Semi-Automated Nail Gun Testing Stand

by

MARCUS J. WAGGONER

Submitted to the
MECHANICAL ENGINEERING TECHNOLOGY DEPARTMENT
In Partial Fulfillment of the
Requirements for the
Degree of
Bachelor of Science
In
MECHANICAL ENGINEERING TECHNOLOGY

at the
OMI College of Applied Science
University of Cincinnati
May 2005

© Marcus J. Waggoner

The author hereby grants to the Mechanical Engineering Technology Department permission to reproduce and distribute copies of the thesis document in whole or in part.

Signature of Author

Certified by
C. Kettil Cedercreutz, Thesis Advisor

Accepted by
Dr. Muttar Al-Ubaidi, Department Head Mechanical Engineering Technology
Abstract

Campbell Hausfeld is a pneumatics company, which is located in Harrison Ohio, with primary market scope focused on air-powered products. Campbell Hausfeld products are recognized worldwide providing DIY homeowners and contractors with the tools they need to get the job done. One of the great challenges in engineering is to determine the life of a new design, or of a production product. The testing of a new or old product could tell you many things about the product, from the material being used, to the stress and strain of all mechanical parts, why the parts failed, how long the part will last, when the part will fail, and what part will fail. By knowing this, improvements in the material or the design could extend the life of the product to its fullest potential.

The current procedure at Campbell Hausfeld for life testing nailers consist of hiring two outside employees from a temporary agency to come in and fire nailers for an eight hour shift. These shifts consist of loading, firing, and reloading any one of the various nailers in which Campbell Hausfeld produces. This type of testing is both long and monotonous, considering testing is complete when the nailer has fired 150,000 nails.

The following design document addresses this form of life testing and the current problem areas associated with this testing and problems with trying to automate some of this process. The purpose of this document is explain in detail the current life testing procedures and the process followed by the Nail Gun Team to create an alternate solution to their testing needs. The purpose of the design work done by our design team was to create a prototype that incorporates an automated solution to Campbell’s problems.

Some of the current problems with Campbell’s life testing are firing of the nails manually, outside personnel are hard to keep for the desired amount of time to complete testing, and the costs and hassle of bringing in outside contractors poses other human resource issues. Campbell Hausfeld would like to eliminate these problems. The current method of testing is unacceptable to Campbell’s research and development division and needs to be addresses to discover alternate solutions.

Though research, brainstorming, and meetings an automated nail gun tester was proposed. This design would not be fully automated do to the complexity, budget, and time of a fully automated system. As a team we research the problem and solutions to Campbell’s testing problems and came up with after extensive research a design of a nailer concept shown in the 3-D Figure #1 below. Granted much work went into this design, and this is an overall design and just the picture alone cannot represent the man-hours behind this concept. Its components of operation were broken among the team members. The three sections dealt with the mode of operation, X-plane, Y-plane, and Z-plane, and all dealt some with the controls needed to operate the system.

My section was the z-axis firing system, which is discussed, in greater detail below in the following sections. My other team members, Mike Orschell and James Doogan dealt with the other two axes of operation and their designs and results will be briefly touched
in this paper. For a more detailed description of their design process, designs, drawings, and calculations one must view their technical write ups for each section. I was also involved in some of the other design calculations dealing with system forces, motor, screw, and bearing sizing but I will not touch greatly on any of these topics as these determinations will be discussed in depth in the X and Y systems design papers by Mike Orschell and James Doogan.

**Figure #1**

The new method of testing created by the Nail Gun Test Stand Design Team incorporates the use of semi-automation to reproduce the manual life testing of nail guns. This new method utilizes the use of computer-controlled movement with the aid and use of stepper motors, pneumatic actuation devices, and control logic. It eliminates the problem elements described later in this document.

After significant testing and trial runs of the testing stand the testing results showed that the device performed over and above the desired design specifications.
# TABLE OF CONTENTS

**COVER PAGE – OCAS AUTHORIZATION SHEET**  
COVER PAGE

**ABSTRACT**  
1-2

**TABLE OF CONTENTS**  
3-6

**FIGURES AND TABLES**  
7

**INTRODUCTION**  
8-12

**PROBLEM ELEMENTS**  
9

**PROBLEM SOLUTIONS**  
9

**OBJECTIVES TABLES**  
10

**OVERALL**  
10

**X-SYSTEM**  
10

**Y-SYSTEM**  
10

**Z-SYSTEM**  
11

**PURPOSE/ OVERALL GENERAL DESIGN REQUIREMENTS**  
12

**DESIGN/ PROTOTYPE DELIVERABLES**  
13-14

**OVERALL**  
13

**MARCUS J. WAGGONER**  
13

**MICHAEL ORSCHELL**  
14

**JAMES DOOGAN**  
14

**EXISTING PRODUCTS EXAMINES**  
15-16

**DAVINCI SYSTEM**  
15
GANTRY X, Y, Z SYSTEM 15
COMPLETE CNC SYSTEM 15

SCHEDULING 17

DESIGN SECTIONS 18-20
  SELECTION OF PREFERRED DESIGN 18
    WEIGHTED DECISION MATRICES 18-19
      OVERALL 18
      INDIVIDUAL 19
  SELECTION OF PREFERRED DESIGN –INDIVIDUAL OBJECTIVES 19-20

OVERALL/ DESIGN OF ELEMENTS OF PREFERRED INDIVIDUAL DESIGN 21-24
  Z-AXIS MOVEMENT DESIGN 21
  CONTROLS DESIGN 21
  GUN FIXTURE DESIGN 22
  ON-MOARD AIR SUPPLY DESIGN 22
  SAFETY SHIELD DESIGN 22-23
  X AND Y GENERAL DESIGN OVERVIEW 23-24

CALCULATIONS 25-27
  LOADING CONDITIONS AND CALCUALTIONS Z-AXIS 25-26
  VIBRATIONAL ANALYSIS OF Z-ACTUATION SYSTEM 26-27

PROTOTYPE CONSTRUCTION 28-31
  MANUFACTURING EQUIPMENT USED 28
  X-AXIS CONSTRUCTION 28-29
  Y-AXIS CONSTRUCTION 29
  Z-AXIS CONSTRUCTION 29-30
  GUN FIXTURE CONSTRUCTION 30
APPENDIX H- CONCEPT A
APPENDIX I- CONCEPT B
APPENDIX J- SCHEDULE
APPENDIX K- BUDGET/ PURCHASED PARTS
APPENDIX L- ASSEMBLY DRAWING
APPENDIX M- GUN FIXTURE
APPENDIX N- GUN FIXTURE
APPENDIX O- CYLINDER BLOCK
APPENDIX P- CYLINDER MOUNTING PLATE
APPENDIX Q- Z ACTUATOR MOUNTED SIDE VIEWS
APPENDIX R- Z ACTUATOR UN-MOUNTED
APPENDIX S- Z-ACTUATOR UNDERNEITH AND SIDE VIEWS
APPENDIX T- CLIPPARD PNEUMATIC CYLINDER AND ELECTRONIC VALVE
APPENDIX U- CYLINDER FOOT BRACKETS AND TUBING
APPENDIX V- AIR COMPRESSOR AND TOGGLE CLAMP
APPENDIX W- COMPLETE TESTER SIDE VIEW RENDER
APPENDIX X- COMPLETE TESTER ANGLED TOP VIEW RENDER
APPENDIX Y- X-AXIS SYSTEM VIEW/ QUICK AIR CONNECTS
APPENDIX Z- X-SLIDES WITH ANGLE SUPPORTS
APPENDIX AA- Y-AXIS SLIDERS/ SUPPORTS/ Z-AXIS SUPPORT RODS ON TABLE
APPENDIX BB- FLOATING Y-AXIS BACK VIEW
APPENDIX CC- FLOATING Y-AXIS FRONT VIEW
APPENDIX DD- TOP VIEW Y-AXIS AND ACTUATION SYSTEM
APPENDIX EE- Y-AXIS ACME SCREW
APPENDIX FF- X-AXIS ACME SCREW
APPENDIX GG- Y-AXIS CARRIAGE MOUNTING PLATE
APPENDIX HH- Y-AXIS SCREW/ NUT DRIVE BLOCK
APPENDIX II- X-AXIS MOUNTING PLATE
APPENDIX JJ- RIGHT ANGLE SUPPORT -LEFT SIDE
APPENDIX KK- RIGHT ANGLE SUPPORT -RIGHT SIDE
APPENDIX LL- Y-AXIS MOTOR MOUNTING PLATE
APPENDIX MM- X-AXIS BOARD HOLDER SUPPORT LEG
APPENDIX NN- AIR SUPPLY MANIFOLD
APPENDIX OO- Y-AXIS CARRIAGE LINEAR BLOCK SLIDE
APPENDIX PP1- X AXIS MOTOR MOUNT PLATE SPACER
APPENDIX PP2- Y AXIS MOTOR MOUNTING BRACKET
APPENDIX PP3- Y-AXIS GUN FIXTURE SUPPORT
APPENDIX QQ- 3-AXIS CONTROL BOX
APPENDIX RR- PROJECT BILL OF MATERIALS
APPENDIX SS- ACTUATOR SPECIFICATIONS AND REQUIRED FORCES
APPENDIX TT- LOADING CONDITIONS DATA TABLES
APPENDIX UU- DEFLECTION AND VIBRATION DATA SHEETS
APPENDIX VV- LOADING CONDITIONS AND BENDING FORCE CALCULATIONS
APPENDIX WW- LOADING CONDITIONS AND BENDING AND ROD DEFLECTION CALCULATIONS
APPENDIX XX- VIBRATIONAL AND NATURAL FREQUENCY ANALYSIS
APPENDIX YY- SAFETY ENCLOSURE IMPACT TEST DATA
APPENDIX ZZ- GUN FIRING FORCE REQUIREMENTS TEST DATA
APPENDIX AAA- CLIENT VERIFICATION DOCUMENTATION
APPENDIX BBB1, 2, 3 – BUILD MACHINERY USED
APPENDIX CCC1- DRIVE ASSEMBLY X AXIS PHOTO
APPENDIX CCC2- DRIVE ASSEMBLY Y AXIS PHOTO
APPENDIX DDD- DRIVE MECHANISMS Z AXIS PHOTO
APPENDIX EEE- PNEUMATIC CONTROL DET-UP PHOTO
APPENDIX FFF- FINAL DESIGN PROTOTYPE PHOTO
APPENDIX GGG- TOP SECTION GUN FIXTURE CNC PROGRAM
APPENDIX HHH- BOTTOM SECTION GUN FIXTURE CNC-PROGRAM

TABLES

(1) TEAM OBJECTIVES 11
(2) X-SYSTEM MEASURABLE OBJECTIVES 11
(3) Y-SYSTEM MEASURABLE OBJECTIVES 11
(4) Z-SYSTEM MEASURABLE OBJECTIVE 12
(5) OVERALL OBJECTIVES/ DELIVERABLES 14
(6) DELIVERABLES – MARCUS WAGGONER 14
(7) DELIVERABLES – MICHAEL ORSCHELL 15
(8) DELIVERABLES – JAMES DOOGAN 15

FIGURES

(1) OVERALL TESTER RENDERED 2
(2) NAIL GUN 9
(3) DA VINCI SYSTEM 16
(4) GANTRY X, Y, Z SYSTEM 16
(5) CNC SYSTEM 16
(6) PRECISION SLIDES 16
(7) HYDRAULIC ACTUATOR 16
(8) NEMA 23 STEPPER MOTOR 25
(9) BENDING STRESS DRAWING 26
(10) ROD DEFLECTION DRAWING 27
INTRODUCTION

In today’s manufacturing world, the presence of research and development is a vital part of the overall products that are produced. The company Campbell Hausfeld is no exception to this rule. Campbell Hausfeld is the sponsor and sole monetary provider for the Nail Gun Team’s design concept and prototype. They have sponsored our team to develop a much-needed testing prototype in order to support their air tools division. This device will be semi-automated and will be much more dependable than the human operators hired to do the work manually. As this document progresses, it will discuss the company background, current air tools life testing, current testing problems, how the problem will be solved, and how decisions are solved, and why such decisions were made by the design team.

Campbell Hausfeld is a pneumatics company, which is located in Harrison Ohio, with primary market focus on air-powered products. Campbell Hausfeld products are recognized worldwide providing DIY homeowners and contractors with the tools they need to get the job done. One of the great challenges in engineering is to determine the life of a new design, or of a production product. The testing of a new or old product could tell you many things about the product, from the material being used, to the stress and strain of all mechanical parts, why the parts failed, how long the part will last, when the part will fail, and what part will fail. By knowing this, improvements in the material or the design could extend the life of the product to its fullest potential.

The current procedure at Campbell Hausfeld for testing nailers consist of hiring two outside employees from a temporary agency to come in and fire nailers for an eight hour shift. This type of testing is both long and monotonous, considering testing is complete when the nailer has fired 150,000 nails. The following document addresses this form of life testing and the current problem areas associated with trying to automate some of this process.

Product life testing of air powered nail guns at Campbell Hausfeld has methods that are cumbersome and costly. Product life testing for nailers consists of manually firing 150,000 nails into standard construction grade pine 2x6 targets. Staffing for this testing requires two employees to work maximum of 160 man-hours, which costs approximately $2000.00 for each test cycle. The current testing set-up has ergonomic deficiencies for current personnel completing testing. Space in the soundproof test area, where life testing must occur, costs money due to the extended use during the testing. With the current testing methods only one nail gun can be tested at a time and the irregular nail patterns waste space on the test boards requiring larger quantities to be used to complete testing. The present set-up depends directly on shop air minimizing the location where testing can occur, and the hiring of outside labor creates problems for both engineering and human
resources. This design document is intended to address all of these concerns. Figure 1 is a representative illustration of the proposed devices being tested.

**Problem Elements**

When examining the life testing process, it was determined that automating the testing process was the best solution to the current life testing problems. The known features include the testing stand, mobility of the stand, moving the bridge in the X-direction in a sequence, holding the guns, gun fixtures, moving the guns in the Y-direction in a sequence, firing the guns (z-direction movement) and returning them after firing in a sequence, portable air set-up, electrical controls, and other needed controls and safety devices needed for safe operation.

**Problem Solutions**

The design solution for our problem is as follows based on research and team collaboration. A semi-automated nail gun test station will be implemented into the Campbell Hausfeld's life-testing program. This new style of testing is based on a portable test stand that will be able to hold two or more guns. The gun fixtures will be able to move in the x, y, and z-axis by utilizing actuators, stepper motors, limit switches and proxy switches. The stand will also support a minimum of (3) 2X6X4 pieces of yellow pine wood, which will be used as targets. Both air and electric will be used to power the nail-gun tester. A computer or programmable logic controller is needed to control the movement and the spacing of the nails. The stand will utilize all current safety measures as deemed by the sponsoring company, and all other applicable safety requirements needed to allow for safe operation of the device. All federal and state safety requirements will be followed as deemed applicable to the new device. Our design agreement with Campbell Hausfeld can be viewed in Appendix AAA.

The following prototype will be developed by the Nail Gun Design Team, which consists of James Donovan, Michael Orschell, and Marcus Waggoner. Mike Orschell is a Drafter/Design for Campbell Hausfeld with approximately 20 years experience in air-powered products. James Doogan is a research and development analyst for Campbell Hausfeld’s air products and has 4 years experience in industry. Marcus Waggoner is a research and development analyst for Lyondell Chemical Company with 10 years experience in material properties testing.

In the tables below as a group we have defined the team objectives and each team member’s problem elements and measurable objectives based on the direction of motion for the device. These tables will address the problems with the current method such as creating a test stand, costs, current methods, ergonomics, and dedicated air and space requirements. The problems and measurable objectives table show the things that the team needs to achieve in order to create a safe semi-automated test stand that reduces
costs, generates better quality data, creates a more ergonomic test environment, and does not require dedicated shop air or testing space.

**Table #1-Team Objectives Table**

<table>
<thead>
<tr>
<th>Problem Elements</th>
<th>Solution Feature</th>
<th>Objective and its Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Method</td>
<td>Semi-automated test stand</td>
<td>Reduce Testing Costs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increase Safety</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increase Consistency</td>
</tr>
<tr>
<td>No Test Stand</td>
<td>Potable Test Stand</td>
<td>Increase Efficiency</td>
</tr>
<tr>
<td>One manual tester</td>
<td>Interchangeable gun fixtures</td>
<td>Multiple Testing Fixtures</td>
</tr>
<tr>
<td>Test Material Wasted</td>
<td>More uniform nail pattern</td>
<td>More Nails per Board</td>
</tr>
</tbody>
</table>

**Table #2 -X-System-Michael Orschell**

<table>
<thead>
<tr>
<th>Problem Elements</th>
<th>Solution Feature</th>
<th>Objective and its Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-axis movement</td>
<td>motors / moveable bridge</td>
<td>moves in the X axis</td>
</tr>
<tr>
<td>Make tester mobile</td>
<td>wheels on table</td>
<td>mobility</td>
</tr>
<tr>
<td>Restraining board</td>
<td>fixture to hold board</td>
<td>stable board</td>
</tr>
<tr>
<td>Quick release for board</td>
<td>clamps</td>
<td>quick release and loading</td>
</tr>
</tbody>
</table>

**Table #3-Y-System-James Doogan**

<table>
<thead>
<tr>
<th>Problem Elements</th>
<th>Solution Feature</th>
<th>Objective and its Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y-axis motion</td>
<td>motors</td>
<td>moves in Y direction</td>
</tr>
<tr>
<td>Holding the gun</td>
<td>bridge design</td>
<td>holds gun fixtures</td>
</tr>
<tr>
<td>Controlling movement</td>
<td>switches / sensors</td>
<td>controls movement in the planes</td>
</tr>
<tr>
<td>Emergency Stops/ safety</td>
<td>kill switch</td>
<td>stops test stand</td>
</tr>
</tbody>
</table>
Table #4-Z-System- Marcus Waggoner

<table>
<thead>
<tr>
<th>Problem Elements</th>
<th>Solution Feature</th>
<th>Objective and its Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharging gun</td>
<td>actuator/ controls</td>
<td>movement in Z-axis</td>
</tr>
<tr>
<td>Gun holder</td>
<td>fixture for guns</td>
<td>holds the gun during operation</td>
</tr>
<tr>
<td>Operational power</td>
<td>solenoid, compressor,</td>
<td>fires the nail gun</td>
</tr>
<tr>
<td></td>
<td>valves</td>
<td></td>
</tr>
<tr>
<td>Nail ricochet</td>
<td>enclosure</td>
<td>material selection for enclosure</td>
</tr>
<tr>
<td>Inexperienced Operators</td>
<td>operation training</td>
<td>easy to operate test stand</td>
</tr>
</tbody>
</table>

After the problem elements were created and possible solutions were determined the design moved to its next phase of analyzing. When the specific problem areas were analyzed several solutions to the design problems were created. With the help of alternate designs, QFD, and weighted decision matrices we determined what design alternatives were the best for us and once they were determined the selections must be measured as to how well they solved the design issues. Many of the design choices were based on cost. The design was employed to do as much as possible for minimal costs. The computer through G-code programming controlled the X and Y movement by operating the stepper motors. The quality of the X and Y movement was determined by how well the motors moved when commanded by the computer and how precise the movements were. This was measured with a linear measuring device to determine how close the motors moved the gun to the desired positions. The Z-axis movement is accomplished with pneumatic cylinders, pneumatic solenoids, electronic valving, and controls, which are explained further in the document, but the operation of this device is measured again by its cycle time, quality of operation how precise the movements are, and does the gun fire when it is supposed to fire. Other objectives are measured more directly. Does the device turn on when it is required, is there sufficient power and air to operate efficiently, does the designed pieces stay in place, and does the nail gun fixture keep the gun firmly in place when testing. Some of the design selections were based on numerical calculations and their quality of operation were also based on numerical calculations. Some examples of this are motor sizing, screw sizes, bearing sizes, support rods, and tubing sizes to name a few. Selection of the safety shield was determined by cost and how well it prevents nails from leaving the test area. Plexiglas was chosen because of its lightness and strength. These selections that we chose were based on careful planning both with engineering calculations, decision matrices, cost analysis, and
feasibility of design in order to satisfy our design objectives. All of the supporting
documents are located in the appendices sections of this document.

As the design developed, the prototype did encounter some limitations as to functionality. These limitations are also directly related to budgeting. If there was more money allotted, then the prototype possibly could have more functionality. During the design development stages, the initial prototype was scaled back from three tester holders to one due to rising part costs and complexity. The z-axis movement was changed from a precision slide to pneumatic actuators, and the ball screw design for the X and Y drives was changes to a cheaper Acme screw drive system. These design limitations were based on cost. Other design limitations such as an automatic board and nail loader were not attempted in this design do to cost, complexity, and time. These systems could be used as another whole design concept to be developed in the future.

This document it will explain our design, building, and testing process as this project proceeded. In particular, this report will cover the design, building, and testing process for the x, y and z directions with the main focus on the z-axis of the prototype. The sections will follow in the order in which they were utilized to develop the working prototype. The appendices sections of these documents will relay visually and numerically all of the design support that makes this prototype the working model it is today.

