Development of the Machine Shop Instruction and the Stirling Engine Project for *2.670: ME Tools*

by
Stacy J. Morris

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ABSTRACT

A new class called *2.670: M.E. Tools*, was added to the undergraduate Mechanical Engineering curriculum in 1995. *2.670* is only offered during I.A.P. and is intended for sophomore students. The purpose of the course is to provide an introduction to machining in the Pappalardo Lab and the Lab for Manufacturing and Productivity, and to engineering computer skills on Project Athena.

In June 1995, the development *2.670: M.E. Tools* began, and in less than seven months, the first class met, on January 8, 1996. This thesis will cover the development of the curriculum and instruction for the machining half of the class, as well as the development and production of the student project, a miniature Stirling Engine.

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TABLE OF CONTENTS

TABLE OF FIGURES

1. INTRODUCTION

1.1 ORIGIN

2.670: ME Tools was created during the revisions of the undergraduate curriculum in 1995. The development of 2.670 started in June 1995. It was first taught during the Independent Activities Period (I.A.P.) of the 1995-1996 M.I.T. academic year, and was added as a required course to the undergraduate curriculum effective for the graduating class of 1998. It is the first required course at M.I.T. which is offered only during I.A.P. This thesis will cover what is required in the development and administration of the machine shop half of this course.

1.2 GOALS

The purpose of creating this new class was to provide students with the tools needed for interactive learning in their future classes. The new curriculum revisions sought to teach students with less straight lecture and more interaction between the faculty and the students. As this would require different skills on the part of the students, *2.670:ME Tools* was created to give the students a thorough introduction to several of the tools necessary for an undergraduate education in the Mechanical Engineering Department at M.I.T.

1.3 INSTRUCTION

There are two distinct parts of 2.670, computer lab instruction and machine shop instruction. This thesis will address the issues concerned with the preparation for and the instruction in the machine shop (for information on the computer lab instruction, see Galendez [1]).

1.3.1 Computer Lab

In the computer lab, students were introduced to several of the computing programs available on the Athena system. They spent one day on an overview of Project Athena (the M.I.T. campus-wide computing system) and the World Wide Web, and one day on XESS (the spreadsheet on Athena designed for science and engineering computing); the instruction for these first two days was in lecture halls, followed by homework assignments on Athena. The students then received instruction on Matlab and Pro/Engineer, for three days consecutive days each, in computer classrooms.

1.3.2 Machine Shop

On the first day of the class, the students were introduced to safety issues in both the shop and in engineering practice. Starting on the second day, they learned, throughout the course, how to use the drill press, the beltsander, the bandsaw, the lathe, the vertical and horizontal mills, as well as how to read use tap/die and drill sizes, and how to layout (mark and scribe). They also observed the Cincinnati Millicron and the Daewoo Lathe. Both the Pappalardo Lab in Building 3 and the Lab for Manufacturing and Productivity (LMP) in Building 35 were utilized to teach the students.

1.3.3 The Stirling Engine

A Stirling engine was used as a teaching tool in both aspects of the course. In the machine shop, every student made slightly more than half the parts of a miniature working Stirling engine, as shown in Figure 1. The students were provided with the other parts, and assembled and debugged their own engine. In the computer lab, students analyzed the Stirling engine in their Xess and Matlab homework assignments.

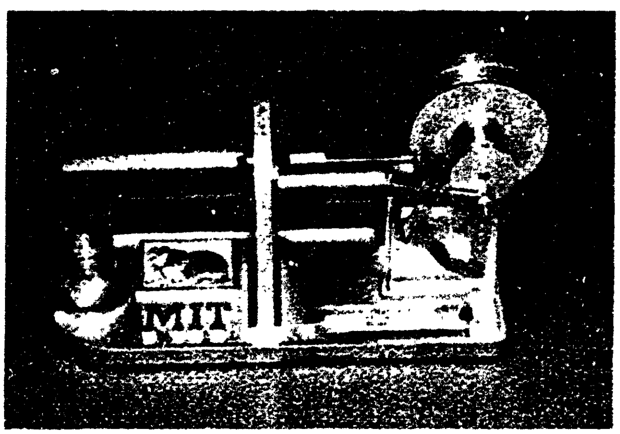

Figure 1. The M.I.T. Stirling Engine [2]

1.4 REQUIREMENTS

The students received six units of pass/fail credit for completion of the course. In order to pass, the students had to attend (or be excused from) all of the class hours, complete all homework (assigned during the World Wide Web, the Xess, and the Matlab sessions), and make all of the required Stirling engine parts. A working Stirling Engine was not a requirement; however, only three students were unable to get their engines running by the end of the class.

1.5 SCHEDULE

Due to the large number of students who needed to take the class (the maximum was set at 160 students), the class was split into two sessions of 80 students each, and within each session, the students were split into four groups of 20 students each.

1.5.1 Sessions

There were two sessions of 2.670 offered, each of which met for nine days over a two week period, with the second Monday as a day off (Martin Luther King Day during the first session). Session 1 met on 1/8/96 - 1/12/96 and on 1/16/96 - 1/19/96, and Session 2 met on 1/22/96 - 1/26/96 and on 1/30/96 - 2/2/96, as shown in Figure 2. Each day, the class met for eight hours, from 8 AM - 12 NOON and from 1 PM - 5 PM.

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1/8 Session 1 Day 1 *first day of IAP*	**1/9** Session 1 Day 2	**1/10** Session 1 Day 3	**1/11** Session 1 Day 4	**1/12** Session 1 Day 5	**1/13** *no class*	**1/14** *no class*
1/15 *no class* [MLK Day]	**1/16** Session 1 Day 7	**1/17** Session 1 Day 8	**1/18** Session 1 Day 9	**1/19** Session 1 Day 10	**1/20** *no class*	**1/21** *no class*
1/22 Session 2 Day 1	**1/23** Session 2 Day 2	**1/24** Session 2 Day 3	**1/25** Session 2 Day 4	**1/26** Session 2 Day 5	**1/27** *no class*	**1/28** *no class*
1/29 *no class*	**1/30** Session 2 Day 7	**1/31** Session 2 Day 8	**2/1** Session 2 Day 9	**2/2** Session 2 Day 10 *last day of IAP*	**2/3** *no class*	**2/4** *no class*

Figure 2. The 2.670 Session Schedule, I.A.P. 1996

1.52 Groups

Within each session, the students were divided into four groups (the students were assigned alphabetically). Two of these groups were in the machine shop in the morning and in the computer lab in the afternoon, and the other two were in the computer lab in the morning and the machine shop in the afternoon, as shown in Figure 3.

Each pair of groups met together during the first two days of computer instruction and then met separately for Pro/Engineer and Matlab instruction (three consecutive days of each). Similarly, they also met separately in the L.M.P. and the Pappalardo Lab (again, three consecutive days of each), until the last two days of class, when they both met in the Pappalardo Lab for assembly of the engines. In order to distinguish between the groups, each group was given a planet name (Mercury, Mars, Venus, Jupiter in Session 1, and Saturn, Uranus, Neptune, Pluto in Session 2).

		Pappalardo Lab	L.M.P	Matlab	Pro/Engineer
Day 1	8 - 9 AM	*Introduction for all groups*			
	9 - 10:30 AM	Mercury/Saturn	Venus/Uranus	Mars/Neptune & Jupiter/Pluto.	
	10:30 - 12 NOON	Venus/Uranus	Mercury/Saturn	*Athena and the WWWeb*	
	1 - 3 PM	[illegible]	Jupiter/Pluto	Mercury/Saturn & Venus/Uranus.	
	3 - 5 PM	Jupiter/Pluto	[illegible]	*Athena and the WWWeb*	
Day 2	8 - 12 NOON	Mercury/Saturn	Venus/Uranus	Mars/Neptune & Jupiter/Pluto. *XESS*	
	1 - 5 PM	[illegible]	Jupiter/Pluto	Mercury/Saturn & Venus/Uranus. *XESS*	
Day 3	8 - 12 NOON	Mercury/Saturn	Venus/Uranus	[illegible]	Jupiter/Pluto
	1 - 5 PM	[illegible]	Jupiter/Pluto	Mercury/Saturn	Venus/Uranus
Day 4	8 - 12 NOON	Mercury/Saturn	Venus/Uranus	[illegible]	Jupiter/Pluto
	1 - 5 PM	[illegible]	Jupiter/Pluto	Mercury/Saturn	Venus/Uranus
Day 5	8 - 12 NOON	Venus/Uranus	Mercury/Saturn	[illegible]	Jupiter/Pluto
	1 - 5 PM	Jupiter/Pluto	[illegible]	Mercury/Saturn	Venus/Uranus
Day 6		*NO CLASS!*			
Day 7	8 - 12 NOON	Venus/Uranus	Mercury/Saturn	Jupiter/Pluto	[illegible]
	1 - 5 PM	Jupiter/Pluto	[illegible]	Venus/Uranus	Mercury/Saturn
Day 8	8 - 12 NOON	Venus/Uranus	Mercury/Saturn	Jupiter/Pluto	[illegible]
	1 - 5 PM	Jupiter/Pluto	[illegible]	Venus/Uranus	Mercury/Saturn
Day 9	8 - 12 NOON	Mercury/Saturn & Venus/Uranus. *Pappalardo Lab (engine assembly)*		Jupiter/Pluto	[illegible]
	1 - 5 PM	Mars/Neptune & Jupiter/Pluto. *Pappalardo Lab (engine assembly)*		Venus/Uranus	Mercury/Saturn
Day 10	8 - 12 NOON	*Pappalardo Lab* open to all four groups *for final engine assembly*			
	1 - 3 PM	All four groups meet for *final lecture and Pi Tau Sigma evaluations*			
	3 - 5 PM	All four groups meet in *Pappalardo Lab for the Stirling Spin Contest*			

Figure 3. The 2.670 Group Schedule, I.A.P. 1996

1.6 REGISTRATION

As the first required class during I.A.P., there was no previously established protocol for registration for the class. For traditional I.A.P. classes, students informally register either late in the Fall Semester or on the first day of the class during I.A.P. However, as a required class with two separate sessions, session assignments (which affected many students travel arrangements) and the total number of students in each session had to be completed prior to the first day of the first session. In order to accomodate these needs, registration for the class was carried out on the World Wide Web during the first week of school in the fall semester. All advisors were sent letters (Appendix 1) notifying them to remind their sophomore students to register for the course. and the students were sent similar letters (see Appendix 1), as well as instructions for starting a web browser and registering for the class (see Appendix 1). The list of students who registered was checked against the list of sophomore students who were registered in October and November as "Course 2", and any "missing" students were notified and asked to register.

2 THE PROJECT: A MINIATURE WORKING STIRLING ENGINE

2.1 THE HISTORY OF THE STIRLING ENGINE

On September 27, 1816, Robert Stirling applied for a patent for an engine, as shown in Figure 4, at the Chancery in Edinburgh, Scotland. By trade, Robert Stirling was a minister in the Church of Scotland and he continued to give services until he was eighty-six years old. In his spare time, however, he built heat engines in his home workshop. Lord Kelvin used one of the working models during some of his university classes. In 1850, the simple and elegant dynamics of the engine were first explained by Professor McQuorne Rankine. Approximately one hundred years later, the term *Stirling engine* was coined by Rolf Meijer in order to describe all types of closed cycle regenerative gas engines.

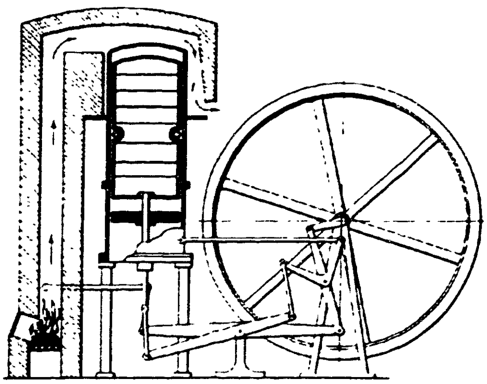

Figure 4. The 1816 Stirling Engine [3]

Stirling engines are unique heat engines because their theoretical efficiency is nearly equal to their theoretical maximum efficiency, known as the *Carnot Cycle* efficiency. Stirling engines are powered by the expansion of a gas when heated, which is followed by the compression of the gas when cooled. The Stirling engine contains a fixed amount of gas which is transferred back and forth between a "cold" end (often room temperature) and a "hot" end (often heated by a kerosene or alcohol burner). The "displacer piston" moves the gas between the two ends and the "power piston" changes the internal volume as the gas expands and contracts.

