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MIDDLETON AEROSPACE MANUFACTURING OPTIMIZATION

A Major Qualifying Project Report

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Abstract

The project group worked with Middleton Aerospace to design an improved manufacturing process for an aircraft engine turbine housing, utilizing six sigma and lean manufacturing concepts to shorten lead-time and improve part flow. The current manufacturing process was studied, a computer simulation of the process was created, and a new process was developed, incorporating changes to cell layout, order of operations, and work in process. The client's specifications were met, and Middleton Aerospace plans to implement the recommended changes.

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Introduction

Middleton Aerospace desires to ramp up turbine casing production capability to meet an expected 200% increase in demand. The focus of the project is to establish a solution for them, utilizing lean processes and flexible fixture design to shorten the lead-time of the manufacturing processes and improve part flow.

In order to tackle this iterative system design-engineering problem, the project was initially split into five stages:

1. Problem Definition
2. Investigation
3. Solution Development
4. Solution Improvement
5. Evaluation and Analysis

The project group began by gathering information on the current manufacturing process, in order to define specific goals for improvement. The gathered data was then organized and sorted in order to allow for an investigation of where bottlenecks and unnecessary steps occur. From this data, the project group was able developed methods to reduce inefficiencies in the manufacturing processes. This included eliminating unnecessary steps and restructuring the manufacturing process to tightly schedule when and where each operation would be performed.

After the methods for improvement were developed, the effectiveness of those improvements was analyzed. Since the length of time it takes to complete a batch of parts is long compared to the length of the project, much of the analysis was derived through simulation.

Background

I. Company Description

Magellan Aerospace Corporation is a diversified supplier of products and services to commercial and defense aircraft manufacturers and operators world-wide. Magellan provides repair and overhaul services as well as the manufacture of high quality components from five operating facilities in Canada and the United States. Services provided include complex repair and overhaul of jet and industrial engines and engine components. Manufactured products include high performance composite and metal structures and critical rotating and non-rotating engine components.

Middleton Aerospace Co. is a division of Magellan Aerospace and 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.

Customers served include Boeing, McDonnell Douglas, General Electric, Bombardier, Rolls-Royce, Pratt & Whitney, Allied Signal, Raytheon, Bell Helicopter Textron, as well as defense departments in Canada, the United States and throughout the world. Each operating facility is dedicated to continued improvement in delivery, quality, and cost performance.

Its manufacturing facility, Middleton Aerospace Corporation, mainly specializes in turbine engine component manufacturing. They produce casings, structural components, and shafts for turbine engines in Middleton, Massachusetts.

II. Part Description

The CF34 engine family is generally considered as a derivative of General Electric's rugged, combat-proven TF34 which powers the U.S. Air Force A-10 and U.S. Navy S-3A. The CF34 has evolved from this solid military experience base as a superior commercial engine with excellent performance margin, durability, and a level of reliability that allows today's 50 to 105 passenger regional jets to be flown with utmost confidence throughout the world.

The high pressure turbine sits directly behind the combustion chamber and receives the brunt of exhaust gas energy. This force will spin the turbine, the driveshaft it rides on and the high pressure compressor. Therefore, the high pressure turbine stator casing has to be able to withstand extreme high temperature and tolerances.

From the manufacturing standpoint, there are a total of 33 different process steps to manufacture this complicated high press turbine casing from release of material to the final product inspection where the part is ready to be delivered to the customer, General Electric.

III. Literary Resources

This is a summary of what the team learned in the on-going process of the MQP:

1. Value Added Analysis

   A process step is value-added if it causes a change in the physical state of the material, in accordance with customer specifications.

    a. Quality(defects, rework, returns)
    b. Cost(materials, productivity, overhead)
    c. Delivery(lead-time)
    d. Eliminate non-value-added (NVA) process steps
    e. Process map
    f. Revised process map
    g. Best quality, cost and delivery

2. Lean Ingredients
    a. Just – In – time processing
    b. Continuous one-piece- flow

3. Lean Implementation Strategy
    a. Teach everyone 5S and start implementing everywhere in the plant Choose a product to become the model line
    b. Implement work cells, continuous one-piece flow, and standard work in final assembly
    c. Build work cells in component fabrication and use kanban to connect them to final assembly

4. Inspiration For Shop Floor
    a. Direct Investigation

5. 5S Training
    a. Sort
    b. Straighten
    c. Scrub
    d. Schedule
    e. Score

6. Work Cell Design
    a. Determine the blocking step
    b. Tag time calculation
    c. Save space that can be used to make other products
    d. Make it easier to communicate
    e. Minimize the distance an operator needs to move to help another
    f. Allow one person to operate multiple machines
    g. Eliminate space for WIP to accumulate
    h. Direct Linear Part Flow

Methodology

The goal of this project was to improve the process used to manufacture the 4145T33G01 High Pressure Turbine Inner Casing at Middleton Aerospace Corporation. Middleton Aerospace defined a number of possible improvements they would like to see implemented, including lead-time reduction, cost reduction, and process streamlining. These results could be reached through one or more changes to the system including changing the layout of machines in the cell, combining processes, or fixture redesign.

Because of the complexity of the project, it was decided to implement a six sigma approach. This defined the problem in 5 specific stages, and shown in Figure 1 below.

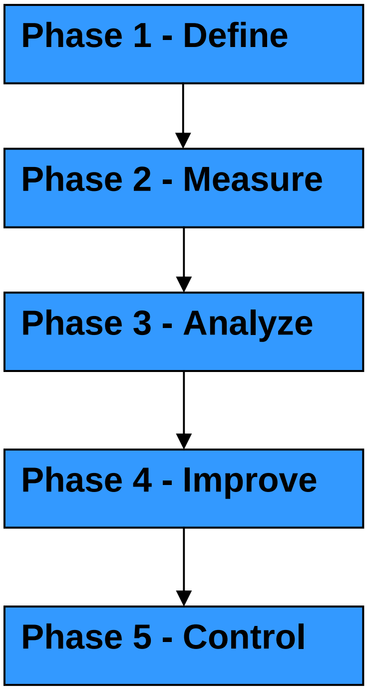


Figure 1: Design Process Flow Chart

In the first phase, the project group defined what the client's specifications were, what would be critical to the quality of the solutions, what defects existed in the current manufacturing process that needed to be resolved, and what the performance standard would be for judging possible solutions.

In the second phase, the project group focused on gathering data on the current process to determine exactly what changes could be implemented to address the defects observed in the Define phase of the project. The various data sources were combined to allow the problem to be more easily visualized.

In the third phase, a computer simulation of the process was developed to allow for the analysis of any improvements.

In the fourth phase, the project group addressed the primary areas of concern, and developed a new order of operations to minimize shipping, a modified cell layout to minimize part movement, and a continuous flow plan to reduce the amount of work in process being held in inventory at the plant.

Finally, in the fifth phase, the improvements were combined with recommendations for the implementation of Kanban and 5s practices to ensure that the new process does not degrade over time.

Phase 1 - Define

In order to establish the client specifications, the characteristics that would be critical to the quality of the solution, the process capability, and a performance standard, the team gathered a great deal of data on the existing process. What follows is a summary of the data collected.

A. Cost Analysis Sheet

One of the first documents received from Middleton Aerospace was labeled as "Cost Analysis", from 2nd Quarter 2005. This provided a look at the process as a whole, and detailed what steps were involved in manufacturing the part. This document can be found as Appendix A.

According to the Cost Analysis, the total Run Hours for the entire process is 36.71 hours. However, this does not translate to the actual lead-time for the part, which the engineers at Middleton quoted as 8 weeks. The cost analysis does not take into account shipping times for those processes done out of the cell, and it does not take into account the fact that the parts are produced in batches, so they may not necessarily move onto the next step until the entire batch is ready to move on.

While the cost analysis sheet was useful in providing an overview of the process, and gave the run times for the each step, it did not give any details of the process, nor did the run times accurately correlate to the actual times it takes to process the part.

B. Tool Sheets

The next documents received were a series of tool sheets. These contained details on machine operation for each process. There were two types of sheets, depending on the type of machine. An example of each is found in Appendix B.

For the lathes, each sheet heading gives the part number (4145T33G01), the operation number, and the machine model. Also included are the revision number, date of creation, and fixture number to be used on that machine for that process. Below the heading, the sheet features a list of all the tools that should be installed on the machine, and in what position they should be placed. It gives the tool holder as well as the insert number for each. The second page shows a simple drawing of each of the tools, with the cutting surface highlighted. The last page gives a drawing of the part as it should look for that process.

The tool sheets for the milling machines are similar. The heading also features the part number, operation number, machine model, fixture used, and revision number. Below these are drawings of generic milling tools with dimensions stated as letters. Next on the sheet is a list of the tools that need to be installed for the process, the tool size, a short description of the tool, and values for the dimensions mentioned in the above drawings. The second page contains instructions for placing the part onto the necessary fixture and any miscellaneous notes on the process.

These tool sheets provided details on what parts and tools were being used in each process, as well as which machines could be used. However, the project group will not need to change any of the tools used, and it was found that many of the machines referenced in the files were no longer in use. The tool sheets can provide useful information when combining processes by allowing the comparison of the tools used in each of the processes.

C. Time Analysis

Because no information is available on which machines are being used for each process, and on what machines were actually in the cell, Middleton Aerospace sent a Time Analysis document. This document was part of a time study they had done earlier. It looks very similar to the Cost Analysis, except that it only features those processes that are performed in-house.

Next to the operations, it lists a standard time, then two separate times, listed as “Man Run Hours” and “Machine Run Hours”, which divide the operation time into the machine run times and the setup and disassembly times. Since the time study was not completed, most of these times are listed as the same, so the document doesn't provide much useful information. However, the document did list the actual machine each operation is performed on, which allows the part flow to be seen more clearly. This allows the project group to identify which machines are being heavily used and where bottlenecks occur when parts are waiting for a machine to be available. A copy of this document can be found in Appendix C.

D. Cell Layout

The cell layout was provided by Middleton Aerospace as a Microsoft Visio file. This provides the cell layout at the current time. The file is drawn to scale, and includes all the benches, fixture storage, and machines. The following chart lists the total number of each of the items shown on the cell layout.

Table 1: Contents of Cell

Machine	# in Cell
Kitamurra	2
SL-75	2
SL-65	1
B/P	1
EL	1
EDM	1
Surf. Plate	2
Fixture Storage	3
Bench	5
Cabinet	2

This information allows the project group to actually see what machines are available to use, and how many there are. As was mentioned earlier, by analyzing the flow through the machines, bottlenecks can be identified. The floor plan can also be used to simulate part flow though the cell to provide a baseline for future modifications. A copy of the Cell Layout can be found in Appendix D.

E. Technical Drawings

A series of technical drawing covering each process in manufacturing of the part, was also acquired. For the lathe and mill operations, there are technical drawings of a cross section of the part. Some of the drawings show the part in its current state, with the final shape superimposed as a dotted line. Drawings for other processes include details to assist to the people performing that operation such as photos showing how to load the part into the machine or onto a fixture, special precautions that need to be taken, or step-by-step instructions for that operation.

These drawing prove very useful in determining what exactly is happening in each step, and when coupled with the other documents, provides a clear understanding of the process. Also, it helps in determining whether process steps can be combined or modified. An example of one of the technical drawings can be found in Appendix E.

F. Green-line Sheet

A tool that Middleton Aerospace uses in deciding how many units to start production of each week is their “Greenline” sheet. The first part of the sheet contains the part name, with a large table below it. Each column of the table refers to the data for a given week. The rows relate to different aspects of the production of the part. There is a row for the number of parts due that week, total parts due up to that week, number of parts promised to GE, number of parts actually shipped to GE that week, total parts made up to that week, and the difference between the total made and the total due. There is also a block for comments. The second part of the sheet shows the number of parts that have gone through certain processes, compared to how many were expected to have at that point. This is shown through the use of a bar graph. The height of the bar shows which week it is, and along the sides of the bar are the values. Along the left side is the expected number of parts produced, and along the right is the actual number of parts produced.

These measurements are taken at several key operations, spaced out along the entire process. The first point is at Material Release, and then at Operations 20, 40, 100, 120, 175, 235, and 280, then ends with number of parts that have been shipped.

These sheets provide an idea of the total number of parts Middleton is making, as well as how many are being made on average each week. It also shows where parts are getting stalled in the flow, since new material is released every few weeks, but the number of parts going through each operation change continuously. Unfortunately, it is impossible to determine which parts are from which batch, and thus how far behind the operations actually are from each other, but this can be estimated by comparing values across operations. Both parts of the Greenline Sheet from 6/27/2005 can be found in Appendix F.

G. Routing Sheet

The routing sheets are packets used to track every part that gets manufactured in the plant, from start to finish. The first page gives the date that the material is released for production, the work order number for the batch, the part number, description, sales order number from GE, raw material, batch size, individual serial number, and process revisions.

The subsequent pages contain a section for each operation in the manufacturing process. Each operation has an individual operation number, and a code is given to tell which machine or company will do that process. For example, lathe operations have the code

NCL, for Numerical Control Lathe. Out-of-house operations contain the name of the company that the parts get sent to, for example Accurate Brazing or Hansen Aerospace. A short description of each operation is provided, along with any important notes. These notes include precautions and instructions for operations that can be performed out of order. Next to the description is an expected run time for the operation. As the operations are completed, a stamp is placed under the run time. The stamp gives a four digit code for the worker who stamped it, along with the date of the stamping.

It is important to note that the run times given are just a rough approximation. According to the engineers at Middleton Aerospace, setup time is amortized over an average-sized batch, and no breakdown of setup time, run time, and wait time is provided. Also, the parts are stamped as a batch, not as each individually leaves the machine. This makes determining wait time and the actual run time difficult. It also makes it difficult to determine how the batch system works, and whether or not they are working at capacity. These factors will need to be determined though other methods, such as interviewing the workers on the floor.

However, the routing sheets provide an outline of total process, including all non-machining operations such as inspections and out-of-house processes not defined elsewhere. They also give an idea of how long it takes to manufacture a batch of parts from start to finish. By comparing the routing sheets for several different parts, it is possible to come up with average times for the total process and individual operations. An example of a routing sheet can be found in Appendix G.

H. Direct Investigation

Through meetings with engineers and workers at Middleton Aerospace, the project group has accumulated additional information. At one meeting, Robert Tariverdian, Director of Engineering, explained that the number of parts they produce is based on customer demand, so they do not necessarily operate at full capacity. This makes it difficult to determine whether any changes the project group makes will actually affect to overall run time, since there is no baseline to compare with. The project group also received estimates on the total number of days it takes for out-of-house operations to be completed once shipping time is factored in. These are given in the following table:

Table 2: Out of House Operation Times

OP #	Time	Vendor
OP 25	3 Days	Accurate Brazing
OP 175	5 Days	Laserfare
OP 210	1 Day	Hansen Aerospace
OP 225	5 Days	Laserfare
OP 235	2 Days	Accurate Brazing
OP 280	1 Day	Hansen Aerospace

These times give an idea of how long the parts will be unavailable for in-cell operation, and show where shipping time can be reduced by combining operations performed by the same vendor. Mr. Tariverdian also informed the project group that parts are shipped as a complete batch. This means that the entire batch must complete all previous operations before any can be sent out. This can increase wait time, possibly by days.

Also, the project group was informed that most inspections are done while the parts are on the machines at each operation to ensure that the part is within tolerance, and is included in the run time. Any inspections done outside the machine, such as Fluorescent Penetrant Inspection (FPI), are given their own operation.

From the meeting, it was also determined that inventory, especially while waiting between operations, is kept within the cell. There is a raw material storage area, but it is rarely used for in-process parts, and a finished goods storage area, where they keep completed parts that have not been shipped.

The project group was informed that the Deburr operations (Operations 150 and 190) Final Mark (Operation 130), and TIG welding (Operation 265) are done outside of the cell, in another area at Middleton Aerospace. Additionally, the project group was able to determine that Operations 175 (Laser drill holes), 190 (Inspection), 205 (Bench Splatter), 215 (Assemble Shield), 225 (Laser weld shield), and 245 (Bench Splatter) could all be combined and done by Laserfare in one shipment. This could result in a significant reduction in lead-time.

Finally, the project group was informed that cell may be moved to a new building in the near future. Thus, if it was desired to move any machines into or out of the cell, or rearrange machines currently in the cell, it could be done during the move.

During another meeting, the project group met with Tony Marino, the man in charge of the cell. He gave a lot of information on the inner workings of the cell and process. First off, it was discovered that many operations are done out of the cell, especially when they need to increase production unexpectedly or when machines are idle. This includes Ops 10, 20, 30, 40, 80, 110, and 120. They can all be done on lathes and mills located elsewhere at the facility. Also, it was learned that there are two working shifts, for a total workday of about 16 hours. This information may be useful during analysis. The following table, Table 3, is provided to show the operations that are currently done inside and outside the cell, based on the information learned during this meeting:

Table 3: In Cell/Out of Cell Operations

OP #	Machine	In Cell	Out of Cell	Outside Vendor
5		✓		
10	SL-65		✓	
20	SL-65		✓	
25				✓
30	EL		✓	
40	SL-75		✓	
80	SL-75		✓	
90	SL-75	✓		
100	SL-75	✓		
110	Kitamurra	✓		
120	Kitamurra	✓		
130	Mark		✓	
140	Kitamurra	✓		
150	Deburr		✓	
160	SL-75	✓		
170	SL-75	✓		
175				✓
180	Kitamurra	✓		
190	Deburr		✓	
205	Deburr		✓	
210				✓
213				✓
215				✓
225				✓
235				✓
245	Deburr		✓	
254			✓	
255	B/P		✓	
265	Weld		✓	
270	B/P		✓	
280				✓
290			✓	
Total Steps		9	15	8
Total Run time		20:09	19:41	NA

I. Current Process

Using all the aforementioned documents and information, a preliminary description of the entire process can be presented, detailing each operation as much as possible with the information available. A more detailed analysis of the operations and flow will be performed later in the project. The technical drawings show the results of each process. The complete process follows:

5 – Release Material: This is the first step in starting the process. A work order is made and the material is tagged with a routing sheet and sent to the cell.

10 – Rough Aft: The first lathe operation. This removes a large amount of material from the aft, and gives the general shape to the part.

20 – Rough Fwd: Similar to OP 10, but does the same on the forward. Removes a lot of material, especially to hollow out the inside forward of the part.

25 – Heat Treat: The batch is then shipped to Accurate Brazing and heat treated for several hours.

30 – Tool Prep: The parts are placed in the engine lathe, and flatness of faces is ensured. This is done due to possible deformation from the heat treatment.

40 – Finish Fwd: The parts are placed into a lathe and the forward face is finished off. Most of the details of the forward side are cut in this step.

80 – Finish Aft Flange: The lathe is used to detail the flange to the final dimensions.

90 – Finish Middle ID: The lathe is used to give the middle diameter its size. Details are not cut yet though.

100 – Finish Forward Grooves: The details for the forward grooves from the middle are cut now.

110 – Mill Pockets Aft Flange: A mill is used to mill out pockets in the flange, as well as drill holes through the flange on either side of the pocket.

120 – Mill and Drill Aft Flange: Several smaller holes are drilled into the flange.

130 – Final Mark: The batch is removed from the cell and brought to a sandblaster. The part number and serial number are blasted onto each part.

140 – Mill and Drill Periphery: Batch is returned to the cell and each is put into mill. Additional details are milled out of the flange, around the pockets and holes.

150 – Deburr and White Light Inspect: The batch is removed from the cell. All the holes and pockets are deburred. All of the parts are then individually inspected for defects.

160 – Finish OD: Final details are cut onto the outside diameter, including details to the flange.

170 – Finish ID Aft Grooves: The grooves on the inside of the part are finished off, and detailed fully.

175 – Laser Drill Holes: The batch is shipped to Laserfare and several extremely small holes are laser drilled into the parts.

180 – Drill ID Pin Holes: When the batch returns to the cell, the mill is used to drill several holes into the parts, located on the inside face.

190 – Local Bench and Inspect: The parts are sent out of cell to have the ID holes deburred with an abrasive pad and sharp edges broken. Inspection of these holes is also done.

205 – Bench Laser Splatter: The laser drilled holes are then cleaned of any debris. Also, the holes are checked to be in tolerance.

210 – FPI: The batch is shipped to Hansen Aerospace, where a Fluorescent Penetrant Inspection is performed on all the holes to ensure there are no cracks or other damage.

213 – Release Hardware: The heat shields are released from inventory at Laserfare and coupled with a part in the process. At this time, the parts are shipped to Laserfare.

215 - Assemble Shield: The heat shields and existing casings are cleaned with alcohol, and then assembled together. Aluminum tape may be used to hold the parts together. A gauge pin is used to inspect the position of the heat shield. This is done at Laserfare.

225 – Laser Weld: The shield is laser welded to the casing.

235 – Heat Treatment: The batch is shipped off to Accurate Brazing and heat treated again.

245 – Bench Laser Splatter: Once back at Middleton Aerospace, the parts are sent out of cell to the bench, and any debris from the welding and heat treatment are removed.

254 – Release Hardware: Kits of bushings and pins are released from inventory and coupled with a casing.

255 – Assemble Bushings and Pins: All grooves are inspected with go/no-go gauges for accuracy of dimensions due to heat treatment. A series of actions are done to install the pins and bushings into the necessary holes. Also, several cleanings of the casing, pins, and bushings are performed, as well as regular inspections to insure correct installation.

265 – Weld Bushings and Pins: The batch is sent to the TIG welder. All the bushings and pins that were installed in the previous operation are welding into place.

270 – Ream Bushings: Back in the cell, the welded bushings are reamed to ensure that they are the correct size on the B/P.

275 – Inspection: This is not mandatory, and is usually not performed.

280 – FPI: The batch is sent to Hansen Aerospace and another FPI is performed. This inspection is meant to check the safety of the welds.

290 – Final Inspection: The batch is shipped back to Middleton Aerospace. A final in house inspection is done to check all final measurements of the casing. They are then ready to be shipped out or sent to storage.

As a result of the initial investigation, the team was able to define a number of defects in the current manufacturing process that were critical to quality:

- Operations are being done on machines other than those specified in the routing sheets
- Many operations are done outside of the cell
- Parts spend a lot of time being shipped to outside vendors or other locations
- Products sit in inventory for extended periods of time
- A batch-and-queue system is used instead of continuous flow
- Need for better communication between management and shop floor
- Although there is a preventive maintenance plan and documentation it does not seem to be proactive or effective

The project group was also is able to develop a data driven measuring system to judge any improvements, using the equation of $Y = X1 +X2 + X3$. In this equation, Y is the indicator of process performance, and is a function of three variables,X1, X2, and X3. X1 and X2 are derived from the client specifications, and are Lead Time Improvement and Implementation of a Lean Process respectively. The team went further by validating the reduction in work in process costs, which is X3.

Phase 2 – Measure

In order to further understand and identify the CTQ characteristics, and to allow for the development of solutions, further analysis was needed. Some of the data gathered needed to be rearranged, and there was a lot of critical information which was spread over multiple documents which needed to be combined.

A. Routing Sheet Analysis

The first step in the analysis was to look at the collection of routing sheets that Mr. Tariverdian had provided. As stated earlier, these routing sheets provided the best insight into the current lead-times, wait times, and product flow. Analysis began by making a table and compiling all the information contained in the 25 routing sheets that were recieved onto a single document.

A column is designated for the work center code (ie. NCL, B/P), machine commonly used, fixture used, Operation #, Operation Description, Estimated Run time (the value found on the routing sheets), and a column for each serial number analyzed. The work center and common machine allowed the project group to see which successive operations required the same machine, and showed when batches of parts were sent out of the cell to outside vendors. The fixture number for each operation was included to allow future analysis of fixture design and utilization. Operation numbers and descriptions were included for reference.

The estimated run time was used to examine the process to find bottlenecks where parts back up while waiting in line for machines to become available. In an ideal manufacturing process, every operation will have the same run time, allowing a constant part flow through the process. Although this is not possible with the existing process, since parts need to be shipped out in batches, attempting to approach equal operation times will improve flow and reduce lead-time.

On the combined routing sheet, the first set of four parts analyzed were started on the same date, and finished on almost the same date, thus were all in the same batch. This meant that stamp dates for the intermediate steps could be analyzed to make assumptions on how the process is run. The dates were color coded, so that it was easy to visualize how batches are formed. The analysis sheet for the first four parts can be found in Appendix H.

Doing this analysis helped give an idea of in the part flow. Since Operations 10 and 20 are both performed on the SL-65, the entire batch goes through Operation 10, and then when they are finished, go through Operation 20. The analysis of the routing sheet seems to confirm this. Once all the parts are done with operation 20,, they are shipped to Accurate Brazing for heat treating. When they get back, it appears that one of the SL-75 is used for Operation 40 and the other for Operation 80 since one of the parts goes through OP 40 after the other 3 parts have already done OP 80. For Operations 90 and 100, it seems that all the parts go through each before the next is started. The stamp dates for all 4 parts are similar for both operations. Both operations use the same fixture, so that would also make sense.

The batch is then sent to the Kitamurra mill for Operations 110 and 120. The run times are very close for the entire batch for both operations, and no parts enter OP 120 before they are all finished OP 110, so it seems that they are held at this step. Again, the same fixture is used for both operations. The entire batch is then sent out-of-cell at the same time to be marked at the sand blaster.

