Design of a 5-Axis Fixture System

Submitted in Partial Fulfillment of the Requirements of the
Major Qualifying Project Program
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Worcester, Massachusetts

Sponsoring Agency: Middleton Aerospace

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27 April 2006

Abstract

The Middleton Aerospace Corporation designs and manufactures specialty aerospace parts for aircraft manufacturers. Many of the parts require sophisticated fixturing in order to be machined. Middleton operates a variety of CNC machine brands all of which have differently designed tables. They needed a way of sharing the fixturing systems with all of the machines. After reviewing the fixtures and machines, we designed, manufactured, and tested a fixturing system which would eliminate the need for different fixtures for each machine.

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Executive Summary

The Middleton Aerospace Corporation designs and manufactures specialty aerospace parts for aircraft manufacturers. They currently used two different types of 5-axis CNC milling machines, which have different work table configurations. Middleton approached WPI with the task of creating a universal fixture system for their two different CNC mills. Creating a universal system would help cut down on manufacturing time and shop costs, and would allow Middleton to operate more efficiently. The requirements of the system are for it to be easy to use, allow for quick change outs and be reconfigurable with previously made fixtures.

The team from WPI approached the problem by first analyzing the current parts Middleton manufactures and the different fixtures they use. After doing the analysis of the different parts and fixtures the team decided the best solution to the problem would be to create a universal machine to fixture interface.

The team recommends creating a sub-plate for each machine table, with the mounting surfaces of both machines identical it would allow fixtures for both machines to be used interchangeably. The plates should be made from A35 plate steel for its durability and ability to resist thermal contraction and expansion during the winter when the shop doors are opened and closed. There will be three sets of mounting holes at defined offset angles to prevent the fixtures from being improperly loaded. The plate will be mounted to the machine table using four bolts located in the four corners. Finally, ball locks will be used to secure the fixtures to the sub-plates. The use of ball locks will drastically cut down on the amount of time it takes to load fixtures in and out of the machine. A preliminary cost analysis shows that if Middleton were to purchase eight plates and incorporate them into their current processes, the plates would pay for themselves in approximately four months by cutting down on the amount of shop hours required.

1.0 Introduction

The Middleton Aerospace Company designs and manufactures specialty aerospace parts for aircraft manufacturers. Many of the parts are highly sophisticated and require several fixtures for machining. For each operation that is performed a different fixture is typically used. This means that each time an operation is complete the part, with its current fixture, must be taken out of the CNC machine and re-fixtured for the next operation. Middleton's current problem is that they operate a variety of CNC machine brands, all of which have differently designed tables. This means that each part's system of fixtures could have fixtures that only fit on a certain CNC machine. If that particular machine is in use or is not working, a new fixture would have to be made for in order to complete the operation on a different machine. The goal of the project is to develop a way for Middleton to use all of their fixtures in all of their CNC machines.

In order to understand the complete manufacturing process of the parts we are dealing with, information needs to be gathered on the current parts and fixturing process at Middleton. Information on the CNC machines will be gathered and the similarities and differences of the tables and fixtures will be analyzed. Based on this data a new process and design will be created. Finally, we will look at the effectiveness of the proposed designs and improvements to verify that it will improve the manufacturing process.

While working on this project there are a number of things we will need to overcome to complete the project. Some of these will include learning the manufacturing process at Middleton Aerospace and the processes used on the parts we are working with. We will also need to learn and understand some of the key processes and methods used in fixture design. By the completion of this project, we intend to be able to present a design system of fixtures to Middleton Aerospace to help optimize their current processes.

2.0 Background and Literature Review

For this project our main focus is fixture design. Much of our research has been focused a few main topics. First our research focused on CNC machining to understand the process of the machining of the part. Next, we researched methods of fixture design to get an understanding of the basic principals of fixture design. We also researched the varying part holding methods to actually hold the part in a fixture.

2.1 5-Axis CNC Machining

Computer Numerical Control (CNC) is a computer assisted process to control general-purpose machines from instructions generated by a processor and stored in a memory system or storage media for present use as well as future use. Controlled machines by numerical command can be adapted to any kind of machine or process that requires direction by human intelligence. In this case, the project deals with 5 Axis Horizontal CNC Machining Centers.

CNC is a specified form of control system where position is the principal controlled variable. Numerical values, representing desired positions of tools and symbolic information corresponding to secondary functions, are recorded in some form (tape, disk, network, etc.) where the information can be stored and revised indefinitely. Hard drives, tape readers, and other converters transform this information into signals that intimately operate servo-mechanisms on each axis of the machine whose motions are to be controlled.[1] Middle Aerospace Corporation currently owns and operates two 5 Axis Horizontal CNC Machining Centers, a Cincinnati T35 and a Mitsui Seiki HU-80.

Five axis controls provide multiple axis-machining capabilities beyond the standard three-axis CNC toolpath movements. The simultaneous contouring axes of a five-axes milling center include the three X, Y, and Z axes; the A axis, which is a rotary tilting of the

[1] Madison. p. 7

spindle , or Z axis, parallel to the A axis; and the B axis, which can be a rotary index table or an additional tilting of the spindle parallel to the X axis.[2]

The basic units of the machine provide the following movements:

- X Axis – Moving column assembly for longitudinal movement
- Y Axis – Moving carrier for vertical movement
- Z Axis – Moving pallet for cross movement
- A Axis – Contouring spindle for pivoting spindle about the X Axis
- B Axis – Contouring table for rotating work piece about the Y Axis
- A Axis – Rotary Spindle for Tool Tilt