**Purpose/Overall Design Requirements** The purpose of the Nail Gun team is to design, build, and test an automated nail gun test station for Campbell Hausfeld’s life testing program. For this project, the test stand will be able to hold two or more guns types and the stand will be able to move in the x, y, and z-axis by utilizing both stepper motors and pneumatic cylinders. The stand will also support a minimum of (3) 2X6X8 yellow pine wood, which will serve as the targets. Both air and electric will run the nail-gun tester. The stand will be portable and will allow for easy maneuverability. A computer will be interfaced to control the movement and the spacing of the nails.

The design, manufacturing, and testing of the new life test unit is comprised of three main elements, which will be addressed by the following team members: Marc Waggoner, Mike Orschell, and Jim Doogan.

**Design/ Prototype Objectives/ Deliverables**
The project objectives are as follows:

Table #5

<table>
<thead>
<tr>
<th>Overall Objectives/ Deliverables</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Provide important life test and field test data.</td>
</tr>
<tr>
<td>• Cost reductions - Current test procedures cost Campbell Hausfeld $12.49 per/hr.</td>
</tr>
<tr>
<td>• Eliminate human error.</td>
</tr>
<tr>
<td>• Increased efficiency, time and money spent more wisely.</td>
</tr>
<tr>
<td>• Eliminate human resource headache (confidentiality form, liability, access badges, etc... of temporary employees)</td>
</tr>
</tbody>
</table>

**Individual Objectives**

The following information is a table of design objectives for Nail Gun Team member: **Marcus Waggoner**. These are the area of focus that my design portion entailed. Although the main focus of this document will be tailored to the design objectives below, there is area of overlap in other portions of the design process in which I participated in which will be discussed in greater detail later in this document. While designing the z-axis movement I was trying to accomplish the following list.

Table #6

<table>
<thead>
<tr>
<th>Deliverables: (Marcus Waggoner)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Provide automated device design that will move a held gun in the z-axis orientation and fire nail on downward stroke (Actuators, Valves, and Solenoids possible Components)</td>
</tr>
<tr>
<td>• Design and Manufacture a device that will securely hold one or more nail guns</td>
</tr>
<tr>
<td>• Design and Manufacture a Safety Enclosure which cannot be Breached by Erratic Nail Fire</td>
</tr>
<tr>
<td>• Design and Fit Nail Gun with Adequate Compressor and Air lines taking Pressure Losses into Account</td>
</tr>
<tr>
<td>• Create Written Documentation Addressing Machine Maintenance, Troubleshooting, and Operation Concerning my Design Points (Manual)</td>
</tr>
</tbody>
</table>

For information purposes my other two-team members’ objectives and deliverables have been included for reference.

Table #7
Table #8

Deliverables: (Mike Orschell)

- Provide a design to allow the testing stand to be easily moved from area to area
- Design the stand so that the footprint does not exceed later specified criteria
- Design and manufacture a manifold that allows use of shop air or portable air supply
- Design compressor mount for stand
- Provide an automated design that will move the test board in the x-axis orientation relative to the tester
- Design and manufacture and fixture that will hold three (2”x6”x4’) pine boards that we hold and release with speed and ease

Deliverables: (James Doogan)

- Provided and automated design that will allow for Y-axis orientation motion for gun movement/Drive System
- Design and Manufacture a device that will securely hold one or more nail gun
- Design and required safety devices that will allow for safe operation of this portion of the tester
- Provided written documentation explaining operational of the designed devices manual

These objectives and deliverables will be accomplished following the project schedule laid out in the schedule section of the appendices sections. The following section describes in general how this schedule is laid out. We did examine some existing products that could possibly meet our requirements and they are described in the following section.

Existing Products Examined
We examined any existing products that were similar to our needs but designed for different purposes. We examined several products on the market but had trouble finding a system that represented all of our needs. The systems below in the three figures are X, Y, Z motion tables that were similar in design to what we required for proper operation of our testing system.

<table>
<thead>
<tr>
<th>Davinci System</th>
<th>Gantry x, y, z System</th>
<th>Complete CNC System</th>
</tr>
</thead>
<tbody>
<tr>
<td>$7,000</td>
<td>$10,045</td>
<td>$20,000</td>
</tr>
</tbody>
</table>

The machines shown above would have probably served our purposes and then some due to their complexity in nature. These multi-axis tables are similar to what we are trying to accomplish with our design, but at significantly less costs due to our budget constraints. So as one can see from the above prices, our design may not be as aesthetically pleasing as the above machines, but will definitely be cheaper in cost to build rather than purchase.

The existing drive devices that I examined were the hydraulic cylinder and the electric, screw actuation system. The hydraulic required a pump and fluid reservoir that was too messy, and the precision electric screw was too costly, mainly $800 dollars for the slide without the motor or mounting hardware.
During our design process we made two company visits to Clippard pneumatics and TSK automation. Both of these visits were very informative and eye opening to my team members and myself.

Scheduling
The plan for designing, fabricating, and testing the automated nailer test stand is laid out in a Gantt chart shown in Appendix J. This schedule has been followed very closely and we were typically ahead of schedule. Some parts of the schedule may be completed earlier than scheduled which may in turn lead to earlier completion and testing of our design.

From examining the following Gantt chart, the proposed schedule for research, design, and manufacturing of the Nail Gun Tester has been preliminarily laid out. From August to December of 2004 the project was in the initial phases of identifying the problem, conducting customer research, initial budgeting, project management and scheduling, and preparing the initial design proposal. From there January though March of 2005 will be spent preparing design ideas, picking our final design, drawing creation, engineering analysis, design freeze, bill of materials, ordering any necessary parts, and our completed design documentation will be created and finalized. From March though May 2005 we will be constructing, fabricating, modifying, and testing our completed design to determine the quality of our constructed design.

To view a more detailed breakdown of the project schedule please examine the following Gantt chart shown on pages 10 and 11 in Appendices J. This timeline does not include the information completed in Senior Seminar detailing the customer research data, which has been incorporated to support the design decisions.

Design Sections
Selection of Preferred Design Overall

Weighted Decision Matrices Descriptions (Overall & Z-Axis Matrix)

During the examination of different concepts a weighted decision matrix was used to determine what was the most feasible and cost effective solution/s to my and our team’s problems. The first decision matrix shown in the design selection appendices section of this document describes three different complete concepts and the second decision matrix describes three different possible drive solutions for the z-actuation system.

The overall design concepts were as follows:

CONCEPT A - Consisted of three independent boards moving in the X-axis, under a firing bridge, with a pneumatic linear device for movement in the Z direction. Cost, part variation, and speed variation were not acceptable. This plan would have consisted of six ACME lead screws, six independent stepper motors, and a lot of programming knowledge.

CONCEPT B - Consisted of a firing bridge riding on linear slides with a pneumatic linear device for movement in the Z direction. Cost, part variation, size, and speed variation were not acceptable. This plan would have consisted of a costly bridge design, more feet of linear slides, PLC’s, programming, and increased cost. For this particular design the boards would have been stationary.

CONCEPT C - Consist of a cross between concepts A and B. This design keeps the boards stationary while a firing bridge is transported on linear slides. A cost reduced bridge design powered by a stepper motor allows for movement in the Y, direction. The Z directional movement is accomplished with a pneumatic sequence of events. All linear motion will be controlled through a control box, which makes programming easier. Programming will be accomplished through various lines of G-code written by software, which interprets CAD files.

If one were to examine the appendices z-axis matrix on page 8, for the overall concept it has certain weighted values given to selected group criteria. The design criteria were as follows: Drive Size & Type, Parts Availability, Manufacturing Cost, Durability, Speed Variation, and Part Variation. Each of the above concepts was scored on these criteria. The scores were also based on information obtained from the house of quality shown in the Appendices research sections. Each of the drives examined had to meet certain safety, reliability, and ease of operation criteria, which were the main points, determined from survey and house of quality determinations. Once all of the criteria and scores were set, matrix calculations determined the best concept with the highest weight value, which
is shown on the decision matrix overall in the appendices sections. It turned out that Concept C was the best overall design. It had the highest overall weight value of 8. Concept B and A were not totally unfeasible, but there initial costs were too high for our budget and there were not as accurate, safe, or as controlled as concept C. Concepts A and B can be seen in Appendices H and I on page 9 following the z-axis decision matrix on page 8 in Appendix G. The final assembly design CAD drawing is shown in Appendix L.

Selection of Preferred Design-Individual Objectives

The Z-axis decision matrix on page 8 in Appendix G following the overall matrix in Appendix F and concepts was another tool utilized to determine the best type of actuation system for the Z-axis movement. The following concepts, descriptions, and overall rating are shown below. To view a detailed analysis from the weighted decision matrix one will need to look in the before stated Appendices F and G. This decision matrix helps determine what concept was the best overall for the design when looking at specific criteria such as part standardization, cost, and size to name a few. By determining certain weight values for each design criteria the best overall design was determined by a numbers rating system.

The drive concepts are as follows:

CONCEPT A - Consisted of a hydraulic actuator cylinder powered by a pump system and activated by a solenoid gate controlling the flow of fluid to power the cylinder. The gun would be mounted to a holder, which in turn would be attached to the hydraulic cylinder. When required the cylinder would move forward. Cost, part variation, and speed variation were not acceptable.

CONCEPT B - Consisted of an electric linear actuator device for movement in the Z direction similar to the set-up as described in concept A except it was slightly cheaper and did not require a hydraulic pump. Cost and part variation was not acceptable. Speed variation was adequate for what was required. This plan would have consisted of more costly parts than our budget would allow and would have to have electrical controls and an extra motor to drive the screw. This idea although good was still too costly for our budget.

CONCEPT C- Consisted of a pneumatic cylinder actuator with solenoid controls either to function on a timing sequence or off of the controller, which will drive the stepper motor with controlled signals. These signals will also be used to activate the electric air valve to allow the pneumatic cylinder to fire at its required times. The Z directional movement is accomplished with a pneumatic sequence of events, which proved to have the lowest cost, excellent speed variations, good durability, and readily available parts. Each of the drives examined had to meet certain safety, reliability, and ease of operation criteria, which were the main points, determined from survey and house of quality
determinations shown in the research appendices of this document. Also from examining existing products on the market enabled the design to follow a needed path based on current prices, research information, and selections that met the design criteria required by the customer based from the surveys and mechanically based on the calculated forces needed to operate the device.

For a more detailed look at the z-axis decision matrix one can view the matrix itself in Appendix G. One can see from this matrix that the pneumatic system had the highest overall rating of the systems examined for the z-actuation system. The Figures #6 and #7 represent two types of z actuators considered.
Z-Axis Movement Design

The design for the z-axis movement is as follows. It was accomplished by utilizing purchased and in-house manufactured pieces. The Z-axis movement for our design project will consist of two double-ended Clippard pneumatic cylinders with a three-inch stroke. These cylinders are mounted to the Y-axis bridge plate shown in the drawings in Appendix GG and interfaced with a pneumatic logic sequence. The trigger mechanism was manufactured from aluminum pieces and a small pneumatic cylinder all attached to the gun fixture. The pneumatic cylinder for the trigger mechanism is based on a fulcrum type set-up. Once the cylinder extends, it pushes the fulcrum down, raising the other side and pulling the trigger. This completes the sequence by firing the nail gun. By firing the gun all by mechanical means, eliminates the problem with the non-existent ergonomic set-up. This type of set-up is also a very cost effective way to fire the gun, thus decreasing testing labor costs. The plates used in the z-actuator are constructed of \( \frac{3}{8} \) “380 aluminum plating. This type of plating was selected because survey results shown in the appendices required that the device be durable. So thicker aluminum plating was chosen over the thinner \( \frac{1}{4} \)” aluminum. The cylinders themselves are represented visually in the purchased parts drawing appendices on page 22 in Appendix T. The cylinders have a 1.5-inch bore cylinder size. These cylinders are easy to operate and have good strength and reliability from test data supplied from Clippard Pneumatics. The cylinders are mounted into a floating C-channel in which the cylinders are mounted to a plate that is part of the y-axis design. This plate is shown in the extra X and Y CAD drawings in Appendix GG. This C-channel is constructed of three separates plates both shown on pages 17 and 18 in Appendices O and P. These pieces will be held together with mechanical fasteners such as hex head screws in three places on the top and bottom of the C channel shape. Their holes were drilled and tapped.

Controls Design

The controls for the operation of this prototype are as follows. The logic sequence is interfaced with an electron valve shown on page 22 in Appendix T, which is then interfaced with a control box also shown in Appendix QQ on page 46 of the appendices sections. The control box is a three-axis system that sends output signals to control all movement. The control box system will be covered in Jim Doogan’s design objectives and Jim will discuss its operation in greater detail. The pneumatic control box, which controls the pneumatic time sequence, is shown in the Appendix EEE. These controls are comprised of pneumatic valves, tubing, and the electronic control valve. The pneumatic counter is also attached to this device. It counts how many pneumatic pulses have been triggered. The pneumatic control valves can be adjusted for height to ensure compatibility with other types of nail guns. The overall programming of the device will be done by all team members to ensure that each person’s device will interact properly with each others designs and operate within the design specifications shown on the devices spec sheet located in Appendix A.
**Gun Fixture Design**

Once it was decided that pneumatic cylinders were to be used the next goal was to develop a fixture that would securely hold the guns while in operation. Pneumatics was chosen due to the performance and reliability. These selections were important to customers based on the survey-compiled data, which states reliability as a top concern for the device. For this application a 6 X 10 X 2-inch plate of 380 aluminum was machined to fit the profile of the gun. Overall the gun holder dimensions are roughly 8 inches by 3 inches, but the design has an irregular shape, which one can see on pages 15 and 16 in Appendices M and N, securely nest the handle of the nail gun and a toggle clamp will hold it in place. A toggle clamp will be mounted by the gun handle and used to secure the test gun in the gun holding fixture. The design of this holder was created in this fashion to create a stable gun holder environment for easy loading and unloading and for safety. The gun holder is also able to hold variety of guns from staple guns to finish nailers. The house of quality again listed safety as one if not the most important design criteria. These values for the house of quality are shown in Appendix E. A representative toggle clamp CAD drawing is viewable in Appendix V. A few other pertinent items for mounting the cylinders to the mounting plate are viewable in Appendix U.

**On Board Air Supply Design**

One objective of our groups design was to accommodate the test fixture with an on-board air supply. This intent was to provide air to the fixture regardless of test stand location. It would allow the fixture to become movable throughout the facility, only relying on a 120V power supply. This objective also encompasses a dual life test, by testing the Campbell Hausfeld contractor compressor, which will serve as the on board air supply system. A twin stack air compressor was provided by Campbell free of charge for the project air supply needs. This was mounted to a shelf on the lower section of the test stand. The supply air will run between 80psi and 100psi. The air pressure is kept low to ensure that safety is not compromised. This air compressor can be viewed in Appendix V or in any of the 3-d overall project drawings where the bottom of the cart is visible. The air compressor solves the problem of supplying air pressure to the pneumatics part of the device and thus eliminating the need for a dedicated air supply source and the need for dedicated space needed near a fixed air supply source.

**Safety Shield Design**

To provide for a safe life test environment, an 18-inch high perimeter enclosure has been constructed around the nail gun table. The enclosure is constructed of ¼-inch Plexiglas material. The shield has a hinged door in the front of the device with locking device in place while in use, and the remaining three sides are attached to the device via machined and drilled angle iron. This enclosure will protect from the possibility of any ricocheted nails. This shield can be seen on any of the 3-D CAD drawings showing the overall project. Appendices W, X, and DDD have good views of the safety shield that surrounds the device. This enclosure was tested with analytical impact equipment and the results
showed that the safety glass had impact strength over 1000lbf. The enclosure was also tested practically by putting a nail gun up to in and firing. The gun did mar the surface but these test conditions are extreme and the shield would only see a vector force at an angle and the force of the impact would be dramatically less than the test conditions. So it was decided that the 1/4-inch Plexiglas enclosure would be adequate for our safety needs. Also two emergency stop buttons will be placed on the system in the event of an immediate shut down. One button will be located on the control box. This button will shut down movement in all axes. Another button will be located on the table. This button will exhaust any high pressure, which is still in the system. The glass enclosure will also have one slide down panel, which will enable the user to change guns and reload nail. When this shield is down the systems power will be deactivated. The safety devices were added from the survey response data shown in the Appendices C and D. CAD drawings of the overall device are shown in the Appendices Drawings and Figures Section for both manufactured and purchased parts. Pages 15 through 18 of the Appendices M, N, O, and P show the manufactured z-axis parts, Appendices Q, R, and S show 3D Z-axis design, and Appendices T, U, and V show major purchased parts for the z-axis in illustrative form. Appendices W, X, Y, Z AA, BB, CC, and DD show 3D drawing of the overall system and X an Y axis systems broken out of the overall design. Appendices EE, FF, GG, HH, II, JJ, KK, LL, MM, NN, OO, and PP display CAD drawings for X and Y system manufactured parts. These pages cover 33 through 45 of the appendices and the system.

Again these CAD drawings with dimensions and tolerances can be viewed in the Design Elements Appendices. Our design team will manufacture the overall CAD assembly drawing shown in the Appendix I and X. The assembly and manufacturing of this device will be determined as we construct the device. The assembly process will be documented, though it is doubtful that this device will be manufactured again for sale so the design for manufacturing of this device will not be examined very closely now or in the immediate future. The selection of certain pieces for this prototype was based largely on cost and information obtained from customer research. Customer research was conducted through in house surveys conducted at Campbell Hausfeld. This information is contained in the Appendices B, C, D, and E. Once the survey information was compiled a house of quality was constructed and the most important design qualities were determined. The house of quality shown in Appendix E was important in the design of the safety shield and helped also in determining selection of the pneumatics for the z-actuation system because the pneumatics are easy and fairly safe to operate. Safety and reliability was of major importance from the survey responses. The pneumatic drive is a very reliable set-up. The calculations performed on this device in conjunction with the information obtained from customer surveys and the House of Quality was invaluable to the progress of the design and construction of the nail gun test stand prototype.

X and Y Axis General Overview

The two other design team members are designing the x-system, the y-system, drive mechanism, and programmable operation. Overall 3-D prototype drawings are shown in
Appendices W, X, Y, and Z. Appendix L shows an overall assembly CAD drawing showing the device with X and Y systems present. When designing these systems we had to determine specific forces needed to move the unit a certain distance in a specified time. We had to determine motor torque requirements, bearing forces, screw forces and life expectancies to name a few. Once we determined the desired force we needed to move the device at a certain speed, all that was left was to determine if the selected motors had enough power, thrust, and torque to meet these specifications. These calculations are explained better in one or both of my other two-team members design papers. The drive motors selected are NEMA 23 stepper motors shown in the figure below.

![Diagram of STP-MTR-23055](image)

**Figure #8**

**Calculations**

*Loading Condition and Calculations for Z Axis*
When the Z-axis operation was examined closely, a few needed values stood out. Mainly the downward force required to initiate the firing of the gun due to the safety mechanism on the tip, the bending forces acting on the cylinder rods and food brackets, the deflection to the support rods caused by the gun holding apparatuses weight, and the vibrational analysis of the support rod system caused by the firing and impact repetition of the Z-actuation system and nail gun. In designing the Z-actuation system, these are the calculations and analyses that were looked at to obtain appropriate design sizes and values. The calculations and equations used to obtain this information was obtained from the Physics, Design of Machine Elements, and Machine Design texts listed in the Reference Section numbers IV, V, and VI. The equations used to determine the following data will be number referenced in the Appendices Calculations Sections.

The main loading conditions that were looked at were gun impact force requirement and bending forces created on the actuator cylinder rods. In Appendix ZZ there is a data sheet with graph representing the force data collected to activate the guns safety mechanism followed by the data points collected over 0.25 inches of test range. The data shows it takes only 3.5lbs to overcome this spring locking safety mechanism. The bending forces calculated represented by the figure below were determined to be roughly 2.225 N-m or 19.75 in-lbs of torque which is significantly less than the load rating on the cylinders. These calculations can be viewed in the Appendix VV with the data tables for bending stresses shown in Appendix TT. The forces that were calculated in the tables were not excessive for the materials used to support and supply them.

Next the amount of deflection that occurs in the rods that support the gun and gun fixture systems was examined and determined. It was determined experimentally that the weight of this system was roughly 10 lbs. This weight was used to determine how much deflection would occur in both rods based on the diameter of rod used. The deflections were determined for rod of 0.5in, 0.75in, and 1.0 in diameters. The calculations were done using the lumped system approach. The figure below represents this system.
The figure above shows how the mounting plate rides on the slide rails and had two major points of contact, which were lumped into one system. When the calculations were done for the amount of deflection the results were good for all three diameters of rods with the smaller diameter rods deflecting more than the thicker diameters. The rod diameter chosen was 0.75 inches and had a deflection of 0.171mm per rod. This rod was chosen because it had minimal deflection, nominal size and we felt that this amount of deflection would not cause any problems with proper operation of the device. The calculations can be viewed in Appendix WW and the data tables are shown in Appendix UU. The bending stress determinations were calculated using formulas obtained from the Reference book # 3, Applied Strength of Materials.

