University of Manitoba

# Riveting Process Fixture Design

Bristol Aerospace Ltd.

MECH 4860 Engineering Design

Final Design Report

Submitted by Team 2

Sasha La Tour

Mo Ran Wang

Qi Li

Zi Bing Xing

Project Advisor: Mr. Mal Symonds
Course Instructor: Dr. Paul Labossiere

Date Submitted: 06/12/10

Department of Mechanical & Manufacturing Engineering

UNIVERSITY OF MANITOBA

December 6, 2010

Dr. Paul Labossiere
Engineering Design Instructor
Mechanical Engineering
75 Chancellor's Circle
E1-546 EITC
Faculty of Engineering
University of Manitoba
Winnipeg, Manitoba
R2T 5V6

Dear Dr. Paul Labossiere:
This report's title is "Riveting Process Fixture Design". It was written and compiled by Team 2, and submitted for evaluation on December 6, 2010.

The purpose of this report is to outlay the design of a new riveting process fixture for a turbofan bypass duct at Bristol Aerospace Ltd. This report details the benefits of the entire fixture, as well as the individual components that make up the fixture. Additional benefits are also explained, as well as recommendations for improving the fixture beyond what is immediately implementable. The design presented in this report reflects the team's optimal solution for the fixture problems with the current riveting process, as well as the client's identified needs.

This report summarizes the design developed by the team for Bristol Aerospace Ltd., and provides details regarding the purpose and benefits of the design's individual features. The design information contained in the report was written by Sasha La Tour, Qi Li, Mo Ran Wang, and Zi Bing Xing.

The team would like to acknowledge the help provided by Dr. Labossiere, Mr. Mal Symonds, and Ms. Aidan Topping for guidance both in and out of class time, the members of Team 10 for providing a revision of the final design report, and the Mechanical and Manufacturing Engineering office for providing binding services. Requests to consult with the team regarding any element of this report would be welcomed at the reader's convenience, and may be submitted to any member of the team.

Yours Truly,

Sasha La Tour
Team Manager – Team #2

# Table of Contents

# List of Figures

# List of Tables

# Abstract

This report details the final design of a turbofan bypass duct riveting process fixture for Bristol Aerospace Ltd. The design was requested to reduce damage to the skin of the ducts during the existing riveting process. A list of client needs was identified, and features were designed to satisfy these needs. These features include supports with adjustable height and angle, as well as a pedal assembly that lifts the entire fixture. Additional features were also developed to further improve the security of the duct, as well as the overall usefulness of the fixture. An analysis of the prototype cost, and the expected final cost of the fixture is presented. Some recommendations are also made for possible improvements to the system at an increased cost and delay in fixture implementation. Finally, the report summarizes the features of the riveting process fixture design, and concludes that the design fulfills the needs of the client.

## 1. Introduction

This document details the final design of a riveting process fixture for a turbofan bypass duct at Bristol Aerospace Ltd. This fixture was designed to solve a specific set of needs outlined by the client. As a manufacturer of quality aerospace engines and components, Bristol Aerospace Ltd. seeks to supply defect-free products to its clientele. The existing riveting process used during the development of turbofan bypass ducts was producing an unsatisfactorily high number of defective ducts, and as such, the need for a new process was identified. The client outlined the following needs during a preliminary visit to the shop floor:

- A single operator riveting process
- A maximum of two operators required for the loading process
- A repeatable process
- An accurate process
- A reduction in part damage
- A reduction in total riveting time
- An accommodation of variable rivet lengths
- A reduction in worker fatigue
- A transition from craftsmanship to process-based assembly
- A support of a bypass duct weighing 25 [kg]
- An accommodation of the duct's varying diameter

From these needs, a clear understanding of the purpose of this project was possible. This purpose, as well as the problem and the scope of this report are described in the following subsections.

## 1.1. Purpose

The purpose of this project was to design a new riveting process fixture for Bristol Aerospace Ltd. The riveting process fixture is used during the production of a turbofan bypass duct. The new design was requested due to the part damage resulting from the existing process. Also, the new design should promote a single operator production process, and reduce both worker fatigue and production cost.

## 1.2. Problem

During the production of a turbofan bypass duct, several processes occur. Near the completion of the duct, after the components of the duct are bonded together, three flanges must be riveted onto the duct. To complete this riveting process, two experienced operators work together, each doing a separate job. The “bucker” holds a metal block against the tip of the rivet, while the “gunner” uses a pneumatic hammer to crush the rivet into the bucking block. The problem with this traditional two man operation is that the success rate of the riveting process is heavily dependent on the craftsmanship of the two operators. There are various flange angles and different rivet sizes to consider throughout the process. If the operator makes any mistake, there is a chance that the fragile duct skin can be damaged. The new design will solve the craftsmanship dependence problem and also result in other production-related improvements.

## 1.3. Scope

This report outlines the design process and the features of the new design. Important details regarding the various features of the design are also presented. Recommendations regarding the implementation of the new riveting fixture, and the production process are presented. Due to the client's in-house manufacturing ability, the design was made to be modifiable by the client. As such, the important details and purposes of the fixture's components are described, but no specific recommendations for parts are made. This design strategy was used to allow the client to reuse hardware to construct this fixture. Additionally, the proposed fixture was designed to be immediately implementable. Therefore, there are several modifications that are recommended to optimize the design with additional components that would need to be ordered or fabricated.

## 3. Features

The new design fixture has many features that are of benefit. These features have been divided into two main categories. The primary features are the independent features that were developed from the client's needs. The additional features are those that were designed to be of additional benefit to the client, or have resulted from a combination of primary features. Before these features are explained, an overview of the fixture is necessary, and is presented in the following subsection.

### 3.1. Design Overview

The new riveting process fixture design fulfills the needs outlined in the introduction. Though these needs were numerous, they were satisfied by the careful design of several main features. These main features are noted on the image of the fixture, displayed in Figure 1.

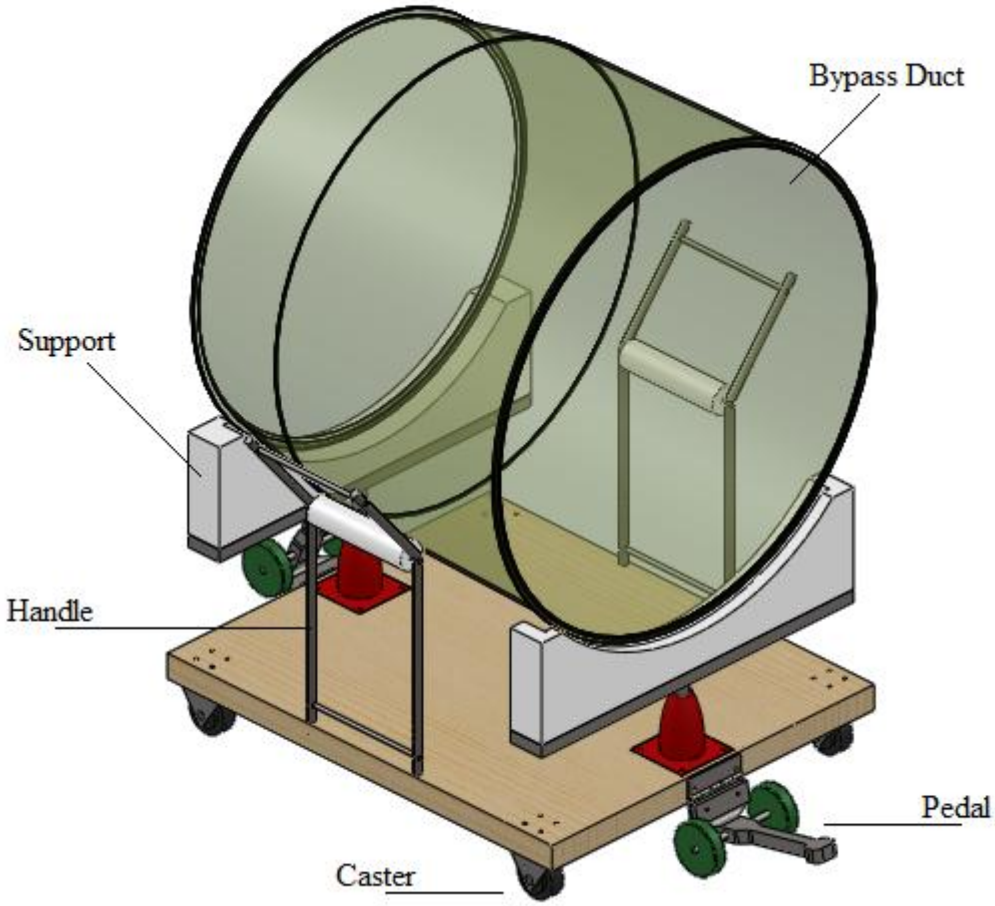



Figure 1. Riveting process fixture.

