

**UNIVERSITY OF MANITOBA – MECH 4860
Final Report
Design of Improved Engine Shipping Containers**

**December 6, 2010
MECH 4860 - Team #10**

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Dear Dr. Labossiere:

Attached is the report titled *Improved Engine Shipping Container* we have prepared as part of the Engineering Design course at the University of Manitoba. The report was completed for the course as well as for our sponsoring company, StandardAero for whom the container was designed.

The enclosed report addresses the problem put forth by StandardAero regarding the current cardboard covers used during the transportation of Pratt & Whitney Canada PT6A engines. At present the cardboard covers are not providing sufficient protection during transportation resulting in engines being damaged due to shipping mishandling. Our team was asked provide a recommendation to StandardAero to better protect their customer's engines. In order to provide an improved shipping container, several concepts are explored in detail. At the request of our sponsor a cost-benefit analysis is included for multiple designs. The cost-benefit analysis can be found in section 4, and provides enlightening information regarding the concepts developed and the current method being used. Based on the results of the cost-benefit analysis and a concept selection matrix, as recommendation was made on the container that best met StandardAero's needs. This design is a one piece plastic stacking cover that works in conjunction with the existing base and cradle. Full details of the recommended design are included in this report.

We would like to thank Dr. Peng, our advisor as well as Chris Laing who provided support and guidance regarding our visual aids. Feel free to contact us at umpohll@cc.umanitoba.ca, should you have any questions or concerns

Sincerely,

Carl Bartel, Eric Pilor, Lisa Roy and Nancy Santoyo
Team 10

Enclosure

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Abstract

StandardAero has experienced difficulty with their current shipping containers for Pratt & Whitney Canada PT6A engines, which are not providing sufficient protection from shipping mishandling. This has resulted in numerous damaged engines and warranty repair costs that StandardAero has been responsible for.

The purpose of this report is to design several new shipping containers that will provide improved engine protection, while being durable, easy to store and still being cost effective. Following brainstorming and concept generation sessions, six concepts have been developed which all meet , in different ways, the criteria identified by the client. At the request of StandardAero, a cost-benefit analysis has been completed and is presented in the report to help identify the most cost-effective solution.

Following the cost-benefit analysis and examination of each concept against the objectives identified, it is recommended that a one piece plastic stacking cover be implemented using StandardAero's existing universal base. This concept provides the best combination of engine protection, durability, easy storage and cost effectiveness. In addition several other improvements have been recommended to help reduce the frequency and cost of shipping damage encountered. By implementing the suggested shipping container and improvements, StandardAero has the potential to significantly reduce the frequency, and extent of shipping damage while at the same time reducing the expense of shipping materials.

1. Introduction

StandardAero has requested that an improved shipping container be designed to better protect their client's PT6A engines during transportation. As the client, StandardAero, has identified several important needs, including storability, cost effectiveness, engine protection and lifespan. Using these objectives as the basis for new designs, many different concepts were considered, with six of these concepts being fully developed as explained in this report. At StandardAero's request, a cost-benefit analysis examining the costs of each of these containers was performed to examine the cost-effectiveness of each option. Using the results of the cost-benefit analysis combined with an evaluation to compare the concepts to the needs identified by the client, a recommendation of the most suitable concept has been made. The recommended concept will successfully meet all the needs laid out by the customer of being cost effective, minimizing storage space required, and providing improved engine protection over current shipping containers.

2. Background

StandardAero provides overhaul and repair service of gas turbine engines to customers around the world. Currently, StandardAero returns PT6A engines to customers in either cardboard or wooden containers, as shown in Figures 1 and 2 respectively, in accordance with the Original Equipment Manufacturer (OEM) specifications. Both of these containers consist of a wooden pallet with a steel base mounted on it that the engine is secured to using shock absorbing mounts. The cardboard or wooden container is then placed over the engine and strapped around the pallet to secure the cover to the base. Both of these containers require that the engine be sealed in a plastic envelope with dehumidifying agent, as seen in Figure 3, prior to being mounted on the base to protect the engine from the moisture.



Figure 1: Cardboard container



Figure 2: Wooden container



Figure 3: Sealed engine on base



Figure 4: Forklift puncture

The cardboard container is currently the most widely used. However, it does not provide sufficient protection when mishandling occurs during transportation. Historical data has shown that there has been an average of five damaged engines per year [1] as a result of shipping mishandling, which includes engines being dropped and forklifts puncturing the container, as shown in Figures 4 and 5. In addition, the cardboard containers can not be stored outdoors, as they will be destroyed if exposed to moisture, and are typically only used for one shipment before being discarded.