**Vibrational Analysis of Z-Actuation System**

The final calculations completed for the device were done to determine the natural frequency of the support rod when hit with a rhythmic impact force from the extending and retracting pneumatic firing mechanism. The system examined was determined to be a uniform, simply supported beam with the mass concentration in the center and taking into account the mass of these rods since their weights are not negligible in these calculations. The equations used were to determine the natural frequency were taken from the Shock and Vibration Handbook shown in the reference section. The natural frequencies were determined for the 0.5in, 0.75, and 1.0in rods, although since the 0.75in...
rod was chosen for our design it is really the only value we are concerned with. The
natural frequency for the 0.75in rod was determined to be 21.64 Hz. We are not sure if
our system will reach this frequency until we go into the testing phase of our design and
if the system does come close to this frequency we can dampen the response of the device
with some sort of damping or insulative material to change its frequency response during
the Z-actuator operation. The natural frequency and vibrational analysis of this systems
calculation can be seen in Appendix XX with corresponding data tables shown in
Appendix UU. If any other calculations are needed during our building process they will
be completed on a needs basis only. Our team has determined that the structural material
is more than adequate to handle any static or dynamic loading that may occur. All
equations obtained for the vibration determinations came from the Reference
number II book, Shock and Vibration handbook by Cyril Harris.

Prototype Build

The building of the semi-automated tester was one that required a multitude of organized
steps. The following list of equipment was used in the manufacturing and machining of
needed parts and fixtures for the nail gun tester. Some of the purchased parts also had machining done to them to make them acceptable for our building purposes. The purchased parts were ordered first so that if machining on them was necessary it could be done in a reasonable amount of time and to make sure parts were correct in size and nature. This enables us to make the work envelope of the table and design would be met. Several purchased parts, which are shown in the budget layout of the appendices, were purchased from several website vendors. Website with the reference numbers 5, 6, 7, 9, and 10. These websites were used to purchase the Table, L-Supports, Screws, Bearings, Screw Holders, Squeeze Blocks, Linear Slides, Stepper Motors, Motor Controller, X-Axis Tracks, and X-Axis Roller Carriages. These major parts are the main structural components of the Nail Gun Test Stand. These parts and their part numbers are displayed in the purchased parts table/list in Appendix K.

**Equipment Used to Construct Semi-Automated Nail Gun Tester**

1) Bridgeport 3 Axis End Mill (1/4, 1/2, and 1 inch mills used)
2) 2 Flute Center Cutting Mill
3) Ball Mill
4) Bridgeport Drill Press
5) MIG Welder
6) 10-20, ¼-20, and 3/8 taps
7) Chop Saw, Band Saw, and Metal Grinder

Representative pictures of the equipment used for part manufacturing can be viewed in Appendix BBB.

The first step was the selection of the test table. This item was purchased instead of build from a catalog. The table was steel constructed and had a maximum weight capacity of 3000 lbs. The testing apparatus located on the surface of the table has a maximum weight of approximately 200 lbs. On the table surface the purchased and machined parts for the X and Y-axis operation will be fastened.

**X-Axis Construction**

Starting with the X-axis, first the tracks are laid and fastened into place using a battery powered drill to create the holes and ¼ inch hex screws to fasten them down. The tracks were ordered to size. They were mounted 2 inches from the front and back sides of the table. The L-brackets, which are the main tester supports, ride on purchased carriages and are attached to the L brackets via ¼ in tapped threads. These L brackets can be viewed on any assembly drawing. These holes were drilled with the Bridgeport drill press. The X-acme screw was mounted to the table via two bearing supports and was attached to the stepper motor with a ¼ inch coupler. The 1 inch screw had to be turned down to a half inch to fit in the support bearing holder then to ¼ inch to be able to be coupled with the stepper motor. This same machining process was also applied to the Y-axis drive screw. It was attached to the L angles in the same fashion. Both of these screws were turned.
down on a Bridgeport lathe. A representative picture of this device can be seen in the build appendices. The X stepper motor was mounted to the table with the aid of a manufactured mounting plate. The X-axis also had holes drilled in the table adjacent to the slide tracks for safety limit switches to be mounted with ¼ inch hex screws. (See corresponding drawings in Appendices II, JJ, KK, MM, and PP to view some hole callouts). Appendix CCC-1 has an actual digital photo of the X-axis prototype.

**Y-Axis Construction**

The Y axis device was comprised of the X-axis L brackets, acme screw and supports, linear slides with supports, carriage plate, carriage support blocks, roller press bearings, motor mounting bracket, and the drive nut holder. The acme screw is mounted to the back side of each L bracket with bearing supports and is turned down to size, similar to the X-axis screw to fit in the bearing supports and couple to the Y-axis drive motor. These mounts are held in place by ¼ inch hex screw with nuts. The holes are through holes in the L brackets for all mounting pieces attached to them. The carriage is constructed of a ½ inch aluminum plate cut to size using a band saw and tap in several locations with a ¼ 20 UNC tapped threads. The hole locations can be seen in the appendices drawing sections. The support blocks were drill with the Bridgeport drill press and have tap locations on them so the are able to be mounted to the carriage plate via through hole through it. The drill holes in the 4 carriage support block, located on the back of the carriage plate, have linear slide bearings pressed into the holes so that they ride smoothly while traveling on the linear slide rods. The ¾ inch slide rods are held into place with brackets which is mounted with through holes in the L Brackets with ¼ inch hex bolts and nuts. This set-up, with dimensions and hole locations can be viewed in the design drawing appendices. The drive motor is mounted to the L bracket via a manufactured motor mount also shown in the drawing appendices. The carriage has tapped holes located on the face of the carriage plate to accept the mounting screws from the foot brackets of the pneumatic cylinders for the z-actuation system. The control box is mounted inside of a steel box welded with a MIG welder to the undercarriage of the table with data supply lines to he two stepper motors and the electronic valve in the pneumatic control box. Electric limit switches and hard stops were mounted to each side of the Y-axis travel to power down the device in case of travel malfunction. (See corresponding drawings in Appendices GG, HH, LL, and OO to view hole callouts). Appendix CCC-2 has an actual digital photo of the Y-axis prototype.

**Z-Axis Construction**

The z-axis build started with the construction of the pneumatic cylinder C-channel. This is where the pneumatic cylinders will be mounted. The C-channel is comprised of three ½ inch aluminum plates. These plates with their dimensions, holes locations, and callouts are shown in the drawing design appendices. These plate cut to size with the Bridgeport band saw shown in the Build Appendices. The holes centers on the plates were punched then drilled with a ¼ inch drill on the Bridgeport drill press. The holes
were then tapped with 10-20 UNC standard thread tap so that the three plates could be assembled with hex head screws. The holes in the plates had a countersink to minimize screw protrusions. The pneumatic cylinders were mounted with nuts placed on the ends of the cylinder rods since they were threaded. The foot brackets fit around the cylinders themselves enabling us to mount the C channel and cylinders to the Y axis carriage’s 3/8 inch through holes. (See corresponding drawings in Appendices O, P, and GG to view hole callouts). Appendix DDD has an actual digital photo of the X-axis prototype.

Gun Fixture Construction

Next was the construction of the gun fixture. This was cut out of a solid piece of aluminum approximately 9” L x 6” W x 2” T. This was inserted in the Bridgeport CNC ball mill and was cut to shape using a program designed by the Nail Gun Team. The CNC programs used to mill this piece are shown in Appendices GGG and HHH. Once cut it had holes drilled on the drill press and tapped with 10-20 standard threads. This piece was then mounted to the C-channel. Next the toggle clamp was mounted over the handle section with hex head screws into 10-20 tapped holes of the gun fixture to secure the gun in place. The air was supplied by the on board air compressor located under the tabletop placed on wood boards. (See corresponding drawings in Appendices M and N to view hole callouts)

Board Holder Construction

One of the design objectives for this device was to create a structure to securely hold the board targets in place during testing. The table was drilled in 6 spots with hole locations shown in the callouts in the drawing appendices. These holes are spaced to fit the 2x6 boards. Solid metal spacers are placed over the holes and are bolted into place with 1/8 inch angle iron cut to length to support the boards and have cut-outs to go around the remaining bolts. The boards are placed in between the square block metal spacers and have another 1’x3’x1/8” metal stock bolted down to hold the boards in place. A support block CAD drawing can be viewed in Appendix MM.

Pneumatic Controls Construction

The pneumatic controls were constructed with a series of mechanical, pneumatic valves located in various positions on the Y-and Z-mechanics of the device. These valves controlled the path of the pneumatic air pulse from the electronic valve. These valves were mounted using Clippard Pneumatics’ special mounting hardware, steel rods, clamps, and connected with 1/8 pneumatic tubing. The pieces were mounted mainly using through drilled 3/16 inch and ¼ inch holes in various locations on the device. The hole call-outs are shown in the drawings in the Design Appendices. The pneumatic controls box is located directly under the tabletop containing all of the pneumatic logic sequence control valves. This box is bolted to the table via ¼ in through holes and hex
head bolts and nuts. A picture of the pneumatic control box can be viewed in the build appendices section. The manifold that was done by the machinist was attached to the underneath side of the table which controls the air supply either to be supply by shop air or onboard air. (See corresponding drawings in Appendix EEE to view hole callouts)

**Trigger Mechanism Construction**

The trigger mechanism is located off of the front side of the gun fixture. This device is comprised of a small pneumatic cylinder, which is part of the pneumatic sequence. The cylinder is attached to a through hole of an aluminum rod and the rod is attached by a center through bolt to a small square rod protruding from the bottom of the gun fixture to create a fulcrum point. One of the teeter-tottering rod ends is located under the trigger mechanism of the gun. Once the gun extends down towards the target, one of the pneumatic valves is depressed causing the signal from the pneumatic controls to send air to the trigger air cylinder thus depressing the trigger on the nail gun. The trigger rod once activated depresses another pneumatic valve that resets the pneumatic sequence for another firing sequence. The trigger mechanism can be seen in the device digital picture in Appendix DDD.

**Safety Shield Construction**

The final part of the build concerned the construction of the safety shield located around the perimeter of the tester. Since the tester is going to be used in house, the device will not be fully enclosed. If this device was going to be sold to the general public, the safety shield would fully enclose the testing mechanics of the device. The shield is held in place with the aid of 1/8 inch steel angle iron cut to 18 inches in the from and 10 inches in the back. The front and back shields are respective in their heights. The side slopes from 18 inches in the front to 10 inches in the rear. The angle iron was drilled with a drill press create through holes. The ¼ inch thick Plexiglas shield was drill with holes respective to the holes in the angle iron pieces. The angle iron was MIG welded to the corners of the table. The two sides and back pieces were mounted with through hole bolts of 1/8 inch with nuts. The front shield had 4 inches of glass cut from each side and had the small pieces mounted to the front angle iron pieces. The remaining large front piece was drilled with a power drill and had hinges attached to in with hex bolts and nuts and was mounted to the front face of the tabletop. Small slide locks are mounted to the small pieces of glass with their counter pieces mounted to the fold down door piece to create a locking position so the door on the front of the device can be opened when maintenance is required and secured back in place during operation. The top section of the glass is covered with a rubber seal to protect the user from contacting any of the sharp edges of the safety shield. (See corresponding photo in Appendices DDD and FFF.) An overall prototype photograph can be viewed in Appendix FFF.

**Prototype Testing**

**X and Y Axis and Voltage Testing**
The next step following the construction of the prototype was the process of testing the functionality of applicable components. The testing of how well the components went together was part of the construction process, and proved to the team that the project was designed well and met design tolerances due to the good parts mating. The testing of X-axis components first involved the rollability of the L brackets on the carriage slides. We visually determined how well the moved on the tracks presenting minimal frictional response and interference. The L-brackets performed well on the tracks and would provide for a smooth operational response when needed. The next step was to test the movability of the Y-axis carriage to make sure it moved freely. From visual tests, the carriage moved freely on the support rods. After it was determined that the X and Y assembly moved freely the X and Y screws were attached and they were tested first by hand rolling them to make sure they moved freely. We powered up the device to test the programming that drives the motors. The voltages were measured with a volt meter to make sure that the voltage of the system didn’t exceed 120v and the motor control box was outputting 28vAC to the motors and 28vDC to the pneumatic, electronic valve. The meter showed these voltages to be within tolerance.

Program Testing

After voltage determinations, the programming was initially tested. The CAD drawings were imported to ensure compatibility with the system. Once the drawings were imported and the program MACH 2 accepted and converted the files, the program was set into motion and the movements were measured to see if they met the design requirements of ¼ inch per movement. The device movement was measured and the movement was ¼ inch per cycle and could be set to more precise movements. The movements were also visually tested to make sure they operated to the precise movements in the desired sequence. After visual and manual measuring the device proved to be in good working order.

Z-Axis and Pneumatics Testing

The air pressure was tested with a pressure gauge and proved to be within the desired range of 80 to 100 psi. After air pressure was determined to be correct, the pneumatic sequence and all applicable pneumatic components were tested to make sure of proper function. The program was run which sent a signal to the electronic valve to start the sequence. The gun fixture moved down, the valve on the bottom depressed, the pneumatic sequence continue and the trigger cylinder extended thus pulling the trigger. The gun fired and the next valve was depressed send the gun to the upward position and this in turn depressed the upper pneumatic valve which put all of the pneumatic devices in the home position. Once in the home position the pneumatic, electronic valve is waiting for the next signal from the 3-axis control box. Once the cycle was run it was visually determined to be operating smoothly and properly.

Board Holder Testing
The board holders were tested practically by firing the nail gun into it during a test run of the device. The board holders proved to be of adequate strength and durability. The holders kept the targets stable and in place during all test runs. They proved to be easy in the operation and function. The test run for these holders prove to be a success.

**Cycle Time Testing**

The final test was to measure the cycle time with a timepiece. The cycle initially was over the desire two second cycle time, but with a little manipulation of the program and stroke length of the cylinders, the cycle time was set to the desired cycle time of two seconds. With more manipulation of the stroke length and the program a cycle time of less than two seconds could probably be achieved.

**Safety Shield Testing**

The testing of the safety shield was done back during the design phase. The shield material was tested a laboratory with a Dynisco Impact tester and proved to have an impact strength of approximately 600 to 1000lbs of force. The shield was also practically tested by shooting a nail gun at it in a controlled environment. The shield marred but never cracks. After testing, it was decided that the shield would provide the needed perimeter protection it was design to achieve. Laboratory impact results for the safety shield can be viewed in the Appendix YY.

**Testing for Cost Reductions**

The cost of testing was one of the problem elements that the Nail Gun Team was trying to reduce for Campbell Hausfeld for their life testing. With the construction and proven function-ability of the nail gun tester we were able to reduce the labor costs for each cycle approximately 50 % from $2000.00 to $1000 and were also able to minimize waste of materials used for testing. It was determined that 3400 nails could be fired into each board with testing prototype. This means testing can be completed with 44 boards instead of the traditional 50 to 70 boards required when the testing was complete manually. With further modifications to the prototype testing cost could be reduced even further. This will be discussed in the recommendations section to follow.

**Conclusions/Recommendations**

From the beginning of this project there was a specific timeline of deliverables and recommendations to spur the Nail Gun Team forward in the design process. Now that the
process has terminated for the design team, numerous conclusions and recommendations for future modifications to the prototype have been discovered. These modifications are the conglomeration of input and advice from the Nail Gun Team, company sponsor, and other qualified technical personnel that will be associated with the device now and in the future. The suggested modifications from the multiple inputs did have overlapping ideas and these will be discussed in the further paragraphs.

At the conclusion of our building and testing of the nail gun test stand, we determined that the design was operating to the standards in which the design team had intended. The movement and firing of the nail operated with precise movement and had precisions within the desired design parameters. The operation, programming, and mechanics of the designed system met or exceeded the design specifications put forth in the beginning of Senior Design Project I as our proof of design agreement. As a team, the design members concluded that the design was sound and a viable product for research testing.

The design team discovered certain upgrades or modifications needed to the test stand after conclusions were made as to the validity and operation of the tester. Outside technical recommendations were also taken into consideration as to possible upgrades to the testing device. The first recommendation was to change the pneumatic drive for the z-axis operation to a precision linear slide. This would decrease cycle time and utilize the third drive output as a stepper motor as it is intended. The second upgrade would be to change the acme screws to precision ball screws to increase X and Y movement to even more precise increments. If this device was going to be sold to the public a full Plexiglas enclosure would be needed to eliminate any safety concerns with the device. The addition of a gas generator would make the testing device fully self sufficient and completely mobile. Another upgrade to the device would be to add multiple testers so that more than one nail gun can be tested at one time. This would involve some firing counter upgrades also. These are the design team’s recommendations along with other technical support recommendations.

The final and most important recommendation/upgrade to the test stand would be to add an automatic nail gun re-loader. This would eliminate the need for a technician to be with the machine on a regular basis. The loader could be set up to load approximately 10000 nails which is the maximum amount of nail space on the three boards mounted to the tester. The addition of this device would make the nail gun tester virtually fully automatic. A technician would have to return every six hours to replace the board targets and reload the auto-nail loader. This would increase the cost savings for Campbell Hausfeld approximately $1000.00 dollars more per test cycle. Campbell Hausfeld technical and managerial personnel also suggested this recommendation.

In conclusion, the current tester met the needs of our sponsoring company. The device is now in service with Campbell Hausfeld’s air products division. The device is currently being used for life testing of finish nailers. With the addition and upgrade of a few devices on the current tester, this device could be patented and sold to other manufacturers of air-powered products for a significant profit.
REFERENCES INFORMATION

The following list of people has contributed to the development of the design of the nail gun life-testing unit. The contributing list of people was not directly cited in the proposal, but they will be identified in the following paragraphs as to their relation to the project and their contributions to the nail gun team at the present time.

From the sponsoring company Campbell Hausfeld the follow list of employees contributed to the development of the nail gun tester: Chuck Shoemaker, Brian Humpert, Bobby Lawrence, Greg Kramer, and James Happy. Chuck Shoemaker and Brian Humpert were the management contributors that approved the project for funding from Campbell. Bobby Lawrence was also a management/ engineer sponsor that gave us input on possible design solutions and design support. Greg Kramer is the lead technician on nail gun life testing at Campbell Hausfeld. He gave input as to the tester itself as to what he would like to see. The nail gun failures from previous testing are given to him for analysis. James Happy is a technician with exceptional mechanical skills dealing with testing devices and mechanisms. He was pivotal in the idea and conceptual stages of the project and is great asset with the ongoing development of the nail gun-testing project from its design to manufacturing.

The following list of people was also very important in the development stages of the design proposal and the design process itself. Several of the U.C faculty was also crucial in the development of this design. They were Kettt Cedercreutz, Paul Weisgerber, and Maria Kreppel. Paul and Maria helped in the initial stages of the proposal. Professor Cedercreutz, our project advisor, was crucial throughout the design process to keep us on track and help us maintain a positive work schedule.

The following list of Technical References were used in the planning, designing, calculating, sizing, and ordering of our design and its components. No direct information was taken from these sources and used in my text of my report. These resources were used for informational purposes only to give me and my teammates direction on the steps necessary to size specific parts for our design and give us a few equations which were basic equations that can be found in any machinists handbooks or physics texts. These books listed as technical references are listed as acknowledgements not directly cited texts. In the appendices calculations sections some of the formulas used will be referenced and to which source they were taken from.