AXIS ORIENTATION

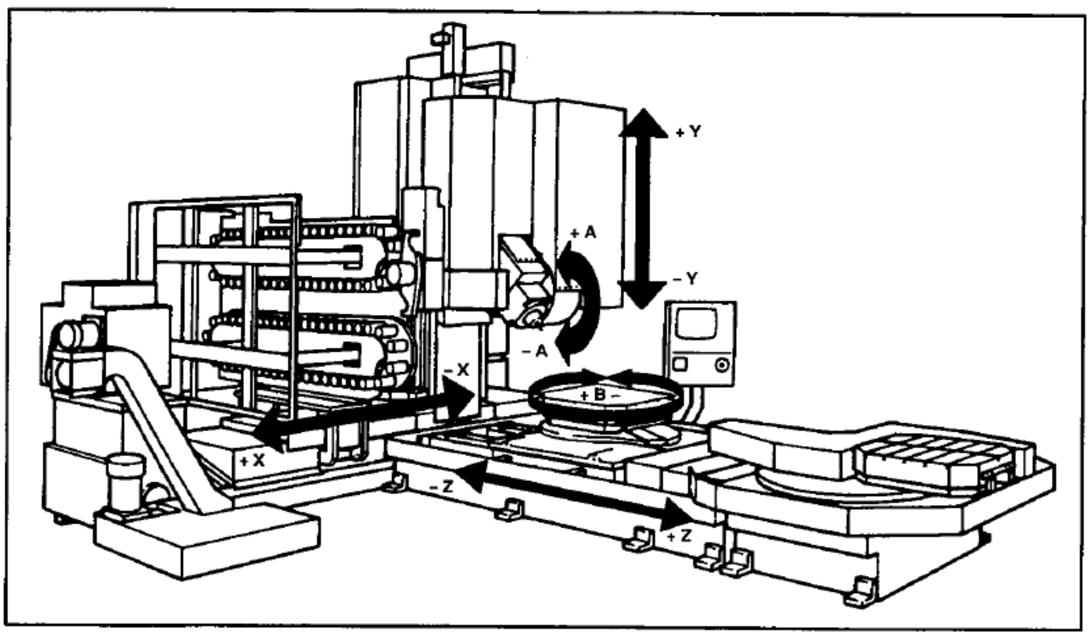
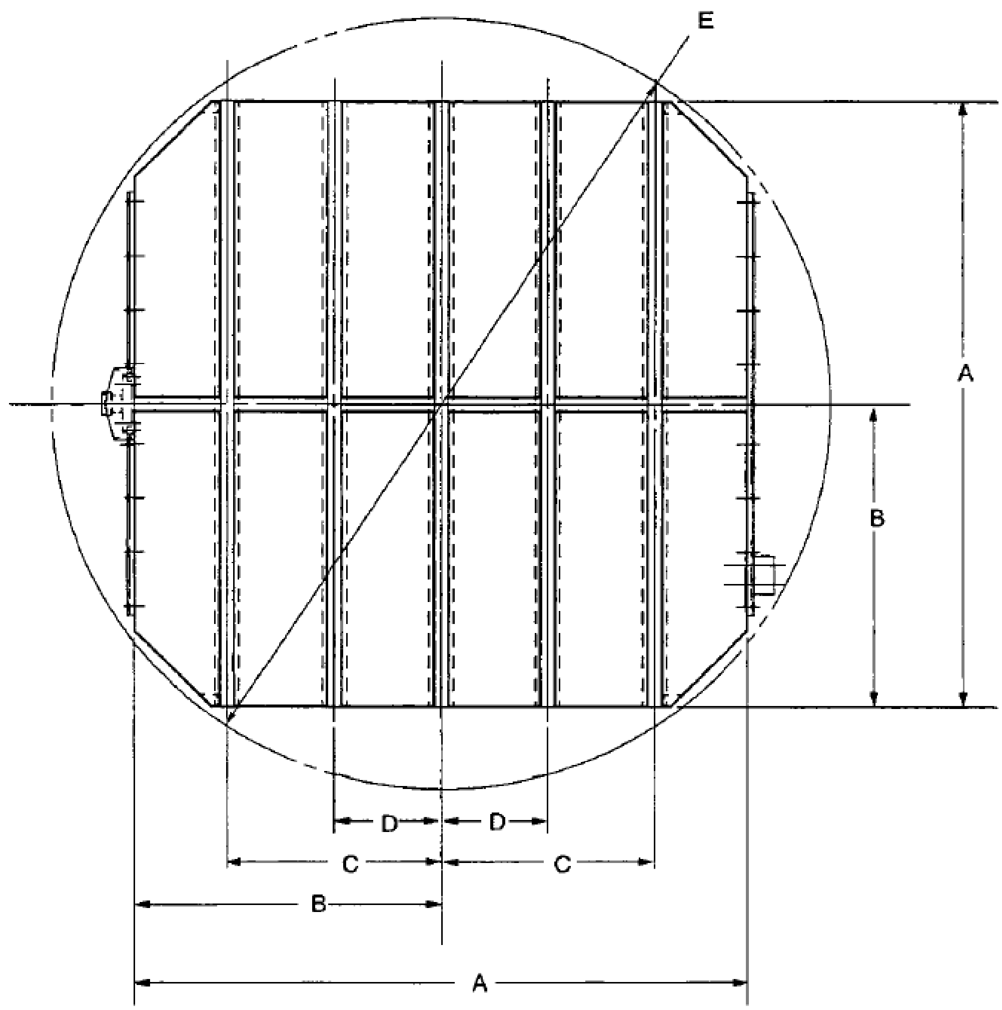


Figure 2.1: The Axis Orientations on the Cincinnati T35

The aspect of the machining center that this project is concerned with is the fixed base unit. It consists of the front base (pallet support) and the rear base (column support) units which are bolted together and supported by adjustable leveling screws. These units form a "T" configuration which provides direct support for all horizontal (X and Z axes) movement. The front base supports the pallet slide and integrates the cross (Z Axis) movement by means of a precision ball screw drive. The rear base supports the column,

[2] Madison. p. 7

which is driven by a ball screw, in a direction perpendicular to the table movement to provide longitudinal (X axis) movement.



MACHINE	A	B	C	D	E
T-35	31.50" 800 mm	15.75" 400 mm	11.000" 279 mm	5.500" 140 mm	40.12" Dia. 1019 mm

Figure 2.2: T-35 Pallet

The machines, integrated with the control, comprises the system and is referred to as a machining center. The machining center has been designed to automatically change tools for milling, drilling, tapping, boring, and reaming; in fact, performs most types of machining operations, all in one handling of the work piece.

2.2 Fixture Design

Before designing a proper fixture, following concerns must be dealt with: “the necessity of multiple fixtures owing to workpiece geometry complexity, the number of workpieces per fixture, the determination of suitable surfaces on the workpiece for locating and clamping, and the sequence of work holding steps. The fixture configuration process would yield the following information:

- Types of locators and clamps
- Positions of locators and clamps
- Clamping sequence and magnitudes of clamping forces

The detailed designs (geometry, dimensions, and tolerances) of individual workholding elements are determined by workpiece geometry, contact information (point, line, or plane contact between the locators and workpiece surfaces), expected frequency of utilization (e.g., batch production versus mass manufacturing), availibility of off-the-shelf standard device geometries, mode of operation (manual versus automatic), and finally conditions of manufacturing (clean-room versus machining with coolants)” (Benhabib 2003).

2.2.1 The “5 steps of fixture design”

By Ray Okolischan, Vice President, Carr Lane Manufacturing Co

Step 1: Define Requirments

Define the problem that needs to be solved and the needs to be met.

Questions that needs to be asked:

- Is the new tooling required for first-time production or to improve existing production?
- If improving an existing job, is the goal greater accuracy, faster cycle times, or both?
- Is the tooling intended for one part or an entire family of parts?

Step 2: Gather/Analyze Information

Collect all relevant data and assemble it for evaluation. The main sources of information are the part print, process sheets, and machine specifications. Keep good notes on all ideas, thoughts, observations, and any other data about the part or fixture for later reference.

4 things that need to be taken into consideration:

- Workpiece specifications – Size and shape of the part, accuracy required, properties of the part material, locating and clamping surfaces, and the size of the run.
- Operation variables – type of operations required to make the part, number of operations performed, sequence of operations, inspection requirements, aand time restrictions.
- Availability of equipment - The tooling designer should verify what equipment will be used for each operation. Typically, equipment criteria include the following factors: types and sizes of machines, inspection equipment, scheduling, cutting tools, and plant facilities.
- Personnel Considerations - Fixture designers should put themselves in the machine operator's shoes and consider all the operational scenarios they can. Designers should consider not only correct usage of the fixture, but also possible incorrect usage. They must ask, "Is there any way for me to hurt myself while operating this equipment?"

Step 3: Develop Several Options

This phase of the fixture-design process requires the most creativity. A typical workpiece can be located and clamped several different ways. The natural tendency is to think of one solution, then develop and refine it while blocking out other, perhaps better solutions. A designer should brainstorm for several good tooling alternatives, not just choose one path right away.

During this phase, the designer's goal should be adding options, not discarding them. In the interest of economy, alternative designs should be developed only far enough to make sure they are feasible and to do a cost estimate.

The designer usually starts with at least three options: permanent, modular, and general-purpose workholding. Each of these options has many clamping and locating options of its own. The more standard locating and clamping devices that a designer is familiar with, the more creative he can be.

Areas for locating a part include flat exterior surfaces (machined and unmachined), cylindrical and curved exterior surfaces, and internal features (such as holes and slots). The choice of standard locating devices is quite extensive.