Figure 5: Damaged engine

All engines that have been subjected to mishandling must be re-inspected and repaired before being installed on the aircraft, resulting in increased costs. Over the past six years the cost of repairs due to shipping damage has exceeded \$402000, for which StandardAero has had to cover a significant portion. The root cause of the shipping damage is mishandling by shipping carriers. This cause cannot be directly addressed, however by providing a more robust shipping container, the damage to the engines can be minimized. A container that provides increased protection will also help StandardAero's image, as there have been customer concerns in the past about their engine, which can be worth as much as \$1.2 million, being returned to them in a cardboard container that provides little protection for their investment.

StandardAero has been closely involved throughout the design process in order to ensure that the resulting solution will meet their needs. In order to do this, StandardAero has requested that several concepts be presented to them along with a cost-benefit analysis. Following several discussions with the client, a survey was designed to allow several StandardAero employees to clearly identify the highest

priority needs that must be met by the redesigned shipping container. The results of the survey and subsequent discussion revealed that, engine protection, container durability, storability, and the solution being cost effective were the most important issues that must be addressed by the new engine shipping container [2]. In addition the containers must meet the minimum requirements outlined by the OEM manuals and shipping regulations. In order to develop concepts for new containers that address the client's needs, these needs were translated into objectives that the final concepts must achieve.

Using these objectives, measurable specifications were then developed to allow the concepts to be evaluated against. It was decided that the new concepts should be capable of preventing a forklift from puncturing the container. As the containers will be stored in an outdoor location when not in use, the material used must not degrade after prolonged exposure to extreme temperatures, snow, rain, and UV rays. The container must also fit onto existing storage shelves in both the indoor and outdoor storage area. In terms of durability, StandardAero expressed an interest in having containers that are reusable for upwards of five years. Another requirement defined by StandardAero was that any new container must be cost effective, which means that the payback period must be no longer than two years. The final request from the client was that the designs incorporate the existing metal bases that are currently mounted on wooden pallets. A modification was recently completed to allow these bases to accommodate multiple engine models, and the client wished to avoid having to dispose of the large number of bases they currently have in inventory.

Using the specifications identified from StandardAero's needs for a new shipping container, seven concepts for a new shipping container have been developed, ranging from a relatively minor change of the cover material used to protect the engine to an entirely new shipping container. A cost-benefit analysis was then performed in order to come to a recommendation on the most suitable concept for StandardAero.

3. Details of Concepts

In order to perform the cost-benefit analysis, seven distinct concepts were fully developed. Some of these concepts followed the same basic idea, however were designed to use different materials and had several different features to improve their functionality. In addition to these six concepts, two benchmarks were also included as a comparison to the new concepts.

The first benchmark was the wooden shipping container currently used, as the protection provided and cost are both well known. Experience has shown that the wooden containers have a lifespan of approximately two years. StandardAero is not interested in acquiring more wooden containers due to limitations of the design, such as requiring fumigation and certification in accordance with ISPM 15 [3] prior to being shipped. Despite these limitations, the wooden container is suitable to use as a baseline comparison for all other containers as the cost, service life and protection provided are well known.

The second benchmark design was the enclosed aluminum shipping container for Pratt & Whitney Canada PT6A engines available from West Coast Weld Tech Inc. These containers provide an aluminum base with an incorporated engine support stand and an aluminum cover, as shown in Figure 6, that allows the container to be pressured with inert gas to protect the engine from corrosion due to moisture. StandardAero currently ships other engine models using a similar design of shipping container from the same company with great success. The cost for this container is \$6138 with a volume discount available if five or more containers are ordered [4]. The goal of the new concepts is to provide similar engine protection to this container with a lower cost.



Figure 6: West Coast Weld Tech aluminum container

The seven concepts that were designed could all be classified in three categories. The first four concepts all were of the same design as the existing wooden containers shown in Figure 2, utilizing the existing wooden pallet and base. The three concepts used different materials, plastic, aluminum and aluminum honeycomb, and each incorporated different features to improve their functionality. The second category of concept was a tapered cover, with similar dimensions to the existing wooden cover, but constructed with no joints, as well as being able to stack inside other covers for storage. Two concepts fit into this category and were constructed of fiberglass and plastic. The final category was a completely enclosed plastic container that would only use the existing metal base, without the wooden pallet. A further description of each of these concepts follows, before the cost-benefit analysis is presented.

3.1 Plastic Cover

Following the current wooden container design, the plastic cover, aluminum cover and aluminum honeycomb cover all were designed using square corners, and inside dimensions of 80" long, 26.5" wide and 28" high. In order to ensure that the covers would fit around the engine, only the interior dimensions were considered to be of importance. The outside dimensions of each of these containers varied slightly

depending on the material chosen, however they are all within the dimensions of the current covers to ensure that they will fit on the pallets.