The websites were used in similar fashion as to the texts explained above. The build sections described above will reference the listed websites as sources for ordering parts necessary for the construction of the tester prototype. These websites provided direction as how to design certain segments of our drive systems and some were used directly for ordering parts. Granted some parts were donated such as most of the equipment from Clippard Pneumatics, which was one of our company visits. TKS Industries was another one of our company visits in which we learned a few things about linear motion devices but later determined that this company, while fitting our products needs, failed to provide cost effective products.
REFERENCES SOURCES (Books, Websites, and Company Visits)

Technical Research Sources

Books-Bibliography


II. **Engineering Vibration.** Inman, Daniel J. Prentice –Hall, Inc. Copyright 1994. Pg. 6, 314


Technical and Vendor Websites

2. [http://www.roymech.co.uk/Useful_Tables/Tribology?Plain_Bearing%20Friction.html](http://www.roymech.co.uk/Useful_Tables/Tribology?Plain_Bearing%20Friction.html)
5. [http://www.clippard.com](http://www.clippard.com) (pneumatics)
6. [http://www.automationdirect.com](http://www.automationdirect.com) (motors)
7. [http://www.xylotex.com](http://www.xylotex.com) (controller)
8. [http://www.geckodrive.com](http://www.geckodrive.com)
10. [http://www.enco.com](http://www.enco.com) (Screws)

Company/Vendor Visits:

1. TKS Industries- Linear Motion Technology
2. Clippard Pneumatics
3. Campbell Hausfeld
## APPENDIX A-DESIGN AGREEMENT PROJECT
### MANUFACTURING SPEC SHEET

### Automated Nailer Test Station

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Automated Nailer Test Station is equipped to handle brad and finish</td>
<td></td>
</tr>
<tr>
<td>nailers for life testing purposes. Through the use of stepper motors and</td>
<td></td>
</tr>
<tr>
<td>linear systems the test station will perform the act of firing 150,000</td>
<td></td>
</tr>
<tr>
<td>nails into a wood target. A controller box and PC will be used to control</td>
<td></td>
</tr>
<tr>
<td>motion in a three axis plane. A user-friendly interface will provide for</td>
<td></td>
</tr>
<tr>
<td>easy operation. Unit cost is approximately $2,500.</td>
<td></td>
</tr>
<tr>
<td>Dimensions</td>
<td>See drawings</td>
</tr>
<tr>
<td>Table</td>
<td>14 gauge steel</td>
</tr>
<tr>
<td>Bearings</td>
<td>Ball bearings</td>
</tr>
<tr>
<td>Mounting</td>
<td>hex screws</td>
</tr>
<tr>
<td>Electrical connections</td>
<td>shielded</td>
</tr>
<tr>
<td>Size</td>
<td>work envelope 4ft X 6ft</td>
</tr>
<tr>
<td><strong>Electrical Data</strong></td>
<td></td>
</tr>
<tr>
<td>Power supply voltage</td>
<td>Standard 120V AC</td>
</tr>
<tr>
<td>Current consumption</td>
<td>Amps (1-5)</td>
</tr>
<tr>
<td>Output voltage</td>
<td>Volts 32VDC</td>
</tr>
<tr>
<td>Current for digital output</td>
<td>Volts 15VDC</td>
</tr>
<tr>
<td><strong>Mechanical Data</strong></td>
<td></td>
</tr>
<tr>
<td>Dimensions</td>
<td>See drawing</td>
</tr>
<tr>
<td>Starting torque</td>
<td>0.136 Nm</td>
</tr>
<tr>
<td>Highest permissible speed</td>
<td>1500 RPM</td>
</tr>
<tr>
<td>Mechanical travel</td>
<td>inches, X, Y, Z</td>
</tr>
<tr>
<td>Mounting</td>
<td>hex screws</td>
</tr>
<tr>
<td>Weight</td>
<td>1000 lbs</td>
</tr>
<tr>
<td>Rapid feed rate</td>
<td>0.25 inch, every 2 seconds</td>
</tr>
<tr>
<td><strong>General Data</strong></td>
<td></td>
</tr>
<tr>
<td>Maximum load static</td>
<td>3000 lbs</td>
</tr>
<tr>
<td>Maximum load dynamic</td>
<td></td>
</tr>
<tr>
<td>Pitch</td>
<td>5 threads per inch</td>
</tr>
<tr>
<td>Ball Screw Dia.</td>
<td>1.5 inch</td>
</tr>
<tr>
<td>Wheels</td>
<td>6in. X 2in. Plastic</td>
</tr>
<tr>
<td>Machine weight</td>
<td>&lt;3000 lbs</td>
</tr>
<tr>
<td>Completion time</td>
<td>150,000 nails</td>
</tr>
<tr>
<td><strong>Environmental Data</strong></td>
<td></td>
</tr>
<tr>
<td>Life time</td>
<td>PVM 6months</td>
</tr>
<tr>
<td>Temperature range</td>
<td>40F-120F</td>
</tr>
<tr>
<td>Vibration</td>
<td></td>
</tr>
<tr>
<td>Shock</td>
<td></td>
</tr>
<tr>
<td>Protection case</td>
<td>Plastic housing</td>
</tr>
<tr>
<td>Air power required</td>
<td>90 psi</td>
</tr>
<tr>
<td><strong>Special Features</strong></td>
<td></td>
</tr>
<tr>
<td>Very robust</td>
<td></td>
</tr>
<tr>
<td>Nail counter</td>
<td></td>
</tr>
<tr>
<td>User friendly interface</td>
<td></td>
</tr>
<tr>
<td>Emergency stop</td>
<td></td>
</tr>
<tr>
<td><strong>Possible Options</strong></td>
<td></td>
</tr>
<tr>
<td>Automatic reload</td>
<td></td>
</tr>
</tbody>
</table>

Michael N. Orschell
Marcus J. Waggoner
James J. Doogan

Professor Kettit Cedercreutz

[Signature]

JAN 25TH, 2005
APPENDIX B- Customer Survey

Automatic Nail-Gun Tester Customer Survey

A group of seniors are attempting to design an Automatic Nail-Gun Tester. Please take 10 minutes to fill out this customer survey and return it to the student marketer.

Please indicate the level of importance you attach to the following aspects of a NGT
1 = low importance  5 = high importance
(maximum number of 5’s that can be selected can be only 5 )


Please list any other improvement features you would like to see in the Nail-Gun tester.

Would you be willing to pay more for digital gages, sensor, nail counter and a senor for low nails in the gun?  Yes No

If you answered yes to the previous question, how much more would you be willing to pay?

What order would you prioritizes in the order of importance to you
   digital gages, sensors, nail counter, a sensor for low nails in the gun

Is there a Nail-Gun tester currently used in your place of employment?

What size limitations would you have?
### APPENDIX C - Compiled Survey Data

#### Appendices I. QFD Information

**Automatic Nail-Gun Tester Customer Survey**

A group of seniors are attempting to design an Automatic Nail-Gun Tester. Please take 10 minutes to fill out this customer survey and return it.

Please indicate the level of importance you attach to the following aspects of a NGT

1 = least importance  
12 = most importance  

(Rank for the least important to the most important)

| 1. Cost of building the tester | 1 (0) 2 (0) 3 (0) 4 (1) 5 (2) 6 (1) 7 (1) 8 (1) 9 (0) 10 (1) 11 (0) 12 (2) | Average Ranking | 8 |
| 2. Mobile | 1 (0) 2 (1) 3 (1) 4 (3) 5 (2) 6 (2) 7 (0) 8 (0) 9 (0) 10 (1) 11 (0) 12 (0) | 4.9 |
| 3. Ease of Maintenance | 1 (0) 2 (0) 3 (0) 4 (0) 5 (0) 6 (1) 7 (1) 8 (0) 9 (4) 10 (3) 11 (1) 12 (0) | 9 |
| 4. Multiple gun holders | 1 (0) 2 (1) 3 (0) 4 (0) 5 (2) 6 (0) 7 (2) 8 (1) 9 (2) 10 (1) 11 (1) 12 (0) | 7.3 |
| 5. Self contained Air supply | 1 (2) 2 (4) 3 (1) 4 (0) 5 (2) 6 (0) 7 (0) 8 (0) 9 (0) 10 (0) 11 (0) 12 (1) | 3.5 |
| 6. Testing stand size | 1 (0) 2 (1) 3 (2) 4 (0) 5 (0) 6 (3) 7 (1) 8 (1) 9 (0) 10 (1) 11 (1) 12 (0) | 6.2 |
| 7. Part standardizing | 1 (0) 2 (0) 3 (2) 4 (1) 5 (1) 6 (1) 7 (1) 8 (3) 9 (1) 10 (0) 11 (0) 12 (0) | 6.1 |
| 8. Durability/ reliability | 1 (0) 2 (0) 3 (0) 4 (0) 5 (0) 6 (0) 7 (1) 8 (1) 9 (1) 10 (1) 11 (3) 12 (2) | 9.2 |
| 9. Noise Sound level when operating | 1 (0) 2 (2) 3 (3) 4 (2) 5 (0) 6 (0) 7 (0) 8 (2) 9 (0) 10 (1) 11 (0) 12 (0) | 4.7 |
| 10. Safety | 1 (0) 2 (1) 3 (0) 4 (0) 5 (0) 6 (0) 7 (0) 8 (1) 9 (1) 10 (1) 11 (1) 12 (5) | 10 |
| 11. Ease of installation | 1 (0) 2 (0) 3 (1) 4 (1) 5 (1) 6 (1) 7 (3) 8 (0) 9 (1) 10 (0) 11 (0) 12 (0) | 5.8 |
| 12. Aesthetics/ appearance | 1 (7) 2 (0) 3 (0) 4 (1) 5 (0) 6 (0) 7 (0) 8 (0) 9 (0) 10 (0) 11 (2) 12 (0) | 3.3 |

Please list any other improvement features you would like to see in the Nail-Gun tester.

Would you be willing to pay more for digital gages, sensor, nail counter and a sensor for low nails in the gun?  
Yes  No

If you answered yes to the previous question, how much more would you be willing to pay?  
Between the cost $1.00 to $20.00

What order would you prioritize in the order of importance to you  
_____digital gages,_____sensor,_____nail counter,_____sensor for low nails in the gun

Is there a Nail-Gun tester currently used in your place of employment?  
Yes  No  Maybe
### APPENDIX D - Actual Survey Results for Each Question

#### Survey Results from Campbell Hausfeld Employees

<table>
<thead>
<tr>
<th>Question #</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey #</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>12</td>
<td>6</td>
<td>7</td>
<td>5</td>
<td>2</td>
<td>11</td>
<td>4</td>
<td>9</td>
<td>8</td>
<td>10</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>10</td>
<td>9</td>
<td>5</td>
<td>12</td>
<td>7</td>
<td>8</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>3</td>
<td>6</td>
<td>8</td>
<td>1</td>
<td>10</td>
<td>5</td>
<td>7</td>
<td>2</td>
<td>9</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
<td>5</td>
<td>10</td>
<td>9</td>
<td>2</td>
<td>6</td>
<td>3</td>
<td>8</td>
<td>4</td>
<td>12</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>4</td>
<td>9</td>
<td>10</td>
<td>2</td>
<td>6</td>
<td>8</td>
<td>11</td>
<td>3</td>
<td>12</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>2</td>
<td>10</td>
<td>9</td>
<td>1</td>
<td>6</td>
<td>3</td>
<td>12</td>
<td>8</td>
<td>11</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>10</td>
<td>5</td>
<td>9</td>
<td>11</td>
<td>2</td>
<td>3</td>
<td>6</td>
<td>12</td>
<td>4</td>
<td>8</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>4</td>
<td>11</td>
<td>7</td>
<td>5</td>
<td>2</td>
<td>9</td>
<td>10</td>
<td>3</td>
<td>12</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>6</td>
<td>4</td>
<td>10</td>
<td>7</td>
<td>5</td>
<td>3</td>
<td>8</td>
<td>11</td>
<td>2</td>
<td>12</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>6</td>
<td>9</td>
<td>2</td>
<td>3</td>
<td>8</td>
<td>7</td>
<td>11</td>
<td>10</td>
<td>12</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Average</td>
<td>8</td>
<td>4.9</td>
<td>9</td>
<td>7.3</td>
<td>3.5</td>
<td>6.2</td>
<td>6.1</td>
<td>9.2</td>
<td>4.7</td>
<td>10</td>
<td>5.8</td>
<td>3.3</td>
</tr>
</tbody>
</table>

- **Average** represents the average of the survey results for each question.
# APPENDIX E- QFD – HOUSE OF QUALITY

## Nail Gun Tester House of Quality

Jim Doogan  
Mike Orschell  
Marc Waggoner

<table>
<thead>
<tr>
<th>Ergonomics</th>
<th>Customer Importance</th>
<th>Testers on Market</th>
<th>Planned Tester</th>
<th>Improvement Ratio</th>
<th>Sales Points</th>
<th>Improvement Ratio</th>
<th>Relative Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ease of Installation</td>
<td>9 3 3 3</td>
<td>5.8 1.0 1.0 1.5 8.7</td>
<td>0.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of maintenance</td>
<td>3 9 3 3</td>
<td>9.0 1.0 3.0 1.5 40.5</td>
<td>0.16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Easy to load guns</td>
<td>9 9 3 3</td>
<td>9.0 1.0 1.0 1.0 9.0</td>
<td>0.04</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strength</th>
<th>Customer Importance</th>
<th>Testers on Market</th>
<th>Planned Tester</th>
<th>Improvement Ratio</th>
<th>Sales Points</th>
<th>Improvement Ratio</th>
<th>Relative Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durable/Reliable</td>
<td>1 9 3</td>
<td>9.2 1.0 3.0 1.5 41.4</td>
<td>0.16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>New Features</th>
<th>Customer Importance</th>
<th>Testers on Market</th>
<th>Planned Tester</th>
<th>Improvement Ratio</th>
<th>Sales Points</th>
<th>Improvement Ratio</th>
<th>Relative Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile</td>
<td>3 9</td>
<td>4.9 1.0 3.0 1.0 14.7</td>
<td>0.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self contained air supply</td>
<td>3 9</td>
<td>3.5 1.0 3.0 1.5 15.8</td>
<td>0.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small Footprint Size</td>
<td>3 9</td>
<td>6.2 1.0 2.0 1.0 12.4</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gun Stabilization</td>
<td>9 9</td>
<td>7.3 1.0 2.0 1.0 21.9</td>
<td>0.09</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parts Standardization</td>
<td>9 3</td>
<td>6.1 1.0 2.0 1.0 12.2</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aesthetically Pleasing</td>
<td>1 9 3</td>
<td>3.3 1.0 2.0 1.0 6.6</td>
<td>0.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Safety Features</th>
<th>Customer Importance</th>
<th>Testers on Market</th>
<th>Planned Tester</th>
<th>Improvement Ratio</th>
<th>Sales Points</th>
<th>Improvement Ratio</th>
<th>Relative Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nail Richochet</td>
<td>9 9</td>
<td>10.0 1.0 2.0 1.0 30.0</td>
<td>0.12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low noise level</td>
<td>3 3</td>
<td>10.0 1.0 1.0 1.0 10.0</td>
<td>0.04</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operator Safety</td>
<td>9 3 9 3</td>
<td>10.0 1.0 3.0 1.0 30.0</td>
<td>0.12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Absolute Importance</th>
<th>0.04 0.07 1.00 0.07 0.50</th>
<th>0.09 1.41 0.05 0.73 0.07 1.07 0.03 0.42</th>
<th>0.08 1.18 0.20 2.94 0.20 3.02 0.07 1.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative Importance</td>
<td>0.04 0.07 1.00 0.07 0.50</td>
<td>0.09 1.41 0.05 0.73 0.07 1.07 0.03 0.42</td>
<td>0.08 1.18 0.20 2.94 0.20 3.02 0.07 1.05</td>
</tr>
</tbody>
</table>

### Target Value

### Units

$
APPENDIX F- Weighted Decision Matrix-Overall Project

Weighted Decision Matrix for Automated Nailer System

<table>
<thead>
<tr>
<th>Design Criterion</th>
<th>Weight Factor</th>
<th>Units</th>
<th>Magnitude</th>
<th>Score</th>
<th>Rating</th>
<th>Magnitude</th>
<th>Score</th>
<th>Rating</th>
<th>Magnitude</th>
<th>Score</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive Size &amp; Type</td>
<td>0.16</td>
<td>Amps</td>
<td>2.8</td>
<td>8</td>
<td>1.28</td>
<td>2.8</td>
<td>8</td>
<td>1.28</td>
<td>2.8</td>
<td>8</td>
<td>1.28</td>
</tr>
<tr>
<td>Parts Availability</td>
<td>0.12</td>
<td>Hours</td>
<td>6.0</td>
<td>5</td>
<td>0.6</td>
<td>4.0</td>
<td>7</td>
<td>0.84</td>
<td>2.0</td>
<td>8</td>
<td>0.96</td>
</tr>
<tr>
<td>Mfg. Cost</td>
<td>0.12</td>
<td>$</td>
<td>4000</td>
<td>3</td>
<td>0.36</td>
<td>3000</td>
<td>6</td>
<td>0.72</td>
<td>2500</td>
<td>9</td>
<td>1.08</td>
</tr>
<tr>
<td>Durability</td>
<td>0.18</td>
<td>Hours</td>
<td>Good</td>
<td>7</td>
<td>1.26</td>
<td>Good</td>
<td>6</td>
<td>1.08</td>
<td>Excellent</td>
<td>9</td>
<td>1.62</td>
</tr>
<tr>
<td>Speed Variation</td>
<td>0.18</td>
<td>Seconds</td>
<td>Good</td>
<td>7</td>
<td>1.26</td>
<td>Good</td>
<td>6</td>
<td>1.08</td>
<td>Excellent</td>
<td>9</td>
<td>1.62</td>
</tr>
<tr>
<td>Part Variation</td>
<td>0.24</td>
<td>inches</td>
<td>Fair</td>
<td>5</td>
<td>1.2</td>
<td>Fair</td>
<td>5</td>
<td>1.2</td>
<td>Good</td>
<td>6</td>
<td>1.44</td>
</tr>
</tbody>
</table>

CONCEPT A - Consisted of three independent boards moving in the X axis, under a firing bridge, with a pneumatic linear device for movement in the Z direction. Cost, part variation, and speed variation were not acceptable. This plan would have consisted of six ACME lead screws, six independent stepper motors, and a lot of programming knowledge.

CONCEPT B - Consisted of a firing bridge riding on linear slides with a pneumatic linear device for movement in the Z direction. Cost, part variation, size, and speed variation were not acceptable. This plan would have consisted of a costly bridge design, more feet of linear slides, PLC's, programming, and increased cost. For this particular design the boards would have been stationary.

PLAN C - Consist of a cross between concepts A and B. This design keeps the boards stationary while a firing bridge is transported on linear slides. A cost reduced bridge design powered by a stepper motor allows for movement in the Y direction. The Z directional movement is accomplished with a pneumatic sequence of events. All linear motion will be controlled through a control box which makes programming easier. Programming will be accomplished through various lines of G-code written by a software which interprets CAD files.
APPENDIX G - Weighted Decision Matrix-Z Axis Actuator Determination

### Weighted Decision Matrix for Automated Nailer System-Z-actuator type

<table>
<thead>
<tr>
<th>Design Criterion</th>
<th>Weight Factor</th>
<th>Units</th>
<th>Magnitude</th>
<th>Score</th>
<th>Rating</th>
<th>Magnitude</th>
<th>Score</th>
<th>Rating</th>
<th>Magnitude</th>
<th>Score</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive Size &amp; Type</td>
<td>0.18</td>
<td>psi or amps</td>
<td>100.0</td>
<td>8</td>
<td>1.44</td>
<td>2.8</td>
<td>8</td>
<td>1.44</td>
<td>80.0</td>
<td>8</td>
<td>1.44</td>
</tr>
<tr>
<td>Parts Availability</td>
<td>0.135</td>
<td>Hours</td>
<td>6.0</td>
<td>5</td>
<td>0.675</td>
<td>3.0</td>
<td>7</td>
<td>0.945</td>
<td>2.0</td>
<td>8</td>
<td>1.08</td>
</tr>
<tr>
<td>Mfg. Cost</td>
<td>0.135</td>
<td>$</td>
<td>1100</td>
<td>1</td>
<td>0.135</td>
<td>900</td>
<td>5</td>
<td>0.675</td>
<td>300</td>
<td>9</td>
<td>1.215</td>
</tr>
<tr>
<td>Durability</td>
<td>0.165</td>
<td>Hours</td>
<td>Good</td>
<td>6</td>
<td>0.99</td>
<td>Good</td>
<td>6</td>
<td>0.99</td>
<td>Excellent</td>
<td>9</td>
<td>1.485</td>
</tr>
<tr>
<td>Speed</td>
<td>0.165</td>
<td>m/s</td>
<td>Poor</td>
<td>1</td>
<td>0.165</td>
<td>Excellent</td>
<td>8</td>
<td>1.32</td>
<td>Excellent</td>
<td>9</td>
<td>1.485</td>
</tr>
<tr>
<td>Part Variation</td>
<td>0.22</td>
<td>inches</td>
<td>Fair</td>
<td>5</td>
<td>1.1</td>
<td>Good</td>
<td>6</td>
<td>1.32</td>
<td>Good</td>
<td>6</td>
<td>1.32</td>
</tr>
</tbody>
</table>

### CONCEPT A
- Consisted of a hydraulic actuator cylinder powered by a pump system and activated by a solenoid gate controlling the flow of fluid to power the cylinder. The gun would be mounted to a holder which in turn would be attached to the hydraulic cylinder. When required the cylinder would move forward. The gun would be mounted to a holder which in turn would be attached to the hydraulic cylinder. When required the cylinder would move forward. Cost, part variation, and speed variation were not acceptable.

### CONCEPT B
- Consisted of an electric linear actuator device for movement in the Z direction similar to the set-up as described in concept A except it was slightly cheaper and did not require a hydraulic pump. Cost and part variation were not acceptable. Speed variation was adequate for what was required. This plan would have consisted of more costly parts than our budget would allow and would have to have electrical controls and an extra motor to drive the screw. This idea although good was still too costly for our budget.