2.2 THE ORIGINS OF THE CURRENT M.I.T. STIRLING ENGINE

The current M.I.T. Stirling Engine was first featured in an article in *Popular Science*. It was developed at Dartmouth University by Roger Howes for use in an Thayer School of Engineering class, *ES 61 Thermodynamics*. The class was first taught in the early eighties, and became a required class for engineering majors in 1994. Roger Howes estimated that at least 1100 engines were built between the inception of the class and the spring of 1996.

2.3 THE M.I.T. STIRLING ENGINE

The Stirling engine was further adapted, during the Summer and Fall of 1995, to fit the needs of 2.670. Each part was designed to teach the students about a different aspect of machining. The final version of the engine is shown in Figure 5 (individual part drawings can be found on pages 70-105; page 65 contains a list of parts and numbers). This section will discuss the teaching benefits several parts of the M.I.T. Stirling Engine.

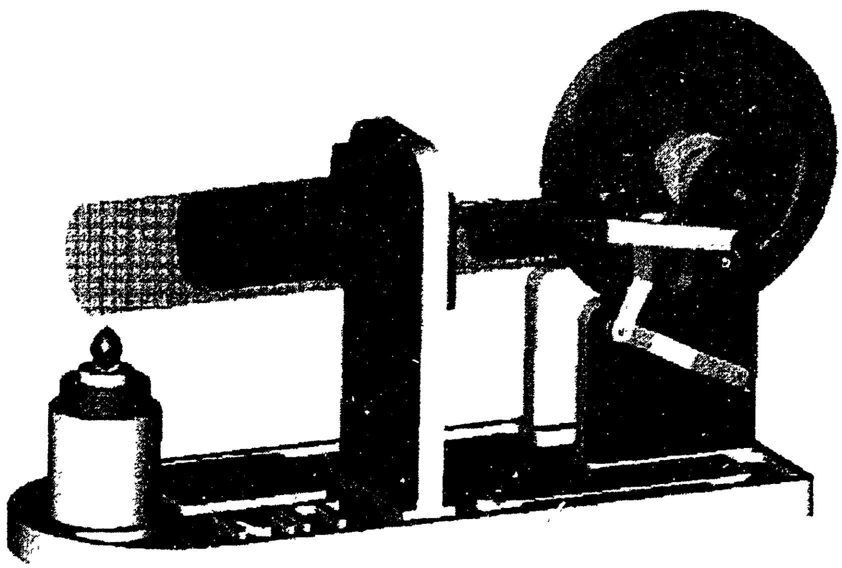

Figure 5. The M.I.T. Stirling Engine [4]

2.3.1 Alcohol Burner (#001)

The alcohol burner consisted of a glass jar and a brass cap. The glass jar was used to store all of the fasteners which the students received. The brass cap was manufactured on the Daewoo Lathe, and had a groove cut for an o-ring. The use of an o-ring insured a tight fit with the glass jar, and showed the students how to obtain a leak-proof fit.

2.3.2 Displacer Cylinder (#002)

The displacer cylinder was silver-soldered, which prevented the application of extremely high temperatures (such as those generated by a blow-torch) at the hot end of the piston.

2.3.3 Cylinder Plate (#004)

This was made by the students in Building 3, where they used a jig to drill five holes in the face, and rounded two of the corners on the beltsander. Since the cylinder plate was made of brass and is 3/8" thick in the direction of drilling, the necessity of applying drilling fluid and "peck" drilling (backing the drill off) was readily apparent. The students traced rounded corners onto their piece, using blue die and a scribe, and then cut off the corners outside of the traced mark on the bandsaw. They finished off the curves on the beltsander, which gave them a feel for the hardness of brass.

2.3.4 Power Cylinder (#005) and Power Piston (#006)

These parts demonstrated Computer Numerical Controlled (CNC) programming and the rapid cycle time which is possible on the Daewoo Lathe.

2.3.5 Gudgeon Block (#007)

This is one of the more difficult parts which the students made on the lathe; because of its small size. After facing and turning the part and drilling a hole through the center on the lathe, the students used the horizontal mill to make the slot.

2.3.6 Power Connecting Lever (#008), Lever Connector (#009), Levers 11 & 12 (#011, #012)

These were the first parts in Building 3 which used the drill press. Since the students used a jig to drill the holes in these levers, and since the levers were 3/16" or less thick, these were relatively easy pieces for students to start on, especially students with little machining experience. The students also rounded the end of each lever on the beltsander, which showed them the importance of holding a piece securely while using the beltsander.

2.3.7 Lever Shaft (#010) and Levers 11 & 12 (#011, #012)

Levers 11 and 12 were soldered to the lever shaft. Although this is not the strongest method of securing a joint, it allowed proper soldering technique to be introduced. Furthermore, it allowed easy adjustment of the angle between levers 11 and 12, which could compensate machining errors in other parts of the students' machines.

2.3.8 Levers 11 & 12 (#011, #012)

These two pieces were bent using a jig. The difficulties of bending metal were explained to the students, and concepts such as spring-back were experienced. They needed to separate levers 11 and 12 from the lever connector, which was determeined by the distance between the holes.

2.3.9 Connector Link (#013)

In drilling the holes of the connector link, the students scribed cross-hatches at the hole locations, and then used a center drill to start the hole. They had to drill all the way across the gap in order to insure that the holes lined up, and this drilling had to be done slowly in order to prevent the collapse of the top flange. The burrs created by drilling had to be filed in order to fit the corresponding pieces between the two flanges.

2.3.10 Displacer Piston Rod (#014)

The students finished the threads at one of the ends of this rod. Since the OD of the rod was only 1/8", the threads were started on the lathe in order to insure that they were aligned squarely. This showed the students the difficulty and importance of making the threads perpendicular to an axis.

At the other end of the rod, the students marked the location of the hole and drilled the hole through. Since the displacer piston rod was made of drill rod, it was absolutely necessary to center drill before attempting to drill the hole through the rod.

2.3.11 Transfer Piston Guide Bushing (#015)

This piece, which was made from hex stock, demonstrated that non-round pieces can be machined on lathes. Additionally, For best engine performance, the fit between the displacer piston rod and the transfer piston guide bushing needed to be as tight as possible, so the center hole of the guide bushing had tight tolerances. The students checked their finish by sliding the rod through the center hole of the guide bushing.

2.3.12 Main Bearing Bushings (#019, #020)

These purchased bearings were sintered bronze, which meant they could be reamed, if necessary. The students had to press-fit the bearings into the bearing plates. If the students hammered the bearings (which caused the bearings to flare out), or had a slight misalignment of the bearing plates, they simply reamed through both bearings, so that the crank web shaft coulc rotate freely.

2.313 Flywheel (#021)

This piece had very short shoulders which needed to be gripped on the lathes. Consequently, it showed the students the difficulties and hazards which can occur on the lathes, as flywheels which were not securely gripped could come out during operation of the lathe.

2.3.14 Bearing Plates (#022, 023)

These were the only pieces which the students used with the vertical mill. Due to time and machine constraints, they only used the mill to drill two holes, but this gave them exposure to the digital read outs, finding a precise location, as well as the operation of the vertical mill.

The students layed out two perpendicular lines on each bearing plate, and used the bandsaw to cut along the lines. They used the beltsander to round the corners, and as with the cylinder plate, this gave them a feeling for the hardness of aluminum.

2.4 THE 2.670 STIRLING SPIN-OFF CONTEST

A contest was held on the last afternoon of class. This included a "Beauty Contest" to determine the best-looking engines, and the "Stirling Spin-off" to determine the fastest engines. Certificates were awarded to winners in two categories, "modified" and "unmodified" engines. "Unmodified" engines were those which were made exactly according to the process plans, and "modified" engines were those which had any modifications from the process plans.

Since the class was developed as an introductory class, some of the students who had prior machine shop experience finished their parts more quickly, so they were encouraged to design and build modifications, such as heat sinks, to improve the efficiency of their engines.

2.4.1 Winners of the 1996 Stirling Spin-Off

Each session of 2.670 held its own Beauty Contest and Stirling Spin-Off; the winners of each are shown in Figure 6.

	Session 1		Session 2	
	Unmodified	Modified	Unmodified	Modified
Beauty Contest	James Lee	Ollie Burlaud	Ray Oshtory	Shawn Stern
Stirling Spin-Off; Max RPM	Bryan Morrissey; 900	Roy Swart; 874	Robert Lentz; 850	R. Lentz; 800

Figure 6. The 1996 Beauty Contest and Stirling Spin-Off Winners

3. THE MACHINE SHOP

In order to meet the requirement of teaching 80 students machining skills in less than 36 hours over two weeks (twice), such that each student could successfully assemble an engine, the optimal schedule which would allow the most learning to take place had to be determined. This included determining the division of student-made parts between machine shops, the division of part fabrication and the "process plans" of each part in both machine shops, the student division between machine shops and within each machine shop, as well as the division of instructors.

As described in Section *1.5.2 Groups*, within each session, the students were divided into four groups of twenty students each, so that, utilizing both machine shops in the morning and afternoon, on most days the maximum number of students in either machine shop was twenty students.

3.1 DIVISION OF PARTS

After deciding which parts would be made by the students, the parts were split between the two machine shops as shown in Figure 7.

Pappalardo Lab	**L.M.P.**
Cylinder Plate (004)	Gudgeon Block (007)
Power Connecting Lever (008)	Transfer Piston Guide Bushing (015)
Lever Connector (009)	Crank Web (017)
Levers 11 & 12 (011, 012)	Flywheel (#020)
Connector Link (013)	
Displacer Piston Rod (014)	
Bearing Plates (021, 022)	

Figure 7. Division of Student-Made Parts between Machine Shops

3.2 DIVISION OF PART PROCESSES AND THE PROCESS PLANS

As mentioned above, the parts needed to be made by the students in such a manner as to minimize waiting time and maximize learning time.

3.2.1 The 2.670 Process Plans

The manufacturing of the parts was divided into separate processes, and *process plans* were developed for each process by the author, in conjuction with Kevin Baron and Fred Cote in the L.M.P, and with Norman Berube and Federico Frigerio in the Pappalardo Lab. A generic process plan is shown in Figure 8.

Part Name *part name here*				**Part Number** *part number here*	**Building** *X**
Material *material of part here*				**Start Size** *start size of part here*	**Process** *X*-N***
Op #	**Workplaces**	**Tools or Part**	**Drawings**	**Instructions and Parameters**	**Complete (✓check)**
010	*Machine or station for this operation*	*Tool or part name needed for this operation*	*Sketch for clarification of this operation, as necessary*	*Detailed instructions and cautionary notes for each operation*	
020				**In "Building" and "Process", X is either "3" for the Pappalardo Lab, or "35" for the L.M.P.*	
030				***In "Process", N is a letter, which is used to distinguish the process plans in each shop.*	
etc.					

Figure 8. A Generic Process Plan

The process plans for each process, as listed in Figure 9, can be found in section *6. The Course Manual*, on pages 69-94.

Pappalardo Lab Process Plans			**L.M.P. Process Plans**		
Process	**Part(s) Invoved in Process**	**Page**	**Process**	**Part Invoved in Process**	**Page**
3-A	Cylinder Plate, Connector Link, and Bearing Plates	69	35-A	Transfer Piston Guide Bushing	85
3-B	Bearing Plates	71-72	35-B	Gudgeon Block	87-88
3-C	Power Connecting Lever Lever Connector, and Levers 11 and 12	75	35-C	Crank Web	89,91
3-D	Cylinder Plate	77	35-D	Flywheel	93,94
3-E	Displacer Piston Rod	79			
3-F	Connector Link	81			
3-G	Cylinder Plate and Bearing Plates	82			

Figure 9. The 2.670 Process Plans and Page Location in this Thesis

3.2.2 The History of the 2.670 Process Plan

The format of the process plans used in 2.670 was developed from a plan used in *2.86: Introduction to Manufacturing* (now 2.008). The origins of this format, however, stretch back many years. As shown in Figure 10, plan organization by separation of operations, tools, and instructions was in use in 1910, the time of the first copyright of the *Textbook of Advanced Machine Tools* [5].

SQUARE THREAD NUT 519

29. To make a Square thread nut, Fig. 27.

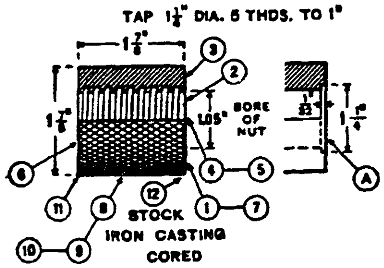

FIG. 27. — SCHEDULE DRAWING OF SQUARE THREAD NUT.

