MECH 4860

Engineering Design

Team 2

Final Design Report

AE2100 Kitting Cart Design

Patrick Guerreiro

Sundeep Ramnath

Mandeep Saggi

Manpreet Grewal

Project Advisor: Dr. Meera Singh

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Dr. Paul Labossiere
Department of Mechanical and Manufacturing Engineering
University of Manitoba
Winnipeg, MB
R3T 2N2

Dear Dr. Labossiere

Team 2 is pleased to submit the AE2100 Kitting Cart Final Design Report. This report details the final design of the Compressor Case Module kitting cart. The report also makes some recommendations to the modification of the current Power Turbine Module kitting cart.

This report has been prepared in accordance with the guidelines outlined by the Mech 4860 Faculty.

Sincerely,

Patrick Guerreiro
Team Leader
StandardAero Kitting Cart Design Team

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Glossary of Terms

MRO	Maintenance, Repair and Overhaul
ARB	Actuating Ring Box
CCM	Compressor Case Module
CCOHS	Canadian Centre for Occupational Health and Safety
ISB	Inner Segment Box
On Condition Maintenance	Maintenance that is performed depending on the condition of the component.
PTM	Power Turbine Module
SVB	Stationary Vane Box
TBO	Time Between Overhauls
VVB	Variable Vane Box

1 Abstract

StandardAero's AE2100 engine servicing facility is facing some issues in dealing with the handling of engine components. Engines are requiring greater levels of dismantling and the current carts used to store, track and transport engine components (kitting carts) are becoming inadequate.

The current carts do not safely handle all of the components that are being dismantled. In order to provide adequate accommodation for the additional components, temporary carts have been procured. The temporary carts provide additional space to store engine components but, because they are general use carts, they do not handle the components in an efficient manner. Thus, the amount of shop floor space required to kit an engine is far too great.

This report discusses the design details for a new CCM kitting cart. The new CCM kitting cart design reduces the overall shop space required to kit an AE2100 CCM to 24.75" by 48". Additionally, the cart can accommodate a CCM in both an assembled or dismantled configuration, further decreasing the floor space required. The wood material provides for easy in-house manufacturing of the cart. Specific accommodations have been made regarding the placement of all CCM components; that is, everything has its specific place. Relatively heavy components, such as the assembled CCM, are placed on a shelf located at approximately waist height reducing the strain on the technicians using the cart. Boxes for miscellaneous components are placed on special trays to make searching for parts easier. Casters provide for ease of mobility of the cart. The total cost of the new CCM kitting cart is

CDN $824.52 and is expected to decrease as technicians become more efficient in manufacturing the cart.

The modifications recommended to the PTM cart will reduce the floor space required for the cart by moving the casters under the cart. Furthermore, the addition of another shelf will allow for better accommodation of power turbine blade trays.

Team 2 believes that the design details discussed in this report adequately address the issues with the current kitting cart system.

2 Introduction

StandardAero, founded in 1911, is one of the biggest independent aviation service businesses which offer MRO services of gas turbine engines around the world [1]. StandardAero services gas turbine power plants from manufacturers such as Pratt & Whitney Canada, Rolls-Royce, Honeywell, General Electric, Vericor and Turbomeca [1]. The engines come from a number of diverse sectors such as air transport, general aviation, helicopter programs, military programs and industrial services [1]. StandardAero's philosophy is to repair parts instead of replacing them. This particular practice has led to the development of new processes in repairing parts which lower repair cost, improve quality, decrease turn-around-time and also optimize the engines performance [1].

The first step in the MRO process is to determine the scope of work to be performed during the shop visit. Older engine models have a specified TBO which means the power plant manufacturer requires that the engine be overhauled after a certain amount of operational hours or cycles. During an overhaul, the engine is fully dismantled into its individual components and every component is meticulously cleaned, inspected and repaired or replaced.

As the technology involved in gas turbine development improves, engine manufacturers are more confident in the design life of their engines. As a result, engine manufacturers may specify an on-condition maintenance program for newer engine models. If an engine is "on-condition", critical parts of the engine undergo an initial inspection to determine the level of disassembly and maintenance required during the shop visit. The on-condition maintenance process reduces the cost in maintaining an engine by reducing the amount of work that is performed during each shop visit.

Once the scope of work is defined, the engine dismantling process begins. Gas turbine engines are usually modular in design. Thus, the engine is dismantled in modules and each module can be disassembled, depending on the scope of work to be performed.

Generally, engine components are very expensive and a suitable handling method is required to store, track and transport them throughout StandardAero's facilities. The carts used by StandardAero to perform the aforementioned function are called "kitting carts". The kitting carts must handle the components in a way that they will not be damaged.

Once all the work has been performed on the engine components, the engine can be reassembled. Engine components and modules are removed from the kitting carts and installed on the engine. The engine undergoes a functional test to determine that it meets the performance standards outlined by the manufacturer. Upon successful completion of the functional test, the engine is then packaged and shipped back to the customer.

2.1 Problem statement

One engine model that StandardAero services in Winnipeg is the Rolls-Royce AE2100 Turboprop engine. The AE2100 engine is commonly used for military transport, lift and maritime patrol applications. This project deals with addressing StandardAero's current issues with the kitting carts that handle the CCM and PTM of the AE2100 engine.

As discussed previously, the purpose of a kitting cart is to provide a suitable means for storing, tracking and transporting engine modules and components within the StandardAero's facility. The AE2100 is a relatively new engine model; it is specified with an on-condition maintenance program. StandardAero is finding that as the engine ages, the scope of work to be performed on the engine is evolving to include a greater level of inspection and disassembly. With the greater level of disassembly, the current kitting carts cannot handle the surplus of parts and, as such, temporary carts are employed. The current system is inefficient and needs to be optimized.

The current kitting carts pose many issues. First, the existing carts do not accommodate components in a specific manner making it is easy to misplace components. Furthermore, the lack of specific storage locations results in inefficient use of shelf space within the cart. Figure 1 shows one of the carts currently used to handle CCM components. It is seen in Figure 1 that each shelf appears full but there is still plenty of unused space between shelves.

Figure 1: Cart for CCM components (Photo taken by the team)

Secondly, a separate cart is required to handle a fully assembled CCM. Figure 2 shows the cart currently used to handle the assembled CCM. The use of the second cart increases the overall floor space required to kit one CCM. Floor space within the AE2100 plant is in high demand due to the large volume of work.

In addition, the second cart is not ergonomically designed. The technician is required to lift the module over a ledge and down to a shelf that is below waist height.

Figure 2: Cart for assembled CCM
(Photo taken by the team)

Finally, some of the current carts pose manoeuvrability issues. The large size of some of the carts makes them difficult to manoeuvre in tight spaces. As StandardAero grows, the amount of space dedicated to engine component storage is being reduced and, as such, smaller more maneuverable carts are desired.

2.2 Problem objectives

The objectives of this project as a whole are primarily to reduce the amount of shop floor occupied by the AE2100 CCM and PTM kitting carts and standardize the location of individual components on the carts thus improving their storage efficiency.

Our first objective will be designing a cart for the CCM that is capable of handling the CCM in a fully assembled and disassembled configuration. The target cart dimensions are 24 inches wide by 48 inches long. The CCM cart will provide improved ergonomics and comply with the guidelines outlined by the CCOHS with regards to the placement of heavy objects and the maximum cart weight [2].

Our second objective is to suggest modifications to the existing PTM cart such that it provides a suitable location for safe handling of power turbine blades.

The final objective is to ensure a reasonable cost for the product. Although no target cost has been specified, measures will be taken to reduce cost whenever possible.

3 Details of the Design

The final design is a compact, ergonomically designed CCM kitting cart. The cart and subassemblies allow for safe and secure handling of all key components of the CCM. The cart includes provisions for a disassembled or fully assembled CCM assembly. Figure 3 shows an overview of the final design with the key features identified.

Figure 3 shows how nearly all of the shelf space on the cart is put to use. The empty portion on the second shelf from the top accommodates the full CCM assembly.

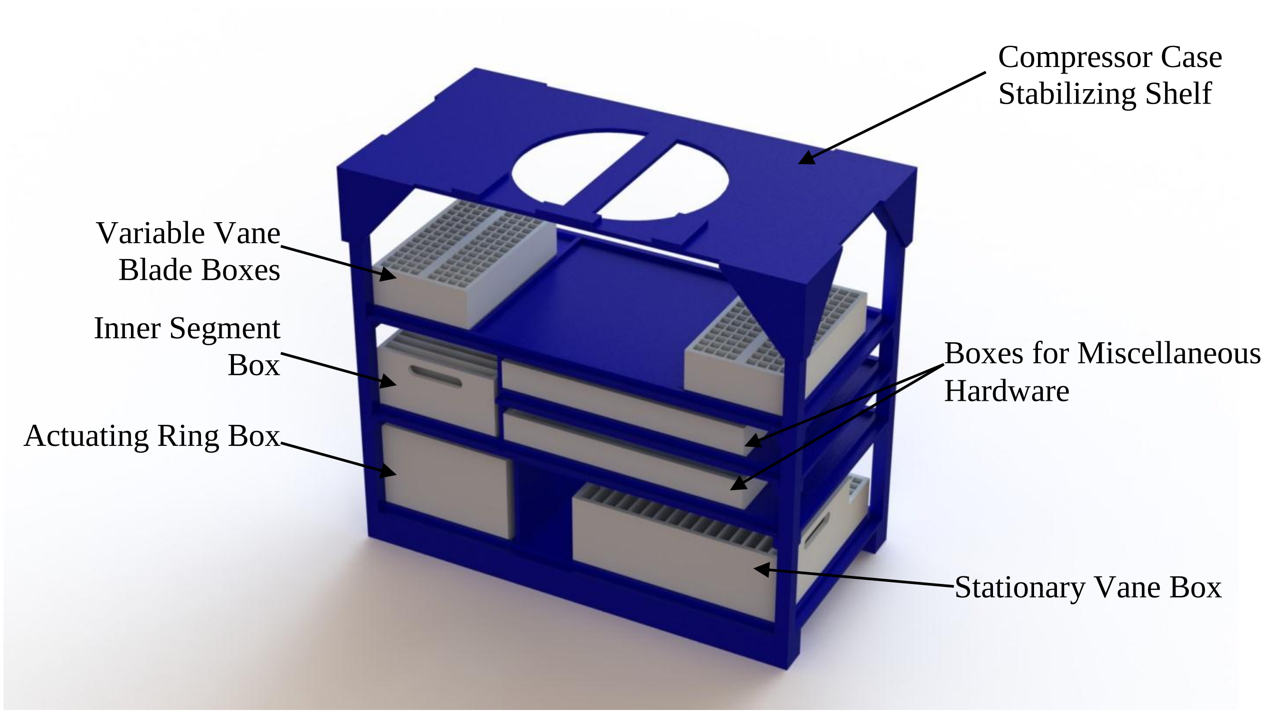

Figure 3: Final cart design

The material specified for construction of the cart and sub-assemblies is standard, construction grade lumber. Lumber is easily procurable and inexpensive. Additionally, lumber simplifies the in-house manufacturing of the cart.