### CONCEPT C
- Consisted of a pneumatic cylinder actuator with solenoid controls either to function on a timing sequence or off of the controller which will drive the stepper motor with controlled signals. These signals will also be used to activate the solenoid air valve to allow the pneumatic cylinder to fire at its required times. The Z directional movement is accomplished with a pneumatic sequence of events. Which proved to have the lowest cost, excellent speed variations, good durability, and readily available parts.
APPENDIX H - CONCEPT A

- Bridge
- Gun Fixtures
- Precision Slides
- Bellows

APPENDIX I - CONCEPT B

- Bridge/ Mounting Plate
- Tracks
- Drive Screw
- Drive Screw
## APPENDIX J - PROJECT SCHEDULE-(FROM SENIOR PROJECT I TO CONCLUSION)

<table>
<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
<th>Jan 2, '05</th>
<th>Jan 9, '05</th>
<th>Jan 16, '05</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
<td>Start Senior Project I Class</td>
<td>1 day</td>
<td>Mon 1/3/05</td>
<td>Mon 1/3/05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>Problem Statement made</td>
<td>1 day</td>
<td>Mon 1/3/05</td>
<td>Mon 1/3/05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>Create Alternate Designs</td>
<td>7 days</td>
<td>Tue 1/4/05</td>
<td>Wed 1/12/05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>Determine Specific Design Solutions to Problem for nail tester</td>
<td>6 days</td>
<td>Fri 1/7/05</td>
<td>Fri 1/14/05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>Create Initial Design Drawings for Project Portions (sketches-CAD)</td>
<td>7 days</td>
<td>Sat 1/15/05</td>
<td>Mon 1/24/05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>Final Drawings, Assembly and Exploded Drawings, Dimensioned</td>
<td>10 days</td>
<td>Tue 1/25/05</td>
<td>Mon 2/7/05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>Initial Design Analysis and Calculations, Static and Dynamic Calculations</td>
<td>6 days</td>
<td>Tue 2/8/05</td>
<td>Mon 2/14/05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>Final Design Analysis and Calculations</td>
<td>7 days</td>
<td>Tue 2/15/05</td>
<td>Wed 2/23/05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>Re-examine Design Ideas to Assure Feasibility</td>
<td>2 days</td>
<td>Thu 2/24/05</td>
<td>Fri 2/25/05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>Determine Fabrication Needs and Processes</td>
<td>4 days</td>
<td>Thu 2/24/05</td>
<td>Mon 2/28/05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>Determine Fabrication Process Steps</td>
<td>3 days</td>
<td>Tue 3/1/05</td>
<td>Thu 3/3/05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>Design Freeze</td>
<td>2 days</td>
<td>Thu 3/3/05</td>
<td>Fri 3/4/05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>46</td>
<td>Create Final Bill of Materials</td>
<td>3 days</td>
<td>Sat 3/5/05</td>
<td>Mon 3/7/05</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### ID 47 - Finalize Written Design Solution, Drawings, Calculations, and Bill of materials
- **Duration**: 9 days
- **Start**: Thu 3/3/05
- **Finish**: Fri 3/11/05
- **Aug 1, '04**: 8/1
- **Aug 8, '04**: 8/8
- **Aug 15, '04**: 8/15
- **Aug 22, '04**: 8/22

### ID 48 - Order Necessary purchased materials
- **Duration**: 3 days
- **Start**: Mon 3/7/05
- **Finish**: Wed 3/9/05

### ID 49 - Create Draft For Submission to Advisor/s
- **Duration**: 6 days
- **Start**: Tue 3/8/05
- **Finish**: Tue 3/15/05

### ID 50 - Present Design Analysis Information to MET Advisor/s
- **Duration**: 1 day
- **Start**: Wed 3/16/05
- **Finish**: Wed 3/16/05

### ID 51 - End Senior Project I
- **Duration**: 1 day
- **Start**: Sun 3/20/05
- **Finish**: Sun 3/20/05

### ID 52 - Review Project Design Get Ready to Build
- **Duration**: 6 days
- **Start**: Mon 3/21/05
- **Finish**: Sun 3/27/05

### ID 53 - Start Senior Project II
- **Duration**: 1 day
- **Start**: Mon 3/28/05
- **Finish**: Mon 3/28/05

### ID 55 - Assure all needed purchased parts are in stock
- **Duration**: 1 day
- **Start**: Tue 3/29/05
- **Finish**: Tue 3/29/05

### ID 56 - Re-examine manufacturing steps
- **Duration**: 2 days
- **Start**: Tue 3/29/05
- **Finish**: Wed 3/30/05

### ID 57 - Start Building Project Part Designed
- **Duration**: 21 days
- **Start**: Thu 3/31/05
- **Finish**: Thu 4/28/05

### ID 58 - Continue Fabrication of NailGun Tester Design Portion
- **Duration**: 21 days
- **Start**: Thu 3/31/05
- **Finish**: Thu 4/28/05
<table>
<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>59</td>
<td>Work with Team to make sure designed part will Join other designed parts</td>
<td>21 days</td>
<td>Thu 3/31/05</td>
<td>Thu 4/28/05</td>
</tr>
<tr>
<td>60</td>
<td>Continue Construction and Project Fabrication</td>
<td>21 days</td>
<td>Thu 3/31/05</td>
<td>Thu 4/28/05</td>
</tr>
<tr>
<td>61</td>
<td>Test Designed Piece to Assure Functionality if Possible</td>
<td>3 days</td>
<td>Fri 4/29/05</td>
<td>Tue 5/3/05</td>
</tr>
<tr>
<td>62</td>
<td>Finalize Fabrication and Bring Project Together</td>
<td>10 days</td>
<td>Tue 5/3/05</td>
<td>Mon 5/16/05</td>
</tr>
<tr>
<td>63</td>
<td>Test Nailer</td>
<td>5 days</td>
<td>Tue 5/10/05</td>
<td>Mon 5/16/05</td>
</tr>
<tr>
<td>64</td>
<td>Get all documents and project written drafts together for senior project paper</td>
<td>47 days</td>
<td>Tue 3/15/05</td>
<td>Mon 5/16/05</td>
</tr>
<tr>
<td>65</td>
<td>Put on finishing touches / Get Ready for TECH EXPO</td>
<td>1 day</td>
<td>Wed 5/18/05</td>
<td>Wed 5/18/05</td>
</tr>
<tr>
<td>66</td>
<td>TECH EXPO</td>
<td>1 day</td>
<td>Thu 5/19/05</td>
<td>Thu 5/19/05</td>
</tr>
<tr>
<td>67</td>
<td>Finalize and Submit Final Project Paper - MET Senior Format Style</td>
<td>16 days</td>
<td>Fri 5/20/05</td>
<td>Thu 6/9/05</td>
</tr>
</tbody>
</table>
## Budget: Breakdown Parts List for Automated Nailer Test Station

**Campbell Hausfeld Allowance:** $2,500

<table>
<thead>
<tr>
<th>No.</th>
<th>PART NUMBER</th>
<th>QTY</th>
<th>DESCRIPTION</th>
<th>EACH</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>U-CPRC20 L.25R.25</td>
<td>2</td>
<td>Coupling (Both Ends Inch Bore)</td>
<td>$12.90</td>
<td>$25.80</td>
</tr>
<tr>
<td>2</td>
<td>U-LAHS 3.00 -.25</td>
<td>2</td>
<td>Angle (Equal Sides)</td>
<td>$23.80</td>
<td>$47.60</td>
</tr>
<tr>
<td>3</td>
<td>U-SHWTM 0.75-H1.25</td>
<td>4</td>
<td>Shaft Supports (Base Mounts Y-axis)</td>
<td>$23.70</td>
<td>$94.80</td>
</tr>
<tr>
<td>4</td>
<td>U-SFJ 0.75-L32.00</td>
<td>2</td>
<td>Precision Linear Shafts</td>
<td>$29.64</td>
<td>$59.28</td>
</tr>
<tr>
<td>5</td>
<td>U-LHFR 0.75</td>
<td>4</td>
<td>Flanged Linear Bushing</td>
<td>$12.50</td>
<td>$50.00</td>
</tr>
<tr>
<td>6</td>
<td>DC408-0230</td>
<td>1</td>
<td>ACME Threads 1&quot; - 5 X 6'</td>
<td>$17.19</td>
<td>$17.19</td>
</tr>
<tr>
<td>7</td>
<td>DC408-0210</td>
<td>1</td>
<td>ACME Threads 1&quot; - 5 X 3'</td>
<td>$9.79</td>
<td>$9.79</td>
</tr>
<tr>
<td>8</td>
<td>DC407-2210</td>
<td>4</td>
<td>ACME Nuts 1&quot;-5</td>
<td>$2.79</td>
<td>$11.16</td>
</tr>
<tr>
<td>9</td>
<td>U-BGHWA 6002ZZ - T2.00-H2.00</td>
<td>1</td>
<td>Bearing with Housing T-Shape Double Bearing</td>
<td>$93.20</td>
<td>$93.20</td>
</tr>
<tr>
<td>10</td>
<td>U-BGHFA 6002ZZ - H2.00</td>
<td>3</td>
<td>Bearing with Housing T-Shape Single Bearing</td>
<td>$46.00</td>
<td>$138.00</td>
</tr>
<tr>
<td>11</td>
<td>JKSG 24 - 700</td>
<td>4</td>
<td>Simplified Linear Guides for Jigs (1 Block + 1 Rail)</td>
<td>$79.60</td>
<td>$318.40</td>
</tr>
<tr>
<td>12</td>
<td>JKSGR24 - 400</td>
<td>2</td>
<td>Simplified Linear Guides for Jigs (1 Rail)</td>
<td>$35.50</td>
<td>$71.00</td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>1</td>
<td>Control box</td>
<td>$403.00</td>
<td>$403.00</td>
</tr>
<tr>
<td>14</td>
<td>NEMA 23-STP-MTR</td>
<td>3</td>
<td>Stepping Motors</td>
<td>$29.00</td>
<td>$87.00</td>
</tr>
<tr>
<td>15</td>
<td>STP-EXT-020</td>
<td>1</td>
<td>20 ft extension cable</td>
<td>$9.00</td>
<td>$9.00</td>
</tr>
<tr>
<td>16</td>
<td></td>
<td>1</td>
<td>Dell Laptop Computer</td>
<td>$0.00</td>
<td>$0.00</td>
</tr>
<tr>
<td>17</td>
<td>Techno</td>
<td>2</td>
<td>8&quot; x 18 L Angle</td>
<td>$115.00</td>
<td>$230.00</td>
</tr>
<tr>
<td>18</td>
<td></td>
<td>1</td>
<td>Table</td>
<td>$249.00</td>
<td>$249.00</td>
</tr>
</tbody>
</table>

**GRAND TOTAL:** $1,914.22

**Balance:** $585.78
FINAL DESIGN PROJECT SPECIFIC APPENDICES

Design Drawings

1. CAD Assembly Drawing
2. Manufactured Parts Drawings Z –Axis (3-D)

Note: See following sheets for CAD Drawings (Assembly and Z parts)
Pages 14-18 removed due to permissions restrictions.

Please refer to the print copy of this report, or contact the College of Engineering and Applied Science Library at the University of Cincinnati for assistance.
APPENDIX Q-- Z-Actuator Mounted Side Views

- Air Cylinders
- Screw and Z-Supports
- Board Holders
- Screw and Z-Supports
- Gun Fixture
- Complete Z-Axis Gun Fixture
- Roller Bearings
- Y-Axis Screw
APPENDIX S- Z-Actuator Un-Mounted under and Side Views

- Angle Support
- Foot Brackets
- Gun Fixture
- Carriage Mounting Plate
- Toggle Clamp
- Air Cylinders
- Air Cylinder C-Channel Mounting Plates
APPENDIX T - Clippard Pneumatic Cylinders Used

APPENDIX T - Clippard Electronic Control Valve for Pneumatic
APPENDIX U - Cylinder Mounting Foot Brackets & Tubing

Part Number: URH1-0804-BKS-050

Polyurethane Hose
1/4" O.D. & 1/8" I.D.
Solid Black
50 Feet

Tubing ID: 0.125 Inches
Tubing OD: 0.25 Inches
Tubing Radius Bend: 0.25 Inches
Tubing Burst Pressure: Approximately 425 psig at 70°F
Tubing Max PSI: 0 to 105 psig at 100°F
Tubing Durometer: 85
Tubing Max Temperature: 120°F

APPENDIX U - Pressure Relief Valves
APPENDIX V - Horizontal Handle Toggle Clamp
APPENDIX W- Complete Tester Side View

- Safety Shield
- Air Compressor
- Cart and Casters
APPENDIX X - Complete Tester Angled Top View

Y -Axis

Z -Axis

X -Axis

X.X = -0.1
X.XX = -0.01
X.XXX = 0.001
ANG. = 0.5
APPENDIX Y - X-Axis System View and Quick Pneumatic Air Connects

(Drive Motor)

Carriage Drive Plate

X-Axis Slide Track
APPENDIX Z— X-Plane Slides-with L Support Angle Brackets

(Twin stacks compressor and Stepper Motor and Acme Screw)
APPENDIX AA - Y-Axis Sliders and Support / Z-Support Rods on X-table

Stepper Motor and Screw

Board Holder Supports
APPENDIX BB - Floating Y-Axis Apparatus Back View

(Drive Nut Holder and Drive Motor)

Squeeze Blocks

Drive Motor/ Screw Coupler
APPENDIX CC - Floating Y-Axis System Front View
APPENDIX DD - Top View of Y-Axis and Actuation System

Roller Bearings and Linear Slide Supports

Stepper Motor and Drive Screw

Angle Supports

Screw Mounting Block Bearings
CAD Drawings

(X & Y manufactured parts)

2D Manufactured Parts for X & Y Planes
Pages 34-47 removed due to permissions restrictions.

Please refer to the print copy of this report, or contact the College of Engineering and Applied Science Library at the University of Cincinnati for assistance.
APPENDIX QQ- Control Box -3 Axis Control

This control box operates three drive systems, two stepper motors and one electronic air valve for the pneumatic actuators. This control unit takes CAD drawings and converts the drawing format into G code programming which is more applicable to Mechanical Engineers.
# APPENDIX RR - Overall Project Bill of Materials

## B.O.M REPORT

<table>
<thead>
<tr>
<th>Qty.</th>
<th>Type</th>
<th>Name</th>
<th>Highlights</th>
<th>Info</th>
<th>File</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Part</td>
<td>TABLE TOP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Part</td>
<td>TABLE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Part</td>
<td>MOTOR MOUNT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Part</td>
<td>STEPPING MOTOR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Part</td>
<td>COUPLING RIGID_SPLIT_CLAMP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Part</td>
<td>ACME THREAD 6FT._1DIA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Part</td>
<td>MOUNTING ACME_DOUBLE_SUPPORT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Part</td>
<td>MOUNTING ACME_SINGLE_SUPPORT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Part</td>
<td>700MM_RAIL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Part</td>
<td>X-AXIS SLIDES</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Part</td>
<td>3X10X5_MOUNTING PLATE_ANGLE_PLATE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Part</td>
<td>SERIES2_RIGHT_ANGE_MOUNTING_PLATE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Part</td>
<td>400MM_RAIL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Part</td>
<td>SHAFT_SUPPORT_P128_USHWTM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Part</td>
<td>LINEAR_SHAFTS_P35_USFJ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Part</td>
<td>FLANGED_LINEAR_BUSHING</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Part</td>
<td>Y-AXIS SLIDE_BLOCK/FLANGED_SUPPORTS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Part</td>
<td>Y-AXIS MOUNTING PLATE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Part</td>
<td>X_PLATE_DRIVE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Part</td>
<td>1X1_SUPPORT_LEG</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Part</td>
<td>1X1_STEEL_ANGLE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Part</td>
<td>18&quot; X 72&quot; SAFETY_GLASS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Part</td>
<td>18&quot; X 36&quot; SAFETY_GLASS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Part</td>
<td>1X1_STEEL_ANGLE_INST_18&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Part</td>
<td>YELLOW_PINE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Part</td>
<td>PNEUMATIC_CYLINDERS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Part</td>
<td>TOP/BOTTOM_CYLINDER_PLATE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Part</td>
<td>NAILER MOUNTING PLATE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Part</td>
<td>GUN_FIXTURE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Part</td>
<td>GUN_CLAMPING_ANGLE_HOLDER</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Part</td>
<td>ANGLE BRACE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Part</td>
<td>ACME_THREAD_3FT._1DIA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Part</td>
<td>AMCE_DRIVE_BLOCK_W_NUT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Sub-Assembly</td>
<td>TOP_LEVEL_ASSEMBLY</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Part</td>
<td>WHEELS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Part</td>
<td>HALFX3X6_PLYWOOD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Sub-Assembly</td>
<td>WL506255ROLLBAR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Sub-Assembly</td>
<td>MANIFOLD_ASSM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>Part</td>
<td>SOCKET HEAD CAP SCREWS</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Z-Actuator Data Tables

APPENDIX SS- Actuator Specs, Forces Required

**Metric Units**

<table>
<thead>
<tr>
<th>Type of Actuator Used</th>
<th>Pneumatic Actuator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actuator Model Number</td>
<td><strong>S00-24-1/2-0</strong></td>
</tr>
<tr>
<td>Weight of Gun</td>
<td>1.165 kg</td>
</tr>
<tr>
<td>Weight of Gun Holder</td>
<td>3.445 kg</td>
</tr>
</tbody>
</table>

**Actuator Dimensions**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>0.187 m</td>
</tr>
<tr>
<td>Width</td>
<td>0.0397 m</td>
</tr>
<tr>
<td>Height</td>
<td>0.0397 m</td>
</tr>
<tr>
<td>Piston Length</td>
<td>0.0635 m</td>
</tr>
<tr>
<td>Piston Diameter</td>
<td>0.0111 m</td>
</tr>
<tr>
<td>Bore</td>
<td>0.0341 m</td>
</tr>
</tbody>
</table>

**Actuator Performance Data**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of Travel (stroke)</td>
<td>0.0254 m</td>
</tr>
<tr>
<td>Max Output Force</td>
<td>1890 N</td>
</tr>
<tr>
<td>Weight</td>
<td>0.348 kg</td>
</tr>
</tbody>
</table>

**Actuator Power Specs**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Push/pull force of actuator at 90 psi</td>
<td>552 kPa</td>
</tr>
<tr>
<td>Push/pull force of actuator at 90 psi</td>
<td>861 N</td>
</tr>
</tbody>
</table>

**Electronic Valve Specs**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Valves</td>
<td>2</td>
</tr>
<tr>
<td>Connector Type</td>
<td>Connector Terminal Wire Leads</td>
</tr>
<tr>
<td>Valve Porting</td>
<td>Normally Closed Universal</td>
</tr>
<tr>
<td>Valve Function</td>
<td>2 Way Valve</td>
</tr>
<tr>
<td>Mounting Style</td>
<td>Standard Mount</td>
</tr>
<tr>
<td>Voltage</td>
<td>6 Volts</td>
</tr>
<tr>
<td>Options</td>
<td>0.025 Orifice</td>
</tr>
<tr>
<td>Seals</td>
<td>Buna Seals</td>
</tr>
</tbody>
</table>

**Description 1:** stainless steel cylinder

**Description 2:** 1 1/2 inches Bore Stainless Steel Cylinder

**Description 3:** Stud Mount, Double Acting, Double Rod

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bore</td>
<td>1.5     inches</td>
</tr>
<tr>
<td>Rod</td>
<td>Double Rod</td>
</tr>
<tr>
<td>Max Psi</td>
<td>250     PSI</td>
</tr>
<tr>
<td>Temperature Range</td>
<td>30 F to 250 F</td>
</tr>
<tr>
<td>Mount</td>
<td>Stud Mount</td>
</tr>
<tr>
<td>Action</td>
<td>Double Acting</td>
</tr>
<tr>
<td>Stroke</td>
<td>1.5000   inches</td>
</tr>
</tbody>
</table>

**Power Factor:** 1.7 sq.in.

At 90 PSI = 153 lbs Force

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ports</td>
<td>1/8 NPT</td>
</tr>
<tr>
<td>Rod Diameter</td>
<td>0.4375  inches</td>
</tr>
<tr>
<td>Weight</td>
<td>0.77    lbs</td>
</tr>
</tbody>
</table>
APPENDIX TT - Loading Conditions Data Tables

### Actuator Plate Design Specifications

<table>
<thead>
<tr>
<th></th>
<th>Aluminum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal Type</td>
<td>Aluminum</td>
</tr>
<tr>
<td>Metal Thickness</td>
<td>0.5 inches 0.0127 m</td>
</tr>
<tr>
<td>Functional Length</td>
<td>9 inches 0.228603 m</td>
</tr>
<tr>
<td>C-Channel Depth</td>
<td>2 inches 0.050801 m</td>
</tr>
<tr>
<td>Functional Width</td>
<td>6 inches 0.152402 m</td>
</tr>
<tr>
<td>Gun Holder Weight(aprox)</td>
<td>5 lbs 2.273 kg</td>
</tr>
<tr>
<td>Gun Weight</td>
<td>5 lbs 2.273 kg</td>
</tr>
<tr>
<td>Actuator Weight</td>
<td>1.5 lbs 0.682 kg</td>
</tr>
<tr>
<td>Total Z-System Weight</td>
<td>11.5 lbs 5.227 kg</td>
</tr>
</tbody>
</table>