The fixture consists of a base mounted on four casters. These casters allow the entire fixture to be moved around on the shop floor. To help direct the fixture, one of the two handles may be used. The actual bypass duct is secured by two support assemblies that are designed to mate with the contoured flange on either end of the duct. The last main feature is the pedal assemblies that allow the operator to lift the entire fixture several centimeters off the floor. This allows for interaction with a compression riveting machine, which will be described section 3.4.3.

### 3.2. Primary Features

There are six primary features that are part of the new design. These features fulfill the client's needs that were identified in the project definition report. Each of these features are described in detail in the following subsections.

#### 3.2.1. Adjustable Height and Angle

In order to make the riveting fixture work with a compression riveter and place the bypass duct in the proper riveting position, the height and angle of the fixture need to be adjustable. This turbofan bypass duct has a unique profile. The bypass duct consists of three flanges (front, middle, and rear) and several panels between these flanges. The flanges each have different dimensions: the diameter of the front flange is 36.03 inches, the diameter of the middle flange is 35.32 inches, and the diameter of the rear flange is 29.17 inches. The angles of flanges are also different: they are, from front to rear, $90^o$, $15^o$ and $12^o$ from the central axis of the duct. The compression riveter works on the top edge of the bypass duct, and the height of compression riveter cannot be adjusted; therefore, the height of the fixture needs to be adjustable. Similarly, the compression riveter can only work at $0^o$ relative to ground, so angular adjustment of the fixture is also necessary. As shown in Figure 2, to achieve the height and angle adjustment, two bottle jacks are used.

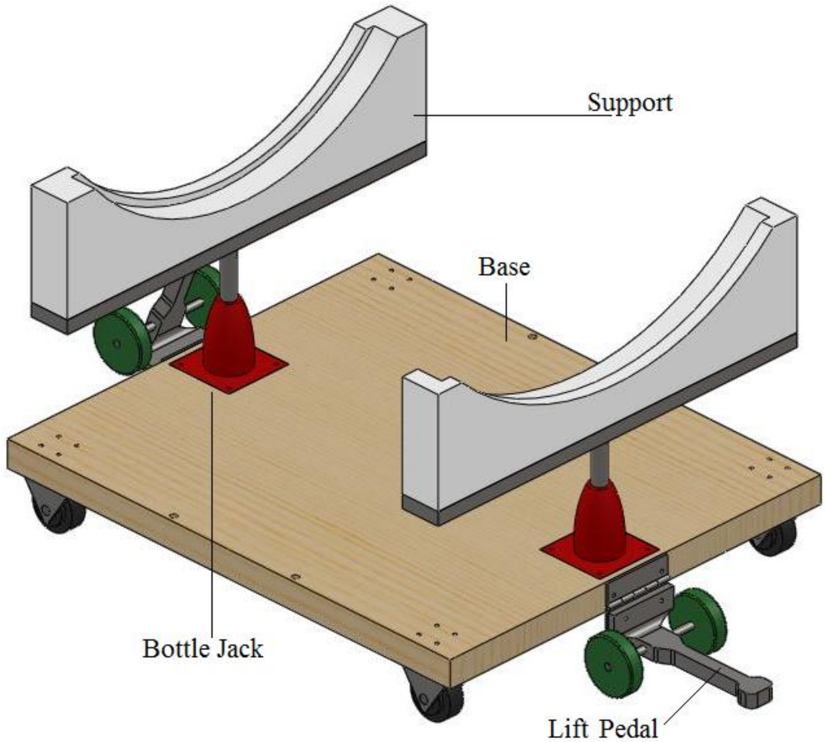



Figure 2. Configuration of riveting fixture.

These two bottle jacks are placed at opposing ends of the base of the fixture. Height adjustment can be achieved by adjusting the heights of both bottle jacks simultaneously, while the angle adjustment can be achieved by adjusting each of the bottle jacks individually.

### 3.2.2. Lift Pedal Function

When the height and angle adjustments are done, the bypass duct can be placed in the compression riveter for riveting. After the first rivet is crushed, the bypass duct needs to be rotated to the next rivet position. The head of the crushed rivet sits in the cup of a bucking pin, which prevents the bypass duct from being rotated. To solve this problem, two lifting pedals were designed to push the duct up and lift the head of the rivet out of the bucking cup. As shown in Figure 3, the lift pedal is a lever. The length of the rod and the position of the pivot point are designed to lift the fixture a minimal, but sufficient distance of 2 cm (Figure 4). Since the fixture is designed to allow riveting at both ends, there are lift pedals at each end of the riveting fixture.

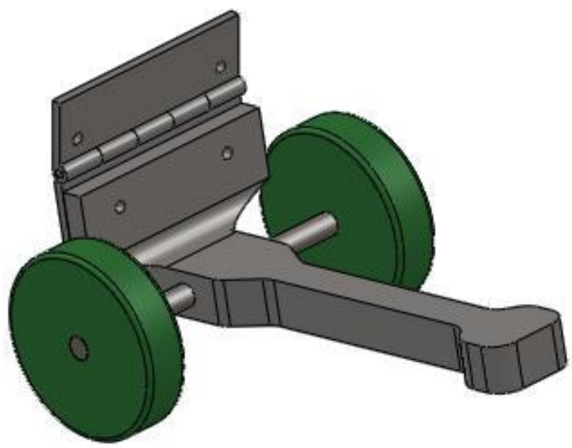


Figure 3. Lift pedal detail.

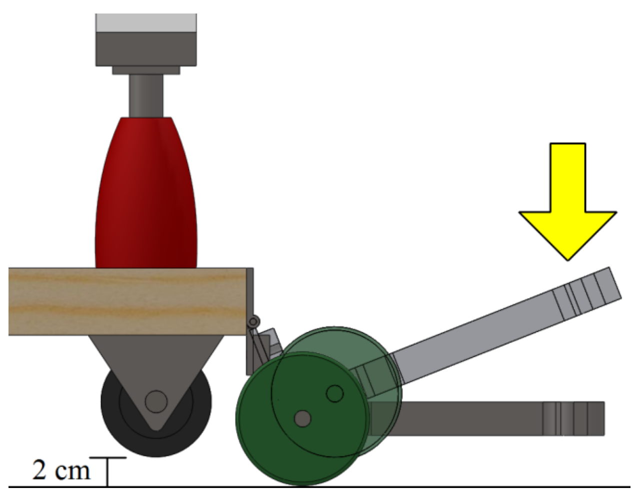



Figure 4. Diagram of lift pedal action.