The overall dimensions of the cart are shown in Figure 4. The floor footprint has been minimized as much as possible. The target specification for cart length of 48” has been met. The overall width dimension is 24.75”, just outside the target specification outlined in the project definition. However, the 0.75” larger than specified dimension is considered acceptable as the cart still occupies significantly less space than the current carts. The supporting shelf for the full CCM assembly is 27” from the bottom of the cart structure. Factoring in the 6” increase in height due to the casters puts the overall height of the supporting shelf at 33”; this dimension satisfies compliance with the CCOHS guidelines for waist height of an average person [2].

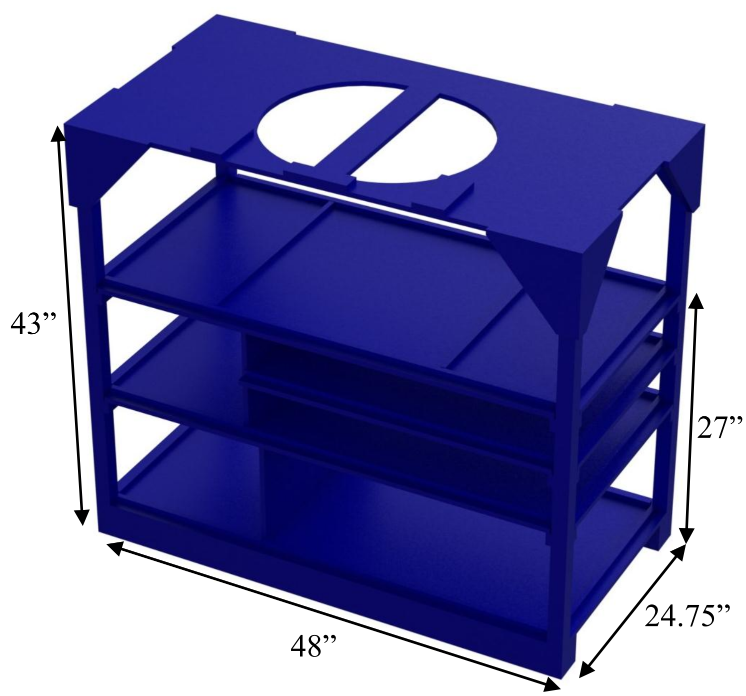

Figure 4: Overall CCM cart dimensions

The following sub-sections detail the key design features of the CCM kitting cart and demonstrate how each feature addresses the project objectives. Detailed drawings and dimensions for the CCM cart structure and all sub-assemblies have been included in Appendix 5: Detailed Drawings.

3.1 Stabilizing Shelf

The stabilizing shelf is a crucial element in accommodating the fully assembled CCM. The stabilizing shelf features are detailed in Figure 5.

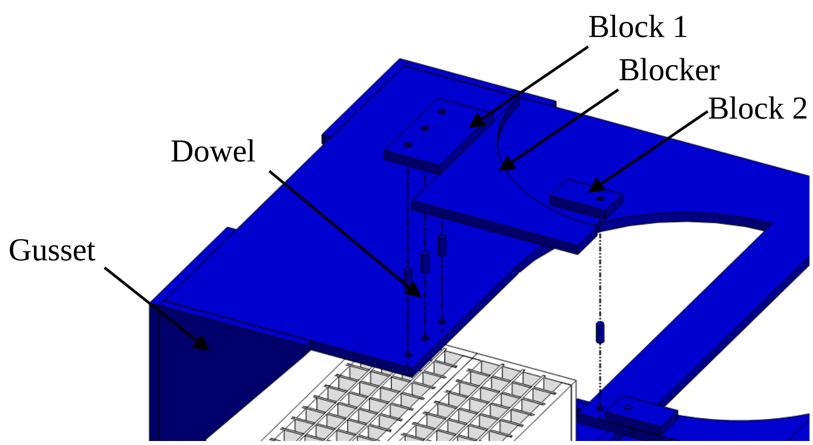

Figure 5: Stabilizing Shelf features

The function of the Blocker is to secure the assembled CCM onto the cart. The Blockers are removable to allow the technician to simply slide the assembled compressor case onto the cart without bending or twisting of the torso. Block 1 and 2 are attached to the Blocker with standard wood screws. The Dowels are glued into the shelf.

In operation, the technician simply slides the Blocker out of place, slides the CCM assembly into position and the blocker is replaced to secure the CCM assembly laterally. Figure 6 shows the blocker removed from the Stabilizing Shelf to allow for insertion of the CCM assembly.

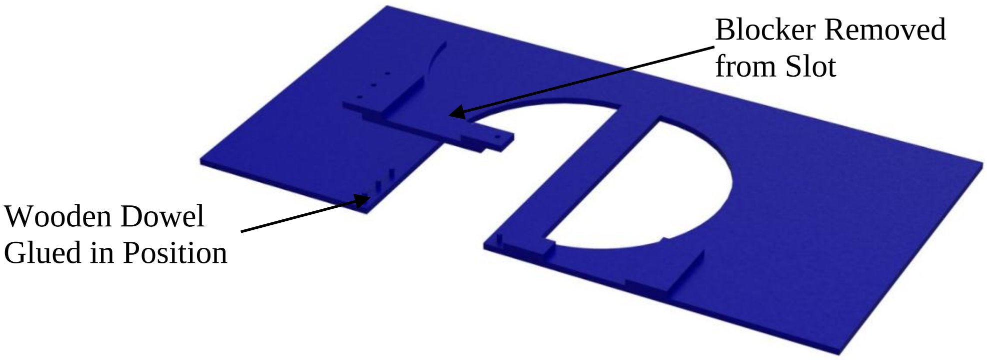

Figure 6: Stabilizing shelf with Blocker removed

The Stabilizing Shelf is attached to the four corner posts using standard wood screws. The gussets (shown in Figure 5) stiffen the cart structure by better transferring transverse loads from the shelf to the posts.

The overall dimensions for the stabilizing shelf are summarized in Figure 7. To prevent damage due to shifting of the CCM assembly, a radius of 9” was chosen to closely follow the approximate 8.5” radius of the CCM assembly.

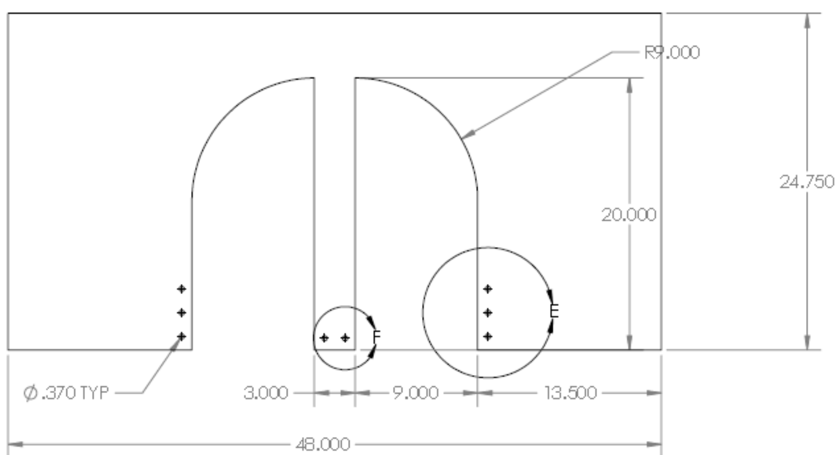

Figure 7: Overall dimensions for the Stabilizing Shelf

The slots are 20” deep to ensure the CCM assemblies are centrally located on the cart. Central loading is desired to reduce the risk of a tip over.

3.2 Component Shelves

The component shelves allow for handling of the components such as the variable vane blades boxes, miscellaneous hardware, actuating ring boxes and stationary vane boxes. There are two component shelves and one partial component shelf. A typical component shelf is outlined in Figure 8.