Specifications: Preparing nut blank. Rough threading. Tapping.
Material, iron casting, cored; weight, 1 lb. 6 oz.
Hardness, 29 to 31 (scleroscope).
High-speed steel or stellite cutting tools.
Time: Study drawing and schedule in advance, 5 min. —
Oil lathe, 4 min. — Bore, thread, and tap nut, 40 min. —
Square, turn, and nurl nut, 28 min. — (All tools furnished.)
Clean lathe, 3 min. — Total, 1 h. 20 min.

SCHEDULE OF OPERATIONS, MACHINES AND TOOLS

OPERATIONS.	MACHINES, SPEEDS, FEEDS.	TOOLS.
Mount in chuck, true up and clamp hard in chuck.	Engine lathe, 12" to 16". 3d speed, or 200 R.P.M.	Independent chuck, chalk.
Rough square, (1), one or two cuts. Feed inward.	2d or 3d speed, or 40 F.P.M. Hand or power feed.	Round-nose tool, or holder and cutter, 15° rake.
Rough bore hole to about 1.03", (2), two or three cuts.	1st or 2d speed, or 40 F.P.M. Medium power feed — 80 to 1".	Boring tool, see p. 504. Inside calipers, rule.
Finish bore hole, (2), two or three cuts.	3d speed, or 60 F.P.M. fine power feed — 140 to 1".	
Or omit boring, bevel corner of hole and drill to size.	2d or 3d speed, or 60 F.P.M.	3 or 4-groove high-speed steel twist drill (1.05"). See p. 410 and *Principles of Machine Work*.

Figure 10. A 1910 Process Plan for Machining a Square Thread Nut [5]

3.2.3 Recommended Changes to the Process Plans

The *Drawings* heading on the process plans should be changed to *Photos*, and pictures of each step (as necessary) should be inserted. This was the original purpose of this column, but was implementation for the 1996 class was impossible due to time constraints. Additionally, perhaps reference numbers could be added for clarity to both the process plans and the part drawings, as in the process plan from 1920.

The process plans for each part should be reviewed each year following the completion of the course, and should be confirmed each year with the machine shop staff who will be helping with the instruction of the students. In particular, the process plans for the displacer piston rod should be revised to minimize accidental bending of the rod. As well, the process plan listed for the crank web has instructions for making the crank web from aluminum stock of 1.5" OD. In 1996, the students were actually given a part which was nearly completed on the Daewoo Lathe. The original process plan was left in this thesis in the event that the option of manufacturing the entire part is given to the students in a following year.

3.3 Division of Students

The division of the 160 students into eight groups of twenty (four groups per two-week session) allowed for a maximum of twenty students, in general, to be present in each machine shop. Additionally, the students worked with partners in both machine shops, which reduced the number of actual student operations to ten. As shown in Figure 11, the students were split into two groups on their first two days in the Pappalardo Lab, to adjust for the number of vertical milling machines, so each half of the students did the processes of the first two days in one of two possible orders, in the Pappalardo Lab. However, in the L.M.P., there were enough lathes to accomodate each pair of students, so the students went through all the processes in parallel, in the L.M.P.

		Pappalardo Lab		**L.M.P.**	
		Instruction	**Max # Students**	**Instruction**	**Max # Students**
Day 1	9 - 10:30 AM	Introduction. Demos. SafetyLecture	20	Introduction. Demos	20
	10:30 - 12 NOON	Introduction. Demos. SafetyLecture	20	Introduction. Demos	20
	1 - 3 PM	Introduction. Demos. SafetyLecture	20	Introduction. Demos	20
	3 - 5 PM	Introduction. Demos. SafetyLecture	20	Introduction, Demos	20
Day 2	8 - 12 NOON	Processes 3-A & 3-B OR Processes 3-C. 3-D & 3-E	10 10	Process 35-B Start 35-A	20
	1 - 5 PM	Processes 3-A & 3-B OR Processes 3-C, 3-D & 3-E	10 10	Process 35-B Start 35-A	20
Day 3	8 - 12 NOON	Processes 3-C. 3-D & 3-E OR Processes 3-A & 3-B	10 10	Finish Process 35-A, Start 35-D	20
	1 - 5 PM	Processes 3-C. 3-D. & 3-E OR Processes 3-A & 3-B	10 10	Finish Process 35-A. Start 35-D	20
Day 4	8 - 12 NOON	Processes 3-F & 3-G	20	Finish Process 35-D. 35-C	20
	1 - 5 PM	Processes 3-F & 3-G	20	Finish Process 35-D, 35-C	20
Day 5	8 - 12 NOON	Processes 3-A & 3-B OR Processes 3-C. 3-D & 3-E	10 10	Process 35-B Start 35-A	20
	1 - 5 PM	Processes 3-A & 3-B OR Processes 3-C, 3-D & 3-E	10 10	Process 35-B Start 35-A	20
Day 6		*NO CLASS*			
Day 7	8 - 12 NOON	Processes 3-C, 3-D & 3-E OR Processes 3-A & 3-B	10 10	Finish Process 35-A, Start 35-D	20
	1 - 5 PM	Processes 3-C. 3-D, & 3-E OR Processes 3-A & 3-B	10 10	Finish Process 35-A. Start 35-D	20
Day 8	8 - 12 NOON	Processes 3-F & 3-G	20	Finish Process 35-D, 35-C	20
	1 - 5 PM	Processes 3-F & 3-G	20	Finish Process 35-D. 35-C	20
Day 9	8 - 12 NOON	Engine Assembly	40	Open for fixing/remaking parts	40
	1 - 5 PM	Engine Assembly	40	Open for fixing/remaking parts	40
Day 10	8 - 12 NOON	Final Assembly	80	Open for fixing/remaking parts	80
	3 - 5 PM	Stirling Spin-Off	80		0

Figure 11. Division of Students between Machine Shops and Processes

3.4 DIVISION OF INSTRUCTORS

With twenty students in each machine shop at one time, at least 4 instructors were needed in each machine shop, in order to have one instructor for every 5 students. This was accomplished by using two technical instructors in each machine shop, two Undergraduate Assistants (UA's) in each shop, and assigning each professor to two of the groups in each session. The professors and the UA's remained with the same groups throughout each session, rotating between machine shops with the students. Additionally, there was a grad TA in the Pappalardo Lab, to assist with instruction on the vertical mill, and the author, who was one of the two Head UA's (the other Head UA, Liv Galendez, was in charge of the computer instruction) also remained in the Pappalardo Lab, in order to assist in the non-mill instruction and oversee the 2.670 office, which was located at one end of the Pappalardo Lab.

The recommended instructor load for each machine shop is shown in Figure 12, along a record of the instructors from 2.670, 1996.

RECOMMENDED INSTRUCTORS	DUTIES	INSTRUCTORS DURING 2.670, 1996	
		NAME	TITLE
Pappalardo Lab			
2 Technical Instructors	Each at one of the three vertical mills to instruct a pair of students.	Dick Fenner Norman Berube	General Manager Project Machinist
2 TA's (or 1 TA and 1 Head UA)	One at the 3rd vertical mill. One in charge of the "office", oversees non-mill processes, and coordination of UA's.	Federico Frigerio Stacy Morris	Grad TA Head UA (one of two)
2 UA's	Rotate between shops with students. In charge of a particular process.	1-2 undergrads	UA
1 Professor	Rotates between shops with students, in shop as possible.	Doug Hart or Kevin Otto	Professor Professor
L.M.P.			
2 Technical Instructors	Oversee all the operations in the L.M.P.	Kevin Baron Fred Cote	Technical Instructors Research Specialist
2 TA's (or 1 TA and 1 Head UA)	Assist the techinical instructors in overseeing the LMP, and coordinate the UA's	(none)	
2 UA's	Rotate between shops with students. In charge of a particular process.	1-2 undergrads	UA
1 Professor	Rotates between shops with students, in shop as possible.	Doug Hart or Kevin Otto	Professor Professor

Figure 12. Division of Instructors between each Machine Shop

3.4.1 Comments on Instructors during 1996 and Recommendations for Future 2.670 Classes

The UA's in 1996 were volunteers from the M.I.T. chapter of Pi Tau Sigma (the Mechanical Engineering National Honor Society. They were juniors and seniors who had not taken the class before, and, unfortunately, time did not permit much instruction before commencement of the class. The UA's all put a great deal of effort into helping 2.670 run smoothly, and undoubtedly assisted a great deal in spite of not having had a chance to go over all of the process plans before the class started. Thus, undergraduate assistants in following years should probably be students who have taken 2.670 in a previous year (or who were UA's in a previous year), so that the necessary instruction of the UA's is minimal, and they can spend their time helping the 2.670 students instead of learning the process plans.

Each of the two professors, Doug Hart and Kevin Otto, were assigned to a morning and afternoon group, and as their schedules allowed, assisted in the instruction in the machine shop (they were each also involved with teaching parts of the computer instruction). They were both in the Pappalardo Lab throughout the entire day on Days 9 and 10, when more than twenty students were present for assembly.

The number of instructors in the Pappalardo Lab was sufficient to insure a 4:1 ratio of students:instructors at all times; however,. additional support in the L.M.P in the form of two TA's or a TA/Head UA combination, comparable to that in the Pappalardo Lab, is necessary to insure the same safe student/instructor ratio at all times in the L.M.P. The author highly recommends ensuring that a Head UA is always stationed in the Pappalardo Lab, in order to deal with all the little things which will inevitably occur during the month of the course.

3.5 Recommended Changes to the M.I.T. Stirling Engine

3.5.1 Alcohol Burner (#001)

Although the glass jar of the alcohol burner was extremely useful during production to store the fasteners, several of the jars were broken during the last couple days when students were walking around the shop with their engines in hand. This could be averted by providing each student with a piece of two-sided sticky tape or small pieces of Velcro with sticky tape on each side so that the jars could be securely fastened inside the indentation in the base.

3.5.2 Displacer Piston (#003)

These were manufactured out-of-house. The displacer piston could be improved by making it out of a material which would act more like a heat exchanger than brass.

3.5.3 Displacer Cylinder (#002) and Cylinder Plate (#004)

The four holes in the cylinder plate which support the bolts which attach the displacer cylinder should be adjusted slightly to form an exact square, so the displacer cylinder would have four possible orientations instead of only two.

3.5.4 Power Connecting Lever (#008), Lever Connector (#009), Levers 11 & 12 (#011, #012)

These parts are made in Building 3 and use a jig for drilling the holes, which makes them great starting parts, especially for students with little machining experience. Unfortunately, because of the rotating schedule of students, the jig makes this process too simple for most of the students who come to Building 3 after Building 35. Students should be given the option to layout the holes and drill the holes using a vise, instead of using the jig, in order to teach them a little more about layout and drilling without jigs.

3.5.5 Lever Connector (#009), Levers 11 & 12 (#011, #012)

The distance between the holes is slightly different between the lever connector and levers 11 & 12. Since the lever connector is straight butlevers 11 and 12 are bent, a frequent mistake was the accidental bending of the lever connector. This could easily be remedied by adjusting the holes in each piece slightly so that all three pieces are identical and any two of the three can be bent.

3.5.6 Displacer Piston Rod (#014)

A frequent problem during assembly was the discovery that the displacer piston rod had become bent. As the fit between the rod and the transfer piston guide bushing is critical to prevent air leakage, the rod must be perfectly straight. This should be emphasized at the start of the class, so the students know to take extra care while drilling the hole in one end and threading the other end.

3.5.7 Crank Web (#016)

The lathe work on this piece was done on the Daewoo Lathe, and students were handed the part to finish by drilling holes with a jig. If they are ahead of schedule in Building 35, students should have the option of making this piece from start, in order to give them more experience with the lathes.

3.5.8 Bearing Plates (#022, 023)

If time and machine availability permit, the students should use the mill to face one of the ends of the bearing plates, in order to get more experience on the vertical mill.

4. PREPARATION FOR THE COURSE

By the end of the Fall Semester, all of the components necessary to run 2.670 should be at M.I.T. There are several categories of materials which must be ordered; the engine components, the fasteners for the engine, the tool kit materials, extra tools for the machine shops, general supplies. In addition, there are a few necessary items which were purchased as start-up materials. Although these do not need to be purchased each year, they should be located prior to the end of the Fall Semester.

4.1 VENDOR INFORMATION

The materials for 2.670 were purchased from a variety of vendors during 1995. The current information for each vendor is listed in Figures 13 (A-L), and 14 (M-Z). In the following sections, vendors may be referred to only by the first part of their name.