The next Operation, 140, is the longest in-house operation, running 5 hours and 11 minutes. Although there are two Kitamurra machines in cell that Operation 140 can be performed on, that is a huge amount of time to devote to single parts, and the bottleneck formed at this step causes the span of 7 days between stamp dates. The entire batch seems to be split into two for the next operation, which is inspection.

Both Operations 160 and 170 are performed on the SL-75 lathes and use the same fixture. It seems as though both operations are done successively for each part, due to the fact that all four parts are stamped the same date for both operations even though the total span is 3 days for the batch. In other words, a part would go through OP 160, be flipped over, and immediately have OP 170 performed on it before moving onto the next part.

Once the entire batch is finished with those operations, they are shipped together to Laserfare for laser drilling. When they return, they are all sent through the mill for OP

180. After this operation, they stay together for almost the rest of the process (Operations 190 through 254). They go to a local inspection and cleaning, then ship to Hansen for further inspection, then to back Laserfare for heat shield assembly and welding. They then travel as a batch to Accurate Brazing for heat treatment, and are returned to Middleton for cleaning.

After they return to the cell and are cleaned, they are split into 2 groups. Once the entire first group finishes the next operation and moves on, the second group is sent through to follow. This is true for the remaining operations, the bushing assembly, TIG welding, reaming, and final inspections. For these final inspections, the parts are sent to Hansen individually, not as a batch.

B. Process Flowchart

With the routing sheets in a form that can be easily analyzed, it was necessary to rearrange the process itself. To assist with visual analysis, a color-coded flowchart was created. This flowchart of the current process can be found in Appendix I.

In this flowchart, each operation is given a box, which contains the operation number and the name of the machine it is performed on. The box is given a color specific to the machine it is performed on. For example, all the operations on the Kitamurra mill are red.

Below each operation box is the estimated run time, found on the routing sheets. An arrow is then leading from the operation to another box, the flow box. The flow boxes are either blue or peach in color. A peach box indicates that it is flowing into or within the cell. A blue box indicates that the part will be shipped out of Middleton Aerospace. Inside the flow box is a number of days. This indicates the average days between the processes on the analyzed routing sheets. There is an arrow leading from each operation to the next. At the end of each row, the process continues on the left of the next row.

By totaling up the times in the blue boxes, it was found that the total shipping/out of cell time is about 43 days. Doing the same for the in-cell boxes comes up with a total of 23 days. Combined, this makes a total 66 days, or about 9 weeks. This average lead-time is close to the estimates that the engineers at Middleton Aerospace gave.

Using the color-coding to notice trends in the flow, it can be seen that the flow is somewhat grouped together by machine. All of the SL-65 operations are together at the beginning, and then four consecutive SL-75 operations occur. Two operations on the Kitamurra follow, then the sand blasting, then back to the Kitamurra. After deburring and cleaning, the parts are sent through two SL-75 operations, shipped to Laserfare, then the Kitamurra and more deburring operations. After those, a series of shipments occur, and when the parts return, they are brought to the bench press, then welded, and then moved back to the bench press. The process ends with in and out-of-house inspections.

A few adjustments could be made from looking at this flowchart. First off, it may be beneficial to group the Kitamurra operations together, Ops 110, 120, 140. This could be done if the sand blasting is done after OP 140, rather than before. Also, if possible, if the

Laserfare operations were grouped together, a lot of time may be saved in shipping. As stated in the Data Gathering section, Bob said this should be possible, as well as doing some of the cleanings and inspections at Laserfare. This may also reduce the time, as well as proved a better flow.

C. Cell Flowchart

The next document to analyze was the Cell Layout. The engineers at Middleton informed the project group that machines could be freely moved around the cell, and it is possibly add or remove machines as well. Therefore, analysis should be done of the floor plan to see if changes could be made to improve flow. The cell itself is very small, and any changes to machine position will have very little effect on the process time, as the transportation time, even completely across the cell, is miniscule when compared to the run times of the operations. However, there may be ways to improve the flow to make things easier for the machinists, and it may be useful to see how the flow through the cell is currently working.

In order to analyze the cell, the Cell Layout was overlaid with arrows representing part movement between operations. Boxes were drawn to represent out-of-cell operations, including operations performed at other companies such as Laserfare. After all the arrows were drawn, operation numbers performed at each position were written in. The modified floor plan can be found in Appendix J.

D. Total Batch Analysis

After the initial routing sheet analysis, another set of routing sheets was received. After examining them, it was determined that 15 of the routing sheets were for parts in a single batch, and by analyzing them as with the previous ones, more information could be inferred. The serial numbers were between BCM95624 and BCM95638. Again, all the stamp dates were put into an Excel spreadsheet and color-coded. The result of this can be found in Appendix K.

All 15 of the parts were started on 6/9/05. From there, 5 of them get finished with OP 10 that day, while the other 10 get finished on 6/10/05. The selection process for OP 20 seems completely random, because the ones that get finished on 6/10/05 are not the ones that finished OP 10 first. Instead, the whole batch gets finished between 6/10/05 and 6/14/05, with no bias on which was done when. After the whole batch finishes OP 20, they are all sent away to get heat treated, and return on 6/16/05.

When they return, they all complete OP 30 on 6/16 or 6/17, then go onto OPs 40 and 80. As stated before, it seems as though these two processes are done on separate machines at the same time. This is supported by the fact that some of the parts finish both operations before other parts have even finished OP 40. After all the parts are done, it looks like both machines are set for OP 90, because all of the parts are put through that operation before any enter OP 100. There is about a week wait before all the parts are done with OP 100.

After OP 100, the process seems to change in demand. Eleven of the parts are put through OP 110 between 7/13 and 7/14. The other 4 do not carry on with the process until 7/26. The parts follow the process as two small batches, about 2 weeks apart for the rest of the way until OP 245, when they get back from the second heat treatment. The faster of the two batches gets further split into 2 more small batches for cleaning (OP 245). Then for the remaining operations, which are bushing assembly and welding, along with final inspections, they are split into even smaller groups of two or three. Thus, two or three parts are finished per day.

Looking at a larger size sample like this sheds more light onto the process. Contrary to the initial assumptions, not all of the parts necessarily follow the entire process through together. It appears that around OP 100, they stall some of the parts to phase the groups 2 weeks apart from each other. This also means that not all 15 in the batch go to Laserfare together or to the other post OP 100 shipments as a whole batch. Furthermore, the final release rate is lower than predicted, since it is only about 2 or 3 per day, rather than half the whole batch per day.

E. Takt Time Calculation

Important to the investigation and later development of a solution is the calculation of the Takt Time. The Takt Time is a measure of how often a finished product must exit the process in order to meet customer demand. If parts are produced slower than the Takt Time, demand will not be met. If parts are produced faster than the Takt Time, the company can make more parts than needed by the customer. Ideally, you want to make parts slightly faster than the Takt Time, so that demand can be met with extra time for unexpected delays.

In order to calculate the Takt Time, the total shift time must be known, as well as any time taken out for lunch and other breaks. By subtracting any break time from the shift time, you are left with the net operating time per shift. This can then be multiplied by the number of shifts per day, giving the total operating time available per day. By then dividing this by the number of parts needed per day, the Takt Time can be found.

In this situation, there are two shifts per day, each at eight hours. The workers have a lunch break of thirty minutes, and a total of twenty minutes for other breaks. This leaves a net operating time of 430 minutes per shift, or 860 minutes per day. Expected demand is about ten parts per week sent to GE, which means two parts per day. By dividing this through, it gives a Takt Time of 430 minutes. A summary of this calculation can be found in Table 4. This value can now be used to formulate a new work plan for each day.

Table 4: Takt Time Calculation

Net Operating Time (2 shifts)		
	Shift (minutes)	480
	Break (minutes)	-20
	Lunch (minutes)	-30
	Net Operating Time per Shift (minutes)	430
	Number of Shifts per Day	2
	Net Operating Time per Day (minutes)	860
Customer Requirements		
	Parts per Week	10
	Parts per Day	2
Takt Time	Time per Part (minutes)	430

F. Work in Process

In order to compare the updated process to the old way, some measures need to be done on the old process. While the lead-time and total process times had already been calculated, which will be useful in comparing the processes, other methods should also be employed, since time isn't the only concern. A common calculation used in manufacturing is the Work in Process (WIP). This is a measure of the total values of all inventory of the part. The value of each part is dependent on where in the process it is. This value is calculated using the value of the raw material, plus the value of labor put into the part up until then and cost of out-of-house operations performed.

Using values obtained from Middleton Aerospace, the inventory cost can be calculated. A rate of $118/hour was used for labor, based on numbers provided. Early in the project, the inventory numbers were calculated from the Greenline Sheets, which provided an estimate of how many parts were in process, and roughly where they were. Later, however, an exact inventory was provided for all parts in process, so that was used to find an idea of the average WIP to be expected. The values for the exact inventory can be found in Appendix L.

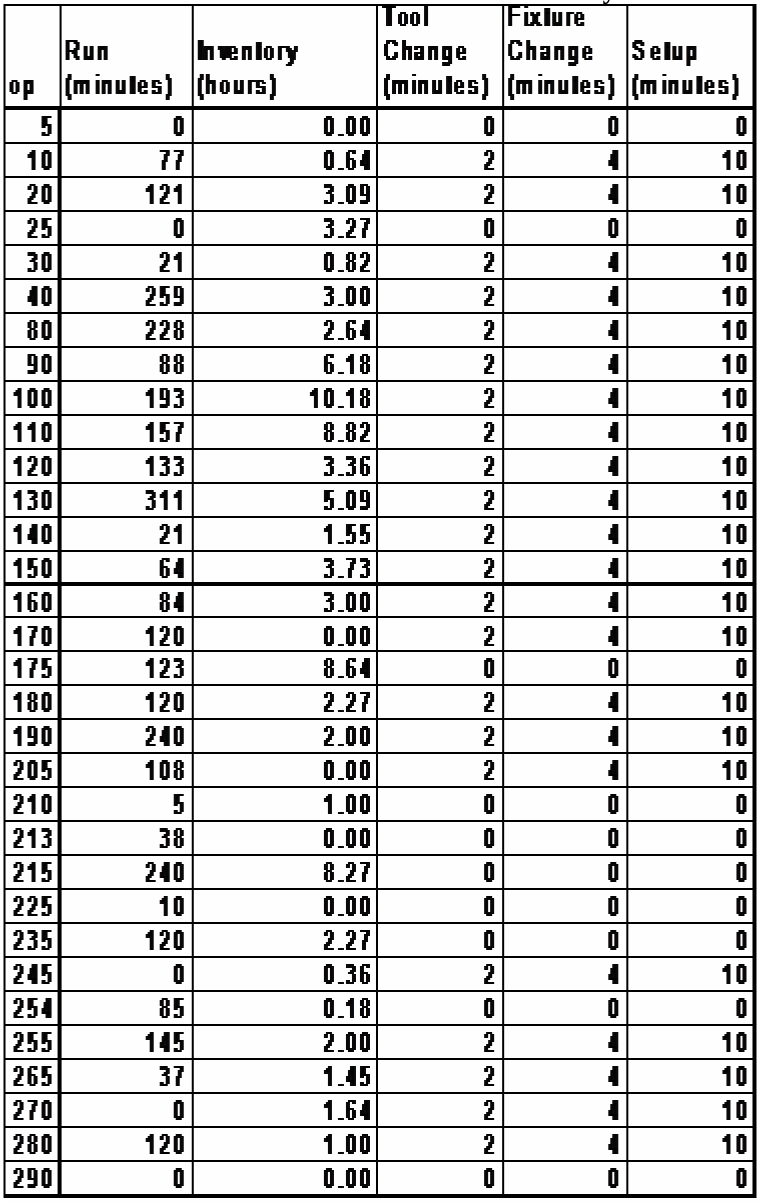
Using these values, the WIP for the current process was found to be about $330,000. This is just a snapshot of the WIP on that day, so it can be expected to fluctuate as new parts are introduced to the process and others get completed and shipped. This value can be used as the benchmark to compare the new process to. A spreadsheet showing the calculations and values for WIP can be found in Appendix M.

Phase 3 – Analyze

The team knew that one of the main client requests was to shorten the lead-time of the manufacturing process. For that reason, the primary function of phase 3 was to measure what the existing and new processes can deliver. Because the lead-time of the part is quite long compared to the length of this project, it was necessary to write a computer simulation using the Matlab software package to determine the value of X1, the variable representing lead-time in the performance standard.

Based on data from Middleton Aerospace collected in Phase 1, the project group focused on what measurable factors should be derived from Phase 2 that would contribute to the lead-time. These factors, setup time, run time, fixture change time and tool change time, determined the structure of the Matlab program. The data gathered in the previous phases were formatted to that they could be input into the program, as shown in Table 5.

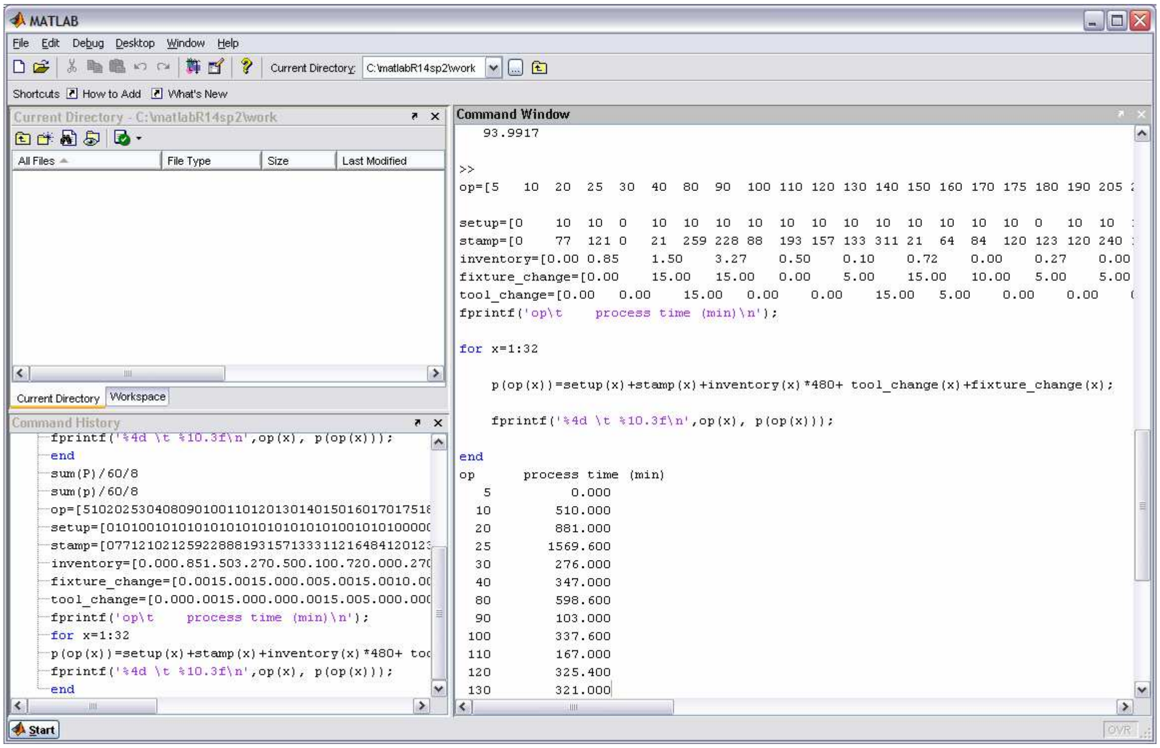
Table 5: Current Process Data Summary



op	Run (minutes)	Inventory (hours)	Tool Change (minutes)	Fixture Change (minutes)	Setup (minutes)
5	0	0.00	0	0	0
10	77	0.64	2	4	10
20	121	3.09	2	4	10
25	0	3.27	0	0	0
30	21	0.82	2	4	10
40	259	3.00	2	4	10
80	228	2.64	2	4	10
90	88	6.18	2	4	10
100	193	10.18	2	4	10
110	157	8.82	2	4	10
120	133	3.36	2	4	10
130	311	5.09	2	4	10
140	21	1.55	2	4	10
150	64	3.73	2	4	10
160	84	3.00	2	4	10
170	120	0.00	2	4	10
175	123	8.64	0	0	0
180	120	2.27	2	4	10
190	240	2.00	2	4	10
205	108	0.00	2	4	10
210	5	1.00	0	0	0
213	38	0.00	0	0	0
215	240	8.27	0	0	0
225	10	0.00	0	0	0
235	120	2.27	0	0	0
245	0	0.36	2	4	10
254	85	0.18	0	0	0
255	145	2.00	2	4	10
265	37	1.45	2	4	10
270	0	1.64	2	4	10
280	120	1.00	2	4	10
290	0	0.00	0	0	0

Setup time refers to the time taken to install the part onto the fixture, as well as other random actions that need to be taken before running the operation. Run time is the average time it takes the machine to carry out the operation. Tool change time is needed for any operations that require different tools from the previous operation carried out on that machine. Inventory time is the average time that the part will be stored in inventory before moving onto the next operation. By setting up an independent variable called

Operation Number, the client would be able to directly determine the lead-time of each operation, as shown in Figure 2.



```
fprintf('%4d \t %10.3f\n',op(x), p(op(x)));
end
sum(P)/60/8
sum(p)/60/8
op=[5102025304080901001101201301401501601701751
setup=[0101001010101010101010101010101001010100000
stamp=[077121021259228881931571333112164841201
inventory=[0.000.851.503.270.500.100.720.000.27
fixture_change=[0.0015.0015.000.005.0015.0010.0
tool_change=[0.000.0015.000.000.0015.005.000.00
fprintf('op\t    process time (min)\n');
for x=1:32
p(op(x))=setup(x)+stamp(x)+inventory(x)*480+ to
fprintf('%4d \t %10.3f\n',op(x), p(op(x)));
end
```

```
   93.9917

>>
op=[5   10  20  25  30  40  80  90  100 110 120 130 140 150 160 170 175 180 190 205

setup=[0    10  10  0   10  10  10  10  10  10  10  10  10  10  10  10  0   10  10
stamp=[0    77  121 0   21  259 228 88  193 157 133 311 21  64  84  120 123 120 240
inventory=[0.00 0.85    1.50    3.27    0.50    0.10    0.72    0.00    0.27    0.00
fixture_change=[0.00    15.00   15.00   0.00    5.00    15.00   10.00   5.00    5.00
tool_change=[0.00   0.00    15.00   0.00    0.00    15.00   5.00    0.00    0.00
fprintf('op\t    process time (min)\n');

for x=1:32

    p(op(x))=setup(x)+stamp(x)+inventory(x)*480+ tool_change(x)+fixture_change(x);

    fprintf('%4d \t %10.3f\n',op(x), p(op(x)));

end
op      process time (min)
   5          0.000
  10        510.000
  20        881.000
  25       1569.600
  30        276.000
  40        347.000
  80        598.600
  90        103.000
 100        337.600
 110        167.000
 120        325.400
 130        321.000
```

Figure 2: Matlab Computer Simulation

The result of the simulation for current process is shown in Table 6. The total lead time was found by the simulation to be 94 days, which correlates closely with the 3 month lead time quoted by the company.

Table 6: Current Results

Op	Process Time (minutes)
5	0
10	401.2
20	1642.2
25	1569.6
30	472.6
40	1707
80	1556.2
90	3069.4
100	5060.4
110	4407.6
120	1774.8
130	2483.2
140	1060
150	1897.4
160	1529
170	151
175	4147.2
180	1236.6
190	1046
205	22
210	480
213	0
215	3969.6
225	0
235	1089.6
245	271.8
254	86.4
255	1100
265	845
270	884.2
280	499
290	0
Total (days)	93

Phase 4 – Improve

With the investigation and analysis of the current process completed, recommendations to improve the process can be given. These are all based on the information collected over several weeks, detailed in the previous sections. The areas of concern that have been determined are summarized below:

1) Multiple operations by the same vendor currently require multiple shipments.

2) Parts need to be removed from a mill for final marking and then returned to the same mill for subsequent operations.

3) Some steps are done on machines located outside the cell, and in some cases in another building.

4) Parts are worked on in batches, leading to a large number of parts sitting in inventory.

5) There is no consistent method for performing operations.

A. Laserfare Operations

The first changes to be made include a revision in the operations done at Laserfare, and when they are performed. It is recommended that both the laser drilling (OP175) and the laser welding (OP 225) be done together, in the same shipment. In addition, Laserfare should be in charged with cleaning up the splatter from their processes (OPs 205 and 245), and inspection of their processes. Therefore, combining all 3 Laserfare processes into a single shipment, requesting Laserfare to work on the splatter clean-up and inspection, making the following OPs 175, 190, 205, 215, 225, 245 in this order and eliminating OP 213 at Laserfare. It should reduce the time required, especially because of the fact that they only need to be shipped out once, instead of twice.

B. Final Marking

A second change the team proposes is to move the Final Marking to after the two milling operations. That is, OP 130 should be moved after OP 140. This will allow the parts to be continuously milled, rather than be milled, moved to get marked, and then return to the mills. This may not seem like a big change now, but it will require less setup time, and less movement around the cell. The result should be less than 5:11 hours, as there is no longer a huge setup time.

C. In Cell Operations

Another change that should be done is to move all possible operations into the cell that can be moved in. This way, they would save time physically moving the parts into and out of the cell for those operations. This could allow those operations to be done faster, as they can be performed right there, when the parts are ready. In addition, it may reduce any chance of damage that could incur during transportation between areas. The operations the project group want to see moved in cell are the inspections (OPs 150, 190, 275, 290), the TIG welder (OP 265), and the sand blaster used in the marking (OP 130). Also, bench operations that are done at the Peabody plant, in particular the bushing operations (OPs 255 and 270) should be done at the Middleton plant, in cell.

Also, it would be advised to discontinue the use of mills and lathes outside of the cell whenever possible. During unexpectedly high demand, this may be necessary, but the cell should be able to operate independently during normal operation. Also, use of in-cell machines for parts other than the T33 should be avoided, so that the cell can be devoted exclusively to production of the T33 HPT. In order to accommodate the addition of an inspection area, benches, and sand blaster, the EDM should be removed from the cell. It is not used for any operation, and is just taking up space. The machine can be moved into a cell for a part that uses it.

D. New Process Flow

A new Process Flowchart was created with the recommend changes. This will later be analyzed for improvements in lead-time, through another simulation of the process. The new flowchart can be found in Appendix N. The operations that have been modified are highlighted with a red box. This refers to those that have been moved to a different part of the process and those that are to be moved into the cell. Please note that the original operation numbers have been kept, for reference purposes.

E. Continuous Flow Model

One of the fundamental concepts of lean manufacturing is that there is continuous part flow. Instead of using a batch and queue system, where a single operation is performed on a batch of parts before moving to the next operation, each part must flow continuously from one operation to the next. This cuts down lead-time, since the time to manufacture a part should be the sum of all the steps, if all the stapes take the same amount of time, and it cuts down on the space required to store the batches waiting for each step.

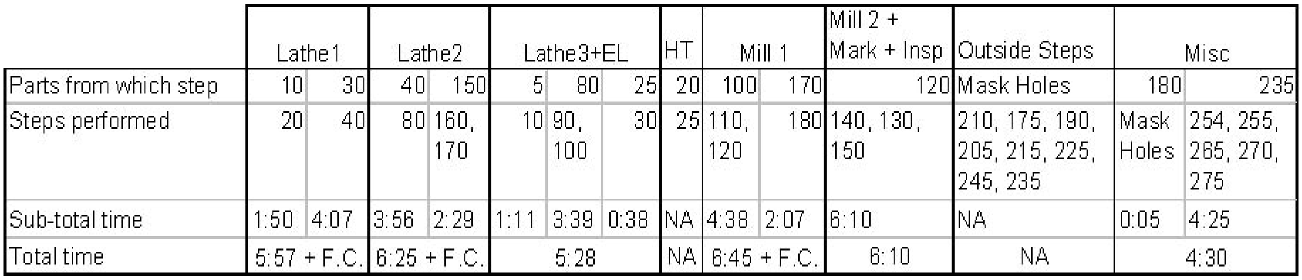
Efficient continuous part flow requires that all steps take essentially the same amount of time. However, in the T33 process, steps range from 20 minutes to over 5 hours, and there is little that can be done to change those times. Therefore, similar steps must be combined into equal blocks of time. Because Middleton Aerospace is currently producing approximately one part a day, and the project goal is to double that, blocks of 8 hours are created. This would allow two blocks to be run every day. No parts are moved until the end of each block, or a kanban system is employed, to ensure that there is never excess inventory sitting around in the cell. Movement to and from outside vendors would also be done using kanban, so that at the end of each block, one part is added to the parts waiting to be shipped and one part is removed from the batch parts received from the vendor. The batches sent to the vendor should be as small as feasibly possible to minimize space used to hold parts.

Dividing all the in-house operations into eight-hour blocks yields six “stations”:

1. First NC lathe
2. Second NC lathe
3. Third NC lathe and the engine lathe
4. First NC mill
5. Second NC mill, marking station, and inspection
6. Bench, TIG Welder, Drill Press, and inspection

Using the given run times to estimate the time to perform each operation, the times to actually perform the operation required by each station were calculated, allowing some extra time for fixture changes and setup. The plan for each station is shown in Table 7. Also, a detailed chart showing the times for all steps can be found in Appendix O.