Several types of plastic were considered for both this cover, and the stacking plastic cover. Based on the design objectives it was determined that the most critical material characteristics were the ability to withstand impact and to be durable when stored outdoors. In order to protect the engine from potential damage due to an accidental fork lift impact, the material chosen must have a high impact resistance throughout the entire range of temperatures that the cover will be exposed to. In Winnipeg, this ranges from -35°C to 30°C . In order to withstand being stored outdoors, the plastic chosen must also be UV stabilized so that it does not begin to degrade when exposed to sunlight for prolonged periods of time.

As the most important aspect of the new shipping container is to protect the engine the first concern was to identify a plastic with high impact strength. Many different plastics possess this characteristic, such as Acrylonitrile Butadiene Styrene (ABS), polycarbonate, and High Density Polyethylene (HDPE). Upon further investigation into some of these plastics, it was found that ABS is designed to have very high impact strength, however most of the commercially available ABS sheets become brittle and lose a significant portion, some as much as 65%, of their room temperature impact strength [5] at temperatures below 0°C . This would be undesirable in the Winnipeg winter, as any impact from a forklift may cause the cover to crack, increasing the potential for engine damage and making the cover unavailable until it can be repaired.

The remaining plastics considered were polycarbonate and HDPE, as both of these materials have high impact strength throughout the range of temperature that will be encountered in service. Ultimately, the decision was made to use HDPE, as polycarbonate has less resistance to UV degradation, has a higher density of 0.0434 lb/in^3 compared to 0.0345 lb/in^3 for HDPE, and is considerably more expensive than HDPE [6]. In addition HDPE is resistant to moisture, various diesel and lubricating oils, petroleum spirits and solvents, all of which the cover may be exposed to during service

[7]. Based on the impact resistance and weight of the material it was decided that ½” thick HDPE would be used to construct the containers as the impact resistance should still exceed the current ¾” thick wooden container, while minimizing the weight compared to thicker plastic.

Based on using ½” thick HDPE the weight of this container would be 136 lbs, which would be too heavy for two employees to lift unassisted. In order to reduce the weight of the container, it was decided that the top of the cover would be left unattached, and several locating blocks would be attached to the bottom, as can be seen in Figure 7. This will allow the vertical sides of the container to be joined, and have handles installed on opposite ends. The handles will allow either two people to lift the sides of the cover, which will now weigh 100lbs, over an engine, or to lift the cover using an overhead crane. The fit of the side panels around the engine can then be verified and the top placed put in place with the help of the locating blocks, before being strapped to the pallet using the same method currently used for the cardboard and wooden containers.



Figure 7: Plastic cover

3.2 Aluminum Cover

While a fully enclosed aluminum container is available as discussed, a concept of an aluminum cover has been developed to fit on the existing pallet and base in an effort to minimize cost. Aluminum was selected because it has several desirable qualities that

would provide StandardAero with a suitable replacement for the current cardboard shipping container. Aluminum is a long lasting material that is weather resistant and will not degrade after prolonged exposure to moisture and UV rays. It is lightweight when compared to other metals while still providing improved engine protection over the cardboard containers. The aluminum cover would be able to be both manufactured and repaired locally, while being fully recyclable at the end of its lifespan.

When developing a cover two approaches were taken, the first of which had the cover as a one piece solid construction and the other split the cover into several collapsible components. The one piece design is similar to the plastic cover described previously, however to simplify the design the top will not be removable. The cover is constructed from five ¼" thick panels welded together. The rectangular cover has inside dimensions of 80" long, 26.5" wide and 28" high and will weigh approximately 192 lbs. Since the cover is too heavy to be lifted by two people, four eyebolts would be installed on the top, as can be seen in Figure 8, to allow the cover to be lifted using an overhead crane.



Figure 8: Aluminum cover

As was mentioned, a collapsible design was also developed using ¼" thick aluminum. The collapsible design has several advantages over the one piece welded cover including each section being lighter than the welded container, and reducing the amount of storage space required. The collapsible design divides the cover into three portions, as can be seen in Figure 9, consisting of the lid, and two L shaped sections that connect to form the four sides of the cover. The lid is constructed from a single piece of

83"x 29" aluminum which allows for the edges bent to form a 1" lip to help easily located the lid over the side panels. As a result the weight of the lid is approximately 58 lbs, which can easily be lifted by two employees. Each of the two L shaped side sections is made by welding a 27"x 28" piece of ¼" aluminum 90° to a 80"x 28" piece, resulting in a section that weighs 73 lbs and can be lifted by two employees. Dividing the cover into several lighter sections eliminates the need for additional lifting equipment, such as overhead cranes or forklifts. In order to connect the sections together, a tongue and groove system, shown in Figure 10, has been designed. Each of the L shaped sections has an aluminum extrusion welded to one edge. This extrusion has a ¼" groove machined in it, into which the ¼" thick aluminum panel from the other section can fit. Once assembled with the lid and strapped to the pallet, this system allows for a tight, secure connection between sections, which will not become separated during shipping.