Company Name	Mailing Address	Phone/Fax	Contact	Comments
Ace Trophy & Atlantic Engraver	469 Wahington Street Boston MA 02110-2409 [Downtown Crossing]	617-542-2424	Dean	They will print up name plates from a list of registered students.
Admiral Metals Service Center Co	11 Forbes Road Woburn, MA 01801-2103	617-933-8300 fax 617-932-3947		
Automatic Tubing Co.	PO Box 3990 888 Lorimer Street Brooklyn, NY 11222-3990	800-527-3091	Benjamin Kaufman	Does not accept 30 day terms for payment for special materials; requires check up front.
Charles Casting	PO Box 451 Franklin, NH 03235	603-934-9370	Lincoln Charles	Does not accept M.I.T. PO#; requires check.
Cole-Parmer Instrument Co.	625 East Bunker Court Vernon Hills, IL 60061	800-323-4340 fax 708-647-7600		
Dave Nugent	575 Province Rd L onia, NH 03246	603-528-0141 (fax same)	David Nugent	Does not accept M.I.T. PO#; requires check.
Edgcomb Steel	PO Box 260 Brookline, NH 03033-0260	603-883-7731		
Home Depot	75 Mystic Avenue Somerville, MA 02145	617-623-0001		
Industrial Aluminum	341 Second Ave Waltham, MA 02154	800-243-1343 fax 617-890-1343		
Kaufman Co. Inc.	110 Second St. Cambridge MA 02141	617-491-5500 fax 617-491-5526		Dick Fenner should contact to arrange for the tools; the money for the tools is provided by Ford Motor Co.
Kaman Industries	A Street Auburn, MA 01501	508-752-1976		
LaVerde's Market	Stratton Student Center	617-621-0733		Mech E Dept has a "standing PO" with LaVerde's.
Lehigh-Armstrong Incorporated	12 Dunham Road Billerica MA 01821-5727	508-663-0010		
L.S. Starrett Co.	121 Crescent St Athol MA 01331-1919	508-249-3551		Donated *Decimal Equivalents and Tap & Drill Sizes* and *Tools & Rules for Precision Measuring*, Kevin Baron should contact for donations.

Figure 13. Vendor Information (A-L)

Company Name	Mailing Address	Phone/Fax	Contact	Comments
McMaster Carr Supply Co.	PO Box 440 New Brunswick NJ 08903-0440	908-329-3200 fax 908-329-3772		
Millard Metal Service Center Inc	PO Box 9054 116 Lindquist Drive Braintree MA 02184-9054	617-848-1400 fax 617-848-337?	Bob Sena	
M.I.T. Coop	Kendall Square	617-499-3200		
MSC Industrial Supply Co.	15 Cabot Road Woburn, MA 01801-1003	800-753-7990		M.I.T. Account # 39577
North End Fabrics	31 Harrison St. Boston, MA	617-542-2763		Does not accept M.I.T. PO#; requires cash or check.
Physics Stock Room	MIT Room 4-355	617-499-3200	T. Coleman	Accepts only M.I.T. five-digit account number.
Pills True Value Hardware	743 Massachusetts Ave. Cambridge, MA 02141	617-876-8310		
Small Parts Inc.	13980 NW 58th Court PO Box 4650 Miami Lakes FL 33014-3115	305-558-1038		
Valenite Inc.	750 Stephenson Highway PO Box 3950 Troy, MI 48007-3950	Literature: 800-544-3336 Tools: 800-488-8695		Donated pocket protectors and *Handy Reference Guide*, Kevin Baron should contact for donations.
VWR	M.I.T. Rm. 18-B90	800-947-4270 x4250 M.I.T. x31881	Maddy	
Walmart	343 Loudon Road Concord, NH 03301	603-226-9312	Len Morrill	
Woolworths	350 Washington Street Boston MA 02108 [Downtown Crossing]	617-357-5353		
Zen Machine Shop	1568 Steamboat Valley Rd PO Box 1658 Lyons CO 80540-1658	303-823-5842 (fax same)	Marty Gould	

Figure 14. Vendor Information (M-Z)

4.2 THE STIRLING ENGINE COMPONENTS

For the 1996 sessions of 2.670, each of the parts of the engine were ordered and produced individually. Although plans are currently underway to have one vendor (*Zen Machine Shop*) provide all of the parts as a single kit, the information for ordering the parts individually is provided in Figure 15 for future reference. The starting materials of the kit are shown in Figure 16, and the finished parts are shown in Figure 17 (ready to be assembled). The total cost of all the parts, as listed, is $13398.89, which comes out to approximately $61 each for 220 kits.

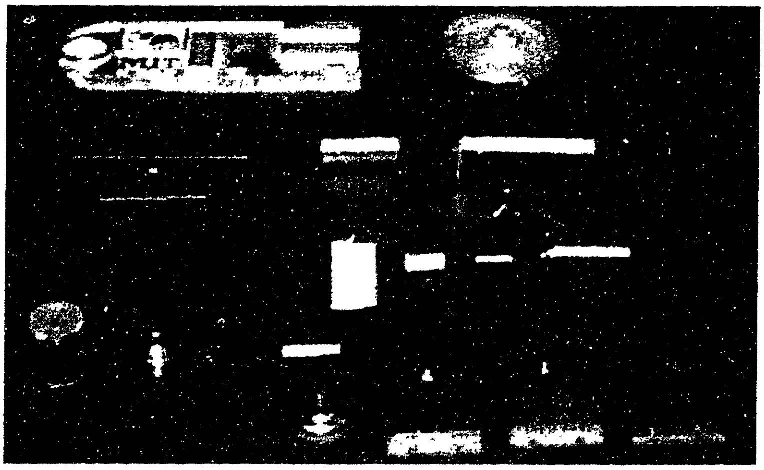

Figure 16. The Starting Materials for the Stirling Engine [2]

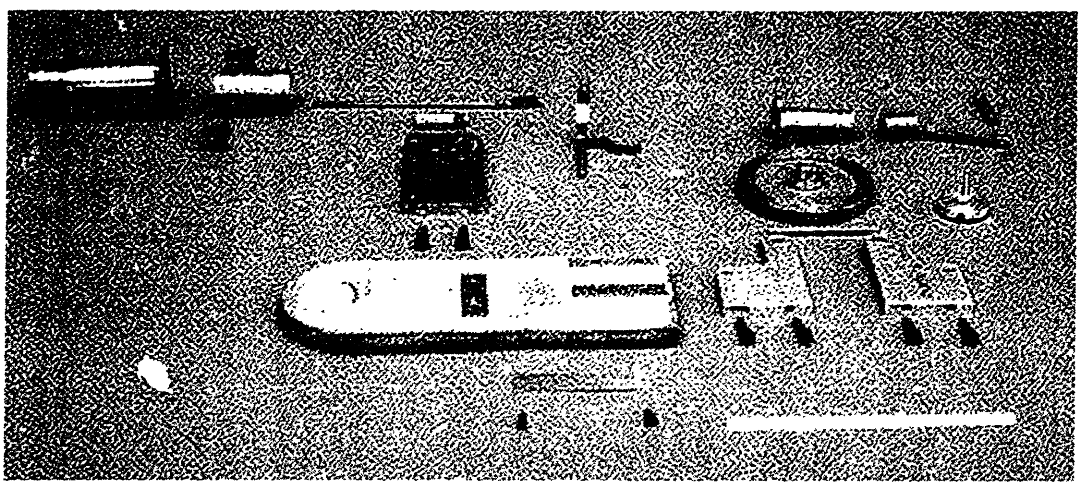

Figure 17. The Finished Parts of the Stirling Engine [2]

#	Part	Size	Material	Vendor	Part Info	Quant	Unit	PPU	Total Cost
1	Wick Material	1/2" X 1 1/4"	Canvas	N.E. Fabrics		40	yard	1.29	51.60
1	Alcohol Burner Jar	16 mL, Specimen Jar	Glass Bottle	VWR	#66015-064	2	144/case	78.40	156.80
1	Alcohol Burner Cap	OD 1 1/4	Free Mach. Brass	Admiral		2	Bars	166.00	332.00
1	Viton O-rings	3/32" WX 5/8" X 13/16"	Black Rubber	McMaster	#9464/K27	5	50/pack	8.93	44.65
2	Displacer Cylinder	1 1/8 OD X 3 1/2"	St Steel	Zen		220	Pieces	12.00	2640.00
3	Displacer Piston	1 1/16" OD X 2"	Brass	Zen		220	Pieces	12.00	2640.00
4	Cylinder Plate	5/16" X 2" X 4"	Brass	Millard		245	each	2.99	732.55
5	Power Cylinder	OD 3/4 X 1/8 Wall X 2 Length	Brass	Automatic		300	Pieces	1.85	555.00
6	Power Piston	1/2" OD	Cold Rolled Steel	Edgcomb		3	Lengths	10.00	30.00
7	Gudgeon Block	1/2" OD X 2"	Aluminum	Edgcomb		3	Lengths	10.00	30.00
8	Power Connecting Lever	3/32" X 1/4"	Free Mach. Brass	Millard		5	Lengths	22.00	110.00
9	Lever Connector	1/16" X 5/16" X 2"	Brass	McMaster	#8954/K999		6' length	1.00	
10	Lever Shaft	3/8" OD X 2"	Dowel Pin	MSC	#060636206	3	100/box	44.11	132.33
11	Lever	1/16" X 5/16" X 2"	Brass	McMaster	#8954/K999		6' length	2.00	
12	Lever	1/16" X 5/16" X 2"	Brass	McMaster	#8954/K999		6' length	2.00	
13	Connector Link	1/4 x 3/4	Free Mach Brass	Admiral		1	Bars	84.00	84.00
14	Displacer Piston Rod	1/8" OD X 5"	Drill Rod	MSC	#06000129	40	3' length	0.92	36.80
15	Transfer Piston Guide Bushing	3/8" Hex X 1.5"	Brass	Admiral		5	Lengths	125.00	625.00
16	Crank Pin	1/8" OD X 0.75"	Dowel Pin	MSC	#06022073	2	100/pack	6.28	12.56
17	Crank Web	1 1/2" OD X 1 1/4"	Aluminum	Edgcomb		2	Lengths	64.00	128.00
18	Crank Web Shaft	3/16" OD X 2.25"	Drill Rod	MSC	#06000087	15	3' Lengths	1.84	27.60
19	Main Bearing Bushings (2)	3/16" ID, 8/16" OD X 3/8"	Sintered Bronze	Kaman	FSB 35-3 #35524	500	each	0.26	130.00
20	Flywheel	3 1/2" OD X 1"	Brass Casting	Ch. Casting		220	each	10.00	2200.00
21	Bearing Plate 21	5/16" X 2" X 3.5"	Alum Flat Bar	Industrial Al		250	each	1.00	250.00
22	Bearing Plate 22	5/16" X 2" X 3.5"	Alum Flat Bar	Industrial Al		250	each	1.00	250.00
23	Base	1/2" X 3" X 8"	Alum Casting	Ch. Casting		220	each	10.00	2200.00

Figure 15. Information for the Stirling Engine Components

4.3 FASTENERS FOR THE STIRLING ENGINE

The fasteners for the Stirling Engine were also all purchased individually. and were mainly provided to the students stored in the alcohol jar. Large excess quantities of the small fasteners should be purchased as these were easily lost on the floor. The information for ordering the fasteners is provided in Figure 18. The total cost for the fasteners, as listed, is $1089.66, or approximately $5 for each of the 220 kits.

4.4 THE STUDENT TOOL KIT

As part of the Stirling Engine Kit, the students also received a tool box with tools. These were mainly provided for the students by a generous donation from Ford Motor Company. In addition, some literature material was provided by Starrett and Valenite. As noted in Figure 13, Dick Fenner should contact Kaufman, Inc. in order to arrange for the tools. The information on the tools is shown in Figure 19, and the 1996 Tool Kit is shown in Figure 20. The total cost of the tool kit in 1996 was $7755.38, or about $35 for each of the 220 kits ($10 with Ford Motor Company's donation).