Table 7: Continuous Flow Block Table



	Lathe1		Lathe2		Lathe3+EL			HT	Mill 1		Mill 2 + Mark + Insp	Outside Steps	Misc	
Parts from which step	10	30	40	150	5	80	25	20	100	170	120	Mask Holes	180	235
Steps performed	20	40	80	160, 170	10	90, 100	30	25	110, 120	180	140, 130, 150	210, 175, 190, 205, 215, 225, 245, 235	Mask Holes	254, 255, 265, 270, 275
Sub-total time	1:50	4:07	3:56	2:29	1:11	3:39	0:38	NA	4:38	2:07	6:10	NA	0:05	4:25
Total time	5:57 + F.C.		6:25 + F.C.		5:28			NA	6:45 + F.C.		6:10	NA	4:30	

If this continuous flow is used, it should output exactly one part per shift, because each operation if performed on exactly one part exactly once per shift. By reversing the order that the steps are performed for the second shift, the fixtures and setup that are in the machine can remain there. Then at the end of the second shift, all the machines will be ready for the next day to start the process over. Also, there is time remaining at the end of each shift to allow for unexpected delays, as well as implement some of the control plans, which are discussed later. A block diagram showing the one-piece flow through the entire new process is shown below in Figure 3.

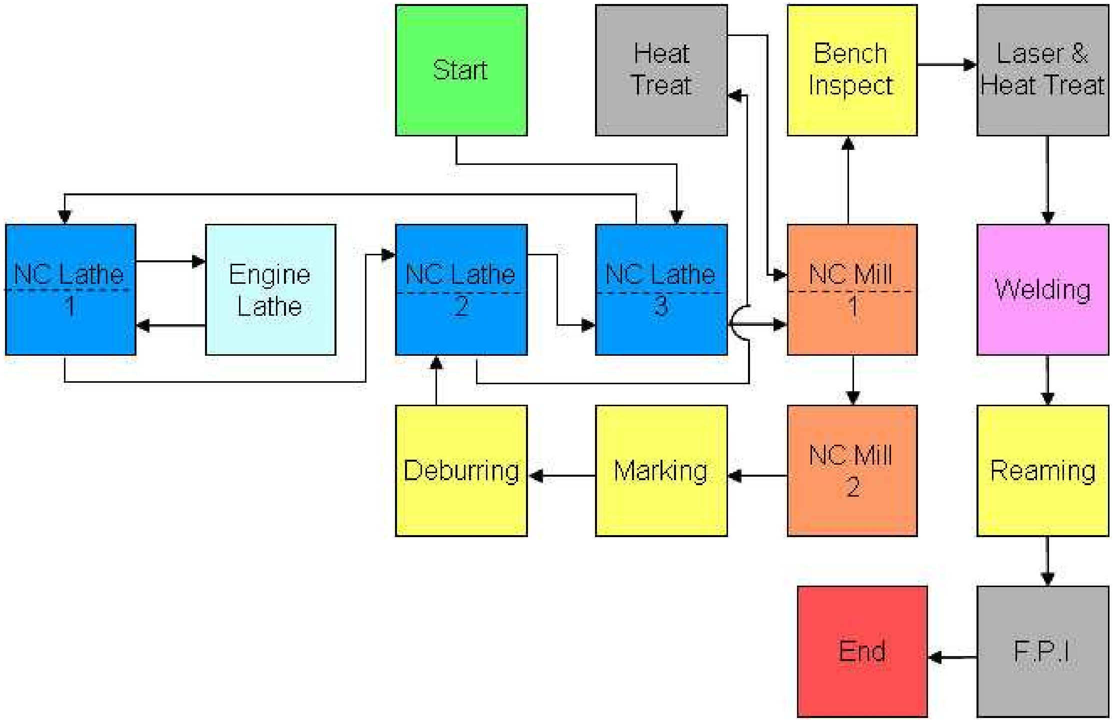


Figure 3: Block Diagram of Piece Flow

F. Floor Plan Improvements

In order to maximize the effectiveness of the continuous flow plan and fully realize the benefits of lean manufacturing, improvements also need to be done to the physical layout of the cell. As was mentioned earlier, the EDM needs to be removed, and the out-of-cell machines brought into the cell. Beyond that, more can be done to minimize the distance parts will move, and improve general flow through the cell. By grouping similar machines together, they can share workspace and storage space, making it easier to find parts and equipment. The recommended floor plan utilizes a U-shape to the machine placement. This plan can be seen below in Figure 4. The numbers applied to the machines are the same as those used in the continuous flow plan, and can be cross-referenced. As was done earlier for the current process, arrows can be drawn onto the floor plan to show the physical movement of a part. This analysis of the new process can be found in Appendix P. It can be seen that the flow is much smoother, with fewer intersecting and overlapping lines, which is an improvement.

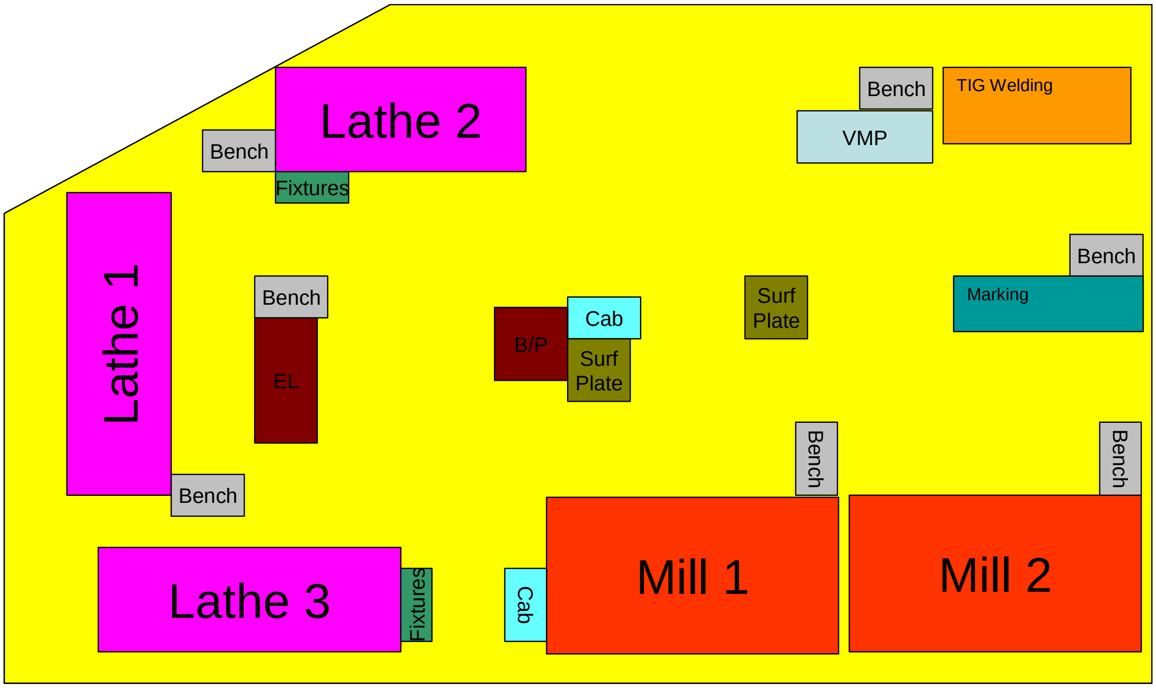


Figure 4: Revised Cell Floor Plan

G. Work in Process Improvements

In addition to finding the time saved, and additional parts per week that are finished by utilizing the principles recommended, the savings in Work in Process needs to be studied. A reduction in the WIP would mean that the company has less money devoted to the part, while still meeting and even exceeding demand. This means less cost to the company, as well as fewer parts in inventory, reducing space used for storage. By rearranging the operations into the new process, and inputting the inventory values that should occur during use of the continuous flow plan, the WIP should be reduced to about $136,000. This represents a 62% reduction in WIP. Also, the actual number of parts in flow is reduced from 84 to 34 parts in process. These values represent a huge improvement for Middleton Aerospace over its current process. A detailed view of how these numbers were obtained can be found in Appendix Q.

H. Fixture Recommendations

By examining the continuous part flow plan, you can notice that there is only one point where a fixture needs to be exchanged for another. This is on Lathe 2. The only other points that require changing fixtures is a replacement of the jaws. Both of these changeovers can be greatly improved through the use of some quick change ball locks. A popular model of these is made by Jergens®, and is called the "Ball Lock Mounting System"™. It utilized bushings in the fixture and mounting plate to locate the fixture. The locks are inserted into the bushings and then a quarter turn is applied with a hex wrench. This tightens the fixture onto the plate with 20,000 pounds of force per ball lock. The position of the fixture is within ±0.0005 inches repeatedly. This reduces setup times significantly. The machine operator no longer needs to bolt on the fixture, check it for accuracy, and then realign it continually to get it into the right position. No locating is necessary. Implementation of these locks should save a lot of time in fixture changes, and reduce the chance of operator error in fixture placement. A drawing of a ball lock is shown in Figure 5.

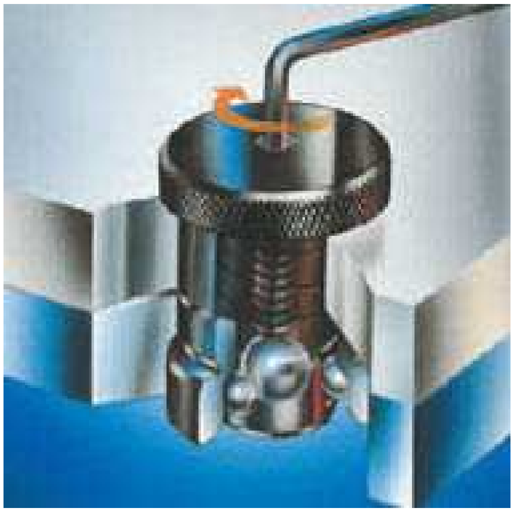


Figure 5: Ball Lock

Application of the ball locks onto the lathe fixtures would require the use of three types of bushings. It would require one primary bushing, with a tolerance of ±0.0004 inches, one secondary bushing, with a tolerance of ±0.0010 inches, and two clearance holes of ±0.0075 inches. This will allow proper alignment of the circular fixtures found on the lathes. The primary bushing would be placed in center of the fixture. The remaining three would be positioned at a set distance from the center, with 120° separating them. A diagram of this application is shown in Figure 6.

Alternatively, for the fixture change on Lathe 2, a flexible fixture combining fixtures T-1599-1 and T-1593-1 into a dual-use fixture could be explored. The ball locks would seem to be a cheaper route to go. The time savings of a flexible fixture would only be around 5-10 minutes, and the additional cost of development and manufacture probably would not make this savings worthwhile.

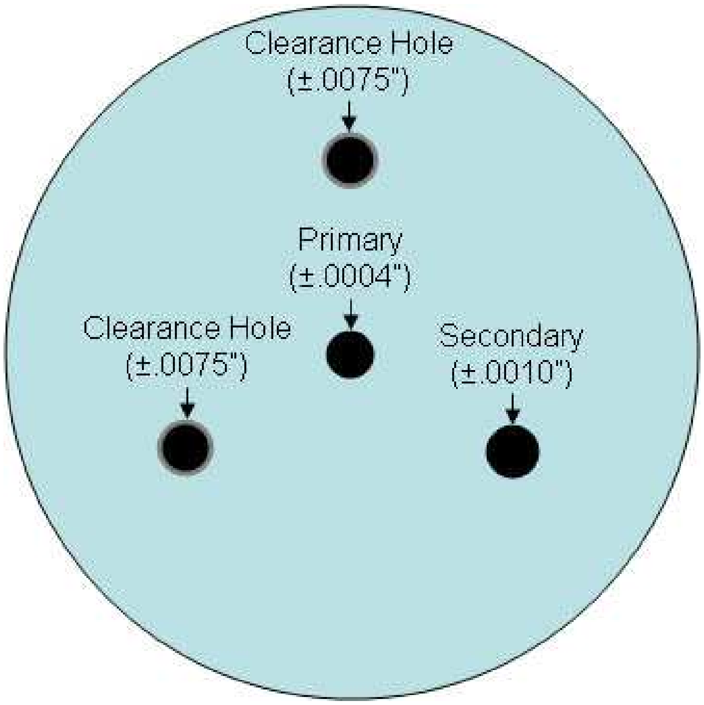


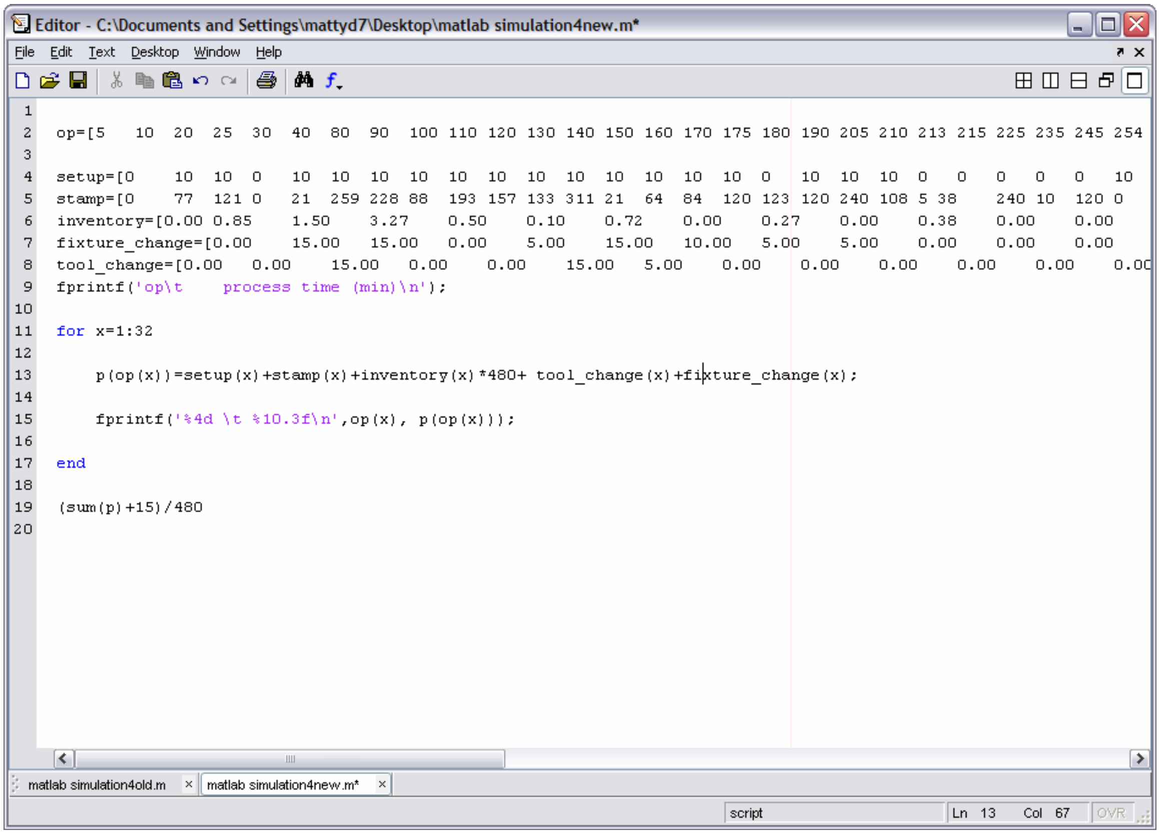
Figure 6: Ball Lock Placement on Fixture

I. Analysis of improvements

The continuous flow plan was analyzed to determine the run time, setup time, inventory time, tool change time, and fixture change time for each of the in-house operations, as shown in Table 8. This data was then combined with the existing times for the out-of-cell operations and prepared for input into the computer simulation developed in phase three. As shown in Figure 7, the program was slightly modified to allow for the addition of the additional masking step that was added into the new process.

Table 8: In House Operations

	Time (minutes)				
Op	run	setup	inventory	tool	fixture
10	71	10	409	0	15
20	110	10	710	15	15
30	38	10	262	0	5
40	247	10	43	15	15
80	235	10	345	5	10
90	76	10	0	0	5
100	143	10	130	0	5
110	143	10	0	0	0
120	135	10	182	0	0
130	15	10	0	0	0
140	276	10	0	0	0
150	79	10	356	0	0
160	44	10	0	3	5
170	105	10	333	3	5
180	127	10	45	0	0
190	66	10	495	0	0
MASK	5	10	0	0	0
255	38	10	0	0	0
265	128	10	0	0	0
270	49	10	0	0	0



```

op=[5   10  20  25  30  40  80  90  100 110 120 130 140 150 160 170 175 180 190 205 210 213 215 225 235 245 254

setup=[0    10  10  0   10  10  10  10  10  10  10  10  10  10  10  10  0   10  10  10  0   0   0   0   0   10
stamp=[0    77  121 0   21  259 228 88  193 157 133 311 21  64  84  120 123 120 240 108 5 38    240 10  120 0
inventory=[0.00 0.85    1.50    3.27    0.50    0.10    0.72    0.00    0.27    0.00    0.38    0.00    0.00
fixture_change=[0.00    15.00   15.00   0.00    5.00    15.00   10.00   5.00    5.00    0.00    0.00    0.00
tool_change=[0.00   0.00    15.00   0.00    0.00    15.00   5.00    0.00    0.00    0.00    0.00    0.00    0.0
fprintf('op\t    process time (min)\n');

for x=1:32

    p(op(x))=setup(x)+stamp(x)+inventory(x)*480+ tool_change(x)+fixture_change(x);

    fprintf('%4d \t %10.3f\n',op(x), p(op(x)));

end

(sum(p)+15)/480

```

Figure 7: Added 15 minutes to the overall lead-time for the new mask operation

As shown in Table 8, the new process shortened the total lead-time to just 29 days, which is less than 1/3 the original lead time.

Table 9: New Process Results

Op	Process Time (minutes)
5	0
10	511
20	903
25	1569.6
30	318
40	339
80	643.6
90	102
100	302.6
110	168
120	338.4
130	34
140	310
150	456.2
160	90.5
170	483.7
175	720
180	189
190	800
205	736
210	494.4
213	720
215	720
225	720
235	720
245	813
254	0
255	134
265	143
270	91
280	493
290	0
Total (days)	29

Phase 5 – Control

With the continuous part flow and other recommendation from Phase 4 implemented, some steps needed to ensure that the work proceeds according to the schedule, and that the process does not revert to the current inefficient process. Also, through the use of careful process control, process cost can be further reduced. The time left at the end of each shift can be used towards these control measures, especially preventative maintenance.

A. Tool Storage

One of the problems that became apparent during discussions with the machine operators was that the tools were not well organized. The workers explained that often fixture and tool changes could take unexpectedly long due to tools that were missing, being used for other machines, or not put back where they belong. In order to remedy this, several simple things can be implemented.

First, each machine is given a bench in the new cell layout. This bench can be used to store tools used on that machine. In order for this to work, each machine should have its own set of tools. Each tool should also be physically marked, designating which machine it belongs to, along with any other information that may be useful (operation number, date of last replacement, etc.). In addition, the benches should have clearly marked storage locations for each tool, preferable in the form of a paint outline in the shape of each tool. This would make it readily apparent if anything is missing or broken.

B. Standard Work

In order to maintain continuous flow, it is critical that a system of "standard work" should be enforced. Every day the same operations should be done in the same manner in the same place at the same time. To assist the company in implementing standard work, the project group developed the continuous flow schedule shown in Appendix O. By doing this, it makes it easy to ensure that all parts are moving through the cell correctly and reduces opportunity for error. It alsot ensures that parts finish on time and meet demand, and makes work easier for the machine operators, since they know what the plan is every day.

C. Preventative Maintenance

With the use of one-piece flow, a single machine failure could hold up the entire production line, since it is not possible to substitute one machine for another which is out of operation. To prevent this from happening, preventative maintenance (PM) is paramount. Several PM steps can be taken to reduce the chance of machine failure. A plan of PM procedures for each machine should be drafted, and then placed on the machine. These procedures should then be given a schedule, so that the operators know how often each procedure should be done. This schedule can be made into a series of checklists. Operators can check daily which procedures need to be taken, perform them, and then sign off on the paper that it was performed. The cell manager can periodically check the lists to make sure that PM has been up to schedule. Cell team members should be involved in all facets of PM and repair, to improve willingness to carry it out, and so they know they are important to keeping the whole process working smoothly.

D. Kanban Storage System

The Kanban System is a method used by many Japanese manufacturers. It is a part of "Just in Time" manufacturing and helps to ensure that the amount of work in process is strictly controlled. In a Kanban system, each operation would have a designated spot to place its output, and would take their input only from the designated spot form the previous step.

For example, Operation 10 would work on a part and place it in a designated bin or rack, and then Operation 20 would remove the part from that location to begin work. If the designated location for output from any operation is occupied at the completion of the operation, it means that there is trouble on a later step, and work should halt until proper part flow is resumed. The operator of the first step should assist to operator on the later step to help overcome the delay.

Similarly, if the input location for an operation is empty at when the operation is supposed to begin, it means that there is a delay in an earlier step, and no work on the later steps should be done until the delay is resolved.

The key to the kanban system is that each storage location should only holds one part, or the number of parts in a shipping batch for the operations that output to or take input from a shipping operation. This helps to ensure that continuous flow is maintained, and allows for easy recognition and remedy of hold-ups in the manufacturing process.

Conclusions and Recommendations

The previous sections have explained a rigorous investigation of the current process, as well as plans that can be implemented to both improve the lead-time and reduce the number of parts in process in the production of the 4145T33G01 turbine casing. These recommendations have been adapted from the theory of lean manufacturing, and are diverse in application to the process as well as in difficulty to implement. Changeover to, and implementation of the recommendations cannot be expected overnight, and will require extreme participation by both management and shop workers to make it work effectively. However, it should be noted that these methods have a proven track record for working for other companies, and if implemented correctly will allow for increased production and revenue. The recommendations provided are several in number, and spread throughout many pages, so a summary is provided below. They are:

1) Consolidate out-of-cell and in-cell processes to improve flow and reduce unnecessary shipments and movement, per Appendix N.

2) Bring all out-of-cell operations into the cell that can be moved. This includes welding, inspections, bushing installation, and marking.

3) Implement the Continuous Flow Plan, as shown in Appendix N, to allow for production of 1 part per shift.

4) Rearrange machines in cell as per Figure 3 to improve part flow through cell and allow easier adaptation to Continuous Flow Plan.

5) Implement use of Fixture Ball Locks to reduce changeover and setup time between operations.

6) Mark all tools and holders to reduce chance of missing parts which could hold up production.

7) Adhere to plan of standard work.

8) Implement procedures for preventative maintenance of machines, to reduce downtime and production hold-ups.

9) Introduce Kanban storage system to ensure continuous flow is maintained.

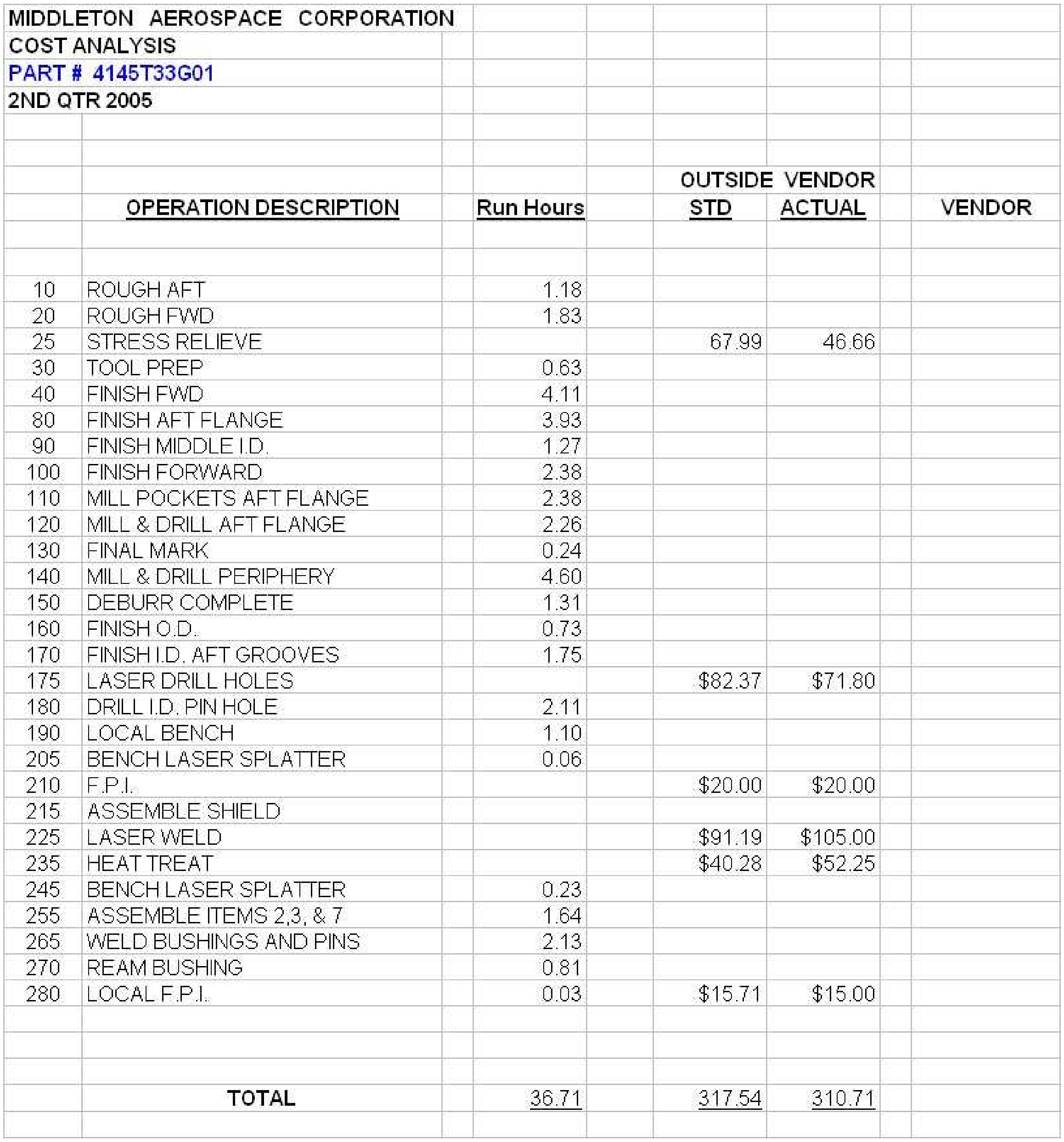
Through implementation of these methods, lead-time can be reduced to 31 days and Work in Process reduced by around 68%. Of course, these are theoretical and require cooperation by all employees to fully realize the benefits of use.

