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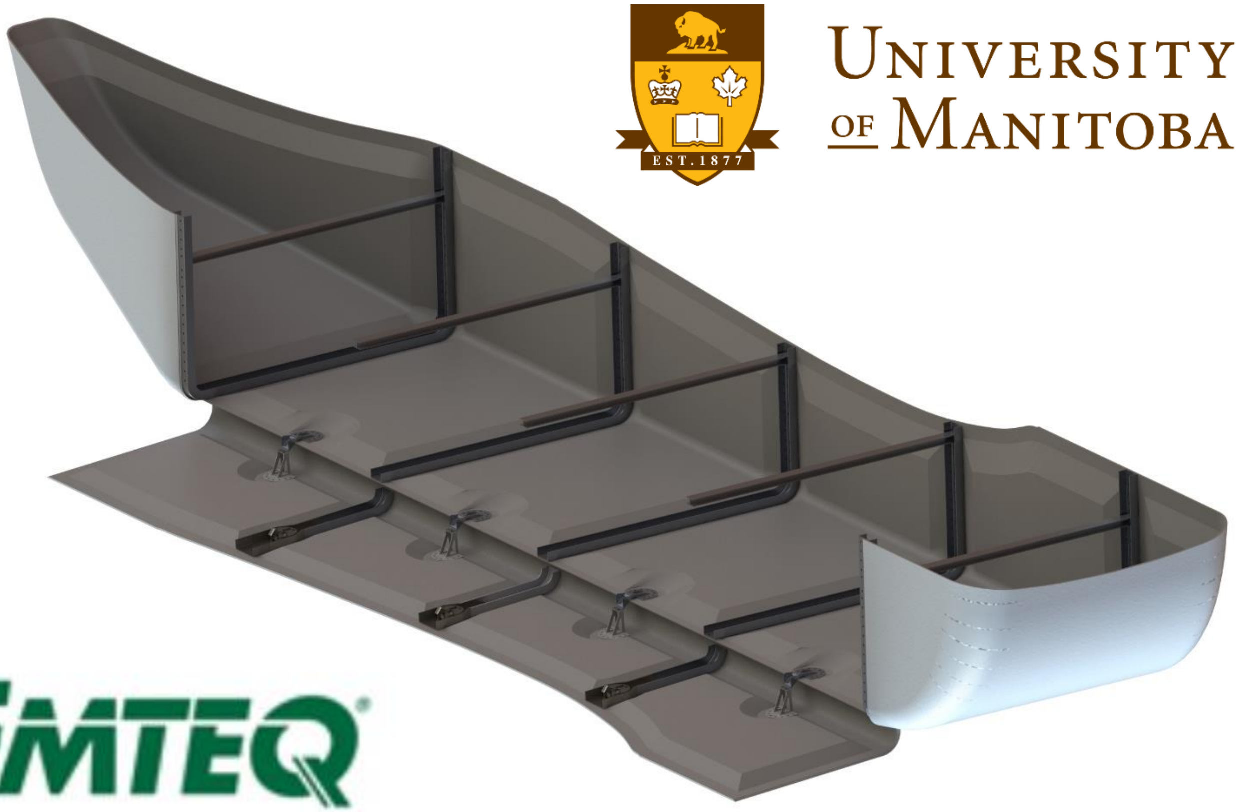

Design of a Cargo Pod for a Pilatus PC-12 by Team #7

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Date Submitted: December 1st 2014

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Subject: Pilatus PC 12 Cargo Pod Design Project

Dear Dr. Paul Labossiere,

Attached is the final report for the design project that was assigned to us on the 10^{th} of September 2014 dealing with the design of a cargo pod for the Pilatus PC 12.

Although initially intended to enable the design of a prototype-ready cargo pod, our scope was refined to only deal with the structure, materials and manufacturing design of this cargo pod. Limitations that were identified included the available attachment area on the aircraft as described by a client provided surface model.

As described in this report, our design solution utilizes a composite and metal construction that enhances both its light weight and strength capabilities, crucial parameters in the aerospace industry. Novel solutions for the hinge and latch mechanisms and for material interactions have been utilized and are discussed in detail. The client defined deliverables are also indicated as are the remaining design steps required to create a prototype of this product.

Thank you, Dear Dr. Paul Labossiere,, for your excellent counsel over the duration of the project. It has helped us to practice and develop our search skills in concept generation, professionalism in dealing with the industry and overall time management. If you have any questions, do not hesitate to contact us at the provided address.

Sincerely,

Mumo Musyoka

Team 7 Delegate

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1 EXECUTIVE SUMMARY

Our client has requested that we formulate the design of a cargo pod intended to be attached to the belly of a Pilatus PC-12 that must fit four hard shell golf bags, per their customer's specification. The pod must have a door on the right side which not only allows for easy loading and unloading of cargo but, must also be removable to allow for attachment of the pod to the aircraft.

The chosen design employs a carbon fiber laminate sandwich structure pod outer shell reinforced with aluminum ribs along its length. The door is an identical carbon fiber laminate sandwich structure reinforced with aluminum ribs in an identical manner. Attached to the door is three latches to hold the door closed, four hinge assemblies to actuate the door, a door jamb allowing for a sealant bead to run along its periphery, and an aluminum channel running along the contact point between the door and the pod's outer shell.

The total cost for this design is $30321.10, well within our budget of $150000 – however by request this total does not include required investments in tooling nor does it attempt to address FAA licensing costs. The pod's weight is 171.4lb, exceeding the suggested maximum of 150lb. Panel deflections are well under an inch in magnitude and a typical safety factor for all components when used as designed is 2.

The attachment mechanism proposed have a generous safety factor of 38 to account for vibration, and eccentric loading, while weighing in at approximate 1.3lb.

2 INTRODUCTION

EMTEQ (now B/E Aerospace) is an engineering and production company operating within the aviation industry. The company offers different products and services as a contractor and also develops and markets innovative solutions of their own. Some of the markets served include air transport, government systems, corporate, VIP and helicopter related markets. Within these markets, EMTEQ specifically engineers and designs products in the following categories: Aerospace structures and interior assemblies, cabin systems, cables and equipment trays, avionics and flight instrumentation, as well as both interior and exterior lighting. Services provided by EMTEQ are integration of system upgrades for a wide variety of aircraft, and certification services for aftermarket aviation systems and products developed by other companies.

EMTEQ is an international company; it has a number of facilities in Canada, United States, Europe and South America, each offering a different array of the products and products mentioned above. EMTEQ's Winnipeg facility (our client) mainly specializes in development and manufacturing of aerospace structures and assemblies, certification, aircraft furnishings, and internal aircraft modifications. EMTEQ Winnipeg's Design and manufacturing capabilities are typically centered in aluminum and aluminum honeycomb sandwich panel construction for its versatility in modern aerospace applications however, more recently the company has begun branching out into design and manufacturing of composite materials for aerospace structures. It is through this expansion in their capability that we, Team 7, have been assigned a contract for developing a cargo pod design for the Pilatus PC-12 aircraft.

The Pilatus PC-12 is a single turboprop powered, mid-size aircraft manufactured by Pilatus Aircraft Ltd. It is designed to be utilitarian, holding between six and nine passengers with varying cargo needs and can be operated by one or two pilots. As a workhorse of companies and organizations ranging from commuter airline companies, freight airlines, air ambulances and numerous national militaries, the PC-12 can be equipped with surveillance equipment, paramedic medical systems, long range communication hardware, or light duty transportation equipment. Fig. 1 below presents a view of the exterior of the aircraft.

FIGURE 1: THE PILATUS PC-12 [1].

Customers of the Pilatus PC-12 have expressed interest in having the ability to store hard shell golf bags external to the onboard cargo hold of the aircraft for use in a Caribbean climate. EMTEQ requires a cargo container large enough to accommodate four golf bags to be mounted on the belly between the wings, front of the main lift flaps, and rear of the front landing gear of the PC-12. EMTEQ has received an inquiry from Pilatus Business

Aviation Limited to provide a proposal for the design and manufacture of a cargo pod with the intended payload being four hard-shell golf bags of a specified size.

The project deliverables are: a 3D model (.IGS format) ready to be made into a prototype, an estimated production cost, an estimated total weight, a complete Bill of Materials(BOM), and a formal report on the design process. The solution needs to be elegant and consistent with the overall design philosophy of the PC-12. Of particular interest is maintaining the PC-12's cruising speed, its ability to take off and land on unimproved runways, and its overall aesthetics.

2.1 PROJECT OBJECTIVES

The purpose of this project is to design an open top cargo pod for the Pilatus PC-12 which can carry four standard sized golf bags and with a budget of 150,000 USD as stated by our client. The cargo pod must protect its contents and cannot be damaged by typical usage or the aerodynamic loads experienced in flight. Attachment of the cargo pod is to be within the outlined area on the belly of the plane; between the wings, front of the main lift flaps, and rear of the front landing gear. Attachment and detachment of the cargo pod is to be quick and easy since EMTEQ's customer would like flexibility in the use of their aircraft. As such the method and procedure of attachment is to be easy and safe for the user as well as ensure safe attachment of the cargo pod to the aircraft.

In addition to these basic requirements we must strive to mitigate the negative effects of the cargo pod's placement on the aircraft's performance. Customers of the PC-12 will expect performance to be virtually unimpacted and as such careful attention will be paid to the pod's overall weight; similarly, the loaded and unloaded weights and the cargo load placement within the pod will be essential in ensuring that the plane's dynamic balance is maintained.

The team intends to design a cargo pod which is as light as possible, as weight is a key characteristic of flight performance. Though we are not expected to quantify the effect of the pod on the PC-12's performance, we will set out to minimize the expected impact though this easily quantified variable. Illustrated on the following page is a preliminary drawing showing the rough shape and dimensions of the pod.

A design that is easily maintained and cleaned is attractive because it helps improve the longevity of the pod. The buyer intends to operate the pods for the lifetime of their aircraft and as such we intend to design the pod such that it is easily cleaned and maintained.

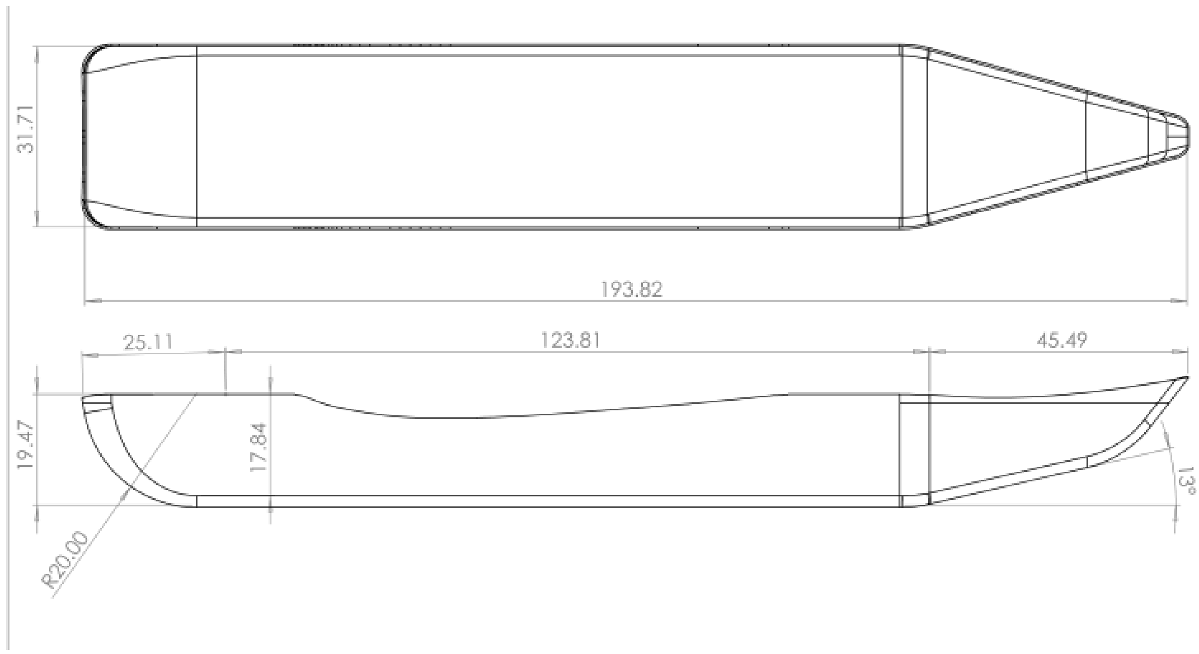

FIGURE 2: DIMENSIONED DRAWING INDICATING A PROFILE OF THE CARGO POD'S SHAPE, PROVIDED BY EMTEQ.

2.2 NEEDS AND SPECIFICATIONS

The following table presents the client needs that we identified and they have been adjusted to include the most current requirements and changes that the client has communicated, as they were several changes made through the course of this exercise. The left column indicates the needs number, the following column describes each need in concise terms, and the rightmost column indicates what impact the need has to the project as a whole. This impact or priority is on a scale of 1-5 with ‘5’ indicating a high impact and ‘1’ indicating a low impact.

TABLE I: UPDATED CLIENT NEEDS

Needs #	Needs	Impact
1	The cargo pod provides sufficient space to fit four standard-size hard-shell golf bags	5
2	The cargo pod provides easy access to the cargo	4
3	The cargo pod utilizes the specified existing mounting points on the aircraft	4
4	The cargo pod's access door is to be located on the right hand side of the aircraft	5
5	The cargo pod ensures golf bags and other cargo are not damaged during the flight	4
6	The maximum cost of the cargo pod is within a given limit	5
7	The cargo pod is as lightweight as possible	4
8	The cargo pod's impact on the aircraft's performance is minimal	5
9	The cargo pod's impact on the aircraft's take off and landing capabilities is nonexistent	5
10	The cargo pod is easy to attach and detach	5
11	The cargo pod volume does not require pressurization.	5
12	The cargo pod protects cargo from moisture ingress	4
13	The cargo pod is easy to use(cargo storage and removal, attachment/detachment)	4
14	The cargo pod's exterior smoothly blends into the belly of the plane	4
15	The cargo pod stays attached to the plane while in flight	5
16	The cargo pod is durable and has long life	3
17	The cargo pod's interior is easy to clean	3
18	The cargo pod does not impact the ground as the aircraft moves on ground	5
19	The cargo pod does not impact the ground during takeoff or landing	5
20	The cargo pod safely drains any moisture trapped within it	2
21	The cargo pod's exterior design fits in with the aesthetics of the PC-12	4
22	The cargo pod's access door is sealed from moisture	5
23	The cargo pod withstands aerodynamic loads during flight	5
24	The cargo pod does not interfere with normal operation of control surfaces	5
25	The cargo pod does not interfere with the normal operation of flaps	5
26	The cargo pod is to be manufactured using materials within EMTEQ's manufacturing capabilities	4
27	The cargo pod is to meet the related safety standards	5
28	The cargo pod does not interfere with aircraft equipment located within and around the attachment region	3
29	A safe attachment procedure for cargo pod attachment is to be designed	4
30	Attachment tools needed for attaching the cargo pod are to be identified/designed	4

These basic customer needs were arrived at through careful review of client consultation proceedings followed by team brainstorming and categorization of associated needs. Following this process we came up with a hierarchy of needs as seen on the following page.

The intent is to categorize needs by correlating each need to a common theme or overarching needs group.

The cargo pod is within budget

- The cargo pod is easy to manufacture
- The cargo pod is to be manufactured using materials within EMTEQ's manufacturing capabilities
- The maximum cost of the cargo pod is within a given limit.

The cargo pod is easy to use

- The cargo pod is easy to attach and detach.
- The cargo pod provides easy access to the cargo
- The cargo pod's access door is to be located on the right hand side of the aircraft.
- The cargo pod provides sufficient space to fit four standard-size hard-shell golf bags
- Attachment tools needed for attaching the cargo pod are to be identified/designed
- The cargo pod is durable and has long life

The cargo pod is safe to use

- The cargo pod is to meet the related safety standards
- A safe attachment procedure for cargo pod attachment is to be designed
- The cargo pod withstands aerodynamic loads during flight(indirect)

The cargo pod protects the cargo

- The cargo pod protects cargo from moisture ingress
- The cargo pod's interior is easy to clean

- The cargo pod ensures golf bags and other cargo is not damaged during the flight.
- The cargo pod safely drains any moisture trapped within it
- The cargo pod's access door prevents moisture ingress
- The cargo pod does not impact the ground as the aircraft moves on ground
- The cargo pod stays attached to the plane while in flight

The cargo pod's impact on aircraft performance is minimal

- The cargo pod does not interfere with operation of flaps
- The cargo pod does not impact the ground during takeoff or landing
- The cargo pod's impact on the aircraft's take-off and landing capabilities is nonexistent.
- The cargo pod is as lightweight as possible.

The cargo pod does not interfere with existing systems and aesthetics of the plane

- The cargo pod's exterior smoothly blends into the belly of the plane
- The cargo pod does not interfere with equipment located within its attachment area
- The cargo pod's exterior design fits in with the aesthetics of the PC-12
- The cargo pod utilizes existing mounting points on the aircraft.

In order to quantify our design's success in meeting the client's needs, we identified all the metrics necessary for this needs analysis. Table II below presents these metrics: the first column lists each of the metrics, the second column shows which needs are covered by the specific metric, a concise description of the metric is provided in the third column, and the fourth shows the impact that the metric has to the overall design. Finally the fifth column indicates the preliminary target specifications that we set out to meet at the beginning of the project. Most of the metrics are defined quantitatively and the remaining few can be evaluated qualitatively.

TABLE II: PROJECT METRICS

Metric #	Need #s	Metric definition	Impact	Units	Target
1	7	Overall weight	5	lbs	150
2	1,2	Total useable volume	5	cu.ft	45
3	1,2,	Maximum depth within the pod	4	in	18
4	1,2,	Maximum length of the cargo pod	4	ft	16-17ft
5	2,4	Ease of access to cargo	4	ea/min	10 min
6	8,	Total drag	2	lbs	N/A
7	10	Time required to attach	5	min	10
8	10	Time required to detach	4	min	10
9	2,13,15	Ease of use	4	subj	
10	6	Overall unit cost	5	USD	150,000
11	6	Estimate of manufacturing and assembly cost	5	USD	< 90,000
12	3, 16	Strength of the attachment system	5	psi	FOS=3
13	24	Maximum deflection of exterior skin	4	in.	~1"
	24	Maximum stress experienced by skin and underlying structure	5	psi	$0.8*\sigma_{yld}$
14	24	Maximum stress experienced within the frame	5	psi	$0.8*\sigma_{yld}$
15		Maximum stress experienced at attachment location		psi	$0.9*\sigma_{yld}$
16		Maximum stress experienced within door frame		psi	$0.8*\sigma_{yld}$
17	4,14, 22	Conformity to plane aesthetics		subj	
18	6	Assembly complexity		Part count	150
		Manufacturing process simplicity		Subj	

		Number of different materials		Integer	6
19	19,20	Horizontal ground clearance		in	18
20	20	Minimum tail end draft for takeoff clearance		degrees	13˚
21	8	Decrease in cruising speed		kts	20 kts
22	7	Empty weight of cargo pod		lbs	150
23	27	Pod and attachment meets all relevant safety standards		Yes/No	Yes
24	11	Power or resources needed for cargo pod use(ideally zero)		hp, psi,	0
25	12,23	Moisture permeability		Subj	Minimal
26	21	Drains any accumulated fluid		Yes/No	Yes

2.3 CONCEPTS

The team produced a number of concepts for different systems on the cargo pod, following the valuation of the performance characteristics previously discussed weighted both with our client and internally; we have arrived at a design which best meets the client's needs and we have provided a detailed conceptual design report as an appendix.

3 DETAIL OF DESIGN

3.1 OVERVIEW OF DESIGN

This section covers a brief overview of the overall design of the cargo pod, depicted below.

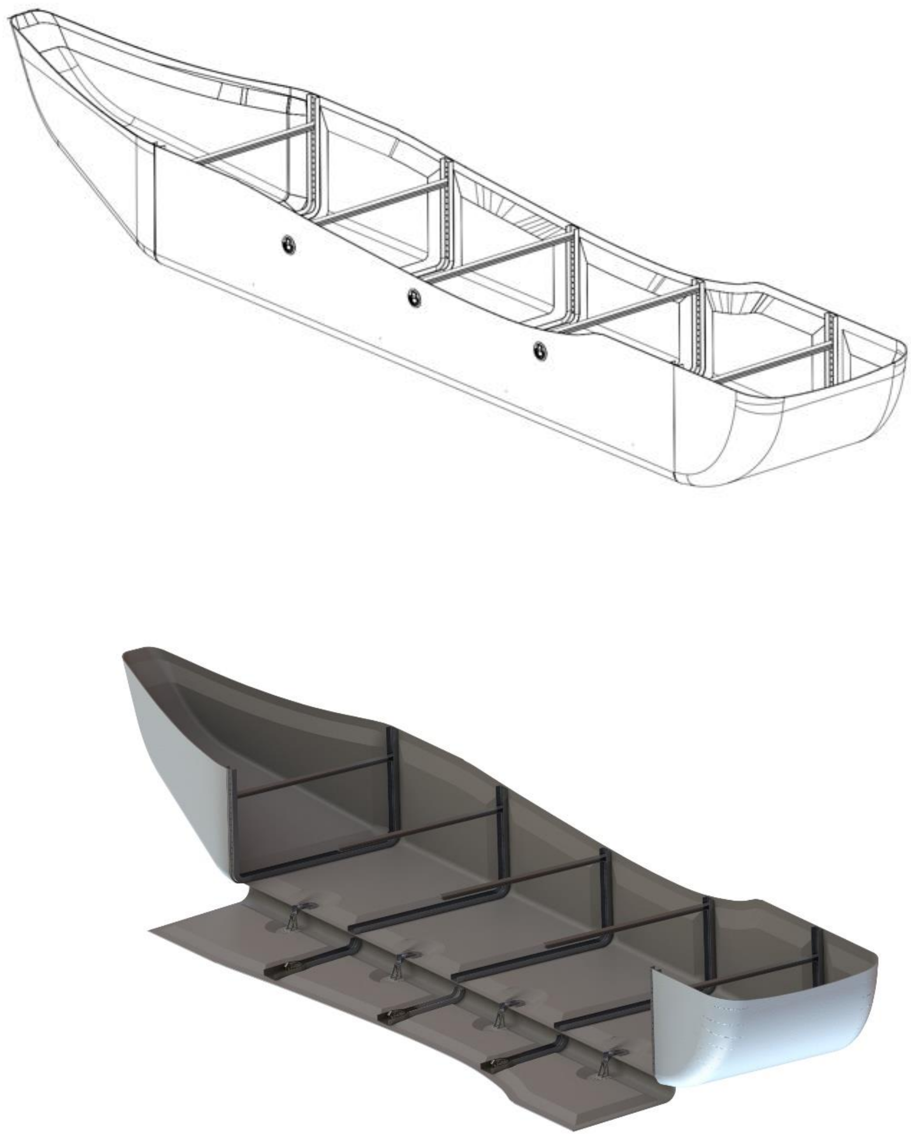

FIGURE 3 CARGO POD OVERVIEW

The pod outer mold line (OML) is defined by the STEP file provided by EMTEQ in the initial stage of the project, further from that there is a full length door along the right side of the pod (defined as the right side of the pilot when flying the plane). The outer surface of the pod is a carbon composite sandwich structure reinforced with aluminum ribs, these ribs are bolted to the outer surface with 668 12-24 countersunk Flat Socket Head Cap Screws. The ribs are then attached to mounting hardware (beyond the scope of this report), which finally attaches to the plane with assorted attachment points which interface with the primary wing ribs on the fuselage of the aircraft.

The door is primarily a CFRP sandwich structure, reinforced with ribs in the same way as the cargo pod as a whole, however these ribs also accommodate the Southco M1-25-41-28 heavy duty latch which interfaces with the ribs to hold the door shut during flight. The door seals against the main body of the pod with a chamfered door jamb which is sealed with a low profile silicone sealant bead along its periphery. In addition, where the door contacts the pod during opening there is an aluminum angle channel running along its length to improve wear resilience.

The door is actuated by four discrete hinge assemblies. The hinge assemblies are all identical, using two cantilevers (one mounted to the door and one mounted to the main body of the pod) and a floating arm suspended between the two cantilevers with a hinge at either end. The hinges are designed to be easily accessed and taken apart – to aid in assembly and disassembly of the pod, as the door will have to be removed to attach or detach the pod.

The pod is attached to the plane through four attachment points, interfacing with the main and rear wing ribs. These attachment points are designed to be mounted using a single shearing bolt as the main load bearing structure.

3.2 MATERIALS

This section covers the material used in the cargo pod. Materials employed in the cargo pod are numerous as the components of the cargo pod have diverse performance requirements; that said, the primary constituents of the cargo pod are Aluminum 6061-T6 and Carbon Fiber Reinforced Polymer (CFRP). Details of material selection for design purposes can be found in subsequent sections.

- The outer skin is a laminated CFRP sandwich structure
- The ribs are extruded Aluminum 6061-T6
- The hinge assembly is entirely machined Aluminum 6061-T6
- The attachment points are made from machined Aluminum 7075-T6
- The door-pod interface is extruded Aluminum 6061-T6
- The latch and latch adapter assembly is Aluminum 6061-T6

3.2.1 ALUMINUM

Aluminum alloy is a lightweight, silvery, soft and ductile alloy. It is the ideal material for use in the aircraft industry because of the metal's low density and comparatively high yield strength relative to other metal of this density. Aluminum is also touted in the aerospace industry for its ability to resist corrosion due to passivation. While pure aluminum will tend to have a yield strength of 7-11 MPa, aluminum alloy can range from 200 – 600 MPa. There are several grade of aluminum ranging from 2xxx, 3xxx, 5xxx, 6xxx, and 7xxx series [2]. For the design of our cargo pod we are most interested in using 6061-T6 and 7075-T6 alloys.

3.2.1.1 6061-T6 ALLOY

6061-T6 alloy is commonly used in aircraft structures such was wings and fuselages. The advantage of using this alloy is that it is easily machined and retains Aluminums characteristic resilience to corrosion. The yield strength is rated for at least 35 ksi, however it is possible to obtain a yield as high as 45 ksi in certain permutations of the formulation [2].

3.2.1.1.1 6061-T6 ALLOY IMPACT TESTING

An experiment was done on 6061-T6 aluminum alloy to analyze the ductility of aluminum alloying by using impact testing. This experiment involves to be prepared at certain temperature range and put under an impact testing device. This also shows us the behavior of the material under different temperature range.

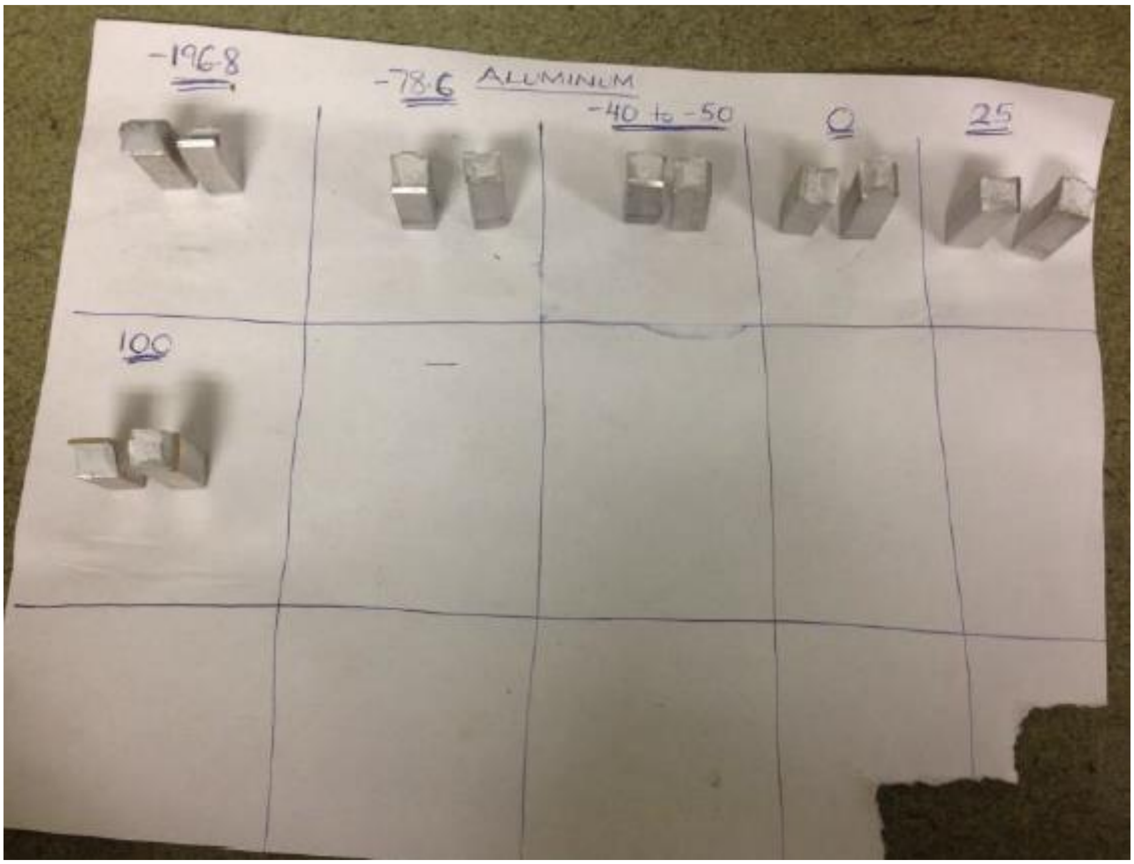

FIGURE 4: SPECIMEN AFTER IMPACT TESTING.

