	**15 days**	**Tue 11/18/14**	**Tue 12/2/14**
43	▦		presentation	15 days	Tue 11/18/14	Tue 12/2/14
44	▦		Poster	10 days	Fri 11/21/14	Sun 11/30/14
45	▦		All report and presentation materials complete	0 days	Mon 12/1/14	Mon 12/1/14



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