### 3.2.3. Nylon Supports

The supports for the bypass duct are an essential element for the protection of the duct during the riveting process. The supports need to hold the bypass duct in a stable position, while allowing the bottle jacks to accomplish the height and angle adjustment. The contours of the supports are designed to fit the contours of the front and rear flanges to make sure the bypass duct is stable during the riveting process. Another support condition was that the support must allow the bypass duct to be rotated when it is held on the fixture. In order to achieve this simple rotation, the supports are covered with a layer of nylon material to reduce the friction between the supports and the duct flanges. This nylon layer also prevents scratching the surface of the bypass duct's flanges.

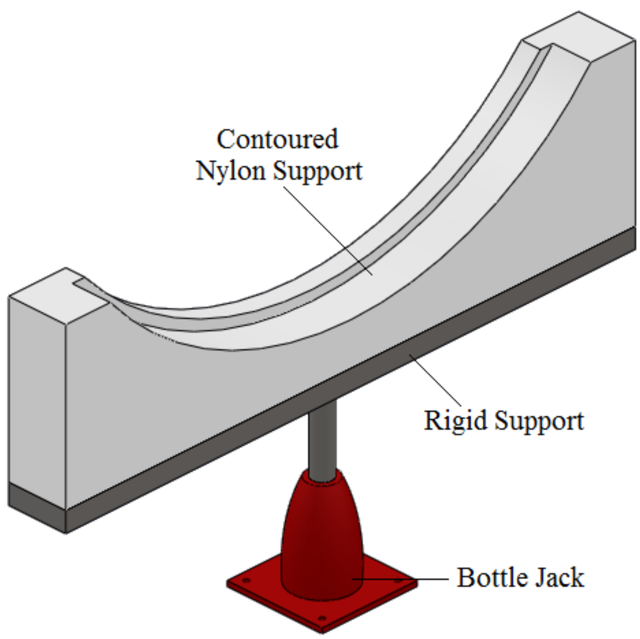



Figure 5. Nylon duct support detail.

### 3.2.4. Repeatability

Repeatability is very important to the riveting process, and is another primary feature of the design. The repeatability of the riveting process fixture is achieved by having fixed points for height and angle adjustment. To limit the adjustment of the supports, two blocks have been designed. The length, width, and height of these two blocks have been calculated to make the riveting flange level at an appropriate height for riveting. At this point, the topmost rivet in the duct sits vertically in the bucking pin cup. The two supports are lifted by the jacks to a sufficient height, at which there is enough space for the blocks to be placed beneath them. After the supports have been lifted, the blocks may be placed beneath them. Lastly, the supports are lowered so they rest on the blocks. This entire procedure is shown sequentially in Figure 6 below:

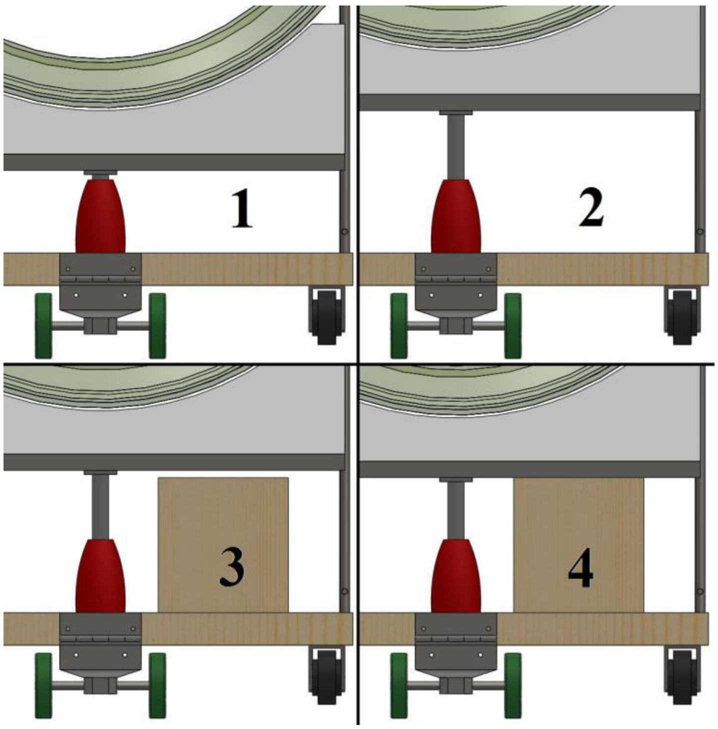



Figure 6. Height adjustment procedure.

By using these two blocks, operators can set the fixture quickly and accurately to the next working position. Therefore, the fixture can bring high repeatability to the riveting process.

### 3.2.5. Side Handles and Secondary Supports

The three flanges that are riveted during the process are located near the end of the duct. Two of the flanges are near the small diameter end of the duct, and the other is at the edge of the large diameter end. As a result, it is necessary to turn the duct and fixture around to rivet all flanges. This process is facilitated with the addition of two handles to the fixture.

In order to secure the bypass duct so that it cannot fall to the side during the riveting process, these handles were designed to be placed on each side of the fixture. One of the two handles is shown below in Figure 7:

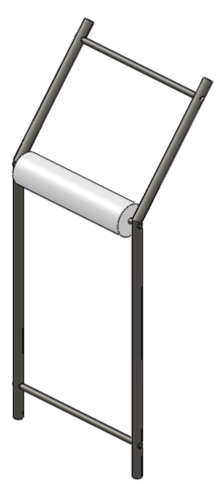


Figure 7. Side handle detail.

These dimensions allow for the handles to adequately support the duct in the event of a primary support failure. The handles also need be rigid enough to hold the weight of the bypass duct. Therefore, it is recommended that the handles be made of steel due its low cost and superior mechanical properties. If a support collapses, the duct must not only be secured, but must also be undamaged. As a result, the middle horizontal beam on the handles must be covered with a foam sleeve. This sleeve protects the skin of the bypass duct from abrasions in the event of a primary support failure.

### 3.2.6. Brake System for the Fixture

As mentioned in the previous subsection, the bypass duct fixture needs to be movable, so the duct can be relocated or turned around. Heavy-duty casters are used in the design to allow for motion in any planar direction, and have a brake assembly so they may be locked in place.

During the bypass duct riveting process, the fixture needs to be held in a fixed position to provide a stable riveting condition. If the fixture is not well locked, it could allow lateral movement which could result in the compression riveter leaving an indent, or “smile,” in the surface of the duct. These smiles are stress concentrators, and may lead to crack initiation and propagation throughout the duct. To eliminate this lateral movement, a locking brake system is essential. Two locking brake systems are proposed for use. The first brake system is that recommended for immediate implementation, the second is for future consideration.

As Figure 8 shows, the simple concept is to use four heavy-duty casters with individual locking brakes. These casters are installed under the flat base of the fixture near the edge. These four casters allow the fixture to move easily in any direction without changing its orientation. Since the bypass duct is heavy, the fixture requires heavy-duty casters to ensure the security of the duct. The downside to this design is that the brakes are not always accessible from the outside of the base. In this case the operator must apply the brake by reaching underneath the fixture. Though this is an inconvenience, these casters are readily available, and allow for immediate implementation of the fixture.

Figure 8. Caster with lever brake [1].

The alternative concept for the braking system is similar to that found on a luggage cart [2]. Since there are handles on the side, a lever and cable brake device can be mounted on the handle. Thus, the operator can easily lock and unlock the fixture when moving the bypass duct.

As the Figure 9 indicates, the braking system consists of a hand-operated brake that is spring (or gravity) actuated and typically engaged. The operator disengages the braking system by pushing a lever near the handle of the fixture, allowing him to move the fixture. The mechanical link from the handle to the brake is enclosed within the frame to reduce potential damage to the mechanism. This mechanical link consists of the lever, and a spring-powered handle that is pushed down to disengage the brake. When the handle is not depressed, the spring-powered handle raises and applies the brake [3]. Therefore, the brakes are automatically locked when the lever is not manually actuated by the operator.