#### Equations Used:
- Device creates a torque arm on the actuator cylinders and y-mechanism
- Bending Moment Force
  - Torque = Force x radius(distance)
- Force to Activate Gun Safety Mechanism
  - Force = mass * acceleration
  - (Force was also determined experimentally with testing equipment)

### System Requirements for Gun Depression

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Required Mass</td>
<td>1.577 kg</td>
</tr>
<tr>
<td>Required Speed</td>
<td>0.3048 m/s</td>
</tr>
<tr>
<td>Z-Acceleration Force</td>
<td>15.47 N</td>
</tr>
<tr>
<td>Z-safety factor(total force)</td>
<td>18.56 N</td>
</tr>
</tbody>
</table>
### APPENDIX UU - Deflection and Vibration Data Sheets Z-Actuator on Support Rods

<table>
<thead>
<tr>
<th>English</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rod Length</td>
<td>32 in</td>
</tr>
<tr>
<td>Rod Diameter(1)</td>
<td>0.5 in</td>
</tr>
<tr>
<td>Rod Diameter(2)</td>
<td>0.75 in</td>
</tr>
<tr>
<td>Rod Diameter(3)</td>
<td>1.00 in</td>
</tr>
<tr>
<td>Rod Metal Type</td>
<td>316L bearing steel</td>
</tr>
</tbody>
</table>

| Material Specifications |
|-------------------------|------------------|
| Hardness | S2900 Chrome alloy steel balls and rollers have a uniform hardness of 38-41 HRc regardless of size or grade. |

| Metal Density | 7800 kg/m³ |
| Rod Modulus of Elasticity (E) | 2.00E+11 psi | 2.07E+08 kPa |
| Rod Ultimate Tensile Strength | 325000 psi | 2240 Mpa |
| Rod Shear Modulus | 1.15E+11 psi | 7.93E+07 kPa |
| Poisson Ratio | 0.30 |
| Bulk Modulus | 2.02E+11 psi | 140 Gpa |

### Formulas Used
\[
E = (0.144605)D^{0.64} \quad \text{Moment of Inertia}
\]
\[
EI = A \cdot t \cdot (\text{Modulus} \cdot \text{Inertia})
\]

\[
Y_0 \text{ or } Y_1 = A \cdot [a_2^2 + X_0^2 (0.5 a_2^2 - Y_0)] \quad \text{Bending Deflection}
\]

<table>
<thead>
<tr>
<th>Known Variables(1/2)</th>
<th>From Calculations Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>A_{21} =</td>
<td>0.0026076 in²</td>
</tr>
<tr>
<td>X_{21} =</td>
<td>14 in</td>
</tr>
<tr>
<td>M_{E}(1/2) in rod =</td>
<td>6.57E-04 in²</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Known Variables(1)</th>
<th>From Calculations Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>A_{21} =</td>
<td>0.0029414 in²</td>
</tr>
<tr>
<td>X_{21} =</td>
<td>8 in</td>
</tr>
<tr>
<td>M_{E}(1) in rod =</td>
<td>4.07E-05 in²</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Known Variables(1)</th>
<th>From Calculations Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>A_{21} =</td>
<td>0.0005151 in²</td>
</tr>
<tr>
<td>X_{21} =</td>
<td>14 in</td>
</tr>
<tr>
<td>M_{E}(1) in rod =</td>
<td>1.29E-04 in²</td>
</tr>
</tbody>
</table>

### Uniform Simply Supported Beam with Mass in Center
\[
NF = \frac{(a^2) \cdot (c^2)}{(L \cdot (m + \frac{1}{2}c^2))} \quad \text{Moment of Inertia}
\]
\[
k = \frac{E \cdot (c^2)}{L^2} \quad \text{Natural Frequency}
\]

<table>
<thead>
<tr>
<th>Natural Frequency Determination Equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>L = length of beam</td>
</tr>
<tr>
<td>(a^2) = Moment of Inertia</td>
</tr>
<tr>
<td>E = Modulus of Elasticity</td>
</tr>
<tr>
<td>c = Center Mass</td>
</tr>
<tr>
<td>k = Stiffness</td>
</tr>
<tr>
<td>NF = Natural Frequency</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Distance Between Support Points</th>
<th>32 in</th>
<th>0.812800808 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance Between Impact Points</td>
<td>8 in</td>
<td>0.20320471 m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Force Applied at Impact Points</th>
<th>Combined (approximated)</th>
<th>10 lbs</th>
<th>44.5 N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Mass on Slides</td>
<td>10 lbs</td>
<td>4.45 kg</td>
<td></td>
</tr>
<tr>
<td>Moment of Inertia (1/2 inch rod)</td>
<td>0.0030608 in²</td>
<td>1.279E-04 in²</td>
<td></td>
</tr>
<tr>
<td>Moment of Inertia (1/4 inch rod)</td>
<td>0.015532 in²</td>
<td>6.465E-05 in²</td>
<td></td>
</tr>
<tr>
<td>Moment of Inertia (1 inch rod)</td>
<td>0.09067 in²</td>
<td>2.813E-05 in²</td>
<td></td>
</tr>
<tr>
<td>Maximum Bending Moment</td>
<td>60 in</td>
<td>27.2 in²</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Deflection of one 1/2 in rod(inches)</th>
<th>0.0339</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y_0 or Y_1 for (1/2 in rod)</td>
<td>0.0610 mm</td>
</tr>
<tr>
<td>X_0 or X_1 for (1/2 in rod)</td>
<td>0.000146 in</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Deflection of one 1/4 in rod(inches)</th>
<th>0.0067</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y_0 or Y_1 for (1/4 in rod)</td>
<td>0.0789 mm</td>
</tr>
<tr>
<td>X_0 or X_1 for (1/4 in rod)</td>
<td>0.000111 in</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Deflection of one 1 in rod(inches)</th>
<th>0.0012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y_0 or Y_1 for (1 in rod)</td>
<td>0.0050 mm</td>
</tr>
<tr>
<td>X_0 or X_1 for (1 in rod)</td>
<td>0.000077 in</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Natural Frequency of (1/2) inch rod</th>
<th>18.45 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Frequency of (1/4) inch rod</td>
<td>21.64 Hz</td>
</tr>
<tr>
<td>Natural Frequency of (1) inch rod</td>
<td>34.96 Hz</td>
</tr>
</tbody>
</table>

APPENDIX VV - Loading Conditions & Bending Force Calculations

Individual Objective Calculations for Z Actuator

Z-Axis Firing System Parameters, Design, Specifications, And Loading Conditions

-Z- Axis Gun firing requires the determination of the bending moment caused by the actuator structure on the unit, the force required to activate the push down safety mechanism of the gun with in the required timeframe, and a mechanism design to activate or over-ride the trigger mechanism to allow the gun to fire. The following equations and calculations were made to determine these need values. Once these are determined the actuation system must be able to provide such forces and withstand any stresses out on it by operation of the system.

Downward Force Required to Activate Gun Firing:

Force Required to Activate Safety Mechanism

\[ F = m \times a, \text{ Must determine force needed to accelerate the gun in the needed timeframe.} \]

Mass of Gun: 5lbs or 2.28 kg, acceleration = 0.024 m/s²

-From experimental testing with an Instron Universal Tester, it was determined that the required force to compress the safety actuation spring is approximately 3.5 lbs of force.

-Thus the required force = 3.5 lbf/ 2.2 (lb/N) *9.81 m/s²

\[ \text{Force} = 15.5 \text{ N} \]
APPENDIX VV - Loading Conditions & Bending Force Calculations

Z-Actuator Design Specs

-Constructed of ½ inch 380 aluminum plating.
-Length of gun holder from plate = 9in or 0.2286m
-Width of gun holder plate = 6in or 0.1524m
-C-Channel Depth = 2in or 0.0508m
-Holder weight = 5lbs = 2.27kg
-Gun Weight = 5lbs = 2.27kg
-Total Z-Actuation System Weight 11.5lbs
-Gun holder clamping force = 350lbs

- The over all design of the Z-actuation system will create a torque arm on the cylinders of the actuation system. The force will be divided between the evenly spaced pneumatic air cylinders.

- Distance of mass center of gun from cylinder rods = 3in or 0.0762m
- Distance of mass center of gun holder from centers = 4in or 0.1016m

- Force of gun = 5 lbf = 22.3 N
- Force gun holder and actuators = 6.5 lbf = 28.99 N

- The combined moment (torques) created = (22.3N*0.0762m) + (28.99N*0.1016N)
- Torque/Moment arm created = 4.45 N-m or 39.5 lb-in
- Each cylinder will be subjected to a torque of 2.225 N-m or 19.75 in-lbs
Deflection Calculations

Deflection Calculations of Y-Motion Guide Rods in Z-axis Applications

(Uniform Simply Supported Beam with Mass in the Center)

Deflection of the steel support rods was analyzed using the moment-area method. The following illustrations demonstrated the graphical data generated using this method: (deflection calculated only takes impact force into account)-other deflection and vibration data analysis is performed taking the mass of the carriage into account when dealing with the natural frequency of the unit when firing in the Z-direction. (Assumed impact load was 10lbs or 4.45 kg)

Know Data About Steel Rods:

$E = 30 \times 10^6$ psi and $E_s = 11.5 \times 10^6$ psi, density = 0.283 lbm/in$^3$, or 7680 kg/m$^3$, $L = 32$ in, Varying Diameters = 0.5, 0.75, 1.0 inches.
Shear Diagram (lbs)

-5lb

Bending Moment Diagram

M_{max}/E*I

Bending Moment / With modulus/inertia Conversion

\[ \begin{align*}
A_{AE1} & \quad \text{X}_{A1} \\
A_{AE2} & \quad \text{X}_{A2}
\end{align*} \]

- 6.45E-4 in\(^{-1}\) ½ in rod
- 1.29E-4 in\(^{-1}\) ½ in rod
- 4.07E-5 in\(^{-1}\) 1 in rod
Deflection Illustration (1/2 inch rod)

\[ t_{ae} = 0.87 \text{mm} \]

Deflection Illustration (3/4 inch rod)

\[ t_{ae} = 0.171 \text{mm} \]

Deflection Illustration (1 inch rod)

\[ t_{ae} = 0.053 \text{mm} \]

Equations Needed:

\[ \text{Moment of Inertial for a Cylinder: } I = \pi d^4 / 64 \quad [\text{III}] \]

\[ E*I = \text{Modulus of Elasticity x Moment of Inertia} \]

\[ M / (E*I) = \text{Maximum Bending Moment} / (\text{Modulus x Inertia}) \]

Equations Needed(cont.):

\[ \text{Maximum Rod Deflection: } Y_e = t_{ae} = [M/E*I] * (A_{AE1} * X_{A1}) + (A_{AE2} * X_{A2}) \quad [\text{III}] \]
APPENDIX WW

$Y_e = t_{ae} = \text{max rod deflection}$

$A_{AE1} = \text{area of square section - see above illustrations}$

$A_{AE2} = \text{area of triangle section - see above illustrations}$

$X_{A1} = \text{distance from end of section to centroid of square area}$

$X_{A2} = \text{distance from end of section to centroid of triangle area}$

*** To determine the deflection at the middle of the beam, one-half of the $M/EI$ diagram is used. You need to find $t_{ae}$, the vertical deviation from point A from the tangent drawn to the deflection curve at point E, the middle of the beam. By theorem use the above provided equation to determine this vertical deviation.

Moment Calculation for ½ inch Rod:

$I = \pi \times d^4 / 64$ \hspace{1cm} [ III ]

$I = \pi \times (0.5)^4 / 64$

$I = 0.0031 \text{ in}^4$

Moment Calculation for ¾ inch Rod:

$I = \pi \times d^4 / 64$ \hspace{1cm} [ III ]

$I = \pi \times (0.75)^4 / 64$

$I = 0.01553 \text{ in}^4$

Moment Calculation for 1 inch Rod:

$I = \pi \times d^4 / 64$ \hspace{1cm} [ III ]

$I = \pi \times (1)^4 / 64$

$I = 0.04908 \text{ in}^4$

Deflection Calculations for ½ inch Rod:

$Y_e = t_{ae} = [M/E*I] * (A_{AE1} \times X_{A1}) + (A_{AE2} \times X_{A2})$ \hspace{1cm} [ III ]

Variable Values:  \hspace{1cm} M = 60 ft-lb,  \hspace{1cm} E = 30 \times 10^6 \text{ psi, } I = 0.0031 \text{ in}^4$

$A_{AE1} = (4\text{in} \times 14\text{in}) = 56\text{ in}^2$

$A_{AE2} = (0.5\text{in} \times 12\text{in}) = 48\text{ in}^2$

$X_{A1} = 12\text{in}$

$X_{A2} = 8\text{in}$

$Y_e = t_{ae} = [60 \text{ ft-lb} / (30 \times 10^6 \text{psi} \times 0.0031 \text{ in}^4) \times (56\text{ in}^2 \times 12\text{in}) + (48\text{ in}^2 \times 8\text{in})]$

$Y_e = t_{ae} = 0.0671\text{in} = 1.74\text{mm between 2 rods}$

$Y_e = t_{ae} = 0.0335\text{in} = 0.87\text{mm per ½ in rod}$

Deflection Calculations for ¾ inch Rod:
APPENDIX WW

\[ Y_e = t_{ae} = \left[ \frac{M}{E \cdot I} \right] \cdot (A_{AE1} \cdot X_{A1}) + (A_{AE2} \cdot X_{A2}) \]  

Variable Values:  
\( M = 60 \) ft-lb, \( E = 30 \times 10^6 \) psi, \( I = 0.01553 \) in\(^4\)  
\( A_{AE1} = \left( 4 \text{ in} \times 14 \text{ in} \right) = 56 \text{ in}^2 \)  
\( A_{AE2} = \left( 0.5 \text{ in} \times 12 \text{ in} \right) = 48 \text{ in}^2 \)  
\( X_{A1} = 12 \text{ in} \)  
\( X_{A2} = 8 \text{ in} \)  
\[ Y_e = t_{ae} = \frac{60 \text{ ft-lb}}{(30 \times 10^6 \text{ psi} \cdot 0.01553 \text{ in}^4)} \cdot (56 \text{ in}^2 \cdot 12 \text{ in}) + (48 \text{ in}^2 \cdot 8 \text{ in}) \]  
\( Y_e = t_{ae} = 0.01341 \text{ in} = 0.341 \text{ mm} \) between 2 rods  
\( Y_e = t_{ae} = 0.00671 \text{ in} = 0.171 \text{ mm} \) per \( \frac{3}{4} \) in rod

Deflection Calculations for 1 inch Rod:  

\[ Y_e = t_{ae} = \left[ \frac{M}{E \cdot I} \right] \cdot (A_{AE1} \cdot X_{A1}) + (A_{AE2} \cdot X_{A2}) \]  

Variable Values:  
\( M = 60 \) ft-lb, \( E = 30 \times 10^6 \) psi, \( I = 0.04908 \) in\(^4\)  
\( A_{AE1} = \left( 4 \text{ in} \times 14 \text{ in} \right) = 56 \text{ in}^2 \)  
\( A_{AE2} = \left( 0.5 \text{ in} \times 12 \text{ in} \right) = 48 \text{ in}^2 \)  
\( X_{A1} = 12 \text{ in} \)  
\( X_{A2} = 8 \text{ in} \)  
\[ Y_e = t_{ae} = \frac{60 \text{ ft-lb}}{(30 \times 10^6 \text{ psi} \cdot 0.04908 \text{ in}^4)} \cdot (56 \text{ in}^2 \cdot 12 \text{ in}) + (48 \text{ in}^2 \cdot 8 \text{ in}) \]  
\( Y_e = t_{ae} = 0.00418 \text{ in} = 0.106 \text{ mm} \) between 2 rods  
\( Y_e = t_{ae} = 0.00209 \text{ in} = 0.053 \text{ mm} \) per 1 in rod
APPENDIX XX- Vibrational Analysis Vibration Analysis of Y-Motion Guide Rods

Natural Frequency Determination of Supporting Rods Vibration Analysis

The natural frequency of the y-axis rods supporting the z-axis, gun firing mechanism must be determined to make sure that the impact cycle caused by the gun firing will not reach this frequency. The unit is to be designed so that the harmonic resonance of the system is not reach thus resulting in catastrophic failure of the designed mechanism. The following calculations and determinations using the Shock and Vibration Handbook and provided equations will be used to determine these required frequency values. [I]

From Chapter 7 of the Shock and Vibration Handbook:

Equations and Variable Descriptions:

Overview: Lumped Parameters—A procedure that is useful in many problems for finding approximations to both the natural frequencies and the mode shapes is to reduce the system with distributed parameters to one having a finite number of degree-of-freedom. This is done by lumping the parameters for each small region into an equivalent mass and elastic element. If the system consists of a rigid mass supported by a single flexible member whose mass is not negligible, the elastic part of the system sometimes can be treated as an equivalent spring; i.e., some of the mass is lumped with the rigid mass. The following formulas are used to determine these approximate values for our designed system. [I], [II]

![Uniform Simply Supported Beam With Mass in the Center](image-url)
APPENDIX XX

Equations:

Natural frequency: $\omega_n = 2\pi f_n$ \[ I \]

Natural frequency: $\sqrt{k/(M+m/2)}$ \[ I \]

$k =$ spring stiffness constant – units Newton / meter = N/m

$k = (48EI) / l^3$ \[ I \]

$E =$ modulus of elasticity, \hspace{1em} I = moment of inertia = $\pi d^4 / 64$, $l =$ length of the rod

$E = 200 \times 10^9 \text{ N/m}^2$, \hspace{1em} $I_{1/2} = 1.2770E-09 \text{ m}^4$, $I_{3/4} = 6.4647E-09 \text{ m}^4$, $I_1 = 2.0432E-08 \text{ m}^4$

$L =$ length = $0.8128 \text{ m}$, Mass = $4.45 \text{ kg}$, density of steel (\(\sigma\)) = $7860 \text{ kg/m}^3$

Mass of Rods = density of material $\times$ rod volume \[ IV, V \]

Calculations for each rod to determine the best and most cost effective solution to negate any catastrophic failure caused by the z-axis motion:

$\frac{1}{2}$ inch rod system analysis:

$k_{1/2} = (48 \times 200 \times 10^9 \text{ N/m}^2 \times 1.2770E-09 \text{ m}^4) / (0.8128 \text{ m})^3$

$k_{1/2} = 12259.2 \text{ N-m}^2 / 0.53697 \text{ m}^3$

$k_{1/2} = 22830 \text{ N/m}$

Mass of $\frac{1}{2}$ in rod = $[(\pi d^2) / 4] \times l \times \sigma$ \[ IV, V \]

Mass of $\frac{1}{2}$ in rod = $[((\pi)(0.013 \text{ m})^2) / 4] \times 0.8128 \text{ m} \times 7860 \text{ kg/m}^3$

Mass of $\frac{1}{2}$ in rod = $0.848 \text{ kg}$

Centralized Mass = $4.45 \text{ kg}$

Natural frequency: $\sqrt{k/(M+m/2)}$ \[ I \]
APPENDIX XX

Natural frequency: \( \sqrt{\frac{22830 \text{ N/m}}{(4.45 \text{ kg} + 0.848 \text{ kg})}} \)

Natural frequency: \( \sqrt{\frac{22830 \text{ kg/s}^2}{(4.45 \text{ kg} + 0.848 \text{ kg})}} \)

Natural frequency: \( \sqrt{\frac{22830 \text{ kg/s}^2}{(4.45 \text{ kg} + 0.848 \text{ kg})}} \)

Natural frequency: \( \sqrt{\frac{4309}{s^2}} \)

Natural frequency: \( 65.54 \text{ radians/sec} \times (\frac{1}{2\pi}) \)

Natural frequency: \( 10.45 \text{ /sec or 10.45 Hz} \)

\( \frac{3}{4} \text{ inch rod system analysis:} \)

\( k_{\frac{3}{4}} = \frac{(48 \times 200 \times 10^9 \text{ N/m}^2 \times 6.4647 \times 10^{-9} \text{ m}^4)}{(0.8128 \text{ m})^3} \)

\( k_{\frac{3}{4}} = \frac{62054 \text{ N-m}^2}{0.53697 \text{ m}^3} \)

\( k_{\frac{3}{4}} = 115564 \text{ N/m} \)

Mass of \( \frac{3}{4} \) in rod = \( [(\pi \times d^2) / 4] \times l \times \sigma \)

[ IV, V ]

Mass of \( \frac{3}{4} \) in rod = \( [(\pi \times (0.019\text{m})^2) / 4] \times 0.8128\text{m} \times 7860\text{kg/m}^3 \)

Mass of \( \frac{3}{4} \) in rod = 1.81 kg

Centralized Mass = 4.45 kg

Natural frequency: \( \sqrt{k/(M+m/2)} \)

Natural frequency: \( \sqrt{\frac{115564 \text{ N/m}}{(4.45 \text{ kg} + 1.81 \text{ kg})}} \)

