Team #1 Supernova
Fixture for Jet Engine Bypass Duct
Final Design Report
Bristol Aerospace Limited
Team Advisor: Malcolm Symonds

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1 Abstract

Team Supernova has been commissioned by Bristol Aerospace Limited to design a fixture for a jet engine bypass duct as part of the University of Manitoba Engineering Design class. Bristol Aerospace manufactures a bypass duct for the Airbus A380 turbofan engine. In the current manufacturing process of the duct workers are at risk of strain injuries from manual manipulation of the part. This report proposes a fixture for the jet engine duct that will eliminate worker strain.

After conducting research and analysis, six conceptual fixture designs were generated. Further screening led to the conclusion that the suspended arm fixture would be the most feasible for this application. During the design phase of the suspended arm fixture another fixture that functions similar to the suspended arm was discovered. This fixture, available from the Anver Corporation, is the fixture that the team chose to pursue.

The fixture will be supplied by Acculift-Airmax, the Winnipeg distributor for Anver. The fixture is a custom, electric powered, vacuum lifter with side grippers capable of 360 degree manual rotation. The fixture will make use of a currently existing electric hoist in the manufacturing plant at Bristol Aerospace. The electric hoist will provide lifting, lowering, and translational motion of the duct, and the fixture would provide the rotational motion. The Anver fixture has a quoted cost of $15,995. A stand for the fixture, designed by the team, has a quoted cost of $448, bringing the total cost of the fixture system to $16,443.

The Anver fixture meets all of the customer’s needs and target specifications. Supernova recommends that Bristol Aerospace purchase the Anver fixture and implement its use in the manufacturing process of the jet engine duct in order to eliminate worker strain.
2 Introduction

Bristol Aerospace manufactures a jet engine bypass duct that is used at the exhaust nozzle of the Airbus A380 turbofan engine. During the manufacturing process the duct must be hoisted, rotated 180 degrees about the horizontal axis, moved from platform 1 to platform 2, and then set down for workers to continue part assembly. The tasks are currently carried out manually by two workers. There is an existing electric hoist in the manufacturing plant but it cannot be used to rotate the duct. Due to the limitations of the electric hoist, workers are required to lift and rotate the duct themselves. The current manufacturing process is an unsafe practice that leads to unnecessary worker strain and risks damage to the part.

This report documents the process of generating ideas to solve this problem and recommends the fixture that Bristol Aerospace must consider implementing in the manufacturing process of the duct. Details and operation of the proposed fixture are discussed further in the report. The project has been completed and the deliverables have been handed over to Bristol Aerospace as per the signed statement of work.

3 Background

As part of the current manufacturing process of the jet engine duct workers are at risk of strain injuries from the manual manipulation of the part. The current process not only presents a safety hazard, but also risks damaging the duct. A new fixture that will eliminate worker strain and maintain the integrity of the part needs to be designed in order to improve the manufacturing process of the jet engine duct.
The customer requests, the fixture must meet certain criteria. The fixture needs to laterally translate, rotate a minimum of 180 degrees on the horizontal axis, and be capable of lifting and lowering the duct between the two platforms. The fixture needs to hold the duct securely and maintain the integrity of the part during attachment and transportation. The fixture also needs to be efficient, taking no more than eight minutes to retrieve the fixture, attach it to the duct, move the duct, detach the fixture, and then return the fixture to its original storage position. The operators must be able to learn how to use the fixture within a 30 minute training session. The fixture must also be easily stored with an overall footprint of no more than 7 feet by 7 feet. Finally, the total costs associated with manufacturing the fixture must not exceed $60,000 [1].

4 Project Objectives

The main objectives of this project are to design a fixture that will hold the duct securely, not damage the part during transportation, incorporate existing infrastructure, and eliminate the physical strain to workers during the manufacturing process of the jet engine duct. Upon project completion the deliverables Bristol will receive are product information about the fixture and a final written report.

5 Target Specifications

The target specifications are designed to exceed the customer needs to increase customer satisfaction. The fixture must be able to lift the 100 pound bypass duct, raise it up 5 feet, move it a distance of 12 feet to the required workstation, and rotate it 180 degrees on the horizontal axis. The duct is seen in both positions in Figure 1. The fixture must have a 13.8 degree angle on the lift face in order to accommodate the taper of the duct’s sleeve. There must be a minimum distance of 35 inches from the center axis of rotation to the horizontal crosspiece in order to accommodate the rotation of
the duct. The fixture must interface with the electric crane via a lifting hook, have an integrated power supply, and be designed to handle the load of the duct with a safety factor of 2. If suction cups are used to attach the fixture to the duct, the suctions cups must be shorter than 18 inches in length. The fixture will have a cycle time of 5 minutes to retrieve the fixture, attach it to the duct, move the duct, detach the fixture, and then return the fixture to its original storage position. The operators will be trained to use the fixture within a 20 minute training session. The fixture will have an overall footprint of less than 7 feet by 7 feet. The estimated cost of manufacturing the fixture will not exceed $20,000 [1].