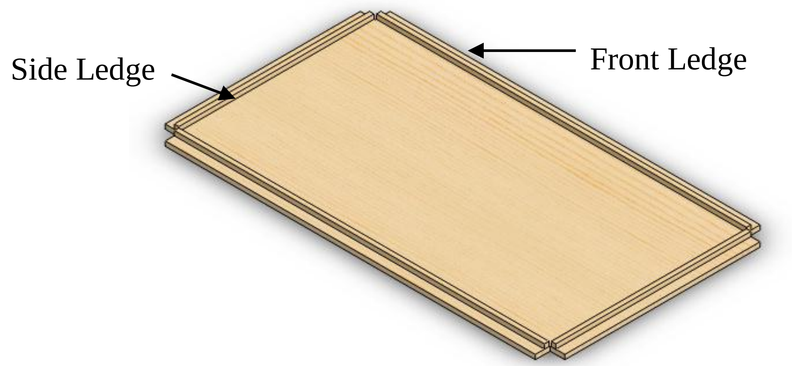

Figure 8: Component shelf assembly

The shelves are fitted with ledges to ensure components do not slide off. The ledges are 0.5" by 0.5" strips of wood that have been cut to length and screwed or nailed into place. In addition to securing components, the ledges also act as stiffeners by slightly increasing the moment of inertia of the shelf cross section.

3.3 Stationary Vane Box, Actuating Ring Box and Inner Segment Box

Some specific CCM components include the stationary vanes, actuating rings, and inner segments. These components are all similar in thickness. Essentially, the components are all semicircles of approximately the same thickness. Thus, the boxes designed for handling of the aforementioned components all poses similar features. Figure 9 shows the overall design for the stationary vane box.

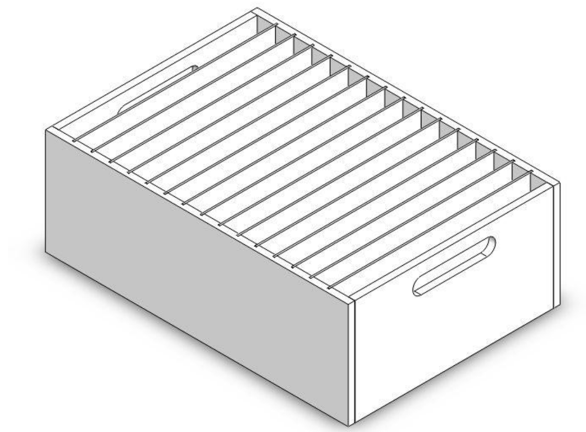

Figure 9: Stationary vane box design

The box consists of two end pieces containing handle cut-outs for ease of use. The sides of the box are slotted to allow insertion of the dividers. The dividers are 1/8" thick pieces that slide into the slots in the sides. An exploded view detailing the individual pieces of the Stationary Vane Box is illustrated in Figure 10.

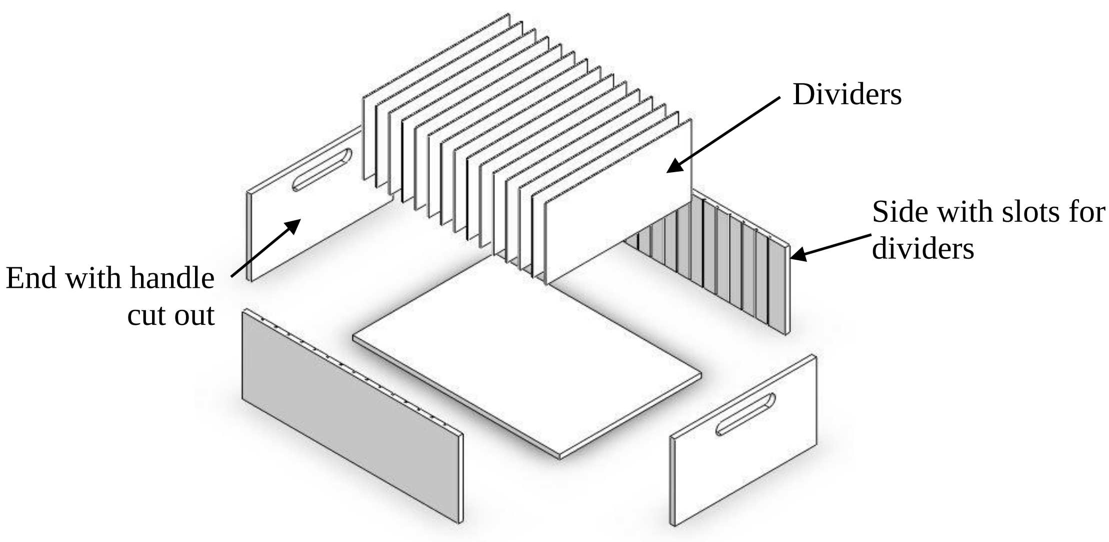

Figure 10: Stationary Vane Box exploded view

The design minimizes the area occupied by each individual component by allowing them to be placed vertically within the slots.

White paint protects the wood material of the box and provides some contrast from the rest of the cart

3.4 Variable Vane Blade Boxes

The compressor case assembly incorporates some stages of variable vanes. To handle the vanes, vane blade boxes have been designed. Figure 11 shows the VVB.

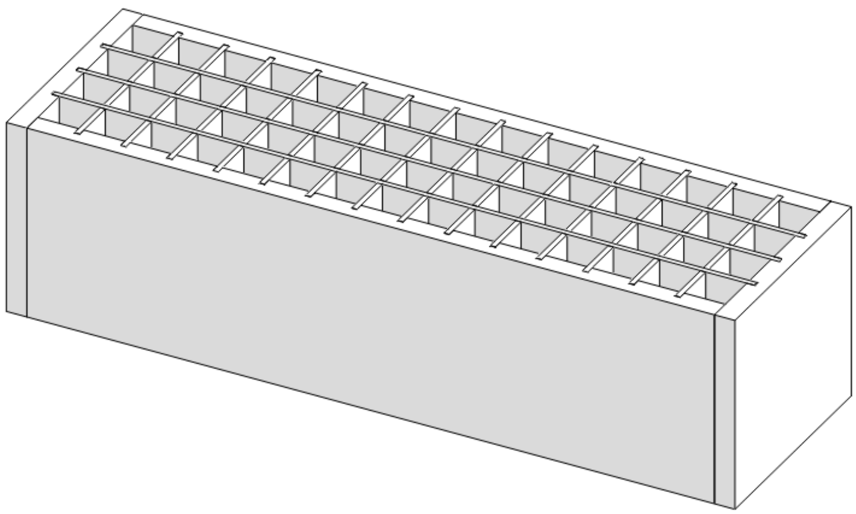

Figure 11: Variable Vane Blade box

The VVB contains transverse and longitudinal dividers to create 1” by 1” slots for the variable vanes. This design allows for easy access of the individual vane blades.

A total of five VVBs are required for accommodation of the vanes for each of the five variable vane stages of the engine. The fact that one box is used for each variable vane stage ensures that the cart remains organized.

3.5 Boxes for Miscellaneous Hardware

Given the complexity of the CCM, there is a tremendous amount of miscellaneous hardware which is currently contained in small cardboard boxes. A total of 19, 3" high boxes are used to contain all of the miscellaneous hardware. Table I lists the breakdown of cardboard boxes that are currently used for miscellaneous hardware.

Table I: BREAKDOWN OF MISCELLANEOUS CARDBOARD BOXES

Quantity	Length (in)	Width (in)
5	5	3
5	10	3
9	10	6

The use of the cardboard boxes has been kept as they are inexpensive and readily available at StandardAero. However, what has been modified is the manner in which the boxes are stored on the kitting cart.

To keep the design compact, the shelves on which the miscellaneous boxes are stored have been placed very close together. To facilitate searching for miscellaneous components on the shelves, two boxes have been designed that adequately accommodate the miscellaneous hardware. The boxes aid in maintaining the overall ergonomics of the cart by allowing the technician to place the tray in a location which prevents awkward body position.

Figure 12 shows the overall dimensions of the miscellaneous hardware box.

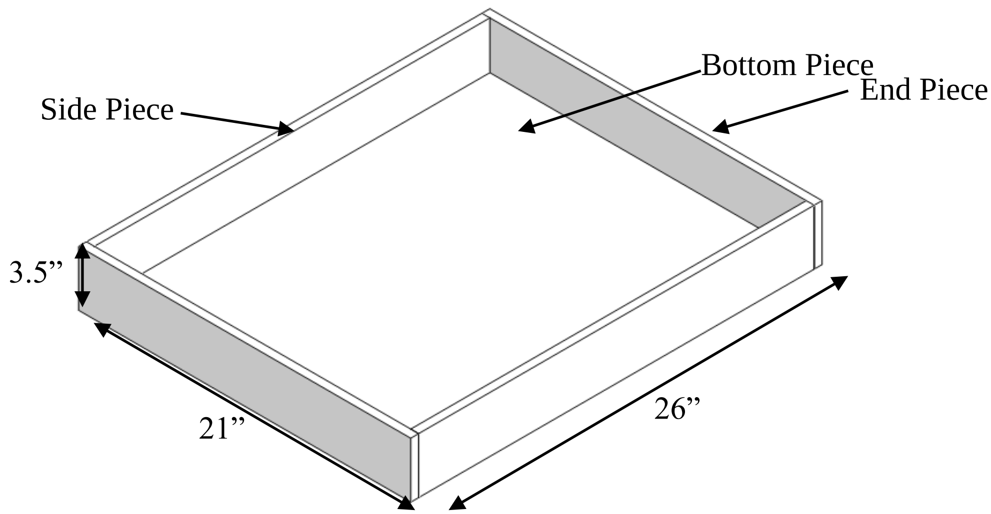

Figure 12: Isometric view of miscellaneous hardware box

3.6 Casters

Commercially available casters have been selected as a means of providing cart mobility. Selecting proper casters depends on factors such as the loaded weight, floor condition and the required manoeuvrability. Since the floor at StandardAero is a flat concrete surface, large diameter casters are not required. The two main factors that affect selection of the kitting cart casters are the loaded weight of the cart and the desired motion characteristics.

Using the CAD model of the cart, an estimate of the weight of the cart including the CCM assembly was found to be approximately 200lbs. Taking into account the occurrence of any accident such as placing heavier components or boxes on the cart, the weight considered for the selection of casters will be one and a half times the expected weight; that is, the casters installed should be able to withstand a weight of 300lbs.