The results we obtain is shown in a graph in figure 4 below based on the specimen in figure 3. It an experimental C_v-T plot of aluminum on impact testing on aluminum.

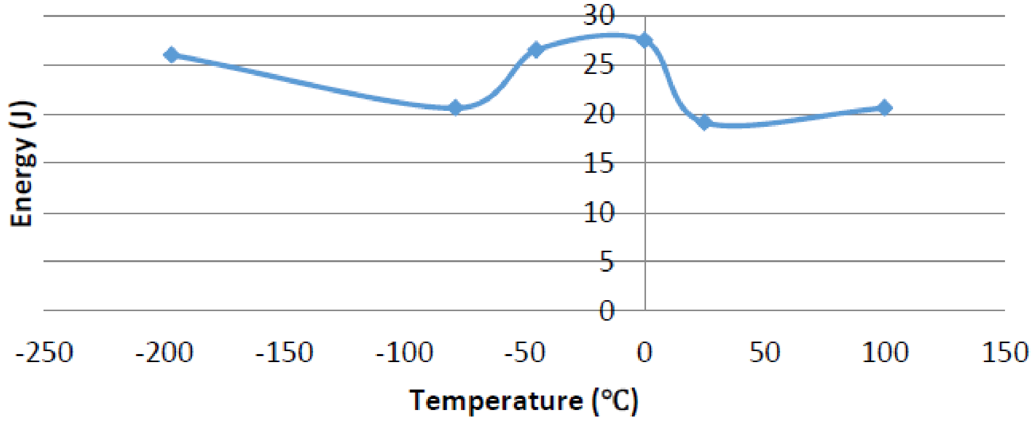

FIGURE 5: E-T PLOT FOR ALUMINUM ALLOY 6061-T6.

The above figure shows that the material is most ductile at a temperature range of -50 – 0°C, however this change is only a small difference compared to other temperature range. What this also means is that we can expect more consistency in ductility over a broad temperature range.

3.2.1.2 7075-T6 ALLOY

Like 6061-T6 alloy, 7075-T6 alloy is commonly used in the aerospace industry, however what sets it aside from 6061-T6 alloy is that 7075-T6 alloy has a higher strength than 6061-T6. Its strength is comparable to 4130 steel. Typically, its yield strength ranges from 63-70 ksi and has a failure elongation of 5 – 11%. However, this additional strength comes at a cost of corrosion resilience; 7075-T6 has inferior corrosion resistance compared to other aluminum alloy and, is typically much more expensive compared to 6061-T6.

3.2.1.3 PURPOSE OF USING TWO DIFFERENT ALUMINUM ALLOYS

Every alloy presents unique advantages and disadvantages. For the purposes of supporting the aerodynamic loads and holding the door onto the pod it is reasonable to use a lower grade alloy as these structures carry less weight. The attachment points use a more robust alloy simply because they are designed to carry the entire weight of the cargo pod. The additional cost of the 7075-T6 alloy is well justified for a structure that can under no circumstances fail while the pod is attached to a plane.

3.2.2 CARBON FIBER REINFORCED POLYMER MATRIX

Epoxy resin matrixes are used when high rigidity with low ductility is desirable, especially when used in combination with carbon fiber. Epoxy resins bind well with numerous different matrix additives such as plasticisers, lubricants, fire retardants, supplementary reinforcements and numerous others [2]. In addition, Epoxy resins are very well established in similar projects from other aerospace companies and therefore detailed information on stress/strain allowable are readily available for furthering the detailed design process.

Carbon Fiber reinforcement was chosen for its excellent tensile properties. Hexcel claims an average 59% fiber volume fraction while maintaining an excellent bond between the fibers and the matrix [3]. This high fiber volume fraction combined with a plain weave (depicted below) allows for very uniform properties in both warp (continuous) and weft (90^0 from continuous) directions.

Sourcing carbon fiber for the panelling is important to consider at every step of the design process because due to the current state of laminate production hundreds of combinations of fiber weaves, resin formulations, resin additives and thus, properties of the final product are available to us. For this reason, and by the lack of finality inherited in our project we have decided to employ a very standard and utilitarian weave and resin combination. Our client has provisionally approved Hexcel G793-5HS Woven CFRP for preliminary estimation purposes.

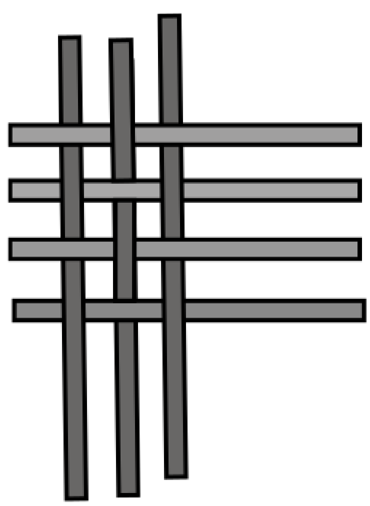

FIGURE 6 PLAIN WEAVE PATTERN [4]

3.2.2.1 CARBON FIBER LAMINATE DESIGN

By their nature, carbon fiber reinforced composite materials have greater strength along the axis of the reinforcements and comparatively lower strength under out of plane and off-axis loading. This vulnerability can be ameliorated somewhat by configuring the individual plies of the laminate structure. Reinforcement directions are denoted in a plain weave as (0/90) and (-45/+45) typically, however other angles are occasionally used in very specific applications [5]. Fiber reinforced composites have the unique ability to address reinforcement directly where it is needed, for instance under tensile loading the reinforcement can run lengthwise allowing the fibers to directly carry the tensile load. Under shear loading where a 45^0 slip plane is suspected, reinforcement can be placed perpendicular to this slip plane, thus improving the material's resilience in shear loading.

Combining different weaves can result in more uniform laminate properties, and as such it is often desirable to stagger plies in a laminate stack-up by orientation. It is possible just with a stack-up with a particular lay-up pattern to replicate the stochastic crystalline slip planes observed in metals by evenly distributing different orientation weaves; the following figure depicts the difference between two common laminate stack ups.

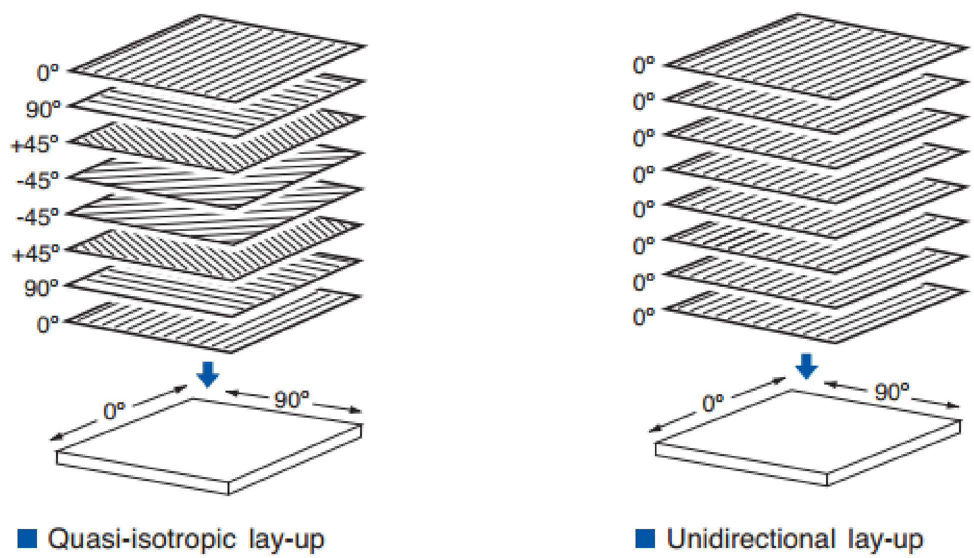

FIGURE 7 LAMINATE PLY ORIENTATION STACKUPS [3]

The advantages of a quasi-isotropic lay-up are fairly self-explanatory, this configuration of laminate plies is used to best suit the resulting laminate structure to loading in any direction, with an isotropy normally reserved for metals. It is worth noting that with all composite stack-ups the weakness is typically found in out of plane shearing, that is, shear loads that cause delamination between lamina. Isotropic layups are balanced over an axis of symmetry, serving both to reciprocate the properties of the plies on the other side of the axis of symmetry but, also has the effect of limiting post-cure deformation.

3.2.2.2 POST LAYUP DEFORMATION

Post-cure deformation (spring-back) is a concern in many composite structures, it is defined as the deviation of the laid up structure from the tool it was laid up upon to its shape after being de-tooled. This post cure effect can be minimized by ensuring that the thermal expansion coefficient is reciprocated throughout the layup.

For example, if one pre-preg lamina is known to have a post cure deflection causing an upward concavity, it is reasonable to assume that if an identical pre-preg lamina is flipped along the long or wide axis and then adhered to the top that this concavity would be eliminated. Tracking the ‘up’ and ‘down’ side of individual lamina in the lay-up will help reduce post cure deformation, however weave deviation in the lamina will still cause some extraneous deformation after cure, affecting the tolerances the process is capable of [6].

3.2.2.3 SACRIFICIAL PLIES

Sacrificial plies will be used wherever fairing is required in order to smooth the surface of the pod. Sacrificial plies are defined as plies that do not contribute to the structural strength of the pod and therefore do not need to follow the splicing guidelines. Sacrificial plies can also be defined as zones in the laminate structure that are being machined away to fit matching regions of the pod together (for example, the door jamb).

3.2.3 FIBERGLASS

Fiberglass will be used to isolate carbon from aluminum and steel, as carbon acts as a dissimilar metal between these two metals [2]. When two dissimilar metals are mated together galvanic corrosion will occur, the production of salt in the ‘battery’ will greatly deteriorate the lifetime strength of both the carbon and metal portions of the pod.

Separating CFRP from metal parts can be done both pre-cure (by using fibreglass atop the CFRP stack up where contact is expected before putting the part in for cure) and post-cure (using fibreglass shims between the CFRP structure and the metallic part). Fiberglass used to separate carbon fiber from metallic parts should be considered sacrificial plies and not part of the structural group.

3.2.4 NOMEX

Nomex composite material will be employed in the form of honeycomb core to separate carbon fiber laminate skins in order to improve their resilience under flexural loading. Nomex core is a series of flat sheets of plain weave Nomex reinforced polymer bonded together along strips such that the neighboring sheets form a honeycomb shape when expanded to their full cell width. This formation of core creates a large surface area for the resin matrix to bond to during cure and will ensure that the resulting panel is cohesive and effectively transfers shear load from the skin to the core [3].

For the purposes of reinforcing and separating the carbon fiber skins we have chosen a 1” thick Nomex core manufactured by Hexcel, called Hexcel HRH10 Nomex 0.125". The nominal cell thickness of this core is 0.125” and it weighs approximately 4 lb/cu.ft.

3.2.5 COMPOSITE PROCESSING

The following subsection addresses composite processing, particularly as it applies to composite sandwich structures formed in a mold. The lamina in a CFRP sandwich structure must be cut from the material roll, laid up on the tool in conjunction with the chosen core, compacted, cured in an autoclave or oven and, finally trimmed to fit the geometry of the final part.

3.2.5.1 CLOTH CUTTING

Cloth cutting is the process in which uncured prepreg CFRP is unrolled and cut to shape for the ply geometries dictated in the laminate schedule [5]. Typically cloth cutting is done either by hand or with NC cloth cutters.

Cloth cutting is a limiting process. Prepreg must be bought in rolls and these rolls are typically of limited width, especially for parts as large as the cargo pod. In addition, the draping of these plies is limited by geometry, contoured radiuses are not accurately described by their surface area and as such must be cut with allowances for weave deviation and unpredictable stretching.

3.2.5.2 LAY UP

Lay-up is the action of laminating individual plies first onto the tool itself and then atop one another sequentially. Ensuring a cohesive bond between subsequent plies during layup has a dramatic effect on the properties of the manufactured part, since load transfer between lamina is only as good as the adhesion between these lamina.

Individual uncured lamina are easily deformed when pulled during lay-up, which can cause deviations both in weave alignment and the actual location of ply edges. These misalignments should be accounted for in design with the safety factor.

3.2.5.2.1 DETOOLING AND SURFACE FINISH CONSIDERATIONS

The surface finish of a composite part is primarily determined by the quality of the tool upon which the part is laid up. The tool surface should be smooth and clear of debris and any contaminants that will detract from the quality of the matrix, or the interlaminar bonding of adjacent lamina [6].

Typically a release agent is employed to prevent the part from adhering itself to the tool, since most polymer matrix materials do not distinguish between reinforcement fibers and the surface of the tool. Release agents will also extend tool life when used correctly, however they may be imprinted onto the part which must be considered in post processing of the part.

3.2.5.2.2 SPLICING

Splicing is when a ply either was not or could not be cut large enough to cover the entire intended area. Splicing plies is necessary on large parts but, should be avoided whenever possible. A small overlap is recommended to ensure adequate load transfer between reinforcement fibers in the spliced zone, exact quantification of this overlap is beyond the scope of this report, however a staggered splice of approximately one inch is recommended [6].

3.2.5.2.3 COMPACTION

Compaction is an intermediate step in the layup of a composite panel and is used in supplement when it is suspected that simply stacking the laminate plies, vacuuming the part and curing it will produce a part with excessive porosity or inadequate interlaminar bonds. The intent of compaction is to promote bonding between the layers by removing the air gap between stacked plies and exposing the resin from neighboring plies to one another. In addition, effective compaction will improve the mechanical properties of a panel due to the lower incidence of porosity. A part should be compacted before it is put in the autoclave to ensure that the part will not be crushed by autoclave pressure [5].

Compaction requires a diaphragm (typically plastic film), a non-stick parting film between the diaphragm and the part and air media between the non-stick parting film and the diaphragm. In addition to these basic building blocks a compaction process will require a sealant bead along the perimeter of the part (typically some distance from the edgeband of the part), at least one valve where the vacuum supply is applied, and core edge supports where required.

3.2.5.3 CURE

In order for the epoxy resin matrix to harden it must be cured. Hexcel has dictated a required cure cycle recommended to obtain optimal properties. Cure will require an autoclave for the resin matrix chosen for the cargo pod. Cure monitoring is very necessary, transducers will be required to monitor temperature on the part to ensure that exothermic reactions do not exceed the temperatures suggested by Hexcel. The exothermic reaction requires heat to be effectively evacuated from the laminate and therefore it stands to reason that thick laminates will tend to heat up excessively due to their higher volume to surface area ratio and the ramp rate of the temperature in the autoclave should be adjusted such that the actual ramp rate of the part does not exceed recommended levels.

3.2.5.4 TRIM

Trimming is a process in which the part as it emerges from the autoclave is trimmed such that it can be handled by technicians and such that it will fit as designed into the cargo pod assembly.

3.2.6 COMPOSITE SANDWICH PANEL DESIGN

This section will cover design guidelines of a simplified, flat plate composite sandwich panel. Expected features on a composite sandwich panel include the cored section, the laminate section, the core-to-edgeband transition, and the edgeband. Sandwich panels typically consist of a skin on either side of the 'core' of the panel. This core serves to both separate the skins of the panel (increasing the inertia of the panel to normal loading) and to incur shear loading in its own right.

The following figure serves as an illustration of the parts of a 'sandwich panel', by definition.

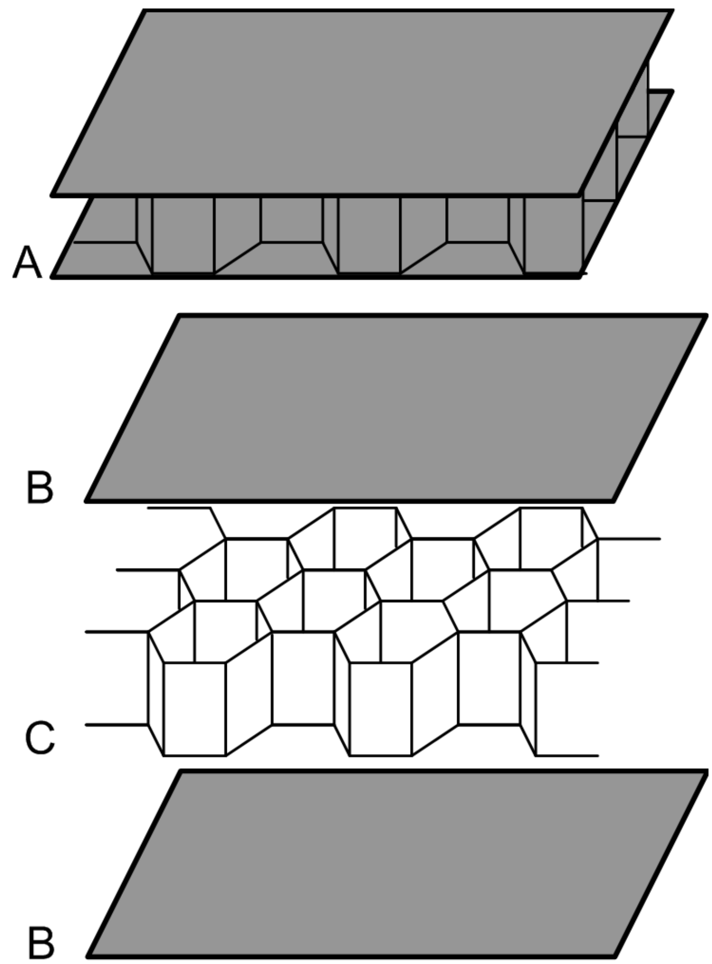

FIGURE 8 CORED PANEL SCHEMATIC [7]

The above schematic does not reflect how a sandwich structure is used under real applications, however. For illustration, see the following figure depicting the interior of the door panel of the cargo pod.

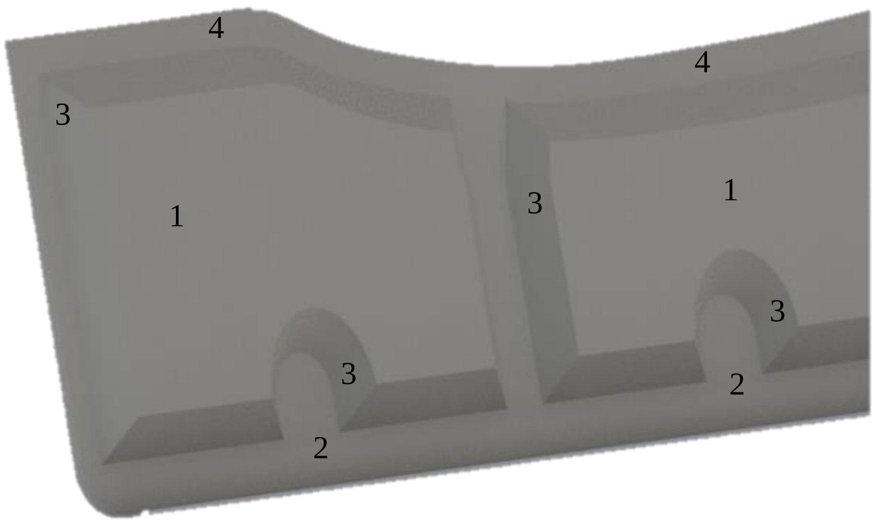

FIGURE 9 CARGO POD DOOR PANEL

TABLE 3 LEGEND

Section	Name
1	Cored Section
2	Laminate Section
3	Core-to-Edgeband Transition
4	Edgeband
5	Tool Side
6	Diaphragm Side

3.2.6.1 CORED SECTION

The cored section of a panel should constitute the majority of its area, as the cored section is considerably more robust than a comparable laminate stackup which does not contain core [3]. The cored section is defined as the area containing full thickness, flat or match contoured core. The cored section is where the panel derives its excellent flexure properties and as such should be present wherever bending loads are expected to be high. Cored sections are not well suited for fastener placement as the core (and therefore most of the height of the panel) does not effectively transfer load to/from the fastener grip.

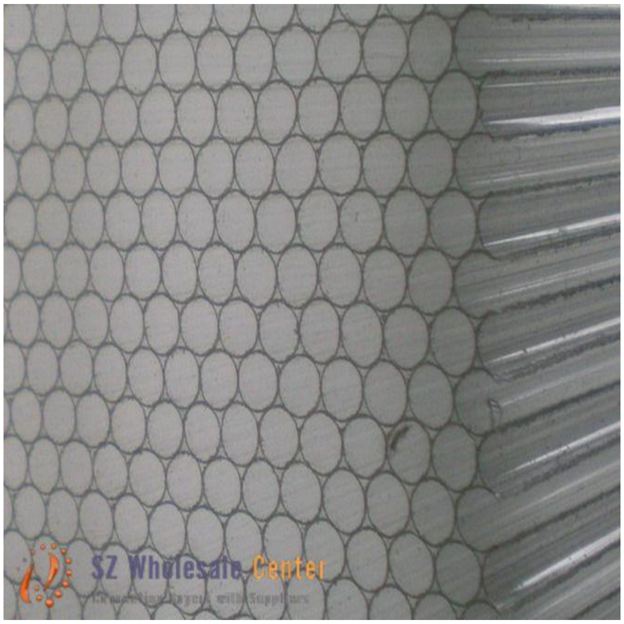

FIGURE 10 NEARLY ISOTROPIC CORE [8]

Core materials can be nearly isotropic or very anisotropic by nature. The core depicted in the above figure is nearly isotropic in both planar bending axis, and the manufacturer states that it has nearly uniform properties in these two axis [8]. This type of core is ideal in theory because it performs similarly to both lengthwise and widthwise flexure however, this core is challenging to work with because it is difficult to form without a weak bending axis (and is therefore best suited to flat paneling), and it is comparatively expensive.

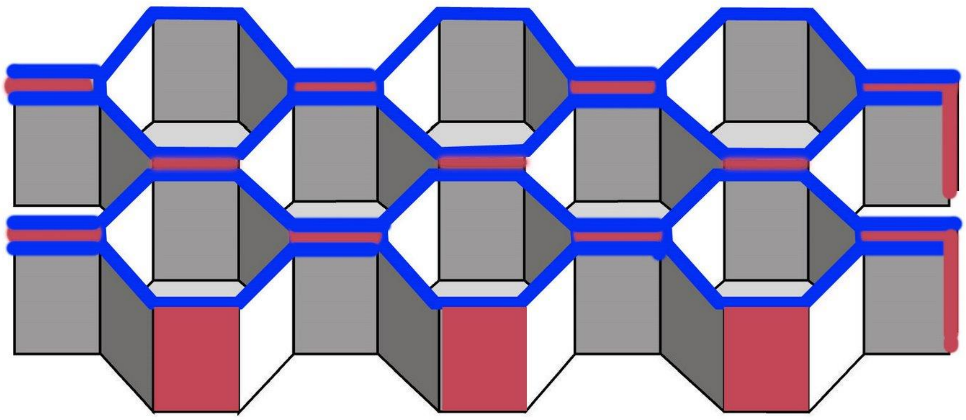

FIGURE 11 ANISOTRPIC HONEYCOMB CORE [9]

A more typical form of core material is depicted above. This type of core is made by bonding sheets of material to one another in the areas depicted as red. This shape is clearly anisotropic, the material is oriented such that it will offer a great deal of resistance in either lengthwise or widthwise directions (depending on its orientation relative to the panel dimensions) but, not both. For the purposes of a long panel under uniform loading it is best practice to align the ribbons (blue) with the longest dimension.

3.2.6.2 LAMINATE SECTION

The laminate section of a panel is outside of the cored and core-to-edgeband transition sections, it is characterized by the fact that no core is present. Laminate sections are typically present where mating features are to be attached to the panel, as is the case for the hinge and rib attachment points on the previous figure depicting the door panel. Laminate sections are better suited for fastener placement as the full thickness of the section will transfer load to the fastener grip. In order to help ameliorate the comparative loss of stiffness in laminate sections, these areas are reinforced with ribs in the cargo pod.

3.2.6.3 CORE-TO-EDGEBAND TRANSITION

The core-to-edgeband transition is the region bridging the gap between the cored section and the laminate or edgeband sections. The core to edgeband transition contains a number of important features including the core edge radius where the core gradually transitions between the laminate section and the chamfered core section. This chamfer is present to minimize the effect of lateral core crush on the panel while the laminate skins aren't viscous enough to stabilize the core. If the core was simply cut square the panel would certainly fail under vacuum, let alone autoclave pressure [6]. Additionally, sudden thickness changes are prone to stress concentrations.

3.2.6.4 EDGEBAND

The edgeband of a composite panel is the outer-most portion of the panel; in most cases the edgeband is a laminate structure. The edgeband of a panel is the most commonly used mating surface; it is the surface which will be drilled to accommodate bolts and machined to match neighboring panels. A typical sandwich panel will be made larger than required, and include a significant amount of extra material along the edgeband to allow for trimming.

The edgeband serves an additional role in manufacturing as it provides additional surface area where the laminate skins can be pushed down by diaphragm pressure. Assuming the laminate plies were laid up properly this region will be clamped down by the diaphragm pressure before the core of the panel can crush laterally, thus ensuring that the panel comes out of cure with the core intact and functioning as intended. The edgeband should be made as large as is feasible without causing an inordinate increase in tooling, material and labor costs [6].

3.2.6.5 TOOL SIDE

The tool side of a composite panel is the side that is pressed against the mold, whether the mold is male or female (not depicted). The tool side is smoother and more uniform than the bag side of the part. The cargo pod's tool side is the outer surface, this was chosen due to EMTEQ's expectation that the outer surface be smooth and have minimal drag.

3.2.6.6 DIAPHRAGM SIDE

The bag side of a composite panel is the side that is only pressed against the diaphragm, it is characteristically less smooth and uniform than the tool side as the still viscous resin does not have a flat, uniform surface to be compressed against during cure. Bag side surfaces are characterized by a dappled appearance which makes them well suited to post-process bonding however, poorly suited for aerodynamics.

3.3 ATTACHMENT MECHANISM

The attachment mechanism consists of a rear attachment assembly and a front attachment assembly. The rear attachment assembly consists of two parts, one attached to the cargo pod and the other attached to the aircraft. When the pod is lifted into position to the attachment, a bolt is put into its place and locked using a fastener the idea is based mostly on ease of manufacturing and cost, which also implies that the design itself is quite simple. A finite element analysis is performed on both parts. The front attachment works the same way as the rear attachment.

3.3.1 REAR ATTACHMENT MECHANISM

We came up with various ideas for the cargo pod attachment part during the concept development. We decided to choose the pin attachment method due to its manufacturability and simplicity.