Figure 20. The 1996 Tool Kit [2]

Part	Size	Material	Vendor	Part Info	Quant	Unit	PPU	Total Cost
Precision Ground Dowel Pin	1/16"OD X 5/16"	St Steel	MSC	#06020028	6	100/box	9.05	54.3
Socket Head Cap Screw	5-40 X 1/4"	Alloy Steel	MSC	#05505029	3	100/box	3.84	11.52
Flat Head Socket Cap Screw	5-40 X 3/8"	Alloy Steel	MSC	#05575048	4	100/box	5.08	20.32
Cup Point Socket Set Screw	6-32 X 1/8"	Alloy Steel	MSC	#05546007	5	100/box	3.37	16.85
Cup Point Socket Set Screw	5/40 X 1/4"	Alloy Steel	MSC	#05545025	5	100/box	3.37	16.85
Socket Head Cap Screws (6)	10-24 X 3/4"	Alloy Steel	MSC	#05508072	15	100/box	5.00	75.00
Socket Head Cap Screw	10-32 x 1/2"	Alloy Steel	MSC	#05498050	6	100/box	4.25	25.50
Socket Head Cap Screw	10-32 x 5/8"	Alloy Steel	MSC	#05498068	6	100/box	4.36	26.16
Socket Head Screws	0-80 X 1/4"	St Steel	Lehigh	#601-01300	400	each	0.13	52.00
Socket Head Screws	0-80 X 5/16"	St Steel	Lehigh	#601-01301	600	each	0.14	84.00
Hex Nuts	0-80	St Steel	Lehigh	#320-11953	800	each	0.14	112.00
Washers	#6	Zinc	Home Depot		6	100/box	2.99	17.94
Rubber Pads	.117"HT x .500" base	black, nonskid	McMaster	#9723/K99	10	100/pack	4.57	45.70
Name Plates	3/4" X 3"	Brass	Ace Trophy		200	each	2.60	520.00
Socket Head Cap Screw	5-40 X 1/4"	Alloy Steel	MSC	#05505029	3	100/box	3.84	11.52

Figure 18. Information for the Stirling Engine Fasteners

Part	Size	Material	Vendor	Part Info	Quantity	Unit	PPU	Total Cost
Tool Boxes	16" with tray	Plastic	WalMart	#0200-2700-983	220	each	5.25	1155.00
Manuals			MITGA		250	each	4.00	1000.00
Short Arm Hex Keys	1/16"		MSC	#75470047	3	100/box	12.80	38.40
Safety Goggles			Kaufman	#91181422	220	each	2.50	550.00
Band-Aids			LaVerde's		4	60/box	2.99	11.96
TOOLS from FORD			Kaufman		200	each	25.00	5000.00
Retractable Utility Knife	99			STN X 10-099				
Screwdriver	3/16" X 3"							
Adjustable Wrench	8"			UTC X 91-8c				0
Long Nose Plier with Cutter	6"							0
Measuring Tape	1/4" x 6'			W616				0
Hex Key Set	#7 7piece			HOL X 56004				
Vise Grips	7"							0
Ball Pein Hammer	8 oz							0
Two Point Scribe				Gen 80				0

Figure 19. Information for the Tool Kits

4.5 TOOLS PURCHASED FOR USE IN THE PAPPALARDO LAB

Most of the tools used by the students for their fabrication of the Stirling Engines were purchased by the staff in the machine shop and charged to 2.670. Some of the tools in the Pappalardo Lab, however, were kept at the "2.670 Office" at one end of the Pappalardo Lab. These purchasing information for these tools is listed in Figure 21. The total cost of these tools listed was $139.08, which is $.63 for each of the 220 kits.

4.6 THE SUPPLIES

There are many important supplies which were kept at the 2.670 Office, such as RTV, lubricant and thread locker, as well as the denatured alcohol, which was kept in safety bottles for the students to use. Additionally, posterboard was purchased in order to put signs up to help the students find the teaching locations, and many rolls of film were used to document the class. These supplies are listed in Figure 22. The total price of all of these supplies is $564.42, which is $2.56 for each of the 220 kits.

4.7 THE START-UP SUPPLIES

Finally, there were some necessary items which were purchased that will not be needed to be purchased every year. These items are listed in Figure 23, and should be located or purchased prior to the end of the Fall Semester. The start-up costs amounted to $2958.39, due to the high price of the casting patterns, which comes out to $13.50 for each of the 220 kits, but this cost will not recur each year.

Part	Size	Material	Vendor	Part Info	Quant	Unit	PPU	Total Cost
Center Drill	#2, 60 deg	Hardened Steel	MSC	#01031020	15	each	1.00	15.00
Countersinks	5/8", 60 deg	Hardened Steel	MSC	#02255404	6	each	12.78	76.68
Drill	#52	Black Nitrided Hardened Steel	MSC	#01188523	24	each	0.31	7.44
Drill	#30	Black Nitrided Hardened Steel	MSC	#01188309	24	each	0.33	7.92
Drill	#7	Black Nitrided Hardened Steel	MSC	#01188077	36	each	0.58	20.88
Drill	F	Black Nitrided Hardened Steel	MSC	#01189067	12	each	0.93	11.16

Figure 21. Information for the Student-Used Tools in the Pappalardo Lab

Part	Size	Material	Vendor	Part Info	Quant	Unit	PPU	Total Cost
Permanent Markers			MIT Coop		10	each	1.55	15.55
Poster Board			MIT Coop		25	each	.90	22.50
Batteries (camera)	AA		LaVerde's		3	4 /pack	3.99	11.97
Film	36 exposure	Kodak	MIT Coop		10	each	5.99	59.90
First Aid Kit			LaVerde's		1	each	6.99	6.99
Reflective Tape	5'		Cole Parmer	08210-62	2	roll	7	14.00
Blue Layout Fluid	4 oz		MSC	#00264036	12	each	4.08	48.96
RTV	3 oz		McMaster	#7583/A12	15	tube	4.03	60.45
3-in-1 Oil			Pill Hardware		10	each	1.59	15.90
Loctite Thread Locker	10 mL		McM	#91458/A140	6	bottle	7.13	42.78
Loctite Superbonder	1 oz		McM	#7567/A21	6	bottle	11.45	68.7
Denatured Alcohol	1 Gallon		Home Depot		4	each	8.99	35.96
Squeeze Bottles	16 oz		McM	#9846/T2	10	bottle	14.48	144.8
Lighters			Pill Hardware		4	each	3.99	15.96

Figure 22. Information for the Supplies

Part	Size	Vendor	Part Info	Quantity	Unit	PPU	Total Cost
Casting Patterns		Dave Nugent		1	two	2450.00	2450.00
Parchment Paper	8 1/2" x 11"	Woolworths		1	100 sheets	8.49	8.49
Funnel Set		Woolworths		1	3 funnels	2.37	2.37
Optical Tachometer		Cole-Parmer	#G-08199-11	2	each	195	390.00
Padlocks		Pill Hardware		2	each	5.99	11.98
Tap Wrench, T-Type, plain	1/4-1/2" capacity	MSC	#05041660	7	each	10.53	73.71
Die Holders, Round Die Stock	1" Die Diameter	MSC	#03720646	7	each	3.12	21.84

Figure 23. Information on the Start-Up Materials

5. STUDENT SURVEYS

5.1 OVERALL

At the end of each session, the students were asked to fill out both the Pi Tau Sigma evaluation and a 2.670-specific survey (see Appendix 2). The students were asked to rate their knowledge of the machine shop and of each of the computer programs before and after the class, as shown in Figure 24.

	Session 1			Session 2		
	Before	After	Change	Before	After	Change
Machine Shop	2.3	4.2	+1.9	2.2	4.1	+1.9
Xess	2.1	3.6	+1.5	2.1	3.5	+1.4
Matlab	2.0	3.4	+1.4	2.1	3.8	+1.7
Pro/Engineer	1.6	3.8	+2.2	1.4	3.7	+2.3

The rating scale was from 1 (no knowledge) to 5 (complete mastery).

Figure 24. Students' Self-Ratings

The students rated themselves on a scale of 1-5 and overall, rated themselves as most improved in Pro/Engineer, followed closely by machining, XESS and Matlab. The improvements were nearly identical in both sessions for Pro/Engineer, machining and Xess, but quite different in Matlab. Some changes were made between the first session and the second in the teaching of Matlab, due to the expressed dissatisfaction of several students during the first session.

The students had many thoughtful comments and suggestions for improvement in all areas of the course, which will be discussed in the remainder of this section.

5.2 Machine Shop

On the surveys, the students were asked to comment on each machine shop individually.

5.2.1 Pappalardo Lab

The students learned many new skills in the Pappalardo Lab, "Soldering, milling, sanding, drilling, scribing, tapping, and reaming. I think it will be extremely useful in the future." (2.1)[1] Overall, students found the pace slow, but they liked being able to set their own pace. As one student wrote, "The pace was excellent - you made your own! For some people, there was too much time allotted for machining, but it was that extra time that gave me the freedom to go slow." (2.55) As described in Section 3, the pace was designed so that students with no prior machine shop experience would be able to successfully complete all of the tasks, and the option of heat sinks or other modifications was added for students who were a bit ahead. One student commented, "I also liked having a full extra day to do extra design and machining. The pace was slow, but we were able to do extra stuff so it was cool." (2.37)

Students suggested having the option to make more of the engine parts, or perhaps making the levers from stock instead of using the jigs. Many students expressed a wish to learn more about the milling machine, such as how to use an end-mill, or how to mill a slot, especially since there was so much extra time. Some students were frustrated by all of the jig work, while others appreciated seeing the precision and time-saving benefits of jigs.

5.2.2 Lab for Manufacturing and Productivity

The students were also exposed to many new skills in the LMP. One student proclaimed, "It was incredible. LMP taught me so much, I went in there expecting to seriously hurt myself and I came out know how to turn, to face, drill, tap, thread, shift gear, and band saw." (2.38) Overall, the pace was just right. Again, students liked being able to set their own pace, but were frustrated by the "bottlenecks" caused by having to wait to use the lathes and other machines.

[1] All survey comments are numberd (X,Y), where X is the session number, and Y is the number of the survey, for reference purposes.

Most students appreciated that they made their parts with less help from jigs; one student philosophically wrote, "It seemed like the success of our actions depended on us a little more; fewer jigs, more room for error. Perhaps I learned a little more." (1.36) They also appreciated being shown how to set the lathes, "I learned how to set spindle speed and feed rate... Allowing us to play with those settings really took the mystery out of the machine." (2.28)

Students would have liked to have been allowed to have machined the crank web entirely from stock if they were ahead of schedule. The students loved seeing the CNC Daewoo Mill and Lathe, but would have liked to learn even more about these or even have a chance to try using them.

5.3 Computer Labs

As with the machine shops, students were asked to comment on each individual section of the computer instruction.

5.3.1 XESS

There were four very different views on XESS. Students who were already familiar with a spreadsheet were either bored or enjoyed learning about the more complex applications of XESS. Students who were unfamiliar with spreadsheets were either lost or found it to be an excellent intro. Many students suggested adding more than one example in class, so as to introduce more basic/common applications, as well as having the homework differ from the class examples, since most students learned mainly from doing the homework. In particular, students would have liked to have seen how to import data, and how they might use XESS in their future classes. After their Matlab course, several students viewed XESS as obsolete, and many wondered why XESS was taught instead of a more common application such as Microsoft Excel. Also, many students suggested teaching XESS in a computer cluster, so that students could follow along on computers during the lecture. A few students even suggested expanding the XESS instruction to two days.

5.3.2 Matlab

Students found the pace of Matlab to be very fast, but most conceded that they would eventually find it useful. Students were rather unhappy with the Matlab instruction, for a few basic reasons. First, it assumed too much prior knowledge on the part of the students. Second, the teaching format was two hours of lecture followed by homework problems. There was a definite consensus among the students that it should have been taught with shorter, more interactive lectures spaced throughout the four hour period so that students could get help on the homework while the instructor was still there. Also, the students found it difficult to follow along on the overhead screen, and would have liked to have documentation of the class lectures, so that they could have something to refer to while doing the homework. While many students wrote that the homework problems were painfully long and difficult, they also said that the homework helped them learn the material. Overall, it could be greatly improved by starting with the basics, providing the students with documentation, by teaching less material at one time, and allowing students to work on homework while the instructor was there to help.

5.3.3 Pro/Engineer

Overall, students were very happy with the Pro/Engineer instruction, found the pace to be just right, and basically, had a lot of "fun". Although several students expressed satisfaction that the "homework" was all finished in class, some students also expressed a desire to have had homework outside of class, in order to help them learn the program without the option of easy help. Also, many students would have liked to have done some modeling of their engines in Pro/Engineer. Overall, nearly all students seemed to feel that they learned a great deal in this section of 2.670.