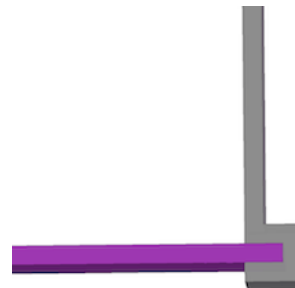
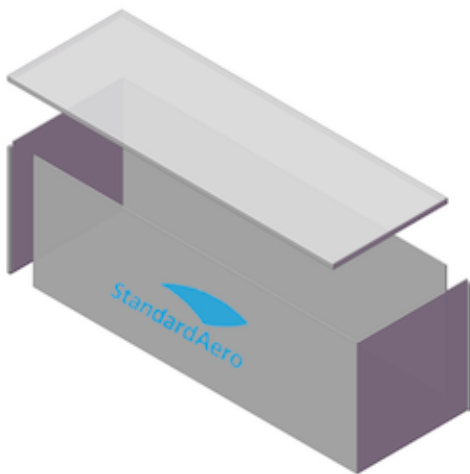


Figure 10: Tongue and groove detail

Figure 9: Collapsible aluminum Cover

Although the collapsible design has several benefits over the one piece welded aluminum, there are also disadvantages, such as assembly time required when packaging an engine for shipping and the possibility of damage to the tongue and groove system that would make the cover unusable. Both of the aluminum covers presented are considered viable option and will be included in the cost-benefit analysis.

3.3 Aluminum Honeycomb Cover

Aluminum honeycomb is an innovative building material that is now being used for a variety of applications, such as cleanroom paneling and displays. The material consists of a layer of aluminum honeycomb sandwiched between two faces of thin aluminum as shown in Figure 11. The result is a light panel that is much stronger than regular aluminum of the same size. As the outside faces are aluminum sheet, this material provides the same benefits as the aluminum container, offering weather protection, while providing increased engine protection during transportation.

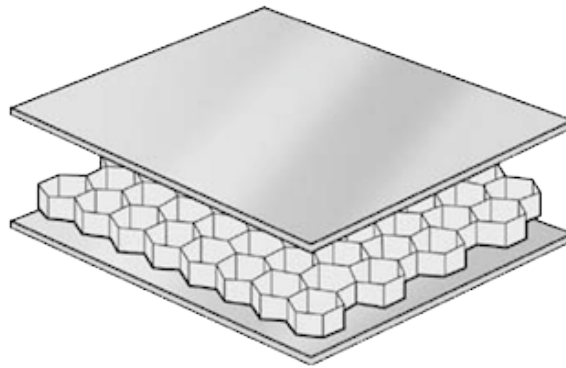


Figure 11: Aluminum honeycomb [8]

The concept for an improved shipping container for the PT6A engines includes a one piece welded cover similar to the regular aluminum concept. The honeycomb panels can be ordered in custom sizes which would allow for less waste material, however in order to keep the cost to a minimum, standard size panels were selected. The selected panels have $3/8$ " aluminum honeycomb bonded to 0.025 " milled aluminum sheet faces providing an overall thickness of $1/4$ ". The one piece welded cover is constructed in the same manner as the one piece welded aluminum concept, however as the lighter material only weighs 50 lbs, there is no need for a collapsible design. The lighter weight also eliminates the need for eyebolts and lifting equipment, as employees can simply lift the cover using handles installed on opposite ends.

3.4 Plastic Stacking Cover

The stacking plastic cover was designed to resemble a plastic storage container, which can be stacked inside other containers to save space. The intent of this design was to manufacture the cover from a single piece of plastic, which would ensure that it would be impenetrable by water. The cover, shown in Figure 12, was designed using the same interior dimensions (80" x 26.5" x 28") at the bottom as the plastic cover to ensure that it would work with the existing wooden pallets and bases. Each of the sides was then tapered inwards 5° to allow for the covers to be stacked inside one another during storage, as shown in Figure 13. In addition to stacking, the taper is also required to remove the cover from the mold following the vacuum forming process.



Figure 12: Tapered Plastic Cover



Figure 13: Stacked Covers

After ensuring that the tapered cover would still provide sufficient space around the engine, the edges were then given a 5" radius to smooth the flow of material during the vacuum forming process and to ensure that there would be no hang ups when the covers were stacked. The material chosen for this container was HDPE, for the same reasons that it was selected for the plastic cover.