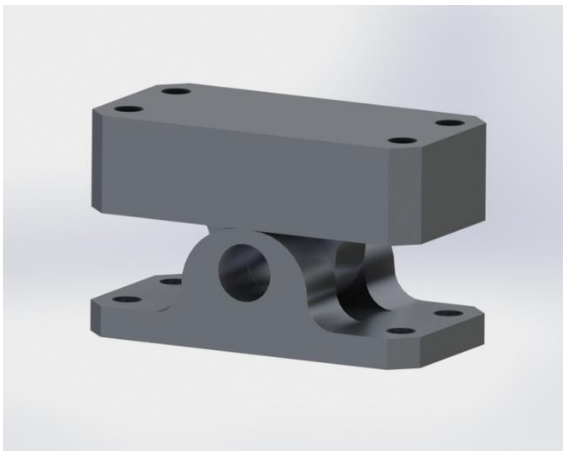

FIGURE 12 REAR ATTACHMENT PARTS ASSEMBLY

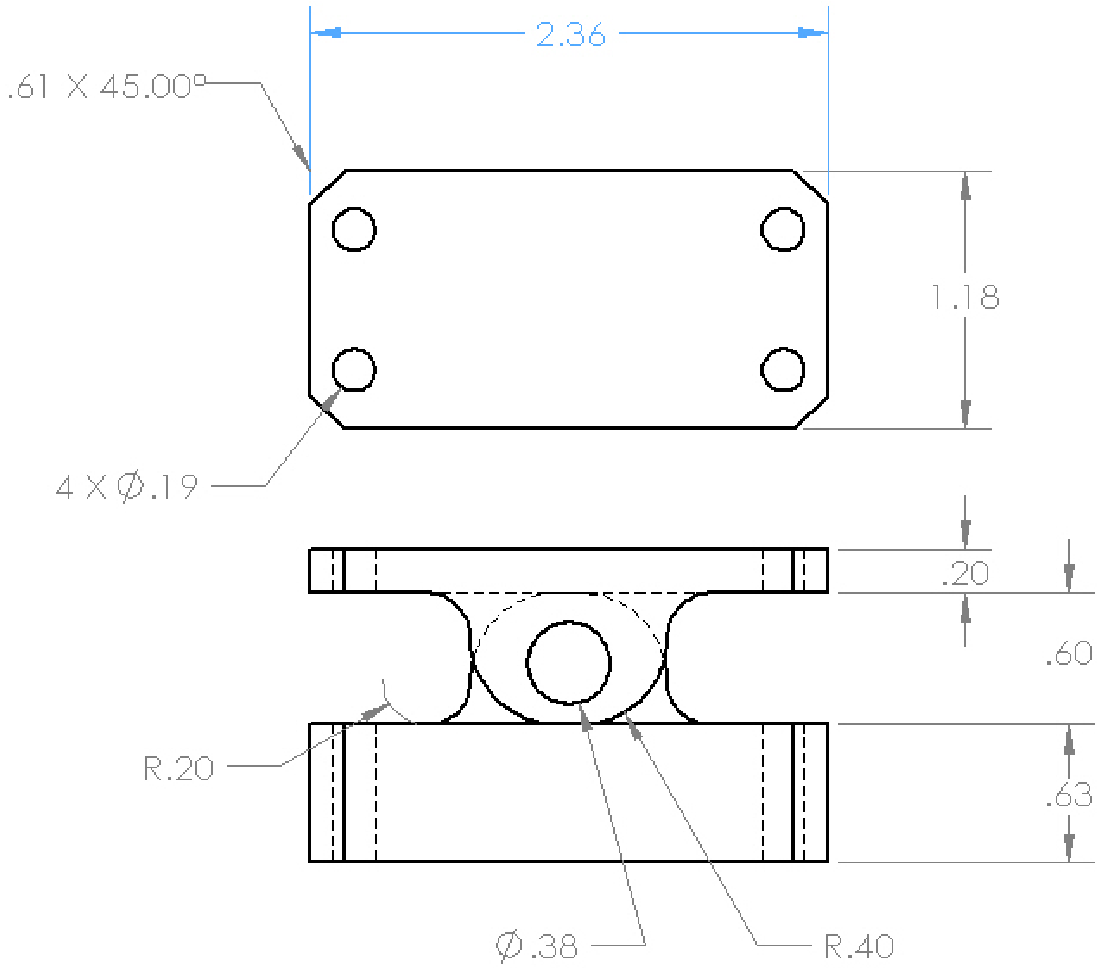

FIGURE 13 DIMENSIONED DRAWING

The attachment parts are made out of 6061-T6 aluminum. 6061-T6 aluminum is commonly used in the aerospace industry due to its light weight and high resistance to corrosion. Attachment part on the aircraft side has one attachment hole and two for the attachment part on the cargo pod side, then AN6-17 locks the whole structure as shown in the following figure. Movement in horizontal axis will be supported by the attachment parts and the weight of the cargo pod will be supported by the AN6-17 bolts.

FIGURE 14 AN6-17 BOLT

We used Solid Works and Inventor 3D programming software to perform the FEA analysis. We assumed that the total weight of the cargo pod and the 4 standard size golf bags is distributed into 4 attachment points uniformly. We assumed that the total weight of the cargo pod was 150 lbs and total cargo weight of 160 lbs. The maximum stress observed was 1.127 ksi at the fillet as shown in the following figure however the safety factor remained above 12 during the analysis.

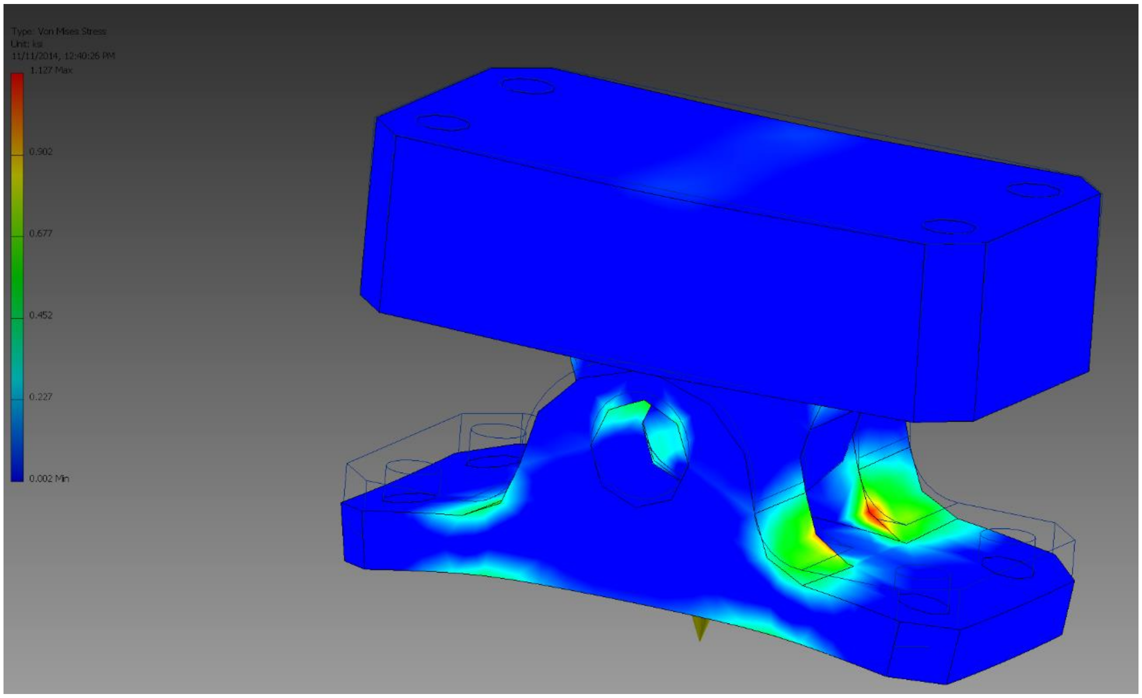

FIGURE 15 STRESS CONCENTRATION ON THE ATTACHMENT MECHANISM

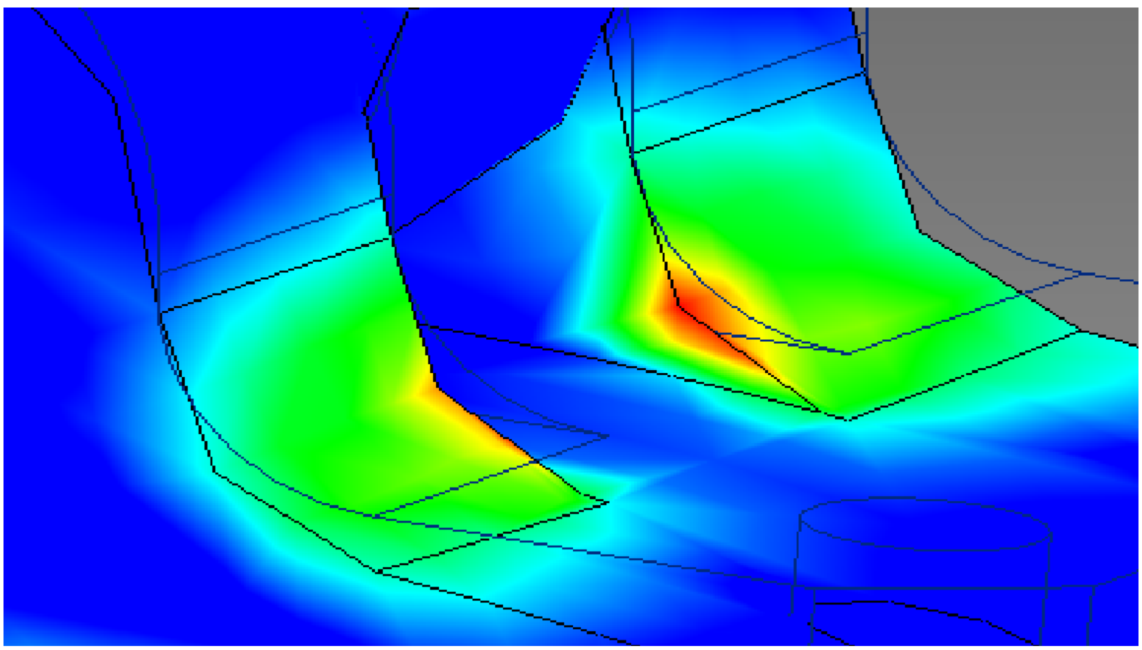

FIGURE 16 STRESS CONCENTRATION AT THE FILLET

3.3.2 FRONT ATTACHMENT MECHANISM

The front attachment in to the aircraft has more surface area compared to the one designed for the rear attachment, however, the trade-off was that that the thickness is much small compared to the rear attachment. The attachment to the cargo pod is also similar to the one designed for the rear attachment with more surface area. The design uses a custom AN7 bolt where the thread length goes through insert as we do not want the threads to undergo any shearing stress.

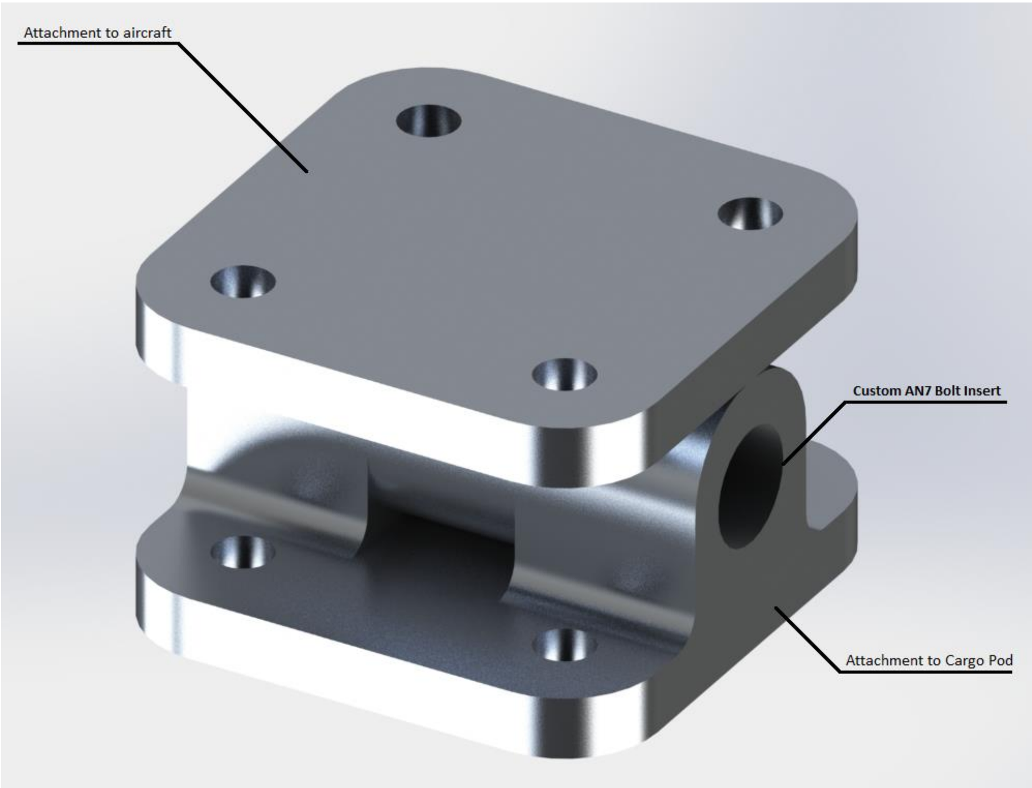

FIGURE 17 ISOMETRIC RENDER

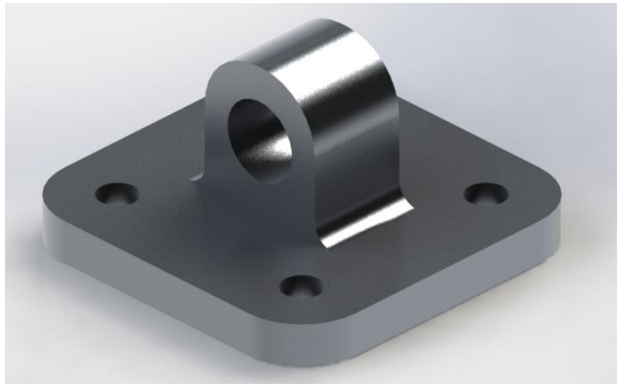

FIGURE 18 ISOMETRIC RENDER, POD ATTACHMENT

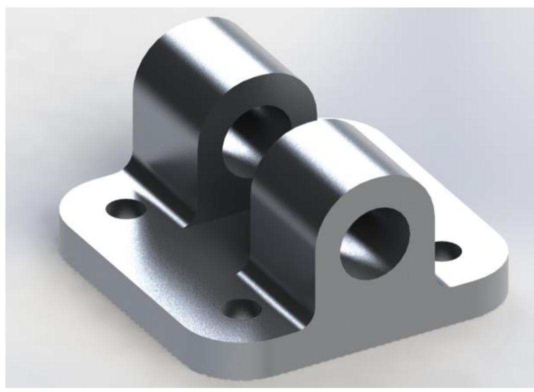

FIGURE 19 ISOMETRIC RENDER, RIB ATTACHMENT

The front attachment is similar to the rear attachment except the attachment to the aircraft is not as thick as compared to the one designed for the rear attachment. Also note that we have more surface area to on the attachment. The attachment assembly and the individual parts are rendered using Solidworks.

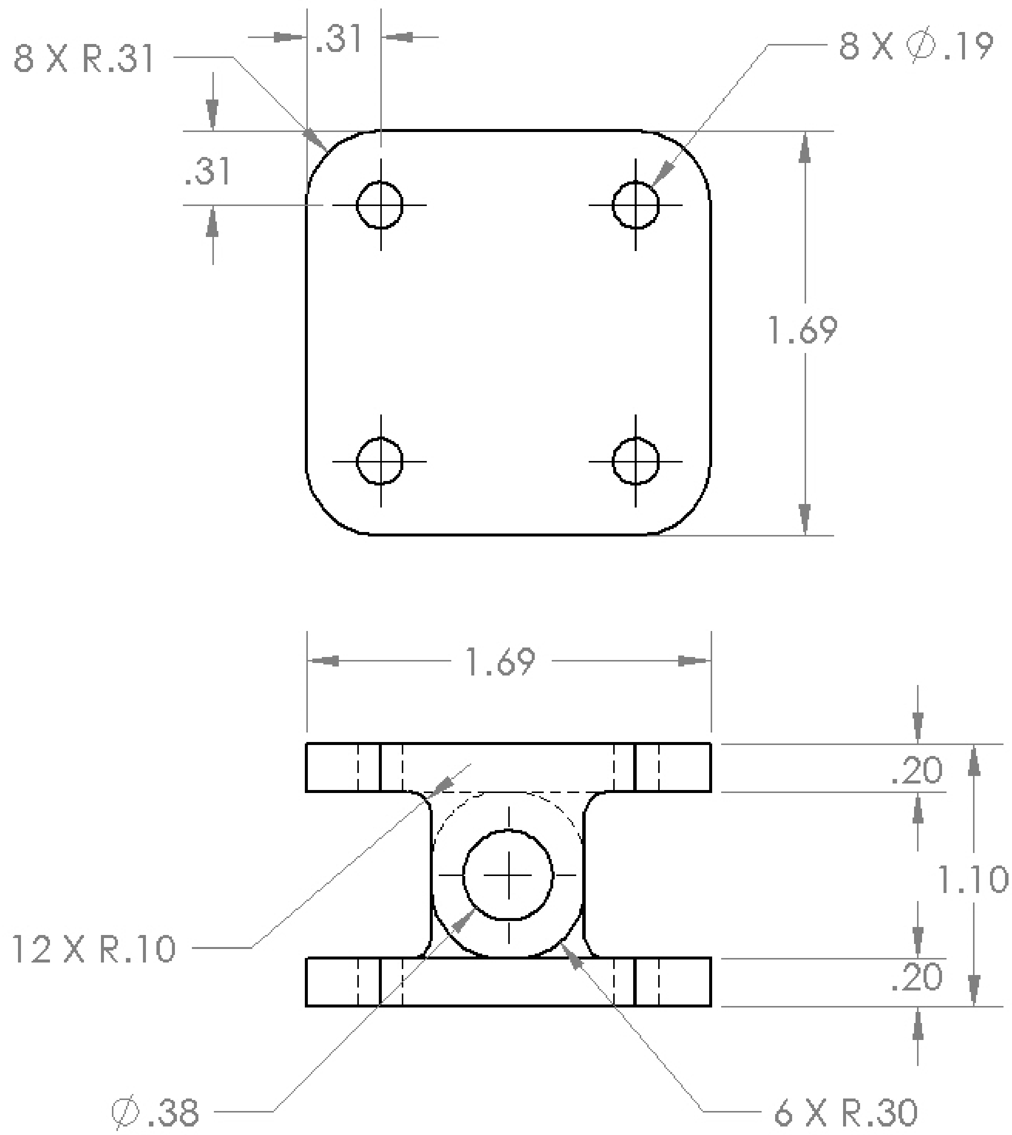

FIGURE 20 DETAILED DRAWING OF THE ATTACHMENT ASSEMBLY

A detailed drawing of the attachment assembly is illustrated in the above figure. The dimension is based on the shape of the original model that was provided by EMTEQ in order to guarantee consistency and compatibility with the aircraft, despite the fact that we did not have access to a model of the aircraft.

3.3.2.1 FEA ANALYSIS ON FRONT ATTACHMENT

For the front attachment, we used Inventor Professional 2015 to perform a finite element analysis. We calculated the force using the same assumption used in the rear attachment. The figure below illustrates our finite element analysis. For the constraint, we selected the bolt holes for the aircraft and cargo pod attachment part.

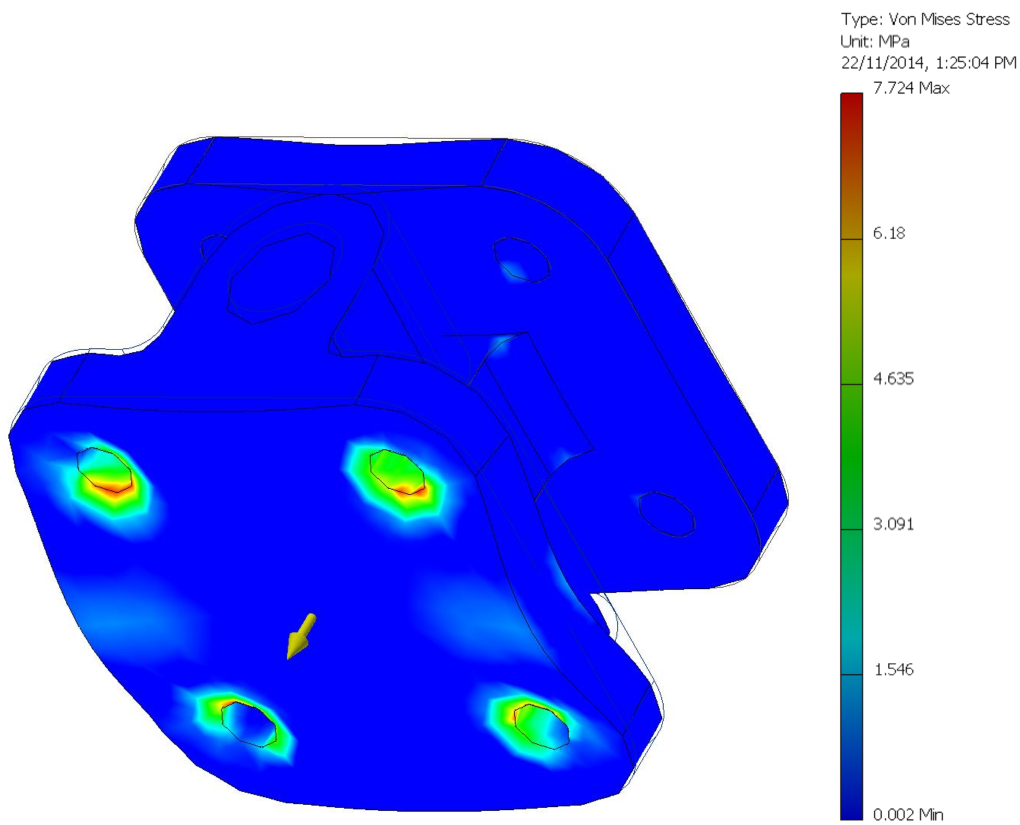

FIGURE 21

When we applied a force 345 N, the areas of highest stress are located near the attachment where the bolts are located. This is expected since a general rule of thumb is that stress will increase a factor of 3 times near the area of the hole [10].

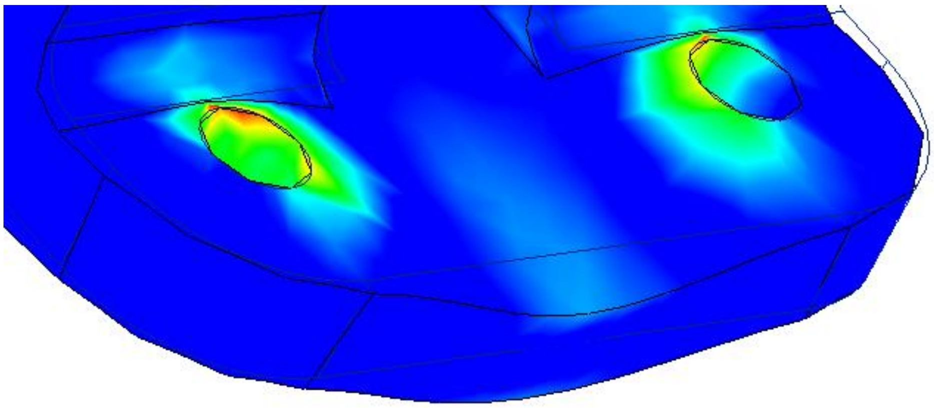

FIGURE 22: STRESSES NEAR THE HOLES.

In the above figure, the maximum stress near the bolt holes is 7.774 MPa and flows throughout the material until it reaches its minimum stress.

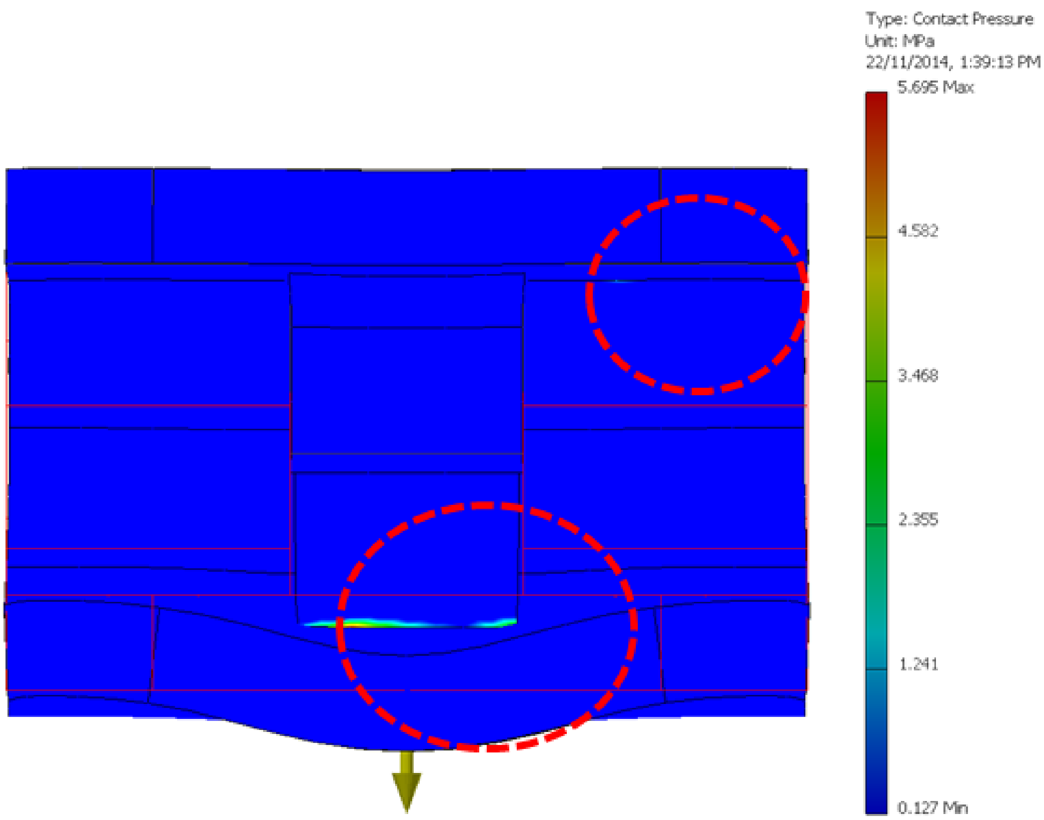

FIGURE 23: SIDE PROFILE

The contact pressure in show in figure 8 only reaches a maximum stress of 5.695 MPa, which is much less than stress on the bolt holes as shown in figure 8. Also note the red circles, which shows where the stress are located. The figure below shows a close up of these stresses.

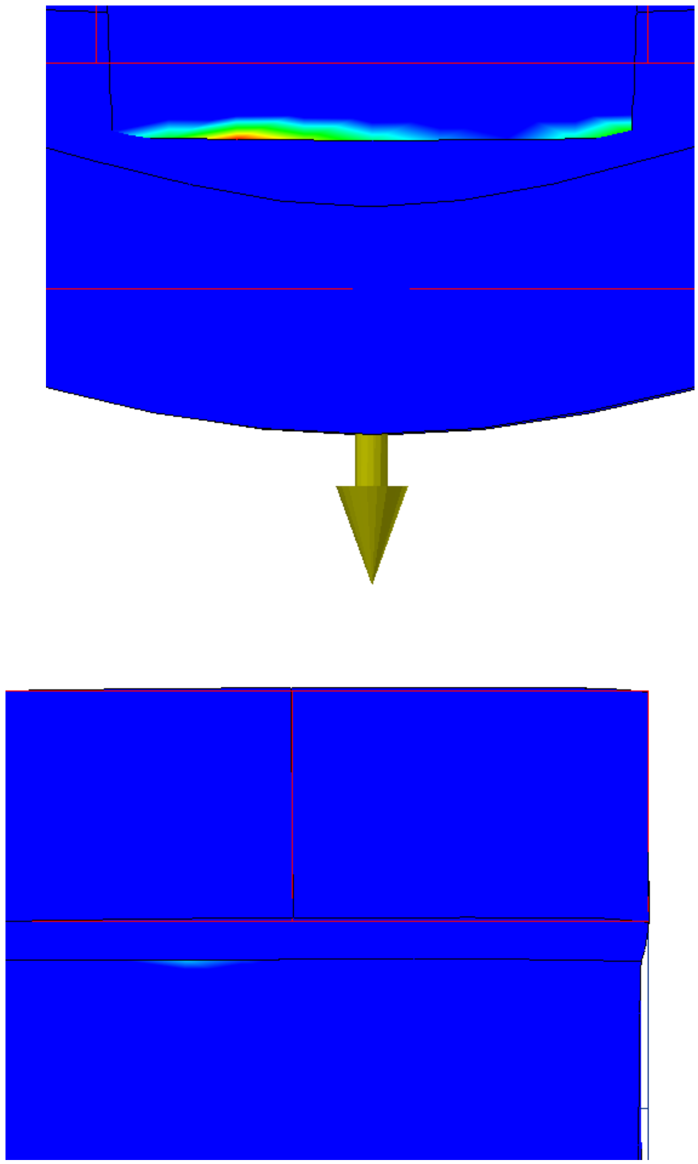

FIGURE 24: STRESS FROM AIRCRAFT ATTACHMENT (LEFT) AND STRESS FROM CARGO POD ATTACHMENT (RIGHT)

When we take a closer look at these stresses, we see that the contact from the aircraft attachment is causing a high amount of stress and the contact from cargo pod attachment is causing stress as well, however, it is not as prominent as shown in the comparison in figure 9.