The principles of Lean Manufacturing can be highly beneficial to companies willing to take the steps to change their manufacturing methods and completely change what they previously believed was efficient manufacturing methods. Even in a company like Middleton Aerospace, where parts with high lead-times and low volume of production are manufactured, use of lean manufacturing can improve the process greatly.

References

1. Regan, Micheal D. and Slattery, Mark., *The Kaizen Revolution – How To Use Kaizen Events To Double Your Profits*, Holden Press, North Carolina, 2000
2. Kalakjian, Serope and Schmid, Steven R., *Manufacturing Engineering and Technology 4th Edition*, Prentice Hall, New Jersey, 2001
3. Jergens Inc.®. Webpage accessed on November 27, 2005 at http://www.jergensinc.com/
4. Lee, Quarterman. *Facilities and Workplace Design*, Engineering and Management Press, Norcross, GA, 1997

Appendix A: Cost Analysis Document

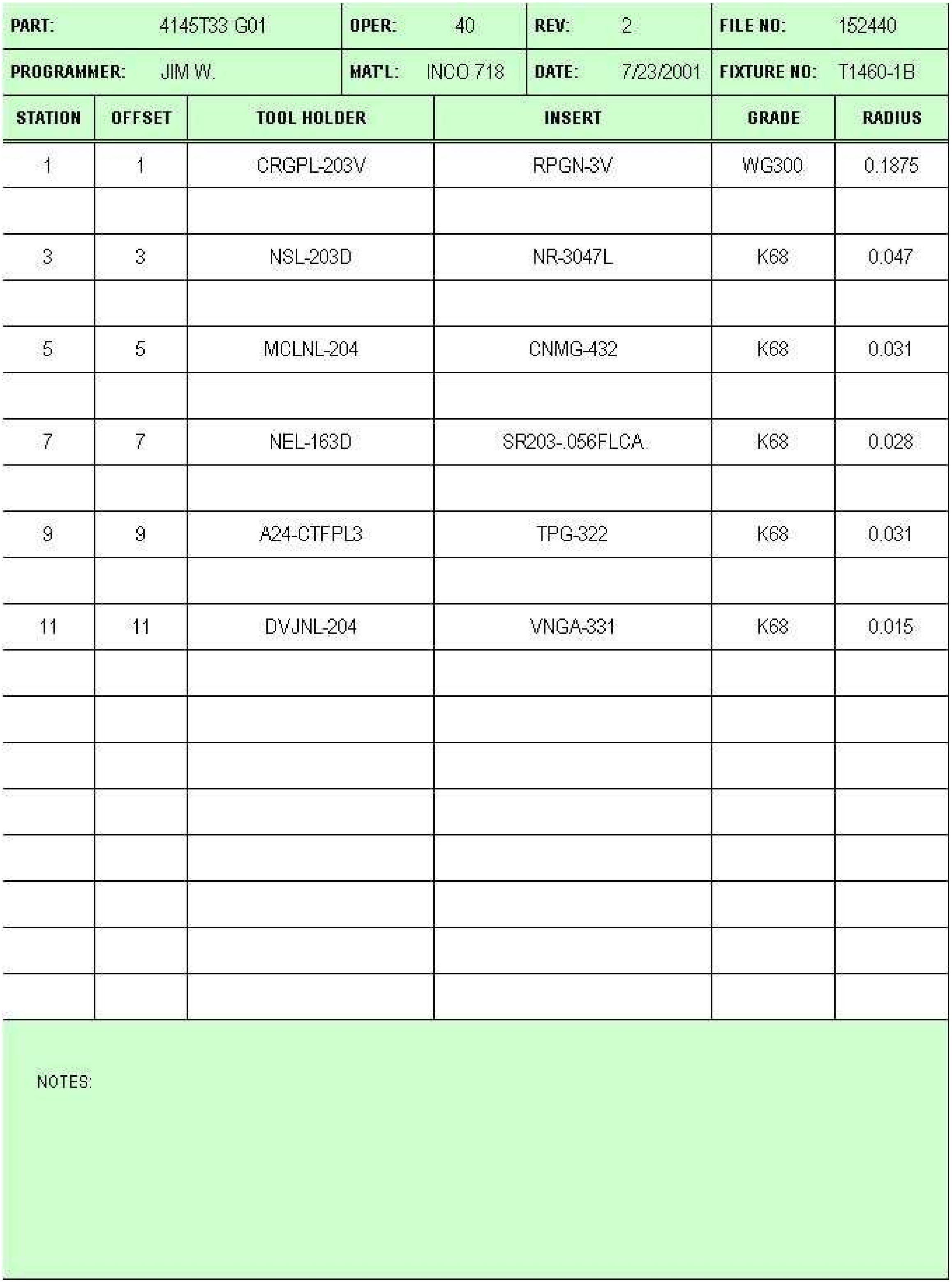


MIDDLETON AEROSPACE CORPORATION
COST ANALYSIS
PART # 4145T33G01
2ND QTR 2005

			OUTSIDE VENDOR		
	OPERATION DESCRIPTION	Run Hours	STD	ACTUAL	VENDOR
10	ROUGH AFT	1.18			
20	ROUGH FWD	1.83			
25	STRESS RELIEVE		67.99	46.66	
30	TOOL PREP	0.63			
40	FINISH FWD	4.11			
80	FINISH AFT FLANGE	3.93			
90	FINISH MIDDLE I.D.	1.27			
100	FINISH FORWARD	2.38			
110	MILL POCKETS AFT FLANGE	2.38			
120	MILL & DRILL AFT FLANGE	2.26			
130	FINAL MARK	0.24			
140	MILL & DRILL PERIPHERY	4.60			
150	DEBURR COMPLETE	1.31			
160	FINISH O.D.	0.73			
170	FINISH I.D. AFT GROOVES	1.75			
175	LASER DRILL HOLES		$82.37	$71.80	
180	DRILL I.D. PIN HOLE	2.11			
190	LOCAL BENCH	1.10			
205	BENCH LASER SPLATTER	0.06			
210	F.P.I.		$20.00	$20.00	
215	ASSEMBLE SHIELD				
225	LASER WELD		$91.19	$105.00	
235	HEAT TREAT		$40.28	$52.25	
245	BENCH LASER SPLATTER	0.23			
255	ASSEMBLE ITEMS 2,3, & 7	1.64			
265	WELD BUSHINGS AND PINS	2.13			
270	REAM BUSHING	0.81			
280	LOCAL F.P.I.	0.03	$15.71	$15.00	
	TOTAL	36.71	317.54	310.71	

Appendix B: Tool Sheets

Example of Lathe Tool Sheet



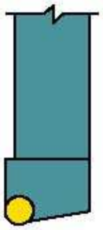
PART: 4145T33 G01
OPER: 40
REV: 2
FILE NO: 152440
PROGRAMMER: JIM W.
MAT'L: INCO 718
DATE: 7/23/2001
FIXTURE NO: T1460-1B

STATION	OFFSET	TOOL HOLDER	INSERT	GRADE	RADIUS
1	1	CRGPL-203V	RPGN-3V	WG300	0.1875
3	3	NSL-203D	NR-3047L	K68	0.047
5	5	MCLNL-204	CNMG-432	K68	0.031
7	7	NEL-163D	SR203-.056FLCA	K68	0.028
9	9	A24-CTFPL3	TPG-322	K68	0.031
11	11	DVJNL-204	VNGA-331	K68	0.015

NOTES:

STATION	OFFSET	BLOCK	EXTENSION
1	1	TURRET	

SET X = 1.5 **SET Z =**



COMMENTS:

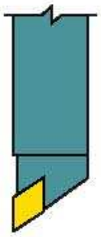
STATION	OFFSET	BLOCK	EXTENSION
3	3	TURRET	

SET X = 1.5 **SET Z =**

COMMENTS:

STATION	OFFSET	BLOCK	EXTENSION
5	5	TURRET	

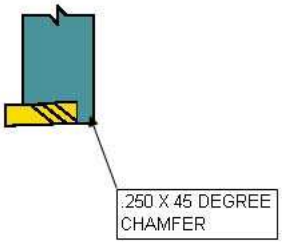
SET X = 1.5 **SET Z =**



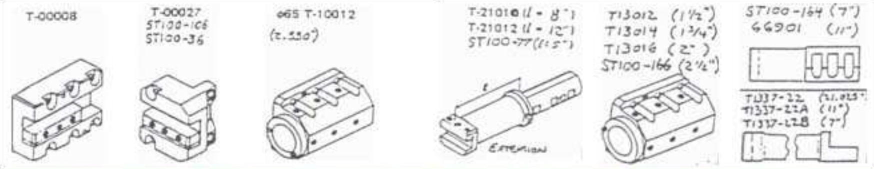
COMMENTS:

STATION	OFFSET	BLOCK	EXTENSION
7	7	TURRET	

SET X = 1.5 **SET Z =**

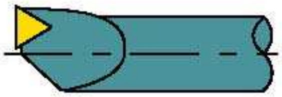


COMMENTS:



STATION	OFFSET	BLOCK	EXTENSION
9	9	T10057	

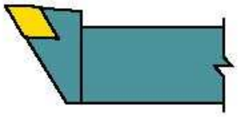
SET X = **SET Z =** 2.5



COMMENTS:

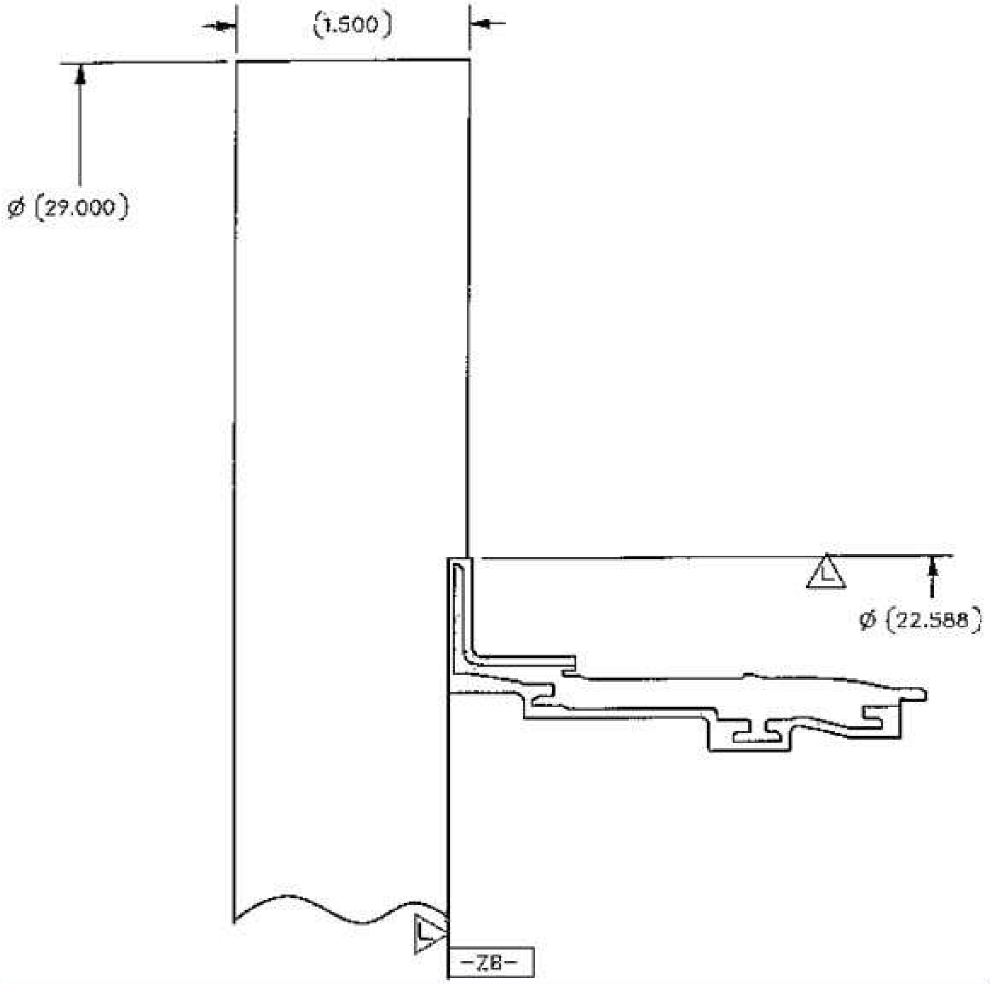
STATION	OFFSET	BLOCK	EXTENSION
11	11	T00093	

SET X = **SET Z =** 1.5



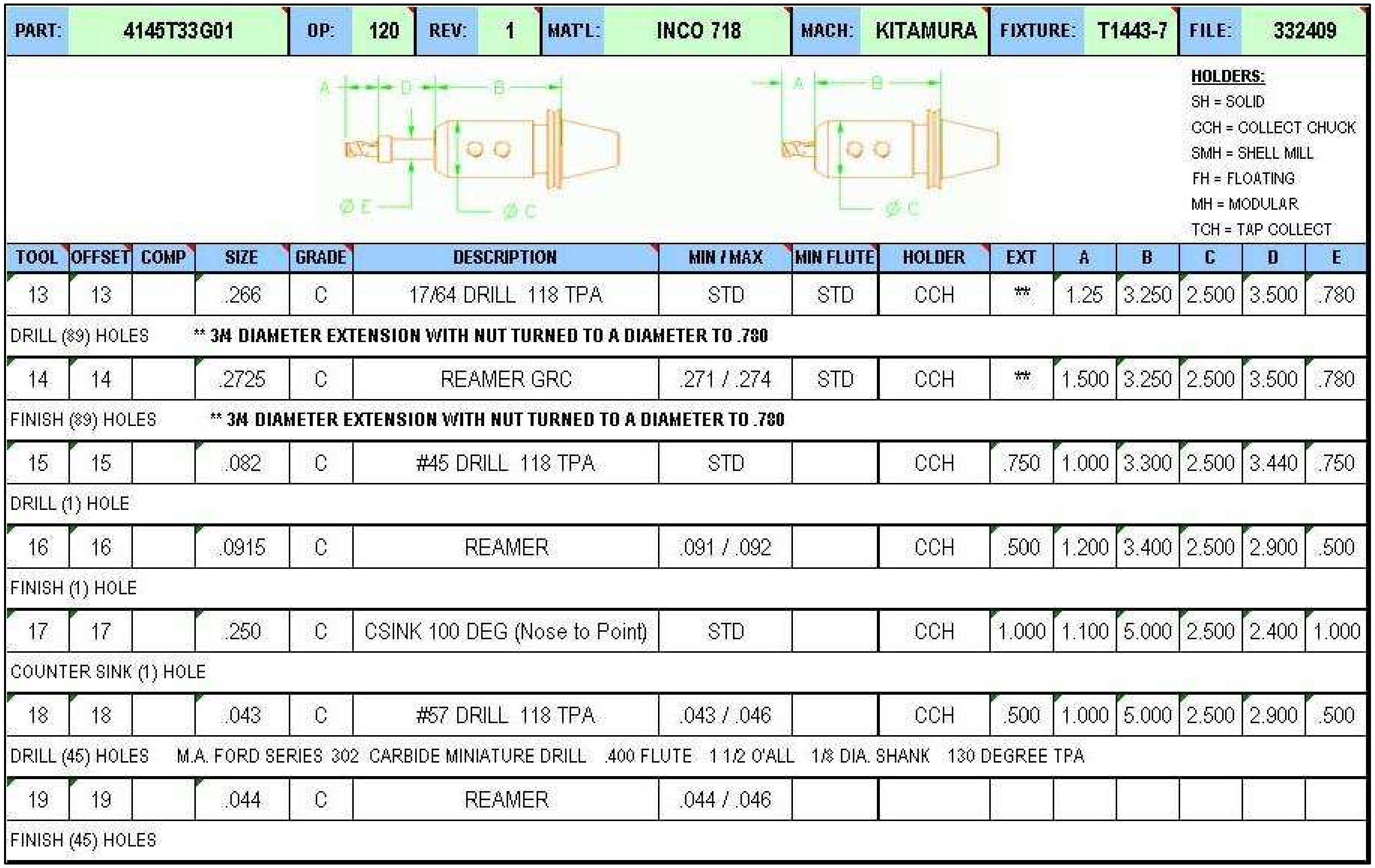
COMMENTS:

PART:	4145T33 G01	**OPER:**	40	**REV:**	2
CHUCK:	12 18 21 24	**FIXTURE NO:**	T1460-1B		
CHUCK PRESS:	XX LBS	**JAWS:**	HARD	SOFT	PIE
TAILSTOCK PRESS:	XX LBS				



NOTES:

Example of Mill Tool Sheet



PART:	4145T33G01	OP:	120	REV:	1	MAT'L:	INCO 718	MACH:	KITAMURA	FIXTURE:	T1443-7	FILE:	332409

HOLDERS:

SH = SOLID
CCH = COLLECT CHUCK
SMH = SHELL MILL
FH = FLOATING
MH = MODULAR
TCH = TAP COLLECT

TOOL	OFFSET	COMP	SIZE	GRADE	DESCRIPTION	MIN / MAX	MIN FLUTE	HOLDER	EXT	A	B	C	D	E
13	13		.266	C	17/64 DRILL 118 TPA	STD	STD	CCH	**	1.25	3.250	2.500	3.500	.780
DRILL (89) HOLES **** 3/4 DIAMETER EXTENSION WITH NUT TURNED TO A DIAMETER TO .780**														
14	14		.2725	C	REAMER GRC	.271 / .274	STD	CCH	**	1.500	3.250	2.500	3.500	.780
FINISH (89) HOLES **** 3/4 DIAMETER EXTENSION WITH NUT TURNED TO A DIAMETER TO .780**														
15	15		.082	C	#45 DRILL 118 TPA	STD		CCH	.750	1.000	3.300	2.500	3.440	.750
DRILL (1) HOLE														
16	16		.0915	C	REAMER	.091 / .092		CCH	.500	1.200	3.400	2.500	2.900	.500
FINISH (1) HOLE														
17	17		.250	C	CSINK 100 DEG (Nose to Point)	STD		CCH	1.000	1.100	5.000	2.500	2.400	1.000
COUNTER SINK (1) HOLE														
18	18		.043	C	#57 DRILL 118 TPA	.043 / .046		CCH	.500	1.000	5.000	2.500	2.900	.500
DRILL (45) HOLES M.A. FORD SERIES 302 CARBIDE MINIATURE DRILL .400 FLUTE 1 1/2 O'ALL 1/8 DIA. SHANK 130 DEGREE TPA														
19	19		.044	C	REAMER	.044 / .046								
FINISH (45) HOLES														

PART:	4145T33G01	OP:	120	REV:	1	MAT'L:	INCO 718	MACH:	KITAMURA	FIXTURE:	T1443-7	FILE:	332409

SETUP INSTRUCTIONS

1 Load the Fixture to the Rotary Table with the Fixture Flat at 6 O'Clock

2 Indicate the Fixture Locating Diameter w/in .001 TIR to Rotary Table CL.

3 Set up the following **Work Coordinate System** in the G55 Register

X0, Y0: Part CL

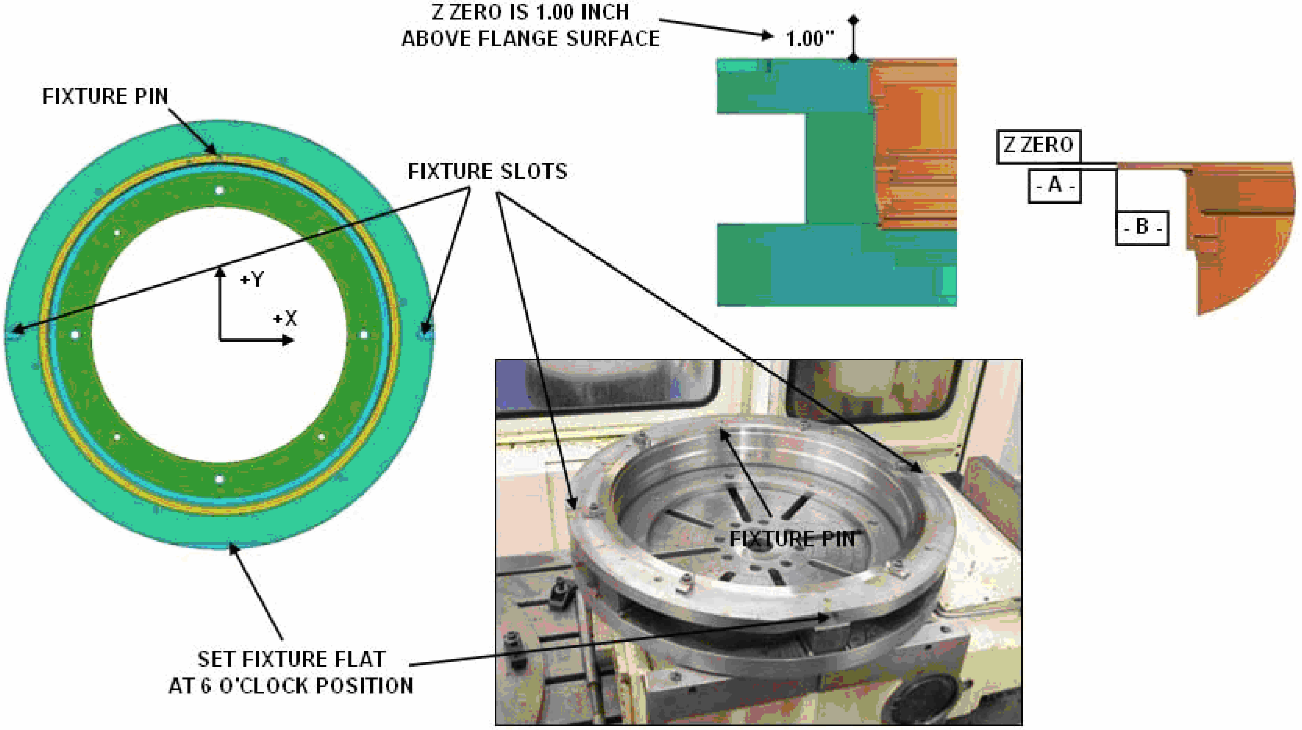
A0: With Fixture Flat at 6 O'Clock, Align Fixture Slots with X-Axis

Z0: Set to Zero ***(Note: Z0 is 1.00 inch above Part Flange Surface in the machining program)***

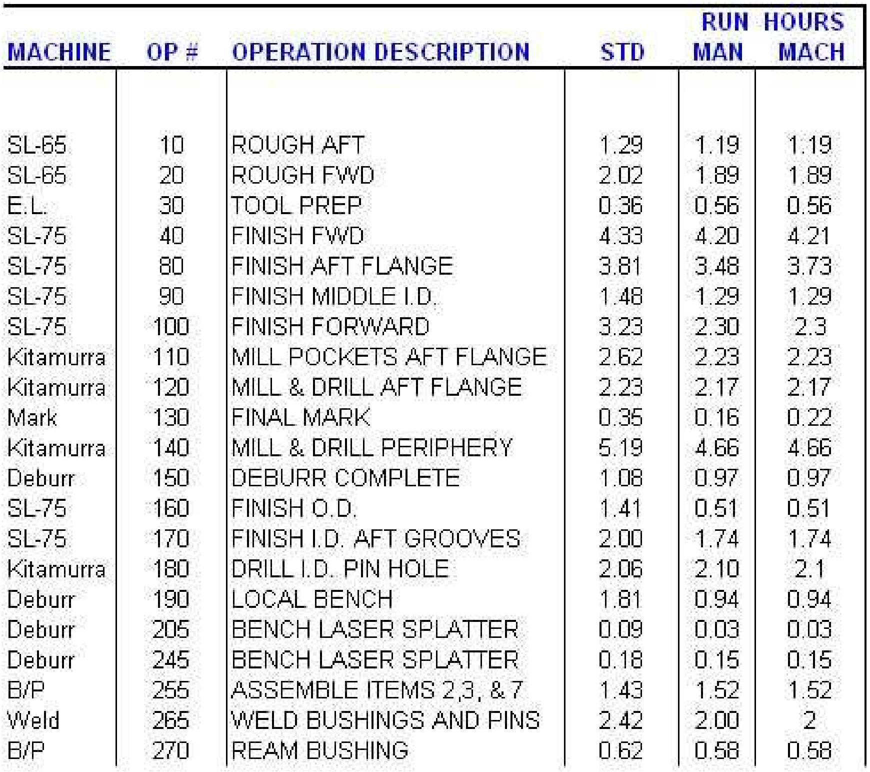
4 Load the part to the fixture. The Fixture Pin at 12 O'Clock goes through the -C- Hole. Tighten all clamps.