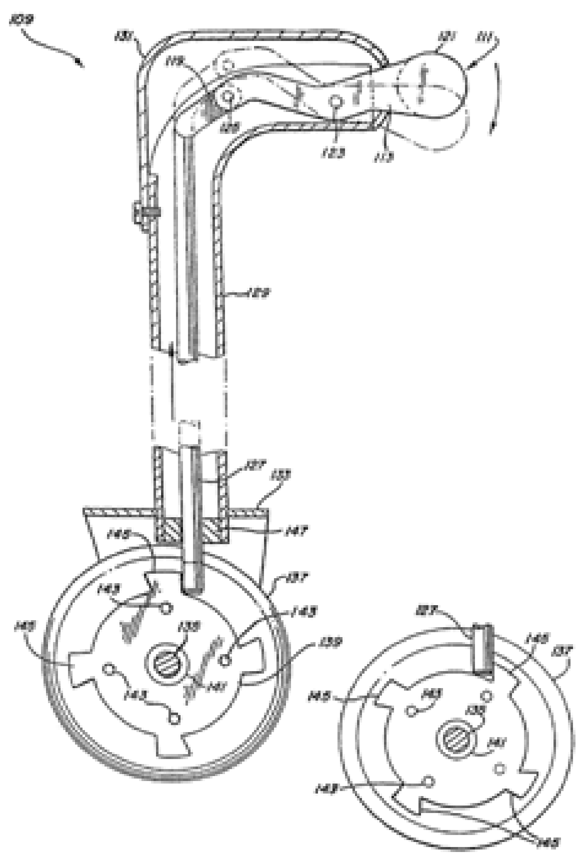


Figure 9. Levered brake mechanism [3].

## 3.3. Summary of Primary Features

The primary features described in section 3.2 are directly related to the additional features presented in section 3.4. In summary, the designed fixture has six primary features. The adjustable height and angle allows the fixture to be used for all three flanges that must be riveted on the duct. The lift pedals allow the duct to be rotated easily to the next riveting position. This process is further facilitated by the contoured nylon supports that secure the exterior flanges of the duct. Repeatability is achieved by fixing the height and angle of the duct with blocks place beneath these nylon supports. More control is achieved with the use of the braking system, as well as the handles on the side of the fixture. The handles also double as secondary supports for the fixture, in the event of a primary support failure. These six primary features are beneficial to the client in other ways, and are presented in the following section as additional features.

## 3.4. Additional Features

Beyond the features that satisfy the client’s needs, the riveting process fixture design has additional features that are beneficial to the client. These features, and their purposes, are discussed in the following subsections.

### 3.4.1. Simplicity

The design promoted in this report is very simple in two different ways. The design is easy to manufacture, and is simple to use during the actual riveting process. This simplicity allows the fixture to be used by operators with a large range of experience, while obtaining consistent and accurate results.

The design has a minimal number of parts to achieve the desired functions. This allows for easy production of the fixture. The first goal of the design is to achieve adjustable height of the duct. To achieve this, two bottle jacks are used for the lifting and lowering functions. The two jacks will support both front and back flanges of the duct assembly. The duct will be in direct contact with two contoured supports. The protection of the duct will be given by two nylon strips located on top of the supports. The support assemblies will be fixed on top of a wooden base which can be made from a plank of two inch wood. Four casters on the bottom of the base allow movement in any direction with relative ease. Handles are added for convenience, and are also used to increase the overall duct security during the relocating and riveting processes. The last component is the foot pedal which gives operators the ability to lift the duct to ease rotation during riveting. Every function is achieved by at most one component. Some components also have additional functions. This ensures the design contains a minimal number of parts.

The fixture is also very easy to use. The operator will put every single rivet into its corresponding hole on the flange. The operator will then locate the riveting fixture with respect to the compression riveter. The fixture is then locked into place by the brakes on the casters. The operator starts the compression riveting process (shown in Figure 10), and lifts and rotates the duct between each rivet with the use of the foot pedal.

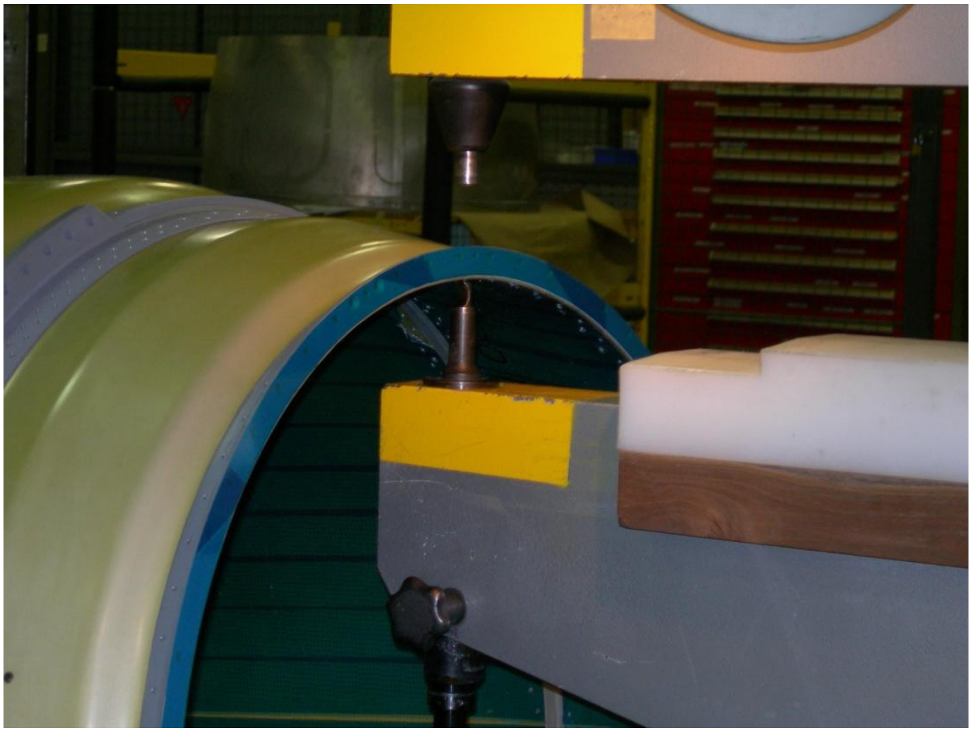


Figure 10. Compression riveting of duct flange.

When the operator needs to change the height of the fixture to achieve different angles for the different flanges, the jacks are lifted, and a block is inserted beneath the support. The bottle jack is very easy to operate and provides sufficient lift for this riveting application. Finally, the handles on each side of the fixture provide ease of movement, and additional protection for the duct in the unlikely event of a support failure. Overall, the fixture is a very user friendly platform.

### 3.4.2. Versatility

The fixture concept is a multi-function concept. The fixture can be used to produce different products other than the bypass duct mentioned in this report. With little modification on the base, the size of the duct can be changed. By allowing for adjustment of the base, the length of the platform can be changed. Also, if the new duct is too big to for the design with two bottle jacks, a third jack can be added in the middle of the base. The original design of the fixture can also facilitate the riveting process for smaller ducts. If the size of the duct must be changed, different wooden supports can be made to adjust to the new size. As with this design, the operators may adjust the height and angle of the different ducts with the bottle jacks. Ultimately, the fixture assembly can be used for riveting operations for different types of engine ducts.

### 3.4.3. One Man Operation

During the design process, the team incorporated components onto the fixture to achieve a single operator production process. The bottle jacks offer easy lift for heavy parts. One operator can easily lift and lower the bypass duct by pumping the jack up, or releasing the hydraulic pressure in the pump at either the front or back support. Due to the fact that both jacks can be adjusted easily by one operator, the angle change can be achieved by one operator. As mentioned before, blocks will be used to make the angle adjustment process a fixed process, so it only requires one operator to complete the task properly.