Figure 1: Jet engine duct at working positions

6 Problem Solutions
Before developing concepts for the duct fixture, a variety of external and internal searches were conducted in order to help generate ideas. A search of lift and turn fixtures currently used in industries such as aerospace, automotive, and chemical processing was performed. From the knowledge gained in the external search, an internal search was conducted using both brainstorming and theory of inventive problem solving (TRIZ) techniques produced various concepts for consideration. A concept combination table was then used to generate six preliminary designs of a fixture for the jet engine duct including: suspended arm, rolling stand with grippers, helium bag, jib crane, robotic arm, and lifting strap with handles.

A decision matrix was used to score each of the designs based on how well the design satisfied the customer’s needs. A pros and cons list was also developed for each design to help determine which designs were the most feasible to implement. A detailed description of concept generation and analysis is shown in Appendix A. Based on the analysis of the six fixtures the suspended arm, rolling stand with grippers, and lifting strap with handles progressed to the secondary design phase. After further consultation with Bristol Aerospace, the suspended arm fixture was selected as the best design suited for this application.

The suspended arm fixture is based on using existing infrastructure within the facility where an electric hoist is used. The fixture would be attached to the electric hoist and then moved to a position just above the duct. One or two workers would attach suction cups located along the arms of the fixture to the duct. Once secure, the fixture would be lifted up and moved via the electric hoist to the proceeding platform. After the part in the fixture is lifted from the platform it will be rotated within the fixture by workers spinning the arms within the bearings of the shaft of the fixture. After the duct is in place, the suction cups can be detached and the fixture would be placed on the storage stand until
required for the next operation. The fixture would be permanently stationed within the working cell, a preliminary design is shown in Figure 2.

![Figure 2: Drawing of the suspended arm fixture](image)

As further research was conducted in order to find suitable suction cups for the fixture, a similar lifting and rotating fixture available from Anver Corporation was discovered [2]. The Anver fixture functions identical to the suspended arm fixture that was developed by the team and the company was contacted for more information. The Anver fixture meets all of the customer’s needs and target specifications, and as such, it is proposed that Bristol Aerospace implement this fixture in order to lift and rotate the jet engine duct. The features and operation of the Anver fixture is discussed in the following section.
7  Details of Design

The suspended arm fixture is the best option to proceed with as it scored the highest in all of the ranking procedures for meeting customer needs and technical specifications. The Anver fixture, similar to the images in Figure 3, functions similar to the suspended arm fixture but has additional features that were not initially designed for the suspended arm. The Anver fixture takes advantage of years of engineering experience in the suction cup field by having Anver design this fixture. What will be received is an out of the box, turnkey system that solves the problem at hand, with a short integration and troubleshooting time. This section will focus on the Anver fixture and will discuss design features, integration of the device into the facility, operation of the fixture, and cost analysis. This section shows how the Anver fixture meets all of the target specifications.

Figure 3: Examples of the Anver fixture [3]
7.1 Design Features

Loading the part is accomplished by moving the fixture into place over the duct by use of the overhead crane. Vertical arms mounted on rollers attached to the horizontal beam allow horizontal adjustment of the open and closed dimensions. The horizontal adjustment of the arms accommodates loading the duct by moving the arms to clear the part when the fixture is moved into position.

Suction cups are used to interface with the duct. The suction cups use a vacuum pump to generate a negative pressure which creates a holding force for each suction cup. The cups are oval-shaped and rated to support 200 lb. The cups provide a fast and reliable means to attach and release the duct without compromising part integrity. To ensure the duct is held securely in the fixture there is a vacuum gauge that displays the level of holding power. The technical specifications Anver agrees to meet are shown in Appendix C – Correspondence.