Similarly, there are countless ways to clamp a part, using a wide array of standard clamping devices. For example, a workpiece can be clamped from the top, or by gripping its outside edge or an internal surface.

For preliminary drawings of the fixture, use several colored pencils. Often black is used to sketch the fixture, red for the part, and blue for the machine tool. Use isometric graph paper to keep the sketch proportional.

The exact procedure used to construct the preliminary design sketches is not as important as the items sketched. Generally, the preliminary sketch should start should start with the part to be fixtured. The required locating and supporting elements, including a base, should be the next items added. Then sketch the clamping devices. Finally, add the machine tool and cutting tools. Sketching these items together helps identify any problem areas in the design of the complete fixture.

Step 4: Choose the Best Option

The fourth phase of the tool-design process is a cost/benefit analysis of different tooling options. Some benefits, such as greater operator comfort and safety, are difficult to express in dollars but are still important. Other factors, such as tooling durability, are difficult to estimate.

In analyzing fixture costs, the emphasis is on comparing one method to another, rather than finding exact costs. Estimates are acceptable. Sometimes these methods compare both proposed and existing fixtures, so that, where possible, actual production data can be used instead of estimates.

To evaluate the cost of any workholding alternative, first estimate the initial cost of the fixture. To make this estimate, draw an accurate sketch of the fixture. Number and list each part and component of the fixture individually. Here it is important to have an orderly method for outlining this information.

For modular fixtures, total component cost should be amortized over the system's typical lifetime. Although somewhat arbitrary, dividing total component cost by 100 (10 uses per year, for 10 years) gives a fair estimate.

The next step is calculating the cost of material and labor for each tooling element. Once again it is important to have an orderly system for listing the data. First list the cost of each component, then itemize the operations needed to mount, machine, and assemble that component. Once those steps are listed, estimate the time required for each operation for each component, then multiply by the labor rate. This amount should then be added to the cost of the components and of the design to find the estimated cost of the fixture.

The total cost to manufacture a part is the sum of per-piece run cost, setup cost, and tooling cost. Expressed as a formula:

$$\text{Cost per Part} = \text{Run Cost} + \frac{\text{Setup Cost}}{\text{Lot Size}} + \frac{\text{Tooling Cost}}{\text{Total Quanity Over Tooling Lifetime}}$$

These variables are described below with sample values from three tooling options: a modular fixture, a permanent fixture, and a hydraulically powered permanent fixture.

Run Cost. This is the variable cost per piece to produce a part, at shop labor rate (material cost does not need to be included as long as it is the same for all fixturing options).

In our example, run costs for the permanent and modular fixtures are the same, while power workholding lowers costs by improving cycle time and reducing scrap.

- Modular fixture: $4.50
- Permanent fixture: $4.50
- Permanent hydraulic fixture: $3.50

Setup Cost. This is the cost to retrieve a fixture, set it up on the machine, and return it to storage after use. The permanent fixture is fastest to set up, the power workholding fixture is slightly slower due to hydraulic connections, and the modular fixture is slowest due to the assembly required.

- Modular fixture: $240
- Permanent fixture: $80
- Permanent hydraulic fixture: $100

Lot Size. This is the average quantity manufactured each time the fixture is set up. In this example, lot size is 100 for all three options.

Tooling Cost. This is the total cost of labor plus material to design and build a fixture. The modular fixture is least expensive because components can be re-used.

- Modular fixture: $341
- Permanent fixture: $1632
- Permanent hydraulic fixture: $3350

Total Quantity Over Tooling Lifetime. This quantity is the lesser of 1) total anticipated production quantity and 2) the quantity that can be produced before the fixture wears out. The following results are obtained by evaluating the cost-per-part formula at different lifetime quantities.

For a one-time run of 100 pieces, the modular fixture is clearly the most economical choice. If 10 runs (1000 pieces) are expected, the permanent fixture is best. For 2500 pieces and above, the power workholding fixture would be the best choice. This analysis assumes that all noneconomic factors are equal.

Pieces	Modular	Permanent	Permanent Hydraulic
100	$10.31	$21.62	$38.00
1000	7.24	6.93	7.85
2500	7.04	5.95	5.84
5000	6.97	5.65	5.17
10,000	6.93	5.46	4.84

Table 2.1: Run Costs

Step 5: Implement the Design:

Use standard components. The economies of standardized parts apply to tooling components as well as to manufactured products. Standard, readily available components include clamps, locators, supports, studs, nuts, pins, and a host of other elements.

Most designers would never think of having the shop make cap screws, bolts, or nuts for a fixture. Likewise, no standard tooling components should be made in-house. The first rule of economic design is: Never build any component you can buy. Commercially available tooling components are manufactured in large quantities for much greater economy. In most cases, the cost of buying a component is less than 20% of the cost of making it.

Labor is usually the greatest cost element in the building of any fixture. Standard tooling components are one way to cut labor costs. Browse through catalogs and magazines to find new products and application ideas to make designs simpler and less expensive.

Use pre-finished materials. Pre-finished and preformed materials should be used where possible to lower costs and simplify construction. These materials include precision-ground flat stock, drill rod, structural sections, cast tooling sections, precast tooling bodies, tooling plates, and other standard preformed materials. Including these materials in a design both reduces the design time and lowers the labor cost.

Eliminate finishing operations. Finishing operations should never be performed for cosmetic purposes. Making a fixture look better often can double its cost. Here are a few suggestions to keep in mind with regard to finishing operations.

- Machine only the areas important to the function and operation of the component. For example, do not machine the edges of a baseplate. Just remove the burrs.
- Harden only those areas of the fixture subject to wear.
- Grind only the areas of the fixture where necessary for operation.

Keep tolerances as liberal as possible. The most cost-effective tooling tolerance for a locator is approximately 30% to 50% of the workpiece's tolerance. Tighter tolerances normally add extra cost to the tooling with little benefit to the process. Where necessary, tighter tolerances can be used, but tighter tolerances do not necessarily result in a better fixture, only a more expensive one.

Simplify tooling details. Elaborate designs often add little or nothing to the function of the fixture. More often, a power clamp can do the same job at a fraction of the cost.

Keep the function and operation of a fixture as simple as possible. The likelihood of breakdowns and other problems increases with complex designs. These problems multiply when moving parts are added to the design. Misalignment, inaccuracy, wear, and malfunctions caused by chips and debris can cause many problems in the best fixture designs.

Reducing design complexity also reduces misunderstandings between the designer and the machine operator. Whenever possible, a fixture's function and operation should be obvious to the operator without instructions.

Once sketches and the basic fixture design have been completed, final engineering drawings, also called shop prints, are used in the toolroom to build the fixture.

The easiest way to reduce manual drawing time is by simplifying the drawing. Words or symbols should be used in place of drawn details where practical. All extra or unnecessary views, projections, and details should be eliminated from the drawing.

Drawing a complete clamp assembly, for example, adds very little to the total design. Simply showing the nose of the clamp, drawn in its proper relation to the workpiece and labeled with its part number, conveys the same information in a fraction of the time.

For drawings that require more detail, use tracing templates to reduce drawing time. These templates show most standard components in several views. If necessary, they may be enlarged or reduced on a copier to any scale needed for a drawing.

Once the proper tracing template is selected, simply slip it under the drawing sheet and align it with the drawing. When the template is properly positioned, tape it down and trace the component on the drawing sheet. Tracing templates save drawing time and improve the quality of the drawing.