As per our client specifications, the cart needs to have four casters on each corner. Contrary to the initial target specifications, StandardAero has suggested that the best way of moving the cart will be to have two swivel casters at one end of the cart and two fixed casters at the opposite end. Therefore, the final design incorporates two swivel castors and two fixed castors. The location of the casters is depicted in Figure 13.

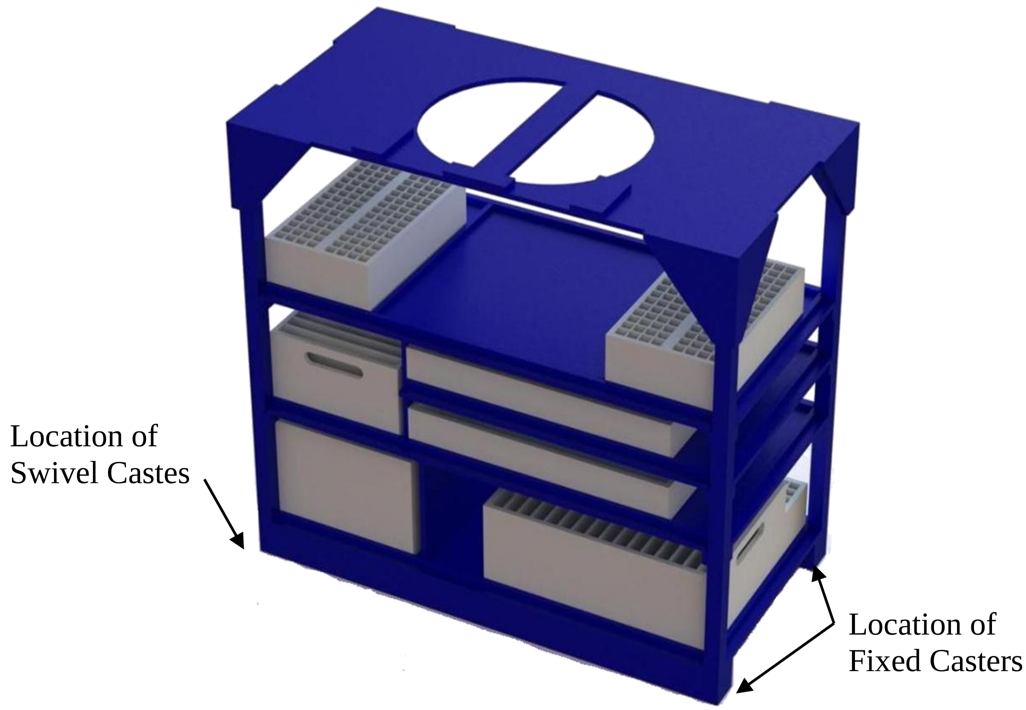

Figure 13: View of cart showing caster location

Since StanadardAero orders their casters from the company 'Casterland', our team decided to contact the company to get more information to be able to choose the appropriate casters. After comparing and evaluating different casters, two LP series casters were chosen. Table II summarizes the castor specifications.

Table II: SUMMARY OF CASTER SPECIFICATIONS

Caster Type	Wheel Diameter	Tread Width	Wheel Type	Capacity	Bearing Type	Overall Height	Top Plate Size	Price per Unit
Fixed	5”	1.25”	Non-Marking Grey Rubber	300 lb	Precision Ball	6”	2-5/8” x 3-3/4”	$13.69
Swivel	5”	1.25”	Non-Marking Grey Rubber	300 lb	Precision Ball	6”	2-5/8” x 3-3/4”	$21.55

3.7 Stress Analysis

A stress analysis on the cart structure has been conducted to verify the sizing of the wooden parts. A basic, hand calculated approach has been conducted since the maximum weight carried by the cart is only 50 lb.

Analysis has been performed on four critical components: the CCM support shelf, the CCM shelf support blocks, the vertical posts and horizontal posts.

The shelf has been approximated as a simply supported beam with two, 25 lb. loads acting at a distance of 20” from either end of the cart. The divider below the supporting shelf has not been considered in an attempt to obtain a more conservative design.

The shear stress at the shelf support has been performed assuming one screw having a diameter of 3/8”. This approach has been used to achieve a conservative result.

The compressive stress in the post was only performed on the basis of ultimate tensile stress. A buckling analysis has not been included due to the fact that the posts are well restrained from lateral motion by the other component shelves and the maximum expected load is only 50 lb.

The bending stress in the bottom horizontal beams has been performed in a similar way to the shelf discussed previously. The beam is assumed to be simply supported with a 150 lb. point load acting at 17.5” from one end. This load is conservative since the total weight of the CCM is only 50lb. In addition, the increase in stiffness due to the bottom shelf has not been considered providing a more conservative result.

The results of the stress analysis are shown in Table III. The design is well below 1 ksi. The ultimate strength for all construction grade lumber or screws is well above 1 ksi.

Table III: STRESS SUMMARY

Item	Max Shear Stress (psi)	Max Normal Stress (psi)
Supporting Shelf	N/A	250
Support Screw	226.35	N/A
Vertical Post	N/A	5.55
Horizontal Beam	N/A	370.66

3.8 Overall Bill of Materials

The overall bill of materials for the cart is shown in Table IV. It depicts the quantity of sub-assemblies and structural components required for the cart. The individual bill of materials for each sub assembly is found in their respective assembly drawings included in Appendix 5: Detailed Drawings.

Table IV: TOTAL BILL OF MATERIALS FOR CCM CART

Item No.	Part Description	Qty.
1	Bottom Shelf	1
2	Component Shelf	2
3	Stabilizing Shelf	1
4	Post	4
5	Blocker	2
6	Block 1	2
7	Block 2	2
8	Horizontal Post	2
9	Front Ledge	2
10	Side Ledge	5
11	Shelf Support 1	10
12	Shelf Support 2	10
13	Top Gusset	8
14	Misc. Box	2
15	ISB	1
16	Divider	1
17	Shelf Support Divider	1
18	VBB Box	5
19	Mid Shelf	1
20	Mid Shelf Side Ledge	2
21	ARB	1
22	SVB	1
23	Bottom Divider	1
24	Dowel	8

3.9 Cost Summary

The cost analysis has been conducted for materials to construct the CCM cart and all sub-assemblies. Also, the estimated labour required for manufacturing has been considered. The overall cost of the CCM kitting cart and assemblies is summarized in Table V.

Table V: OVERALL CCM CART COST SUMMARY

Item	Cost per Unit	QTY	Total Cost
Cart	$ 163.17	1	$ 163.17
ARB	$ 12.77	1	$ 12.77
ISB	$ 6.92	1	$ 6.92
SVB	$ 13.32	1	$ 13.32
Misc. Boxes	$ 6.46	2	$ 12.92
VBB	$ 5.48	5	$ 27.42
Total for CCM Kitting Cart and Boxes:			**$ 236.52**

The materials used for the cart are all standard grade lumber available at Home Depot.

It is expected that it will take one and a half work days for two Journeyman Carpenters to manufacture the cart. Table VI summarizes the estimated cost of labour.

Table VI: LABOUR COST BREAKDOWN

Number of Work Days (8 hours/day)	Number of Carpenters	Hours Required per Carpenter	Cost per Hour [3]	Total Cost of Labour
1.5	2	12	$ 24.50	**$ 588.00**

The total price for one CCM kitting cart is estimated to be CDN $824.52.

A detailed breakdown for the cost analysis is provided in Appendix 4: Detailed Cost Analysis.

4 Recommendations for Modification of the PTM cart

The PTM cart does not allow for safe handling of loose turbine blades. The recommended modification is to add one additional shelf to the cart that will be used only for holding power turbine blade boxes. The shelf should be positioned just far enough below the top of the cart to place the blade boxes. The shelf will accommodate the PT shaft in a manner similar to the existing shelves.

The casters on the PTM cart currently protrude from the edge of the cart. It is proposed that the protruding sections of the wooden post holding the casters be cut flush with the edge of the cart and that the casters be relocated such that they sit flush with the cart edge.

5 Conclusion

StandardAero's AE2100 engine servicing facility is becoming very crowded. Floor space within the shop is at a premium and the current carts used for kitting engine modules are being found to be insufficient. A new kitting cart design that incorporates a good balance between floor footprint, ergonomics and cost is required.

This report discusses the design details for a new CCM kitting cart. The new CCM kitting cart design reduces the overall shop space required to kit an AE2100 CCM to 24.75" by 48". Additionally, the cart can accommodate a CCM in both an assembled or dismantled configuration, further decreasing the floor space required. The wood material provides for easy in-house manufacturing of the cart. Specific accommodations have been made regarding the placement of all CCM components; that is, everything has its place. Relatively heavy components, such as the assembled CCM, are placed on a shelf located at approximately waist height reducing the strain on the technicians using the cart. Boxes for miscellaneous components are placed on special trays to make searching for parts easier. Casters provide for ease of mobility of the cart. The total cost of the new CCM kitting cart is CDN $824.52 and is expected to decrease as technicians become more efficient in manufacturing the cart.

The modifications recommended to the PTM cart will reduce the floor space required for the cart by moving the casters under the cart. Furthermore, the addition of another shelf will allow for better accommodation of power turbine blade trays.

6 References

[1] StandardAero, November 2011. [Online]. Available: http://www.standardaero.com/about_us/default.aspx.

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Appendix 1: Concepts considered, Selection Criteria & Analysis

Through brainstorming processes and concept research, six different cart designs have been formed. The concept analysis involves critically examining the possible designs in an attempt to choose the best features.