To rotate the part, the suction cups are mounted a pivot that will allow 180 degrees rotation on the horizontal axis. The fixture is designed such that the axis of rotation is about the duct’s center of mass. By ensuring that the fixture is attached to the part where the fixture’s center of rotation is collinear with the center of mass of the part, any tendency of the part to shift while in the fixture is eliminated. To guarantee the fixture is attached collinear with the center of mass of the duct, there will be blocks attached to platform 1 and 2 set at a height such that the fixture aligns with the center of mass of the part. The positional blocks are explained in detail in section 7.3 of the report.

Translation of the duct from platform 1 to platform 2 is accomplished through operation of the overhead crane. Operators will be responsible for positioning the fixture on the part and positioning the part on the platform while it is in the fixture.
Storage of the fixture will be done by a dedicated stand, shown in Figure 4, designed specifically for this purpose. The stand will hold the fixture between uses and will be installed within reach of the overhead crane. A single operator is able to use the fixture from start to finish.

![Figure 4: Storage stand for fixture](image)

### 7.2 Device Integration

To implement the fixture, minimal changes will occur in the manufacturing environment. A storage stand must be designed and installed which will be responsible for holding the fixture while it is not in use. The overhead crane will be used to lift and move the fixture while empty, or with the part in it. A power source of 120V must be accessible at the hook to provide power to the vacuum pump that is onboard the fixture. Operator training on how to use the fixture is the final step to integrate the Anver fixture into production. The goal is to have the operators trained in a 20 minute training session on how to operate all aspects of the fixture.
7.3  Description of Operation

The fixture will be kept on the storage rack and when it is required, an operator will bring the overhead crane to it. The hook of the crane must be attached to the lifting eye and the power source connected to the fixture for the vacuum pump. Once the hook of the crane and the power supply are connected to the fixture, it is lifted off the storage stand and moved to the location of the duct. The fixture is lowered over the duct on platform 1, with the arms in the open position to ensure that the arms do not accidently come into contact with the duct. The arms index a height control block on the platform that aligns the fixture’s rotation axis with the center of mass of the duct as shown in Figure 5. The arms will be pushed into position by an operator such that the suction cups make contact with the surface of the duct. At this point the vacuum pump is switched on and the suction cups hold the part securely. In the case of a power loss, a check valve on the vacuum line ensures the part is not released from the suction cups during fixture use. Once the suction cups have reached the set pressure shown on the vacuum gauge, the fixture is ready to lift the part.

Figure 5: Duct on platform 1 with index blocks
Lifting is performed by the overhead crane. The duct is lifted such that the axis of rotation is a minimum height of 3ft above any surface to ensure that the part has clearance to rotate 180° without any interference. Rotation of the duct is accomplished through manual manipulation of the duct in the fixture by an operator. There will be no strain on the operator during part lift, rotation, and translation since the duct is fully supported within the fixture.

Once the operator moves the fixture and duct assembly to the required platform, the assembly will be lowered into place. To maintain positional consistency, there are docking blocks attached to the platform that interface with the vertical arms on the fixture as shown in Figure 6. The fixture is set onto the blocks which are set to a height that also allows the duct to rest on the table. The vacuum to the suction cups is then turned off and the part is released from the fixture. The fixture is then placed back on the storage rack until needed for the next operation.

Figure 6: Duct on platform 2 with index blocks
7.4 Cost Analysis

The total cost of the project is based from the prices given by suppliers and is summarize in TABLE I. Acculift-Airmax, the Winnipeg distributor for Anver, quoted the lift and rotate fixture at $15,995.00 as a complete unit, FOB Bristol Aerospace. The storage rack designed by the team and built by TPG Pritchard Machine was quoted at $448.00 complete. The quotations from suppliers are shown in Appendix C – Correspondence. The total cost for the lift and turn fixture to be operational in the manufacturing process is $16,403. Additional costs to be considered are a 120 V power supply at the hook of the lift for the fixture.

<table>
<thead>
<tr>
<th>Item</th>
<th>Supplier</th>
<th>Quoted Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspended Arm Vacuum Fixture</td>
<td>Acculift-Airmax</td>
<td>$15,995.00</td>
</tr>
<tr>
<td>Fixture Stand</td>
<td>Pritchard Machine</td>
<td>$448.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>$16,443.00</strong></td>
</tr>
</tbody>
</table>

8 Project Management

Team Supernova consists of the team leader Omar Maqsood, administrative coordinator Marc Tiefenbach, document coordinator John Dahl, and graphic coordinator Bao Nguyen. The team leader organized team meetings, delegated tasks, oversaw team operation, and served as a liaison between Bristol Aerospace and the team. The administrative coordinator prepared minutes for team meetings, ensured the team was informed about tasks to be completed for subsequent meetings, and kept track of the team’s progress with respect to the work breakdown structure and Gantt chart shown in Appendix D – Work Breakdown Structure & Gantt Chart. The document coordinator prepared outlines for all written work, compiled and formatted information for reports, and performed final revisions before any work was printed for submission. The graphic coordinator maintained and updated the
team’s work breakdown structure and Gantt chart, prepared visual aids for oral presentations, and designed posters for presentations. This section describes how the team approached the problem, the techniques that were used, and the challenges that were faced in order to complete the project.