The main drawback to the plastic stacking cover is the weight associated with the design. When constructed using ½" thick HDPE, the weight of the cover is approximately the same as the previous plastic cover (approximately 140 lbs), however

there is no option to reduce the weight by removing the top as the cover is a single piece. Several ideas were considered to deal with the heavy weight of this container. Due to the design of the mold for the vacuum forming process, internal handles could not be added, as the cover could then not be removed from the mold. Another option was to add handles, or lifting points to the sides of the cover, however these would interfere with stacking the covers during storage. It was decided that the most suitable solution to provide a lifting method was to add four eyebolts to the top of the cover similar to the aluminum cover shown in Figure 8. An additional advantage of the eyebolts is that they will prevent the covers from becoming stuck together when stacked by supporting the cover above.

3.5 Fiberglass Stacking Cover

A second concept was developed using the same tapered stacking design, however instead of being manufactured out of plastic, it would be made from hand laid fiberglass. This cover has the same features as the plastic cover, being able to stack and being manufactured with no joints that could allow moisture to enter over time, while still working with the existing pallet and base. The cover will be held to the base using the strapping system currently used with the cardboard and wooden containers.

The main advantage to the fiberglass cover is that it can be manufactured locally. The outside layer of the cover would consist of a colored gel coat, which will provide protection from the weather, while protecting it from degrading due to UV exposure. The cover will be laid up using chopped strand fiberglass mat, to minimize the cost, while providing sufficient impact protection to protect the engines. Similar to the plastic stacking cover, the weight of the fiberglass cover is of concern. Once constructed the cover will be 1/8" thick and weigh approximately 125 lbs, which will require eyebolts to be installed in the same manner as the plastic cover shown in Figure 12.

3.6 Enclosed Plastic Cover

The design of the enclosed plastic container includes both a base and cover that are designed to latch together, sealing the engine from any harsh environments. The cover has been designed to utilize StandardAero's existing universal metal base by removing them from the current wooden pallets and remounting them on the plastic base. This will help to minimize cost of manufacture and avoid the client being left with a large number of excess bases.

The enclosed container would be manufactured out of high strength, UV stabilized high density polyethylene (HDPE) material using the rotational molding technique. This is the same material and technique used to construct the containers that StandardAero currently uses for transport of propeller components, as shown in Figure 14. This material is similar to that used in the other plastic concepts, and allows the construction of a container that is durable, and dent resistant while being impervious to moisture, chemicals and harsh environmental conditions. The design would also be lightweight compared to the enclosed metal containers owned by several customers, with a total weight of approximately 180 lbs. Based on the mechanical properties of the HDPE material, and experience with the propeller containers, this design would have no problem withstanding the extreme winter temperatures they would be exposed to in Winnipeg during the winter.



Figure 14: Propeller container

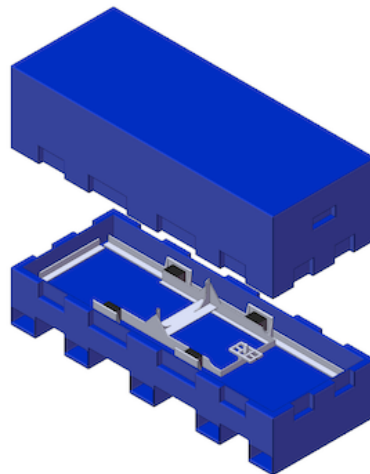


Figure 15: Enclosed HDPE concept

The enclosed plastic container, shown in Figure 15 is designed with two sections, the cover and the base. The cover portion has outside dimensions of 84" x 33" x 23" (L x W x H) and a wall thickness of 2". The base has overall dimensions of 84"x33"x16" including the skids underneath the container. A reinforced metal frame, such as the one shown in Figure 16 would be bolted into the relief channels in the bottom of the base to allow the existing universal base to be mounted to it. The base has sides that extend 6" above the upper surface to allow the cover to be secured to it, while being low enough to avoid interfering when securing the engine to the base. A gasket is also included around the top edge of the base to seal the container from harsh environments.



Figure 16: Reinforced metal frame

Additional features that were added to the design include 12 latches, four on each long side and two on each shorter side to allow the cover to be quickly secured to the base. Four eyebolts were also included to allow an overhead crane to be used to lift the cover over the base when installing an engine. The skids located under the container would be sufficiently spaced and reinforced so that they can be used by a forklift to lift the container for loading.

Each of the concepts presented above address the objectives of the project in different ways. All seven designs meet the most important objective of providing increased engine protection by meeting or exceeding the protection provided by the wooden benchmark container. In service, there has been several situations where

engines have still received damage when shipped in wooden containers, and may still do so in the proposed concepts, however the negative consequences of providing further strength, such as increased weight and cost, outweigh the potential savings from engine damage. Despite the fact that no guarantee can be made that these new concepts will completely eliminate engine damage during shipping, they will provide a significant improvement over the existing cardboard covers, and minimize the risk and extent of damage.