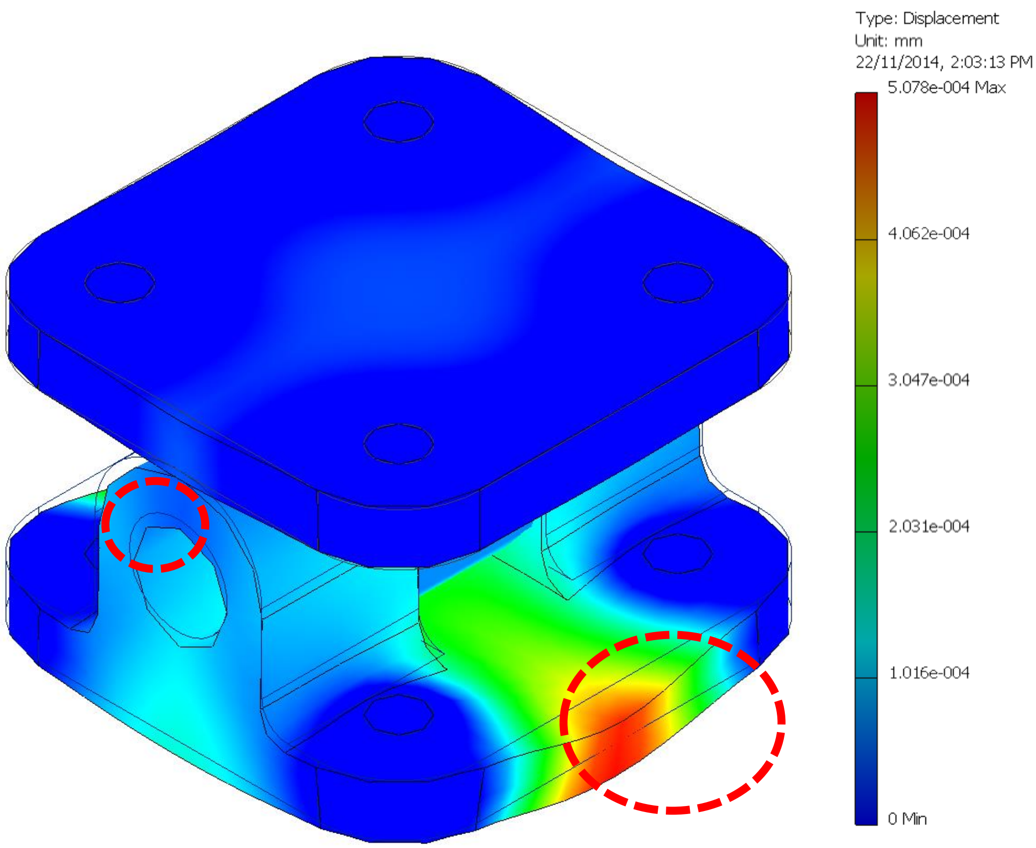

FIGURE 25: FEA ANALYSIS ON DEFLECTION.

When we look at the deflection, most of the deflection is happening on the cargo pod attachment part which is underlined by the red circle in figure 10.

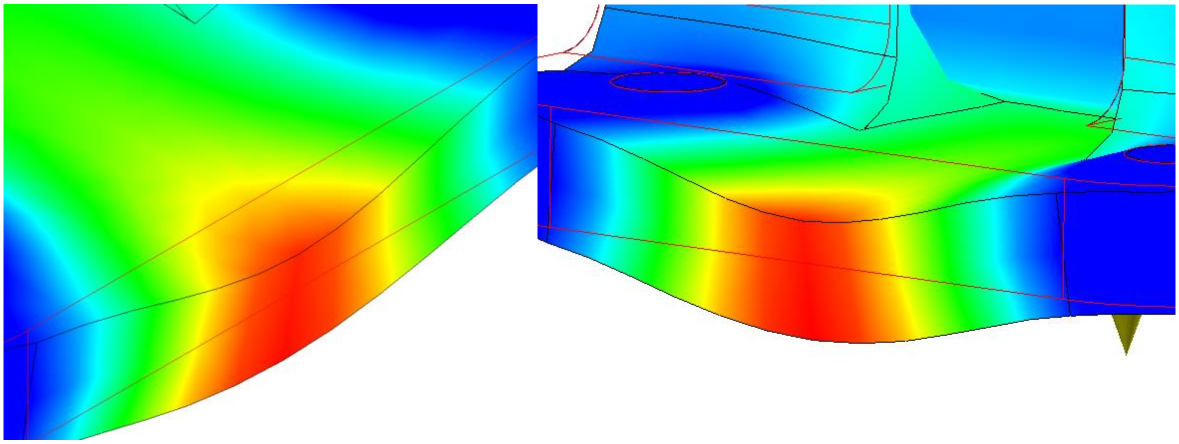

FIGURE 26: DEFLECTION ON CARGO POD ATTACHMENT. VIEWED FROM THE LEFT (TOP) AND VIEWED FROM THE RIGHT (BOTTOM).

The stress in figure 11 is a close up view of the location of the maximum deflection which is 0.0005 mm. On the other side, the same thing is happening in where the maximum deflection is a mirrored to the left side of the cargo pod attachment part. This is expected due to the symmetry of the attachment design.

3.4 DOOR DETAILED DESIGN

The following discussion will present the design details of the door, its frame and any associated fixtures that connect it to the cargo pod.

3.4.1 DOOR DESIGN OVERVIEW

For the two distinct door components, metal frame and composite structure, we had preliminary concepts which were generated in the concept generation phase, the summary of which can be found in the appendix. Both of the top two concepts had a birdcage frame as the main structural component of the door. The basic form of the metal frame for both would have been a rectangular perimeter frame with about five equally spaced vertical members attached to the top and bottom of the perimeter frame for enhanced rigidity. The exterior skin that was to be coupled to this structure was either an aluminum skin, for the first concept, or a carbon fiber composite shell, for the second concept, and both of these exteriors were to be attached to the frame either by rivets or bolts. In order to reduce skin deflection caused by dynamic loading, several cored composite panels would be bonded internally to the skin for added rigidity or in the case of the composite shell, the two could be combined to form a single cored structure.

Our final door design, however, did not embody the final concepts mentioned above. Seen in the figure below, the design comprises a composite structure which incorporates the skin reinforcing panels into the composite skin, and vertical metal ribs for added reinforcement. The reinforcing panels provide rigidity and maintain the skin's external shape as it experiences dynamic surface loads during flight. The vertical ribs enable the whole structure to serve as a contact frame by transferring loads from the cargo pod and enabling the overall pod structure to be lighter and rigid. The overall dimensions of the door are a length of 124 inches and a minimum height of 16 inches at the lowest point and a maximum height of 20.25 inches at the highest point. This height variation is necessary for accommodating the wing root fairing on the Pilatus PC-12.

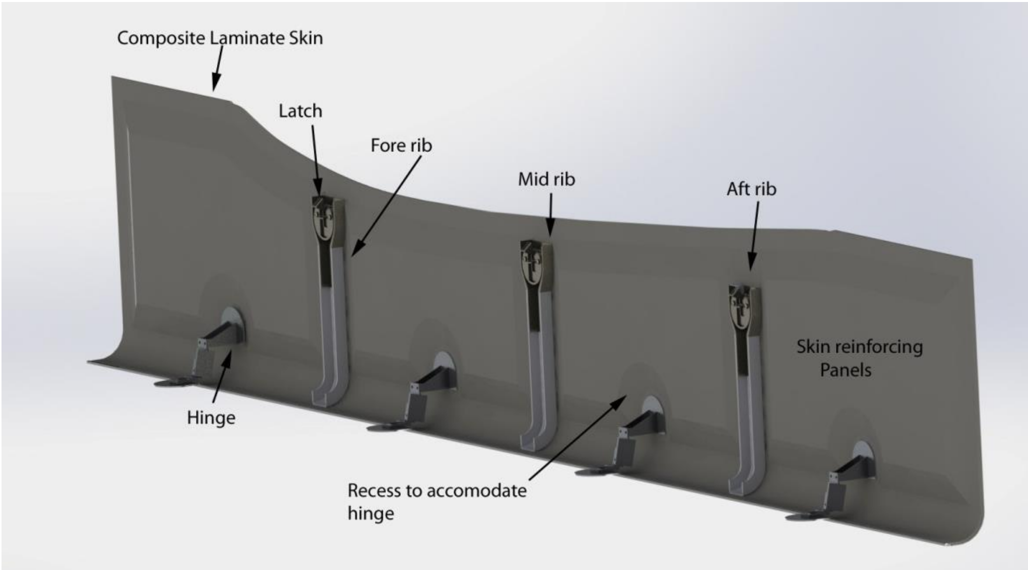

FIGURE 27: INTERNAL VIEW OF DOOR; RIBS, PANELS AND HINGE IN VIEW

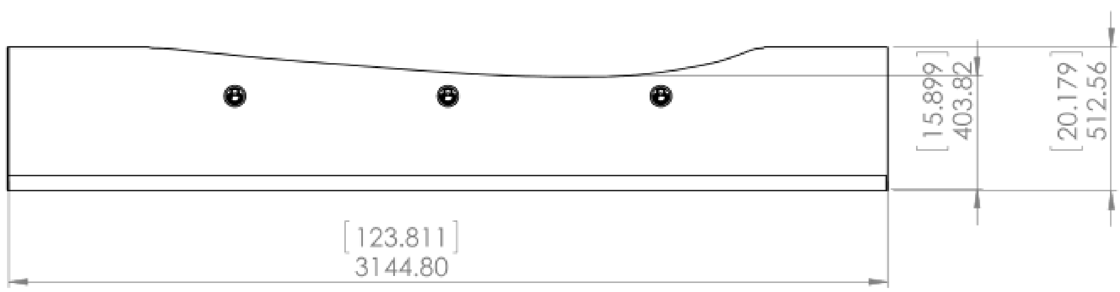

FIGURE 28: DOOR DRAWING, EXTERNAL VIEW

3.4.2 METAL FRAME DESIGN

There are three vertical ribs along the length of the door with two on each ends. The vertically oriented ribs, made of 6061 T6 aluminum alloy and are of the same length of 11.7 inches in order to accommodate the special fitting used to attach the latch mechanism. The ribs have a U-profile cross section with a base width of 2 inches, flange thickness of 1 inch, and a profile thickness of one eighth of an inch. As can be seen, the ribs are mostly straight with a small section toward the bottom having a constant radius bend meant to accommodate the curved transition in the door's profile where the wall meets the bottom.

At both the top and bottom ends of each rib are pads roughly perpendicular to the longitudinal axis of the ribs and their purpose is to provide frame contact between the door and the pod via corresponding contact pads on the cargo pod's frame. These pads, which are also made from 6061 T6 aluminum, need a precise fit in order for proper load transfer to occur. This is facilitated by having an elastic material bonded to the contact side of the patch and the material of choice for this part is a high density rubber sheet which has long life and is easily replaceable.

Rib attachment to the composite structure is the same as that for ribs in the main cargo pod structure since the rib profiles and loading requirements are similar. It is accomplished by fastening using 12-24 Flat Head Socket-head Cap Screws spaced every inch and in rows of two, each fastener equidistant from the flange and rib centerline.

3.4.3 LATCH ATTACHMENT DESIGN

Due to the complex design parameters involved in designing a latch, we chose to pick an off-the –shelf unit that met our design goals. Additionally since the revised project scope eliminated seal design and pod attachment method design, we were not able to set exact targets for the strength required to keep the door closed during flight. Assuming the cargo is properly secured, the sum of the forces acting on the door during flight include the static reaction load exerted by the door seal on the door due to pressurization for optimum sealing and external aerodynamic loads as the plane manoeuvres. Together with clarification of the load paths associated with exterior forces as they are transmitted through the attachment sub structure, a clearer picture of the required latching force would have been obtained.

Therefore a reasonable amount of latching force was chosen based on research into different latch applications and the selected latches. Our client also suggested different manufacturer catalogs for latch selection based on his experience in the aerospace industry. We narrowed down the specific design to a compression type latch since it enables compression of a seal placed between the door and frame by having higher latching forces than latches of comparable size [11]. To satisfy this requirement, a simplified but heavy duty latch construction ensures longevity and consistent performance.

The latch that was chosen is the SouthCo M1-25-41-28 compression latch [12] as seen in the figure below. The manufacturer specifies that the latch has a maximum static load of 825 N, is operable from -18˚C to 60˚C and passes various standards for vibration resistance, moisture protection, corrosion resistance and securing of enclosures for different applications. The latch has an overall diameter of 76mm (3 inches) and a depth of about 42mm (1.65 inches). For our application, we chose the top rib ends on the door as the attachment location, instead of at the composite surface, with a latch keep mounted on the I-profile horizontal ribs. This was designed so as to keep ensure high loads were maintained within the metal frame. Since the door frame has three ribs, three latches were required. Detailed drawings of the latch are provided in the Appendix.

FIGURE 29: SOUTHCO M1-25-41-28 COMPRESSION LATCH

As seen in the above figure and discussed in the ribs section, the overall base width of the ribs is around 1.5 inches while the latch has an outer diameter of three inches and requires a 2.5 inch diameter mounting hole. Since it needs to be mounted to the ribs, there exists no physical means of mounting this latch directly onto the rib while maintaining the rib's original structure. Therefore a rib fitting was devised onto which the latch can be mounted and which provides a connection between the latch and the door rib. The rib fitting is made from 6061 T6 aluminum, as are the ribs and is a machined piece. Below is a figure illustrating the assembly of these three key parts.

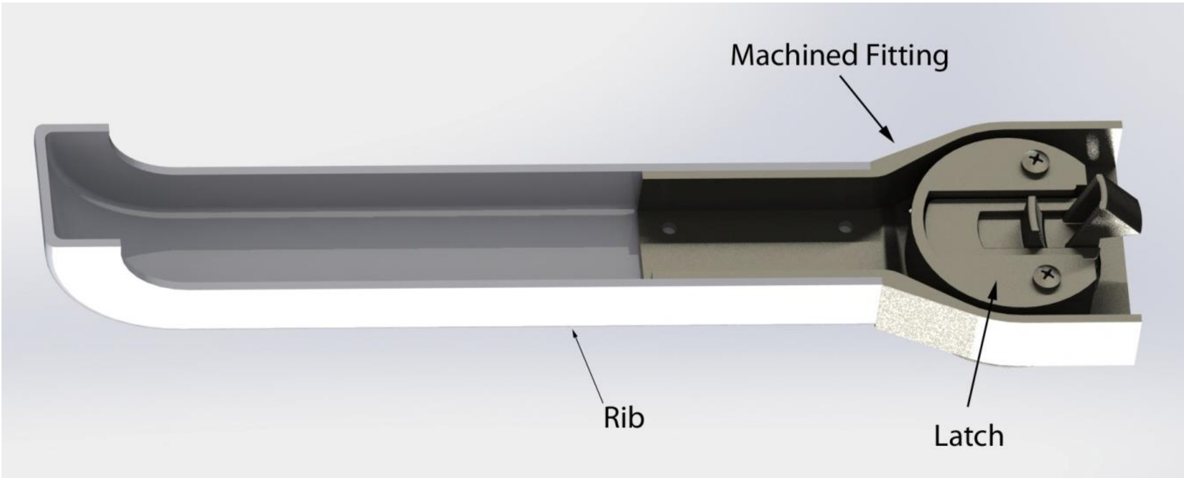

FIGURE 30: INTERNAL VIEW OF RIB, RIB FITTING AND LATCH

In effect, the rib fitting is an extension of the rib itself and therefore in determining loads associated with its attachment to the composite skin, the same methodology as for ribs is followed (refer to the ribs section).Towards the right, the rib fitting has a larger base width to accommodate the latch mounting hole, and also the mounting holes required for attaching it to the laminate composite skin. Further down, its profile narrows down so as to snugly fit within the rib. As seen in the figure below, the transition from the rib to the fitting, on the skin side, is continuous while on the fitting's interior surface, there is a filleted ramp transition.

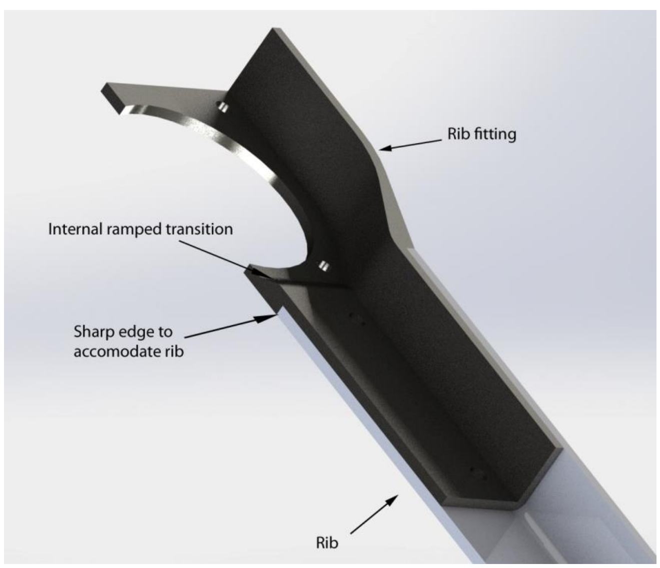

FIGURE 31RIB FITTING CROSS SECTION

These two profiles, especially adjacent to the skin, have been chosen so as to ensure maximum contact and therefore consistent load transfer through the fitting. In depth analysis would be required to optimize this shape but without data for the cargo pod attachment and door seal, further analysis at this point would be inaccurate. However a key refinement would include extension of the forward and aft rib fittings close to the upper edge of the door in order to reduce any skin flex caused by seal pressure when the door is closed. This extension in length would also aid in creating a location for mounting the upper contact pads required to create load transfer between the upper and lower parts of the pod's structure. Below is a drawing illustrating the overall dimensions of the fitting.

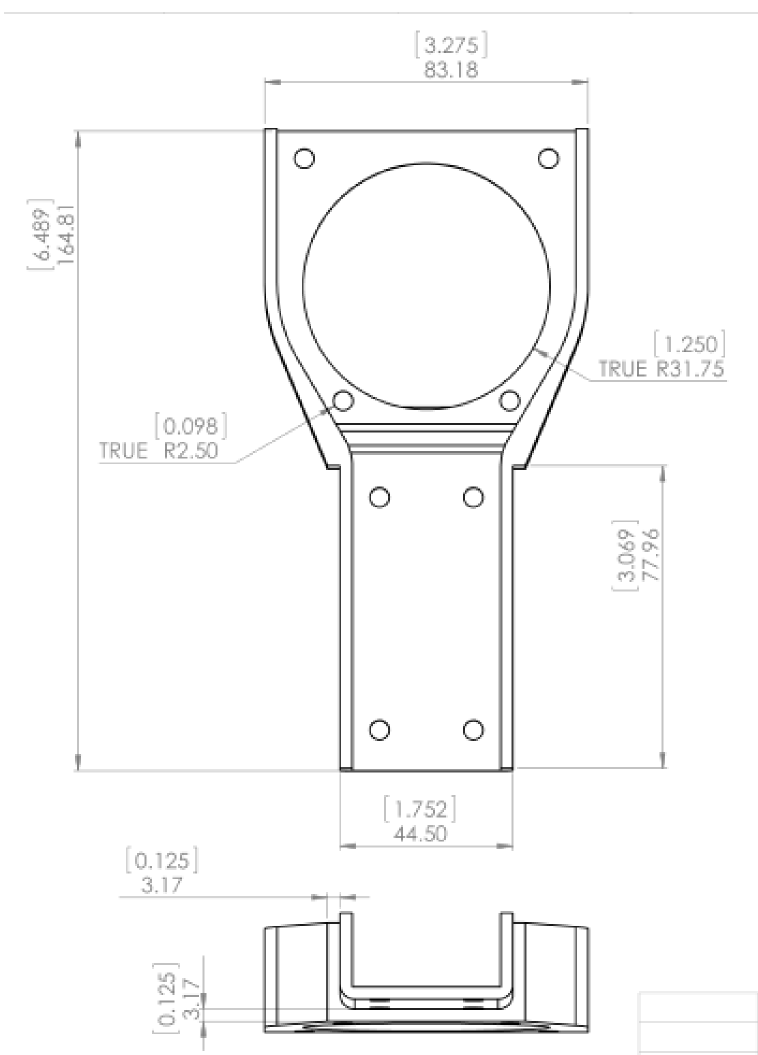

FIGURE 32: RIB FITTING DRAWING (IN [INCHES] AND MM)

It should be noted that our final model is slightly smaller (order of less than 2mm) in order to fit in the client provided exterior surface model. This was a crucial dimensioning decision because it enables the client to easily accommodate our final design into any tooling based on *their* original surface model. In other words, it is easier to accommodate a slightly smaller form into a female mould, by way of filler material, than it is to accommodate a form larger than the available mould. As such, after determining the cargo's required volume, sizing of the structure's thickness is carried out beginning with the inner components and layers, and working outwards in order to come up with the required outer dimensions.

The carbon fiber composite structure for the outer skin was chosen over the aluminum skin because, as can be seen, the cargo pod's exterior has a highly complex shape and creating an aluminum skin to accommodate it would require both expensive metal forming tooling to be created and skilled technicians for the assembly process. In terms of manufacturability, a composite skin/shell structure has the added benefits of relatively cheaper tooling and lower production time. Another added benefit is the lower overall weight of the composite construction compared to its aluminum counterpart.

The outer composite laminate skin has a thickness of one fifth (0.2) of an inch, and merges seamlessly with the outer profile of the pod when the door is closed. To simplify manufacturing, we would propose integration of the skin reinforcing panels and the skin shell into one cored composite structure. However this is not a high priority therefore the panels could also be manufactured separately then bonded to the skin afterwards. One half inch thick Nomex core material sandwiched between 1/10 inch thick carbon fiber laminate will be the materials of choice for these panels.

Since as seen in the figure below there is a variance in the door's height along its length, the panel sizes will have to be accommodated to this shape accordingly. Also seen in the same figure and are the recessed areas for the four door hinges, located along the door's bottom section, which need a flat area for firm hinge attachment to the door skin. The panels have to accommodate this as well and it will be a centrally located semicircular cut-out from the panel's bottom edge with a radius of two inches and this is seen in Fig. D1's bottom section.

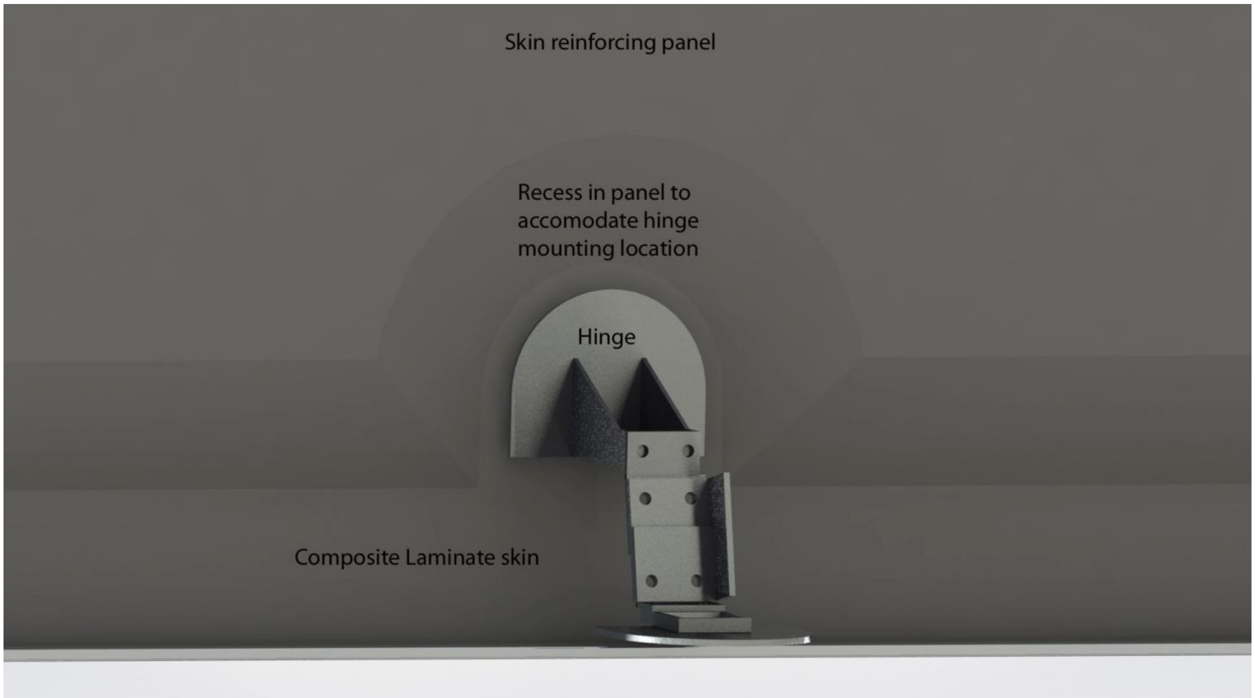

FIGURE D33: RECESSED COMPOSITE SURFACE FOR HINGE MOUNTING

3.4.5 EDGE TREATMENT FOR SKIN LAMINATE AND REINFORCING PANEL CORE

Considerations of the edge profiles for both the reinforcing panels and the composite skin were made due to the critical purposes that both structures serve.

3.4.5.1 REINFORCING PANEL CORE EDGE PROFILE

The area around the attached panel where it transitions to the underlying skin laminate is referred to as the core to edge band transition and is a critical area for manufacturing considerations. As explained in Section 3.2.6: Composite Sandwich Structures, at its edge the core needs a gradual transition from its maximum thickness down to the underlying base laminate in order to prevent core crush under composite cure pressures. This is more crucial for thicker cores such as the ones used for this cargo pod. In our case, we chose a chamfered profile of around 15 degrees as seen in the figure below due to requiring minimal core-edge processing and laminate layup considerations.

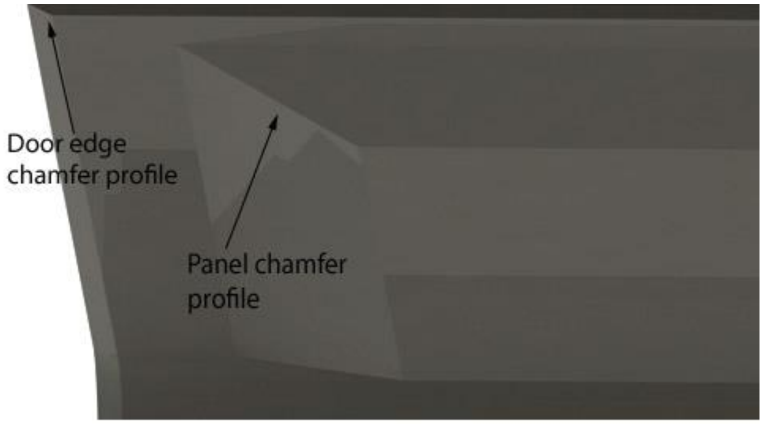

FIGURE 34: CHAMFER PROFILES FOR THE DOOR AND PANEL EDGES

3.4.5.2 LAMINATE SKIN EDGE PROFILE

Similarly, we chose a chamfered edge profile for the composite skin around the door's outer edge as the above figure shows. However this was purely to establish continuity between the pod's and the door's outer profile once the door is closed. The figure below shows that the receiving edge surface on the pod fits properly with the door's chamfered profile and this enhances usability by eliminating any interference as the door hinges outwards. Although the skin edge is relatively thin, other edge profiles such as a square cut would have led to interference along the left and right door edges during door usage. This would lead to premature edge wear, which would negatively affect the part as the skin also serves structural duties. Although door seals are no longer part of the design scope, our door provides a flat surface around the edge to accommodate the seal mounted on the pod's corresponding recessed surface.

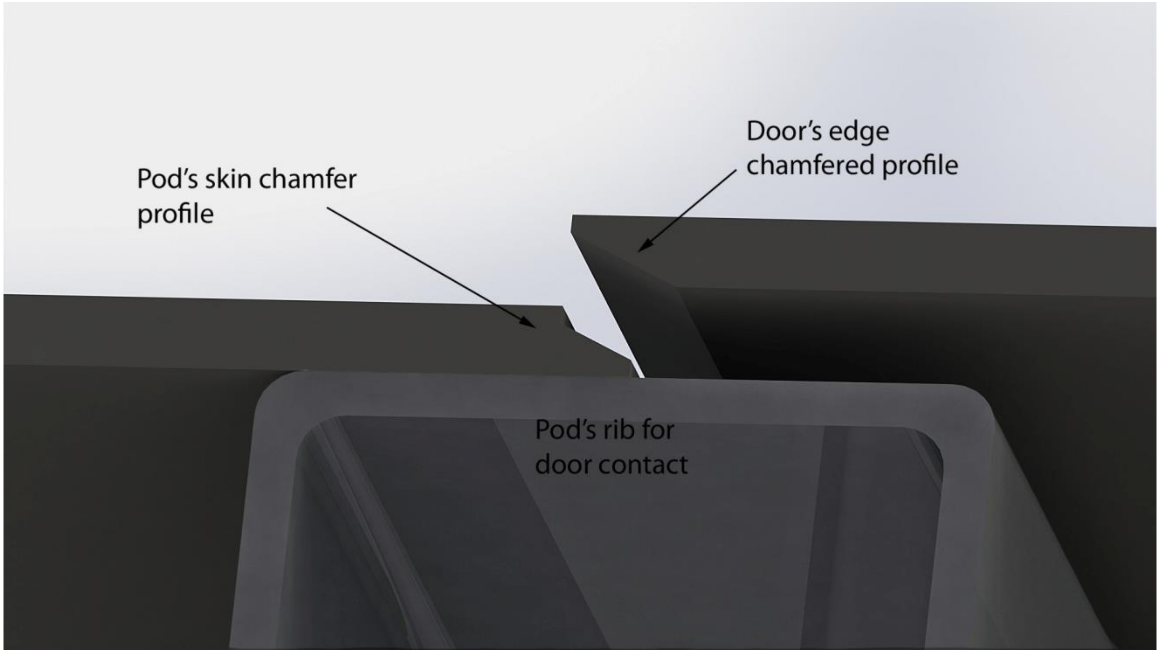

FIGURE 35: CLOSE UP VIEW OF MATCHING DOOR AND CARGO POD EDGE CHAMFER PROFILES

3.4.6 MATERIALS AND MANUFACTURING CONSIDERATIONS

There are several materials and manufacturing considerations that have to be taken into account when combining the three constituent parts of the door; the laminate skin, cored panels and U-profile aluminum ribs. Great care has to be taken in order to ensure original targets for design parameters such as strength, dimensional accuracy and part longevity are met. This depends mostly on the various material interactions and the accommodations made to eliminate them.