5.4 Safety

Nearly all students thought that the learning environment in both the machine shops was safe, and many students commented that "safety was well-emphasized" (2.27) and that the instructors "always stressed safety first" (2.32). One person with previous shop experience claimed that "During all my time in wood shops and machine shops, the last two weeks were easily the safest." (1.36) However, although one student thought that "Both labs were very safe. To hurt yourself you would have to actively try. They gave good instructions," (1.15) another student reported that "Instructions was adequate, but didn't stop me from soldering my leg and breaking a reamer and having a jig fly across the room because my drill bit broke and getting a piece of metal in my finger." (2.34) Perhaps some additional safety instruction was needed, as other comments from students indicated that students should be given more thorough safety instructions in the Pappalardo Lab, particularly on how to grip material while sanding and bandsawing, as well as instructions on using clamps while drilling.

5.5 Schedule

While many students complained about the early class time, they also recognized the need for as much time as possible in order to complete the class within two weeks. Additionally, nearly all the students found the schedule to be "clear and structured." (2.21) Interestingly, three students in three out of the four possible combinations of machine shop and computer lab order made a point of writing down their group name and saying that they thought their order was perfect, but that they were worried that it might have been less so for the other groups! There were three main suggestions: 1)change the hours from 8-5 to 9-6, 2)offer the course for half a day over the four weeks, 3)switch between Matlab and Pro/Engineer in order to give students a chance to let the instruction sink in and finish the Matlab homework. Although the first suggestion is unlikely, since there are too many athletic team practices from 5-7, the four-week-half-day idea could be offered as an option to students, and all interested students could simply be balanced out between all of the other sections. The third suggestion could also work, but it would need to be discussed with the Matlab and Pro/Engineer instructors in order to insure that no continuity would be broken as a result.

6. THE 2.670 COURSE MANUAL

The following pages contain the *2.670 Course Manual* from the 1996 session of 2.670, exactly as the students received it. The part drawings should be updated and perhaps done in Pro/Engineer. The process plans should be revised and updated yearly, as discussed in *Section 3.2.3.* The numbers at the left and right sides of the pages are the numbers of the pages in the actual manual (any missing page numbers refer to blank pages), and the numbers in the center are the page number in this thesis.

Finally, the *transfer piston guide bushing* should be renamed the *displacer piston guide bushing,* in order to be consistent with the rest of the naming scheme. For consistency, however, it was called the *transfer piston guide bushing* throughout this document.

2.670

MECHANICAL ENGINEERING TOOLS

IAP 1996

TABLE OF CONTENTS

INSTRUCTORS

Professors

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COURSE OBJECTIVES

The objective of this course is very simple: to give you the opportunity to equip yourself with the skills and the tools you will need in your subsequent Mechanical Engineering courses. This course will introduce you to the fundamentals of both machine tool and computer tool use. You will work with a variety of machine tools including the bandsaw, milling machine, and lathe, and with a variety of the Athena network and Athena-based software packages, including Matlab, Xess, and Pro/Engineer.

The emphasis will be on giving you the opportunity to learn by self paced problem solving. You will get as much out of this experience as you put into this course. The material will focus upon using computer tools, not programming or developing algorithms. You will find, however, that this destinction between using and programming computer tools is rather fuzzy, as you usually have to do both.

GRADING

The grading for this course is pass/fail. Passing is determined by completing the material. After each four hour period, we will assess whether you passed the material of that period. Passing the material means completing the material in the manner prescribed by the instructors. For computer assignments, this means completing the assignments so that the output of the assignment is well formatted and correct. For the machining assignments, this means completing the assignments so that the shape, tolerances and finish are within specification. You do not have to have a complete working engine by the end of the two week session. A honest effort at each 4 hour period is what is required, as determined by your section instructor.

You must pass all four hour periods, no exceptions. If you fail a 4 hour period, you must make arrangements to pass it later during the sixth day make-up period or on the tenth day. Failing more than two of the four hour periods is beyond the means of most students to pass the course. There is no makeup beyond your two week session.

This course is designed to be completed within the allotted time. You will have ample time and resources to easily complete the material of each 4 hour period within that period. ***Therefore, it is very important to be in class, and to always BE ON TIME.*** If you choose to arrive late to class, you are stealing from yourself. This is an in-class learning experience, and we will not wait for individuals who choose to arrive late. Please help yourself and the others in your section, and be on time.

SESSION 1 STUDENTS

MACHINING AM / COMPUTER PM		COMPUTER AM / MACHINING PM	
MERCURY	**VENUS**	**MARS**	**JUPITER**
Holly Allen	Christa Ansbergs	Amy Banzhaf	George Benson
Seth Birnbaum	Melanie Born	Nathaniel Bower	Olivier Burlaud
Michael Butville	Kelly Chan	Heidi Chang	Khanmisay Chanthaboun
Wendy Cheng	Hao Chien	Hubert Choi	Allison Christenson
Kathleen Coffey	Gareth Coote	Rebecca Dailey	David Day
Adalberto Diaz	Daniel Dobbs	Brendan Donovan	Lawrence Durant
Dennis Evangelista	Winston Fan	Joseph Ferreira	Joseph Foley
Joel Ford	Philipp Frei	Jesse Geraci	Anthony Gonzalez
Reginald Green	Shantel Hansen	Seppo Helava	Don Hyun
Peter Jaffe	Steven Jens	Maria Kamvysselis	Joseph Kim
Leonard Kimble	Catherine Koh	Eugene Lee	James Lee
Alex Lian	Eileen Liu	Jason Martinez	Youssef Marzouk
Christopher McMillan	Andrew Mccraith	Norman Metcalfe	Anna Mierzejewska
John Miller	Bryan Morrissey	Benjamin Nunes	Timocin Pervane
Long Phan	Kearne Prendergast	Gisele Proulx	Indran Ratnathicam
Nathaniel Riley	Jeffrey Rosen	David Schiller	Courtney Shiley
Matthew Slayter	Luke Sosnowski	Nathan St. Michel	Lara Suh
Roy Swart	Charles Tam	Troy Thorson	Kevin Trexler
Priscilla Wang	Robert White	James Williams	Stacey Wong
MelodyYung	Matt Ziskin		

SESSION 2 STUDENTS

MACHINING AM / COMPUTER PM		COMPUTER AM / MACHINING PM	
SATURN	**URANUS**	**NEPTUNE**	**PLUTO**
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Damon Bramble	Christopher Bruce	Fabio Brunet	Sami Busch
Catalina Buttz	Diana Buttz	Luis Cardenas	Brandon Carrus
Lawrence Chao	Alankar Chhabra	JungYoon Choi	Sally Chou
Alex Chu	Sandra Chung	Paul Collins	Allison Conner
Richard Conway	Timothy Delfausse	Sigfrido Delgado	Juan Deniz
Roland Desrochers	John Dibacco	Dennis Dougherty	Janis Eisenberg
David Estrada	Keith Fife	Hector Godinez	Nicholas Hirschi
Brett Johnson	Aaron Julin	Daniel Keating	Yvonne Kim
David Kurd	Zachary Lee	Robert Lentz	Jorge Lopez
Miguel Lopez	Gilberto Marquez	Christina Martinez	Brett Mckeone
Baldemar Mejia	Garth Mitchell	Kenneth Michlitsch	Jose Montes de Oca
Victor Morales	David Naffziger	Linda Nguyen	Thao Nguyen
Eric Nielsen	Will Nielsen	Rayshad Oshtory	Megan Owens
Hector Padilla	Ian Peir	Keith Perry	Lisa Poyneer
Cecilia Prieto	Jeralyn Reese	Antonio Reyes	Luis Romero
Angel Sanchez	Jaime Sarabia	Tye Schlegelmilch	Mads Schmidt
Kirk Seward	Jennifer Shin	Molly Sims	Shawn Stern
Duane Stevens	Tokeem Talbot	Helen Trapp	Paula Valdivia y Alvarado
Ariatna Villegas-Vazquez	Scott Whitehead		

MERCURY

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Michael Butville
Wendy Cheng
Adalberto Diaz
Dennis Evangelista
Joel Ford
Reginald Green
Peter Jaffe
Leonard Kimble
Alex Lian
Christopher McMillan
John Miller
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Matthew Slayter
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Matlab UA: Abbe Cohen
Pro/Engineer UA's: Sieu Dong, Alex Goodwin

Schedule

DAY	TIME	LOCATION
1 (M 1/8)	8 - 9 am	Room 3-270 - Introduction
	9 - 10:30 am	Building 3 - Pappalardo Lab
	10:30 - 12 noon	Building 35 - Lab for Manufacturing and Productivity
	1- 5 pm	Room 1-390 - Athena and the WWWeb
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5 (F 1/12)	8 - 12 noon	Building 35 - LMP
	1 - 5 pm	Room 3-462 - Matlab
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	1 - 5 pm	Room 4-035 - Pro/Engineer
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	1 - 5 pm	Room 4-035 - Pro/Engineer
9 (Th 1/18)	8 - 10 am	Building 3 - Pappalardo Lab
	10 - 12 noon	Building 35 - LMP
	1 - 5 pm	Room 4-035 - Pro/Engineer
10 (F 1/19)	8 - 3 pm	Building 3 - Pappalardo Lab: Final Assembly
	3 pm	Building 3 - STIRLING SPIN CONTEST

VENUS

Students

Christa Ansbergs
Melanie Born
Kelly Chan
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Gareth Coote
Daniel Dobbs
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MARS

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Nathaniel Bower	Brendan Donovan	Eugene Lee	David Schiller
Heidi Chang	Joseph Ferreira	Jason Martinez	Nathan St. Michel
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JUPITER

Students

George Benson
Olivier Burlaud
Khanmisay Chanthaboun
Allison Christenson
David Day
Lawrence Durant
Joseph Foley
Anthony Gonzalez
Don Hyun
Joseph Kim
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	3 pm	Building 3 - STIRLING SPIN CONTEST

SATURN

Students

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Damon Bramble
Catalina Buttz
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Alex Chu
Richard Conway
Roland Desrochers
David Estrada
Brett Johnson
David Kurd
Miguel Lopez
Baldemar Mejia
Victor Morales
Eric Nielsen
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Schedule

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	9 - 10:30 am	Building 3 - Pappalardo Lab
	10:30 - 12 noon	Building 35 - Lab for Manufacturing and Productivity
	1- 5 pm	Room 1-390 - Athena and the WWWeb
2 (T 1/23)	8 - 12 noon	Building 3 - Pappalardo Lab
	1 - 5 pm	Room 26-100 - XESS
3 (W 1/24)	8 - 12 noon	Building 3 - Pappalardo Lab
	1 - 5 pm	Room 3-462 - Matlab
4 (Th 1/25)	8 - 12 noon	Building 3 - Pappalardo Lab
	1 - 5 pm	Room 3-462 - Matlab
5 (F 1/26)	8 - 12 noon	Building 35 - LMP
	1 - 5 pm	Room 3-462 - Matlab
6 (M 1/29)		No Class!
7 (T 1/30)	8 - 12 noon	Building 35 - LMP
	1 - 5 pm	Room 4-035 - Pro/Engineer
8 (W 1/31)	8 - 12 noon	Building 35 - LMP
	1 - 5 pm	Room 4-035 - Pro/Engineer
9 (Th 2/1)	8 - 10 am	Building 3 - Pappalardo Lab
	10 - 12 noon	Building 35 - LMP
	1 - 5 pm	Room 4-035 - Pro/Engineer
10 (F 2/2)	8 - 3 pm	Building 3 - Pappalardo Lab: Final Assembly
	3 pm	Building 3 - STIRLING SPIN CONTEST

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Jennifer Shin
Tokeem Talbot
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5 (F 1/26)	8 - 12 noon	Building 3 - Pappalardo Lab
	1 - 5 pm	Room 4-035 - Pro/Engineer
6 (M 1/29)		No Class!
7 (T 1/30)	8 - 12 noon	Building 3 - Pappalardo Lab
	1 - 5 pm	Room 3-426- Matlab
8 (W 1/31)	8 - 12 noon	Building 3 - Pappalardo Lab
	1 - 5 pm	Room 3-426- Matlab
9 (Th 2/1)	8 - 10 am	Building 35 - LMP
	10 - 12 noon	Building 3 - Pappalardo Lab
	1 - 5 pm	Room 3-426- Matlab
10 (F 2/2)	8 - 3 pm	Building 3 - Pappalardo Lab: Final Assembly
	3 pm	Building 3 - STIRLING SPIN CONTEST