A compression riveter is also used to greatly simplify the riveting task. These machines are nick-named “squeezers” on the shop floor, because they use a squeezing motion to work the rivet rather than the traditional two man hammer operation. A compression riveter is shown with a bypass duct in Figure 11:

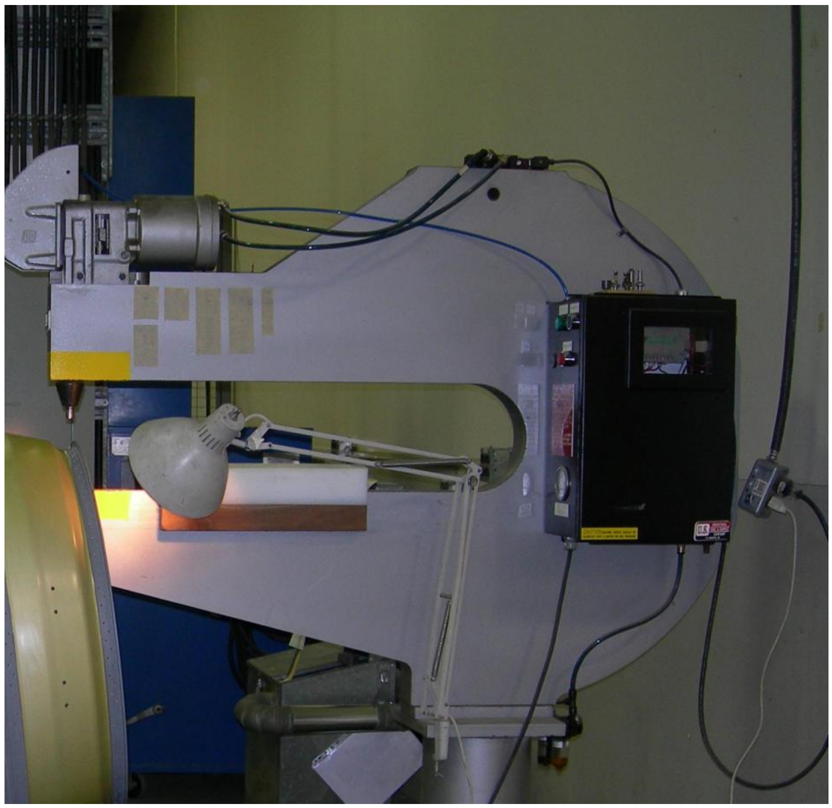


Figure 11. Compression riveter.

The machine is very important to this project because it is the key component in the one man riveting process. As mentioned before, the traditional riveting process needs two operators, and the success of the traditional riveting process is highly dependent on the craftsmanship of the two operators. In other words, the traditional riveting process is purely dependant on the performance of the involved operators. However, the compression riveter eliminates the human factor and performs consistently for every rivet. During the riveting process, the designed fixture will use the riveting machine, which will increase the success rate of the riveting process and reduce production cost.

#### 3.4.4. High Manoeuverability

The manoeuvrability of the platform was also of consideration for the design. There are two major points of manoeuvrability: the size of the fixture unit and the weight of the unit. The actual dimensions for the base are given in Appendix C.

When the size of the base was considered, the team decided to go with the minimum amount of space required to hold the engine bypass duct assembly. The small, stable, low-profile design of the fixture is advantageous during the relocation process, as it allows the fixture to be navigated through tight corners and narrow channels on the factory shop floor. It also saves valuable space in front of the compression riveting machines. If the fixture is not in use, the smaller sized design allows for minimal use of storage space.

The weight of the fixture was also taken into consideration during the design process. The weight of the fixture can affect how easy it is to move the duct from one location to the next. Most parts of the design are made of lightweight materials. The main platform consists of wood, while the protective supports are nylon materials. These light materials reduced the need for heavier, more complicated support systems. Handles and foot pedals can be made from aluminum alloys. The bottle jacks are the heaviest parts on the fixture assembly, but due to the lifting capacity of these jacks, only the smallest size of bottle jack is necessary. These components result in a minimal weight for the fixture.

# 4. Riveting Process Fixture Components

The recommended fixture design contains components that were selected with consideration given to the in-house manufacturing ability of Bristol Aerospace Ltd., as discussed with the client. There are two subsections for the riveting process fixture components: those required for immediate implementation of the fixture, and those recommended for further development of the fixture.

## 4.1. Immediate Implementation Components

The components used in the prototype of the fixture are directly applicable to the final design. Ultimately, the fixture was built to the specifications of the design, which are provided in Appendix C, though the base was not built to the appropriate width and length due to the availability of precut lumber. The necessary components for the fixture are as follows:

- 1 - wooden 2” base
- 4 - heavy-duty braked casters
- 2 - handle assemblies (see Appendix C for complete assembly details)
    - 4 - long, angled steel bars
    - 6 - short, straight steel bars
    - 2 - foam sleeves

(List continued on next page)

- 2 - pedal assemblies (see Appendix C for complete assembly details)
    - 2 – aluminum bars, bent 90°
    - 4 - wheels
    - 2 - axles
- 2 - support assemblies (see Appendix C for complete assembly details)
    - 2 - two-ton bottle jacks
    - 2 - steel support braces
    - 2 - contoured nylon supports

#### 4.1.1. Prototype Cost

A prototype of the design was built for $110 after taxes. This prototype consisted of one base with four casters, two support assemblies, and one pedal assembly. The prices for each assembly are shown below in Table I:

**TABLE I: PROTOTYPE COSTS**

| Parts | Cost |
|---|---|
| Base | N/A |
| Casters | $22.36 |
| Support Assembly | $26.77 |
| Pedal Assembly | $53.46 |
| Misc. Hardware | $7.41 |
| Labour | N/A |

The cost of the pedal assembly was higher than should be expected, as it was assembled from threaded plumbing components, which eliminated the need for welding. All parts used for the prototype, as well as all parts required for the design, are available for comparable prices at Princess Auto and McDiarmid Lumber in Winnipeg, Manitoba.

### 4.1.2. Riveting Process Fixture Cost

Using the information from table I as a rough estimate, the total cost for one riveting process fixture is approximately $300, plus applicable labour charges. The cost of both handles was estimated at $100, as they consist of bent and welded steel piping only, plus an additional sleeve of foam. The additional pedal assembly was valued at the same cost as the prototype pedal assembly. Finally, an additional buffer of $35 was introduced to account for varying costs.

## 4.2. Further Development Components

In addition to the parts recommended for immediate implementation of the fixture, the team investigated several other components that may be of interest to the client.

The team looked into the use of two electric lifts to be used in place of the hydraulic bottle jacks. While no suitable system was found, several electrical lift tables are available. The use of these tables has been discussed with the client as an alternative to the recommended design.

The team also looked into existing vertical compression riveter designs. The idea was to come up with a design where the duct was supported vertically, and a vertical compression riveter was used to work on the engine bypass duct from the side. This idea would eliminate the need for a lift and tilt feature on the fixture, and would further simplify the process. Unfortunately, a suitable vertical compression riveter could not be found for the bypass duct riveting process.

## 5. Conclusion

In conclusion, this report proposes a new design for a riveting process fixture for Bristol Aerospace Ltd. The new design eliminates the craftsmanship-dependant two man operation by introducing a process that may be completed by one operator. Throughout the project, various research methods were used to come up with the final design for the project. A constantly evolving design process allowed for objective analysis of the benefits of the different proposed concepts. These concepts were refined to a final, optimal design. This design was based on the concepts of duct security, ease of operation, ease of manufacturing, as well as overall function and simplicity. The final design incorporates such features as contoured nylon supports, and padded secondary supports to eliminate the risk of part damage from the fixture. Another key feature of the design is its mobility, and interaction with a compression riveting machine, which allows the riveting process to be completed by one operator. The design also incorporates a fixed height riveting process, thus reducing the need for an experienced operator. As evidenced in this report, the new engine bypass duct riveting fixture satisfies and exceeds the requirements of Bristol Aerospace Ltd., and should be used in future riveting process operations.