Carbon fiber composites do not react well if in non-bonded contact with each other. Such scenarios occur where the closed door meets the cargo pod. As such we have designed accommodations for contact prevention around the door's perimeter. Along the left and right sides of the door are flat sections of exposed composite skin which will meet flat sections of aluminum ribbing on the corresponding pod surface and this is shown in the figure below. The door is not shown but the hinge on the bottom and the exposed rib on the right side indicate its location. The rib's location was dictated by structural design but its presence ensure no contact occurs between carbon composite surfaces.

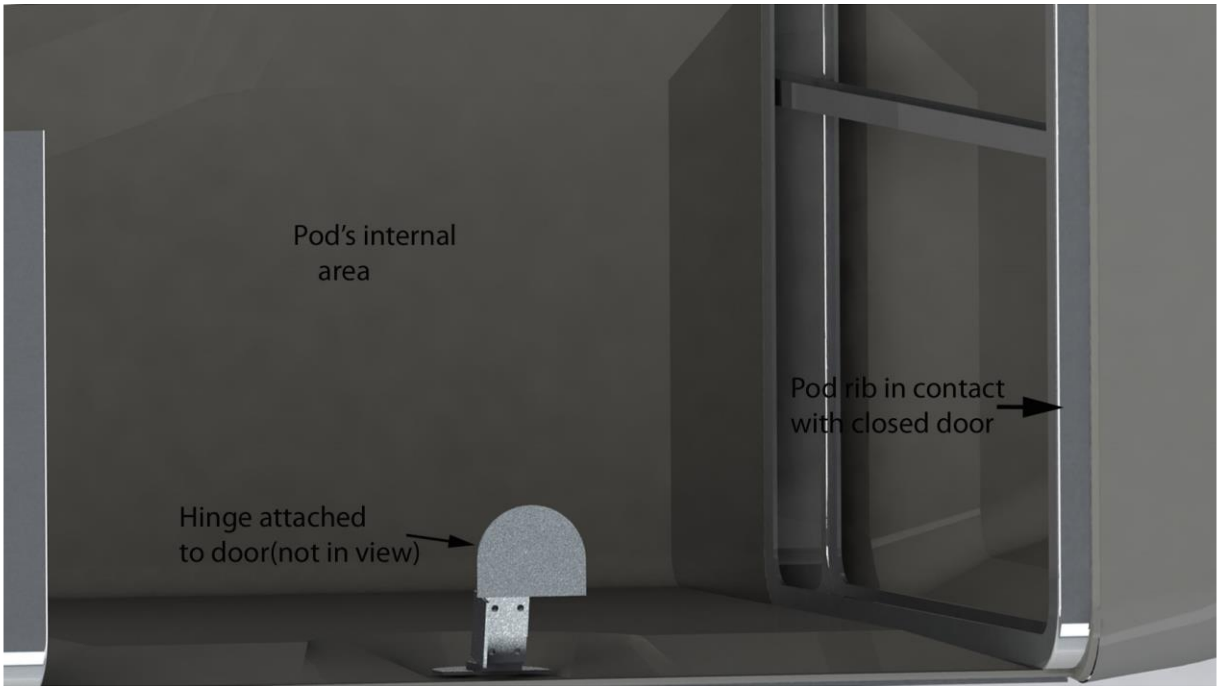

FIGURE 36: CARGO POD'S DOOR OPENING PERIMETER RIB

For the door's bottom edge, there is an L-profile aluminum extrusion bonded to the skin laminate and this is to ensure no pressure contact exists for the carbon fiber surfaces in this location. This is seen in the figure below. The dimensions of this extrusion are as follows: 0.05" profile thickness, flange thicknesses of one fifth inch and overall length equal the door's length(124"). The door's top edge is not in contact with any carbon fiber material and therefore is not considered in these regards. However, in the closed position, the pressurized door seal will ensure a small standoff distance exists between door and fuselage surfaces.

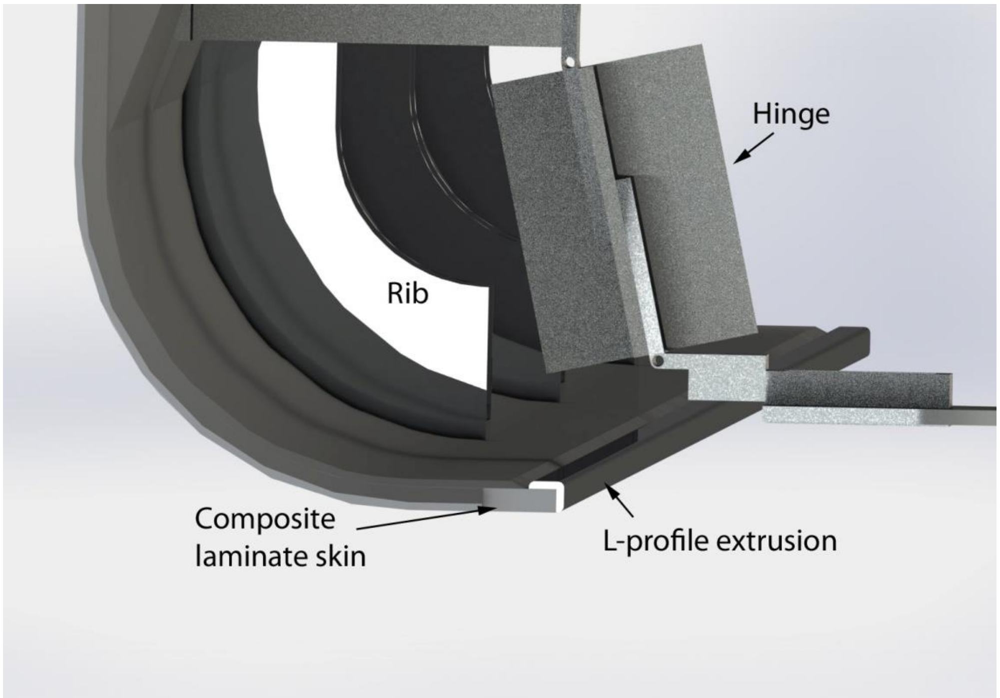

FIGURE 37: BONDED ALUMINUM EXTRUSION (L-PROFILE) ALONG DOOR'S BOTTOM EDGE

Since the door has both aluminum and carbon fiber composite components attached to each other, and it is know that galvanic reactions occur between carbon fiber and aluminum which weakens both materials, it is prudent to create a solution to prevent this reaction. The most common solution utilized in the composites industry will be applied here; a fibreglass layer will be bonded to all the laminate surfaces where metal attachment is to occur. This will be on all the door's composite surfaces where rib mounting occurs and along the door's bottom edge for accommodation of the L-profile extrusion.

Further details in regards to composites processing, panel design, rib design, hinge attachment and component drawings can be found in their respective sections and appendices.

3.5 HINGE ASSEMBLY DESIGN

The door will be attached to the main pod body at four discrete hinges located within the cargo pod. Discrete hinges were chosen for ease of sealing the edges of the door and for ease of door installation. With the current design the door mounted cantilever and the pod mounted cantilever can be attached individually and attached with the floating arm, simplifying the installation of the door. The chosen design for the hinge assembly is depicted below.

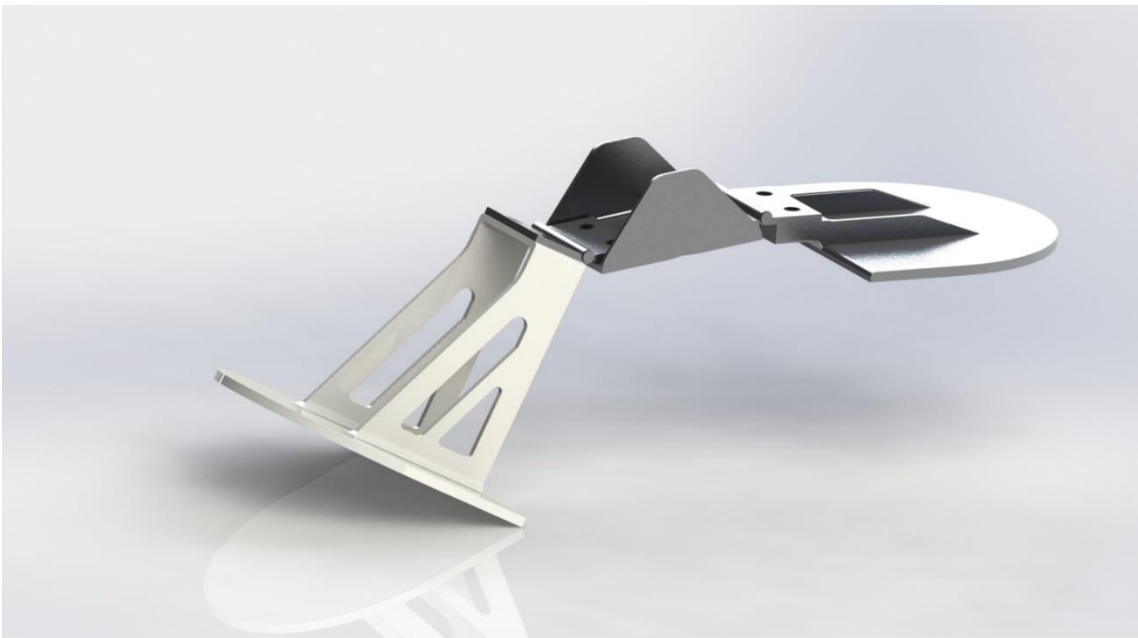

FIGURE 38 DOOR HINGE ASSEMBLY

A floating arm hinge was chosen due to its ability to accommodate complex movements in order to clear the outer skin of the aircraft. This design also maintains lateral clearance requirements without requiring shortening of the door in order to function properly. Due to the required vibration analysis of the assembly in order for EMTEQ to have any confidence in a chosen hinge design, and given the lack of time and resources to perform thorough vibration testing on a prototype of the assembly, treat all following analysis as a preliminary proof-of-concept.

The overall geometry of the hinge has to reflect the 2” fillet along the side of the pod. The hinge mechanism must swing such that it does not rise above the starting point (causing it to interfere with the wing-to-body fairing), nor can it move laterally without first moving toward the ground (to unload the sealant beads along its perimeter). The following sketch layout was formulated to allow for a hinge that conforms to these qualities with a minimum of extraneous motion; for detailed dimensions, see the assembly file.

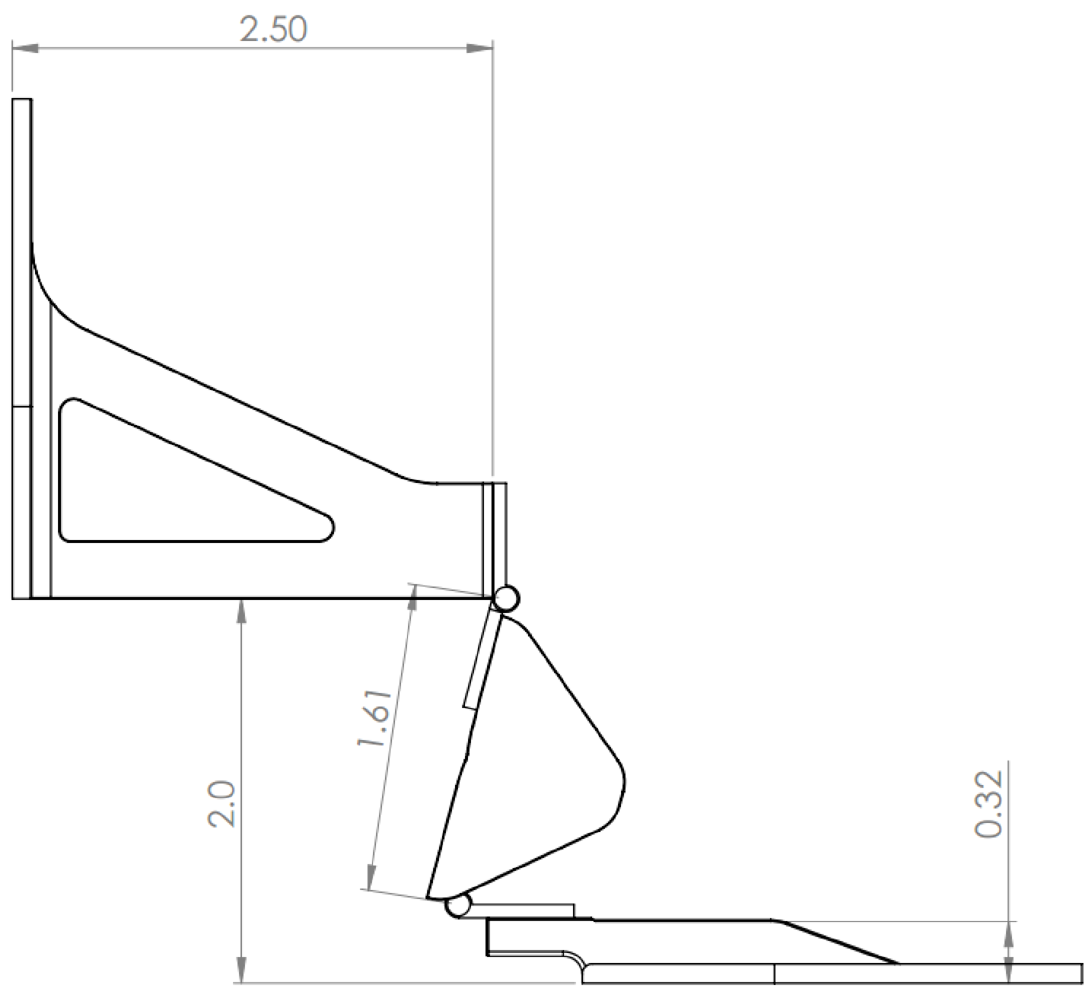

FIGURE 39 DOOR ASSEMBLY DIMENSIONS

The above figure shows how the hinge as designed will fit into the female radius where the door and the cargo pod unibody meet. In order for the hinge to function as required (holding the door shut while in flight while allowing crew to open it in order to access the cargo) the hinges depicted will have to be spring-loaded. For this reason the hinge assembly does not rest at 90^0 angles relative to each component, as this would make it easier for a turbulence impulse load to jar the seal along the door's edges loose.

The hinge elements are designed to accommodate the stress associated with the door resting open and a certain amount of misuse; for this purpose we have assumed a weight of 490N (110lb) must be accounted for in all elements of the hinge. As the structure is a door which one must reach over in order to load cargo in to the pod we intend to accommodate a great deal of misuse, and therefore a safety factor of ten over the weight of the door (44lb) was used to analyze the individual members of the hinge. The additional 396 pounds should accommodate a worker leaning on the door or dropping a golf bag on the door before pushing it in the rest of the way.

For the purposes of explaining the kinematics of the door, its motion will be divided into two parts: translation and sweep. The primary purpose of the floating arm actuation point is to provide the translation – moving the door away from the wing-to-body fairing. Secondary to that is the sweep of the door, occurring principally at the pivot point at the end of the door cantilever. These two motions are not mutually exclusive in reality, the door opens with the two pivot points in tandem.

FIGURE 40 DOOR, HINGE AND POD (CLOSED)

Since the flange of the door rests on the base of the pod it provides a contact point behind and off center of the hinge, this is accounted for with the hinge on the door cantilever portion, which allows the structure to pivot on this offset contact point, lowering the outer edge of the door away from the wing to body fairing of the plane.

FIGURE 41 DOOR, HINGE AND POD (OPENING)

After this stage of motion the floating arm begins to pivot, lowering the door as a whole away from the pod and allowing further sweeping of the door on the door cantilever pivot point. This in-tandem motion continues until the floating arm bottoms out on the edge of the pod, with a total sweep at the door of approximately 89.2^0 and a downward translation of 2 inches.

FIGURE 42 DOOR, HINGE AND POD (OPEN POSITION)

3.5.2 POD CANTILEVER

The pod cantilever is mounted to the pod unibody with bolts along its perimeter. The pod cantilever is designed to accommodate shearing force, as such it has a large area and is of a minimum height (as increased height will greatly increase experienced stress).

The door cantilever was analyzed with FEA software (Solidworks Simulation^{TM}) using the bolt plate as a fixture, and a torque loading defined normal to the mating face at a magnitude of 10N*m = 110lb*0.65in. Gravitational effects are assumed to be minimal. The goal for a factor of safety is 2.

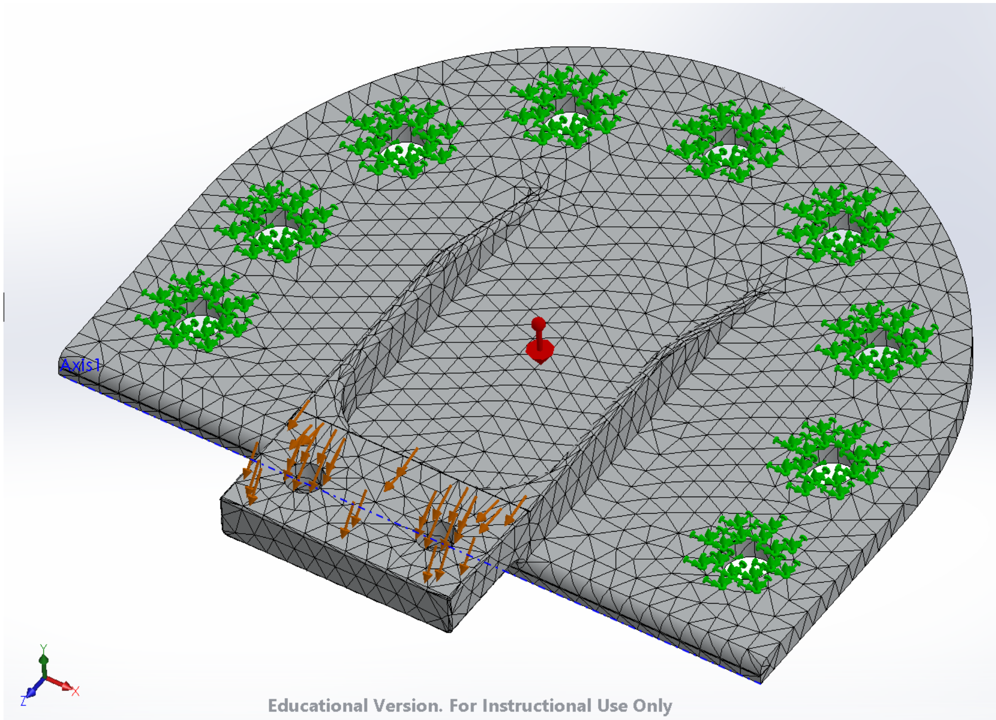

FIGURE 43 POD CANTILEVER MESH, FIXTURES AND LOADS

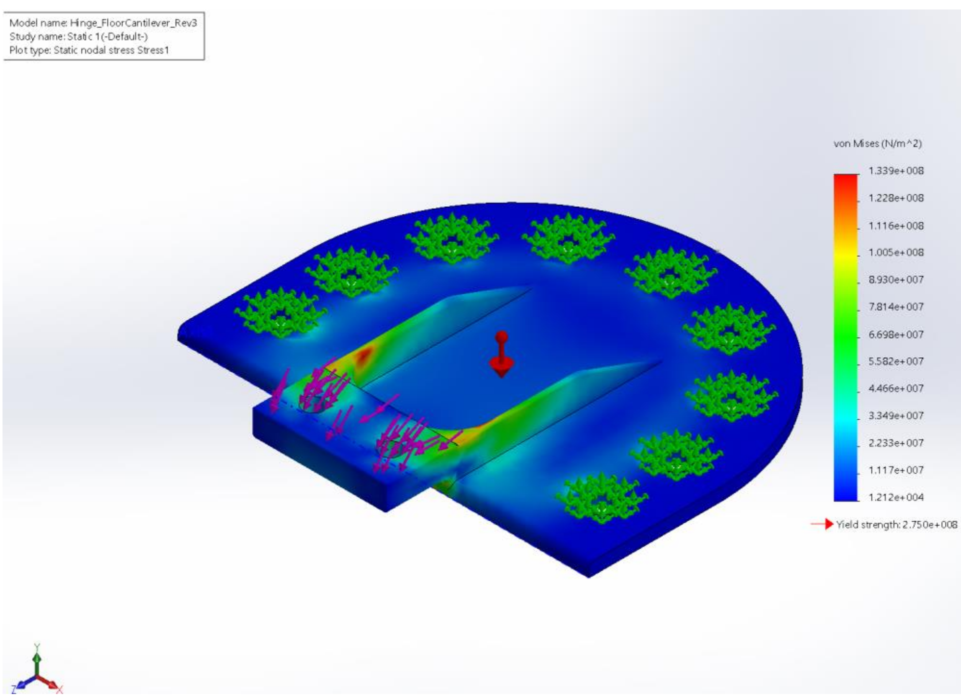

FIGURE 44 POD CANTILEVER STRESS PLOT

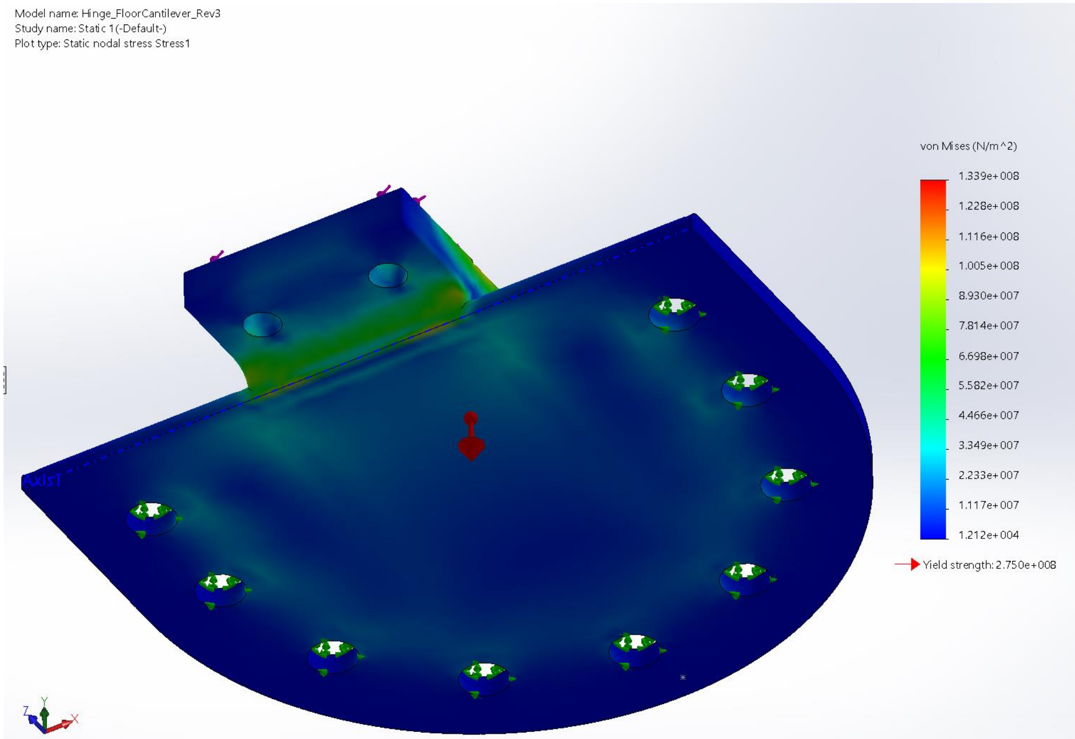

FIGURE 45 POD CANTILEVER STRESS PLOT (BELOW)

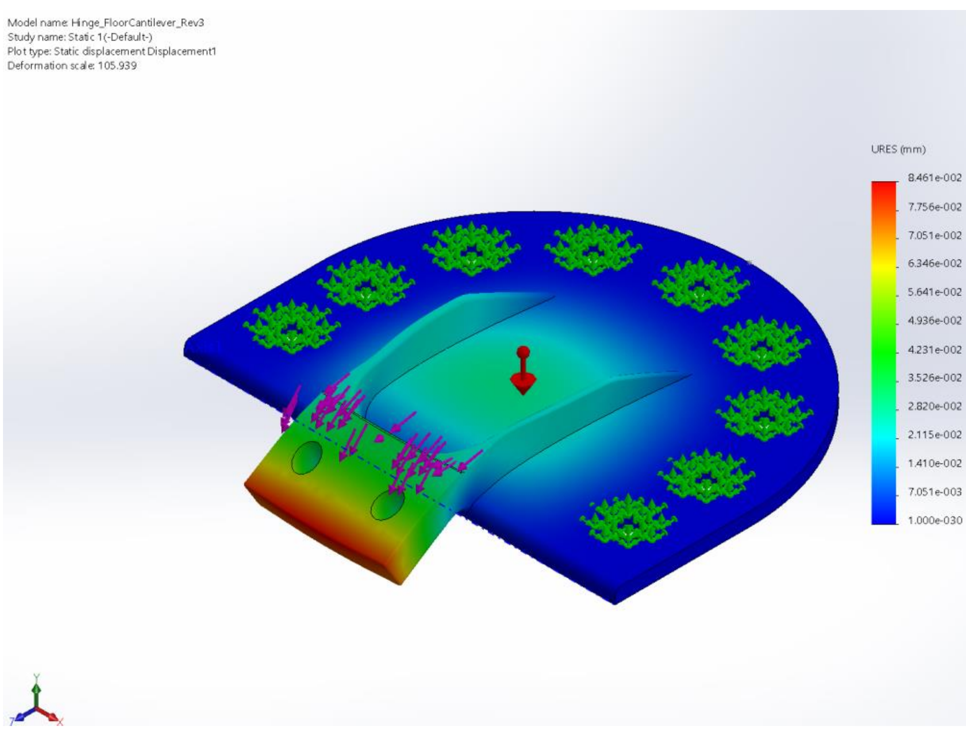

FIGURE 46 POD CANTILEVER DISPLACEMENT PLOT, EXAGGERATED DEFLECTION

The pod cantilever portion of the hinge consists of a bolt plate; a short, tapered U shaped cantilever and a hinge mounting flange. The overall shape maintains the desired profile for a high shear structure, and a chamfered transition between the bolt plate and the U shaped column is present to reduce stress concentration.

3.5.3 DOOR CANTILEVER

The door cantilever is mounted to the door paneling with bolts along its perimeter. Unlike the pod cantilever, the height is dictated by the overlap between the door and the pod unibody, and therefore the length of the door cantilever is considerable. For this reason the door cantilever contains a number of features aimed to improve its handling of the expected shear loads.

The door cantilever was analyzed with FE software using the bolt holes in the bolt plate as a fixture. The faces of the holes (0.216" OD) were affixed to a reference plane on the other side of the bolt plate. A torque loading defined normal to the mating face at a magnitude of 38N*m = 110lb*2.5in. Gravitational effects are assumed to be minimal. Mesh is concentrated on the upper most face which is expected to experience the most stress. Target FOS is 2.