5 Start the machining program.

Note: Use CAUTION when loading/unloading the part to ensure Heatshield is not DAMAGED.

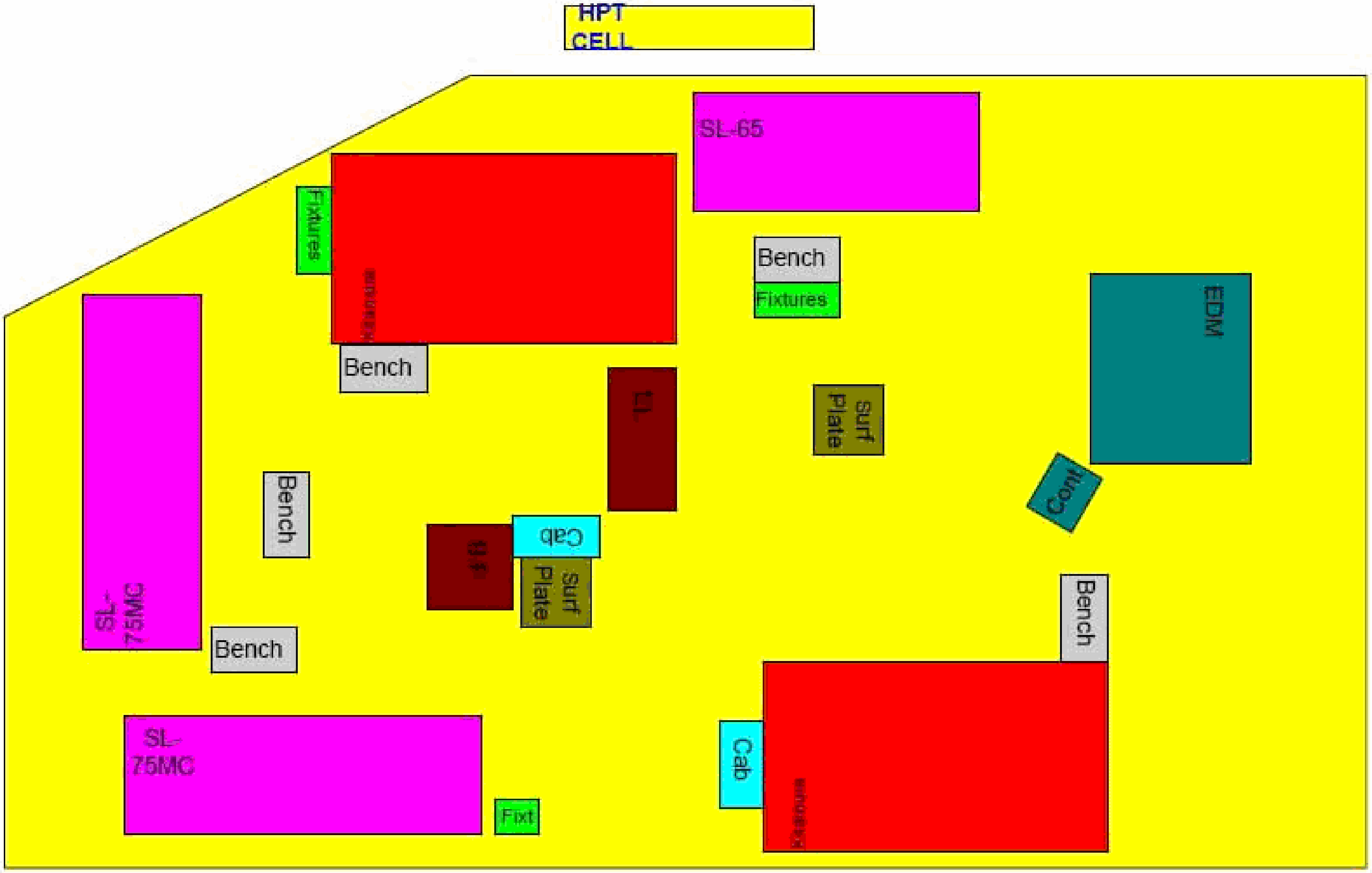


Appendix C: Time Analysis

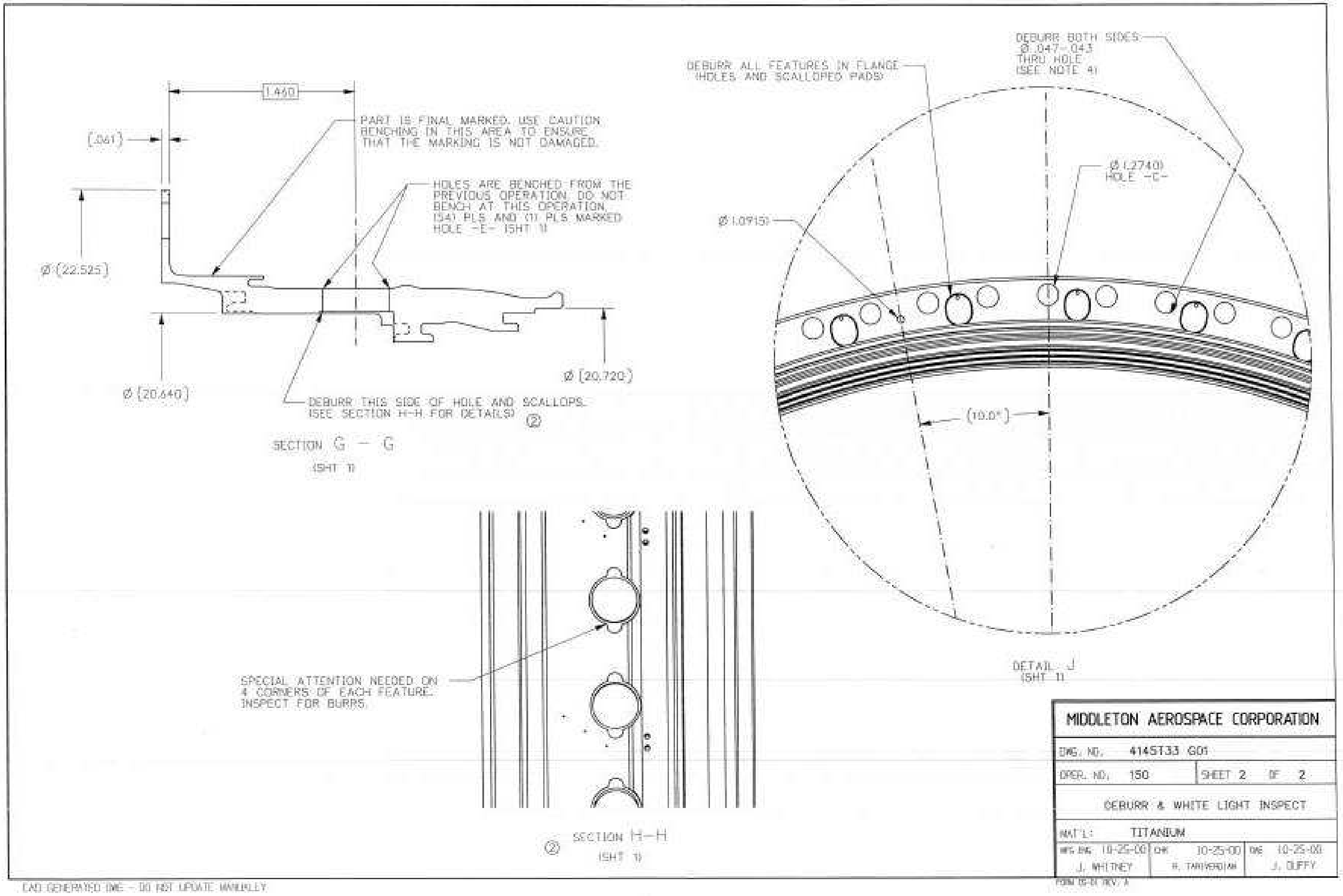


				RUN HOURS	
MACHINE	OP #	OPERATION DESCRIPTION	STD	MAN	MACH
SL-65	10	ROUGH AFT	1.29	1.19	1.19
SL-65	20	ROUGH FWD	2.02	1.89	1.89
E.L.	30	TOOL PREP	0.36	0.56	0.56
SL-75	40	FINISH FWD	4.33	4.20	4.21
SL-75	80	FINISH AFT FLANGE	3.81	3.48	3.73
SL-75	90	FINISH MIDDLE I.D.	1.48	1.29	1.29
SL-75	100	FINISH FORWARD	3.23	2.30	2.3
Kitamurra	110	MILL POCKETS AFT FLANGE	2.62	2.23	2.23
Kitamurra	120	MILL & DRILL AFT FLANGE	2.23	2.17	2.17
Mark	130	FINAL MARK	0.35	0.16	0.22
Kitamurra	140	MILL & DRILL PERIPHERY	5.19	4.66	4.66
Deburr	150	DEBURR COMPLETE	1.08	0.97	0.97
SL-75	160	FINISH O.D.	1.41	0.51	0.51
SL-75	170	FINISH I.D. AFT GROOVES	2.00	1.74	1.74
Kitamurra	180	DRILL I.D. PIN HOLE	2.06	2.10	2.1
Deburr	190	LOCAL BENCH	1.81	0.94	0.94
Deburr	205	BENCH LASER SPLATTER	0.09	0.03	0.03
Deburr	245	BENCH LASER SPLATTER	0.18	0.15	0.15
B/P	255	ASSEMBLE ITEMS 2,3, & 7	1.43	1.52	1.52
Weld	265	WELD BUSHINGS AND PINS	2.42	2.00	2
B/P	270	REAM BUSHING	0.62	0.58	0.58

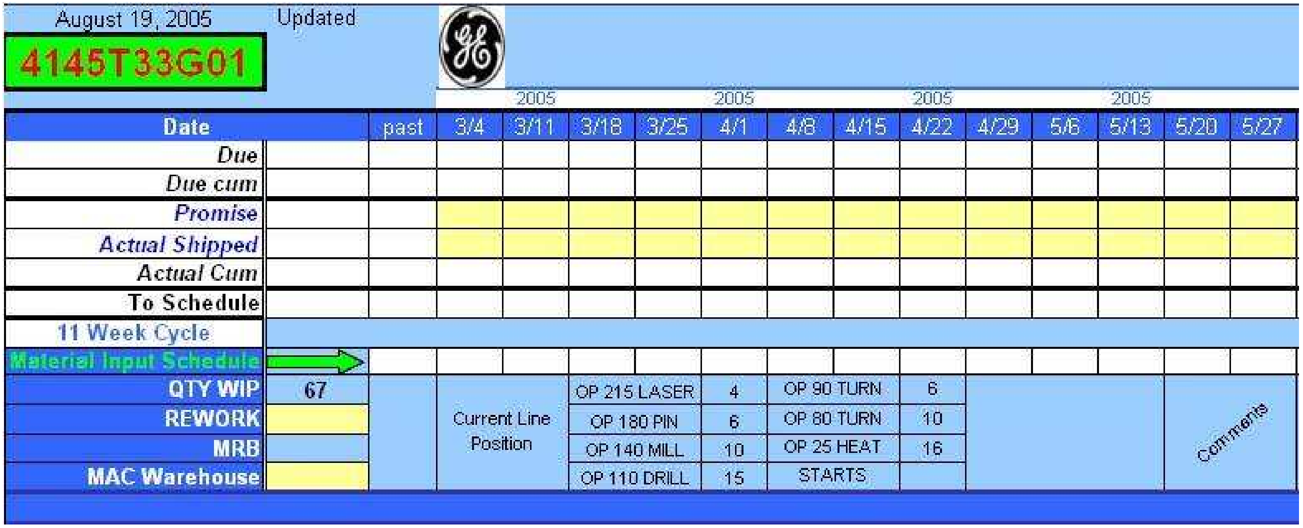
Appendix D: Cell Layout



Appendix E: Example of Technical Drawing



Appendix F: Greenline Sheets



August 19, 2005 Updated

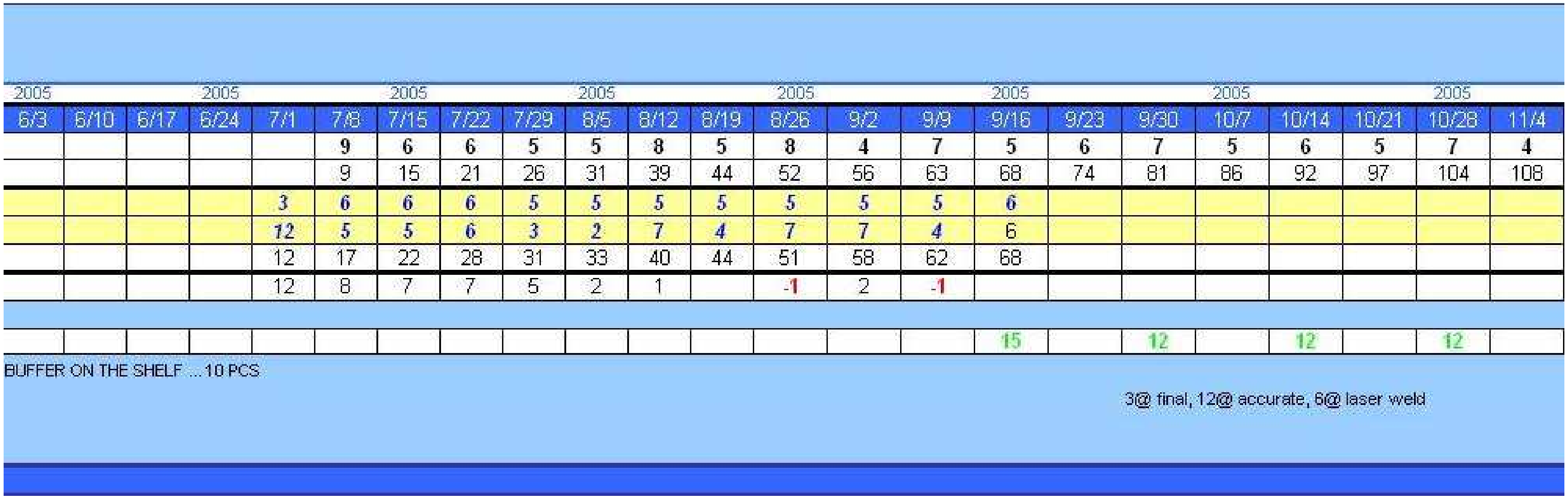
4145T33G01

2005 2005 2005 2005

Date		past	3/4	3/11	3/18	3/25	4/1	4/8	4/15	4/22	4/29	5/6	5/13	5/20	5/27
Due															
Due cum															
Promise															
Actual Shipped															
Actual Cum															
To Schedule															
11 Week Cycle															
Material Input Schedule															

QTY WIP	67	Current Line Position	OP 215 LASER	4	OP 90 TURN	6
REWORK			OP 180 PIN	6	OP 80 TURN	10
MRB			OP 140 MILL	10	OP 25 HEAT	16
MAC Warehouse			OP 110 DRILL	15	STARTS	

Comments



2005 2005 2005 2005 2005 2005 2005 2005

	6/3	6/10	6/17	6/24	7/1	7/8	7/15	7/22	7/29	8/5	8/12	8/19	8/26	9/2	9/9	9/16	9/23	9/30	10/7	10/14	10/21	10/28	11/4
Due						**9**	**6**	**6**	**5**	**5**	**8**	**5**	**8**	**4**	**7**	**5**	**6**	**7**	**5**	**6**	**5**	**7**	**4**
Due cum						9	15	21	26	31	39	44	52	56	63	68	74	81	86	92	97	104	108
Promise					***3***	***6***	***6***	***6***	***5***	***5***	***5***	***5***	***5***	***5***	***5***	***6***							
Actual Shipped					***12***	***5***	***5***	***6***	***3***	***2***	***7***	***4***	***7***	***7***	***4***	6							
Actual Cum					12	17	22	28	31	33	40	44	51	58	62	68							
To Schedule					12	8	7	7	5	2	1		-1	2	-1								
11 Week Cycle																							
Material Input Schedule																15		12		12		12	

BUFFER ON THE SHELF ...10 PCS

3@ final, 12@ accurate, 6@ laser weld

Material P.O.#
727007

Mat'l Commits

Updated

4145T33G01

GENERAL ELECTRIC COMPANY

Buffer =(MAC Warehouse)

	W/E			MATERIAL STARTS 11		OP 20 ROUGH 10		OP 40 FINISH TURN 9		OP 100 FINISH TURN 8		OP 120 MILL 7		175 LASER DRILL 5		235 HEAT TREAT 3		OP 280 FPI 1		SHIP		W/E
				SCHD	ACT	SCHD	ACT	SCHD	ACT	SCHD	ACT	SCHD	ACT	SCHD	ACT	SCHD	ACT	SCHD	ACT	SCHD	ACT	
	9/8			440	434	440		440		440		440		440		440		440		440		9/8
	9/1			440	434	440		440		440		440		440		440		440		433		9/1
	8/25			440	434	440		440		440		440		440		440		433		426		8/25
	8/18			440	434	440		440		440		440		440		440		426		418		8/18
	8/11			440	434	440		440		440		440		440		433		418		410		8/11
	8/4			440	434	440		440		440		440		440		426		410		402		8/4
	7/28			440	434	440		440		440		440		433		418		402		394		7/28
	7/21			440	434	440		440		440		440		426		410		394		386		7/21
	7/14			440	434	440		440		440		433		418		402		386		377		7/14
	7/7			440	434	440		440		433		426		410		394		377		370		7/7
	6/30			440	434	440		433		426		418		402		386		370		362		6/30
	6/23	20		440	434	433		426		418		410		394		377		362		355		6/23
	6/16			433	414	426		418		410		402		386		370		355		344		6/16
	6/9			426	414	418		410		402		394		377		362		344		335		6/9
	6/2	20		418	414	410		402		394		386		370		355		335		328		6/2
	5/26			410	394	402		394		386		377		362		344		328		320		5/26
	5/19			402	394	394		386		377		370		355		335		320		309		5/19
	5/12	20		394	394	386		377		370		362		344		328		309		301		5/12
	5/5			386	374	377		370		362		355		335		320		301		292		5/5
	4/28	20		377	374	370		362		355		344		328		309		292		286		4/28
	4/21			370	354	362		355		344		335		320		301		286		278		4/21
	4/14	15		362	354	355		344		335		328		309		292		278		271		4/14
	4/7			355	339	344		335		328		320		301		286		271		264		4/7
	3/31	15		344	339	335		328		320		309		292		278		264		257		3/31
	3/24			335	324	328		320		309		301		286		271		257		249		3/24
	3/17	15		328	324	320		309		301		292		278		264		249		244		3/17
	3/10			320	309	309		301		292		286		271		257		244		236		3/10
	3/3	15		309	309	301		292		286		278		264		249		236		231		3/3
	2/24			301	294	292		286		278		271		257		244		231		221		2/24
	2/17	12		292	294	286		278		271		264		249		236		221		211		2/17
	2/10			286	282	278		271		264		257		244		231		211		202		2/10
	2/3	15		278	282	271		264		257		249		236		221		202		196		2/3
	1/27			271	267	264		257		249		244		231		211		196		189		1/27
	1/20	15		264	267	257		249		244		236		221		202		189		181		1/20
	1/13			257	252	249		244		236		231		211		196		181		174		1/13
	1/6	15		249	252	244		236		231		221		202		189		174		164		1/6
	12/30			244	237	236		231		221		211		196		181		164		159		12/30
	12/23	15		236	237	231		221		211		202		189		174		159		155		12/23
	12/16			231	222	221		211		202		196		181		164		155		148		12/16
	12/9	15		221	222	211		202		196		189		174		159		148		143		12/9
	12/2			211	207	202		196		189		181		164		155		143		140		12/2
	11/25	15		202	207	196		189		181		174		159		148		140		136		11/25
	11/18			196	192	189		181		174		164		155		143		136		130		11/18
	11/11	12		189	192	181		174		164		159		148		140		130		123		11/11
	11/4			181	180	174		164		159		155		143		136		123		118		11/4
	10/28	12		174	180	164		159		155		148		140		130		118		114		10/28
	10/21			164	168	159		155		148		143		136		123		114		107		10/21
	10/14	12		159	168	155		148		143		140		130		118		107		102		10/14
	10/7			155	156	148		143		140		136		123		114		102		96		10/7
	9/30	12		148	156	143		140		136		130		118		107		96		91		9/30
	9/23			143	144	140		136		130		123		114		102		91		84		9/23
	9/16	15	T	140	144	136		130		123		118		107		96		84		78		9/16
	9/9		N/A	136	129	130	129	123	113	118	103	114	97	102	82	91	72	78	66	73	62	9/9
	9/2	15	R	130	129	123	114	118	99	114	99	107	92	96	72	84	60	73	60	66	58	9/2
	8/26		N/A	123	114	118	114	114	94	107	91	102	74	91	60	78	60	66	51	62	51	8/26
	8/19	10	R	118	114	114	94	107	94	102	91	96	74	84	60	73	60	62	48	54	44	8/19
	8/12		N/A	114	104	107	94	102	94	96	91	91	69	78	48	66	41	54	41	49	41	8/12
	8/5	10	R	107	104	102	94	96	94	91	73	84	60	73	41	62	41	49	31	41	31	8/5
	7/29		N/A	102	94	96	94	91	94	84	73	78	60	66	41	54	41	41	31	36	26	7/29
	7/22		N/A	96	94	91	94	84	80	78	65	73	55	62	37	49	29	36	27	31	23	7/22
	7/15		N/A	91	94	84	94	78	78	73	61	66	55	54	37	41	29	31	21	25	17	7/15
	7/8	15	R	84	94	78	79	73	77	66	61	62	48	49	30	36	22	25	14	19	12	7/8
	7/1		N/A	78	79	73	79	66	68	62	55	54	42	41	28	31	12	19	8	10	6	7/1
	6/24		N/A	73	79	66	79	62	63	54	49	49	41	36	23	25	8	10	8	10	6	6/24
	6/17		N/A	66	79	62	64	54	49	49	49	41	34	31	23	19	8	10	8	10	2	6/17
	6/10		R	62	79	54	64	49	49	41	49	36	34	25	23	10	8	10	8	10	2	6/10
	6/3		N/A	54	79	49	64	41	49	36	49	31	34	19	23	10	8	10	8	10	2	6/3
	5/27		N/A	49	79	41	64	36	49	31	49	25	34	10	23	10	8	10	8	10	2	5/27
	5/20		R	41	79	36	64	31	49	25	49	19	34	10	23	10	8	10	8	10	2	5/20
	5/13		R	36	79	31	64	25	49	19	49	10	34	10	23	10	8	10	8	10	2	5/13
	5/6		N/A	31	79	25	64	19	49	10	49	10	34	10	23	10	8	10	8	10	2	5/6
	4/29		R	25	79	19	64	10	49	10	49	10	34	10	23	10	8	10	8	10	2	4/29
	4/22		N/A	19	79	10	64	10	49	10	49	10	34	10	23	10	8	10	8	10	2	4/22
	4/15		N/A	10	79	10	64	10	49	10	49	10	34	10	23	10	8	10	8	10	2	4/15
	4/8		N/A	10	79	10	64	10	49	10	49	10	34	10	23	10	8	10	8	10	2	4/8
	4/1		N/A	10	79	10	64	10	49	10	49	10	34	10	23	10	8	10	8	10	2	4/1
	3/25		N/A	10	79	10	64	10	49	10	49	10	34	10	23	10	8	10	8	10	2	3/25
	3/18		N/A	10	79	10	64	10	49	10	49	10	34	10	23	10	8	10	8	10	2	3/18
	3/11		N/A	10	79	10	64	10	49	10	49	10	34	10	23	10	8	10	8	10	2	3/11
	3/4		N/A	10	79	10	64	10	49	10	49	10	34	10	23	10	8	10	8	10	2	3/4
	past			10	79	10	64	10	49	10	49	10	34	10		10	8	10	8	10	2	past