Computers are rapidly replacing drawing boards as the preferred tool for preparing engineering drawings. Almost every area of design is affected by the computer. Computers, from large mainframes to micros, are becoming standard equipment in many design departments.

A standard tooling library often is used to add the fixturing components and elements to the drawing. Using a standard library in designing the fixture dramatically reduces drawing time. All components are drawn to full scale in a variety of views. Scaling down is best done in the final drawing, not when storing standard-component drawings. Storing a large fixture base at 1/4 scale does little good, because all components will have to be 1/4 scale to fit on it. For ease of use, all components should be stored at full scale. Each component can be called up from the library and placed on the drawing where it is required.

A CAD system also can be useful during the initial phase of the workholder design as numerous tooling options are developed. CAD is sometimes faster than sketching by hand, especially when detailed cost estimates are required.

Once drawings have been thoroughly checked, the next step is actually building the actual fixture. During the building stage, the designer should make sure the toolroom personnel know exactly what must be done when making the fixture. By periodically checking with the fixture builder, the designer can help eliminate any possible misunderstandings and speed the building process. If there are any difficulties with the design, the designer and builder, working together, can solve the problems with a minimum of lost time.

After the fixture is completed and inspected, it should be tested. The fixture is set up on the machine tool and several parts are run. The designer should be on hand to help solve any problems. When the fixture proves itself in this phase, it is ready for production.

2.2.2 Work Holding

Work holding in manufacturing is the restriction of movement of a part or work piece for the purpose of allowing a fabrication or application of an assembly process. A fixture is a “work holding device used in machining and assembly for securely locating and holding the work piece without providing a built-in guidance to the manufacturing tool. Fixtures, must provide maximum accuracy (including measures to prevent incorrect work holding) and be designed for ease of mounting and clamping of the work piece by humans or robots” (Benhabib 2003).

Design of a fixture requires the examination of the work piece’s geometry, the fabrication processes, and the specific machines to be used. The work piece’s geometry includes the material, mechanical properties, and tolerances of the work piece. The fabrication process involves the tool paths, machining and/or assembly forces, and the environment containing the work piece. The fixture must be able to hold the work piece in place while it is subjected to external forces (Benhabib 2003).

2.2.3 Locating

A solid body has twelve degrees of freedom (DOF) of mobility in three-dimensional free space: six degrees of linear movement freedom along the X, Y and Z axes and six of rotational freedom along the X, Y and Z axes. The goal of a fixture is to “eliminate all mobility and simultaneously provide adequate support to the workpiece to counteract external forces” (Benhabib 2003).

The principle rule of locating a workpiece is the 3-2-1 rule. The use of six locators is enough to fully restrict a workpiece’s degrees of freedom. The first location restricted is the largest plane of the workpiece, also know as the primary plane. Three locators are placed on this plane restricting X and Y rotational and Z linear motion. The second largest surface, the secondary plane requires two locators eliminating Z rotational and X linear motion. The final locator is used on the smallest surface restricting Y linear motion. The remaining degrees of freedom can be restricted by a clamping device (Drozda 1989), (Benhabib 2003).

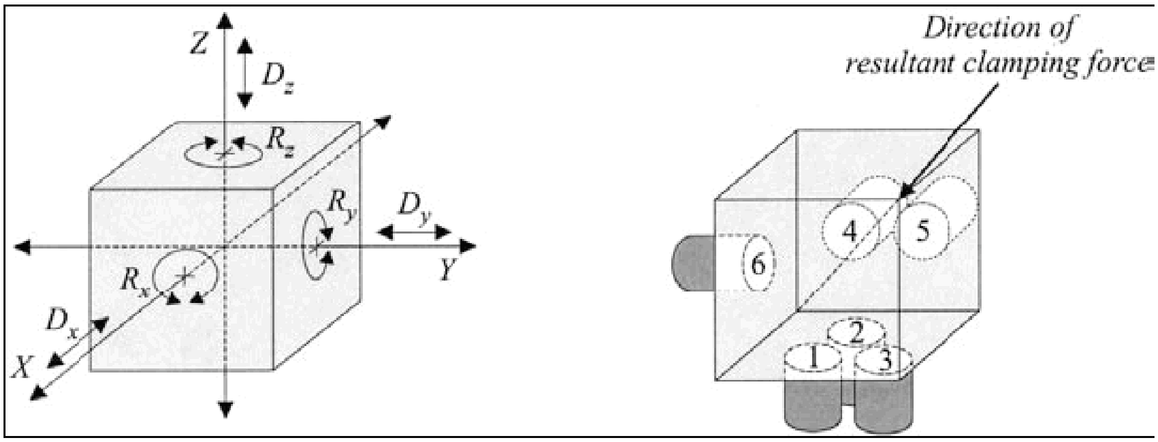


Figure 2.3: Degrees of Freedom & 3-2-1 Rule

For the better accuracy, locators should make contact with machined parts of the workpiece. This is not always possible and placement of the locators is determined by the workpieces's stress analysis. Locators may be placed on the edge, underneath or in existing holes on the workpiece. (Boyes 1985)

2.3 Part Holding Methods

One of the major areas to consider when completing a fixture design is the method in which the part is held. The fixture design will specify where the part can be held, but then care needs to be taken as to the choice of the type of holding. There are varying was of part holding, and each has it own benefits and drawbacks. The choice of holding methods depends on many factors including but not limited to tolerances, part material, forces on the part, and the fixture design itself.

2.3.1 Bolting

Bolting to the machine table is the simplest and most basic way to hold a fixture or workpiece in place. Most machine tables have sets of channels cut into them that act as guides for the bolts and braces to hold the bolts in place. When a part/fixture is secured using the bolting method the machine operator places the piece on the table and runs the bolts through the holes on the workpiece/fixture. Then once the piece is in place the operator tightens the nuts onto the bolts with a wrench.

2.3.2 Clamping

The clamping method uses vises and clamps to hold the workpiece/fixture. The clamps are usually bolted down to the cutting table in the machine, and not really meant to be moved. The clamp can be tightened manually with a wrench, or can be tightened with hydraulics or pneumatics. Clamps can be made to hold many types of part/fixtures (round, square and awkward shapes), and are much faster than bolting each workpiece/fixture down. Restriction of movement with clamps will vary because, unlike the other methods, clamping relies heavily on friction to hold the piece in place. Unlike the other holding methods, clamping may not fully restrict movement on and about all axis's.

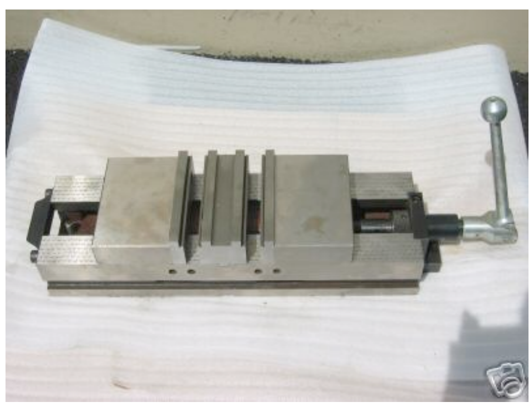


Figure 2.4: Machine Vice

2.3.3 Ball Locks

The Ball lock system is unique, instead of having the machine operator bolt down the fixture, all that is required is for the operator to place the fixture into the mounts and give each lock a quarter turn with a hex wrench. The turn of the wrench forces ball bearings in the shank to press out and create tension with the receiving bushing. The use of ball locks in fixture design is more efficient than traditional clamping or bolting by cutting down on process time.

The ball lock system has three main components:

Figure 2.5, 2.6, 2.7: Ball Lock Locating Shank, Linear Bushing, and Receiving Bushing.