NEPTUNE

Students

Jarrod Beglinger
Fabio Brunet
Luis Cardenas
JungYoon Choi
Paul Collins
Sigfrido Delgado
Dennis Dougherty
Hector Godinez
Daniel Keating
Robert Lentz
Christina Martinez
Kenneth Michlitsch
Linda Nguyen
Rayshad Oshtory
Keith Perry
Antonio Reyes
Tye Schlegelmilch
Molly Sims
Helen Trapp

Staff

Professor: Doug Hart
Head UA: Liv Galendez
Machine Shop UA's: J.D. Albert, Don Hyun
Matlab UA: Bob Apodaca
Pro/Engineer UA's: Jeffrey Dulik, Isela Villanueva, Yedil Workeneh

Schedule

DAY	TIME	LOCATION
1 (M 1/22)	8 - 9 am	Room 3-270 - Introduction
	9 - 12 noon	Room 1-390 - Athena and the WWWeb
	1 - 3 pm	Building 3 - Pappalardo Lab
	3 - 5 pm	Building 35 - Lab for Manufacturing and Productivity
2 (T 1/23)	8 - 12 noon	Room 3-133 - XESS
	1 - 5 pm	Building 3 - Pappalardo Lab
3 (W 1/24)	8 - 12 noon	Room 3-462 - Matlab
	1 - 5 pm	Building 3 - Pappalardo Lab
4 (Th 1/25)	8 - 12 noon	Room 3-462 - Matlab
	1 - 5 pm	Building 3 - Pappalardo Lab
5 (F 1/26)	8 - 12 noon	Room 3-462 - Matlab
	1 - 5 pm	Building 35 - LMP
6 (M 1/29)		No Class!
7 (T 1/30)	8 - 12 noon	Room 4-035 - Pro/Engineer
	1 - 5 pm	Building 35 - LMP
8 (W 1/31)	8 - 12 noon	Room 4-035 - Pro/Engineer
	1 - 5 pm	Building 35 - LMP
9 (Th 2/1)	8 - 12 noon	Room 4-035 - Pro/Engineer
	1 - 3 pm	Building 3 - Pappalardo Lab
	3 - 5 pm	Building 35 - LMP
10 (F 2/2)	8 - 3 pm	Building 3 - Pappalardo Lab: Final Assembly
	3 pm	Building 3 - STIRLING SPIN CONTEST

PLUTO

Students

Sabrina Birnbaum
Sami Busch
Brandon Carrus
Sally Chou
Allison Conner
Juan Deniz
Janis Eisenberg
Nicholas Hirschi
Yvonne Kim
Jorge Lopez
Brett Mckeone
Jose Montes de Oca
Thao Nguyen
Megan Owens
Lisa Poyneer
Luis Romero
Mads Schmidt
Shawn Stern
Paula Valdivia y Alvarado

Staff

Professor: Kevin Otto
Head UA: Stacy Morris
Machine Shop UA's: Jennifer Dickson, Johnny Chang
Matlab UA: Bob Apodaca
Pro/Engineer UA's: Jeffrey Dulik, Isela Villanueva, Yedil Workeneh

Schedule

DAY	TIME	LOCATION
1 (M 1/22)	8 - 9 am	Room 3-270 - Introduction
	9 - 12 noon	Room 1-390 - Athena and the WWWeb
	1 - 3 pm	Building 35 - Lab for Manufacturing and Productivity
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2 (T 1/23)	8 - 12 noon	Room 3-133- XESS
	1 - 5 pm	Building 35- LMP
3 (W 1/24)	8 - 12 noon	Room 4-035 - Pro/Engineer
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	1 - 5 pm	Building 35 - LMP
5 (F 1/26)	8 - 12 noon	Room 4-035 - Pro/Engineer
	1 - 5 pm	Building 3 - Pappalardo Lab
6 (M 1/29)		No Class!
7 (T 1/30)	8 - 12 noon	Room 3-426 - Matlab
	1 - 5 pm	Building 3 - Pappalardo Lab
8 (W 1/31)	8 - 12 noon	Room 3-426 - Matlab
	1 - 5 pm	Building 3 - Pappalardo Lab
9 (Th 2/1)	8 - 12 noon	Room 3-426 - Matlab
	1 - 3 pm	Building 35 - LMP
	3 - 5 pm	Building 3 - Pappalardo Lab
10 (F 2/2)	8 - 3 pm	Building 3 - Pappalardo Lab: Final Assembly
	3 pm	Building 3 - STIRLING SPIN CONTEST

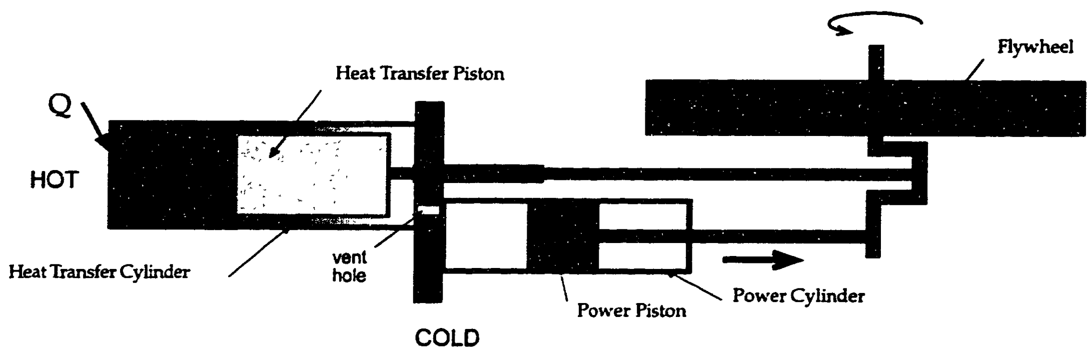
STIRLING ENGINE CYCLE

Your engine operates on a closed regenerative thermodynamic cycle, the *Stirling cycle.* Unlike an internal combustion engine, your engine has no valves and does not intake or exhaust gas. The air inside your engine is trapped. Heat is converted to mechanical work by alternately pushing the air from the cold side of the engine to the hot side. On the hot side, the air heats, increasing the pressure inside the engine. On the cold side, the air cools, decreasing the pressure inside the engine. This change in internal pressure pushes the *power piston* back and forth in the *power cylinder* causing the *flywheel* to rotate. The *flywheel,* in turn, pushes the *displacer piston* back and forth, moving air from the cold side of the engine to the hot side and back.

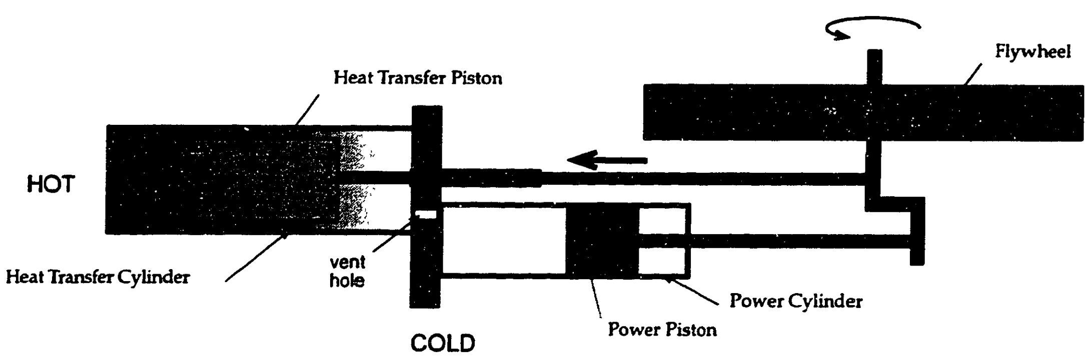
The efficiency of your Stirling cycle engine is improved over more conventional engine cycles through the use of thermodynamic regenerative processes. The displacer piston fits loosely in the *displacer cylinder.* As air moves past it from the hot side to the cold side, the displacer piston absorbs some of the heat from the air. As the air moves back from the cold side to the hot side, the displacer piston releases this heat back to the air. In this way, some of the energy that would otherwise be lost is reclaimed during each engine cycle. In principle, a Stirling cycle engine can have near ideal (Carnot cycle) efficiency. Your engine, however, will lose energy from friction, from poor heat transfer between the flame and the air inside the engine, and from heat conduction between the hot side of the engine and the cold side, through the walls of the displacer piston and cylinder.

THE FOUR STEPS OF THE STIRLING ENGINE CYCLE

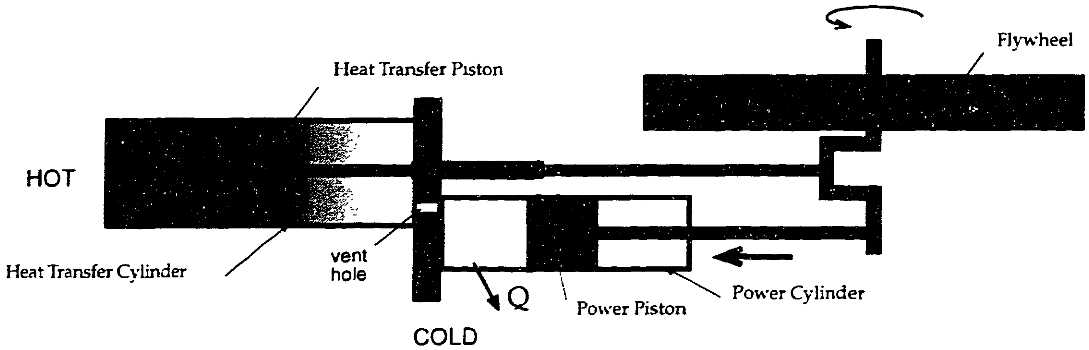
I. *Expansion*
II. *Transfer of air from HOT to COLD side*
III. *Contraction*
IV. *Transfer of air from COLD to HOT side*



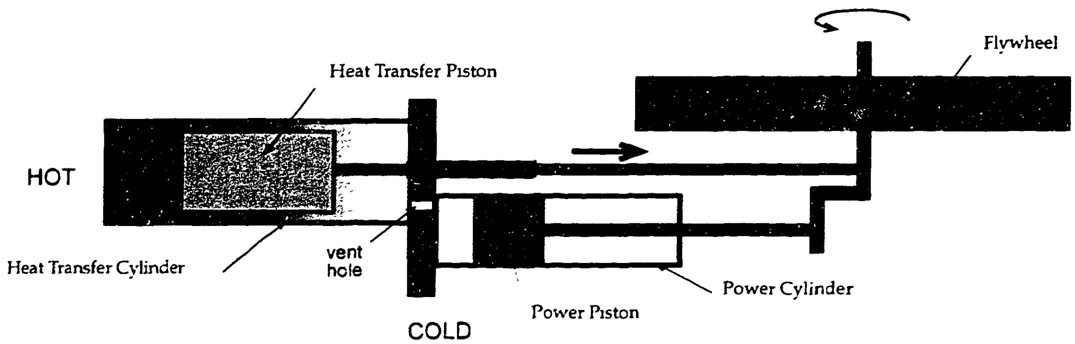
I. ***Expansion*** **-** The air is heated by the flame and expands, pushing the power piston outward and turning the flywheel.



II. ***Transfer of Air from HOT to COLD Side*** **-** The hot air is pushed to the cold side of the engine by the displacer piston. Some of the heat of the air is absorbed by the displacer piston as the air moves by it.