4. Cost-Benefit Analysis

In order to determine the concepts that best meet the client's needs, StandardAero has requested that a cost-benefit analysis be performed to present the cost, lifespan and estimated savings of each concept. As discussed earlier, over \$402 000 in repairs due to shipping damage has occurred over the past six years. While it is impossible to estimate the cost of these repairs associated with each of the new shipping containers, as there is always a risk of damage to the engine, each of the concepts presented will reduce the likelihood of damage due to impacts and mishandling when compared to the existing cardboard cover. This will lead to a significant reduction in the repairs that StandardAero will be responsible to cover.

In order to determine the payback period for each of the concepts, an understanding of the current costs was first required. As mentioned, the cardboard containers are typically only used for a single shipment, as they become damaged and are difficult to store in the limited indoor space available. StandardAero keeps a supply of these containers, and when obtained from a local Winnipeg company, the covers cost \$89 for the thicker side wall portion, plus \$40 for the thinner top cap for a total of \$129 per engine shipped. There are also costs associated with wear on the wooden pallets and bases, however this has been excluded from the cost-benefit analysis as several of the concepts will continue to use these, and the new concepts that do not use them will also require periodic maintenance.

Through discussions with StandardAero's shipping personnel it has been estimated that a reusable shipping container, such as any of the concepts presented, would likely be able to ship an average of one engine per month. This includes time required to ship the engine to the customer and receive the crate back. Based on this average of 12 uses per year, and the assumption that a new cardboard container would be used each time if shipped using current methods, the equivalent cost of shipping 12 engines using cardboard containers would be \$1548. This is the value that will be used to determine the payback period for each of the new concepts. In addition it was determined that an average of 15-20 engines are shipped every month, based on this it was estimated that approximately 25-30 reusable containers would be needed to ensure that there was always a container available for shipping.

The cost-benefit analysis, shown in Table I, provides the individual cost for each of the concepts presented, as well as the benchmark and currently used concepts. An estimated lifespan, based on containers made from similar material and discussions with industry experts, is provided as well as the cost for materials and manufacturing of a single container. A payback period is then calculated, based on the assumption that each container can be used 12 times per year, and that a new cardboard cover would be used in its place each time. Finally an estimated cost per use is calculated based on the formula shown in Figure 17.

$$\text{Cost Per Use} = \frac{\text{Cost}}{\text{Lifespan}[\text{years}] \times \text{Uses Per Year}}$$

Figure 17: Cost per use equation

TABLE I: ESTIMATED COSTS

Concept	Estimated Lifespan (Years)	Cost	Payback Period (Years)	Estimated Cost Per Use
Cardboard Cover	1 Use	\$129.00	X	\$129.00
Wooden Cover	2	\$600.00	0.39	\$25.00
West Coast Weld Tech Aluminum Container	15	\$6 138.00	3.97	\$34.10
3.1 Plastic Cover	10	\$1 349.00	0.87	\$11.24
3.2.1 Aluminum Cover	15	\$1 297.00	0.84	\$7.22
3.2.2 Collapsible Aluminum Cover	15	\$1 000.00	0.65	\$5.56
3.3 Aluminum Honeycomb Cover	8	\$1 000.00	0.65	\$10.42
3.4 Plastic Stacking Cover	10	\$1 200.00	0.77	\$10.00
3.5 Fiberglass Stacking Cover	5	\$1 002.00	0.65	\$16.70
3.6 Enclosed Plastic Container	10	\$4 500.00	2.90	\$37.50

All of the costs for these containers were determined by contacting manufacturing companies to obtain estimates. Through these discussions it was determined that all of the concepts presented are possible to manufacture. For the purposes of the cost-benefit analysis the highest price of a quoted range was always used, and the prices presented do not include price breaks for ordering multiple containers. A more detailed breakdown of the quotes received as well as information on the companies contacted is provided in Appendix A.

The only container that did not receive a quote strictly for the price per container was the stacking plastic cover. Due to the vacuum forming process, specific tooling would be required with an upfront cost of approximately \$12500 dollars. With the tooling completed, the cost for materials and manufacturing of each cover is

approximately \$700. In order to include this concept in the cost-benefit analysis, it was assumed that 25 covers would be ordered in total, and the tooling cost was divided evenly between all of them, adding an additional \$500 per cover.