The receiving bushing is mounted on the table, the linear bushing goes into the hole on the work piece/fixture (to protect it from scrapes and mars) and the locating shank goes through the hole and locks into the receiving bushing.

3.0 Methods

In order to development a solution for the project there are several steps that need to be taken. We will start by analyzing the parts, machining process, fixtures, and tables on the CNC machines. We will then look for which aspect of the manufacturing process can be changed in order to solve this problem. Once that has been done we can do a cost analysis to see how much it will cost to solve the problem and how much money can actually be saved.

3.1 Part Analysis

Part analysis is an important first step in the design of a fixture. In our design we will first look at many major areas of the parts we are designing fixtures for. These areas include the major concepts of part geometry and machining processes. There are also many smaller areas to look at including, but not limited to: part material, mechanical properties, part tolerances, part dimensions, machine tool paths, workshop environment, and tooling and machine forces.

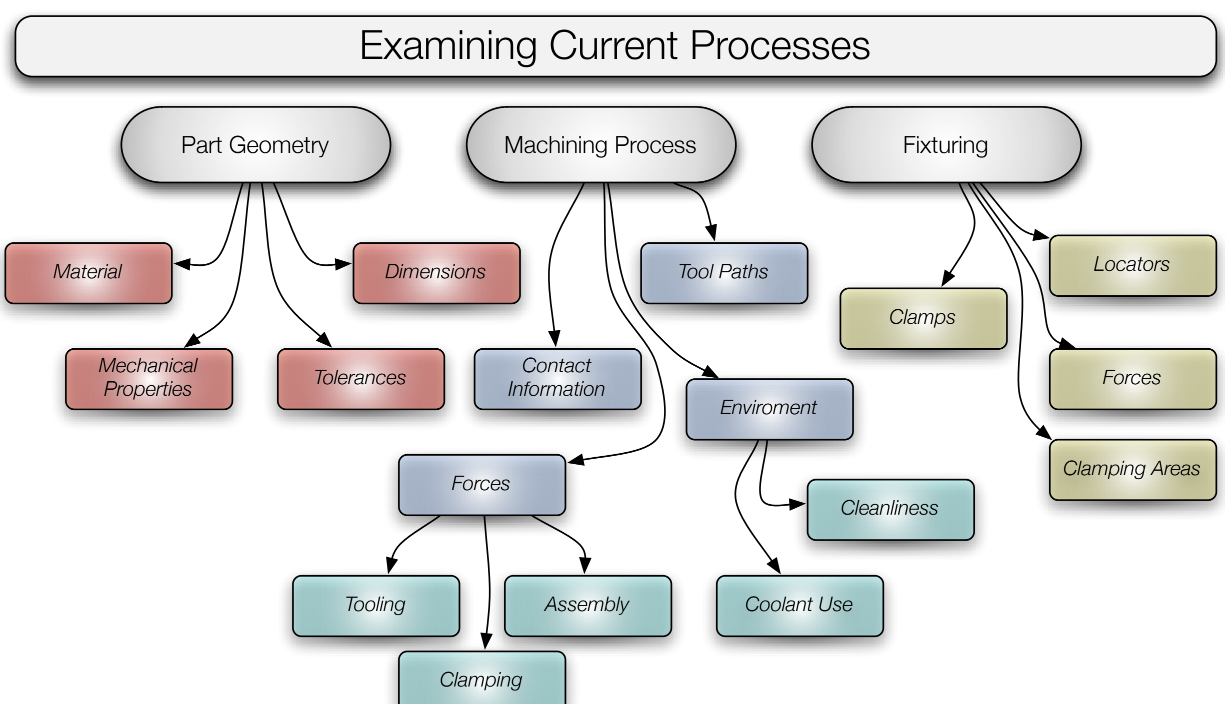


Figure 3.1: Examining Current Processes Flow Diagram

3.2 Current Fixture Analysis

As part of this project we would like to improve upon what Middleton Aerospace already has in use and not present any designs that may be counterproductive. We will be looking at the current operations of Middleton Aerospace for certain parts. This information will be a valuable tool in our design of a new fixturing system to improve upon what Middleton has in place currently.

3.3 Sub Plate Design

Through our research we will design a new fixturing system for some of the parts Middleton Aerospace produces. This system will consist of two major components, a machine table to fixture interface and a fixture to part interface. With this design the current CNC machines in use at Middleton with be able to have a "universal fit" machine table. This will allow for a great increase in functionality and usability. The fixture to part interface will hold the part securely while it is being machined.

3.4 Design Analysis

The fixture analysis of our design will be the final step of our project. This will include an analysis of the usability, tolerances of the part and fixturing system, tool paths, and stresses on the part. The analysis will verify that the fixturing system will be practical, useable, and efficient.

4.0 Results and Analysis

To start we requested drawings of some typical parts that are machined at Middleton. We were given two CAD drawings of fan housings and one of a gear housing. We then looked at the drawings of the fixtures that go with each of these parts. We listed the similarities and differences and matched the fixtures with their respective operations. Much of this analysis can be reviewed in Appendix C.

After analyzing the fixtures and parts we look closely at the tables of the two different machines they are operating. Each table had the same length and width dimensions of 31.5 x 31.5 inches. The tables also have the corners removed making them the same shape. The major problem is that their interface to the fixtures are very different. The top of the table is what the fixture is mounted onto. The HU80 and the T-35 both use T-bolt channels to attach fixtures to the tables. These channels are shaped so a T-nut will lock into the channel and not rotate. The sizes of the channels are very comparable to each other and Middleton already has the hardware for the use of the tables. The major difference in between the two tables is the orientation of these channels. On the HU80, the channels run 90 degrees from each other from the center of the table. In the center of the table is a center hole for center locating. On the T-35, the channels run parallel to each other on the face of the table. The T-35 does not have a center hole for locating but a perpendicular channel, different to the T-bolt channels, for locating. The difference in the pattern and location of these features create the need for different fixtures for the different tables.

Currently when a part needs to have an operation machined they pick which machine that can be use at the time to perform the operation. This depends on which machines are being used or are operational at the time. If the T-35 is being used or is not operational then the part must be machined in the HU80. Once they know which machine they will be using they must develop and build a fixture for the part for that particular operation. The fixture that is required for the particular operation may already be designed and built but if it was originally made for the T-35 and they need to machine the part in the HU80 then a new fixture must be created. This requires a lot of time and money to produce.

To make a fixture for aerospace parts is not an easy task. These parts are generally several feet in diameter and weight hundreds of pounds. In addition they are made of expensive materials and are highly sophisticated. When a fixture is designed for a part there are many things that need to be considered. The type of material, the material removal rate, and tool paths need to be analyzed so that a fixture, that will securely fasten the part to the table while the operation runs, can be created.

In manufacturing, the cost of fixtures must be considered when giving a customer a quote on a product, when several sets of fixtures are required the cost can add up quickly. These fixtures not only have to be added into the price but they also cannot be thrown out after they are done using them. The customer owns the fixtures, so Middleton must store the fixtures in the event they need to use them again. This takes up a lot of storage space and becomes a nuisance to move around the warehouse.

Machining an aerospace part requires several fixtures when working with just one style of CNC table but when more need to be created to use a different table the amount can increase drastically. Not only does this become expensive it also creates more room for errors in machining. The parts must be constantly refixured, oriented, and moved between different machines. During these processes the parts can potentially dropped, bumped, cracked, or set up incorrectly. These mistakes are always a potential no matter what your manufacturing process is but the more the parts have to be moved around and refixtured the more the risk is increased for damaging them.