The team’s greatest strengths were organization, work ethic, and group dynamics which allowed the project to be completed promptly and to the team’s satisfaction. Organization was crucial due to the short duration of the project; the following techniques were used to keep the team on task. Meetings were organized a minimum of one day prior, and an agenda for that meeting was prepared and distributed to the team shortly after the meeting was organized so that the team would have at least a day to prepare required material. Meetings were structured to conform as close as possible to the agenda so that all tasks would be addressed. Time was saved at the end of each meeting to schedule the following meeting while all team members were present. Before the end of each meeting, future tasks were delegated to individual team members. The team leader outlined the general scope of what needed to be done prior to the next meeting to define a definite direction and goal for the team. During team meetings both the administrative coordinator and team leader would take notes, shortly after each meeting the administrative coordinator would prepare minutes to be approved by the team leader before distribution to the team. By constantly referring to the team’s work breakdown structure and Gantt chart, the team was able to remain on task and keep the end goal of the project in mind. Organizational skills of the team as a whole allowed the project to be completed on time.

The team’s superior work ethic also helped with completing the project. Individual tasks were assigned before the end of each meeting, these tasks were given a short duration to complete, sometimes only a day. The workload was divided amongst team members to accomplish tasks more efficiently, but it required that each team member work enthusiastically and dedicate a significant amount of time to the team. There were few task delays throughout the project but that did not hinder
the progress of the team, as those who did not complete what was required at the time ensured that the work was completed by the next meeting. Hard working individuals made the team stronger, and allowed the team to prepare a well written report.

The team’s dynamics allowed the team to function as a single unit within a group setting and this was advantageous as it enabled individual team members to rely and trust each other. Brainstorming sessions were held in team meetings and were structured in a way so that each team member would have a chance to express his ideas without interruption. Constructive commentary was given by the other teammates in order to help build on ideas or politely dismiss ideas that were unfeasible. Each team member was given equal opportunity to speak and equal opportunity to lead group discussions in order to ensure a strict level of fairness. Tasks were assigned to each team member equally, and consideration was given to members engaged in other, more pressing, work for other classes. Assigned tasks were completed individually but revisions were carried out by the team as a whole. Each piece of written work was first revised individually by each team member and then the entire team would revise the piece together so that the team would be satisfied with the content of the report. Again, constructive commentary was used so that each teammate’s ideas could be built upon, not entirely ignored. Being able to function dynamically as a group promoted positive team relations which allowed the project to be completed in a productive, focussed manner.

The toughest challenge the team faced was time management. Having only 13 weeks to complete the project meant that tasks needed to be performed promptly and each teammate had to be strictly dedicated to the team. Exceptional organizational skills kept the team on task, and with a strong work ethic exhibited by all team members, the required work was completed on time. Another time management issue arose when the team tried to make contact with Anver. A contact at Anver was supposed to send the team information about a suction cup fixture used for rotating objects by
November 24; however, due to American Thanksgiving, that information was not disclosed until December 1, effectively reducing the amount of time the team had to finalize the written report and prepare for the oral presentation. Again, due to the team’s strong work ethic and dynamics, the team managed to finish the required work and catch up to the deadline as outlined by the Gantt chart.

Team Supernova consists of four hardworking individuals that bring a unique set of skills and attributes to the team. Each teammate was assigned a specific role with different responsibilities and through daily communication the team functioned as a single unit. To complete the project in 13 weeks, the preceding project management strategies were employed. The team’s organizational skills, work ethic, and dynamics allowed the project to be completed on time and to the team’s satisfaction.
9 Summary and Recommendation

Team Supernova has been commissioned by Bristol Aerospace Limited to design a fixture for a jet engine bypass duct. Bristol Aerospace manufactures a bypass duct for the Airbus A380 turbofan engine. In the current manufacturing process workers are at risk of strain injuries from manual manipulation of the part. After conducting research and analysis, six conceptual fixture designs for the duct were generated, and the suspended arm fixture was selected as the design most suitable for this manufacturing application. Further research led to the discovery of a similar fixture available from Anver Corporation. The Anver fixture was selected as the solution the team pursued.