Supplier

Material Input Plan

MRB →

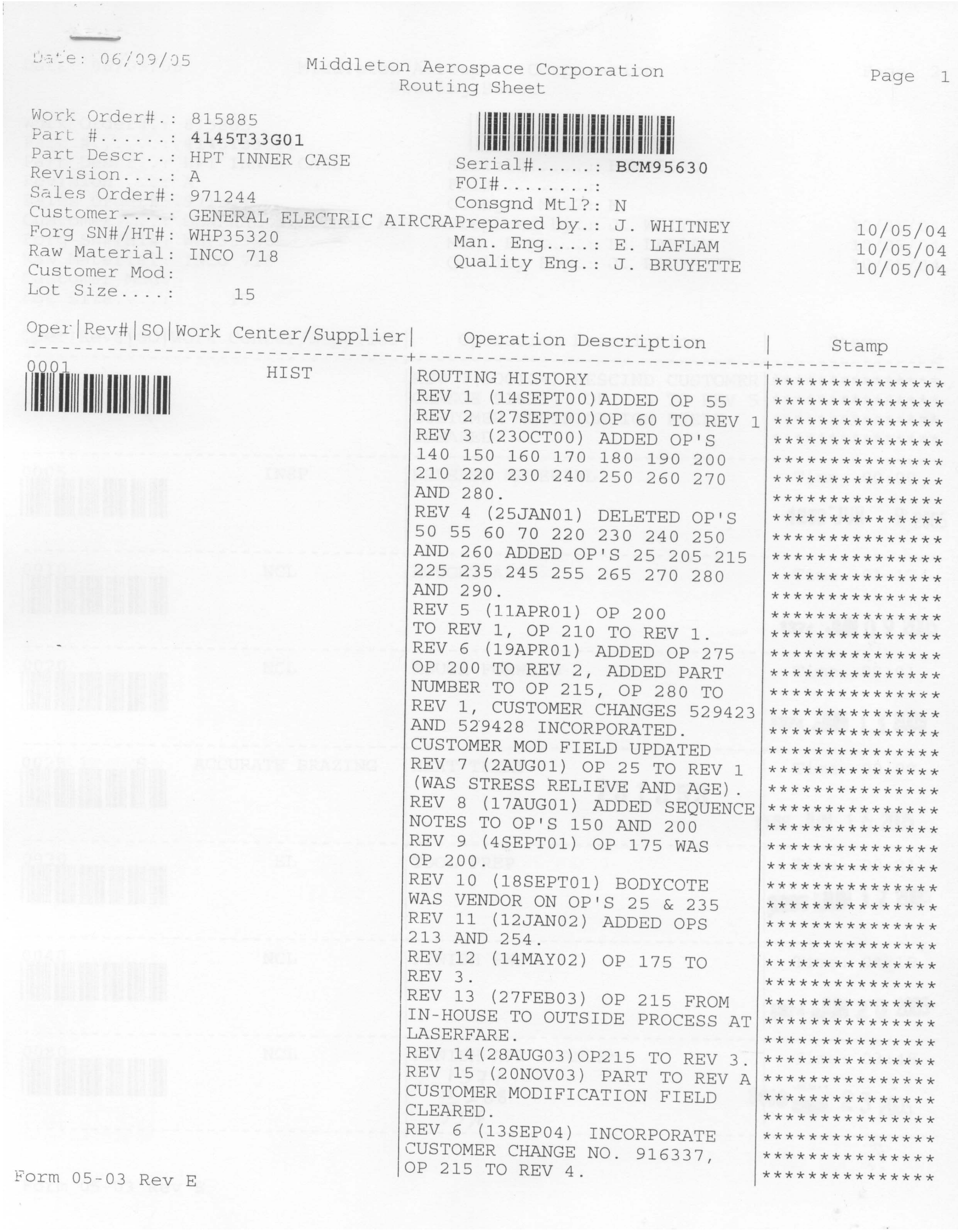
Input Delivery Schedule here by date Do not Accumulate

↓

1/0/00	7
9/8/06	7
9/1/06	7
8/25/06	8
8/18/06	8
8/11/06	8
8/4/06	8
7/28/06	8
7/21/06	9
7/14/06	7
7/7/06	8
6/30/06	7
6/23/06	11
6/16/06	9
6/9/06	7
6/2/06	8
5/26/06	11
5/19/06	8
5/12/06	9
5/5/06	6
4/28/06	8
4/21/06	7
4/14/06	7
4/7/06	7
3/31/06	8
3/24/06	5
3/17/06	8
3/10/06	5
3/3/06	10
2/24/06	10
2/17/06	9
2/10/06	6
2/3/06	7
1/27/06	8
1/20/06	7
1/13/06	10
1/6/06	5
12/30/05	4
12/23/05	7
12/16/05	5
12/9/05	3
12/2/05	4
11/25/05	6
11/18/05	7
11/11/05	5
11/4/05	4
10/28/05	7
10/21/05	5
10/14/05	6
10/7/05	5
9/30/05	7
9/23/05	6
9/16/05	5
9/9/05	7
9/2/05	4
8/26/05	8
8/19/05	5
8/12/05	8
8/5/05	5
7/29/05	5
7/22/05	6
7/15/05	6
7/8/05	9
7/1/05	
6/24/05	
6/17/05	
6/10/05	
6/3/05	
5/27/05	
5/20/05	
5/13/05	
5/6/05	
4/29/05	
4/22/05	
4/15/05	
4/8/05	
4/1/05	
3/25/05	
3/18/05	
3/11/05	
3/4/05	
past	
Buffer	10

LINE OF BALANCE WORKSHEET

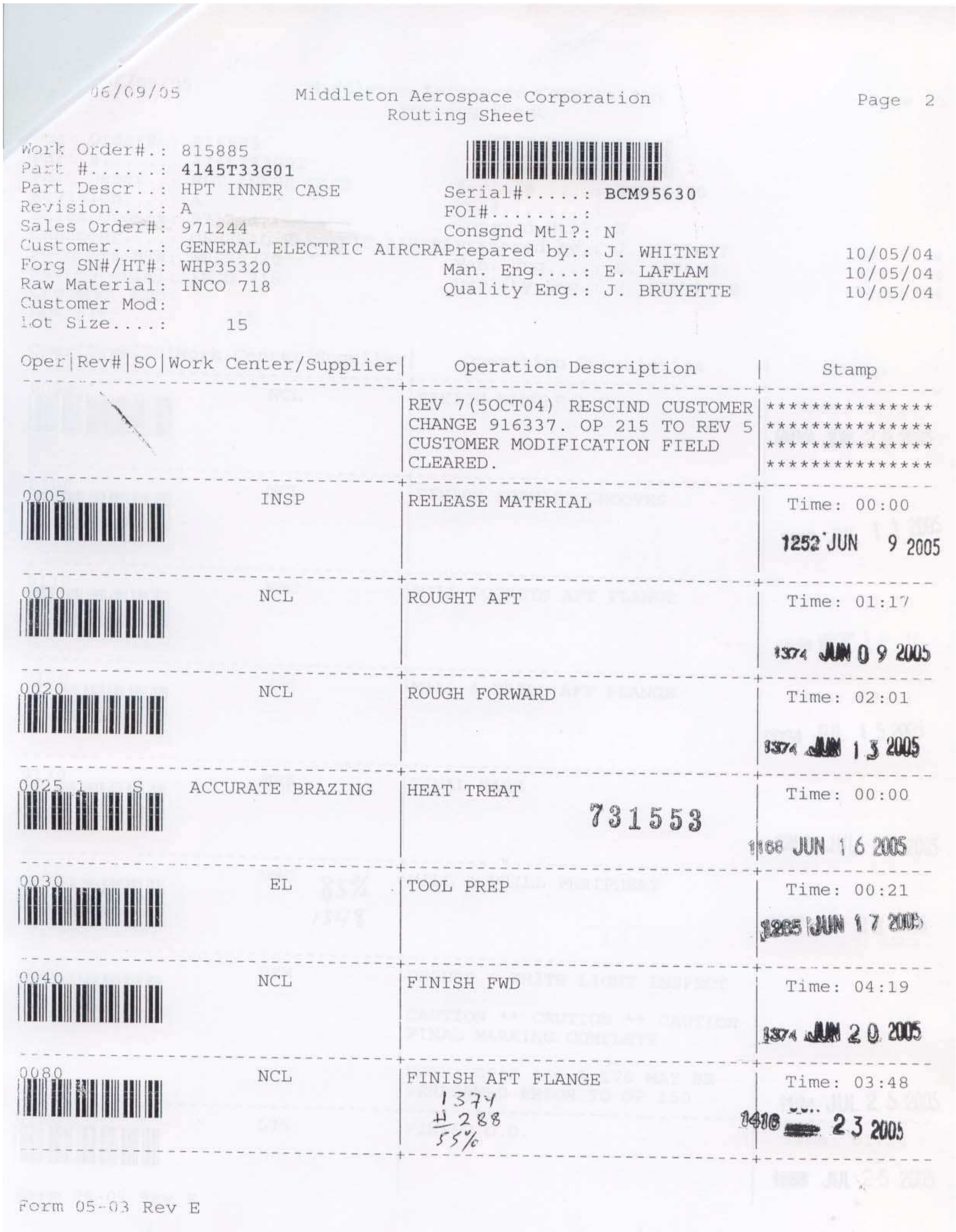
Appendix G: Routing Sheet Example



```
Date: 06/09/05          Middleton Aerospace Corporation                    Page  1
                                Routing Sheet

Work Order#.: 815885
Part #......: 4145T33G01
Part Descr..: HPT INNER CASE
Revision....: A                         Serial#.....: BCM95630
Sales Order#: 971244                    FOI#........:
Customer....: GENERAL ELECTRIC AIRCRAPrepared by.: J. WHITNEY           10/05/04
Forg SN#/HT#: WHP35320                  Man. Eng....: E. LAFLAM         10/05/04
Raw Material: INCO 718                  Quality Eng.: J. BRUYETTE       10/05/04
Customer Mod:
Lot Size....:      15

Oper|Rev#|SO|Work Center/Supplier|     Operation Description      |    Stamp
---------------------------------+--------------------------------+---------------
0001                HIST         |ROUTING HISTORY                 |***************
                                 |REV 1 (14SEPT00)ADDED OP 55     |***************
                                 |REV 2 (27SEPT00)OP 60 TO REV 1  |***************
                                 |REV 3 (23OCT00) ADDED OP'S      |***************
                                 |140 150 160 170 180 190 200     |***************
                                 |210 220 230 240 250 260 270     |***************
                                 |AND 280.                        |***************
                                 |REV 4 (25JAN01) DELETED OP'S    |***************
                                 |50 55 60 70 220 230 240 250     |***************
                                 |AND 260 ADDED OP'S 25 205 215   |***************
                                 |225 235 245 255 265 270 280     |***************
                                 |AND 290.                        |***************
                                 |REV 5 (11APR01) OP 200          |***************
                                 |TO REV 1, OP 210 TO REV 1.      |***************
                                 |REV 6 (19APR01) ADDED OP 275    |***************
                                 |OP 200 TO REV 2, ADDED PART     |***************
                                 |NUMBER TO OP 215, OP 280 TO     |***************
                                 |REV 1, CUSTOMER CHANGES 529423  |***************
                                 |AND 529428 INCORPORATED.        |***************
                                 |CUSTOMER MOD FIELD UPDATED      |***************
                                 |REV 7 (2AUG01) OP 25 TO REV 1   |***************
                                 |(WAS STRESS RELIEVE AND AGE).   |***************
                                 |REV 8 (17AUG01) ADDED SEQUENCE  |***************
                                 |NOTES TO OP'S 150 AND 200       |***************
                                 |REV 9 (4SEPT01) OP 175 WAS      |***************
                                 |OP 200.                         |***************
                                 |REV 10 (18SEPT01) BODYCOTE      |***************
                                 |WAS VENDOR ON OP'S 25 & 235     |***************
                                 |REV 11 (12JAN02) ADDED OPS      |***************
                                 |213 AND 254.                    |***************
                                 |REV 12 (14MAY02) OP 175 TO      |***************
                                 |REV 3.                          |***************
                                 |REV 13 (27FEB03) OP 215 FROM    |***************
                                 |IN-HOUSE TO OUTSIDE PROCESS AT  |***************
                                 |LASERFARE.                      |***************
                                 |REV 14(28AUG03)OP215 TO REV 3.  |***************
                                 |REV 15 (20NOV03) PART TO REV A  |***************
                                 |CUSTOMER MODIFICATION FIELD     |***************
                                 |CLEARED.                        |***************
                                 |REV 6 (13SEP04) INCORPORATE     |***************
                                 |CUSTOMER CHANGE NO. 916337,     |***************
Form 05-03 Rev E                 |OP 215 TO REV 4.                |***************
```



06/09/05 Middleton Aerospace Corporation Page 2
Routing Sheet

Work Order#.: 815885
Part #.......: 4145T33G01
Part Descr..: HPT INNER CASE
Revision....: A
Sales Order#: 971244
Customer....: GENERAL ELECTRIC AIRCRA
Forg SN#/HT#: WHP35320
Raw Material: INCO 718
Customer Mod:
Lot Size....: 15

Serial#.....: BCM95630
FOI#........:
Consgnd Mtl?: N
Prepared by.: J. WHITNEY 10/05/04
Man. Eng....: E. LAFLAM 10/05/04
Quality Eng.: J. BRUYETTE 10/05/04

Oper|Rev#|SO|Work Center/Supplier	Operation Description	Stamp
	REV 7(5OCT04) RESCIND CUSTOMER CHANGE 916337. OP 215 TO REV 5 CUSTOMER MODIFICATION FIELD CLEARED.	*************** *************** *************** ***************
0005 INSP	RELEASE MATERIAL	Time: 00:00 1252 JUN 9 2005
0010 NCL	ROUGHT AFT	Time: 01:17 1374 JUN 09 2005
0020 NCL	ROUGH FORWARD	Time: 02:01 1374 JUN 13 2005
0025 1 S ACCURATE BRAZING	HEAT TREAT 731553	Time: 00:00 1168 JUN 16 2005
0030 EL	TOOL PREP	Time: 00:21 1265 JUN 17 2005
0040 NCL	FINISH FWD	Time: 04:19 1374 JUN 20 2005
0080 NCL	FINISH AFT FLANGE 1374 H 288 55%	Time: 03:48 1416 [illegible] 23 2005

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6/09/05

Middleton Aerospace Corporation
Routing Sheet

Page 3

Work Order#.: 815885
Part #......: 4145T33G01
Part Descr..: HPT INNER CASE
Revision....: A
Sales Order#: 971244
Customer....: GENERAL ELECTRIC AIRCRA
Forg SN#/HT#: WHP35320
Raw Material: INCO 718
Customer Mod:
Lot Size....: 15

Serial#.....: BCM95630
FOI#........:
Consgnd Mtl?: N
Prepared by.: J. WHITNEY 10/05/04
Man. Eng....: E. LAFLAM 10/05/04
Quality Eng.: J. BRUYETTE 10/05/04

Oper	Rev#	SO	Work Center/Supplier	Operation Description	Stamp
0090			NCL	FINISH MIDDLE I.D.	Time: 01:28 0919 JUN 29 2005
0100			NCL	FINISH FORWARD GROOVES	Time: 03:13 1362 JUL 11 2005
0110			VMC	MILL POCKETS AFT FLANGE	Time: 02:37 1349 JUL 14 [illegible]
0120			VMC	MILL & DRILL AFT FLANGE	Time: 02:13 0034 JUL 15 2005
0130			MRK	FINAL MARK	Time: 00:21 1267 JUL 18 2005
0140			VMC 85% 1348	MILL & DRILL PERIPHERY	Time: 05:11 1349 JUl 22 2005
0150			BEN	DEBURR & WHITE LIGHT INSPECT CAUTION ** CAUTION ** CAUTION FINAL MARKING COMPLETE NOTE: OP'S 160 & 170 MAY BE PERFORMED PRIOR TO OP 150	Time: 01:04 1194 JUL 25 2005
0160			L75	FINISH O.D.	Time: 01:24 1258 JUL 25 2005

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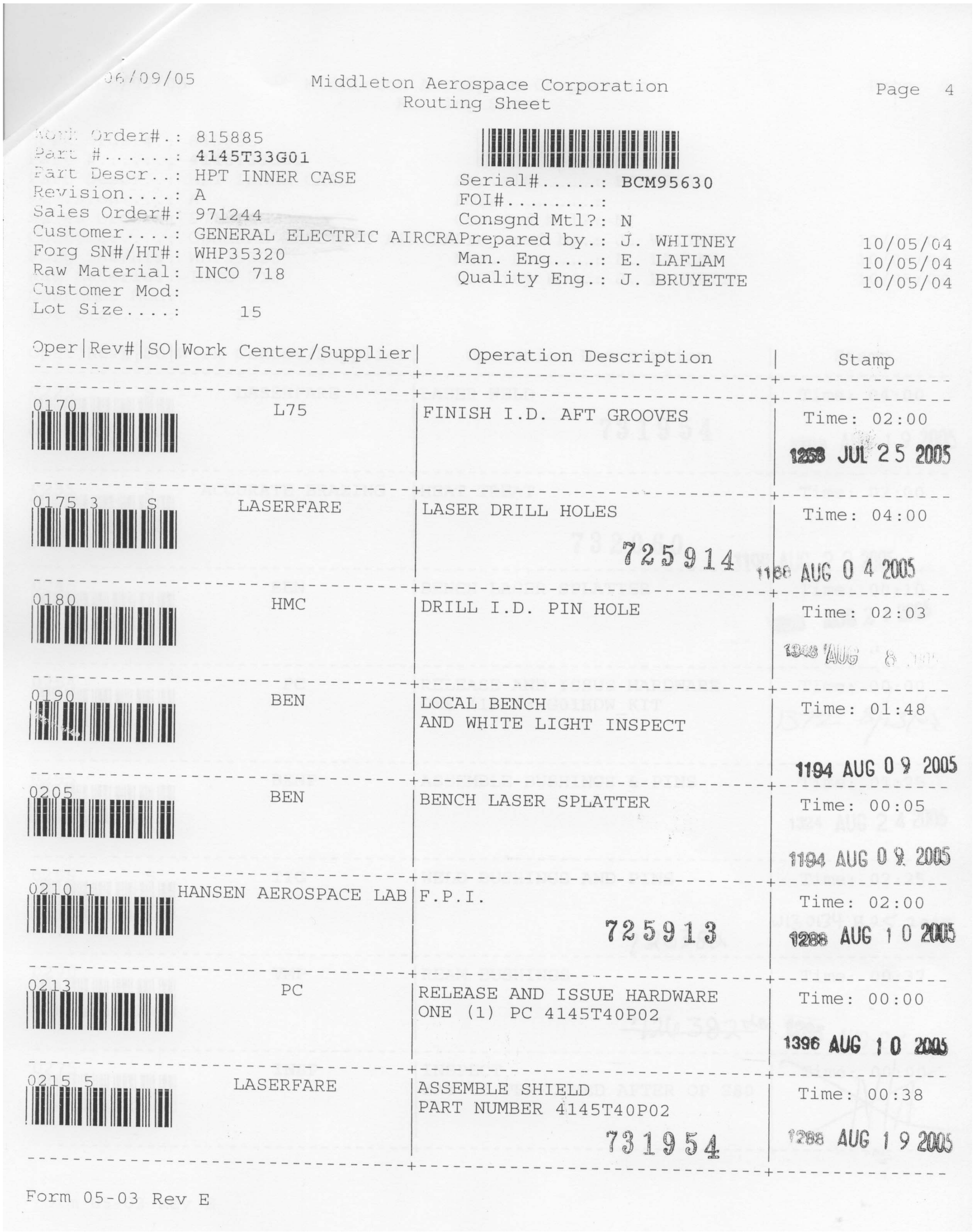

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Routing Sheet

Work Order#.: 815885
Part #......: 4145T33G01
Part Descr..: HPT INNER CASE
Revision....: A
Sales Order#: 971244
Customer....: GENERAL ELECTRIC AIRCRA
Forg SN#/HT#: WHP35320
Raw Material: INCO 718
Customer Mod:
Lot Size....: 15

Serial#.....: BCM95630
FOI#........:
Consgnd Mtl?: N
Prepared by.: J. WHITNEY 10/05/04
Man. Eng....: E. LAFLAM 10/05/04
Quality Eng.: J. BRUYETTE 10/05/04

Oper	Rev#	SO	Work Center/Supplier	Operation Description	Stamp
0170			L75	FINISH I.D. AFT GROOVES	Time: 02:00 1258 JUL 25 2005
0175	3	S	LASERFARE	LASER DRILL HOLES 725914	Time: 04:00 1168 AUG 04 2005
0180			HMC	DRILL I.D. PIN HOLE	Time: 02:03 1348 AUG 8 [illegible]
0190			BEN	LOCAL BENCH AND WHITE LIGHT INSPECT	Time: 01:48 1194 AUG 09 2005
0205			BEN	BENCH LASER SPLATTER	Time: 00:05 1194 AUG 09 2005
0210	1		HANSEN AEROSPACE LAB	F.P.I. 725913	Time: 02:00 1288 AUG 10 2005
0213			PC	RELEASE AND ISSUE HARDWARE ONE (1) PC 4145T40P02	Time: 00:00 1396 AUG 10 2005
0215	5		LASERFARE	ASSEMBLE SHIELD PART NUMBER 4145T40P02 731954	Time: 00:38 1288 AUG 19 2005

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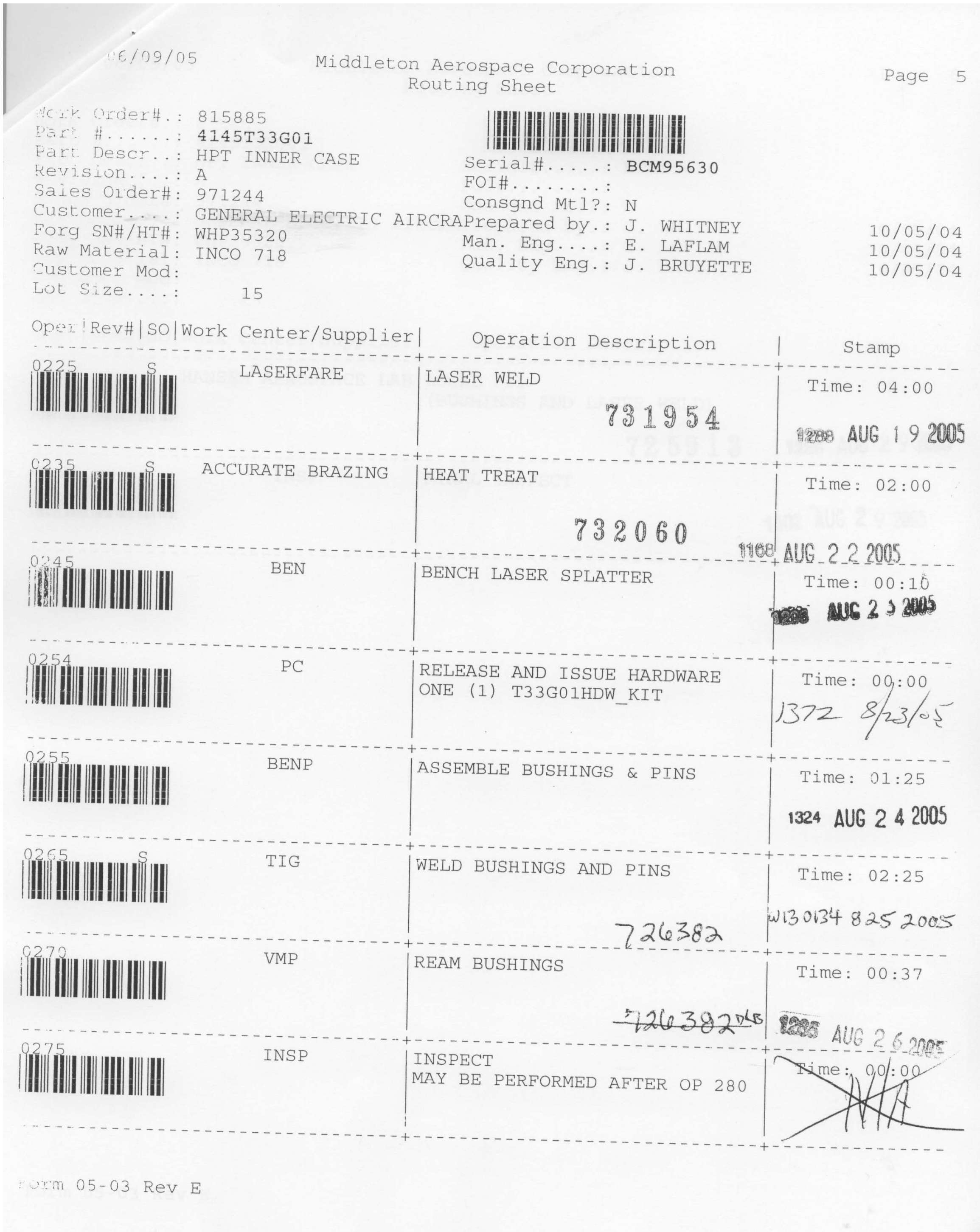

06/09/05

Middleton Aerospace Corporation
Routing Sheet

Page 5

Work Order#.: 815885
Part #......: 4145T33G01
Part Descr..: HPT INNER CASE
Revision....: A
Sales Order#: 971244
Customer....: GENERAL ELECTRIC AIRCRA
Forg SN#/HT#: WHP35320
Raw Material: INCO 718
Customer Mod:
Lot Size....: 15

Serial#.....: BCM95630
FOI#........:
Consgnd Mtl?: N
Prepared by.: J. WHITNEY 10/05/04
Man. Eng....: E. LAFLAM 10/05/04
Quality Eng.: J. BRUYETTE 10/05/04

Oper	Rev#	SO	Work Center/Supplier	Operation Description	Stamp
0225		S	LASERFARE	LASER WELD 731954	Time: 04:00 1288 AUG 1 9 2005
0235		S	ACCURATE BRAZING	HEAT TREAT 732060	Time: 02:00 1108 AUG 2 2 2005
0245			BEN	BENCH LASER SPLATTER	Time: 00:10 1288 AUG 2 3 2005
0254			PC	RELEASE AND ISSUE HARDWARE ONE (1) T33G01HDW_KIT	Time: 00:00 1372 8/23/05
0255			BENP	ASSEMBLE BUSHINGS & PINS	Time: 01:25 1324 AUG 2 4 2005
0265		S	TIG	WELD BUSHINGS AND PINS 726382	Time: 02:25 W130134 825 2005
0270			VMP	REAM BUSHINGS ~~726382~~ DLB	Time: 00:37 1285 AUG 2 6 2005
0275			INSP	INSPECT MAY BE PERFORMED AFTER OP 280	~~Time: 00:00~~ N/A