Overall Cart Layout

The overall cart layout is frame with shelves. As shown in Figure 14, an assembly supporting shelf will be placed at waist height of an average person to support the assembled CCM. A stabilizing shelf will be used to stabilize the assembled CCM. The compressor guide vanes and actuating rings will be contained on the lower shelves. More shelves/storage boxes may be added as the team sees fit throughout the design development process.

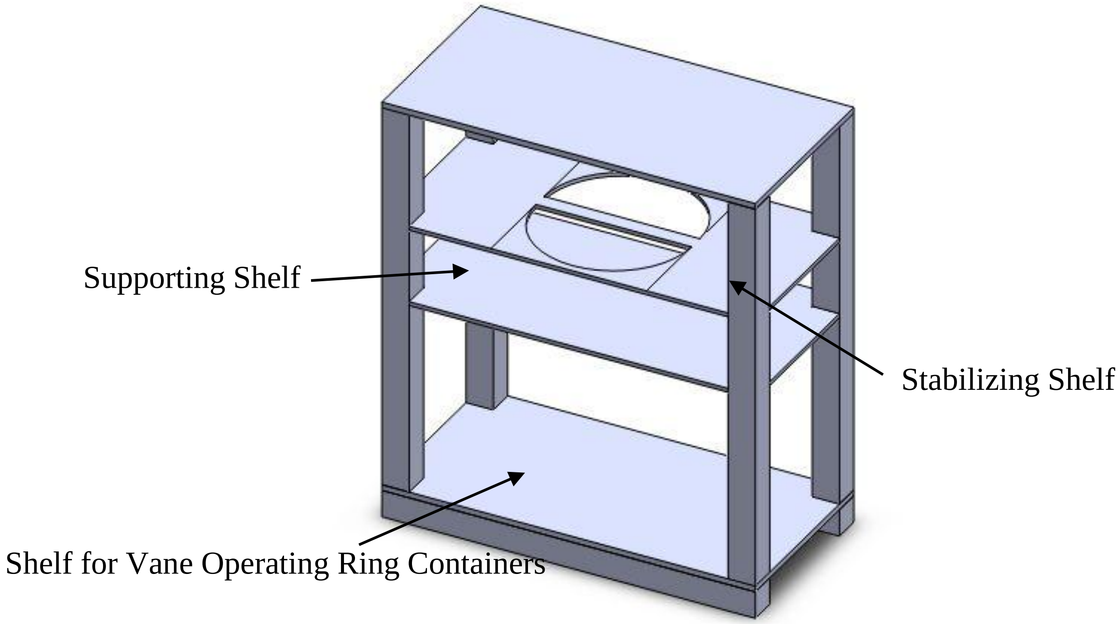

Figure 14: Overall cart layout

Handling of Assembled Configuration

The major feature of the cart design is the need to handle an assembled CCM efficiently and securely. This section outlines the concepts for handling the compressor case module on the cart in the assembled configuration.

When fully assembled, the CCM consists of two semi-cylindrical components. Figure 15 illustrates an approximate top view of the CCM assembly. This assembly can weigh approximately fifty pounds and is extremely expensive. Therefore, the method of handling must be secure and still allow for storage of other components.

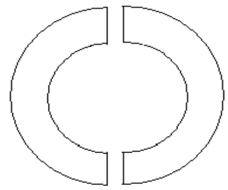

Figure 15: Top View of assembled compressor case

Six different stabilizing shelf concepts were developed by the team. Each of the six designs is outlined in the following sections.

Two Slots on One Side

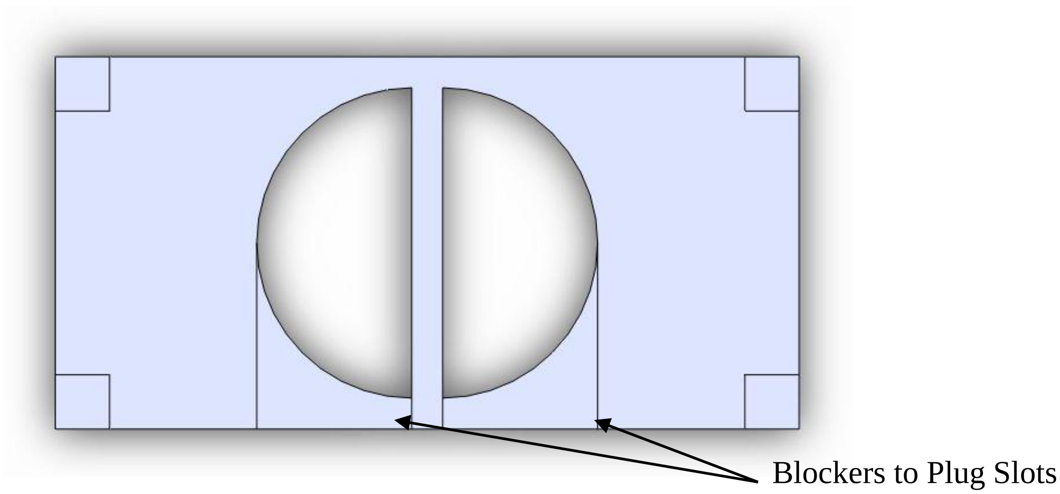

Figure 16: Design 1 top view of stabilizing shelf

Design 1 is a simple design that has two semi circles that allow for handling of the CCM assembly. As shown in Figure 16 the two pieces are supported by blockers once the pieces have been placed in the cart. This configuration allows for relative ease of handling of the CCM assembly as well as good security.

Three Semi-Circle Design

This particular design has ¾ of a circle to hold the compressor case modules together in the centre and two semicircles to hold the modules separately facing opposite to each other. Due to the wide opening in the middle, the design lacks engine security. On the other hand, the wide space in the centre allows the technician to work more efficiently on each part separately.

A disadvantage of this design is the large floor footprint required to accommodate the third semi circle. Thus this design is not strongly considered.

Single Slot Design

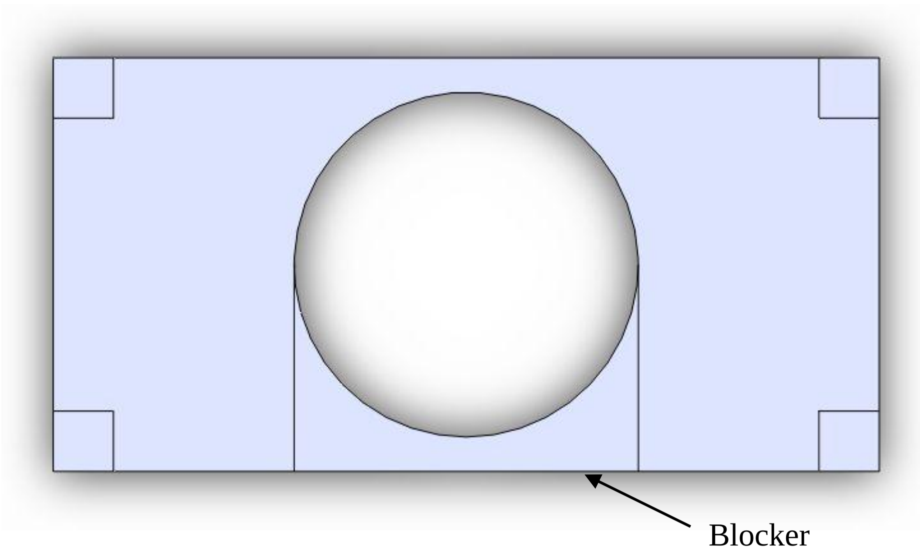

Figure 17: Design 3 top view of stabilizing shelf

The design shown in Figure 17 has a single U-type opening in the design to accommodate the CCM assembly. The two parts can be separated by a wooden plank to avoid surface contact with each other. The design is capable of holding the compressor case modules safely and securely at one location. The empty space left on the top shelf can be used to store the miscellaneous parts used for the CCM assembly. In contrast, this design makes it difficult for the technician to access the CCM part on the far side of the cart. This shelf design is easy to manufacture at the facility and economically safe due to low maintenance cost.

Two Side Access Design A

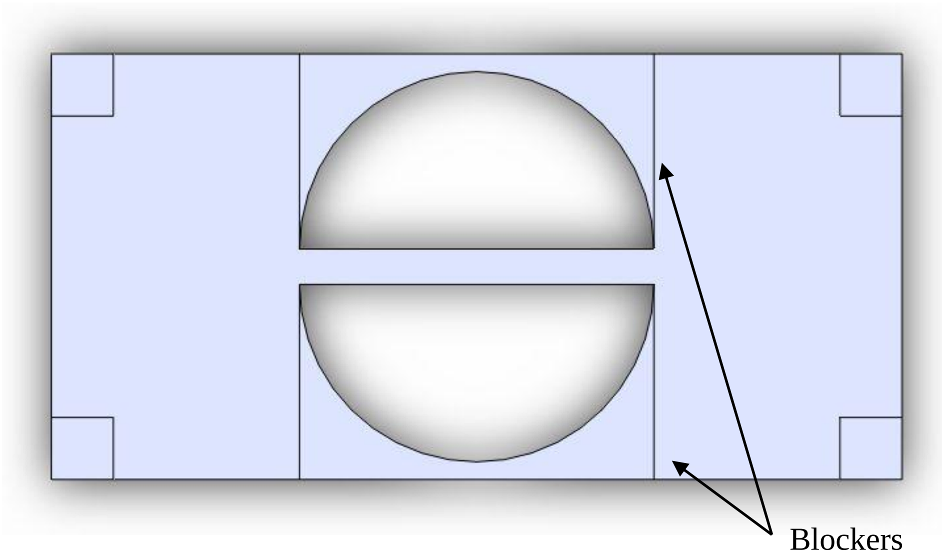

Figure 18: Design 4 top view of stabilizing shelf

As shown in Figure 18, this design has two openings, one on each side, that allow storage of the CCM assembly. The two openings allow access to both halves of the CCM assembly and make it easy for a technician to secure the assemblies on the cart. The design has the advantage of working on one module while not disturbing the other section..