The fixture will be supplied by Acculift-Airmax, the Winnipeg distributor for Anver. The fixture is a custom, electric powered, vacuum lifter with side grippers capable of 360 degree manual rotation. The fixture will make use of a currently existing electric hoist in the manufacturing plant at Bristol Aerospace. The electric hoist will provide lifting, lowering, and translational motion of the duct, and the fixture would provide the rotational motion. The Anver fixture has a quoted cost of $15,995. A stand for the fixture, designed by the team, has a quoted cost of $448, bringing the total cost of the fixture system to $16,443.

The Anver fixture meets all of the customer requirements and target specifications as outlined in this report. The project’s objectives have been met—a fixture has been selected that will hold the duct securely, not damage the part during transportation, incorporate the use of existing infrastructure, and eliminate the physical strain to workers during the manufacturing process of the jet engine duct. Bristol will be given product information about the Anver fixture and this final report which completes the team’s list of deliverables.
In conclusion, Supernova recommends that Bristol Aerospace purchase the Anver fixture and implement its use in the manufacturing process of the jet engine duct in order to eliminate worker strain.
10 References


This information was given to us during a site visit meeting with our project contact at Bristol Aerospace.


Anver is an American-based company that manufacturers suction cups, vacuum pumps, and different types of vacuum lifting devices. Anver manufactures a particular vacuum lift that meets all of Bristol’s needs.


Anver is an American-based company that manufacturers suction cups, vacuum pumps, and different types of vacuum lifting devices. This webpage depicts a particular fixture similar to the one that Anver has quoted for the team and the webpage shows a video of the fixture’s operation.
Appendix A - Concepts and Analyses
A.1 Concept Generation

In order to develop a feasible solution to the manufacturing problem faced by Bristol Aerospace, various features of a potential fixture for the duct were defined in a concept combination table seen in TABLE II. By integrating ideas presented in the table, six different conceptual designs were generated.

<table>
<thead>
<tr>
<th>Solutions</th>
<th>Customer Needs</th>
<th>Horizontal/Vertical Translation</th>
<th>Securely Hold Part</th>
<th>Rotate Duct</th>
<th>Be Efficient</th>
<th>Be User Intuitive</th>
<th>Maintain Part Integrity</th>
<th>Easily Stored</th>
<th>Lift and Lower Duct</th>
<th>Variable Positions Throughout Rotation</th>
<th>Easily Handled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric gantry hoist</td>
<td>Importance</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>Light</td>
</tr>
<tr>
<td>Expanding bag (friction fit)</td>
<td></td>
<td>Arms on a swivel</td>
<td>Fast clamping</td>
<td>Keep it simple</td>
<td>Soft clamp faces</td>
<td>Small</td>
<td>Reduce duct weight for workers</td>
<td>Lighting mechanism on rotation</td>
<td>Light</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roller stand with hoist</td>
<td></td>
<td>Clamps on edges</td>
<td>Bearing ring</td>
<td>Limited loads by fixture</td>
<td>Visual cues</td>
<td>Minimal interaction with duct</td>
<td>Collapsible</td>
<td>Electric hoist</td>
<td>Manual stop</td>
<td>Small</td>
<td></td>
</tr>
<tr>
<td>Assisted manual labour</td>
<td></td>
<td>Strap around circumference</td>
<td>Manual spin</td>
<td>Limited duct interaction</td>
<td>Fool proof</td>
<td>Minimal part strain</td>
<td>Non-existent</td>
<td>Cherry picker</td>
<td>Positional control</td>
<td>Soft covering</td>
<td></td>
</tr>
<tr>
<td>Jib crane</td>
<td></td>
<td>Gripping gloves</td>
<td>Single pivot</td>
<td>Easily transported</td>
<td>Color code/letter matchup</td>
<td>Reliable holding of the duct</td>
<td>Sliding arms on stand</td>
<td>No sharp edges</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automated</td>
<td></td>
<td>Suction cups</td>
<td>Location precision</td>
<td>Quick interface</td>
<td>Automated</td>
<td>Easily transported</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The six concepts generated were: suspended arm, rolling stand, lifting strap with handles, helium bag, robotic arm, and jib crane. The six proposed designs are discussed further in the following sections.
A.2 Suspended Arm

The suspended arm fixture in Figure 7 would be suspended from an overhead hoist. The hoist would perform the lifting, lowering, and translating duties, and the fixture would allow for the duct to be rotated around a central shaft. The suspended arm fixture was determined to be the most feasible solution due to its ease of operation, its use of existing infrastructure, and its ability to reduce the risk of worker injury.