## 6. References

[1] Y. H. Caster Co. Ltd. (2010)."image.jpg," in Diytrade.com [Online]. Available: http://www.diytrade.com/china/4/products/147189/3_x1_TPR_caster_75mm.html [Nov. 25, 2010].

[2] Hand deactivated shopping cart automatic braking system, by P. D'Arca. (2008, July 8). *United States Patent 7395902* [Online]. Available: http://www.freepatentsonline.com/7395902.pdf [Nov. 28, 2010].

[3] Self-locking wheel, Raymond Joseph, Schiltigheim; Roger Manin. (1971, Nov 30). Patent 887968 [Online]. Available: http://www.freepatentsonline.com/3623575.pdf [Nov. 28, 2010].

## Appendix A - Concept Consideration

There are four various concepts that were ultimately selected for further development in this project, based on specific design parameters. These parameters included the weight of the fixture, the installation and manufacturing difficulty, the size of the fixture, its stability, and overall cost. Various aspects and components from these concepts were used in the final fixture design presented in this report. The details of each of these concepts are described and compared in the following sections.

## A.1 Concept A: Two Degree of Freedom Fixture

This designed fixture consisted of four individual supports, each of which has two degrees of freedom. The supports have a rotational foot in order to move the bypass duct, as well as independently adjustable height. The two degrees of freedom provide the angle and the height of the duct, and can be adjusted at the same time. The main advantage of this concept is that the bypass duct can be adjusted to multiple orientations. Figure 12 shows the structure of concept A.

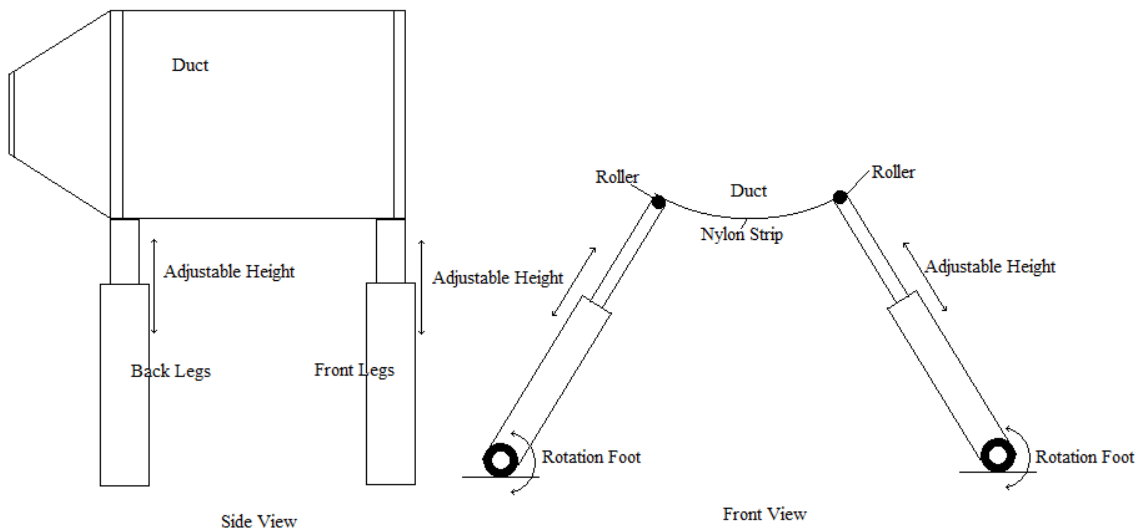



Figure 12. Concept A: Two degree of freedom fixture.

## A.2 Concept B: Height Consideration Fixture

The height of the compression riveter is also considered in this case, since the riveter can provide a stationary condition for the riveting process. The compression riveter is fixed at a height of 48.5 inches, and has a throat length of 28 inches. Compared with the duct diameter of 37 inches, there is limited space for the fixture beneath the riveter. Therefore, the fixture was modified to hold the bypass duct on the top of squeezer, so that the height of fixture could be adjusted easily. The main disadvantage of this design is that the bypass duct is difficult to rotate. Figure 13 shows the structure of concept B.

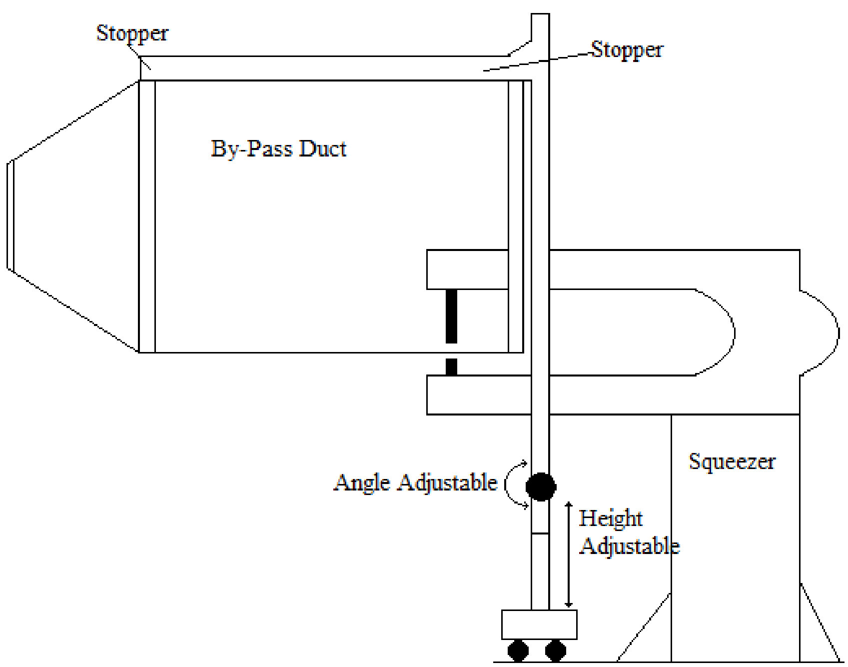



Figure 13: Concept B: Height consideration fixture.

### A.3 Concept C: Single Support Jack Design

This concept was based heavily on recommendations from the client, as well as existing riveting process fixtures. The concept has a bottle jack on the bottom that provides the capability of adjustable height. The bypass duct is held by an adjustable wooden support at each end. In addition, three blocks are used to keep the riveting surface leveled. The advantage of this concept is its ease of use and low manufacturing cost. Figure 14 shows the structure of concept C.