As there is limited knowledge about the lifespan of these new concepts and materials, the lifespans presented are the best estimates possible. The fiberglass stacking cover is expected to have the shortest life span of five years, as this concept is the most difficult to properly repair. This is followed by the aluminum honeycomb concept, with an estimated life span of eight years, and the three plastic covers, each with an estimated lifespan of ten years. The lifespan of the aluminum cover was estimated to be similar to the commercially available containers, of approximately 15 years. There are many factors that can increase or decrease the lifespan of these containers, mainly the damage that is encountered, however with proper repair and care, each of these concepts has the potential to be useful indefinitely. These estimates simply represent an average lifespan before it becomes more economical to replace the containers.

5. Recommendation

Following the cost benefit analysis, a concept selection matrix, shown in Table 2, was used to provide a recommendation on which concept best addresses StandardAero's needs. The matrix included all seven concepts discussed in the cost benefit analysis as well as the wooden and West Coast Weld Tech benchmark designs.

The selection criteria used related directly to the objectives that were developed from the customer's needs. The most critical of the criteria was the protection provided to the engine by the container, thus this criteria was given the heaviest weighting of 50. Following the engine protection, the next most important objective was the cost, for which it was decided that the cost per use discussed in the cost-benefit analysis would be used. The cost per use was given a weighting of 25. The weather resistance of the container, reusability, and storability of each container were considered to be the next

most important criteria, and were given a weight of 10 each. Finally, StandardAero identified that the weight of the shipping container was a consideration, but not critical, thus the container weight was given a weight of only 5.

In order to have a baseline comparison for each of the new concepts, the existing wooden benchmark was given a score of 3 for each of the six selection criteria. Each of the new concepts was then scored based on whether they provided an improvement over the wooden cover, with 5 being the highest score and 1 being the lowest. The score for each criteria was then multiplied by the weight of that criteria and added up for each concept to obtain the concept’s final score.

TABLE 2: CONCEPT SELECTION MATRIX

Criteria	Weight	Wooden Cover	West Coast Weld Tech Aluminum Container	Plastic Cover	Aluminum Cover	Collapsible Aluminum Cover	Aluminum Honeycomb Cover	Plastic Stacking Cover	Fiberglass Stacking Cover	Enclosed Plastic Container
Engine Protection	50	3	5	5	5	5	4	5	3	5
Weather resistance	10	3	4	5	4	3	4	5	5	5
Cost per use	25	3	2	4	5	5	4	4	4	2
Weight	5	3	1	3	2	3	5	3	3	2
Reusability	10	3	5	5	5	5	5	5	4	5
Storability	10	3	2	3	3	4	3	5	5	1
Score		330	415	495	505	510	445	515	405	420
Rank		9	7	4	3	2	5	1	8	6

The concept selection matrix revealed that the concept that best fit StandardAero’s needs was the plastic stacking cover followed by the collapsible aluminum concept and the aluminum cover. It is therefore recommended that StandardAero implement the plastic stacking cover as a replacement for the current

cardboard shipping containers. A detailed drawing of the plastic stacking cover is provided in Appendix B.

In addition to the implementation of new shipping containers several other improvements have been identified to help reduce the amount of damage to engines due to shipping mishandling. The first method identified is to include better identification of the fragile contents on the container itself. The current cardboard cover, shown in Figure 1, is labeled as containing a gas turbine engine, however only has relatively small written warnings to handle with care and not to drop. As StandardAero ships engines around the world, it is recommended that the fragile symbol, shown in Figure 18, be incorporated to further communicate the message of careful handling, especially when the containers are shipped to countries where English is not the primary language. It is recommended that this improvement be incorporated into any new shipping container that is implemented, as well as the current cardboard covers when more are ordered in the future.



Figure 18: Fragile symbol [9]



Figure 19: Shockwatch impact indicator [10]

Another recommendation to help protect the engine during shipment and to quickly identify the potential for damage is to fix a Shockwatch impact indicator, shown in Figure 19, to each container before it is shipped out. These indicators are calibrated to detect any impact over a predetermined value. When this occurs a vial of dye is released into the clear viewing window, turning it to a highly visible red color [11]. By

placing this indicator onto each container before shipping, it can be visually inspected upon arrival at the destination to ensure that the container has not been dropped or impacted. If the indicator indicates that an impact has occurred, then the engine can be further inspected for damage. These indicators would not be useful for the current cardboard covers, as this material is not stiff enough to ensure the accuracy of the indicator, however it would be useful for any of the concepts presented. The cost to implement these Shockwatch indicators is low, approximately \$2.50 per indicator, which can also remain attached to the container and be reused provided it has not experienced a shock.

6. Conclusion

Six distinct concepts of engine shipping container have been designed in order to help StandardAero achieve their goal of providing improved resistance to shipping damage, while being cost effective, easy to store and long lasting. Based on an evaluation of each concept against these needs and a cost-benefit analysis it has been recommended that a plastic stacking cover be introduced to work with the existing wooden pallet and base. In addition, several other improvements have been identified that will help to reduce the severity and frequency of shipping damage, such as better identification and shock indicators. By incorporating all of these recommendations, StandardAero will be able to reduce the frequency of engine damage, saving the expense of costly repairs, and ensuring that their customers receive their engines on time and ready for service.