Two Sided Access Design B

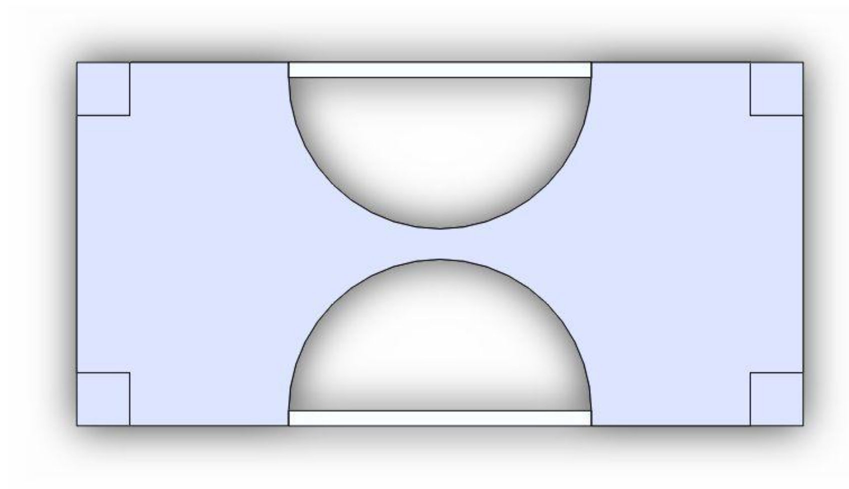

Figure 19: Design 5 top view of stabilizing shelf

The particular design has two C-shaped opening on both sides to accommodate the compressor case modules as shown in Figure 19. The two opening makes it easier for two technicians to work on the modules at the same time but it can be challenging for a single technician. The design has the advantage of working on one module while not disturbing the other section. Since, the design has large, flat openings on both the sides it makes it challenging to hold the parts securely.

Central Separated Design

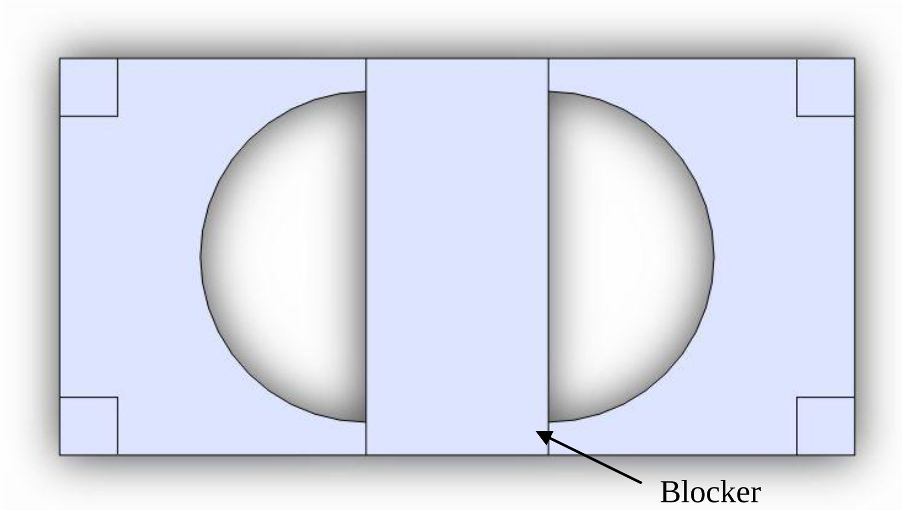

Figure 20: Design 6 top view of stabilizing shelf

This design shown in Figure 20 has two semicircles to hold the modules separately facing opposite to each other. The wide opening will allow the technician to work easily and effectively on the case modules but compromising its safety as the technician may have to bend awkwardly to slide the CCM assemblies into position.

Cart Manouvering

To facilitate movement of the cart around the shop floor the cart shall be fitted with swivel castors on all four corners. Swivel castors will allow the cart to be manoeuvred in any direction. Furthermore, placement of swivel castors on all four corners will allow the cart to be pivoted about its central axis.

Selection of appropriate castors will be based on the total weight of the cart including all engine components that the cart is designed to handle. However, since the CCOSH regulations limit human powered carts to five hundred pounds, the maximum load all four castors will have to withstand shall be five hundred pounds.

Miscellaneous Components

When the CCM is disassembled, there are many small components that need to be stored on the cart. These miscellaneous components are buttons, nuts, bolts and washers. In order to accommodate each type, StandardAero is using a thick card board boxes. Since miscellaneous components are generally small, they may be stored in trays or bins on many locations on the cart. Further development will determine suitable locations.

Guide Vanes

Trays divided into small compartments (similar to the one depicted in Figure 21) may be used for handling guide vanes as well as turbine blades (for the PTM cart). Locations for tray placement on the cart will be determined through further development.

Figure 21: Guide vane and turbine blade tray concept

Vane Actuating Rings

The vane actuating rings may be stored in a slotted box as shown in Figure 22. The idea is similar to that of the guide vane tray but custom tailored to handle the different size actuating rings.

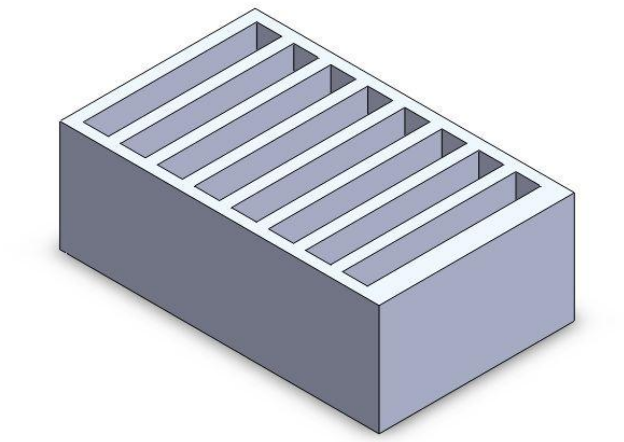

Figure 22: Vane actuating ring container

Concept Selection

In order to select a suitable concept a logical means of evaluating each design is required. The combination of a screening matrix (Table VII) and a scoring matrix (Table IX) has been used to eliminate concepts that do not adequately meet the selection criteria. The selection criteria used in the screening matrix and scoring matrix is based off the target needs and specifications developed previously.

Table VII: CONCEPT SCREENING MATRIX

	CONCEPT VARIANTS					
SELECTION CRITERIA	Design 1	Design 2	Design 3	Design 4	Design 5	Design 6
Easy to manoeuvre	+	+	+	0	0	+
Easy to manufacture	+	+	+	0	+	+
Economical	+	+	-	+	+	+
Easy to accommodate parts and assemblies	+	0	-	+	0	0
Able to hold engine components	+	+	-	+	+	+
Ease of use by technician (ergonomics)	+	0	-	0	0	0
Securely hold engine components	0	0	0	+	0	+
Space to accommodate dismantled parts	+	+	+	+	+	+
Minimum maintenance	+	+	+	-	+	+
PLUS	8	7	4	5	5	7
SAMES	1	2	1	3	4	2
MINUS	0	0	4	1	0	0
NET	8	7	0	4	5	7
RANK	1	2	5	4	3	2
CONTINUE?	Yes	Yes	No	No	Yes	Yes

The screening matrix evaluates the designs based on a plus (+), same (0) and minus (-). The sign is based on how well the design meets the selection criteria. After each design is evaluated, a net calculation is done. The four designs that result in the greatest number of positives are selected for further scoring.

A scoring matrix is used to narrow down the four chosen designs from the initial screening process to three. The scoring matrix evaluates and filters the concepts such that each design is graded on a scale of 1-5 and the three designs with highest scores are selected for further development.

Table VIII: SCORING MATRIX SCALE DEFINITIONS

Scale	Description
1	Unacceptable
2	Poor
3	Acceptable
4	Good
5	Excellent

The criteria selected remain the same as the criteria in the screening process but this time they are given a weighting factor according to their importance. For example, the client does not consider the cost to be of great significance. Thus, it is weighed at 5 percent. The need to accommodate parts and assemblies is of greater importance which results in a weighting of 15 percent.

After rating all designs, the scores for each criterion and concept are multiplied by their individual factors. The scores are then totalled for each design concept and a decision is made as to which concepts will proceed for further analysis. The final design will combine the most appealing aspects of the top three designs (Design 1, 2, and 6).

Table IX: CONCEPT SCORING MATRIX

		Design Concepts							
		1		2		5		6	
SELECTION CRITERIA	**Weight**	**Rating**	**Weighted score**	**Rating**	**Weighted score**	**Rating**	**Weighted score**	**Rating**	**Weighted score**
Easy to manoeuvre	10	5	50	5	50	5	50	5	50
Easy to manufacture	5	5	25	4	20	5	25	4	20
Economical	5	5	25	4	20	4	20	4	20
Easy to accommodate parts and assemblies	15	5	75	4	60	3	45	4	60
Able to hold engine components	15	5	75	5	75	5	75	5	75
Ease of use by technician (ergonomics)	15	5	75	4	60	3	45	4	60
Securely hold engine components	15	5	75	3	45	3	45	4	60
Space to accommodate dismantled parts	15	5	75	3	45	3	45	3	45
Minimum maintenance	5	4	20	4	20	4	20	4	20
Total score	100		495		395		370		410
Rank			1		3		4		2
Develop concept?		Yes		Yes		No		Yes	

Sensitivity Analysis

A Sensitivity analysis is a technique used to determine how different values of an independent variable will impact a particular dependent variable under a given set of assumptions [4]. There are different ways of performing a sensitivity analysis but the simplest form is to vary one value in the model by a given amount and to compare the result with the one obtained from concept scoring.