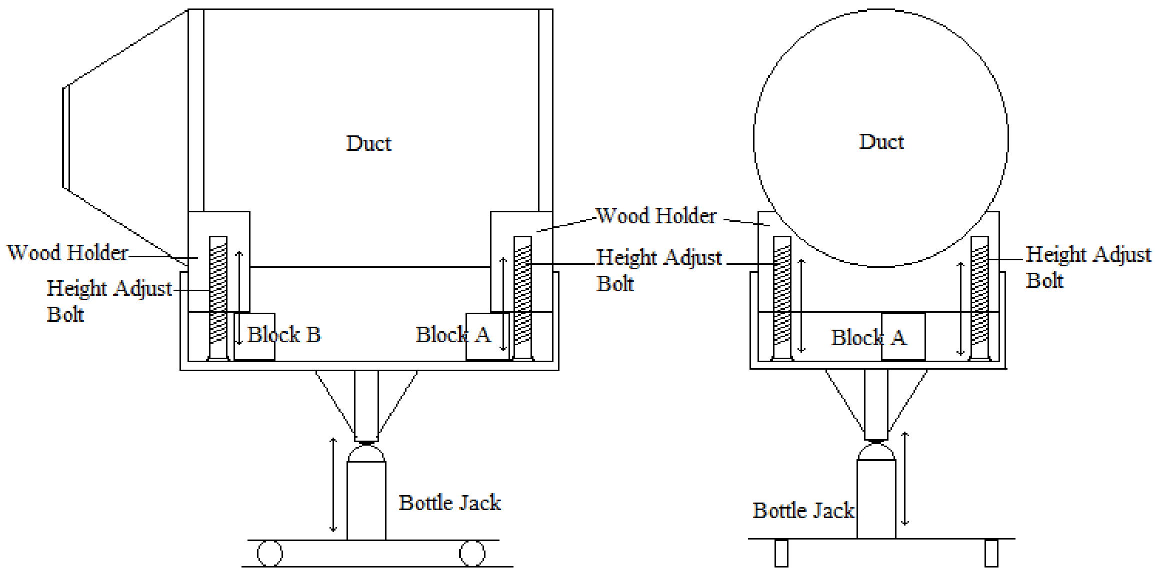



Figure 14: Concept C: Single support jack design.

### A.4 Concept D: Near Final Design

This is the concept that was shown to the client at the last visit before the completion of the final design. The major concern with concept C was the issue of duct security. As a result, this fixture design has a bottle jack at each end under a support. In order to obtain a level riveting surface, the two bottle jacks can be adjusted to different heights which result in specific duct angles. In addition, two side handles allow for easy relocation of the duct, and provide backup support in the event of a primary support failure. The advantages of this concept include better durability, stability, and safety. The design is also easy to use and has a low manufacturing cost. Figure 15 shows the structure of concept D.

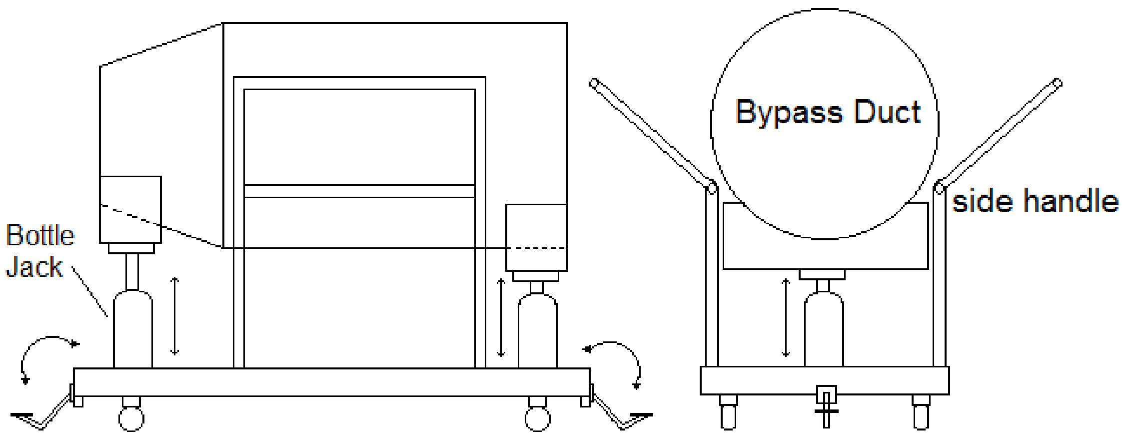



Figure 15. Concept D: Near final design fixture.

## Appendix B - Selection Criteria & Analysis

The concept decision matrix was employed to analyze and compare the four concepts presented in Appendix A. The design criterion were selected to reflect the client's needs, and were weighed based on the team's opinion of relevance and importance. The following table shows the concept decision matrix for bypass fixture.

**TABLE II: CONCEPT DECISION MATRIX FOR DUCT FIXTURE**

| | | Alternatives | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Selection Criteria | Weight | Concept A | | Concept B | | Concept C | | Concept D | |
| | | Rating | Weighted Score | Rating | Weighted Score | Rating | Weighted Score | Rating | Weighted Score |
| Mass | 1 | 1 | **1** | 2 | **2** | 1 | 1 | 3 | **3** |
| Installation Difficulty | 3 | 1 | **3** | 3 | **9** | 2 | 6 | 5 | **15** |
| Manufacture Difficulty | 2 | 1 | **2** | 3 | **6** | 2 | 4 | 4 | **8** |
| Size | 4 | 3 | **12** | 3 | **12** | 1 | 4 | 3 | **12** |
| Stability | 5 | 1 | **5** | 0 | **0** | 1 | 5 | 4 | **20** |
| Labour Experience requirements | 5 | 3 | **15** | 1 | **5** | 4 | 20 | 4 | **20** |
| Number of workers | 4 | 3 | **12** | 3 | **12** | 3 | 12 | 4 | **16** |
| Manufacture Cost | 1 | 1 | **1** | 3 | **3** | 2 | 2 | 4 | **4** |
| Operation Cost | 4 | 2 | **8** | 1 | **4** | 3 | 12 | 4 | **16** |
| Net Score Rank | 29 | 16 | 59 | 19 | 53 | 19 | 66 | 35 | 114 |

As mentioned before, the weighted scale used was set by the team in terms of relevance and importance. The scale ranges from 0-5, with five denoting the most crucial design elements. As Table I shows, the weighted score is equal to the rating multiplied by the weight of each concept. Figure 16 shows the calculation process of the concept decision matrix and clearly represents the advantage of concept D.