Natural frequency: \( \sqrt{\frac{115564 \text{ kg/s}^2}{(4.45 \text{ kg} + 1.81 \text{ kg})}} \)

Natural frequency: \( \sqrt{18461 \text{ /s}^2} \)

Natural frequency: \( 135.87 \text{ radians/sec} \times (\frac{1}{2\pi}) \)

Natural frequency for \( \frac{3}{4} \) in simply supported rod: 21.64 /sec or 21.64 Hz
APPENDIX XX

1 inch rod system analysis:

\[ k_1 = \frac{48 \times 200 \times 10^9 \text{ N/m}^2 \times 2.0432 \times 10^{-8} \text{ m}^4}{(0.8128 \text{ m})^3} \]

\[ k_1 = 196147 \text{ N-m}^2 / 0.53697 \text{ m}^3 \]

\[ k_1 = 365284 \text{ N/m} \]

Mass of 1 in rod = \[ \frac{\pi d^3}{4} \times l \times \sigma \]

[ IV, V ]

Mass of 1 in rod = \[ \left( \frac{\pi (0.025 \text{ m})^3}{4} \right) \times 0.8128 \text{ m} \times 7860 \text{ kg/m}^3 \]

Mass of 1 in rod = 3.13 kg

Centralized Mass = 4.45 kg

Natural frequency:

\[ \sqrt{\frac{k}{M+m/2}} \]

\[ \sqrt{\frac{365284 \text{ N/m}}{4.45 \text{ kg} + 3.13 \text{ kg}}} \]

\[ \sqrt{\frac{365284 \text{ kg/s}^2}{(4.45 \text{ kg} + 3.13 \text{ kg})}} \]

\[ \sqrt{48191 / \text{s}^2} \]

Natural frequency: 219.52 radians/sec * (1 / 2\pi)

Natural frequency for 1 in simply supported rod: 34.96 /sec or 34.96 Hz
Graph:

Results Table:

<table>
<thead>
<tr>
<th>Test</th>
<th>Temperature (Deg F)</th>
<th>Impact velocity (lb/s)</th>
<th>Maximum load (lb)</th>
<th>Total energy (ft lb)</th>
<th>Thickness (in)</th>
<th>Energy to max load (ft lb)</th>
<th>Deflection at max load (in)</th>
<th>Energy to failure (ft lb)</th>
<th>Deflection at failure (in)</th>
<th>Support</th>
<th>Form</th>
<th>Velocity slowdown (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>73</td>
<td>7.32</td>
<td>70.86</td>
<td>0.46</td>
<td>0.0700</td>
<td>0.36</td>
<td>0.10</td>
<td>0.42</td>
<td>0.12</td>
<td>1.5</td>
<td>SHEET</td>
<td>-1.45</td>
</tr>
<tr>
<td>2</td>
<td>73</td>
<td>7.34</td>
<td>300.48</td>
<td>2.45</td>
<td>0.2800</td>
<td>2.18</td>
<td>0.14</td>
<td>2.44</td>
<td>0.15</td>
<td>1.5</td>
<td>SHEET</td>
<td>0.95</td>
</tr>
<tr>
<td>3</td>
<td>73</td>
<td>7.26</td>
<td>1366.95</td>
<td>11.23</td>
<td>0.3750</td>
<td>3.25</td>
<td>0.05</td>
<td>11.18</td>
<td>0.18</td>
<td>3.0</td>
<td>SHEET</td>
<td>1.88</td>
</tr>
<tr>
<td>Average</td>
<td>72.775</td>
<td>586.0964</td>
<td>4.7118</td>
<td>0.2417</td>
<td>1.8314</td>
<td>0.0989</td>
<td>4.6788</td>
<td>0.1531</td>
<td>0.4645</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Std. Dev</td>
<td>0.0419</td>
<td>702.9974</td>
<td>5.7292</td>
<td>0.1581</td>
<td>1.4630</td>
<td>0.0432</td>
<td>5.7192</td>
<td>0.0317</td>
<td>1.7164</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Test Comment:
October 14, 2004

From: Michael N. Orschell  morschell@campbellhausbeld.com  (765)-647-4428
       Marc Waggoner  marcus.waggoner@equisterchern.com  (513)-738-0590
       Jim Doogan  jdoogom@hampbellhaufeld.com  (513)-347-0835

Funding Request

Project Title: Nail-gun Tester
Program Area: Senior Project
Grant time Period: from 10/5/2004 to 7/20/2005
Requested Amount: $2,500

Use of Funds: Proposal to design an implementation of a nail-gun test station for Campbell Hausfeld

Ownership: The owner of all design patents, schematics, drawings, programs, manuals and tester will be Campbell Hausfeld.

Mission Statement: To design, build, and test an automated nailer test station for Campbell Hausfeld.

Background:
Campbell Hausfeld is a pneumatics company, which is located in Harrison Ohio, with primary market focus on air-powered products. Campbell Hausfeld products are recognized worldwide providing DIY homeowners and contractors with the tools they need to get the job done. One of the great challenges in engineering is to determine the life of a new design or a production product. The testing of a new or old product could tell you many things about the product, from the material being used, to the stress and strain of all mechanical parts, why the parts failed, how long the part will last, when the part will fail, and what part will fail. By knowing this, improvements in the material or the design could extend the life of the product to its fullest potential. The current procedure at Campbell Hausfeld for life testing nailers consist of hiring two outside employees from a temporary agency to come in and fire nailers for an eight hour shift. These shifts consist of loading, firing, and reloading any one of the various nailers in which Campbell Hausfeld produces. This type of testing is both long and somewhat boring, considering testing is complete when the nailer has fired 150,000 nails.

Project Description/Needs:
Campbell Hausfeld needs an automated test fixture. For this project, the test stand will be able to hold two or more guns. The stand will be able to move in the x, y, and z-axis by utilizing both limit and proxy switches. The stand will also support a minimum of (3) 2X6X4 yellow pine wood, which is used to shoot the nail into. The nail-gun tester would be either ran by air or electric. In this project both might be used. The stand would be portable and would allow for easy maneuverability. A computer is needed to control the movement and the spacing of the nails. The computer could be used to count the number of nails being fired.

100 Production Drive * Harrison, Ohio 45030 * (513) 367-4811 * Fax: (513) 367-3176
Deliverables:
Provide important life test and field test data.
Cost reductions- Current test procedures cost Campbell Hausfeld $12.49 per/hr.
Eliminate human error.
Increased efficiency, time and money spent more wisely.
Eliminate human resource headache (confidentiality form, liability, access badges, etc...of temporary employees)

Market Opportunities
Selling product to similar manufacturing companies.

In conclusion of our senior project will deliver a report, presentation, calculations and drawings of the design project. There will be a working concept of this nail-gun tester to review.

Authorization by: [Signature]

Date:
10/14/04

10/15/04
Build Appendices

APPENDIX BBB-1 - Manufacturing Equipment Used (Rep Pics)

Bridgeport CNC Mill

MIG Welder
APPENDIX BBB-2

Band Saw

Drill Press

Grinder
APPENDIX BBB-3

Lathe
Nail Gun Tester Stand Digital Photographs

APPENDIX CCC-1- Drive Assembly X-Axis (Actual)

APPENDIX CCC-2- Drive Assembly for Y-Axis (Actual)
APPENDIX DDD- Drive Mechanisms Z-Axis
(Actual)
APPENDIX FFF- Final Design Prototype
APPENDIX GGG - Top Section of Gun Fixture CNC PROGRAM

0 BEGIN PGM 799 INCH
1 TOOL DEF 3 L2.0 R+0.5000

97 L X-2.9448 Y-4.3 R0 F100 M
98 L X-2.75 R0 F100 M
99 L Y-4.0226 R0 F100 M
100 L X-3.0566 R0 F100 M
101 L X-3.109 Y-4.0994 R0 F100 M
102 L X-3.1094 Y-4.1 R0 F100 M
103 CR X-3.5254 Y-4.55 R+2.125 DR- R0 F100 M
104 L X-2.5 R0 F100 M
105 L Y-4.0226 R0 F100 M
106 L X-2.75 R0 F100 M
107 L X-3.7726 R0 F100 M
108 L X-3.1917 R0 F100 M
109 L X-3.2342 Y-3.8393 R0 F100 M
110 L X-3.3152 Y-3.958 R0 F100 M
111 L X-3.3155 Y-3.9585 R0 F100 M
112 CR X-4.8615 Y-4.7726 R+1.875 DR- R0 F100 M
113 L X-7.8 R0 F100 M
114 L Y-4.8 R0 F100 M
115 L X-2.25 R0 F100 M
116 L Y-3.7726 R0 F100 M
117 L X-2.75 R0 F100 M
118 L Y-3.5226 R0 F100 M
119 L X-3.3451 R0 F100 M
120 CR X-3.4408 Y-3.6985 R+1.0 DR- R0 F100 M
121 L X-3.5213 Y-3.8166 R0 F100 M
122 L X-3.5217 Y-3.8171 R0 F100 M
123 CR X-4.8615 Y-4.5226 R+1.625 DR- R0 F100 M
124 L X-8.05 R0 F100 M
125 L Y-5.05 R0 F100 M
126 L X-2.0 R0 F100 M
127 L Y-3.5226 R0 F100 M
128 L X-2.75 R0 F100 M
129 L Y-3.2726 R0 F100 M
130 L X-3.5297 R0 F100 M
131 CR X-3.6473 Y-3.5576 R+0.75 DR- R0 F100 M
132 L X-3.7275 Y-3.6752 R0 F100 M
133 L X-3.7278 Y-3.6756 R0 F100 M
134 CR X-4.8615 Y-4.2726 R+1.375 DR- R0 F100 M
135 L X-8.3 R0 F100 M
136 L Y-5.3 R0 F100 M
137 L X-1.75 R0 F100 M
138 L Y-3.2726 R0 F100 M
139 L X-2.75 R0 F100 M
140 L Y-3.0226 R0 F100 M
141 L X-3.7595 R0 F100 M
142 L X-3.7596 Y-3.0245 R0 F100 M
143 L X-3.7678 Y-3.1645 R0 F100 M
144 CR X-3.8539 Y-3.4168 R+0.5 DR- R0 F100 M
145 L X-3.9337 Y-3.5338 R0 F100 M
146 L X-3.9339 Y-3.5342 R0 F100 M
147 CR X-4.8615 Y-4.0226 R+1.125 DR- R0 F100 M
148 L X-8.55 R0 F100 M
149 L Y-5.55 R0 F100 M
150 L X-1.5 R0 F100 M
151 L Y-3.0226 R0 F100 M
152 L X-2.75 R0 F100 M
APPENDIX GGG

09 L Y-3.0226 R0 F100 M
410 L X-2.75 R0 F100 M
411 L Y-2.7726 R0 F100 M
412 L X-3.7595 R0 F100 M
413 CR X-4.009 Y-3.0065 R+0.25 DR+ R0 F100 M
414 L X-4.0091 Y-3.0088 R0 F100 M
415 L X-4.0092 Y-3.0098 R0 F100 M
416 L X-4.0174 Y-3.1498 R0 F100 M
417 CR X-4.8615 Y-3.7726 R+0.875 DR- R0 F100 M
418 L X-4.0604 Y-3.3927 R0 F100 M
419 L X-4.8615 Y-3.7726 R+0.875 DR- R0 F100 M
420 L X-8.8 R0 F100 M
421 L Y-5.8 R0 F100 M
422 L X-1.25 R0 F100 M
423 L Y-3.0226 R0 F100 M
424 CR X-1.5 Y-2.7726 R+0.25 DR+ R0 F100 M
425 L X-2.75 R0 F100 M
426 L Y-2.5226 R0 F100 M
427 L X-3.7595 R0 F100 M
428 CR X-4.2587 Y-2.9951 R+0.5 DR+ R0 F100 M
429 L X-4.267 Y-3.1351 R0 F100 M
430 L X-4.3439 Y-3.2479 R0 F100 M
431 CR X-4.8615 Y-3.5226 R+0.625 DR- R0 F100 M
432 L X-9.05 R0 F100 M
433 L Y-6.05 R0 F100 M
434 L X-1.0 R0 F100 M
435 L Y-3.0226 R0 F100 M
436 CR X-1.5 Y-2.5226 R+0.5 DR+ R0 F100 M
437 L X-2.75 R0 F100 M
438 L Y-4.2726 R0 F100 M
439 L Z-1.4703 R0 F50 M
440 L X-2.925 R0 F100 M
441 L X-2.9448 Y-4.3 R0 F100 M
442 L X-2.75 R0 F100 M
443 L Y-4.0226 R0 F100 M
444 L X-3.0566 R0 F100 M
445 L X-3.109 Y-4.0994 R0 F100 M
446 L X-3.1094 Y-4.1 R0 F100 M
447 CR X-3.5254 Y-4.55 R+2.125 DR- R0 F100 M
448 L X-2.5 R0 F100 M
449 L Y-4.0226 R0 F100 M
450 L X-2.75 R0 F100 M
451 L Y-3.7726 R0 F100 M
452 L X-3.1917 R0 F100 M
453 L X-3.2342 Y-3.8393 R0 F100 M
454 L X-3.3152 Y-3.958 R0 F100 M
455 L X-3.3155 Y-3.9585 R0 F100 M
456 CR X-4.8615 Y-4.7726 R+1.875 DR- R0 F100 M
457 L X-7.8 R0 F100 M
458 L Y-4.8 R0 F100 M
459 L X-2.25 R0 F100 M
460 L Y-3.7726 R0 F100 M
461 L X-2.75 R0 F100 M
462 L Y-3.5226 R0 F100 M
463 L X-3.3451 R0 F100 M
464 CR X-3.4408 Y-3.6985 R+1.0 DR- R0 F100 M
465 L X-3.5213 Y-3.8166 R0 F100 M
466 L X-3.5217 Y-3.8171 R0 F100 M
467 CR X-4.8615 Y-4.5226 R+1.625 DR- R0 F100 M
468 L X-8.05 R0 F100 M
469 L Y-5.05 R0 F100 M
470 L X-2.0 R0 F100 M
471 L X-3.5226 R0 F100 M
472 L X-2.75 R0 F100 M
473 L X-3.2726 R0 F100 M
474 L X-3.5297 R0 F100 M
475 CR X-3.6473 Y-3.5576 R+0.75 DR- R0 F100 M
476 L X-3.7275 Y-3.6752 R0 F100 M
477 L X-3.7278 Y-3.6756 R0 F100 M
478 CR X-4.8615 Y-4.2726 R+1.375 DR- R0 F100 M
479 L X-8.3 R0 F100 M
480 L Y-5.3 R0 F100 M
481 L X-1.75 R0 F100 M
482 L Y-3.2726 R0 F100 M
483 L X-2.75 R0 F100 M
484 L Y-3.0226 R0 F100 M
485 L X-3.7595 R0 F100 M
486 L X-3.7596 Y-3.0245 R0 F100 M
487 L X-3.7678 Y-3.1645 R0 F100 M
488 CR X-3.8539 Y-3.4168 R+0.5 DR- R0 F100 M
489 L X-3.9337 Y-3.5338 R0 F100 M
490 L X-3.9339 Y-3.5342 R0 F100 M
491 CR X-4.8615 Y-4.0226 R+1.125 DR- R0 F100 M
492 L X-8.55 R0 F100 M
493 L Y-5.55 R0 F100 M
494 L X-1.5 R0 F100 M
495 L Y-3.0226 R0 F100 M
496 L X-2.75 R0 F100 M
497 L Y-2.7726 R0 F100 M
498 L X-3.7595 R0 F100 M
499 CR X-4.009 Y-3.0065 R+0.25 DR+ R0 F100 M
500 L X-4.0091 Y-3.0088 R0 F100 M
501 L X-4.0092 Y-3.0098 R0 F100 M
502 L X-4.0174 Y-3.1498 R0 F100 M
503 CR X-4.0604 Y-3.2759 R+0.25 DR- R0 F100 M
504 L X-4.14 Y-3.3927 R0 F100 M
505 CR X-4.8615 Y-3.7726 R+0.875 DR- R0 F100 M
506 L X-8.8 R0 F100 M
507 L Y-5.8 R0 F100 M
508 L X-1.25 R0 F100 M
509 L Y-3.0226 R0 F100 M
510 CR X-1.5 Y-2.7726 R+0.25 DR+ R0 F100 M
511 L X-2.75 R0 F100 M
APPENDIX GGG

624 CR X-4.5889 Y-4.4995 R+1.625 DR- R0 F100 M
625 CR X-4.8567 Y-5.05 R+2.0 DR- R0 F100 M
626 L X-2.0 R0 F100 M
627 L Y-3.5226 R0 F100 M
628 L X-3.3615 R0 F100 M
629 CR X-3.5365 Y-3.8384 R+1.625 DR- R0 F100 M
630 L X-4.7876 Y-4.2706 R+1.375 DR- R0 F100 M
631 CR X-5.4368 Y-5.3 R+1.75 DR- R0 F100 M
632 L X-3.7404 Y-3.6936 R0 F100 M
633 CR X-4.8567 Y-5.05 R+2.0 DR- R0 F100 M
634 L X-2.0 R0 F100 M
635 L Y-3.5226 R0 F100 M
636 CR X-3.7404 Y-3.6936 R+1.375 DR- R0 F100 M
637 L X-3.9442 Y-3.5489 R0 F100 M
638 CR X-4.8615 Y-4.0226 R+1.125 DR- R0 F100 M
639 L X-5.0042 R0 F100 M
640 L X-6.5 Y-5.41 R+1.5 DR- R0 F100 M
641 L Y-3.55 R0 F100 M
642 L X-1.5 R0 F100 M
644 L X-3.0226 R0 F100 M
645 L X-3.7434 R0 F100 M
646 L X-3.7524 Y-3.0863 R0 F100 M
647 CR X-3.9442 Y-3.5489 R+1.125 DR- R0 F100 M
648 L X-4.148 Y-3.4042 R0 F100 M
649 CR X-4.8615 Y-3.7726 R+0.875 DR- R0 F100 M
650 L X-5.25 R0 F100 M
651 L X-3.91 R0 F100 M
652 CR X-6.5 Y-5.16 R+1.125 DR- R0 F100 M
653 L X-8.8 R0 F100 M
654 L Y-5.8 R0 F100 M
655 L X-1.25 R0 F100 M
656 L Y-3.0226 R0 F100 M
657 CR X-1.5 Y-2.7726 R+0.25 DR+ R0 F100 M
658 L X-3.7595 R0 F100 M
659 CR X-3.977 Y-2.8993 R+0.25 DR+ R0 F100 M
660 L X-3.9869 Y-2.9209 R0 F100 M
661 CR X-3.9988 Y-3.0441 R+0.8293 DR- R0 F100 M
662 CR X-4.148 Y-3.4042 R+0.8751 DR- R0 F100 M
663 L X-4.3519 Y-3.2594 R0 F100 M
664 CR X-4.8615 Y-3.5226 R+0.625 DR- R0 F100 M
665 L X-5.45 R0 F100 M
666 CR X-5.5 Y-3.5726 R+0.05 DR+ R0 F100 M
667 L X-3.91 R0 F100 M
668 CR X-6.5 Y-4.91 R+1.0 DR- R0 F100 M
669 L X-9.0 R0 F100 M
670 L X-9.05 Y-4.96 R+0.05 DR+ R0 F100 M
671 L Y-6.05 R0 F100 M
672 L X-1.0 R0 F100 M
673 L Y-3.0226 R0 F100 M
674 CR X-1.5 Y-2.5226 R+0.5 DR+ R0 F100 M
675 L X-3.7595 R0 F100 M
676 CR X-4.2005 Y-2.7869 R+0.5 DR+ R0 F100 M
677 L X-4.2255 Y-2.8414 R0 F100 M
678 L X-4.2372 Y-2.878 R0 F100 M
679 CR X-4.2452 Y-3.0018 R+0.5793 DR- R0 F100 M