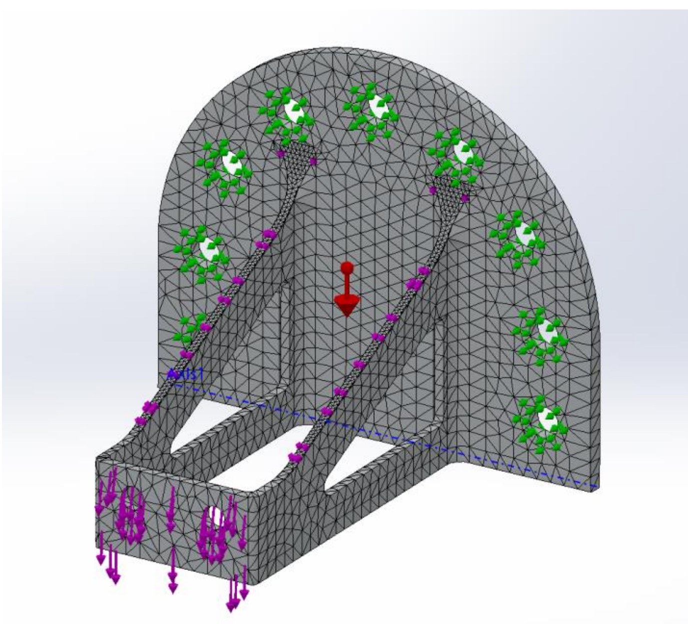

FIGURE 47 DOOR CANTILEVER MESH, LOADING AND FIXTURES

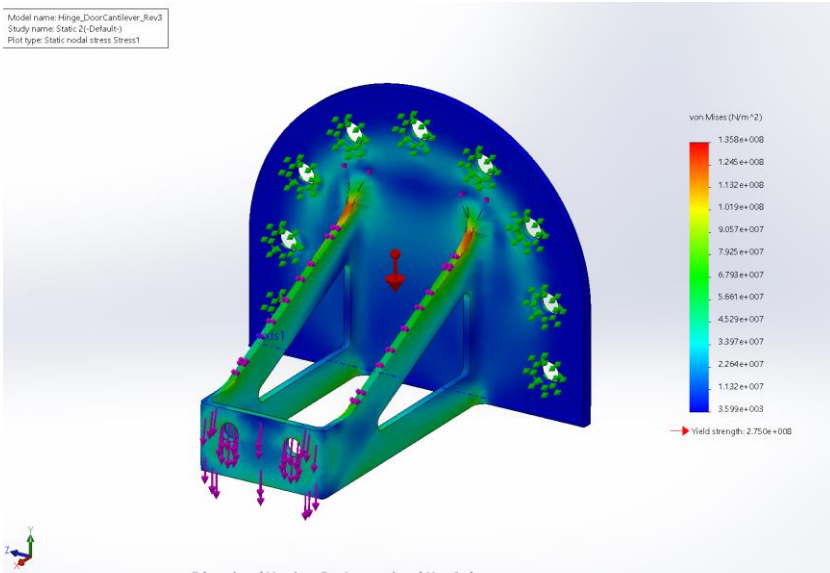

FIGURE 48 FIGURE 48 DOOR CANTILEVER STRESS PLOT

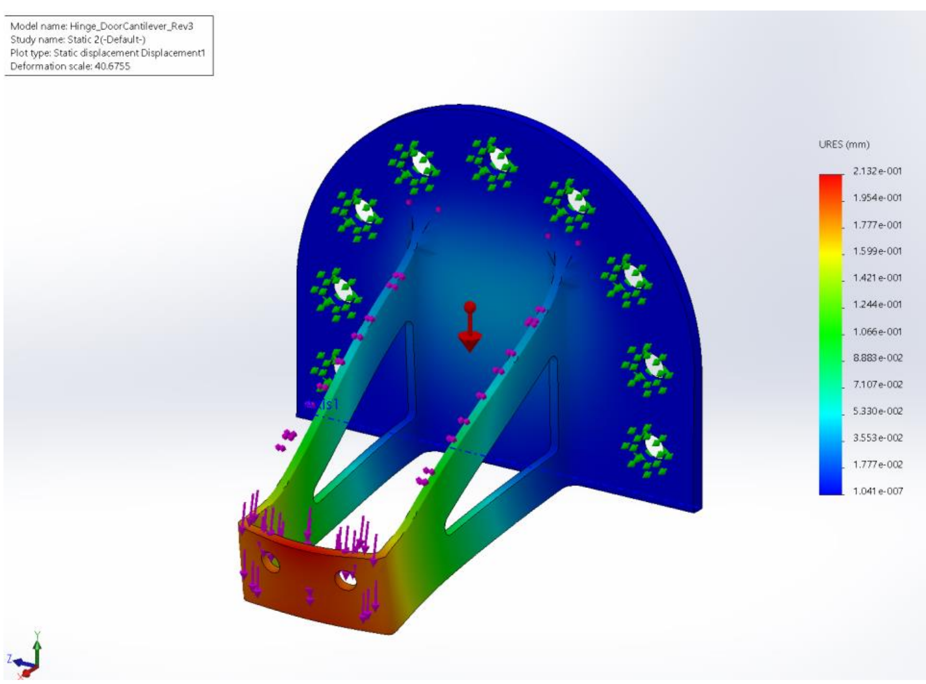

FIGURE 49 DOOR CANTILEVER DISPLACEMENT PLOT; DISPLACEMENTS EXAGGERATED

The door cantilever consists of a bolt plate, two cantilevers forming a U shape perpendicular to the expected shear load, and a flat mounting point for the hinge. High stresses were found near the interior edge of either flange, and along exterior radiused features as expected.

3.5.4 FLOAT ARM

The float arm is designed for both tension and bending, as it is expected that this member of the hinge will rest on the floor of the cargo pod. The length of the floating arm is precisely defined to accommodate the range of motion intended for the hinge, in fact if a 90^0 closed angle is desired, the floating arm should be the height of the radius on the door, minus the height of the pod cantilever.

The door cantilever was analyzed with FE software using the bolt holes as a fixture and a torque loading defined normal to the bolt hole faces at the opposing end of 5N*m = 0.5*110lb*0.7in. Gravitational effects are assumed to be minimal.

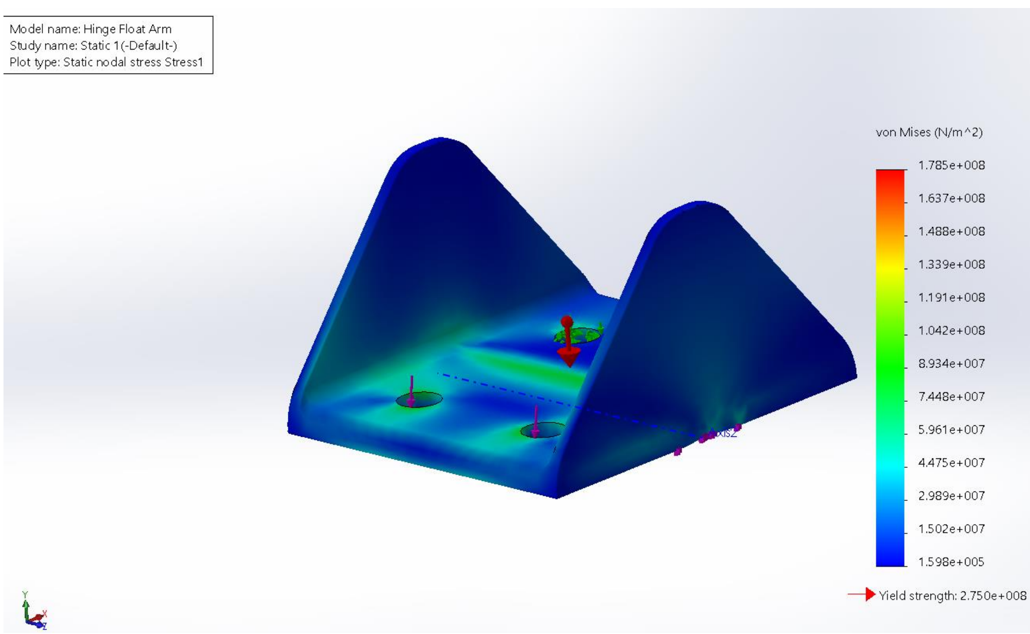

FIGURE 50 FEA ANALYSIS OF HINGE FLOAT ARM

The floating arm is designed to accommodate mounting points for the hinge on the same side from both the door cantilever and the pod cantilever. To resist the expected bending moment a flange is also present along the periphery of the floating arm, toward the interior of the pod to allow access to the pins in the hinges for easy removal of the door. The part is notched along the bottom where it is expected to rest against the edge of the pod while the door is fully open. Extraneous stresses were recorded near the notch in the bottom of the part, however, outside of these small highly concentrated zones the safety factor of the part did not drop below 2.

3.6 POD SHELL DESIGN

The other shell of the cargo pod has the role of carrying the aerodynamic loads from the OML of the pod to the ribs along the interior of the pod. The only fastening method considered to bridge append the skin to the ribs was countersunk bolts, as they offer the best blend of strength and maintaining an aerodynamic outer surface of the cargo pod. The outer shell is cored in sections, which tapers to a laminate structure where the ribs attach.

A number of pod shell concepts were considered, with the basic requirement from our client being low overall deflection, stresses amicable to repeated loading cycles with simple panel stress/deflection calculations to justify our choice. Ultimately, a CFRP skin adhered to 1” thick nomex core proved to be the most attractive option, offering an excellent compromise between weight, price and manufacturability.

Initial concepts were limited to metallic constructs, sheet Aluminum skin over low density Aluminum honeycomb core. This option was attractive because these are materials that EMTEQ has easy access to and has experienced technicians already on site to accommodate the new product. Challenges incurred with this construction include having to form the Aluminum honeycomb core to fit the proposed contours of the pod, this on top of our contact’s interest in a composite sandwich structure ultimately ended our exploration of this design.

Switching to a composite sandwich structure required a number of alterations to the design philosophy, as composites have unique manufacturing and assembly requirements when compared to metals. With a composite structure it is not desirable to fasten metallic stringers and stiffeners to the cored section, so this required a great deal of rethinking the layout of our pod. With an all metal construction ribs can stiffen the panels as often as necessary however, with composite panels that require a core chamfer in order to make fastener attachment points, this is a great deal less convenient. It was for this reason that we looked into splitting up the paneling as little as possible, starting with four and ultimately ending up with five ribs between the front and end caps.

A monocoque structure was considered however, due to the size of the pod the effective load transfer from the skin of the monocoque to the mounting points comes into question. Though EMTEQ did not require a detailed stress analysis of the structure, part of the reason this idea was not pursued was due to the complex process required to adequately analyze it. Mounting a monocoque structure to discrete mounting points on the frame of the plane while not transferring too much load into the wing-to-body fairing was also a concern and ultimately ended that avenue of design consideration.

The chosen design, a cored shell with aluminum ribs running along the mid-section allows for the best aspects of both previously discussed designs. The composite outer shell is relatively light and very robust, and since load is transferred into the ribs and from the ribs to the attachment points on the belly of the plane we can be much more confident that the cargo pod will not damage the wing-to-body fairing.

3.6.1 LAMINATE SCHEDULE DESIGN

Even though a detailed stress and deflection analysis of the structure of this cargo pod is beyond the scope of this project, a certain amount of information about the expected stresses and deformations is valuable. For the purpose of setting up getting this insight and applying it for the rib spacing, a simplified panel deflection analysis was performed, following the Hexcel Panel Design Handbook [13]. For this purpose the cargo pod was split into sections as depicted below:

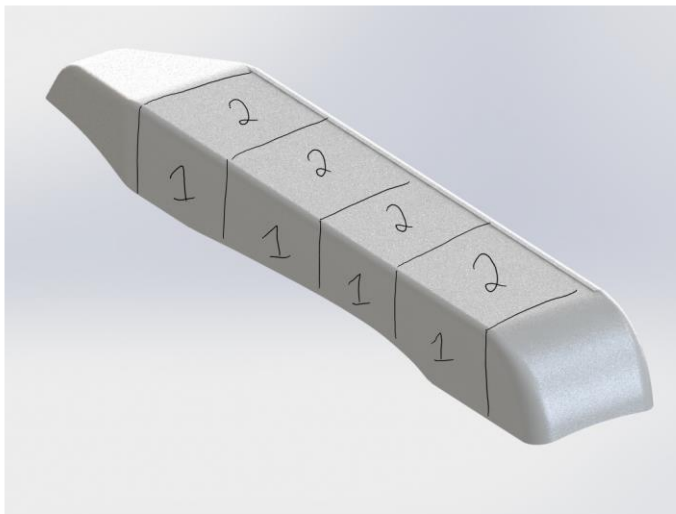

FIGURE 51 POD EXTERIOR, DIVIDED INTO SECTIONS

These section divisions were assumed to behave as simply supported plates to reduce the complexity of the analysis. This assumption is assumed to be valid for determining required spacing between ribs and should not be used to determine actual panel deflections or stress values in the panel skins.

The number of ribs required was assumed to be four as a baseline, given the total length of the straight section of the pod as provided by our client, this resulted in a total length of 3150mm. For the sake of simplifying this analysis further, the largest (and therefore worst case) section size was assumed for each section.

3.6.1.1 SUMMARY OF EQUATIONS

$$L = Length\ of\ panel$$

$$W = Width\ of\ panel$$

$$b = larger\ of\ L, W$$

$$a = smaller\ of\ L, W$$

$$A = Area\ of\ panel\ (L * W)$$

$$t_f = Skin\ thickness$$

$$t_c = Core\ thickness$$

$$h = Panel\ center\ to\ center\ height\ (t_f + t_c)$$

Three plate coefficients are used for the simply supported plate assumption. The first metric is the L:W ratio.

$$\frac{b}{a} = Greater\ of\ (L/W)\ or\ (W/L)$$

R is the second plate coefficient, the ratio of the longitudinal and transverse core shear modulus; defined as

$$R = \frac{G_{L,Core}}{G_{W,Core}}$$

V is the plate coefficient, a ratio of the skin tensile modulus and thickness, compared with the width of the panel and the transverse core shear modulus, defined as

$$V = \frac{\pi^2 E_f * t_f * h}{2b^2 * G_w * \lambda}$$

These values are then used to find the values of constants K_1, K_2 and K_3

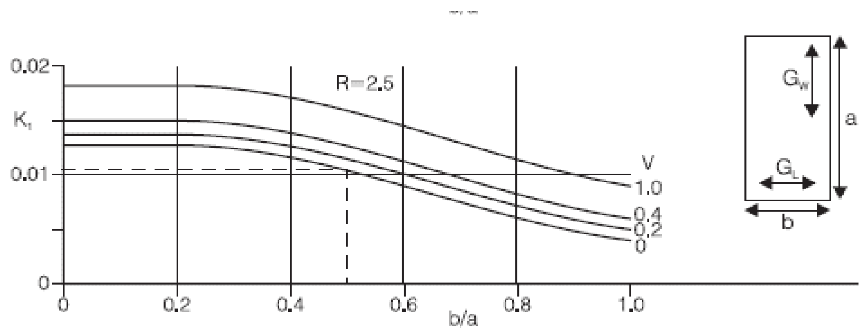

FIGURE 52 K1 VS B/A AND V

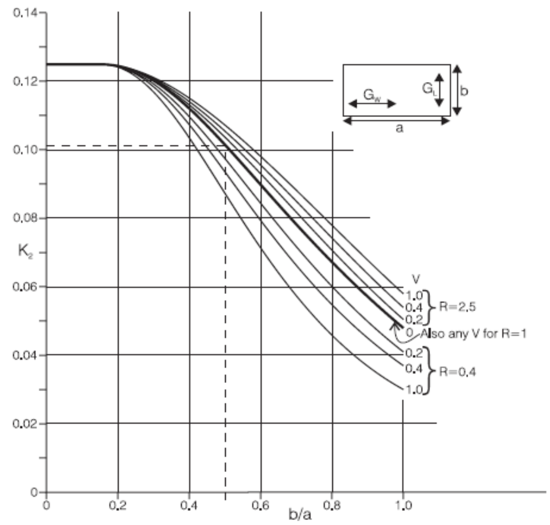

Figure 2 - K_2 for determining facing stress σ

FIGURE 53 K2 VS B/A AND V

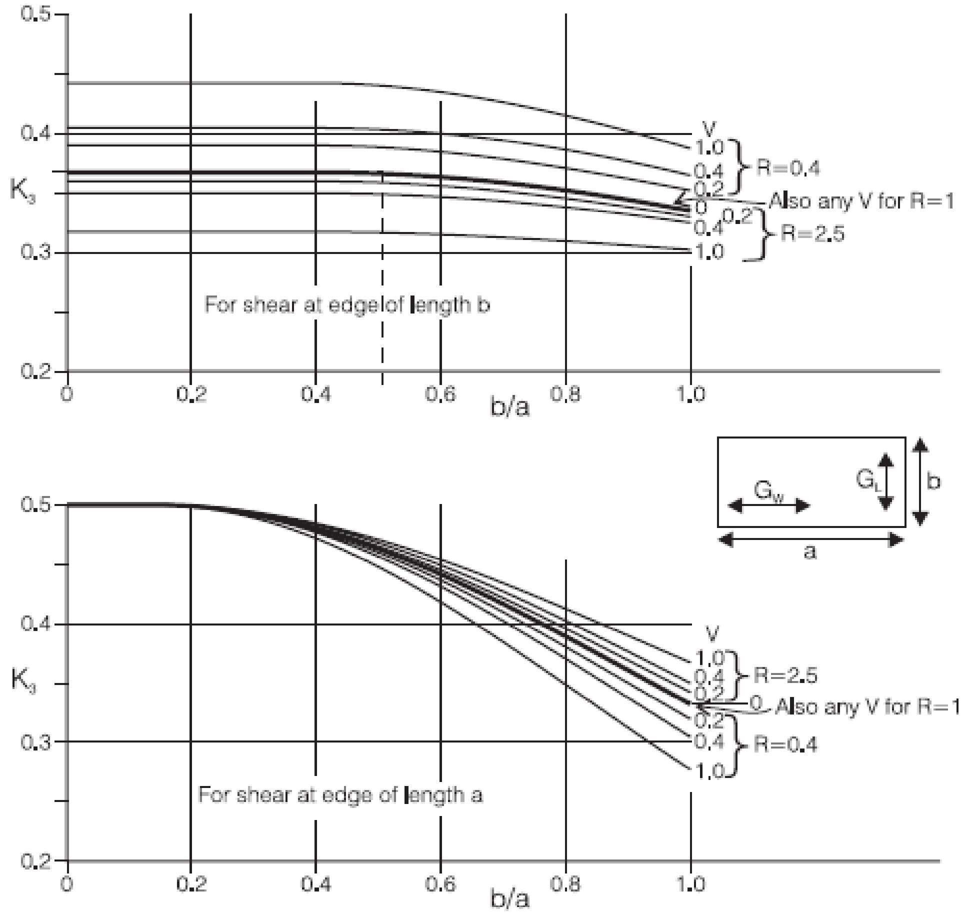

Figure 3 - K_3 for determining maximum core shear stress t_c

FIGURE 54 K3 VS B/A AND V

$$\text{Deflection} = \boldsymbol{\delta} = \frac{2K_1\, q\, b^4 \boldsymbol{\lambda}}{E_f\, t_f\, h^2}$$

$$\text{Facing Stress} = \boldsymbol{\sigma}_f = \frac{K_2\, q\, b^2}{h\, t}$$

$$\text{Core Shear} = \boldsymbol{\tau}_c = \frac{K_3\, q\, b}{h}$$

FIGURE 55 DEFLECTION, FACING STRESS AND CORE SHEAR EQUATIONS

3.6.1.2 ISOTROPY ASSUMPTION

The described analysis assumes that the skins are isotropic, that is that the coupling matrix B for the lay-up of both skins is near zero. For the materials used:

TABLE 4 CHOSEN LAMINATE PROPERTIES

Skin Material: Hexcel G793-5HS Woven CFRP					
Tensile Str	1.16E+05	psi	Thickness	0.1	In
E	1.02E+07	psi	h	1.1	in
v	0.33				

Core Material: Hexcel HRH10 Nomex 0.125" cell					
Density	0.00231481	(lb/in^3)	R	1.8	
Thickness	1	in	G(L)	9137.387	psi
E	27557.1993	psi	G(W)	5076.326	psi

Using a free Classical Laminate Theory analysis suite called The Laminator™, an analysis of a proposed quasi-isotropic lay-up was performed. For the input data above, an ABBD stiffness matrix was generated to confirm that the isotropy assumption is justified.

Layer	Ply Angle
1	0.0
2	0.0
3	45.0
4	0.0
5	45.0
6	90.0
7	-45.0
8	0.0
9	-45.0
10	90.0
11	90.0
12	-45.0
13	0.0
14	-45.0
15	90.0
16	45.0
17	0.0
18	45.0
19	0.0
20	0.0

FIGURE 56 PROPOSED LAMINATE SCHEDULE

This schedule is symmetric around ply 10 and 11, every 45 degree ply is reciprocated with a -45 degree ply (since the proposed 5 harness weave is not symmetric), and uses fewer 45/-45 degree ply orientations since high shear loading isn't anticipated in the paneling. Note that the total thickness of this lay-up is 0.21 inches, however the panel deflection equations define the skin thickness as the laminate thickness on top and below the core, hence 0.105 inches

This laminate schedule results in an ABD stiffness matrix of:

```
 3.909e+008   2.403e+007   0.000e+000   -5.093e-011  -4.093e-012  -6.821e-013
 2.403e+007   3.788e+008   1.956e-008   -4.093e-012  -8.004e-011  -4.547e-013
 0.000e+000   1.956e-008   1.774e+008   -6.821e-013  -4.547e-013  -7.276e-011

-5.093e-011  -4.093e-012  -6.821e-013    1.210e+003   6.778e+001   9.741e+000
-4.093e-012  -8.004e-011  -4.547e-013    6.778e+001   1.107e+003   9.741e+000
-6.821e-013  -4.547e-013  -7.276e-011    9.741e+000   9.741e+000   5.279e+002
```

FIGURE 57 ABD STIFFNESS MATRIX

Since the coupling terms (the B matrices) are all miniscule compared to D matrix values, we can assume that the panel with this laminate schedule will behave as an isotropic skin, for the purposes of this analysis.

3.6.1.3 ANALYSIS RESULTS

The results of this analysis are tabulated below.

TABLE 5 PANEL PROPERTIES

#	L (in)	W (in)	A (in^2)	b/a	R	V	K1	K2	K3
1	29.68	20.18	**598.95**	**0.68**	**1.8**	**1.4**	**0.012**	**0.12**	**0.37**
2	29.68	32.88	**975.89**	**0.90**	**1.8**	**1.4**	**0.008**	**0.12**	**0.37**

This results in deflection and stress values of:

TABLE 6 PANEL ANALYSIS RESULTS

Q[psi]	δ[in]	σ (face)[psi]	τ (Core)[psi]
70	**0.20**	**3.11E+04**	**475**
70	**0.95**	**8.26E+04**	**774**

Per conference with our client, these values are acceptable justification for this preliminary design of the rib spacing and panel skin lay up.

3.6.2 THE FRONT CLOSEOUT

The geometry of the front closeout of the outer shell was defined by the OML that EMTEQ provided. The front closeout is expected to endure the most aerodynamic loads while in flight, both from breaking the slipstream around the plane and due to the wide shape required in order to accommodate the golf bags.

The front closeout is a composite sandwich monocoque structure consisting of a symmetrical layup of ten Hexcel G793-5HS Woven CFRP plies adhered to either side of 1.0" 4lb/ft^3 Hexcel HRH10 Nomex core. This relatively light Nomex core has the primary purpose of separating the two skins in order to improve flexural properties of the closeout, as this type of structure should not experience significant through thickness shearing.

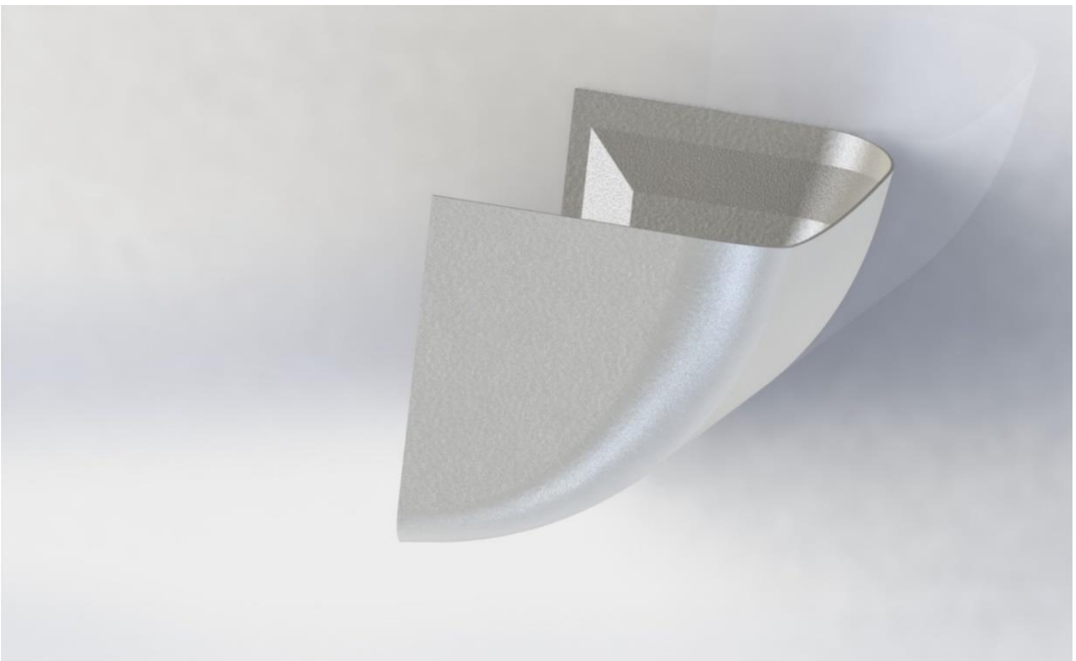

FIGURE 58 FRONT CLOSEOUT CONTOUR

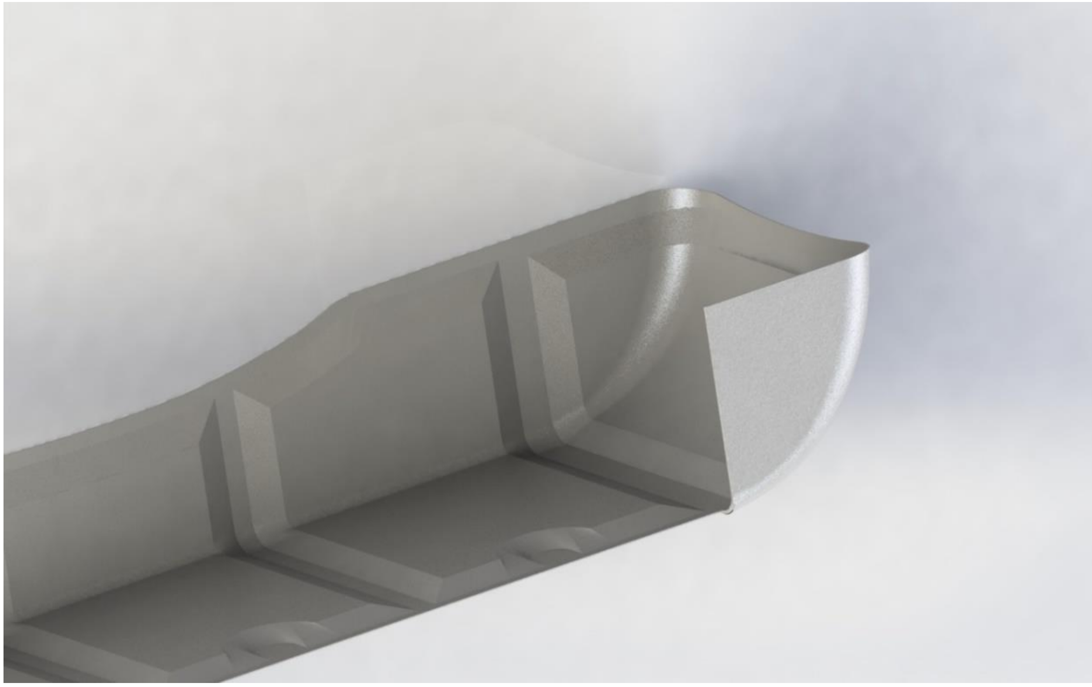

FIGURE 59 FRONT CLOSEOUT TRANSITION

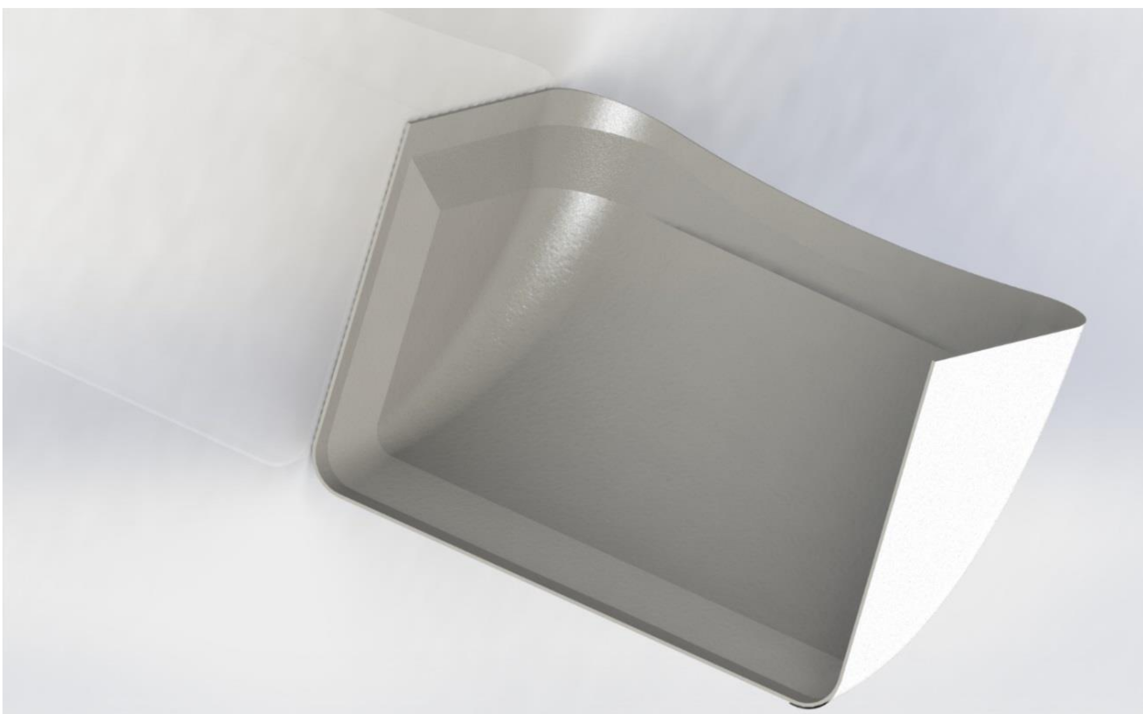

FIGURE 60 FRONT CLOSEOUT INTERIOR

3.6.3 THE MID SECTION

The Mid Section of the cargo pod will carry the majority of the cargo's weight, and as such is equipped with ribs to ameliorate the effect of this added loading. In addition, due to the presence of a slipstream along its exterior combined with the aerodynamic loads of the plane moving through air, this portion of the pod will experience a great deal of interlaminar shear.