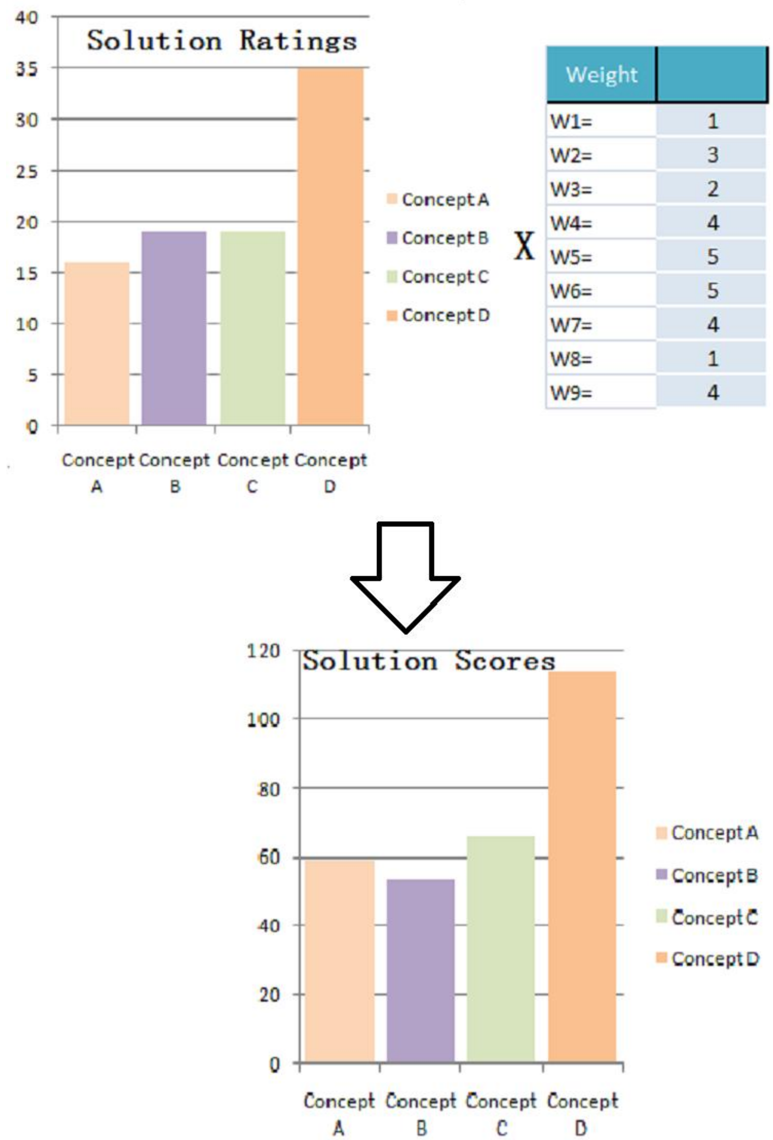


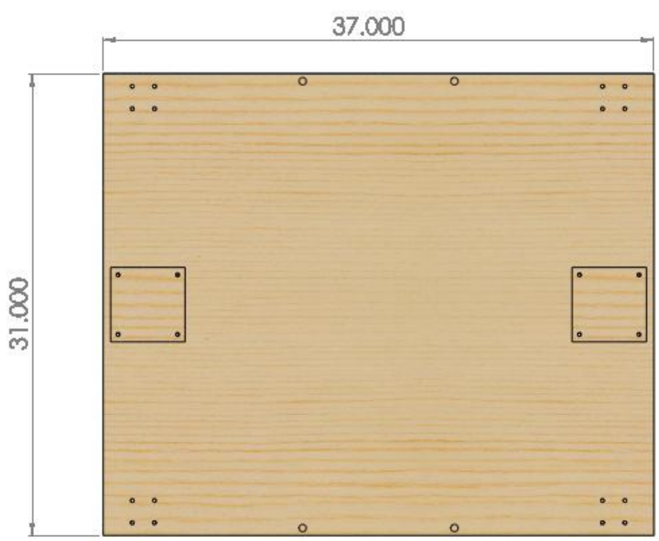

Figure 16: Selection criteria calculations.

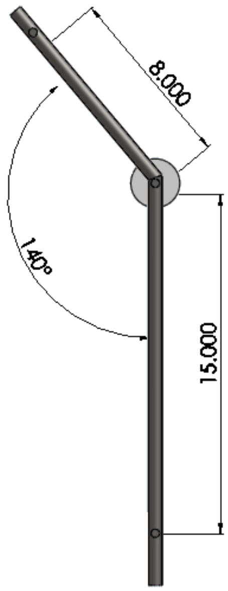
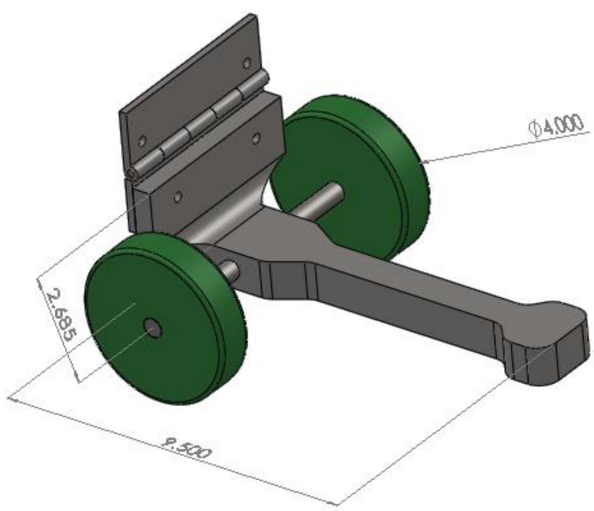
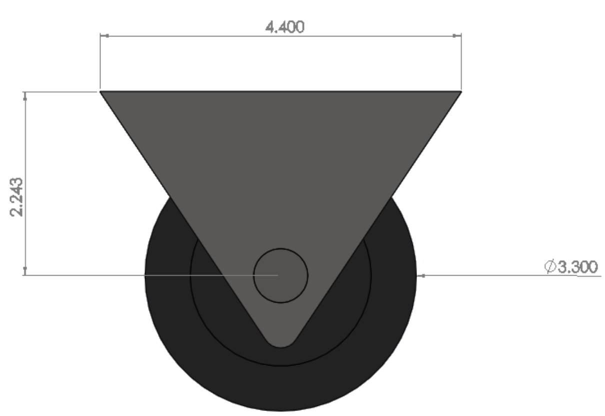
The solution ratings are the sum of the ratings of each concept, while the solution scores reflect the weighted ratings.  In either case, it can be seen that concept D was rated as the strongest design by the team.

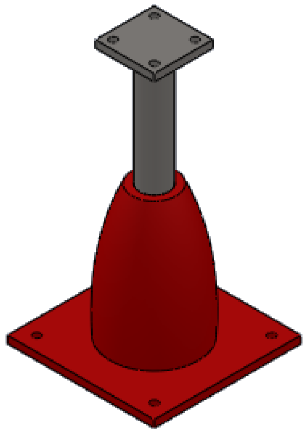
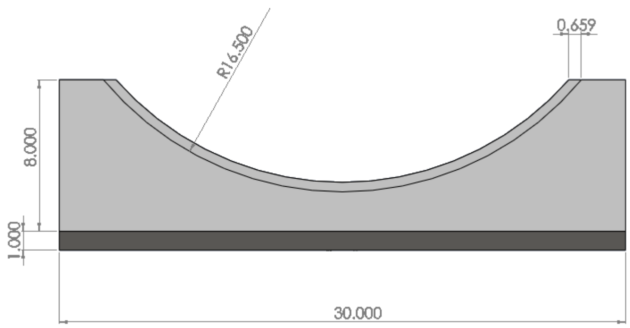
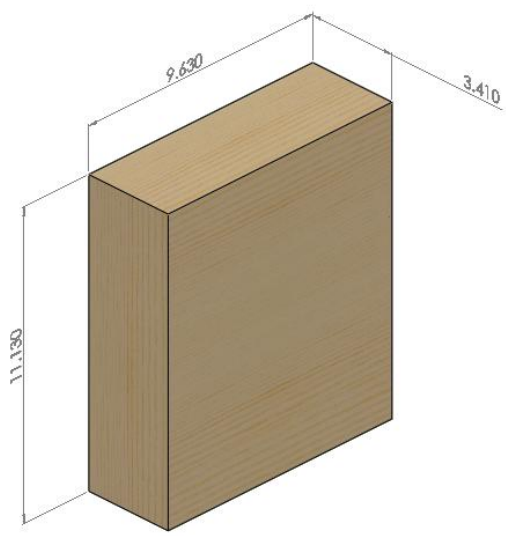
## Appendix C – Design Specifications

Due to the in-house manufacturing capability of Bristol Aerospace Ltd., as well as the availability of existing components, specific parts have not been recommended for the construction of the turbofan bypass duct riveting process fixture. Specific details relevant to the construction of a fixture for the exact duct dimensions have been provided to the client, but are not presented here. Instead, the necessary information for the construction of a functioning riveting process fixture is presented in Table III, though it is not specific to the duct used throughout the project.

TABLE III: DESIGN COMPONENT SPECIFICATIONS

| **Part** | **Dimensions** | **Additional** | **Notes** |
|---|---|---|---|
| Base |   | T: 2” | All components fastened to the base are centered and positioned 0.5” from the edge. |

| | | | |
|---|---|---|---|
| Handle |  | D: ¾”<br>L: 10” | Sleeve is 3” cylinder of foam |
| Pedal |  | N/A | The pedal must allow 2 cm of lift when it is depressed. As a result, the hinge must be positioned in such a way that the wheels extend 2 cm below the casters. |
| Caster |  | T: 2.2” | (See Pedal) |

| | | | |
|---|---|---|---|
| Jack |  | N/A | Standard profile 2 ton jack. 5" lift |
| Support |  | T: 3" | Opposing radius is 18.5", height must total 11" |
| Block |  | N/A | Assumes support heights are 9" and 11" |