7. References

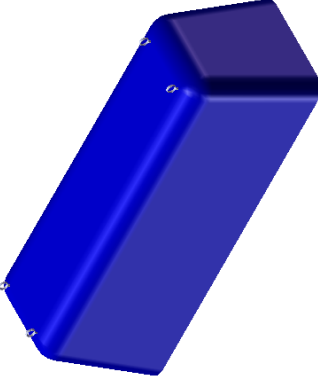
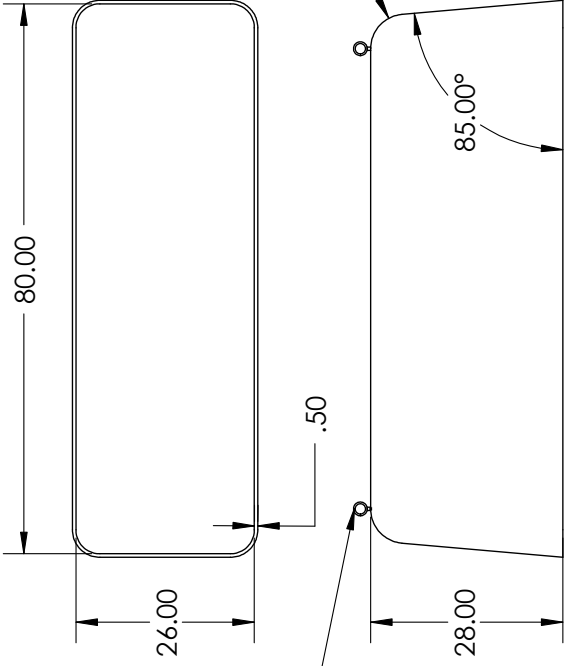
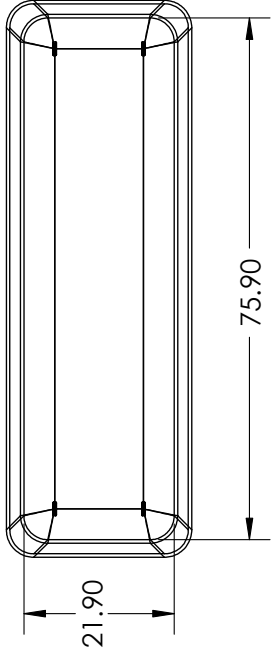
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Appendix A: Concept Manufacturing Costs

All manufacturing companies are located in Winnipeg, except those noted.

Concept	Manufacturing Company	Material Cost	Labour Cost	Tooling Cost	Total Cost
Cardboard Container	Induspac	\$129		N/A	\$129
Plastic Cover	Phantastic Mobile Plastic Repair	\$749	\$600	N/A	\$1349
Aluminum Cover	Forrest Tool & Die	\$781	\$416-516	N/A	\$1297
Aluminum Honeycomb Cover	Pacific Panel	\$422	N/A	N/A	\$1000
	Forrest Tool & Die	N/A	\$428-578		
Plastic Stacking Cover	Hagans Plastic Co. (Grand Prairie, Texas)	\$500-750	N/A	\$10000-15000	\$1200
Fiberglass Stacking Cover	Structural Composites	\$1002		N/A	\$1002
Enclosed Plastic Container	Trimcast Rotomoulders (Victoria, Australia)	\$4500		N/A	\$4500

Appendix B: Plastic Stacking Cover Drawings

4 x 1" Eyebolt

80.00

26.00

.50

28.00

85.00°

R5.00

12.94

85.00°

27.00

R5.00

21.90

75.90

85.00°

R5.00

UNLESS OTHERWISE SPECIFIED:		DRAWN	NAME	DATE
DIMENSIONS ARE IN INCHES			C. Barfel	12/3/2010
TOLERANCES:		CHECKED		
FRACTIONAL ± 1/2		ENG APPR.		
ANGULAR: MACH ± 0.5 BEND ± 0.5		MFG APPR.		
TWO PLACE DECIMAL ± 0.5				
THREE PLACE DECIMAL ± 0.005				
INTERPRET GEOMETRIC TOLERANCING PER:		Q.A.		
MATERIAL: HDPE (blue)		COMMENTS:		
FINISH: USED ON				
NEXT ASSY				
APPLICATION				

TITLE: Plastic Stacking Cover

SIZE DWG. NO. REV A 1 A

SCALE: 1:24 WEIGHT: SHEET 1 OF 1

1 2 3 4 5

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