In the first analysis, a distinctive weight for each criterion with a range of 1 to 20 was employed. The larger range had a considerable weight on the third, fourth, fifth and sixth criteria. After analysing and ranking each design, the ranking was the same as in the concept scoring and the first ranked concept was clearly separated with the other three.

The second analysis was done to reduce the disparity between the least and most important criterion. The range was changed to 1 to 10, with multiple criteria sharing the same weighting factor. The ranked concept retained their individual position.

A third analysis was performed with a weighting factor range of 5 to 10 and this time the weight of the least desirable criteria was increased. When compared to the above results, the ranking remained the same.

The sensitivity analysis showed that the results provided more distinction between the ranks of the concepts and all ranked designs kept their positions.

Concept Integration

The concept integration combines the ideas analysed throughout the previous sections of this appendix. Analysis of the screening and scoring matrices as well as a group decision has lead to the selection of the best design.

The concept screening process leads to the conclusion that the two slot stabilizing shelf design is most suited. The two slot design is simple and provides good support and allows sufficient room for other components.

Swivel castors will be selected for all four corners of the cart. Swivel castors are a cheap and easy means of providing the suitable manoeuvrability characteristics.

A slotted box will be used for handling of the compressor guide vanes and turbine blades. The slotted boxes allow for easy placement of all components with minimum floor footprint.

Appendix 2: Structural Analysis

The maximum normal stress in the cart is determined by $\sigma_m = \frac{M}{S}$ where M is the bending moment in the shelf and S is the section modulus. A Free Body Diagram (FBD) representing the forces acting on the shelf is shown in Figure 23.

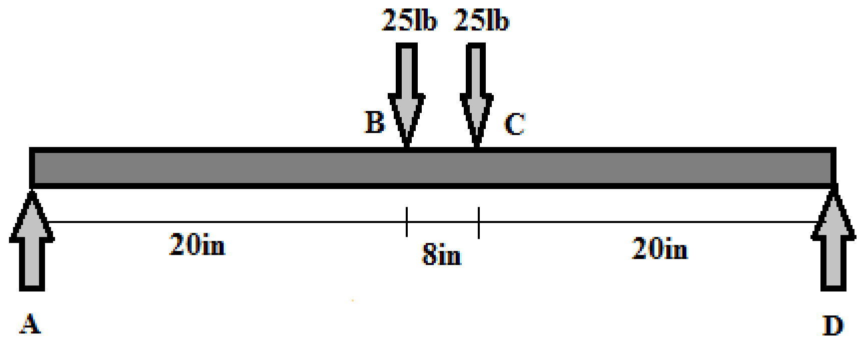

Figure 23: FBD of CCM supporting shelf

Point A:

$$\sum M_A = 0;\ \mathrm{M_A} - 25\mathrm{lb}(0\mathrm{in}) = 0$$

$$\mathrm{M_A} = 0$$

$$\sum \mathrm{F_y} = 0; 25\mathrm{lb} - \mathrm{V_1} = 0$$

$$\mathrm{V_1} = 25\mathrm{lb}$$

Point B:

$$\sum M_B = 0;\ \mathrm{M_B} - 25\mathrm{lb}(20\mathrm{in}) = 0$$

$M_B = 500 lb.in$

$\sum F_y = 0; 25lb - 25lb - V_2 = 0$

$V_2 = 0$

Point C:

$\sum M_C = 0;\ M_C - 25lb(28in) + 25lb(8in) = 0$

$M_C = 500 lb.in$

$\sum F_y = 0; 25lb - 25lb - 25lb - V_3 = 0$

$V_3 = 25lb$

Point D:

$\sum M_D = 0;\ M_D - 25lb(48in) + 25lb(28in) + 25lb(20in) = 0$

$M_D = 0 lb.in$

$\sum F_y = 0; 25lb - 25lb - 25lb + 25lb - V_4 = 0$

$V_4 = 0$

Maximum Normal Stress in the shelf occurs at point B and C where there is maximum bending moment present. Therefore, $\sigma_m = \frac{500lb.in}{\frac{(48)(0.5^2)}{6}} = 250 lb/in^2$

The shear and bending moment diagram representing the forces acting on the shelf is shown in Figure 24.

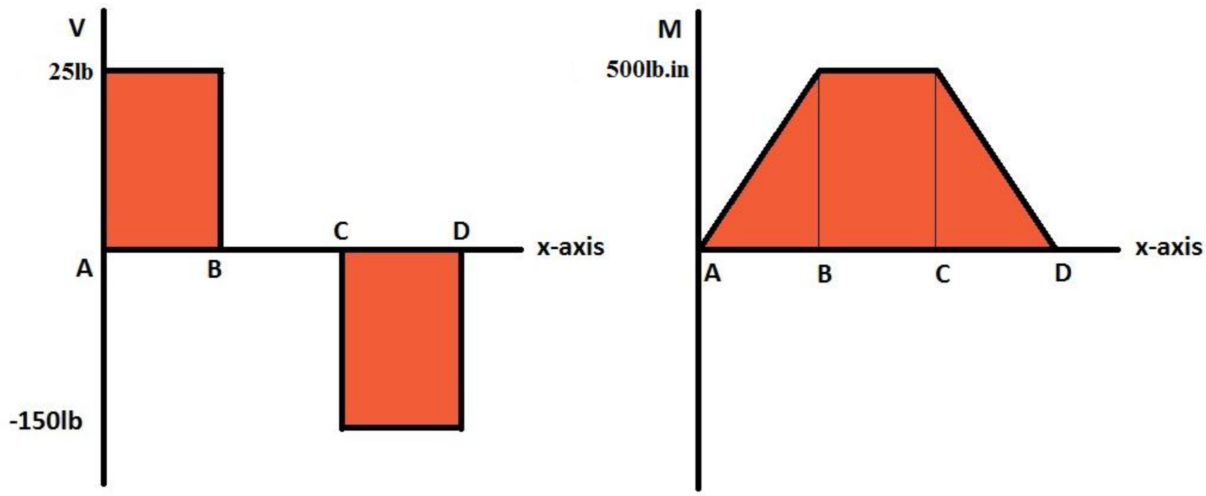

Figure 24: Shear and moment diagram

Determine the Shear Stress acting on the bolt:

A bolt with 0.375in diameter is used to hold the shelf with the post. The shear stress on the bolt is calculated as $\tau = \frac{P}{A}$ where τ is the shear stress, P is the load applied and A is the area of the bolt. Thus, shear stress calculated at on one bolt is $\tau = \frac{25\text{lb}}{(\pi)(0.1875^2)} = 226.35\text{lb/in}^2$

A schematic view of stresses acting on the bolt is shown in figure 24:

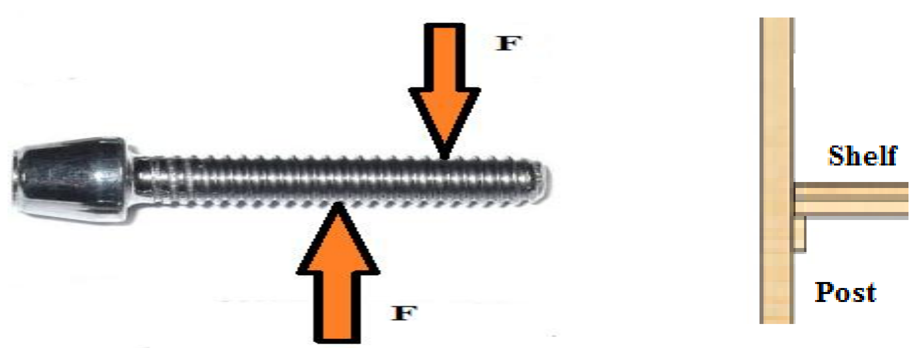

Figure 25: Example of shear force acting on a screw 2D image of shelf support location

Normal force acting on the post:

The normal force acting on the post is calculated as $\sigma_x = P/A$ where P is the load applied on the post and A is the area of the post. It is assumed that the total load applied on the structure is distributed among the four posts. Hence, the load P is found to be 50lb/4 posts = 12.5lb on each post. The area A is $A = 1.5in x 1.5in = 2.25in^2$

The normal force acting on one post is found to be:

Normal Stress ($\boldsymbol{\sigma_x}$) = $\frac{P}{A} = \frac{12.5\ lb}{1.5in\ X\ 1.5in} = 5.55 lb/in^2$

Stress Analysis at the bottom of the beam:

We consider 150lb load applied at bottom shelf of the beam. The stress calculations are shown below.

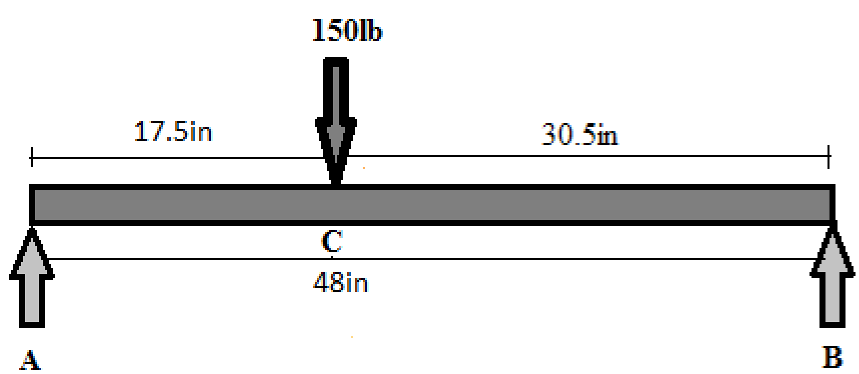

Figure 26: FBD of horizontal beam

Stress acting at the corners of the shelf A_y and B_y is calculated to be:

$$\sum M_A = 0;\ 150\text{lb}(17.5\text{in}) + B_y(48\text{in}) = 0$$

$$\mathbf{B_y = 54.68lb}$$

$$\sum F_y = 0; A_y + B_y - 150\text{lb} = 0$$

$$A_y + 150\text{lb} - 54.68\text{lb} = 0$$

$$\mathbf{A_y = 95.31lb}$$

The Moment is maximum at a point where the load is applied.

$$\sum M_C = 0; -(95.31\text{lb})(17.5\text{in}) + M_C = 0$$

$$\mathbf{M_C = 1668lb.in}$$

Normal stress acting on the bottom beam is

$$\boldsymbol{\sigma = \frac{P}{A} = \frac{150lb}{3inx3in} = 16.67lb/in^2}$$

Appendix 3: Discussion of Manufacturing and Assembly Processes

The manufacturing and assembly processes considered for the project are those that are available within StandardAero since the carts will be manufactured in-house. Currently, StandardAero uses some carts made of standard, construction grade lumber. The lumber is easy to manufacture with and inexpensive to procure. In addition, the loads that will be supported by the cart in service are relatively small. Super strong materials or welds are not required. Therefore, lumber was a clear choice of material.