Figure 7: Suspended arm fixture
A.3 Rolling Stand

The rolling stand in Figure 8 functions similar to the suspended arm fixture except the translational motion is provided by the actual movement of the fixture on its wheels and the lifting and rotating is provided by adjustable arms on the fixture. Ease of storage of the lift and turn fixture is a customer requirement, and the rolling stand does not meet this requirement in that it is relatively large and difficult to store.

![Figure 8: Rolling stand](image-url)
A.4 Lifting Strap with Handles

The lifting strap concept in Figure 9 consists of a strap with handles that makes it easier to manipulate the duct. The lifting strap was considered primarily due to its simplicity and low manufacturing cost. The lifting strap would still require the manual labour from two operators and does not eliminate the risk of injury. Due to the lifting strap’s similarity to the current lifting process, the lifting strap is not a preferred solution.
A.5 Helium Bag

The helium bag in Figure 10 consists of a bag filled with helium that can be attached to the duct to make the duct easier for workers to lift. When the bag is filled with helium, the bag will expand and friction will hold the bag securely inside the duct while making the duct lighter and more manageable for workers to lift. The helium bag design does not resolve the safety issues involved with handling the duct, and as such, was not considered as a viable solution.
A.6 Robotic Arm

A programmed robotic arm, such as the one in Figure 11, would be the most efficient solution of all the proposed designs. A robotic arm may be placed in a central location which, when programmed, will pick up, move, rotate, and release the duct at specified locations and orientations. The robotic arm is a costly investment and research has shown that it is outside of the budget for this project; therefore it will not be considered [7].

![Robotic arm](image-url)
A.7 Jib Crane

A jib crane, such as the one in Figure 12, would be used to lift, lower, and translate the duct and workers would be required to manually rotate the duct and assist with setting it down. The jib crane replaces the electric hoist, making it a redundant machine, and the jib crane design does not address the safety issues with the current manufacturing process. Due to the jib crane’s redundancy, it was not considered as a potential solution.

Figure 12: Jib crane [9]
A.8 TRIZ Analysis

The following TRIZ techniques were used to improve the six conceptual designs.

1. Segmentation

The suspended arm fixture and the rolling stand with hoist are both designed to have arms that operate independently of the rest of the fixture allowing for the duct to be rotated and translated simultaneously. The robotic arm design is also made of multiple independent parts (independent rotation at each of the joints) which allows the duct to be rotated and translated simultaneously.

3. Local Quality

The suspended arm fixture uses the electric hoist to lift and lower the duct and the arms on the spindle allow for the duct to be rotated. The rolling stand uses its arms to lift, lower and rotate the duct and the wheels make it extremely mobile allowing it to transport the duct around the facility if necessary. The robotic arm is capable of transporting the duct but the fittings on the arm can be designed so as to be used for other applications within the manufacturing shop.

6. Universality

The helium bag design has the opportunity to be used as both a lifting device and also as a cleaning device in that the helium, after use, could be used to blast away chips or loose material.

7. Nested Doll

The lifting strap with handles can be designed with straps that are stored within the handle and are released by unlatching a locking mechanism (similar to a measuring tape) which would result in easier storage.
11. Beforehand Cushioning

The suspended arm fixture and the rolling stand with hoist can both be equipped with a mesh net that is attached near the bottom of their frame which will catch the duct should one or more of the arms or clamps fail.

15. Dynamics

The suspended arm fixture, rolling stand with hoist and robotic arm all have adjustable arms which would allow the fixtures to be used for multiple applications. The hoist from the jib crane can be used to lift multiple objects and the lifting strap with handles can be used for applications of similar weight and nominal size.

20. Continuity of Useful Action

The rolling stand with hoist can be designed with locking wheels to make it stand in place which may make it possible for work to be done on the duct while the duct is held in the fixture, eliminating any need for a platform. The robotic arm can be designed rigid enough to hold the duct in place which may allow for the same work to be done on the duct during suspension.

23. Feedback

All of our designs, excluding the lifting strap with handles, can be equipped with sensors on the clamps or suction cups of the arms which can tell how much force or stress is being applied to the duct at any given time to ensure the duct’s safety.