The rib cross section was chosen with the guidance of our client, channel stock with dimensions of 2”x1”x0.13” was selected as it is a standard size and within the capabilities of EMTEQ facilities to bend to shape. These ribs mock the contour of the interior of the pod (that is, offset 0.2” from the OML EMTEQ provided for the pod), and therefore requires two 2” radius bends.

The spacing of the ribs within this section was designed earlier in this section, with the 29.68 inch value being the largest space between any two adjacent ribs. Since the intended function of the mid-section is to carry the golf bags we decided that the pouch on the golf bags should fit between two adjacent ribs, at the front and back of this section of the pod, in order to give us an additional two inches of total width to fit the golf bags inside the pod.

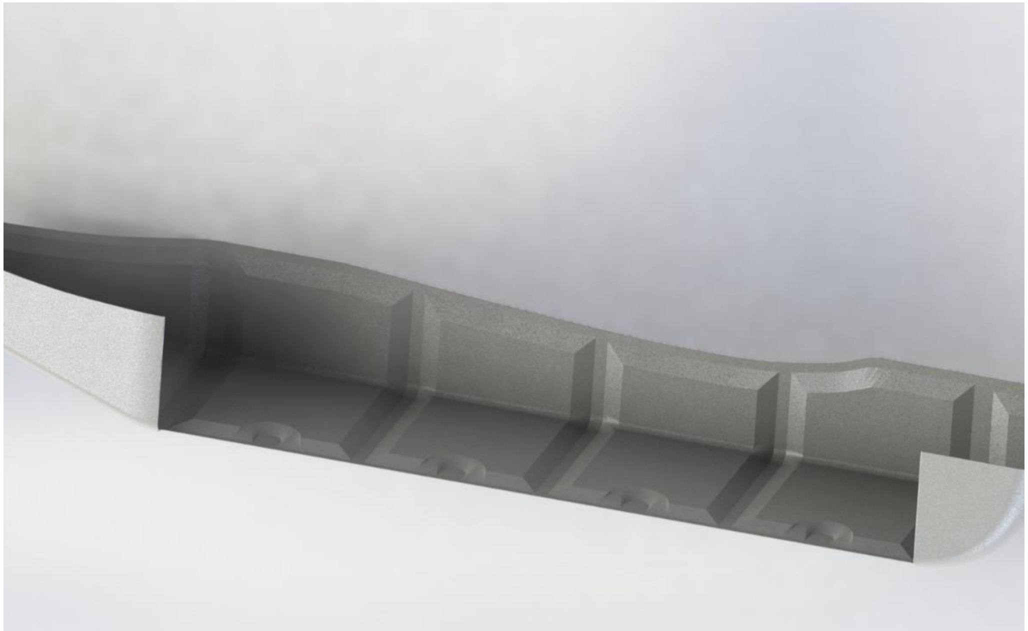

FIGURE 61 PANEL MID-SECTION WITHOUT RIBS

3.6.3.1 PANEL-RIB FASTENING DESIGN

In order to provide our client a more accurate preliminary bill of materials for this design, a simplified bolted fastener design was carried out. A number of assumptions are used to simplify the process.

1. The pivot point of the bending (and the moment balance) is at the fillet of the rib profile as depicted.

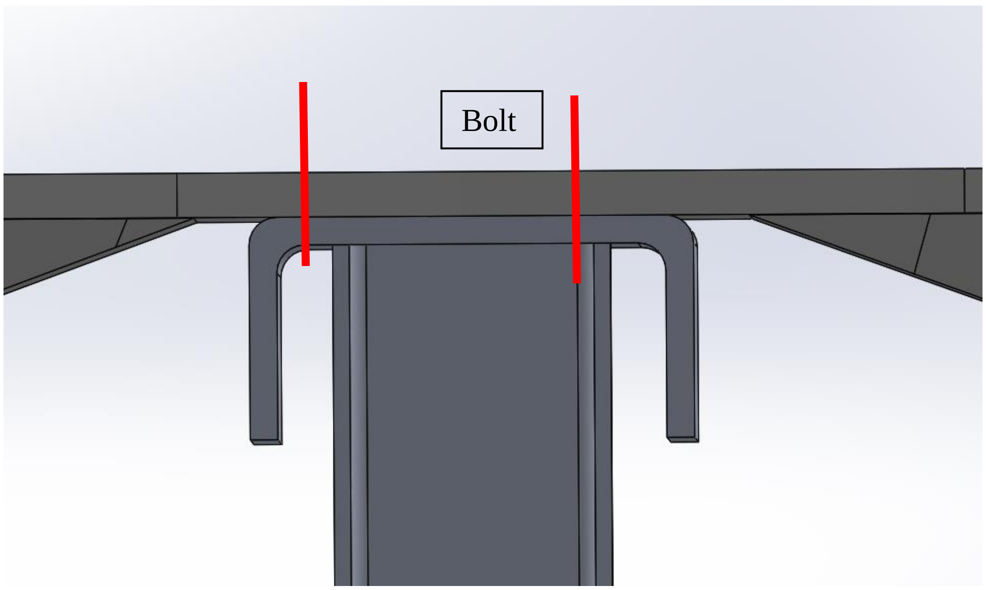

FIGURE 62 BOLT LOCATION RELATIVE TO PIVOT POINT

2. Two rows of bolts is ideal, and they shall be evenly spaced from the flanges and the center of the rib profile.
3. Each bolt supports the panel adjacent to it equally in a perfectly symmetrical fashion
4. The reaction force of the two columns of bolts must be greater than the pressure load on the panel
5. The strength of these bolts is approximately 85ksi [14]
6. The Tensile Area of the bolts is given by the expression:

$$Area = \frac{Pressure\ Load\ on\ Panel}{(\#\ of\ bolts) * 42.5ksi}$$

Using the panel sizes dictated in the panel design section:

TABLE 7 BOLT SPACING LOADING

#	Length	Width	Area (in^2)	q	q*A (psi)	q*A/2 (psi)
1	29.68	20.18	598.9424	70	41925.968	20962.984
2	29.68	32.88	975.8784	70	68311.488	34155.744

TABLE 8 BOLT SPACING FOR PANEL SECTION 1

Spacing	# of bolts	Load per bolt	Tensile Area	Bolt Size
0.5”	41	511.3	0.012	8-32 (0.164”)
0.75”	27	776.4	0.0183	12-24 (0.216”)
1”	21	998.2	0.0234	12-24 (0.216”)

TABLE 9 BOLT SPACING FOR PANEL SECTION 2

Spacing	# of bolts	Load per bolt	Tensile Area	Bolt Size [15]
0.5”	66	517.5	0.0122	8-32 (0.164”)
0.75”	44	776.3	0.0183	12-24 (0.216”)
1”	33	1035	0.0243	¼-20 (0.25”)

Based on this analysis the optimal bolt size and spacing is 12-24 Countersunk Bolts, spaced 1” apart on Panel 1 and spaced 0.75” apart on panel 2.

Rib	Rows	Bolts Per Row	
1	1	86	86
2	2	86	172
3	2	86	172
4	2	86	172
5	1	86	86
Total:			**688**

3.6.4 THE DOOR JAMB

The door jamb runs along where the door and the cargo pod's outer shell meet. This door jamb is required to maintain a seal between the two bodies however, as minimal loading is expected along its extent it only serves as a fairing between the body of the pod and the edge of the door.

The reciprocated door jamb on the mid-section of the pod requires fairing in order to not disrupt the slipstream of the plane, and therefore this feature is smoothed out in the model. The door jamb faces should be match machined to ensure proper contact during flight.

3.6.5 THE AFT CLOSEOUT

The aft closeout of the cargo pod runs along the wing to body fairing and along the aft fuselage, gradually closing out the slipstream envelope around the cargo pod. This feature of the structure is expected to incur a similar extent of interlaminar shear as the mid-section of the pod and relatively little loading normal to its surface, and therefore we expect the structural requirements to be similar to the mid-section, spare the requirements for ribs along its length. For this reason we do not anticipate the stack up required to change at all from the mid-section, it will maintain the previously discussed Hexcel G793-5HS Woven CFRP laminate schedule, adhered to 1.0" 4lb/ft^3 Hexcel HRH10 Nomex core.

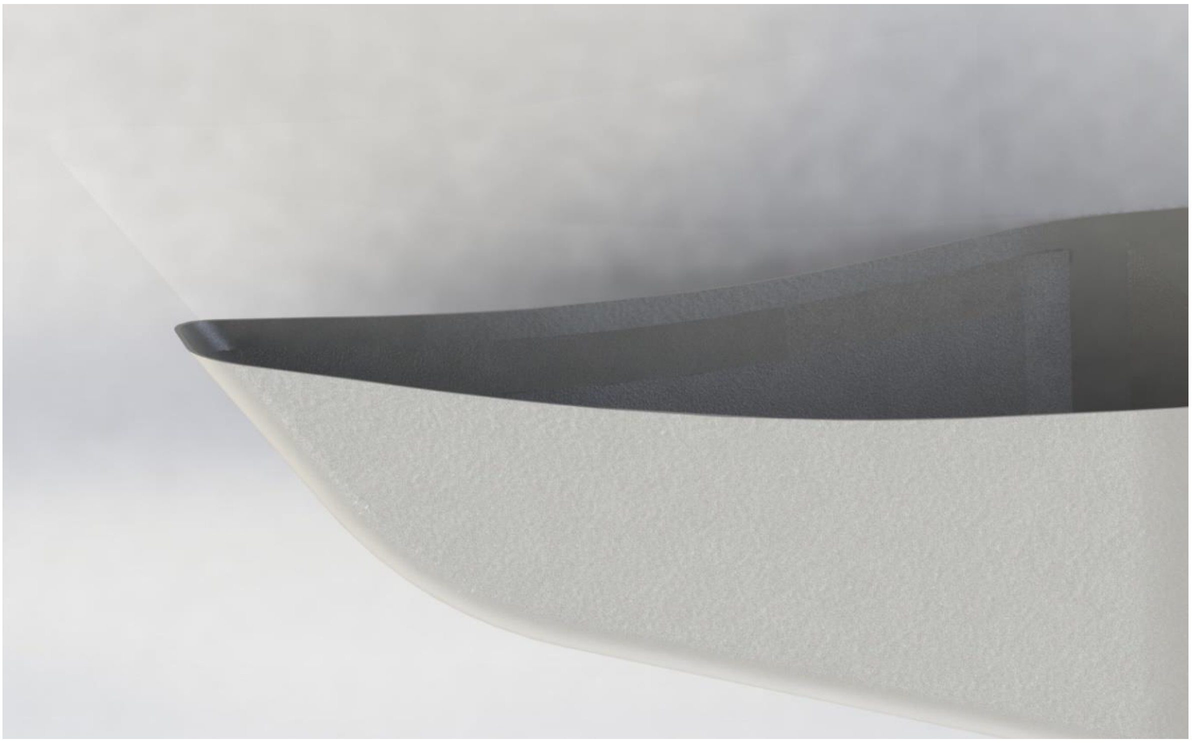

FIGURE 63 AFT CLOSEOUT EXTERIOR

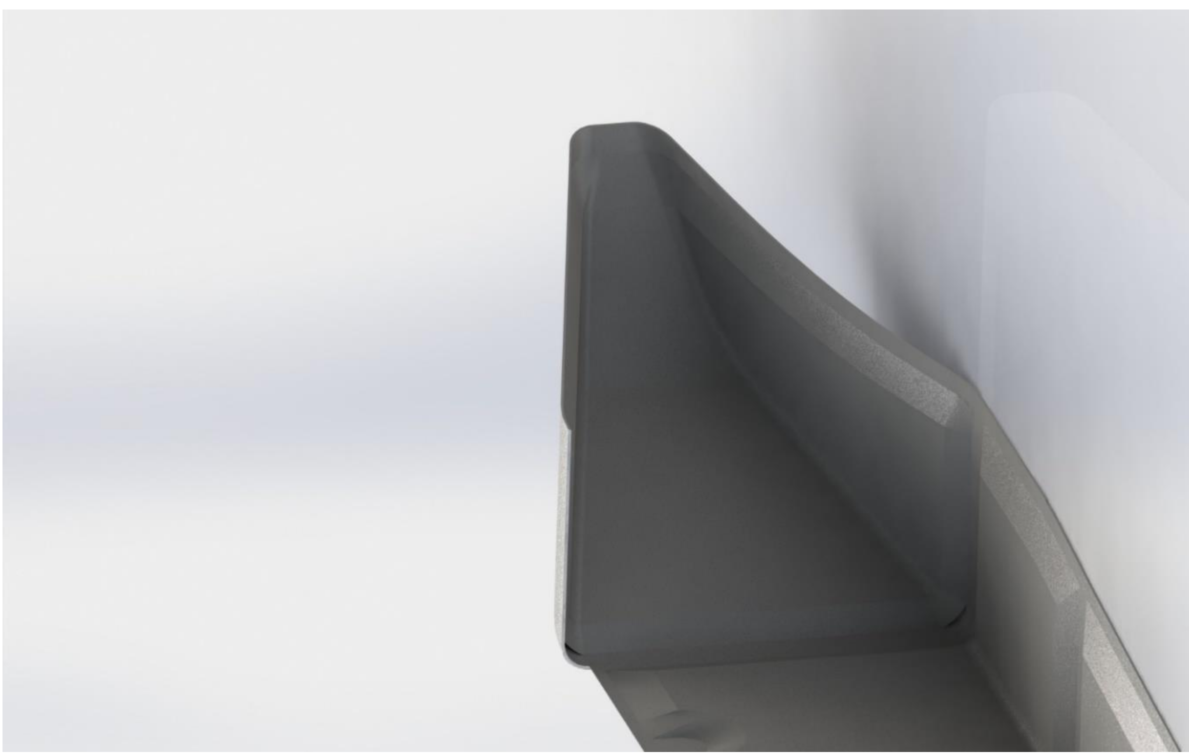

FIGURE 64 AFT CLOSEOUT TRANSITION

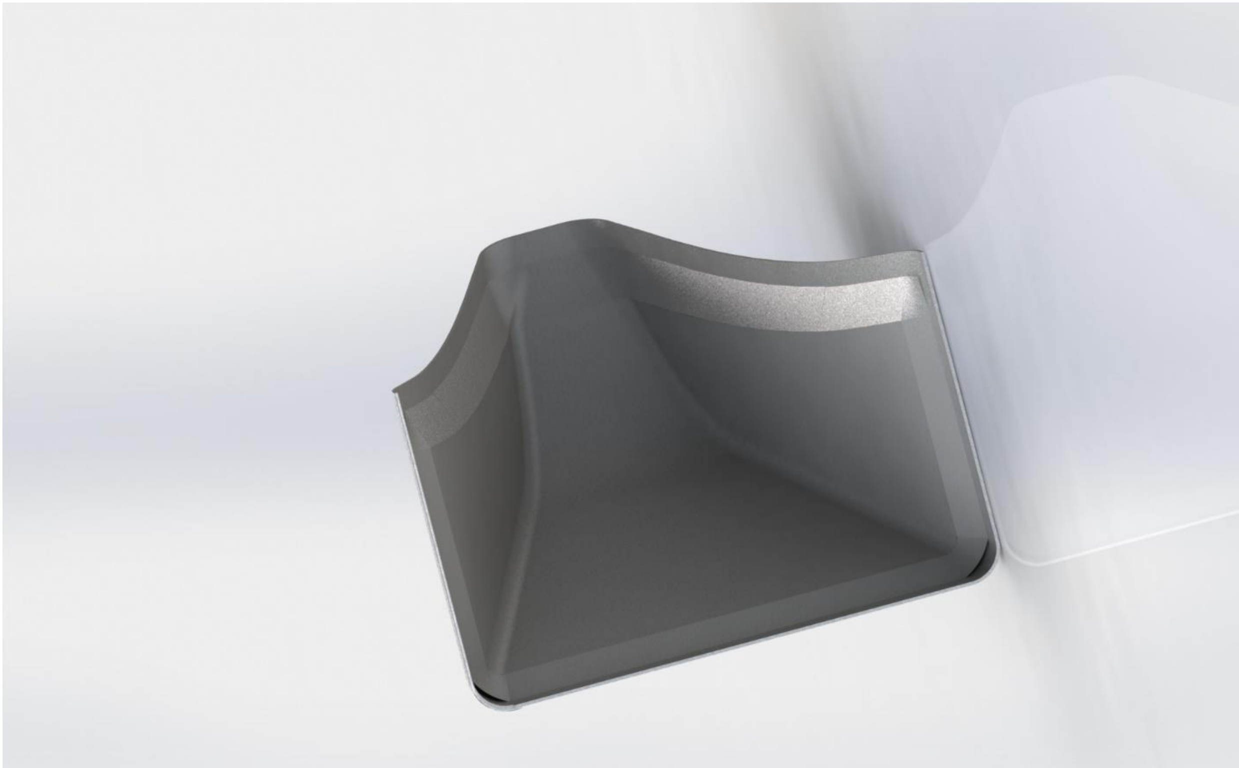

FIGURE 65 AFT CLOSEOUT INTERIOR

3.7 COST ANALYSIS

The following is a cost estimate for the materials and labor that would be needed to construct the any cargo pod variation based on Tables XII and XIII. This includes composites, metals, fasteners, labor, manufacturing processes and so on. Beneath each of the tabulated summaries is a note providing any special details related to the specific cost evaluation. Terms such as the tail end cap, mid-section, and front end cap refer to the front, middle and rear of the cargo pod, respectively.

TABLE 10 AREA ESTIMATE NEEDED FOR CARBON FIBER COMPOSITE

Section	Length	Width	Area (sqft)	Waste (0/90)	Waste (45/-45)	Effective area per ply
Tail end cap	45.5	47	14.85	0.1	0.2	17.08
Mid-section	123.8	49.25	42.34	0.2	0.3	52.93
Door	123.8	20	17.20	0.2	0.3	21.49
Front end cap	25.11	30.5	5.32	0.2	0.2	6.38
Total			79.71			97.89

Note: A waste column was added for both 0/90 and 45/-45 plies in order to cover the material that would be wasted between stencils on the cloth cutter bed. Since the tail end cap is triangular, it will waste very little material when cut in 0/90, and due to the long length of the mid-section and door they will likely waste a great deal in 45/-45.

TABLE 11 COST ESTIMATE FOR CARBON FIBER PREPREG [16]

Section	Ply count	Total Area (ft^2)	Roll Width (ft)	Total yardage	Unit Cost	Cost
Tail end cap	15	256.2	5	17.1	$70	$1195.48
Mid section	15	794.0	5	52.9	$70	$3705.16
Door	15	322.4	5	21.5	$70	$1504.64
Front end cap	20	127.6	5	8.5	$70	$595.66
Total		1500.2		100		$7000.95

Note: Since the front end cap is not split like the door and mid-section, additional reinforcing plies should be employed in order to maintain a uniform strength since strength of the carbon fiber will be lost from the draping required to fit it into radii on both sides of the section.

TABLE 12 AREA ESTIMATE NECESSARY FOR NOMEX CORE

Core	Length	Width	Height	Waste	Total Area
Tail end cap	40.5	42	1	0.3	2211.3
Mid-section	118.81	44.25	1	0.1	5783.1
Door	118.81	15	1	0.1	1960.4
Front end cap	20.11	25.5	1.25	0.1	564.1
Total					10518.8

TABLE 13 COST ESTIMATE FOR NOMEX COMPOSITE MATERIAL [17]

Core	Total Area (sqft)	Unit cost (/sqft)	Total Cost
Tail end cap	15.36	$7.5	$115.17
Mid-section	40.16	$7.5	$301.20
Door	13.61	$7.5	$102.10
Front end cap	3.92	$7.5	$29.38
Total	73.05		$547.85

Note: We were unable to find a price for fiberglass core, nor were our RFQs replied to so we carried out this section of the cost report on Nomex core, a cheaper yet lower strength alternative.

TABLE *XIV*: COST ESTIMATE FOR ALUMINUM EXTRUSION USE [16]

Rib	Length (in)	Unit Cost $/96in	Bends	Unit Cost (/bend)	Total Cost
Front	69.25	18.88	2	$16	$50.88
Second	66	18.88	2	$16	$50.88
Third	64	18.88	2	$16	$50.88
Fourth	64	18.88	2	$16	$50.88
Fifth	65	18.88	2	$16	$50.88
Total					$254.4

Note: Each bird cage rib runs along the side of the pod and along the floor in a U shape. All ribs contain two 90^0 bends with a radius of 2”, our unit cost per bend is based off an estimate from FSAEonline [17].

3.7.1 LABOR COST

In order to improve the accuracy of the cost estimate of this design, and to reflect the design work needed to carry this product to a state where a prototype can be made, our client has requested that we add the cost of one experienced Aerospace Engineer to work on the project for a forty hour week – the amount of time the team has estimated to be required to carry the cargo pod from its current state to something that can be prototyped and pursued further. The hourly cost of this engineer was dictated by our client. Four hours to familiarize the engineer with the project, its goals and current state. Fifteen hours for composite stack-up definition and analysis. Fifteen hours to connect the attachment points and the ribs of the pod, including the conceptual design of the structure and formal analysis of aerodynamic loading. Finally, eight hours to provide drawings, models and instructions necessary to create the first prototype.

TABLE 15 ENGINEERING LABOR COST

Number of Engineer(s)	Rate/time	Total time required	Total
1	$100/hour	42 hours	$4200

3.7.2 COST ANALYSIS OF MANUFACTURING PROCESSES

Manufacturing of the frame, access door and attachment will be done by a contractor. The detailed manufacturing process cost is as follows:

TABLE 16 MANUFACTURING PROCESS COSTING

Process	Unit Cost	Amount	Cost
Cure, Autoclave	$ 50.00/m^2	9.09m^2	$454.5
Lamination, Manual	$ 35.00/m^2	140m^2	$4900.00
Ratchet <= 25.4 mm	$ 0.75/unit	730units	$547.50
Adjustment - Misc.	$ 5.00/unit	73units	$365.00
Assemble, 1 kg, Interference	$ 0.19/unit	15units	$2.85
Assemble, 1 kg, Line-on-Line	$ 0.13/unit	15units	$1.95
Assemble, >10 kg, Interference	$ 1.88/unit	1unit	$1.88
Cut (scissors, knife)	$ 0.06/cm	25152cm	$1509.12
Drilled holes < 25.4 mm dia.	$ 0.35/hole	760 holes	$266.00
Hand Finish - Material Removal	$ 2.00/cm^3	3030 Cm^3	$6060.00
Hand Finish - Surface Preparation	$ 0.02 /cm^2	90900 cm^2	$1818.00
Machining	$0.04/$cm^3$	3650 Cm^3	$ 146.00
Tube bends	$ 0.75/bend	10 bends	$7.50
Tube cut	$ 0.15/cut	15 cuts	$2.25
Total			$16095.08

3.7.2.1 PROCESS COSTING DETAILS

Process	Details
Cure, Autoclave	The surface of the laminated material must be cured, this area is simply the OML provided by EMTEQ.
Lamination, Manual	Three times the area of each ply, assuming that three laminators are required
Ratchet <= 25.4 mm	Installation of a single bolt.
Adjustment - Misc.	One 'adjustment' per ten bolts.
Assemble, 1 kg, Interference	The assembly of the hinges, attachment points, and rib sections.
Assemble, 1 kg, Line-on-Line	Placement of the above parts on the pod
Assemble, 10 kg, Interference	Installation of the door on the pod
Cut (scissors, knife)	Defined as the total perimeter of the individual lamina
Drilled holes < 25.4 mm dia.	Drilled holes for the bolts, through the pod and the ribs.
Hand Finish - Material Removal	Assuming waste (that needs to be removed by hand) of 3%.
Hand Finish - Surface Preparation	All surfaces that are cured must first be prepared
Machining	Approximately 4000cm^3 of Aluminum must be machined away.
Tube bends	Each rib is bent twice
Tube cut	Each rib is cut three times.

3.7.2.2 HINGE ASSEMBLY COSTING

3.7.2.2.1 THE POD CANTILEVER

The pod cantilever is machined from a single piece of Aluminum 6061-T6 billet. Two machining passes will be required in order to cut away all the removed material.

TABLE 17 POD CANTILEVER COSTING

Material	Aluminum 6061 T6	Part Name	Hinge: Pod Cantilever
Work Envelope (in)	4	3.4	0.35
Total Volume (in^3)	0.9	Work Envelope (in^3)	4.76
Machined Volume (in^3)	3.86	Machining Cost	$ 3.80
Machining Set Ups	2	Set up Cost	$ 2.60
Holes Drilled (ea)	11	Holes Drilled Cost	$ 2.20
Total cost: $8.60			

3.7.2.2.2 THE DOOR CANTILEVER

Two possible machining processes were explored for the Door Cantilever, since the part has such a large work envelope compared to its actual volume. Wire EDM offers considerable per unit savings in production cost (11% of unit cost) if production volume merits the additional process.

TABLE 18 COSTING FOR THE DOOR CANTILEVER

Material	Aluminum 6061 T6	Part Name	Hinge: Door Cantilever
Work Envelope	4	2.5	3
Total Volume (in^3)	1.03	Work Envelope (in^3)	30
Cut Length (in)	7	Wire EDM Cost	$ 3.56
Total Volume	1.03	Work Envelope (in^3)	22.8
Machined Volume (in^3)	21.77	Machining Cost	$ 21.41
Machining Set Ups	2	Set up Cost	$ 2.60
Holes Drilled (ea)	11	Holes Drilled Cost	$ 2.20

Total cost: $29.77

Material	Aluminum 6061 T6	Part Name	Hinge: Pod Cantilever
Work Envelope	4	2.5	3
Total Volume (in^3)	1.03	Work Envelope (in^3)	30
Machined Volume (in^3)	28.97	Machining Cost	$ 28.50
Machining Set Ups	2	Set up Cost	$ 2.60
Holes Drilled (ea)	11	Holes Drilled Cost	$ 2.20

Total cost: $32.30

3.7.2.2.3 FLOAT ARM

The Float arm is easily machined from a single piece of Aluminum 6061-T6 billet. A single machining pass is required to produce all the design features.

TABLE 19 COSTING FOR THE FLOAT ARM

Material	Aluminum 6061 T6	Part Name	Hinge: Float Arm
Work Envelope	1.5	0.85	1.3
Total Volume (in^3)	0.25	Work Envelope (in^3)	1.6575
Machined Volume (in^3)	1.4075	Machining Cost	$ 1.38
Holes Drilled (ea)	4	Holes Drilled Cost	$ 0.40

3.7.2.2.4 ASSEMBLY COST

The total cost of the hinge assembly is tabulated below. Individual fastener costs are in the fastener section.