After analyzing these problems our team could see that many of these problems were stemming from the fact that the machines had different style tables. If Middleton's 5-axis CNC machines had similar tables the amount of fixtures required would drastically reduce. When the T-35 was in use they could switch to the HU80 and still use the same fixtures. The amount of fixtures in the warehouse and shop would be reduced. Now time will not be wasted moving heavy fixtures around. The risk of damaging the parts would go down because the parts would be handled less and there would be less chance of a part being mis-fixtured. The results of using this system can be seen below in figure 4.1.

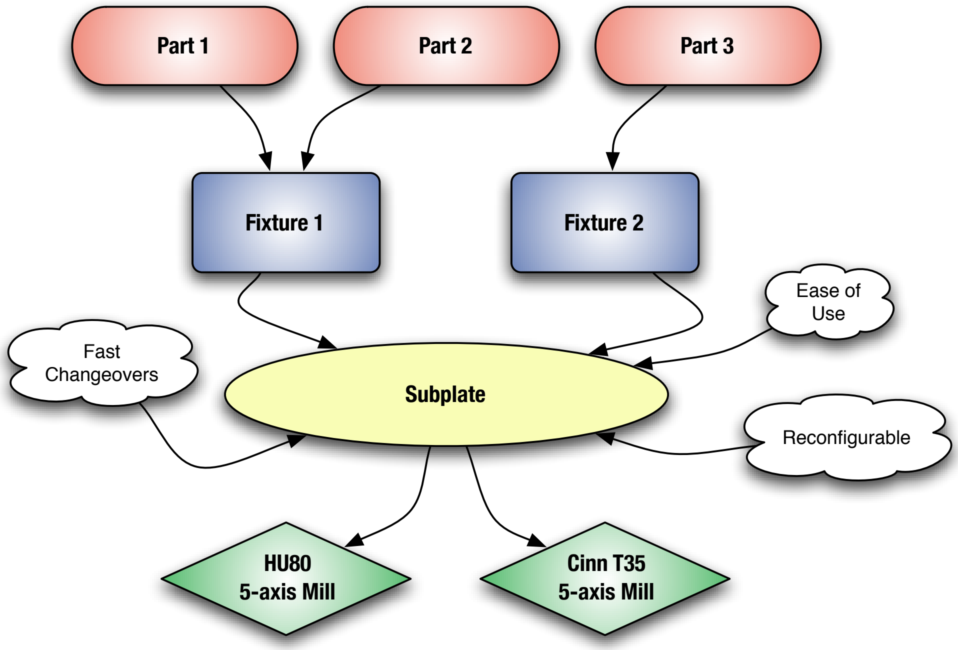


Figure 4.1: Fixturing System Flow Chart

4.1 Sub Plate Design

The fixture is located and attached on the sub plate in three ways. The first is to ensure the fixture is located in the center of the table/sub plate. This is done by using the already existing center locators on the current fixtures. The center locators differ in size but sleeves can be added to the sub plate to guarantee a proper fit and true center positioning. The largest center locator is 1.968 in. in diameter.

The other method is rotational locating. This is done by placing a locating hole on the sub plate for proper loading. The employee loading the fixture and part would only have to align the rotational locator to a hole in the fixture. This locator is the second fail safe for proper loading. The fixture is then bolted to the sub plate using the designed hole pattern.

The fixture system is attached to the sub plate to the designed hole pattern. The designed hole pattern is in the 0°-105°-135° orientation to ensure proper loading of the fixture every time. The designed hole pattern is the third and final fail safe for proper loading. The designed hole pattern will also “eliminate all mobility and simultaneously provide adequate support to the workpiece to counteract external forces” (Benhabib 2003). The hole pattern can be seen in Figure 4.2.

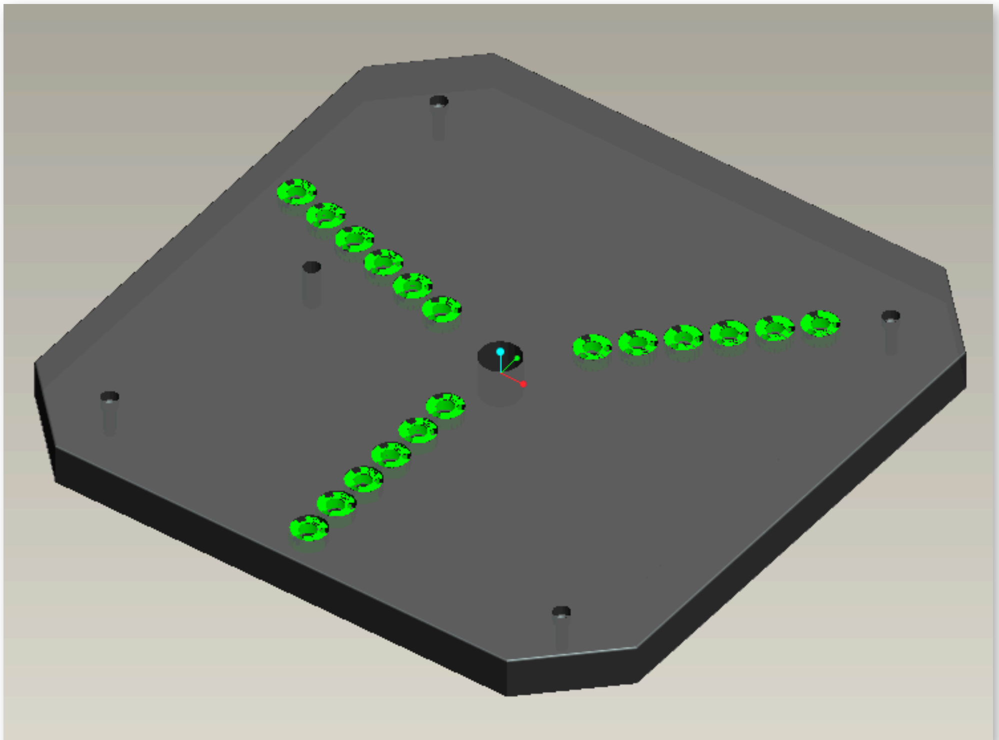


Figure 4.2: Proposed Sub-plate Design and Hole Pattern

The sub plate was designed to bolt to the table in four corner locations using four ½-13 Bolts and T-nuts as seen in Figure 4.3 on the following page. The sub plate is designed to be the same dimensions as the table. To secure the sub plate to the table it needs to be aligned over the edges of the machine table and in the proper orientation to correlate to what the machine programing requires. The sub plate is then bolted down to the machine table using the four bolt holes in the sub plate and t-channel nuts.