29. Pneumatic or Hydraulic Solutions

The robotic arm and jib crane designs may employ pneumatic or hydraulic technologies in their use.
34. Discarding and Recovering

The helium from the helium balloon design can be recovered via a dual pumping system that both pressurizes the bag and removes the helium for storage in a separate container.

**A.9 Selection Criteria**

The various selection criteria for a final concept were selected based on the customer’s needs and target specifications. A decision matrix, as shown in TABLE III, was constructed in order to decide which designs would continue to the secondary design phase. Note that the decision matrix only scores each design based on the described criteria, it does not take into account other factors that determine whether the particular design is feasible or not.
Keeping the overall rank of each concept in mind, three designs were selected based on simplicity, cost, and ease of implementation. The three concepts selected to continue to the secondary design phase were the suspended arm fixture, rolling stand, and lifting strap. Further consultation with Bristol led to the decision that the suspended arm was the most feasible fixture for the required application.
Appendix B – Stress Analysis of Duct
The main objectives of this project are to design a fixture that will hold the duct securely, not damage the part during transportation, and eliminate the physical strain to workers during the manufacturing process of the jet engine duct. The Anver fixture uses suction cups to fix itself to the duct, and to use this method, a simulation must be done prior to implementation to determine if the suction cups will damage the duct. The simulation was performed using the SolidWorks package finite element analysis (FEA) software.

To run the analysis, a simplified model of the sleeve of the duct—the element the suction cups come in contact with—was created in SolidWorks and the yield strength of the beta-21-titanium material was set to 1200MPa. By simplifying the model of the sleeve, the complexity of the problem was reduced which resulted in fewer program failures and a reduced process time. Restraints were made at the interface of the suction cups and the sleeve, and a distributed load was applied at the opposite end which covered the suction cup surface area of 350cm². To accommodate the worst possible scenario, the applied force at the suction cup was equal to the total weight of the duct (100lb). To simulate the effect of gravity, the distributed load of 500N was not distributed evenly; more of the load was concentrated at the opposing end of the duct as shown in Figure 13.

![Figure 13: Restraints and loading](image-url)
As can be seen in Figure 14 and Figure 15, the maximum deflection of the duct is 35cm and the maximum stress is 800MPa which occurs at the interface between the suction cups and duct sleeve. The remaining area of the sleeve experiences a stress of approximately 1MPa. It must be noted that the FEA model represents only the sleeve of the duct, not the entire duct assembly, and the maximum stress and deflection would decrease if the entire assembly was considered. That said, even in the worst scenario presented by the analysis, the maximum stress applied to the duct is less than the yield strength of beta-21-titanium meaning that the suction cups of the Anver fixture will not damage the duct during transportation.
Appendix C – Correspondence
Good Afternoon John;

I spoke with the engineer today and he is very backed up. I should also explain the process….

They come up with a price and present that and they don’t actually generate actual drawings until an order is placed.

I could provide you with some sort of concept drawing but the actual drawings are not produced until an order is placed. (on custom lifters like this)

Basically the engineer comes up with a concept and a price for a device that will do the desired lift (from drawings provided) but they can’t afford to spend the time doing drawings without some sort of commitment…

Feel free to call me with any questions.

My engineer hopes to have a price for me for Wednesday of next week.

**Bruce Logan**  | ( 204 837 8367 ext 230 |7  204 786 2621 |TF:  888 317 8880 |*
bruce@acculift.ca

**Acculift Airmax Inc.**

455 Lucas Ave.

PO Box 63 Grp 200 RR 2

Winnipeg MB  R3C 2E6

-----Original Message-----
From: umdahl2@cc.umanitoba.ca [mailto:umdahl2@cc.umanitoba.ca]
Sent: Monday, November 15, 2010 1:30 PM
To: Bruce Logan
Subject: Re: Vacuum Lift

Hi Bruce,

The center of mass sits at 15 inches from the very bottom face (wide end) of the duct centered on the diameter. This may look out of place but in the actual model there are features that are not shown in the simplified drawing I sent you.
Acculift-Airmax

Also I have written down some Technical Specs that may assist in the design of this fixture.

1 - Rotate the duct through the center of mass.
2 - Horizontal opening adjustment of 50 - 70 inches.
3 - 13.8° loft on lift face.
4 - 35 inch minimum from center of rotation to horizontal beam to accommodate rotation.
5 - Safety factor of 2 minimum for lift rating
6 - Suction cups must be 2" from top of cone and 1" from the bottom of the cone
7 - Overhead crane is available

Some concerns that I have are:

A - The longevity of the suction cups and how much they may deteriorate over time
B - What kind of power will be needed for the fixture
C - Safety measures in case of power failure. I recall you saying that there is a check valve to
hold the vacuum, I was wondering if there is a surface finish vs. vacuum leakage rate
   table or something like that, which can be referenced.