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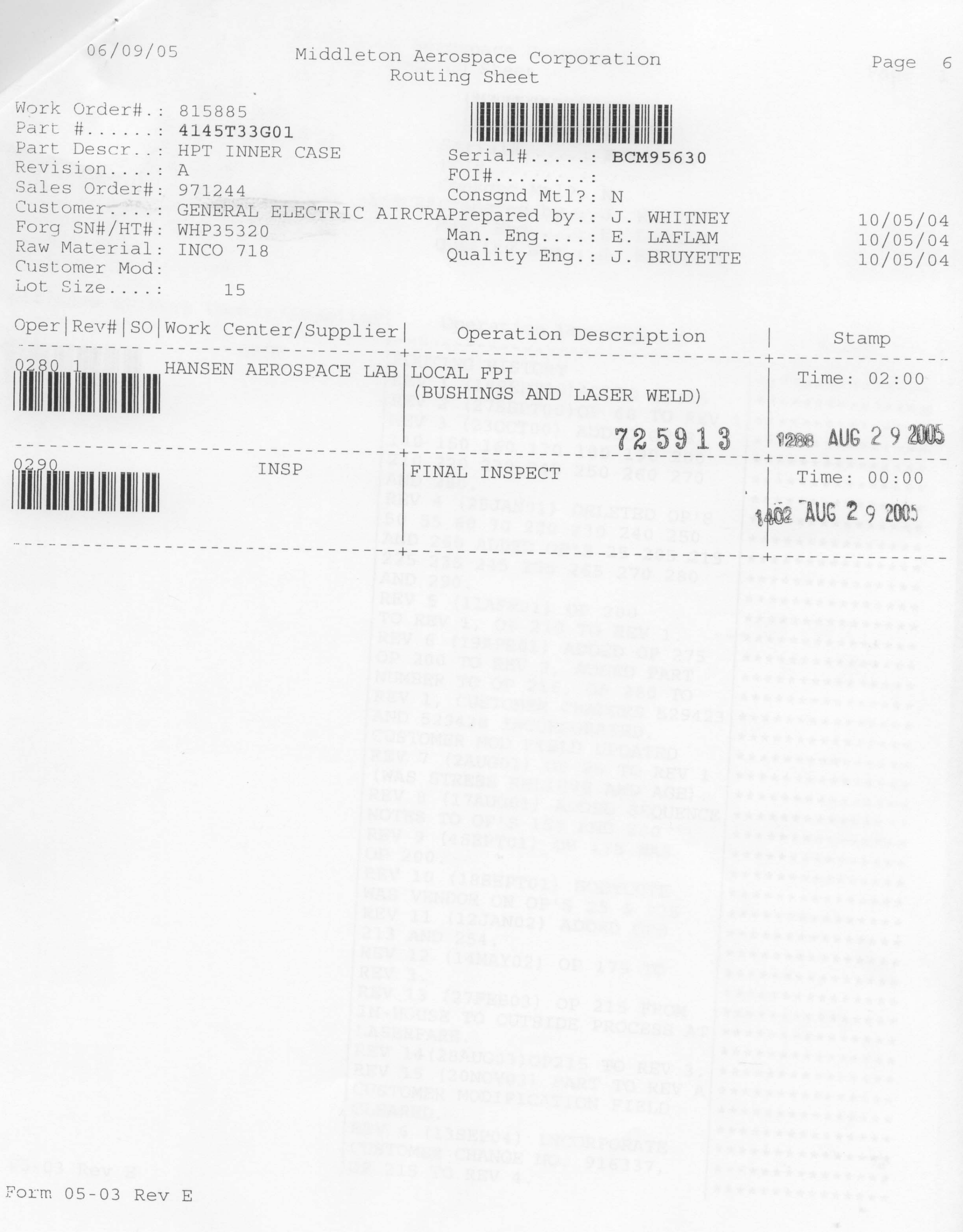

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Middleton Aerospace Corporation
Routing Sheet

Page 6

Work Order#.: 815885
Part #......: **4145T33G01**
Part Descr..: HPT INNER CASE
Revision....: A
Sales Order#: 971244
Customer....: GENERAL ELECTRIC AIRCRA
Forg SN#/HT#: WHP35320
Raw Material: INCO 718
Customer Mod:
Lot Size....: 15

Serial#.....: **BCM95630**
FOI#........:
Consgnd Mtl?: N
Prepared by.: J. WHITNEY 10/05/04
Man. Eng....: E. LAFLAM 10/05/04
Quality Eng.: J. BRUYETTE 10/05/04

Oper	Rev#	SO	Work Center/Supplier	Operation Description	Stamp
0280	1		HANSEN AEROSPACE LAB	LOCAL FPI (BUSHINGS AND LASER WELD) 725913	Time: 02:00 1288 AUG 29 2005
0290			INSP	FINAL INSPECT	Time: 00:00 1402 AUG 29 2005

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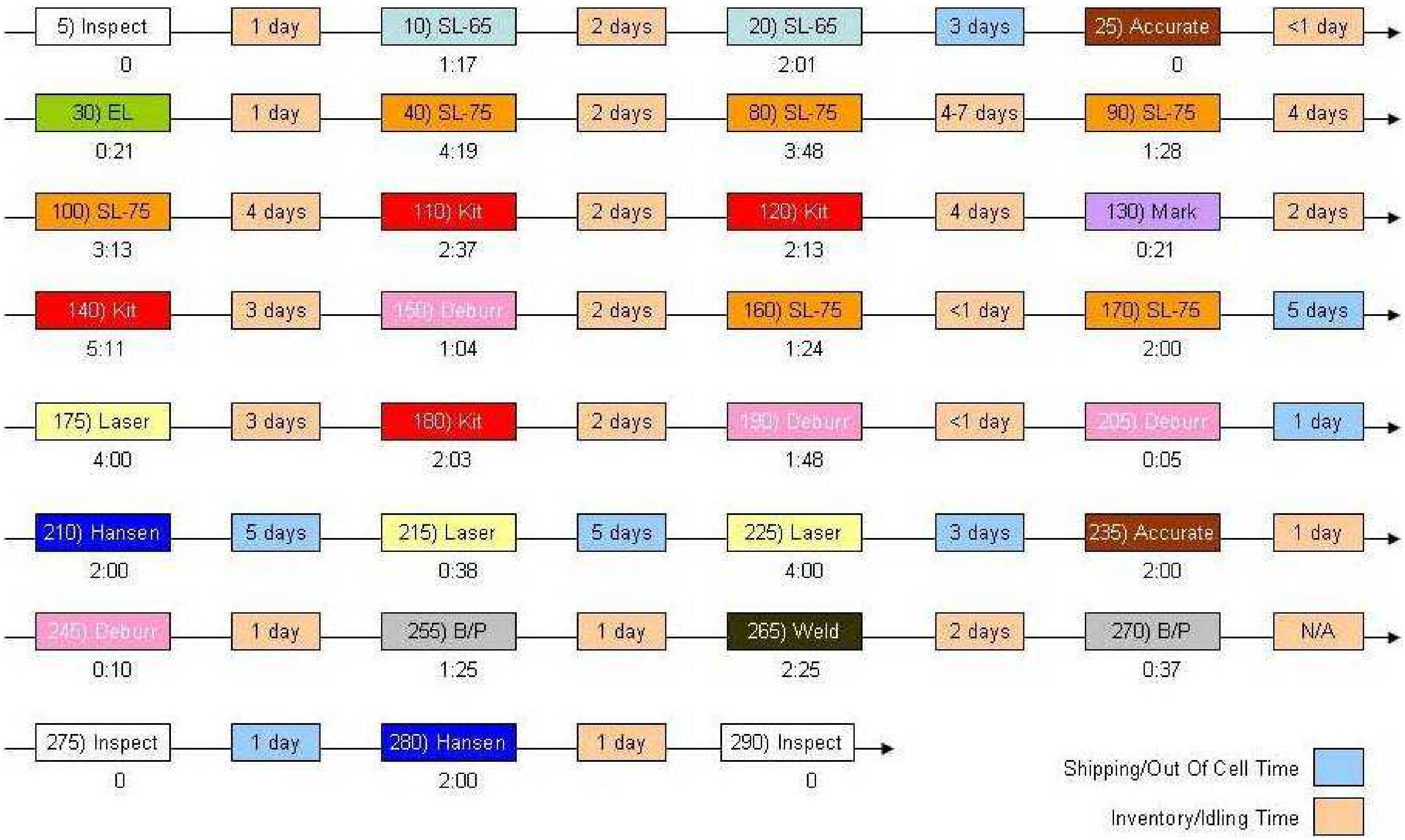
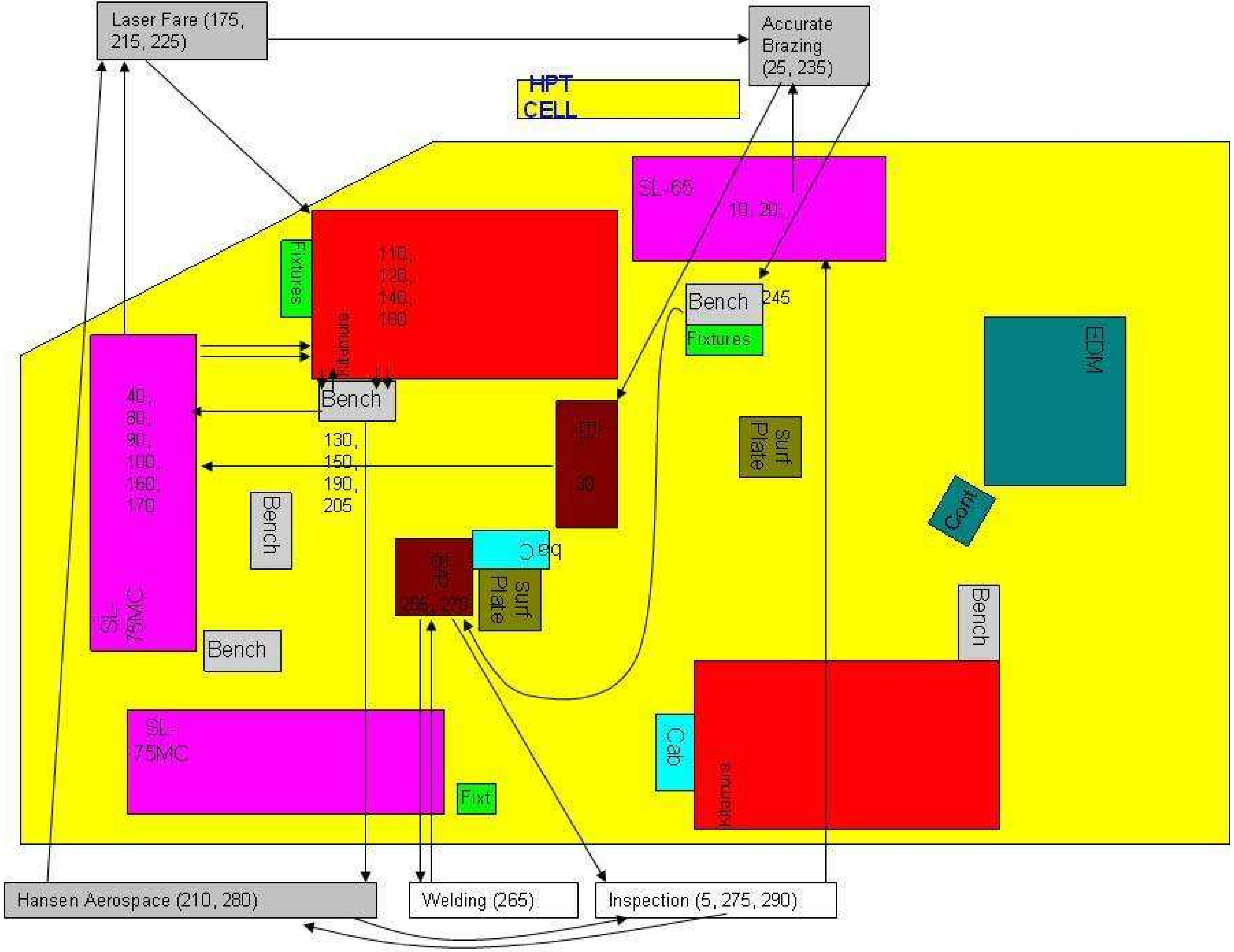
Appendix H: Routing Sheet Analysis

Work Center	Machine	Fixture	Op #	Operation	Stamp Time	BCM 95625	BCM 95629	BCM 95631	BCM 95632
INSP			5	Release Mat’l	0	6/9	6/9	6/9	6/9
NCL	SL-65	PIE JAWS	10	Rough Aft	1:17	6/10	6/10	6/9	6/10
NCL	SL-65	PIE JAWS	20	Rough Fwd	2:01	6/13	6/13	6/13	6/13
Accurate			25	Heat Treat	0	6/16	6/16	6/16	6/16
EL	EL		30	Tool Prep	0:21	6/16	6/16	6/17	6/17
NCL	SL-75	T1460-1B	40	Finish Fwd	4:19	6/17	6/ 22	6/ 17	6/ 17
NCL	SL-75	T1599-3	80	Finish Aft	3:48	6/ 24	6/ 24	6/ 20	6/ 21
NCL	SL-75	T1545-1	90	Finish Middle ID	1:28	6/ 28	6/29	6/28	6/28
NCL	SL-75	T1545-1	100	Finish Fwd Groove	3:13	7/8	6/30	7/8	7/8
VMC	Kitamurra	T1443-7	110	Mill Pockets Aft Flange	2:37	7/12	7/12	7/13	7/13
VMC	Kitamurra	T1443-7	120	Mill & Drill Aft Flange	2:13	7/15	7/14	7/14	7/14
MRK	Mark		130	Final Mark	0:21	7/18	7/18	7/18	7/18
VMC	Kitamurra	T1443-7	140	Mill & Drill Periphery	5:11	7/25	7/19	7/21	7/18
BEN	Deburr		150	Deburr and White Light Insp.	1:04	7/26	7/26	7/25	7/25
L75	SL-75	T1593-1	160	Finish OD	1:24	7/28	7/28	7/26	7/27
L75	SL-75	T1593-1	170	Finish ID Aft Groove	2:00	7/28	7/28	7/26	7/27
Laser			175	Laser Drill Holes	4:00	8/4	8/4	8/4	8/4
HMC	Kitamurra	T1545-4	180	Drill ID Pin Hole	02:03	8/6	8/6	8/8	8/8
BEN	Deburr		190	Local Bench and White Light Insp.	1:48	8/9	8/9	8/9	8/9
BEN	Deburr		205	Bench Laser Splatter	0:05	8/9	8/9	8/9	8/9
Hansen			210	FPI	2:00	8/10	8/10	8/10	8/10
PC			213	Release and Issue Hardware	0	8/10	8/10	8/10	8/10
Laser			215	Assemble Shield	0:38	8/19	8/19	8/19	8/19
Laser			225	Laser Weld	4:00	8/19	8/19	8/19	8/19
Accurate			235	Heat Treat	2:00	8/22	8/22	8/22	8/22
BEN	Deburr		245	Bench Laser Splatter	0:10	8/23	8/23	8/23	8/23
PC			254	Release & Issue Hardware	0	8/23	8/23	8/23	8/23
BENP	B/P		255	Assemble Bushings & Pins	1:25	8/24	8/24	8/23	8/23
TIG	Weld		265	Weld Bushings & Pins	2:25	8/26	8/26	8/24	8/24
VMP	B/P		270	Ream Bushings	0:37	8/29	8/29	8/25	8/25
INSP			275	Inspect	0	NA	NA	NA	NA
Hansen			280	FPI	2:00	8/30	8/30	8/25	8/25
INSP			290	Inspect	0	8/30	8/30	8/26	8/26

Appendix I: Process Flowchart



Appendix J: Spaghetti Chart



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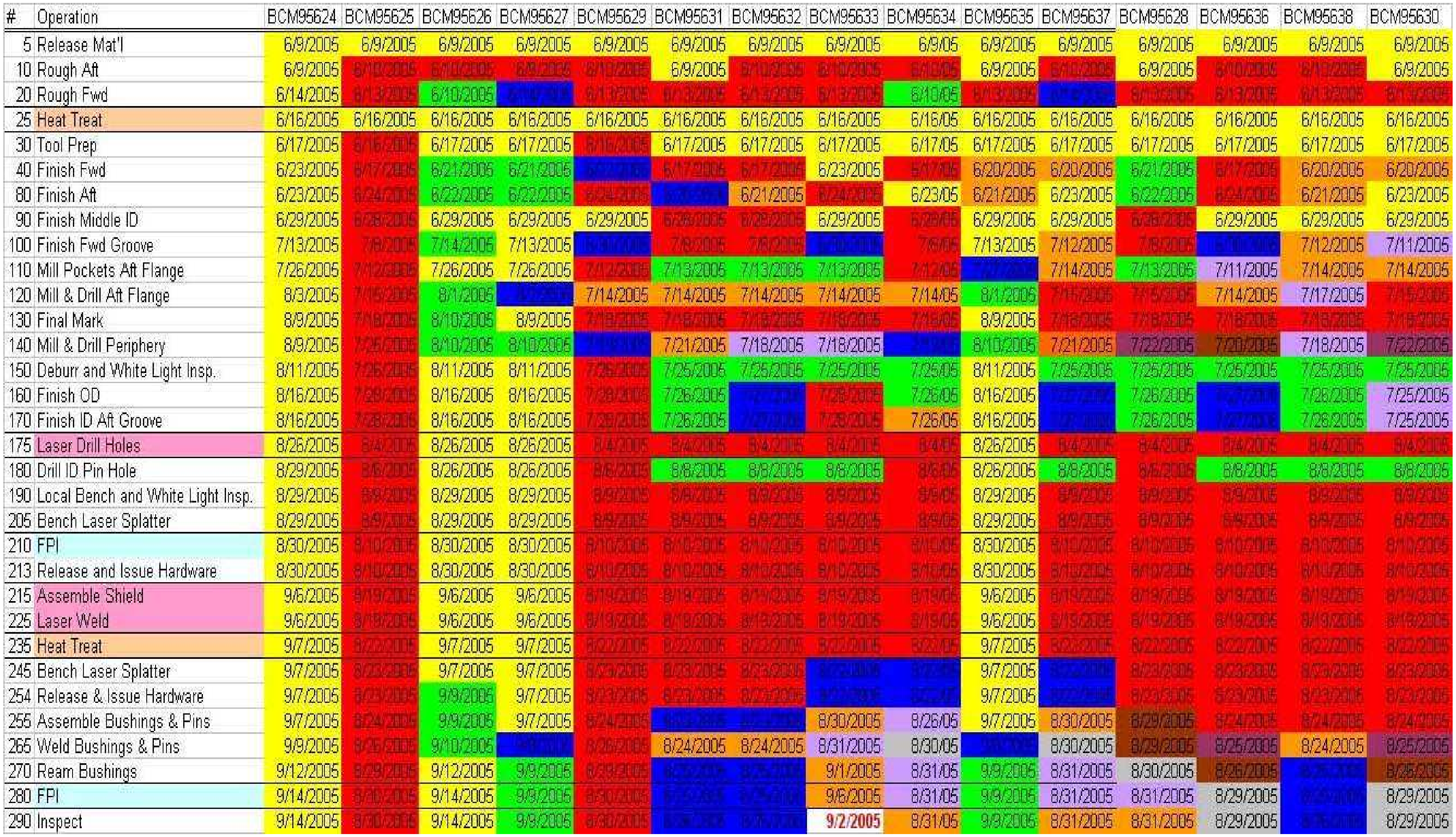
Appendix K: Total Batch Analysis