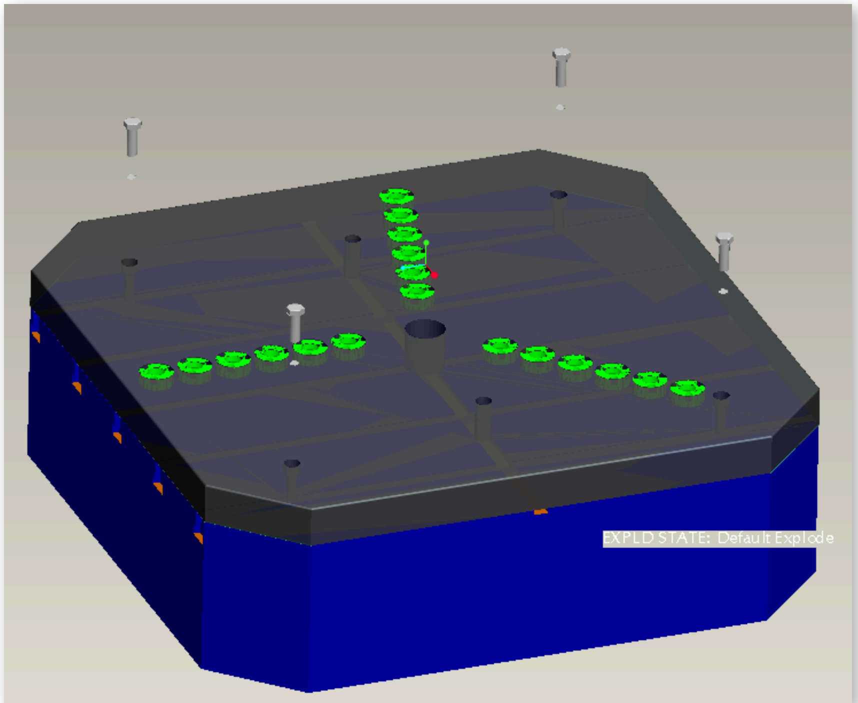


Figure 4.3: Subplate to Table Attachment

To secure the fixtures to our sub-plate we will be using a ball lock system, manufactured by Carr Lane. There are two different mounting options for the receiving bushings in the system we will be using, face-mount and back-mount. The face-mount bushings are installed from the top of the plate into a counter bored hole. Within the main hole will be three small threaded holes for the bushing to bolt into. The back mount holes are installed from the bottom of the plate into a slip-fit bored . Our design uses the face-mount bushings installed in the top of the subplate. The bushing system is shown in Figure 4.4.

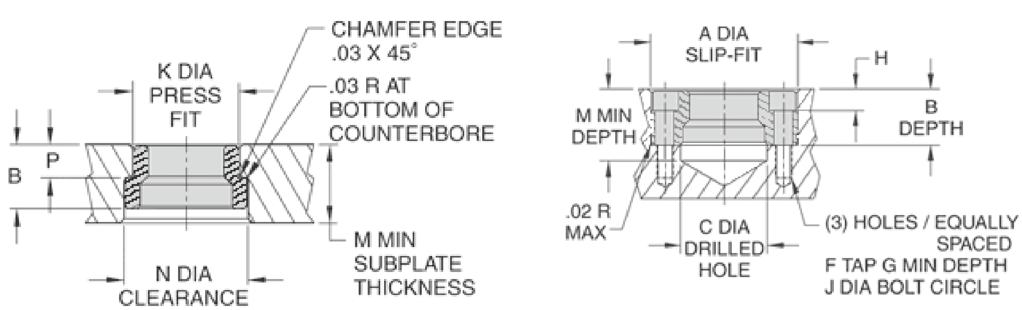


Figure 4.4: Ball Lock System

Each bushing must be installed approximately .012 inches below the top of the sub plate. Depending on the length and type of locating shank used, each ball lock will be able to produce between 750 and 20,000 pounds of holding force. The locating shanks can accommodate up to a two inch thick fixture. However; if the fixture is thicker than two inches, the holes can be counter bored to the proper depth.

4.1.1 Dimensions

The designs of both the sub plate for the HU80 and T35 were size to correspond to the same size of the machine tables. This eliminates many design considerations in the machine due to clearances in interference with the machine itself. The thickness of the sub plate was designed to be four inches, as requested by Middleton Aerospace. We felt that this was unnecessarily high and recommended that a height of two inches would be sufficient. Two inches would give enough room to install the ball locks and there would be enough material to support any fixture while not restricting the lock out dimensions of the machines.

4.1.2 Material

There are many different types of materials that we could choose from for the sub-plate. After making visits to the machine shop and asking several questions we feel that A36 commercial plate steel should be used. Plate steel is a strong durable material that can be purchases in a variety of thicknesses. One of the biggest reasons why we chose it was the fact that the temperature in the shop changes drastically when loading doors are opened and closed in the winter. This can cause some metals, such as aluminum, to contract and expand. Steels temperature can change within our limits and not deform. If we chose a material that could deform it would make loading and unloading very difficult. It could also effect machining if a part was left on the plate while it deformed and then machining resumed.

4.2 Fixture Modifications

As part of our design, modifications will need to be done to the fixtures currently in use at Middleton. Each fixture will need three holes through the base of the fixture and liner bushings installed in each hole. There is enough material on all fixtures for these modifications to take place. After the modifications are complete, the final system will look like Figure 4.5. In Figure 4.5, a pseudo fixture is used to show the practicality of the system.

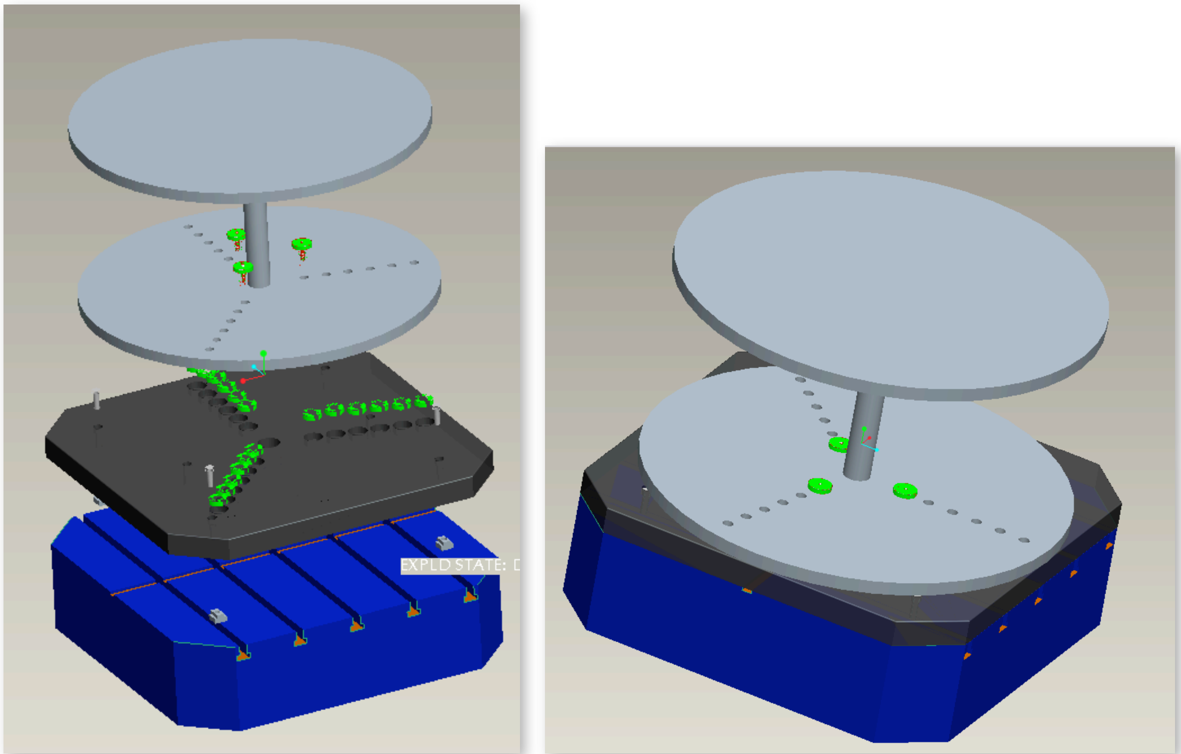


Figure 4.5: Fixturing System Mock-Up Exploded and Assembled View

4.3 Cost Analysis

The approximate cost of sub-plate construction for Middleton Aerospace including necessary machining and ball lock system is $3200 per plate if it were made in house. This cost is based on a ratio of 1 minute of labor = 1 inch of cutting. Cutting 1 inch of metal does not take 1 minute but this ratio will make up for the time it takes to load, unload, draw out, and measure the material. Time was added for grinding of the top of the plate to ensure it is even and drilling time for the holes. Middleton requires construction of eight (8) plates. As shown in figure 4.6 on the next page, it is projected that Middleton Aerospace will regain the cost of implementing the system in as little as four months.