As for how the cart components are assembled, research was conducted into how the current wood carts are assembled. The team looked at the current PTM cart. Areas of deficiencies, if any, were noted in an attempt to simplify the new design. One example of a deficiency is in the support of the casters. Wooden posts on the PTM cart protrude from the side of the cart causing a possible trip hazard.

Appendix 4: Detailed Cost Analysis

The detailed cost analysis was conducted for all of the structural material required for the CCM cart. The analysis is based on the prices of lumber at Home Depot in Winnipeg. The standard cost for the required lumber is summarized in Table X.

Table X: SUMMARY OF MATERIAL RETAIL COST

Type	Standard Dimensions (in)	Price
Plywood (1/2)	1/2 X 48 X 96	$ 36.22
Plywood (1/8)	1/8 X 48 X 96	$ 16.00
Plywood (1/4)	1/4 X 48 X 96	$ 24.97
Post	3 X 3 X 96	$ 5.40
Post	2 X 2 X 96	$ 4.77
Post	1/2 X 1/2 X 96	$ 2.23

The cost analysis is conducted by first calculating the unit cost of the material. The unit cost is the cost per square inch for sheet material or cost per inch length for post material. Once the unit cost of the material is known, the area or length of required material for each component is calculated. The total cost is calculated by multiplying the unit cost by the amount of material being used. All material cost details are outlined in Table XI to Table XVII.

Table XI: CCM CART STRUCTURE MATERIAL

Item	Material	Length (in)	Width (in)	Area (in^2)
Stabilizing and Support Shelves	Plywood (1/2)	48	24.75	1188
Divider 1	Plywood (1/2)	21.75	11	239.25
Divider 2	Plywood (1/2)	21.75	11.5	250.125
Support Strip	Plywood (1/2)	21.75	1	21.75
Middle Shelf	Plywood (1/2)	32	24.75	792
Small Supporting Elements	Plywood (1/2)	2	1.25	2.5
Large Supporting Elements	Plywood (1/2)	32	24.75	792
Horizontal Posts	Post (3x3)	48	N/A	N/A
Vertical Posts	Post (2x2)	39	N/A	N/A
Side Ledge	Post (1/2x1/2)	21.5	N/A	N/A
Front Ledge	Post (1/2x1/2)	44.75	N/A	N/A
Gussets	Plywood (1/2)	N/A	N/A	39.63
Fixed Casters	N/A	N/A	N/A	N/A
Swivel Casters	N/A	N/A	N/A	N/A

Table XII: CCM CART STRUCTURE COST SUMMARY

Item	Unit Cost	Cost per Part	Quantity	Total Cost
Stabilizing and Support Shelves	$ 0.0079	$ 9.34	4	$ 37.35
Divider 1	$ 0.0079	$ 1.88	1	$ 1.88
Divider 2	$ 0.0079	$ 1.97	1	$ 1.97
Support Strip	$ 0.0079	$ 0.17	1	$ 0.17
Middle Shelf	$ 0.0079	$ 6.23	1	$ 6.23
Small Supporting Elements	$ 0.0079	$ 0.02	2	$ 0.04
Large Supporting Elements	$ 0.0079	$ 6.23	3	$ 18.68
Horizontal Posts	$ 0.0563	$ 2.70	2	$ 5.40
Vertical Posts	$	$ 1.94	4	$ 7.75

	0.0497			
Side Ledge	$ 0.0232	$ 0.50	9	$ 4.49
Front Ledge	$ 0.0232	$ 1.04	6	$ 6.24
Gussets	$ 0.0079	$ 0.31	8	$ 2.49
Fixed Casters	$ 13.6900	$ 13.69	2	$ 27.38
Swivel Casters	$ 21.5500	$ 21.55	2	$ 43.10
		Total for Cart Structure:		**$ 163.17**

Table XIII: ARB COST SUMMARY

Item	Material	Length (in)	Width (in)	Area (in^2)	Unit Cost	Cost per Part	Quantity	Total Cost
End	Plywood (1/2)	18.5	10	185	$ 0.0079	$ 1.45	2	$ 2.91
Side	Plywood (1/2)	14.625	10	146.25	$ 0.0079	$ 1.15	2	$ 2.30
Bottom	Plywood (1/2)	18.5	13.625	252.063	$ 0.0079	$ 1.98	1	$ 1.98
Divider	Plywood (1/8)	18.8	9.5	178.6	$ 0.0035	$ 0.62	9	$ 5.58
					Total for Actuating Ring Box:			**$ 12.77**

Table XIV: ISB COST SUMMARY

Item	Material	Length (in)	Width (in)	Area (in^2)	Unit Cost	Cost per Part	Quantity	Total Cost
End	Plywood (1/2)	12.5	7	87.5	$ 0.0079	$ 0.69	2	$ 1.38
Side	Plywood (1/2)	14.625	7	102.375	$ 0.0079	$ 0.80	2	$ 1.61
Bottom	Plywood (1/2)	12.5	13.625	170.313	$ 0.0079	$ 1.34	1	$ 1.34
Divider	Plywood (1/8)	12.8	6.5	83.2	$ 0.0035	$ 0.29	9	$ 2.60
					Total Cost for Inner Segment Box:			**$ 6.92**

Table XV: SVB COST SUMMARY

Item	Material	Length (in)	Width (in)	Area (in^2)	Unit Cost	Cost per Part	Quantity	Total Cost
End	Plywood (1/2)	15	8	120	$ 0.0079	$ 0.94	2	$ 1.89
Side	Plywood (1/2)	22.875	8	183	$ 0.0079	$ 1.44	2	$ 2.88
Bottom	Plywood (1/2)	21.875	15	328.125	$ 0.0079	$ 2.58	1	$ 2.58
Divider	Plywood (1/8)	15.3	7.5	114.75	$ 0.0035	$ 0.40	15	$ 5.98

					Total Cost for Stationary Vane Box:	**$ 13.32**

Table XVI: MISCELLANEOUS BOX COST SUMMARY

Item	Material	Length (in)	Width (in)	Area (in^2)	Unit Cost	Cost per Part	Quantity	Total Cost
End	Plywood (1/2)	21	3.5	73.5	$ 0.0079	$ 0.58	2	$ 1.16
Side	Plywood (1/2)	25	3.5	87.5	$ 0.0079	$ 0.69	2	$ 1.38
Bottom	Plywood (1/2)	25	20	500	$ 0.0079	$ 3.93	1	$ 3.93
							Total Per Box:	**$ 6.46**

Table XVII: VANE BLADE BOX COST SUMMARY

Item	Material	Length (in)	Width (in)	Area (in^2)	Unit Cost	Cost per Part	Quantity	Total Cost
End	Plywood (1/2)	5.375	4.75	25.5313	$ 0.0079	$ 0.20	2	$ 0.40
Side	Plywood (1/2)	16.75	4.75	79.5625	$ 0.0079	$ 0.63	2	$ 1.25
Bottom	Plywood (1/4)	16.75	4.375	73.2813	$ 0.0054	$ 0.09	1	$ 0.09
Longitudinal Divider	Plywood (1/8)	17.1	4.5	76.95	$ 0.0035	$ 0.27	14	$ 3.74
Transverse Divider	Plywood (1/8)	4.75	4.5	21.375	$ 0.0035	$ 0.07	3	$ 0.22
							Total Cost for Variable Blade Box:	**$ 5.48**

It is important to note that the calculated material cost is only for material used; that is, it is assumed that there is no significant scrap. Additionally, the prices used in the cost analysis are Home Depot Winnipeg retail prices. If many carts are to be constructed, it is possible to obtain a reduced bulk material unit price. Therefore, for this project, the retail price for material used is sufficient in obtaining an approximate cost for material for the CCM cart.

The wood construction simplifies the manufacturing process. It is anticipated that the total build time of the cart and all sub-assemblies will be one and a half, eight hour days for two Journeyman Carpenters. The approximate cost of one Journeyman Carpenter in Manitoba is $24.50/hour [3]. The total cost of labour is summarized in Table XVIII.

Table XVIII: LABOUR COST SUMMARY

Number of Work Days (8 hours/day)	Number of Carpenters	Hours Required per Carpenter	Cost per Hour	Total Cost of Labour
1.5	2	12	$ 24.50	**$ 588.00**

It is important to note that the time to construct a CCM kitting cart is likely to decrease as the technicians gain experience in building the carts. Therefore, the total manufacturing cost is expected to decrease with time.

The total cost for materials and labour for the CCM kitting cart is CDN $824.52. No target cost has been specified by StandardAero.

Appendix 5: Detailed Drawings

The drawings outlined in this section provide all the dimensional details of all cart components. These drawings are provided for reference only.