TABLE 20 COSTING FOR THE HINGE ASSEMBLY

Process	Unit Cost	Amount	Cost
Ratchet <= 25.4 mm	\$ 0.75/unit	104units	\$78.00
Adjustment - Misc.	\$ 5.00/unit	10units	\$50.00
Assemble, 1 kg, Interference	\$ 0.19/unit	15units	\$2.85
Drilled holes < 25.4 mm dia.	\$ 0.35/hole	104 holes	\$36.40
Hand Finish - Surface Preparation	\$ 0.02 /cm^2	160 cm^2	\$8.00
Machining	\$0.04/cm^3	3368 cm^3	134.72
Total			\$309.97

TABLE 21 DETAILS OF THE HINGE ASSEMBLY COSTING

Process	Comments
Ratchet <= 25.4 mm	All bolts must be fastened with a ratchet
Adjustment - Misc.	One ‘adjustment’ every five bolts
Assemble, 1 kg, Interference	Assemble each part onto the assembly
Drilled holes < 25.4 mm dia.	Holes drilled through the aluminum and the pod
Hand Finish - Surface Preparation	Preparing the Aluminum surface of the hinge pod and door cantilevers for contact with the carbon fiber pod and door.
Machining	Total machining cost of the components

3.7.2.3 LATCH COST

The latch itself is a purchased component, available for $323.19 per unit (includes entire assembly and bolts) [18].

TABLE 22 COSTING FOR THE LATCH ATTACHMENT PLATE

Material	Aluminum 6061 T6	Part Name	Latch attachment plate
Work Envelope	7.8	3.27	1
Total Volume (in^3)	3.61	Work Envelope (in^3)	25.5
Machined Volume (in^3)	21.8	Machining Cost	$ 21.34
Holes Drilled (ea)	6	Holes Drilled Cost	$ 1.20

Total cost: $22.54 each

TABLE 23 LATCH ASSEMBLY COST

Process	Unit Cost	Amount	Cost
Ratchet <= 25.4 mm	$ 0.75/unit	24 units	$18.00
Adjustment - Misc.	$ 5.00/unit	3 units	$15.00
Assemble, 1 kg, Interference	$ 0.19/unit	9 units	$1.71
Drilled holes < 25.4 mm dia.	$ 0.35/hole	18 holes	$36.40
Machining	$0.04/cm^3	1600 cm^3	$64.02
Latch	$323.19/ ea	3	$969.57
Total			$1104.70

TABLE 24 COSTING FOR ASSEMBLY OF LATCHES TO DOOR

Process	Unit Cost
Ratchet <= 25.4 mm	All the bolts to be tightened in the entire assembly
Adjustment - Misc.	One adjustment per latch assembly
Assemble, 1 kg, Interference	Three assembly stages per latch; assembling the latch, attaching the keep to the bird cage, attaching the latch to the door rib.
Drilled holes < 25.4 mm dia.	Every hole drilled in the latch attachment plate
Machining	The total volume of aluminum machined out of an ingot with the required exterior dimensions
Latch	The price for each latch assembly, bought from the manufacturer.

3.7.3 FASTENERS COSTS

All fasteners present in the rib assembly are FHSC 12-24, Flat Head Socket Cap screws in ¾" length. The best price we could find with adequate performance was $9.48 per pack of ten [14], coupled with Alloy steel nuts at $3.94 per pack of 50 [15]. The pod attachment hardware uses custom AN7 bolts [19], furnishing these bolts is are AN960-08 Washers (pack of 100) [20], and AN365-6 Nuts [21].

Fasteners	Unit Cost	Amount	Cost
Alloy Steel FHSC	$ 9.48/ 10ea	69	$654.12
Alloy Steel Nut	$3.94/ 50ea	12	$47.28
AN7 stainless custom bolt	$ 25.00/ unit	4	$100.00
AN 960-08 Washer	$ 2.79/ 100 ea	1	$2.79
AN 365-6 Nut	$ 0.99/ unit	4	$3.96
Total			$808.15

3.7.4 SUMMARY OF TOTAL COST

Section	Cost
CFRP Bodywork	$7000.95
Aluminum	$254.40
Nomex Core	$547.85
Labour	$4200.00
Manufacturing Processing	$16095.08
Hinge Assembly	$309.97
Fasteners	$808.15
Latches	$1104.70
Total	$30321.10

The total cost of our cargo pod design came out to be $30321.10. Though FAA licensing costs and tooling costs could not be determined at this time we are confident that this total will be well within the suggested budget of $150000.

4 SUMMARY

The objectives of this project were to meet the client needs that were stated in the introduction. This was to be achieved by designing a cargo pod with features that met the target specifications and ensured a coherent design. A summary of specific client needs together with the stated specifications has been indicated Section 2.2: Needs and Specifications, and have been summarized in the table below. Notice that several needs were eliminated or modified as the project proceeded due to changes in the overall scope.

TABLE XXV: PROJECT NEEDS AND TARGET SPECIFICATIONS

Needs #	Needs	Target specifications (Units)
1	The cargo pod provides sufficient space to fit four standard-size hard-shell golf bags	Internal volume of 45 cu.ft, external length of 16.5 ft, internal depth of 18 inches
2	The cargo pod provides easy access to the cargo	Internal volume of 45 cu.ft; Rate of cargo removal of 10 min per piece of luggage
3	The cargo pod utilizes the specified existing mounting points on the aircraft	Factor of Safety(FOS) of 3 for the attachment system for 0.9 σ_{yld} (yield stress) of the chosen material
4	The cargo pod's access door is to be located on the right hand side of the aircraft	Rate of cargo removal of 10 min per piece of luggage, conformity to plane's aesthetics
5	The cargo pod ensures golf bags and other cargo are not damaged during the flight	Cargo securing within the pod removed from project scope
6	The maximum cost of the cargo pod is within a given limit	Manufacturing cost below 90,000 USD, cost to customer at 150,000 USD
7	The cargo pod is as lightweight as possible	Maximum empty weight of 150 lb
8	The cargo pod's impact on the aircraft's performance is minimal	Cargo pod conforms to provided exterior surface model
9	The cargo pod's impact on the aircraft's take off and landing capabilities is nonexistent	Cargo pod conforms to provided exterior surface model
10	The cargo pod is easy to attach and detach	Access to the
11	The cargo pod volume does not require pressurization.	0 watts, 0 psi required for operation of the cargo pod

12	The cargo pod protects cargo from moisture ingress	Subjective, depends on sealing systems (no longer within scope)
13	The cargo pod is easy to use(cargo storage and removal, attachment/detachment)	Subjective, depends on design features
14	The cargo pod's exterior smoothly blends into the belly of the plane	Cargo pod conforms to provided exterior surface model
15	The cargo pod stays attached to the plane while in flight	Attachment system meets FOS of 3 for dynamic and static loads exerted on pod
16	The cargo pod is durable and has long life	Stress on skin and underlying structure below $0.8\sigma_{yld}$ (yield stress) of the component's material, attachment fixture below 0.9 σ_{yld} (yield stress) of the chosen material
17	The cargo pod's interior is easy to clean	Subjective, non-intrusive interior, and exterior surfaces
18	The cargo pod does not impact the ground as the aircraft moves on ground	Cargo pod conforms to provided exterior surface model ensuring max external depth of 18 inches
19	The cargo pod does not impact the ground during takeoff or landing	
20	The cargo pod safely drains any moisture trapped within it	Subjective
21	The cargo pod's exterior design fits in with the aesthetics of the PC-12	Subjective, cargo pod conforms to the provided exterior surface model
22	The cargo pod's access door is sealed from moisture	Subjective, depends on sealing systems (no longer within scope)
23	The cargo pod withstands aerodynamic loads during flight	Stress on skin and underlying structure below $0.8\sigma_{yld}$ (yield stress) of the component's material, attachment fixture below 0.9 σ_{yld} (yield stress) of the chosen material
24	The cargo pod does not interfere with normal operation of control surfaces	Not within project scope, exterior surface model provided
25	The cargo pod does not interfere with the normal operation of flaps	
26	The cargo pod is to be manufactured using materials within EMTEQ's manufacturing capabilities	Restricted to use of aluminum, carbon fiber composites and fiberglass composite materials and the associated mfg. processes.
27	The cargo pod is to meet the related safety standards	Construction processes meet EMTEQ's
28	The cargo pod does not interfere with aircraft equipment located within and around the attachment region	Client assurance that location of provided external surface model does not interfere with equipment
29	A safe attachment procedure for cargo pod attachment is to be designed	Removed from project scope
30	Attachment tools needed for attaching the cargo pod are to be identified/designed	Removed from project scope

The detailed design section has demonstrated that the stated target specifications have been met through the design sections as has been stated. A reiteration of the details of the major design features and how they used to meet the client needs as well as project objectives will commence beginning with the cargo pod structure and frame design, door design, attachment design, and the chosen manufacturing processes.

4.1 CARGO POD STRUCTURE AND FRAME DESIGN

The cargo pod structure was divided into two components, the composite shell and the underlying aluminum frame, and its design alone met a majority of the project objectives. For the composite shell the objectives were to provide an aerodynamic exterior surface, provide adequate interior volume to hold the cargo, ensure a lightweight design, provide attachment locations for integrated and peripheral components and ultimately ensure that overall costs are not exceeded as the majority of material is used in this area. The aluminum frame was designed to meet the following objectives: provide a rigid base to support the composite shell while enabling a sufficient volume for holding the internal cargo, provide a physical connection to the attachment point substructure and provide a secure attachment for the door latch.

For the composite shell, deflection due to aerodynamic loads was reduced by using a laminate thickness of 0.2 inches bonded to chamfered core panels with a thickness of 1 inch. These dimensions were determined by using panel defection analysis for both static loads(total mass of cargo pod) and dynamic loads(aerodynamic and acceleration loads). In this way, the cargo is protected from harsh vibrations, deflections and possible catastrophic failure of the composite structure had weaker profiles been used.

At the same time, the material use was optimized to ensure an overall lightweight design and minimized costs. Several attachment locations have been provided for the integrated aluminum reinforcing structure by providing regular spacing between the reinforcing panels. Peripheral components that need to be attached to the pod shell are the door hinges and these too have a panel free laminate section around the right floor edge of the cargo pod shell.

The underlying aluminum structure is fastened at the locations provided between the reinforcing panels in such a way that no deflection relative to the composite section occurs under any load, static or dynamic. Additionally, the overall rib side profile does not exceed the panel thickness which ensures a constant surface along the floor and wall sections and helps to achieve a useable 45 cu.ft of volume.

4.2 DOOR DESIGN

Using the updated project scope, the main functions of the cargo pod door are: to protect the cargo, to ensure easy access to the cargo pod's interior on the right side and to ensure that aerodynamic loads are not exceed on the cargo pod's surface. Indirectly, the door design also has influence on the structural performance of the cargo pod. On a minor level, the cargo pod's door needs to maintain aesthetic appeal of the cargo pod by conforming to its design. These functions were fully met through the design features of the door.

Easy access into the interior of the pod was accomplished by having a rectangular door size of approximately 17 sq.ft and a corresponding access area on the pod itself. This space was kept completely open by integrating the door's aluminum structural members into its composite structure. The integrated members serve to stiffen the door profile and minimize possible vibrations due to aerodynamic loads. They also serve as a contact frame for load transfer between the upper and lower parts of the cargo pod when the door is in the closed position which helps in reducing the overall weight of the cargo pod.

Design of the latching system and latch attachment components ensures protection of the cargo from external forces during flight and also on the ground. A machined aluminum fitting has been designed to fit on both the rib and the skin structure in order to enable ample area for latch attachment of different designs. A latch has been chosen which provides the required securing strength to keep the door closed in all conditions.

The composite structure provides a means of transferring the external aerodynamic loads to the internal structure while minimizing any deflections that would alter the pod's profile and thus its aerodynamic performance. A composite laminate skin with a thickness of 0.2 inches coupled to reinforcing cored composite panels bonded to the interior ensures minimal deflection under aerodynamic loads. The smooth exterior also conforms to the provided pod's exterior surface model and therefore meets both the cargo pod's expected aerodynamic performance and aesthetics

4.3 ATTACHMENT DESIGN

For the attachment system, the client needs the following requirements met; a firm attachment to the aircraft's mounting points, maintaining a surface compatible to the corresponding mounting location on the aircraft, and creation of an easy to use attachment system. We focused on creating the attachment fixtures that bridge the gap between the cargo pod's structure and the aircraft structure. As seen in the attachment section, there are two types of fixtures, one for the two front attachment locations, and the other for the two rear attachment locations. Each fixture consists of two main pieces, one attached to the aircraft structure and the other to the cargo pod structure. The mechanism of attachment is simple and involves the use of a custom designed bolt to locks the two parts through a common bore once two are aligned in the attachment position.

The provided mating surfaces for the aircraft-side attachment piece was adhered to and this ensures minimal adjustments and refinements are needed to put it into operation. The simple yet strong attachment method ensures an easy and safe to use system that is long lasting and can withstand the loading conditions experienced during flight.

4.4 MANUFACTURING METHODS AND PROCESSES

The materials and manufacturing methods associated with the construction of the designed features have been considered. Although a main client concern was to design the features in such a way that they can be easily manufactured at EMTEQ facilities, our material and manufacturing processes have not been affected in any way. The three main materials used in our cargo pod are carbon fiber prepreg material, Nomex core material and 6061 T6 aluminum U and L-profile extrusions. For each of these materials there are various manufacturing processes, depending on the pod component being manufactured.

For the main cargo pod and door structures, carbon fiber prepreg is measured, cut up and laid up in a mould that conforms to the desired exterior profile before being prepared for curing using several processes such as vacuum bagging and compaction. The sane is done for the cored panels by sandwiching Nomex core material between carbon fiber prepreg sheets. Different machining processes are done on the cured parts to ensure a precise fit and finish.

For the underlying aluminum ribbed structure, U, I and L-profile ribs with the required profile dimensions are bent and/or cut to fit in the required application. The two sections, composites and metal sections, are joined together using fasteners depending on the required strength for the particular area.

4.5 SAFETY

Throughout the design of the aforementioned features, safety was always a key consideration. First and foremost, we ensured that the end user's experience did not cause injury or harm due to ambiguous or difficult to operate features. This was accomplished by designing easy to use components such as the pin attachment fixtures, three piece detaching hinge and an unobstructed access area into the cargo pod. Secondly, we considered safety during the manufacturing processes involved in creating the cargo pod. As detailed in the materials and manufacturing section, we chose well established techniques of composites manufacturing, tube bending and metal fastening processes because they are tried and true processes with safety for the manufacturing team as the main consideration.

4.6 PROJECT CLOSEOUT

The table below reiterates the design summaries discussed above and presents a tabulated view of how our design features met the specified targets for each client need.

TABLE 26: DESIGN FEATURES IN MEETING THE CLIENT NEEDS

Need#	Need Statement	Design Feature	Explanation of how client needs' specifications are met by the design features
1	The cargo pod provides sufficient space to fit four standard-size hard-shell golf bags	Composite shell, Aluminum frame	Low-profile composite skin, panel and aluminum rib structure ensures 45 cu.ft of internal volume
2	The cargo pod provides easy access to the cargo	Door	Large door ensures 17 sq.ft of rectangular access

3	The cargo pod utilizes the specified existing mounting points on the aircraft	Pin attachment fixtures	Mounting fixtures exceed a FOS of 3(actual around 15)
4	The cargo pod's access door is to be located on the right hand side of the aircraft	Door	Door located on the right side
5	The cargo pod ensures golf bags and other cargo are not damaged during the flight	Cargo pod structure,	Composite shell and aluminum frame can withstand loading conditions, firm attachment fixtures and door latching mechanism
6	The maximum cost of the cargo pod is within a given limit	Material, manufacturing selection	Final cost is well within $150000 budget.
7	The cargo pod is as lightweight as possible	Material selection for all features	Maximum weight of the cargo pod estimated to be around 170 lbs
8	The cargo pod's impact on the aircraft's performance is minimal	Cargo pod exterior profile	Cargo pod conforms to provided exterior surface model
9	The cargo pod's impact on the aircraft's take off and landing capabilities is nonexistent	Cargo pod exterior profile	Cargo pod conforms to provided exterior surface model
10	The cargo pod is easy to attach and detach	Attachment fixtures	Attachment fixtures rely on pin and
11	The cargo pod volume does not require pressurization.	Outside scope	Seal design outside of scope, current features do not need power or pressurization to function
12	The cargo pod protects cargo from moisture ingress	Outside scope	Seal design outside of current scope, accommodations made for seal placement close to fuselage-pod interface
13	The cargo pod is easy to use(cargo storage and removal, attachment/detachment)	Door access way design, attachment fixtures, cargo pod design	Simple pin-insert attachment system ensures quick attachment, overall performance depends on attachment sub-frame design which is out of scope , easy access through door, unconstructive interior
14	The cargo pod's exterior smoothly blends into the belly of the plane	Cargo pod exterior	The provided exterior surface model ensures this
15	The cargo pod stays attached to the plane while in flight	Attachment fixtures	Strong attachment fixtures have a FOS of 15 for loaded pod weight of over 450lbs.

			attachment sub-frame design required for optimization
16	The cargo pod is durable and has long life	Overall components design	Skin thickness of 0.2”, composite panel of 1” and U-profile aluminum ribs ensure the pod is resilient to vibrations, aerodynamic loads and other loads experienced during operation
17	The cargo pod’s interior is easy to clean	Interior structure design	Overall rib thickness not greater than panel height on the interior floor and walls
18	The cargo pod does not impact the ground as the aircraft moves on ground	Cargo pod exterior	Cargo pod’s exterior conforms to the provided surface model; client assurance that the resulting exterior surfaces are safe for normal aircraft operation
19	The cargo pod does not impact the ground during takeoff or landing	Cargo pod exterior	
20	The cargo pod safely drains any moisture trapped within it	Out of scope	Outside of the project scope.
21	The cargo pod’s exterior design fits in with the aesthetics of the PC-12	Cargo pod exterior	Exterior shape constrained by the provided exterior surface model
22	The cargo pod’s access door is sealed from moisture	Outside of scope	Seal design not within final project scope, accommodations for its placement made around door perimeter and the corresponding surface on the pod.
23	The cargo pod withstands aerodynamic loads during flight	Composite structure design	Panel deflection formulae used in designing skin, and core panel thicknesses and overall rib profiles. Dimensions ensure materials are below $0.90\sigma_{yld}$(yield strength)
24	The cargo pod does not interfere with normal operation of control surfaces	Cargo pod exterior	Cargo pod’s exterior conforms to the provided surface model; client assurance that the resulting exterior surfaces are safe for normal aircraft operation
25	The cargo pod does not interfere with the normal operation of flaps	Cargo pod exterior	
26	The cargo pod is to be manufactured using materials within EMTEQ’s manufacturing capabilities	Material and manufacturing processes	Material selection ensured to be within EMTEQ’s mfg capabilities. 6061 T6 aluminum, carbon fiber and Nomex core utilized together with standard fasteners and mfg processes

27	The cargo pod is to meet the related safety standards	All components	Consultation with client ensures mfg processes conform to those used at EMTEQ.
28	The cargo pod does not interfere with aircraft equipment located within and around the attachment region	Attachment fixtures, attachment location	Client assurance that fuselage area above cargo pod mounting location is free from sensitive equipment
29	A safe attachment procedure for cargo pod attachment is to be designed	Outside of scope, design consideration made	Attachment procedure design no longer within project scope, however the designed attachment fixtures are easy to use
30	Attachment tools needed for attaching the cargo pod are to be identified/designed	Outside of scope, design considerations made	No tools required in using the designed attachment fixture, however full attachment procedure design no longer within project scope.

5 DELIVERABLES

The firm deliverables that the client specified were the overall cost, weight of the structure, a bill of materials, a CAD model of the complete pod and finally the processes required to fully manufacture the components designed within the project's scope. The overall cost of manufacturing the pod is $30321.30, its overall weight is approximately 171.4 pounds as designed and the bill of materials are stated in the BOM. Detailed dimensions of all designed components are available in the assembly file, and drawings for select purchased components have been included in the appendices of this report.

Manufacturing processes for the designed components have also been determined and specified within each component's design section. They mostly include composite manufacturing using carbon fiber, fibreglass and Nomex materials for the pod's main structure and door, and aluminum manufacturing processes associated with bending and attachment. Also, attachment of metal components to polymer based composites by the use of bonding and fasteners has been specified. Bonding is used in attaching the door's L-profile rib to the bottom edge of the door while fasteners are used for attaching the ribs, hinges and latches to the composite structure.

5.1 THE ASSEMBLY FILE

The assembly file has been provided to our client contact Graham Smerchanski. It should be understood that though the body of the pod is represented by a solid body, once a finalized choice of CFRP is made the OML surface will change. In order for the dimensions of the components of our design to be valid, the model will have to be adjusted; fix and separate the interior surface of the pod body, and offset surfaces (spaced accordingly with the expected cured ply thickness) representing each ply of the intended laminate structure. For this reason matching holes are not present in the pod's body.

5.2 THE BILL OF MATERIALS

ITEM NO.	PART NUMBER	QTY.
1	Pod Unibody	1
2	Bird Cage Frame	1
	2nd Pod Rib	1
	3rd Pod Rib	1
	4th Pod Rib	1
	Aft Pod Rib	1
	Front Pod Rib	1
	Bird Cage I Beam	5
3	Door Assembly	1
	Door	1
	Door Contact Angle Channel	1
	Latch-Rib Assembly	1
	Ribs_1	1
	Bird Cage I Beam_1	1
	Latch and rib adapter assembly	1
	-M1-25-41-28_Imported	1
	-M1-25-41-28_m1_screw_m5_phillips_clf Duplicate7	2
	-M1-25-41-28_M1_2.5_INCH_PAWL_32mm_GRIP	1
	-M1-25-41-28_M1_2.5_Inch_Deep_Cup_Bracket_clf Duplicate3	1
	-M1-25-41-28_M1_2.5_INCH_HOUSING_clf Duplicate2	1
	Latch attachment plate	1
	Mid Door Rib-V2	1
	Latch Keep V2	1
	Aft Door Rib Latch Assembly	1
	Aft Door Rib	1
	Latch and rib adapter assembly	1
	-M1-25-41-28_Imported	1
	-M1-25-41-28_m1_screw_m5_phillips_clf Duplicate7	2
	-M1-25-41-28_M1_2.5_INCH_PAWL_32mm_GRIP	1

	-M1-25-41-28_M1_2.5_Inch_Deep_Cup_Bracket_clf Duplicate3	1
	-M1-25-41-28_M1_2.5_INCH_HOUSING_clf Duplicate2	1
	Latch attachment plate	1
	Front Door Rib Latch Assembly	1
	Latch and rib adapter assembly	1
	-M1-25-41-28_Imported	1
	-M1-25-41-28_m1_screw_m5_phillips_clf Duplicate7	2
	-M1-25-41-28_M1_2.5_INCH_PAWL_32mm_GRIP	1
	-M1-25-41-28_M1_2.5_Inch_Deep_Cup_Bracket_clf Duplicate3	1
	-M1-25-41-28_M1_2.5_INCH_HOUSING_clf Duplicate2	1
	Latch attachment plate	1
	Front Door Rib	1
	Aft Attachment Plate Extension	1
4	Hinge Assembly	4
	Hinge_FloorCantilever_Rev3	1
	Hinge_DoorCantilever_Rev3	1
	Hinge Cantilever Portion	2
	Hinge Float Arm Portion	2
	Hinge Float Arm	1
	Hinge Pin	2

5.3 THE COST SUMMARY

Section	Cost
CFRP Outer Shell	$7000.95
Aluminum	$254.40
Nomex Core	$547.85
Labour	$4200.00
Manufacturing Processing	$16095.08
Hinge Assembly	$309.97
Fasteners	$808.15
Latches	$1104.70
Total	$30321.10

5.4 FUTURE RECOMMENDATIONS

As has been indicated several times throughout this report, there were several objectives that, over the course of the project, were eliminated from the overall project scope due to limitations in time and analysis techniques available for our use. However, had these objectives been accomplished, they would have enabled the design of a market-ready cargo pod and therefore we still considered the further analysis that would be required in carrying them out. The following are the key areas that will need to be developed in order to fully complete the pod's design: attachment substructure design, attachment methods design and sealing methods design.

Designing the attachment substructure will bridge the gap between the attachment fixtures and the frame of the design and thus fully define the attachment performance of the pod. Design of the attachment methods deals with how the pod is physically moved from an unattached state to an attached state on the aircraft. Accomplishing this will redefine the capabilities of the structural design and internal cargo pod volume. Finally, design and selection of sealing methods will fully define moisture ingress rates into the cargo pod and also help with further refinement of the required door latching mechanisms and attachment procedures depending on the required pressurization forces.

6 REFERENCES

[1] Pilatus International, "The Pilatus PC-12: The World's Greatest Single Exceeding Expectations Everywhere"," Pilatus Corporate, 15 September 2014. [Online]. Available: www.pilatus-aircraft.com/#10. [Accessed 5 November 2014].

[2] G. E. Dieter, ASM Handbook Volume 20: Materials Selection and Design, Chicago: ASM International, 1997.

[3] Hexcel, "Prepreg Technology," 3 March 2008. [Online]. Available: http://www.hexcel.com/Resources/DataSheets/Brochure-Data-Sheets/Prepreg_Technology.pdf. [Accessed 10 November 2014].

[4] NXM555, "Plain Weave," Wiki Commons, 5 July 2009. [Online]. Available: http://commons.wikimedia.org/wiki/File:Plainweave.svg. [Accessed 20 November 2014].

[5] D. B. D. S. L. Miracle, ASM Handbook 21: Composites, Chicago: ASM International, 2001.

[6] Composites Innovation Centre, *Introduction to Composites Design Lecture,* Winnipeg, 2014.

[7] G. W. Herbert, "Diagram of a composite sandwich panel showing complete panel, face plates/sheets and honeycomb core.," Wikipedia Commons, 21 September 2006. [Online]. Available: http://commons.wikimedia.org/wiki/File:CompositeSandwich.png. [Accessed 23 November 2014].

[8] SZ Wholesaler, "PC Honeycomb Core," 15 May 2008. [Online]. Available: http://www.sz-wholesaler.com/p/1172/1174-1/pc-honeycomb-core-605766.html. [Accessed 20 November 2014].

[9] DJAYTCH99, "Honeycomb Core Blogspot," 2 May 2009. [Online]. Available: http://honeycombcore.blogspot.ca/. [Accessed 20 November 2014].

[10] D. P. Labossiere, *Cracking and Fracture, Lecture for MECH 4650,* Winnipeg: University of Manitoba, 2014.

[11] SouthCo, "Engineered Access Solutions," 15 June 2014. [Online]. Available: http://asp-us.secure-zone.net/v2/index.jsp?id=111/182/833. [Accessed 2014 22 November].

[12] SouthCo, "M1 Push-to-Close Latch," 12 March 2014. [Online]. Available: http://www.southco.com/static/Literature/m1.en.pdf. [Accessed 22 November 2014].

[13] Hexcel, Honeycomb Sandwich Design Manual, Chicago: Hexcel, 2000.

[14] McMaster Carr, "Aloy Steel Flat-Head Socket Cap Screws," 22 November 2014. [Online]. Available: http://www.mcmaster.com/#socket-head-cap-screws/=ut5uhb. [Accessed 22 November 2014].

[15] McMaster Carr, "Serrated Flange Hex Locknut," 21 July 2014. [Online]. Available: http://www.mcmaster.com/#94831a615/=ut66bs. [Accessed 29 November 2014].

[16] Online Metals Custom Metal and Plastics Supply, "Extruded Architectural Aluminum Bare Channel 6061 T6," 15 August 2014. [Online]. Available: https://www.onlinemetals.com/merchant.cfm?pid=1062&step=4&showunits=inches&id=297&top_cat=60. [Accessed 11 October 2014].

[17] Formula SAE, "Downloads For Competition," SAE International, 20 October 2014. [Online]. Available: www.fsaeonline.com. [Accessed 2 November 2014].

[18] Boat Owner's Warehouse, "Barrel Latch," 1 November 2014. [Online]. Available: http://www.boatownerswarehouse.com/product_p/383218.htm. [Accessed 29 November 2014].

[19] Aircraft Spruce, "Catalog: AN7 Bolts," 15 June 2014. [Online]. Available: http://www.aircraftspruce.com/catalog/hapages/an6.php?clickkey=26442. [Accessed 29 November 2014].

[20] Aircraft Spruce, "Product Catalog: AN7," 15 June 2014. [Online]. Available: http://www.aircraftspruce.com/catalog/hapages/an970flatwashers.php. [Accessed 29 November 2014].

[21] Aircraft Spruce, "Catalog: AN7 Nuts," 15 June 2014. [Online]. Available: http://www.aircraftspruce.com/catalog/hapages/an365_2.php. [Accessed 29 November 2014].

[22] A. Composites, "Carbon Fiber Room Temperature Storage Prepreg," 6 January 2014. [Online]. Available: http://www.acpsales.com/Carbon-Fiber-Room-Temperature-Storage-Prepreg.html. [Accessed 23 October 2014].

[23] Fibre Glast Developments Corporation, "Nomex Honeycomb," 1 February 2014. [Online]. Available: http://www.fibreglast.com/product/Nomex_Honeycomb_1562/Vacuum_Bagging_Sandwich_Core . [Accessed 23 October 2014].