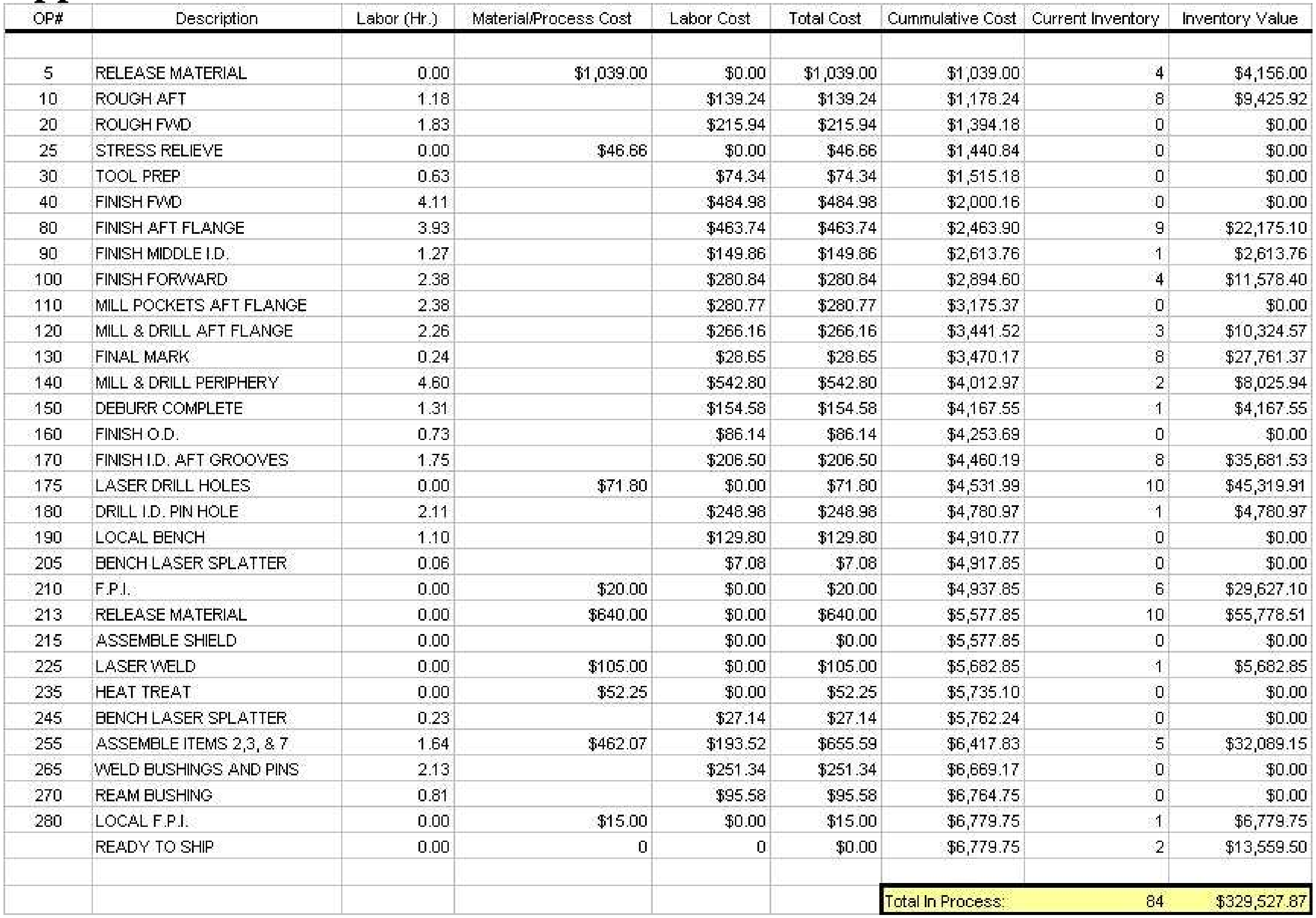


#	Operation	BCM95624	BCM95625	BCM95626	BCM95627	BCM95629	BCM95631	BCM95632	BCM95633	BCM95634	BCM95635	BCM95637	BCM95628	BCM95636	BCM95638	BCM95630
5	Release Mat'l	6/9/2005	6/9/2005	6/9/2005	6/9/2005	6/9/2005	6/9/2005	6/9/2005	6/9/2005	6/9/05	6/9/2005	6/9/2005	6/9/2005	6/9/2005	6/9/2005	6/9/2005
10	Rough Aft	6/9/2005	6/10/2005	6/10/2005	6/9/2005	6/10/2005	6/9/2005	6/10/2005	6/10/2005	6/10/05	6/9/2005	6/10/2005	6/9/2005	6/10/2005	6/10/2005	6/9/2005
20	Rough Fwd	6/14/2005	6/13/2005	6/10/2005	[illegible]	6/13/2005	6/13/2005	6/13/2005	6/13/2005	6/10/05	6/13/2005	[illegible]	6/13/2005	6/13/2005	6/13/2005	6/13/2005
25	Heat Treat	6/16/2005	6/16/2005	6/16/2005	6/16/2005	6/16/2005	6/16/2005	6/16/2005	6/16/2005	6/16/05	6/16/2005	6/16/2005	6/16/2005	6/16/2005	6/16/2005	6/16/2005
30	Tool Prep	6/17/2005	6/16/2005	6/17/2005	6/17/2005	6/16/2005	6/17/2005	6/17/2005	6/17/2005	6/17/05	6/17/2005	6/17/2005	6/17/2005	6/17/2005	6/17/2005	6/17/2005
40	Finish Fwd	6/23/2005	6/17/2005	6/21/2005	6/21/2005	[illegible]	6/17/2005	6/17/2005	6/23/2005	6/17/05	6/20/2005	6/20/2005	6/21/2005	6/17/2005	6/20/2005	6/20/2005
80	Finish Aft	6/23/2005	6/24/2005	6/22/2005	6/22/2005	6/24/2005	[illegible]	6/21/2005	6/24/2005	6/23/05	6/21/2005	6/23/2005	6/22/2005	6/24/2005	6/21/2005	6/23/2005
90	Finish Middle ID	6/29/2005	6/28/2005	6/29/2005	6/29/2005	6/29/2005	6/28/2005	6/28/2005	6/29/2005	6/28/05	6/29/2005	6/29/2005	6/28/2005	6/29/2005	6/29/2005	6/29/2005
100	Finish Fwd Groove	7/13/2005	7/8/2005	7/14/2005	7/13/2005	[illegible]	7/8/2005	7/8/2005	[illegible]	7/6/05	7/13/2005	7/12/2005	7/8/2005	[illegible]	7/12/2005	7/11/2005
110	Mill Pockets Aft Flange	7/26/2005	7/12/2005	7/26/2005	7/26/2005	7/12/2005	7/13/2005	7/13/2005	7/13/2005	7/12/05	[illegible]	7/14/2005	7/13/2005	7/11/2005	7/14/2005	7/14/2005
120	Mill & Drill Aft Flange	8/3/2005	7/15/2005	8/1/2005	[illegible]	7/14/2005	7/14/2005	7/14/2005	7/14/2005	7/14/05	8/1/2005	7/15/2005	7/15/2005	7/14/2005	7/17/2005	7/15/2005
130	Final Mark	8/9/2005	7/18/2005	8/10/2005	8/9/2005	7/18/2005	7/18/2005	7/18/2005	7/18/2005	7/18/05	8/9/2005	7/18/2005	7/18/2005	7/18/2005	7/18/2005	7/18/2005
140	Mill & Drill Periphery	8/9/2005	7/25/2005	8/10/2005	8/10/2005	[illegible]	7/21/2005	7/18/2005	7/18/2005	[illegible]	8/10/2005	7/21/2005	7/22/2005	7/20/2005	7/18/2005	7/22/2005
150	Deburr and White Light Insp.	8/11/2005	7/26/2005	8/11/2005	8/11/2005	7/26/2005	7/25/2005	7/25/2005	7/25/2005	7/25/05	8/11/2005	7/25/2005	7/25/2005	7/25/2005	7/25/2005	7/25/2005
160	Finish OD	8/16/2005	7/28/2005	8/16/2005	8/16/2005	7/28/2005	7/26/2005	[illegible]	7/28/2005	7/26/05	8/16/2005	[illegible]	7/26/2005	[illegible]	7/28/2005	7/25/2005
170	Finish ID Aft Groove	8/16/2005	7/28/2005	8/16/2005	8/16/2005	7/28/2005	7/26/2005	[illegible]	7/28/2005	7/26/05	8/16/2005	[illegible]	7/26/2005	[illegible]	7/28/2005	7/25/2005
175	Laser Drill Holes	8/26/2005	8/4/2005	8/26/2005	8/26/2005	8/4/2005	8/4/2005	8/4/2005	8/4/2005	8/4/05	8/26/2005	8/4/2005	8/4/2005	8/4/2005	8/4/2005	8/4/2005
180	Drill ID Pin Hole	8/29/2005	8/8/2005	8/26/2005	8/26/2005	8/6/2005	8/8/2005	8/8/2005	8/8/2005	8/8/05	8/26/2005	8/8/2005	8/6/2005	8/8/2005	8/8/2005	8/8/2005
190	Local Bench and White Light Insp.	8/29/2005	8/9/2005	8/29/2005	8/29/2005	8/9/2005	8/9/2005	8/9/2005	8/9/2005	8/9/05	8/29/2005	8/9/2005	8/9/2005	8/9/2005	8/9/2005	8/9/2005
205	Bench Laser Splatter	8/29/2005	8/9/2005	8/29/2005	8/29/2005	8/9/2005	8/9/2005	8/9/2005	8/9/2005	8/9/05	8/29/2005	8/9/2005	8/9/2005	8/9/2005	8/9/2005	8/9/2005
210	FPI	8/30/2005	8/10/2005	8/30/2005	8/30/2005	8/10/2005	8/10/2005	8/10/2005	8/10/2005	8/10/05	8/30/2005	8/10/2005	8/10/2005	8/10/2005	8/10/2005	8/10/2005
213	Release and Issue Hardware	8/30/2005	8/10/2005	8/30/2005	8/30/2005	8/10/2005	8/10/2005	8/10/2005	8/10/2005	8/10/05	8/30/2005	8/10/2005	8/10/2005	8/10/2005	8/10/2005	8/10/2005
215	Assemble Shield	9/6/2005	8/19/2005	9/6/2005	9/6/2005	8/19/2005	8/19/2005	8/19/2005	8/19/2005	8/19/05	9/6/2005	8/19/2005	8/19/2005	8/19/2005	8/19/2005	8/19/2005
225	Laser Weld	9/6/2005	8/19/2005	9/6/2005	9/6/2005	8/19/2005	8/19/2005	8/19/2005	8/19/2005	8/19/05	9/6/2005	8/19/2005	8/19/2005	8/19/2005	8/19/2005	8/19/2005
235	Heat Treat	9/7/2005	8/22/2005	9/7/2005	9/7/2005	8/22/2005	8/22/2005	8/22/2005	8/22/2005	8/22/05	9/7/2005	8/22/2005	8/22/2005	8/22/2005	8/22/2005	8/22/2005
245	Bench Laser Splatter	9/7/2005	8/23/2005	9/7/2005	9/7/2005	8/23/2005	8/23/2005	8/23/2005	[illegible]	[illegible]	9/7/2005	[illegible]	8/23/2005	8/23/2005	8/23/2005	8/23/2005
254	Release & Issue Hardware	9/7/2005	8/23/2005	9/9/2005	9/7/2005	8/23/2005	8/23/2005	8/23/2005	[illegible]	[illegible]	9/7/2005	[illegible]	8/23/2005	8/23/2005	8/23/2005	8/23/2005
255	Assemble Bushings & Pins	9/7/2005	8/24/2005	9/9/2005	9/7/2005	8/24/2005	[illegible]	[illegible]	8/30/2005	8/26/05	9/7/2005	8/30/2005	8/29/2005	8/24/2005	8/24/2005	8/24/2005
265	Weld Bushings & Pins	9/9/2005	8/26/2005	9/10/2005	[illegible]	8/26/2005	8/24/2005	8/24/2005	8/31/2005	8/30/05	[illegible]	8/30/2005	8/29/2005	8/25/2005	8/24/2005	8/25/2005
270	Ream Bushings	9/12/2005	8/29/2005	9/12/2005	9/9/2005	8/29/2005	[illegible]	[illegible]	9/1/2005	8/31/05	9/9/2005	8/31/2005	8/30/2005	8/26/2005	[illegible]	8/26/2005
280	FPI	9/14/2005	8/30/2005	9/14/2005	9/9/2005	8/30/2005	[illegible]	[illegible]	9/6/2005	8/31/05	9/9/2005	8/31/2005	8/31/2005	8/29/2005	[illegible]	8/29/2005
290	Inspect	9/14/2005	8/30/2005	9/14/2005	9/9/2005	8/30/2005	[illegible]	[illegible]	9/2/2005	8/31/05	9/9/2005	8/31/2005	8/31/2005	8/29/2005	[illegible]	8/29/2005

Appendix L: Exact Inventory 11/5/05

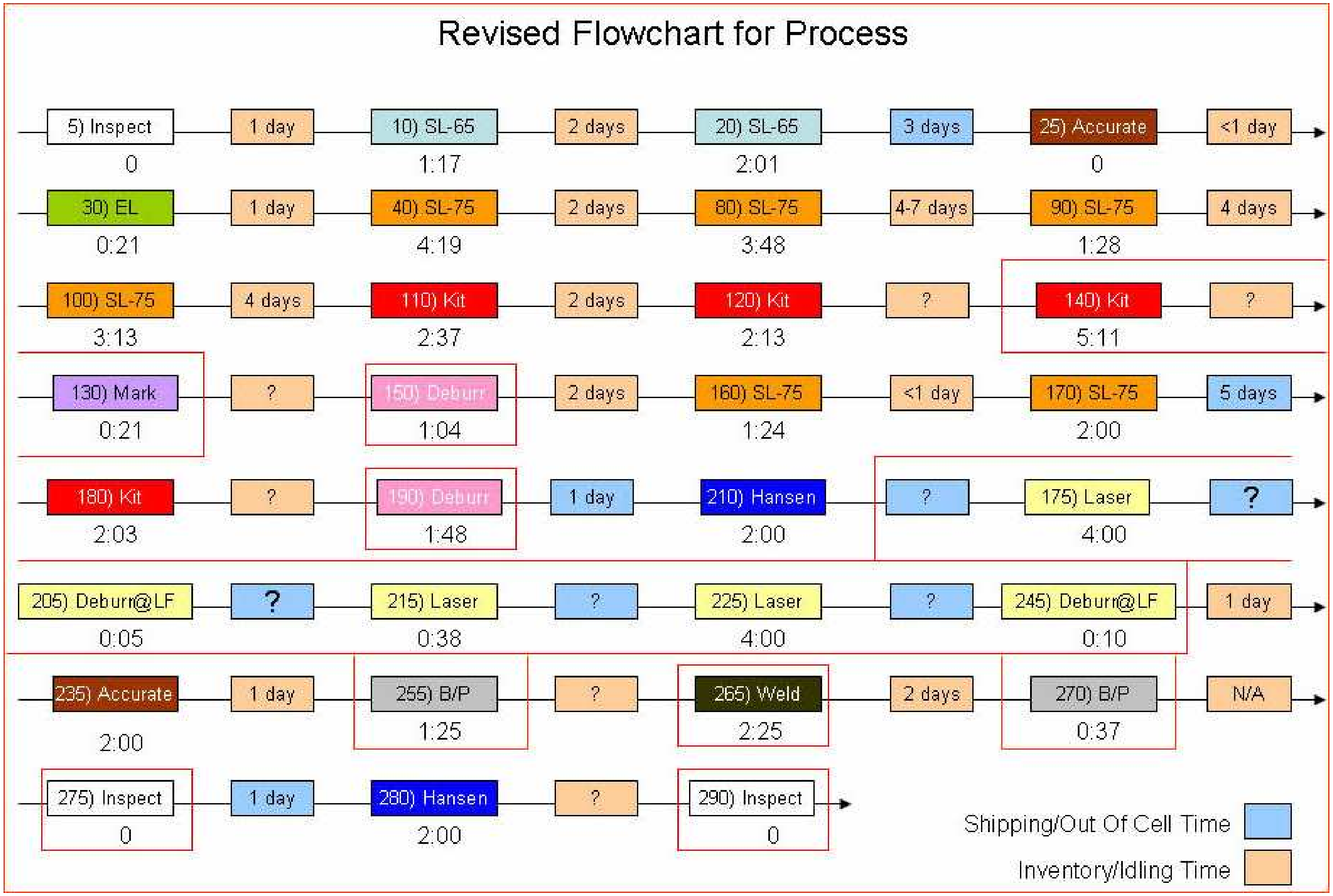
Invt Tag #	Loc	(JOB NO.) W/O #	Part #	Oper #	Qty #
01079	E	816357	4145T33G01	5	4
01080	E	816357	4145T33G01	10	8
01016	E	816271	4145T33G01	80	4
01084	E	816271	4145T33G01	80	5
01086	E	816271	4145T33G01	90	1
01082	E	816203	4145T33G01	100	1
01083	E	816271	4145T33G01	100	2
00773	MRB	815976	4145T33G01	100	1
01010	D	816203	4145T33G01	120	1
01011	D	816236	4145T33G01	120	2
01074	E	816236	4145T33G01	130	7
00563	MRB	815113A	4145T33G01	130	1
01023	G	816236	4145T33G01	140	2
01022	G	816236	4145T33G01	150	1
01202	A	816203	4145T33G01	170	8
00791	J	815778	4145T33G01	175	1
00576	MRB	815268	4145T33G01	175	1
01117	OV	816203	4145T33G01	175	8
00550	MRB	815196	4145T33G01	180	1
00798	A	816150	4145T33G01	210	6
00751	E	816114	4145T33G01	213	1
01118	OV	816150	4145T33G01	213	9
01252	MRB		4145T33G01	225	1
00777	MRB	815722	4145T33G01	254	1
00091	P-F	816114	4145T33G01	255	2
00095	P-F	816114	4145T33G01	255	2
00575	MRB	815076A	4145T33G01	280	1
00585	MRB	814299	4145T33G01	290	1
00922	E	816114	4145T33G01	290	1

Appendix M: WIP Calculation



OP#	Description	Labor (Hr.)	Material/Process Cost	Labor Cost	Total Cost	Cummulative Cost	Current Inventory	Inventory Value
5	RELEASE MATERIAL	0.00	$1,039.00	$0.00	$1,039.00	$1,039.00	4	$4,156.00
10	ROUGH AFT	1.18		$139.24	$139.24	$1,178.24	8	$9,425.92
20	ROUGH FWD	1.83		$215.94	$215.94	$1,394.18	0	$0.00
25	STRESS RELIEVE	0.00	$46.66	$0.00	$46.66	$1,440.84	0	$0.00
30	TOOL PREP	0.63		$74.34	$74.34	$1,515.18	0	$0.00
40	FINISH FWD	4.11		$484.98	$484.98	$2,000.16	0	$0.00
80	FINISH AFT FLANGE	3.93		$463.74	$463.74	$2,463.90	9	$22,175.10
90	FINISH MIDDLE I.D.	1.27		$149.86	$149.86	$2,613.76	1	$2,613.76
100	FINISH FORWARD	2.38		$280.84	$280.84	$2,894.60	4	$11,578.40
110	MILL POCKETS AFT FLANGE	2.38		$280.77	$280.77	$3,175.37	0	$0.00
120	MILL & DRILL AFT FLANGE	2.26		$266.16	$266.16	$3,441.52	3	$10,324.57
130	FINAL MARK	0.24		$28.65	$28.65	$3,470.17	8	$27,761.37
140	MILL & DRILL PERIPHERY	4.60		$542.80	$542.80	$4,012.97	2	$8,025.94
150	DEBURR COMPLETE	1.31		$154.58	$154.58	$4,167.55	1	$4,167.55
160	FINISH O.D.	0.73		$86.14	$86.14	$4,253.69	0	$0.00
170	FINISH I.D. AFT GROOVES	1.75		$206.50	$206.50	$4,460.19	8	$35,681.53
175	LASER DRILL HOLES	0.00	$71.80	$0.00	$71.80	$4,531.99	10	$45,319.91
180	DRILL I.D. PIN HOLE	2.11		$248.98	$248.98	$4,780.97	1	$4,780.97
190	LOCAL BENCH	1.10		$129.80	$129.80	$4,910.77	0	$0.00
205	BENCH LASER SPLATTER	0.06		$7.08	$7.08	$4,917.85	0	$0.00
210	F.P.I.	0.00	$20.00	$0.00	$20.00	$4,937.85	6	$29,627.10
213	RELEASE MATERIAL	0.00	$640.00	$0.00	$640.00	$5,577.85	10	$55,778.51
215	ASSEMBLE SHIELD	0.00		$0.00	$0.00	$5,577.85	0	$0.00
225	LASER WELD	0.00	$105.00	$0.00	$105.00	$5,682.85	1	$5,682.85
235	HEAT TREAT	0.00	$52.25	$0.00	$52.25	$5,735.10	0	$0.00
245	BENCH LASER SPLATTER	0.23		$27.14	$27.14	$5,762.24	0	$0.00
255	ASSEMBLE ITEMS 2,3, & 7	1.64	$462.07	$193.52	$655.59	$6,417.83	5	$32,089.15
265	WELD BUSHINGS AND PINS	2.13		$251.34	$251.34	$6,669.17	0	$0.00
270	REAM BUSHING	0.81		$95.58	$95.58	$6,764.75	0	$0.00
280	LOCAL F.P.I.	0.00	$15.00	$0.00	$15.00	$6,779.75	1	$6,779.75
	READY TO SHIP	0.00	0	0	$0.00	$6,779.75	2	$13,559.50
						Total In Process:	84	$329,527.87

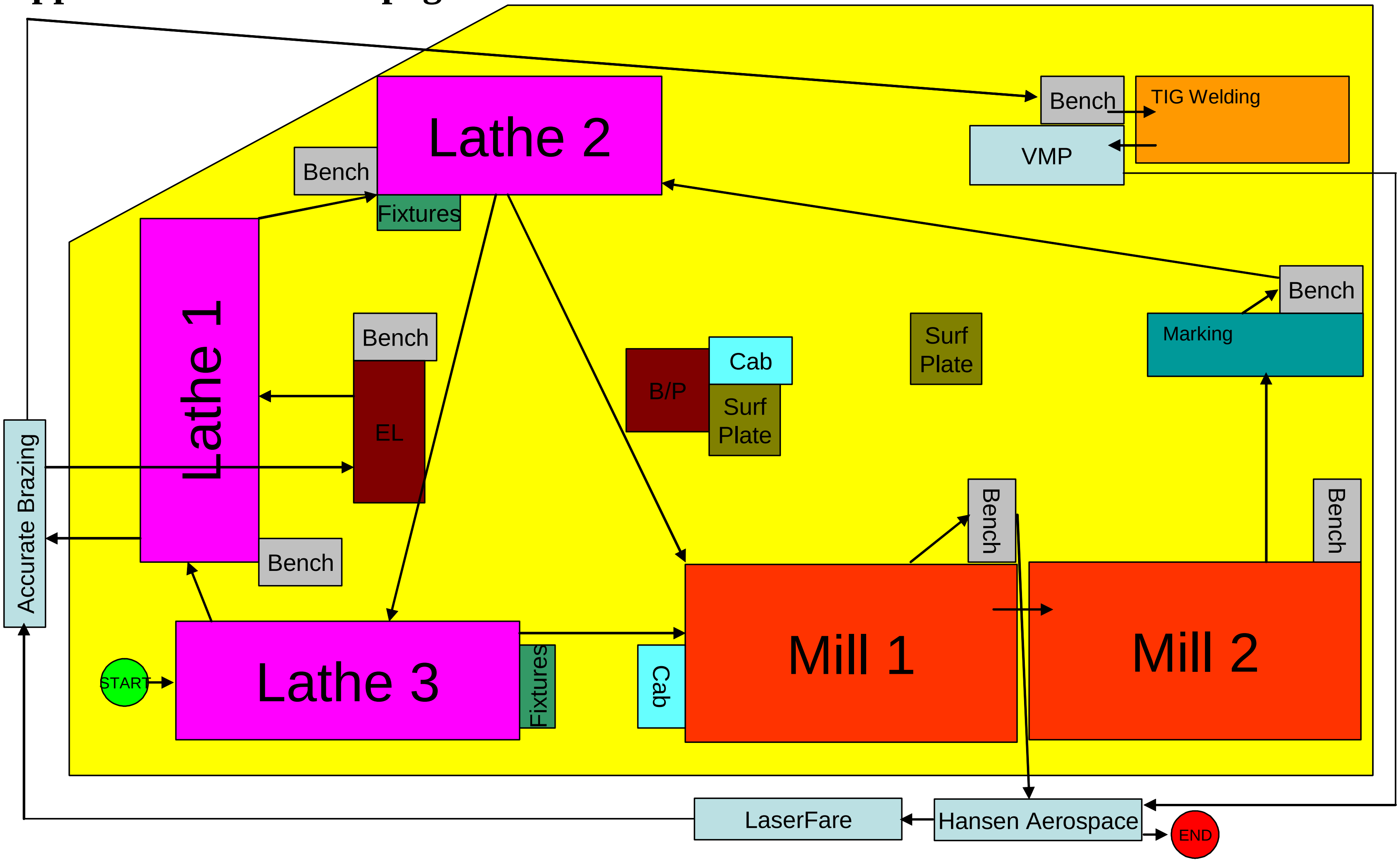
Appendix N: Revised Process Flowchart



Appendix O: Continuous Flow Plan

	Lathe 1		Lathe 2		Lathe 3+EL		Heat Treatment	M1		Mill 2 + Mark + Insp		Outside Steps	Mi
0:00	Op 20 1:50 (0:10-2:00)	Setup (0:00-0:10)	Op 80 3:56 (0:10-4:06)	Setup (0:00-0:10)	Op 10 1:11 (0:10-1:21)	Setup (0:00-0:10)	Op 25 (NA)	Op 110 2:23 (0:10-2:33)	Setup (0:00-0:10)	Op 140 4:36 (0:10-4:46)	Setup (0:00-0:10)	NA	Op 190 1:06 (0:10-1:16)
0:15													
0:30													
0:45													
1:00													
1:15						Jaws to Fixture Change :30 (1:21-1:51)							Mask Holes (1:26-1:31)
1:30													Op 255 1:38 (1:41-3:19)
1:45					Setup (1:51-2:01)								
2:00		Jaws to Fixture Change :30 (2:00-2:30)				Op 90 1:16 (2:01-3:17)							
2:15													
2:30	Tool Change (2:30-3:00)								Setup (2:33-2:43)				
2:45								Op 120 2:15 (2:43-4:58)					
3:00	op 40 4:07 (3:10-7:17)	Setup (3:00-3:10)											
3:15					Setup (3:17-3:27)								
3:30						Op 100 2:23 (3:27-5:50)							Op 265 2:08 (3:29-5:37)
3:45													
4:00				Fixture Change (4:06-4:26)									
4:15			Tool Change (4:26-4:36)										
4:30				Setup (4:36-4:46)									
4:45			Op 160 :44 (4:46-5:30)						Setup (4:58-5:08)	Op 130 :15 (4:56-5:11)	Setup (4:46-4:56)		
5:00								Op 180 2:07 (5:08-7:15)			Setup (5:11-5:21)		
5:15										Op 150 1:19 (5:21-6:40)			
5:30			Op 170 1:45 (5:40-7:25)	Setup (5:30-5:40)									
5:45					Setup (5:50-6:00)								Op 270 :49 (5:47-6:36)
6:00						Op 30 :38 (6:00-6:38)							
6:15													
6:30													
6:45													
7:00													
7:15													
7:30													
7:45													
8:00													

Appendix P: Revised Spaghetti Chart



Appendix Q: WIP Calculation for Continuous Flow Plan

OP#	Description	Labor (Hr.)	Material/Process Cost	Labor Cost	Total Cost	Cummulative Cost	Current Inventory	Inventory Value
5	RELEASE MATERIAL	0.00	$1,039.00	$0.00	$1,039.00	$1,039.00	1	$1,039.00
10	ROUGH AFT	1.18		$139.24	$139.24	$1,178.24	1	$1,178.24
20	ROUGH FWD	1.83		$215.94	$215.94	$1,394.18	4	$5,576.72
25	STRESS RELIEVE	0.00	$46.66	$0.00	$46.66	$1,440.84	4	$5,763.36
30	TOOL PREP	0.63		$74.34	$74.34	$1,515.18	1	$1,515.18
40	FINISH FWD	4.11		$484.98	$484.98	$2,000.16	1	$2,000.16
80	FINISH AFT FLANGE	3.93		$463.74	$463.74	$2,463.90	1	$2,463.90
90	FINISH MIDDLE I.D.	1.27		$149.86	$149.86	$2,613.76	0	$0.00
100	FINISH FORWARD	2.38		$280.84	$280.84	$2,894.60	1	$2,894.60
110	MILL POCKETS AFT FLANGE	2.38		$280.77	$280.77	$3,175.37	0	$0.00
120	MILL & DRILL AFT FLANGE	2.26		$266.16	$266.16	$3,441.52	1	$3,441.52
140	MILL & DRILL PERIPHERY	4.60		$542.80	$542.80	$3,984.32	0	$0.00
130	FINAL MARK	0.24		$28.65	$28.65	$4,012.97	0	$0.00
150	DEBURR COMPLETE	1.31		$154.58	$154.58	$4,167.55	1	$4,167.55
160	FINISH O.D.	0.73		$86.14	$86.14	$4,253.69	0	$0.00
170	FINISH I.D. AFT GROOVES	1.75		$206.50	$206.50	$4,460.19	1	$4,460.19
180	DRILL I.D. PIN HOLE	2.11	$71.80	$248.98	$320.78	$4,780.97	1	$4,780.97
190	LOCAL BENCH	1.10		$129.80	$129.80	$4,910.77	4	$19,643.08
210	F.P.I.	0.00	$20.00	$0.00	$20.00	$4,930.77	0	$0.00
175	LASER DRILL HOLES	0.00		$0.00	$0.00	$4,930.77	0	$0.00
205	BENCH LASER SPLATTER	0.00		$0.00	$0.00	$4,930.77	0	$0.00
213	RELEASE MATERIAL	0.00	$640.00	$0.00	$640.00	$5,570.77	0	$0.00
215	ASSEMBLE SHIELD	0.00		$0.00	$0.00	$5,570.77	0	$0.00
225	LASER WELD	0.00	$105.00	$0.00	$105.00	$5,675.77	0	$0.00
245	BENCH LASER SPLATTER	0.00	$52.25	$0.00	$52.25	$5,728.02	0	$0.00
235	HEAT TREAT	0.00		$0.00	$0.00	$5,728.02	4	$22,912.08
255	ASSEMBLE ITEMS 2,3, & 7	1.64	$462.07	$193.52	$655.59	$6,383.61	0	$0.00
265	WELD BUSHINGS AND PINS	2.13		$251.34	$251.34	$6,634.95	0	$0.00
270	REAM BUSHING	0.81		$95.58	$95.58	$6,730.53	0	$0.00
280	LOCAL F.P.I.	0.03	$15.00	$3.75	$18.75	$6,749.28	4	$26,997.12
	READY TO SHIP	0.00	0	0	$0.00	$6,749.28	4	$26,997.12
						Total In Process:	34	$135,830.81