This should be enough to get this rolling. Any questions please call me, otherwise I'll give you a
shout Wednesday morning to see where we stand.

Thanks again,

John Dahl

U of M

At Sat, 6 Nov 2010 00:40:51 +1100, Bruce Logan wrote:
Good Morning Mr. Dahl;

I received a note from ANVER, our vacuum lift manufacturer and they tell me you are interested in some sort of special vacuum lifting device. I don't have a phone number for you or I would have called you. If you don't mind giving me a call I would be glad to try and help you out with your application.

Bruce Logan    | * 204 837 8367 ext 230 | 7 204 786 2621 | TF: 888 317 8880 | *
bruce@acculift.ca

[cid:image001.png@01CB7CC5.270D5DA0]

Acculift Airmax Inc.

> 455 Lucas Ave.

> PO Box 63 Grp 200 RR 2

> Winnipeg MB  R3C 2E6

Pritchard Machine

--John, your cost on one stand is,---$ 448.00--Taxes extra---Regards T. Peluso.

-----Original Message-----
From: umdahl2@cc.umanitoba.ca [mailto:umdahl2@cc.umanitoba.ca]
Sent: Wednesday, December 01, 2010 3:59 PM
To: Tony Peluso
Subject: Price Request
TECHNICAL SPECIFICATIONS

Electric Powered Vacuum Lifter Side Gripper with 360° Manual Rotation

- Rated load capacity - 200 lbs.
- Electric power required - 115v/1ph/60Hz
- Vacuum generator with Vacuum Leakage Sensor
- Load Beam Length – 90 in.
- Lifter includes two side arms approximately 36 in. long with end mounted rotating oval vacuum pads.
- Dimensions of oval vacuum pads – 10.5 by 3.75 in.
- Oval vacuum pads are mounted on a 13.88° angle.
- Side arms provided with locking slide brackets for adjustment along the load beam.
- One pivoting side arm to assist pad placement and vacuum attach/release.
- 360° manual rotation with detents every 90°.
- Slide valve for vacuum attach/release
- Approximate vacuum lifter height – 68 in.
- Approximate vacuum lifter weight – 275 lbs

APPROVAL DRAWINGS
- Approval drawings are supplied typically 1-3 weeks after receipt of deposit. LEAD TIME BEGINS AFTER the final "approved" Approval Drawings have been returned to, and accepted by, Acculift Airmax Inc.
QUOTATION

CLIENT CONTACT: Mr. John Dahl  
COMPANY: University of Manitoba

TELEPHONE:  
SALESMAAN: Bruce Logan  
DATE: 12/1/2010

<table>
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<tr>
<th>QUANTITY</th>
<th>DESCRIPTION</th>
<th>UNIT PRICE</th>
<th>TOTAL</th>
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| 1        | CUSTOM Vacuum Operated Lifting/Tilting Device  
- see TECHNICAL SPECIFICATIONS sheet for details | 15995.00   | $15,995.00 |

Approval drawings 1-3 weeks
F.O.B.: Winnipeg  
DELIVERY: Lifting Device 7-9 weeks after  
TERMS: 50% w/order, 50% w/delivery

TERMS & CONDITIONS
This quotation is valid for 15 days. Pricing does not include GST & PST. A deposit of 50% will be required on all orders exceeding $5000.

Creating a Safe & Productive Workplace

ACCULIFT AIRMAX INC.
Appendix D – Work Breakdown Structure & Gantt Chart
Work Breakdown Structure

(# of Expected Hours spent in brackets)
<table>
<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
<th>Predecessors</th>
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<tbody>
<tr>
<td>1</td>
<td>1st Logbook, Gantt Chart, Meeting Minutes Review/Update</td>
<td>10 days</td>
<td>Thu 16/09/10</td>
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<td>4</td>
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<td>Tue 02/11/10</td>
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<tr>
<td>5</td>
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<td>5 days</td>
<td>Wed 03/11/10</td>
<td>Tue 09/11/10</td>
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<td>Prepare for Definition Oral</td>
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<td>Definition Oral</td>
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<td>Fri 08/10/10</td>
<td>Fri 08/10/10</td>
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