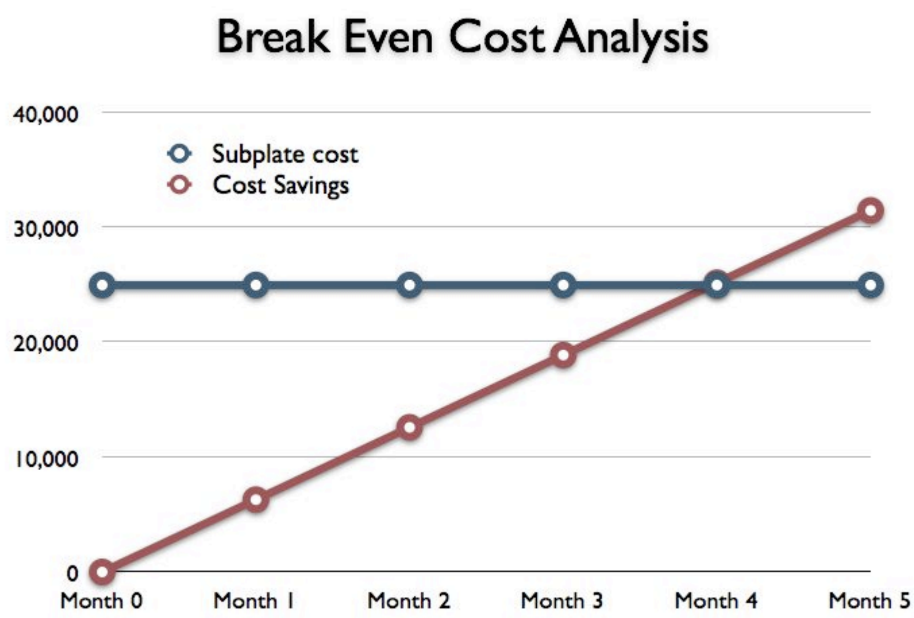


Figure 4.6: Break Even Cost Analysis of Sub-plate Design

5.0 Conclusion

The proposed fixturing system has been presented to Middleton Aerospace Corporation and they are very pleased. They have plans to implement our designs into their shop as soon as possible These designs will allow for faster load and unload times and cut down on the number of man hours required on each operation. These changes fulfill a significant demand from Middleton Aerospace's customers to produce a large volume of parts while also maintaining quality and lowering prices.

References

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Appendices

Appendix A: Sponsor Description

Middleton Aerospace Corp.
206 S. Main St.
Middleton, MA 01949
Phone: (978)774-6000
Fax: (978)777-5640

Middleton Aerospace Co. manufactures critical rotating and non-rotating parts for major engine builders in the United States as well as for a number of the world's armed forces. The company applies the latest CAD/CAM technology, is ISO 9002 certified and retains Mil-9858 and AQAP-4 approvals, to meet the stringent demands of its customers. Employing approximately 125 people, Middleton manufactures both prototype and production parts, using numerically controlled machines, and can turn, mill and grind parts as large as 60 inches in diameter.

Middleton is known as a world class manufacturer of aircraft engine cases and frames. They have also established themselves as a state of the art producer of complex shafts for aircraft engines. Their new flexible manufacturing Cell for shafts opened in 1997, in Peabody Ma., is creating great interest from many customers.

Appendix B: Project Timeline

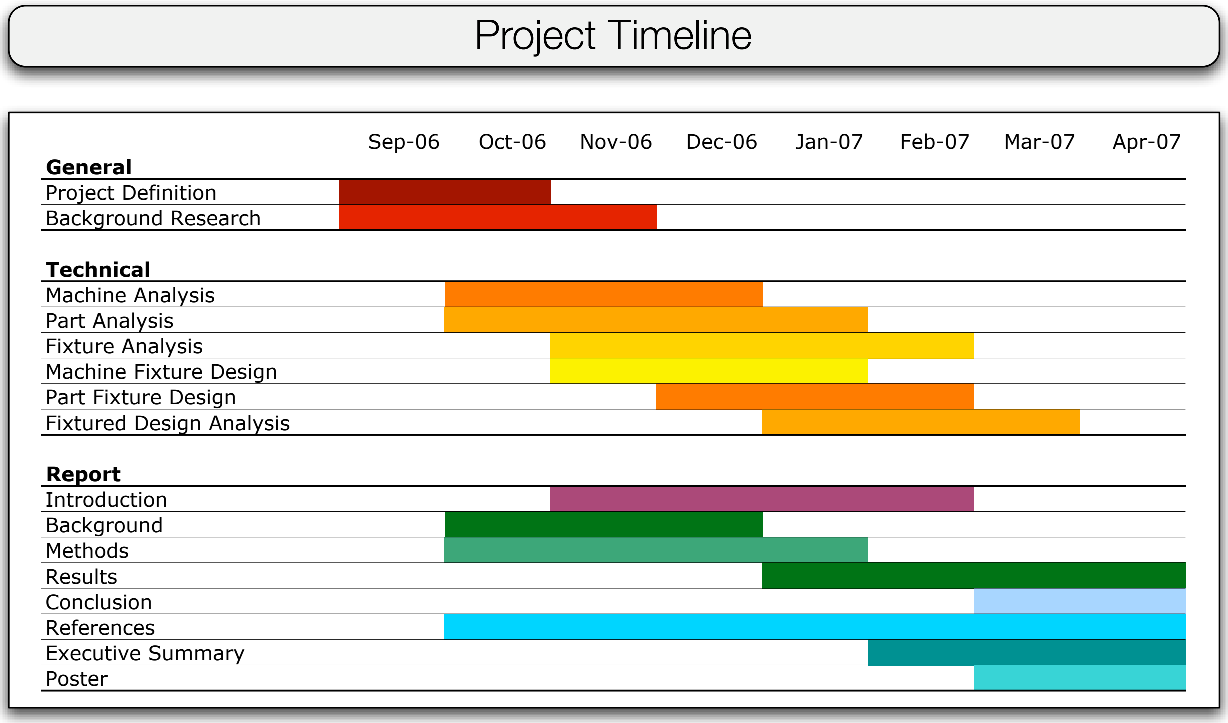

Figure B.1: Estimated Project Timeline

Appendix C: Part Analysis

Removed for security reasons, please contact the authors for more information.

Appendix D: Additional Files

The following additional electronic files are also included as part of this project:

- carrlane-20blrc-default.prt
- carrlane-20bls100-def-793238418.prt
- carrlane-20bls100-default_2_ass.prt
- carrlane-20bls100-default_20bls.prt
- carrlane-20bls100-default_14201.prt
- carrlane-20bls100-default_mball.prt
- carrlane-50bls200-default_2_ass.prt
- carrlane-50bls200-default_mball.prt
- cinasm.asm
- cincytnut.prt
- cintable2.prt
- fixturemqp.prt
- hu80asm.asm
- hu80bolt275.prt
- hu80sub2in1-2-13.prt
- hu80table.prt
- subplateand20balllock.asm
- t35sub2in-1-2-13.prt