680 CR X-4.3519 Y-3.2594 R+0.625 DR- R0 F100 M
681 R0 M
682 L X-2.9448 Y-4.3 R0 F100 M
683 L Z-2.0303 R0 F50 M
684 L X-2.75 R0 F100 M
685 CR X-4.2726 R0 F100 M
686 L X-2.925 R0 F100 M
687 L X-2.9448 Y-4.3 R0 F100 M
688 CR X-4.555 R0 F100 M
689 L X-2.5 R0 F100 M
690 L Y-4.0226 R0 F100 M
691 L X-3.058 R0 F100 M
692 CR X-3.5254 Y-4.55 R+2.125 DR- R0 F100 M
693 L X-2.9448 R0 F100 M
694 L Y-4.8 R0 F100 M
695 L X-2.25 R0 F100 M
696 L Y-3.7726 R0 F100 M
697 L X-3.2032 R0 F100 M
698 CR X-4.3988 Y-4.7146 R+1.875 DR- R0 F100 M
699 L X-4.4335 Y-4.8 R0 F100 M
700 L X-2.9448 R0 F100 M
701 L Y-5.05 R0 F100 M
702 L X-2.0 R0 F100 M
703 L Y-3.5226 R0 F100 M
704 L X-3.3615 R0 F100 M
705 CR X-4.5889 Y-4.4995 R+1.625 DR- R0 F100 M
706 CR X-4.8567 Y-5.05 R+2.0 DR- R0 F100 M
707 L X-2.9448 R0 F100 M
708 L Y-5.3 R0 F100 M
709 L X-1.75 R0 F100 M
710 L X-3.2726 R0 F100 M
711 L X-3.5386 R0 F100 M
712 CR X-4.7876 Y-4.2706 R+1.375 DR- R0 F100 M
713 CR X-5.4368 Y-5.3 R+1.75 DR- R0 F100 M
714 L X-2.9448 R0 F100 M
715 L Y-5.55 R0 F100 M
716 L X-1.5 R0 F100 M
717 L Y-3.0226 R0 F100 M
718 L X-3.7437 R0 F100 M
719 L X-3.744 Y-3.0248 R0 F100 M
720 L X-3.7524 Y-3.0819 R0 F100 M
721 L X-3.7557 Y-3.1047 R0 F100 M
722 CR X-4.8615 Y-4.0226 R+1.125 DR- R0 F100 M
723 L X-5.0042 R0 F100 M
724 CR X-6.5 Y-5.41 R+1.5 DR- R0 F100 M
725 L X-8.55 R0 F100 M
726 L Y-5.55 R0 F100 M
728 L Y-5.8 R0 F100 M
729 L X-1.25 R0 F100 M
730 L Y-3.0226 R0 F100 M
731 CR X-1.5 Y-2.7726 R+0.25 DR+ R0 F100 M
732 L X-3.7595 R0 F100 M
733 CR X-3.9747 Y-2.8954 R+0.25 DR+ R0 F100 M
734 L X-3.9865 Y-2.9178 R0 F100 M
735 L X-3.9908 Y-2.9842 R0 F100 M
736 L X-3.9916 Y-2.9901 R0 F100 M
737 L X-3.9996 Y-3.0473 R0 F100 M
738 L X-4.0014 Y-3.0587 R0 F100 M
739 CR X-4.8615 Y-3.7726 R+0.875 DR- R0 F100 M
740 L X-5.25 R0 F100 M
741 L Y-3.91 R0 F100 M
742 CR X-6.5 Y-5.16 R+1.25 DR- R0 F100 M
743 L X-8.8 R0 F100 M
744 L Y-5.8 R0 F100 M
745 L X-2.9448 R0 F100 M
746 L Y-6.05 R0 F100 M
747 L X-1.0 R0 F100 M
748 L Y-3.0226 R0 F100 M
749 CR X-1.5 Y-2.5226 R+0.5 DR+ R0 F100 M
750 L X-3.7595 R0 F100 M
751 CR X-4.2331 Y-2.8622 R+0.5 DR+ R0 F100 M
752 L X-4.2374 Y-2.8777 R0 F100 M
753 CR X-4.2392 Y-2.9555 R+0.4221 DR- R0 F100 M
754 L X-4.2472 Y-3.0127 R0 F100 M
755 CR X-4.8615 Y-3.5226 R+0.625 DR- R0 F100 M
756 L X-5.45 R0 F100 M
757 CR X-5.5 Y-3.5726 R+0.05 DR+ R0 F100 M
758 L Y-3.91 R0 F100 M
759 CR X-6.5 Y-4.91 R+1.0 DR- R0 F100 M
760 L X-9.0 R0 F100 M
761 CR X-9.05 Y-4.96 R+0.05 DR+ R0 F100 M
762 L Y-6.05 R0 F100 M
763 L X-2.9448 R0 F100 M
764 L Z0.1 R0 F100 M
765 CALL LBL 1 REP
766 STOP M25
767 END PGM 799 INCH

APPENDIX GGG
APPENDIX HHH -CNC Program Bottom Part of Fixture

<table>
<thead>
<tr>
<th>Line</th>
<th>CNC Command</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>BEGIN PGM 799 INCH</td>
</tr>
<tr>
<td>1</td>
<td>TOOL DEF 3 L2.0 R+0.5000</td>
</tr>
<tr>
<td>2</td>
<td>LBL 1</td>
</tr>
<tr>
<td>3</td>
<td>TOOL CALL 0 Z S 60.000</td>
</tr>
<tr>
<td>4</td>
<td>L X0.0 Y0.0 R0 F5999 M03</td>
</tr>
<tr>
<td>5</td>
<td>LBL 0</td>
</tr>
<tr>
<td>6</td>
<td>TOOL CALL 03 Z S 100</td>
</tr>
<tr>
<td>7</td>
<td>L X-2.75 Y-7.2726 Z0.1 R0 F5999 M03</td>
</tr>
<tr>
<td>8</td>
<td>L Z-0.25 R0 F50 M</td>
</tr>
<tr>
<td>9</td>
<td>L Y-4.2726 R0 F100 M</td>
</tr>
<tr>
<td>10</td>
<td>L X-2.925 R0 F100 M</td>
</tr>
<tr>
<td>11</td>
<td>L X-2.9448 Y-4.3 R0 F100 M</td>
</tr>
<tr>
<td>12</td>
<td>L X-2.75 R0 F100 M</td>
</tr>
<tr>
<td>13</td>
<td>L Y-4.0226 R0 F100 M</td>
</tr>
<tr>
<td>14</td>
<td>L X-3.0566 R0 F100 M</td>
</tr>
<tr>
<td>15</td>
<td>L X-3.109 Y-4.0994 R0 F100 M</td>
</tr>
<tr>
<td>16</td>
<td>L X-3.1094 Y-4.1 R0 F100 M</td>
</tr>
<tr>
<td>17</td>
<td>CR X-3.5254 Y-4.55 R+2.125 DR- R0 F100 M</td>
</tr>
<tr>
<td>18</td>
<td>L X-2.5 R0 F100 M</td>
</tr>
<tr>
<td>19</td>
<td>L Y-4.0226 R0 F100 M</td>
</tr>
<tr>
<td>20</td>
<td>L X-2.75 R0 F100 M</td>
</tr>
<tr>
<td>21</td>
<td>L Y-3.7726 R0 F100 M</td>
</tr>
<tr>
<td>22</td>
<td>L X-3.1917 R0 F100 M</td>
</tr>
<tr>
<td>23</td>
<td>L X-3.2342 Y-3.8393 R0 F100 M</td>
</tr>
<tr>
<td>24</td>
<td>L X-3.3152 Y-3.958 R0 F100 M</td>
</tr>
<tr>
<td>25</td>
<td>L X-3.3155 Y-3.9585 R0 F100 M</td>
</tr>
<tr>
<td>26</td>
<td>CR X-3.5254 Y-4.55 R+2.125 DR- R0 F100 M</td>
</tr>
<tr>
<td>27</td>
<td>L X-2.5 R0 F100 M</td>
</tr>
<tr>
<td>28</td>
<td>L Y-4.0226 R0 F100 M</td>
</tr>
<tr>
<td>29</td>
<td>L X-2.75 R0 F100 M</td>
</tr>
<tr>
<td>30</td>
<td>L Y-3.7726 R0 F100 M</td>
</tr>
<tr>
<td>31</td>
<td>L X-3.1917 R0 F100 M</td>
</tr>
<tr>
<td>32</td>
<td>L X-3.2342 Y-3.8393 R0 F100 M</td>
</tr>
<tr>
<td>33</td>
<td>L X-3.3152 Y-3.958 R0 F100 M</td>
</tr>
<tr>
<td>34</td>
<td>CR X-3.5254 Y-4.55 R+2.125 DR- R0 F100 M</td>
</tr>
<tr>
<td>35</td>
<td>L X-2.5 R0 F100 M</td>
</tr>
<tr>
<td>36</td>
<td>L Y-4.0226 R0 F100 M</td>
</tr>
<tr>
<td>37</td>
<td>L X-2.75 R0 F100 M</td>
</tr>
<tr>
<td>38</td>
<td>L Y-3.7726 R0 F100 M</td>
</tr>
<tr>
<td>39</td>
<td>L X-3.1917 R0 F100 M</td>
</tr>
<tr>
<td>40</td>
<td>CR X-3.5254 Y-4.55 R+2.125 DR- R0 F100 M</td>
</tr>
<tr>
<td>41</td>
<td>L X-2.5 R0 F100 M</td>
</tr>
<tr>
<td>42</td>
<td>L Y-4.0226 R0 F100 M</td>
</tr>
<tr>
<td>43</td>
<td>L X-2.75 R0 F100 M</td>
</tr>
<tr>
<td>44</td>
<td>L Y-3.7726 R0 F100 M</td>
</tr>
<tr>
<td>45</td>
<td>L X-3.1917 R0 F100 M</td>
</tr>
<tr>
<td>46</td>
<td>CR X-3.5254 Y-4.55 R+2.125 DR- R0 F100 M</td>
</tr>
<tr>
<td>47</td>
<td>L X-2.5 R0 F100 M</td>
</tr>
<tr>
<td>48</td>
<td>L Y-4.0226 R0 F100 M</td>
</tr>
<tr>
<td>49</td>
<td>L X-2.75 R0 F100 M</td>
</tr>
<tr>
<td>50</td>
<td>L Y-3.7726 R0 F100 M</td>
</tr>
<tr>
<td>51</td>
<td>L X-3.1917 R0 F100 M</td>
</tr>
<tr>
<td>52</td>
<td>CR X-3.5254 Y-4.55 R+2.125 DR- R0 F100 M</td>
</tr>
<tr>
<td>53</td>
<td>L X-2.5 R0 F100 M</td>
</tr>
<tr>
<td>54</td>
<td>L Y-4.0226 R0 F100 M</td>
</tr>
<tr>
<td>55</td>
<td>L X-2.75 R0 F100 M</td>
</tr>
<tr>
<td>56</td>
<td>L Y-3.7726 R0 F100 M</td>
</tr>
<tr>
<td>57</td>
<td>L X-3.1917 R0 F100 M</td>
</tr>
<tr>
<td>58</td>
<td>CR X-3.5254 Y-4.55 R+2.125 DR- R0 F100 M</td>
</tr>
<tr>
<td>59</td>
<td>L X-2.5 R0 F100 M</td>
</tr>
<tr>
<td>60</td>
<td>L Y-4.0226 R0 F100 M</td>
</tr>
<tr>
<td>61</td>
<td>L X-2.75 R0 F100 M</td>
</tr>
<tr>
<td>62</td>
<td>L Y-3.7726 R0 F100 M</td>
</tr>
<tr>
<td>63</td>
<td>L X-3.1917 R0 F100 M</td>
</tr>
<tr>
<td>64</td>
<td>CR X-3.5254 Y-4.55 R+2.125 DR- R0 F100 M</td>
</tr>
<tr>
<td>65</td>
<td>L X-2.5 R0 F100 M</td>
</tr>
<tr>
<td>66</td>
<td>L Y-4.0226 R0 F100 M</td>
</tr>
<tr>
<td>67</td>
<td>L X-2.75 R0 F100 M</td>
</tr>
<tr>
<td>68</td>
<td>L Y-3.7726 R0 F100 M</td>
</tr>
<tr>
<td>69</td>
<td>CR X-3.5254 Y-4.55 R+2.125 DR- R0 F100 M</td>
</tr>
<tr>
<td>70</td>
<td>L X-2.5 R0 F100 M</td>
</tr>
<tr>
<td>71</td>
<td>L Y-4.0226 R0 F100 M</td>
</tr>
<tr>
<td>72</td>
<td>L X-2.75 R0 F100 M</td>
</tr>
<tr>
<td>73</td>
<td>L Y-4.0226 R0 F100 M</td>
</tr>
<tr>
<td>74</td>
<td>L X-2.75 R0 F100 M</td>
</tr>
<tr>
<td>75</td>
<td>L Y-4.0226 R0 F100 M</td>
</tr>
<tr>
<td>76</td>
<td>L X-2.75 R0 F100 M</td>
</tr>
<tr>
<td>77</td>
<td>L Y-4.0226 R0 F100 M</td>
</tr>
<tr>
<td>78</td>
<td>L X-2.75 R0 F100 M</td>
</tr>
<tr>
<td>79</td>
<td>L Y-4.0226 R0 F100 M</td>
</tr>
<tr>
<td>80</td>
<td>L X-2.75 R0 F100 M</td>
</tr>
<tr>
<td>81</td>
<td>L Y-4.0226 R0 F100 M</td>
</tr>
<tr>
<td>82</td>
<td>L X-2.75 R0 F100 M</td>
</tr>
<tr>
<td>83</td>
<td>L Y-4.0226 R0 F100 M</td>
</tr>
<tr>
<td>84</td>
<td>L X-2.75 R0 F100 M</td>
</tr>
<tr>
<td>85</td>
<td>L Y-4.0226 R0 F100 M</td>
</tr>
<tr>
<td>86</td>
<td>L X-2.75 R0 F100 M</td>
</tr>
<tr>
<td>87</td>
<td>L Y-4.0226 R0 F100 M</td>
</tr>
<tr>
<td>88</td>
<td>L X-2.75 R0 F100 M</td>
</tr>
<tr>
<td>89</td>
<td>L Y-4.0226 R0 F100 M</td>
</tr>
<tr>
<td>90</td>
<td>L X-2.75 R0 F100 M</td>
</tr>
<tr>
<td>91</td>
<td>L Y-4.0226 R0 F100 M</td>
</tr>
<tr>
<td>92</td>
<td>L X-2.75 R0 F100 M</td>
</tr>
<tr>
<td>93</td>
<td>L Y-4.0226 R0 F100 M</td>
</tr>
<tr>
<td>94</td>
<td>L X-2.75 R0 F100 M</td>
</tr>
<tr>
<td>95</td>
<td>L Y-4.0226 R0 F100 M</td>
</tr>
<tr>
<td>96</td>
<td>L X-2.75 R0 F100 M</td>
</tr>
<tr>
<td>97</td>
<td>L Y-4.0226 R0 F100 M</td>
</tr>
<tr>
<td>98</td>
<td>L X-2.75 R0 F100 M</td>
</tr>
<tr>
<td>99</td>
<td>L Y-4.0226 R0 F100 M</td>
</tr>
<tr>
<td>100</td>
<td>L X-2.75 R0 F100 M</td>
</tr>
<tr>
<td>101</td>
<td>L Y-4.0226 R0 F100 M</td>
</tr>
<tr>
<td>102</td>
<td>L X-2.75 R0 F100 M</td>
</tr>
</tbody>
</table>
APPENDIX HHH

216 L X-3.5297 R0 F100 M
217 CR X-3.6473 Y-3.5576 R+0.75 DR R0 F100 M
218 L X-3.7275 Y-3.6752 R0 F100 M
219 L X-3.7278 Y-3.6756 R0 F100 M
220 CR X-4.8615 Y-4.2726 R+1.375 DR R0 F100 M
221 L X-8.3 R0 F100 M
222 L Y-5.3 R0 F100 M
223 L X-1.75 R0 F100 M
224 L Y-3.2726 R0 F100 M
225 L X-2.75 R0 F100 M
226 L Y-3.0226 R0 F100 M
227 L X-3.7595 R0 F100 M
228 L X-3.7596 Y-3.0245 R0 F100 M
229 L X-3.7678 Y-3.1645 R0 F100 M
230 CR X-3.8539 Y-3.4168 R+0.5 DR R0 F100 M
231 L X-3.9337 Y-3.5338 R0 F100 M
232 L X-3.9339 Y-3.5342 R0 F100 M
233 CR X-4.8615 Y-4.0226 R+1.125 DR R0 F100 M
234 L X-8.55 R0 F100 M
235 L Y-5.55 R0 F100 M
236 L X-1.5 R0 F100 M
237 L Y-3.0226 R0 F100 M
238 L X-2.75 R0 F100 M
239 L Y-2.7726 R0 F100 M
240 L X-3.7595 R0 F100 M
241 CR X-4.009 Y-3.0065 R+0.25 DR R0 F100 M
242 L X-4.0091 Y-3.0088 R0 F100 M
243 L X-4.0092 Y-3.0098 R0 F100 M
244 L X-4.0174 Y-3.1498 R0 F100 M
245 CR X-4.0604 Y-3.2759 R+0.25 DR R0 F100 M
246 L X-4.14 Y-3.3927 R0 F100 M
247 CR X-4.8615 Y-3.7726 R+0.875 DR R0 F100 M
248 L X-8.8 R0 F100 M
249 L Y-5.8 R0 F100 M
250 L X-1.25 R0 F100 M
251 L Y-3.0226 R0 F100 M
252 CR X-1.5 Y-2.7726 R+0.25 DR R0 F100 M
253 L X-2.75 R0 F100 M
254 L Y-2.5226 R0 F100 M
255 L X-3.7595 R0 F100 M
256 CR X-4.2587 Y-2.9951 R+0.5 DR R0 F100 M
257 L X-4.267 Y-3.1351 R0 F100 M
258 L X-4.3439 Y-3.2479 R0 F100 M
259 CR X-4.8615 Y-3.5226 R+0.625 DR R0 F100 M
260 L X-9.05 R0 F100 M
261 L Y-6.05 R0 F100 M
262 L X-1.0 R0 F100 M
263 L Y-3.0226 R0 F100 M
264 CR X-1.5 Y-2.5226 R+0.5 DR R0 F100 M
265 L X-2.75 R0 F100 M
266 L Y-4.2726 R0 F100 M
267 L Z-1.0 R0 F50 M
268 L X-2.925 R0 F100 M
269 L X-2.9448 Y-4.3 R0 F100 M
270 L X-2.75 R0 F100 M
271 L Y-4.0226 R0 F100 M
272 L X-3.0566 R0 F100 M
273 L X-3.109 Y-4.0994 R0 F100 M
274 L X-3.1094 Y-4.1 R0 F100 M
275 CR X-3.5254 Y-4.55 R+2.125 DR R0 F100 M
276 L X-2.5 R0 F100 M
277 L Y-4.0226 R0 F100 M
278 L X-2.75 R0 F100 M
279 L Y-3.7726 R0 F100 M
280 L X-3.1917 R0 F100 M
281 L X-3.2342 Y-3.8393 R0 F100 M
282 L X-3.3152 Y-3.958 R0 F100 M
283 L X-3.3155 Y-3.9585 R0 F100 M
284 CR X-4.8615 Y-4.7726 R+1.875 DR R0 F100 M
285 L X-7.8 R0 F100 M
286 L Y-4.8 R0 F100 M
287 L X-2.25 R0 F100 M
288 L Y-3.7726 R0 F100 M
289 L X-2.75 R0 F100 M
290 L Y-3.5226 R0 F100 M
291 L X-3.3451 R0 F100 M
292 CR X-3.4408 Y-3.6985 R+1.0 DR R0 F100 M
293 L X-3.5213 Y-3.8166 R0 F100 M
294 L X-3.5217 Y-3.8171 R0 F100 M
295 CR X-4.8615 Y-4.5226 R+1.625 DR R0 F100 M
296 L X-8.05 R0 F100 M
297 L Y-5.05 R0 F100 M
298 L X-2.0 R0 F100 M
299 L X-3.5226 R0 F100 M
300 L X-2.75 R0 F100 M
301 L Y-3.2726 R0 F100 M
302 L X-3.5297 R0 F100 M
303 CR X-3.6473 Y-3.5576 R+0.75 DR R0 F100 M
304 L X-3.7275 Y-3.6752 R0 F100 M
305 L X-3.7278 Y-3.6756 R0 F100 M
306 CR X-4.8615 Y-4.2726 R+1.375 DR R0 F100 M
307 L X-8.3 R0 F100 M
308 L Y-5.3 R0 F100 M
309 L X-1.75 R0 F100 M
310 L Y-3.2726 R0 F100 M
311 L X-2.75 R0 F100 M
312 L Y-3.0226 R0 F100 M
313 L X-3.7595 R0 F100 M
314 L X-3.7596 Y-3.0245 R0 F100 M
315 L X-3.7678 Y-3.1645 R0 F100 M
316 CR X-3.8539 Y-3.4168 R+0.5 DR R0 F100 M
317 L X-3.9337 Y-3.5338 R0 F100 M
318 L X-3.9339 Y-3.5342 R0 F100 M
319 CR X-4.8615 Y-4.0226 R+1.125 DR R0 F100 M
320 L X-8.55 R0 F100 M
321 L Y-5.55 R0 F100 M
322 L X-1.5 R0 F100 M
323 L Y-3.0226 R0 F100 M
324 L X-2.75 R0 F100 M
325 L Y-2.7726 R0 F100 M
APPENDIX HHH
APPENDIX HHH

760 L X-9.0 R0 F100 M
761 CR X-9.05 Y-4.96 R+0.05 DR+ R0 F100 M
762 L Y-6.05 R0 F100 M
763 L X-2.9448 R0 F100 M
764 L Z0.1 R0 F100 M
765 CALL LBL 1 REP
766 STOP M25
767 END PGM 799 INCH