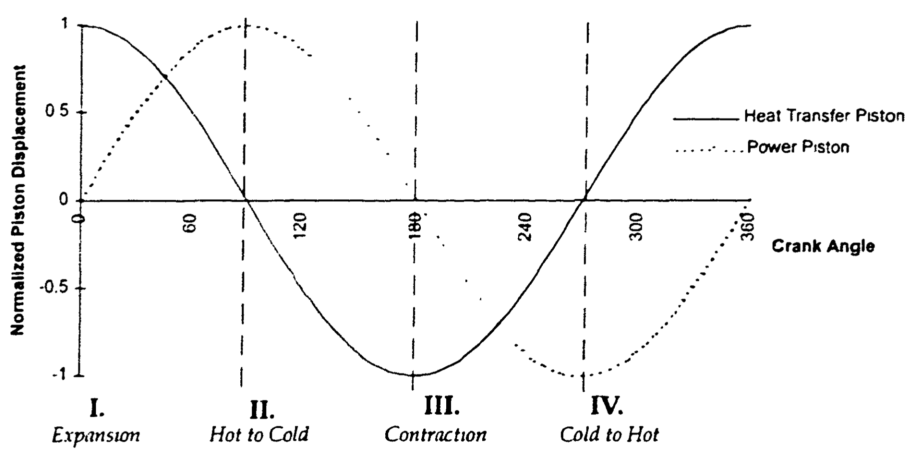


III. ***Contraction -*** The air cools and contracts, pulling the power piston inward and turning the flywheel.



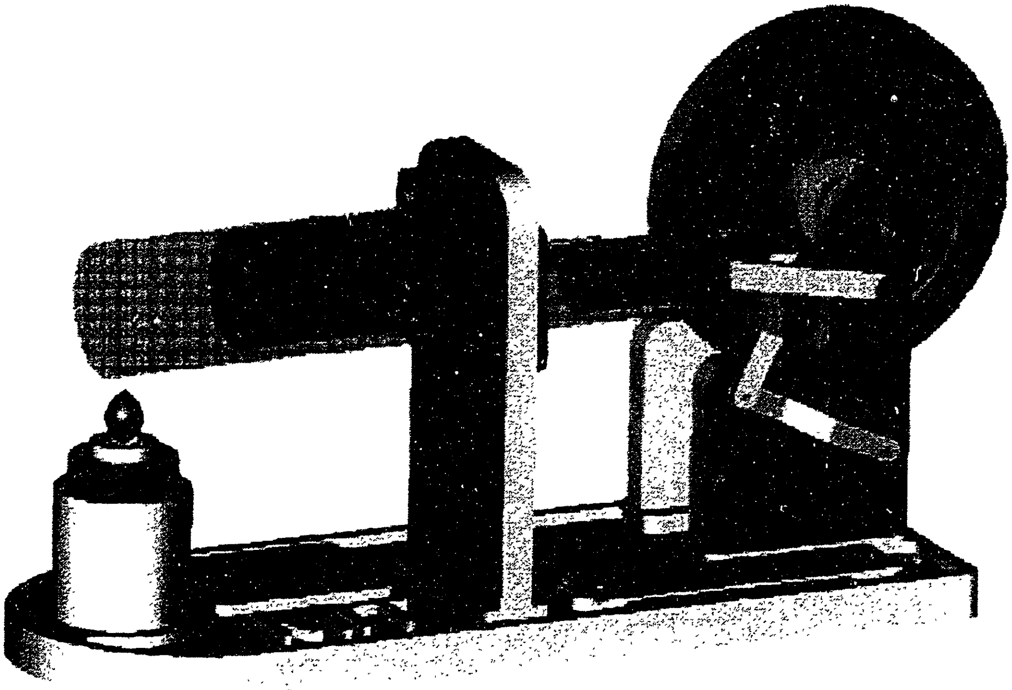
IV. ***Transfer of Air from COLD to HOT Side -*** The cold air is pushed back to the hot side of the engine by the displacer piston, completing the cycle. The displacer piston releases some of its stored heat and warms the air, as it moves to the hot side.

*Note that the flywheel cranks (levers 011 and 012) for the displacer piston and the power piston are offset 90° from each other.



15

THE MIT STIRLING ENGINE



16

LAB SAFETY

SAFETY GLASSES MUST BE WORN AT ALL TIMES!!

- Long hair ***must*** be tied back.
- Appropriate clothing ***must always*** be worn:

  No open shoes, sandals, or rollerblades.

  No baggy or loose clothing.

  Always wear safety glasses!

- ***NO*** running in lab.
- ***Always ask*** an instructor to help you find the tools you need.
- ***Never EVER*** operate a machine which you haven't been taught to operate.
- ***Never EVER*** operate a machine when you feel tired or sick.
- When in doubt, ***ALWAYS ASK*** for help.
- And once again, safety glasses ***MUST*** be worn at ***ALL*** times.

ENGINE SAFETY

PLEASE READ THIS AND THE DENATURED ETHYL ALCOHOL SAFETY SHEET ON PAGES 19-20 BEFORE ATTEMPTING TO START YOUR ENGINE!!

- ***Always*** let your engine cool before attempting to pick it up.
- ***Always*** run your engine in a well ventilated area.
- ***Never*** burn anything other than stove grade alcohol in your engine.
- ***Never*** attempt to fill your the alcohol burner while it is hot.
- ***Never*** run your engine near any flammable material.
- ***Never*** let your engine run unattended.
- ***Never*** store your engine with alcohol in it.

NOTE - ***Never EVER*** heat your engine with a torch to try and get it to run. The torch will melt the solder which holds the heat transfer cylinder together (don't laugh - we have seen this happen a number of times!). You can, however, place a wet cloth or ice cube on the cold side of the engine, which will greatly improve its performance.

Mallinckrodt

Material Safety Data

Emergency Phone Number: 314-982-5000

Mallinckrodt, Inc., Science Products Division, P.O. Box M, Paris, KY 43061.

ETHYL ALCOHOL DENATURED

PRODUCT IDENTIFICATION:

Synonyms: Denatured ethyl alcohol; alcohol; potato alcohol

Formula CAS No.: 64-17-5

Molecular Weight: 46.07

Chemical Formula: C_2H_6O (major component)

Hazardous Ingredients:
CAS# 67-56-1 Methyl alcohol
141-78-6 Ethyl acetate
108-10-1 Methyl isobutyl ketone
8006-61-9 Gasoline

PRECAUTIONARY MEASURES

DANGER! MAY BE FATAL IF SWALLOWED.
HARMFUL IF INHALED. FLAMMABLE!
AFFECTS CENTRAL NERVOUS SYSTEM. MAY CAUSE BLINDNESS.
CAUSES IRRITATION.

Keep away from heat, sparks and flame.
Keep container closed.
Use with adequate ventilation.
Wash thoroughly after handling.
Avoid contact with eyes, skin and clothing.
Avoid breathing vapor.

EMERGENCY/FIRST AID

If swallowed, induce vomiting immediately by giving two glasses of water and sticking finger down throat. Never give anything by mouth to an unconscious person. If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. In case of contact, immediately flush skin or eyes with plenty of water for at least 15 minutes. In all cases call a physician.
SEE SECTION 5.

DOT Hazard Class: Flammable Liquid

19

SECTION 1 Physical Data

Appearance: Clear, colorless liquid.

Odor: Mild odor.

Solubility: Infinite in water.

Boiling Point: 78°C (172.4°F)

Melting Point: <-114°C (-173°F)

Specific Gravity (water = 1): 0.80

Vapor Density (Air=1): 1.6

Vapor Pressure (mm Hg): 47 @ 25°C (77°F)

Evaporation Rate: (BuAc = 1):ca. 3.3

SECTION 2 Fire and Explosion Information

Fire:
Flammable. Fire data is for ethyl alcohol:
Flash point: 13°C (55°F) (closed cup).
Auto ignition temperature: 422°C, (793°F)
Flammable limits in air, % by volume:
lel = 3.3, uel = 19.0.
Dangerous fire hazard when exposed to heat or flame.

Explosion:
Above flash point, vapor-air mixtures are explosive within flammable limits noted above.

Fire Extinguishing Media:
Dry chemical, foam or carbon dioxide. Water spray may be used to keep fire exposed containers cool. Water may be used to flush spills away from exposures and to dilute spills to non-flammable mixtures.

Special Information:
In the event of a fire, wear full protective clothing and NIOSH-approved self-contained breathing apparatus with full facepiece operated in the pressure demand or other positive pressure mode. Vapors can flow along surfaces to distant ignition source and flash back.

SECTION 3 Reactivity Data

Stability:
Stable under ordinary conditions of use and storage.

Hazardous Decomposition Products:
May produce carbon monoxide and carbon dioxide when heated to decomposition.

Hazardous Polymerization:
Will not occur.

Incompatibilities:
Strong oxidizers, heat and sources of ignition.

SECTION 4 Leak/Spill Disposal Information

Ventilate area of leak or spill. Remove all sources of ignition. Clean-up personnel require protective clothing and respiratory protection from vapors. Contain and recover liquid when possible. Collect as hazardous waste and atomize in a suitable RCRA approved combustion chamber, or absorb with vermiculite, dry sand, earth or similar material for disposal as hazardous waste in a RCRA approved facility. Do not flush to sewer!

Ensure compliance with local, state and federal regulations.

64

SECTION 5 Health Hazard Information

A. EXPOSURE / HEALTH EFFECTS

Inhalation:
Inhalation may cause irritation to the upper respiratory tract. Prolonged exposures to high concentration may cause drowsiness, loss of appetite, and inability to concentrate.Methyl alcohol component affects vision by acting upon the optic nerve. Exposure may result in vision impairment or blindness.

Ingestion:
Can cause gastritis, vomiting, central nervous system depression, headache, and dizziness. Other symptoms may parallel those from inhalation exposure.

Skin Contact:
May cause irritation. Prolonged contact may produce discoloration. Skin absorption of methyl alcohol component may occur with symptoms paralleling those of inhalation exposure

Eye Contact:
May cause severe irritation. Splashes may cause pain, blurred vision, and eye damage.

Chronic Exposure:
Prolonged skin exposure may cause drying and cracking of skin. May affect the nervous system. May cause vision impairment, liver injury and pancreatitis.

Aggrevation of Pre-existing Conditions:
Persons with pre-existing skin disorders or eye problems, or impaired kidney or respiratory function may be more susceptible to the effects of the substance.

B. FIRST AID

Inhalation:
Remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Call a physician.

Ingestion:
If swallowed, induce vomiting immediately by giving two glasses of water, or milk if available and sticking finger down throat. Call a physician immediately. Never give anything by mouth to an unconscious person.

Skin Exposure:
Remove any contaminated clothing. Wash skin with soap or mild detergent and water for at least 15 minutes. Get medical attention if irritation develops or persists.

Eye Exposure:
Wash eyes with plenty of water for at least 15 minutes, lifting lower and upper eyelids occasionally. Get medical attention immediately.

C. TOXICITY DATA (RTECS, 1982)

Ethyl alcohol: Oral rat LD50: 7060 mg/kg Inhalation rat LC50: 20,000 ppm/10H Mutation references cited. Reproductive effects cited. Irritation skin rabbit: 400mg open mild eye rabbit 100mg/24H severe Methyl alcohol: Oral rat LD50: 5628 mg/kg Skin rabbit LD50: 20 gm/kg. Mutation references cited. Reproductive effects cited. Ethyl acetate: Oral rat LD50: 11300 mg/kg Inhalation rat LC50: 1600 ppm/8H

SECTION 6 Occupational Control Measures

Airborne Exposure Limits:
-OSHA Permissible Exposure Limit (PEL):
1,000 ppm (TWA) for Ethyl Alcohol
200 ppm (TWA) for Methyl Alcohol
400 ppm (TWA) for Ethyl acetate
-ACGIH Threshold Limit Value (TLV):
1,000 ppm (TWA) For Ethyl Alcohol
200 ppm (TWA) 250 ppm (STEL) skin for Methyl Alcohol
400 ppm (TWA) for Ethyl acetate

Ventilation System:
A system of local and/or general exhaust is recommended to keep employee exposures below the Airborne Exposure Limits. Local exhaust ventilation is generally preferred because it can control the emissions of the contaminant at its source, preventing dispersion of it into the general work area. Please refer to the ACGIH document, "Industrial Ventilation, A Manual of Recommended Practices", most recent edition, for details.

Personal Respirators: (NIOSH Approved)
If the TLV is exceeded a full facepiece chemical cartridge respirator may be worn up to the maximum use concentration specified by the respirator supplier. Alternatively, a supplied air full facepiece respirator or airlined hood may be worn.

Skin Protection:
Gloves and lab coat, apron or coveralls.

Eye Protection:
Use chemical safety goggles. Contact lenses should not be worn when working with this material. Maintain eye wash fountain and quick-drench facilities in work area.

SECTION 7 Storage and Special Information

Protect against physical damage. Store in a cool, dry well-ventilated location, away from any area where the fire hazard may be acute. Outside or detached storage is preferred. Separate from oxidizing materials. Containers should be bonded and grounded for transfers to avoid static sparks. Storage and use areas should be No Smoking areas. Use non-sparking type tools and equipment.

••

STIRLING ENGINE PART NUMBERS AND NAMES

1	Alcohol Burner Cap
2	Displacer Cylinder
3	Displacer Piston
4	Cylinder Plate
5	Power Cylinder
6	Power Piston
7	Gudgeon Block
8	Power Connecting Lever
9	Lever Connector
10	Lever Shaft
11	Lever 011
12	Lever 012
13	Connector Link
14	Displacer Piston Rod
15	Transfer Piston Guide Bushing
16	Crank Pin
17	Crank Web
18	Crank Web Shaft
19	Main Bearing Bushings
20	Flywheel
21	Bearing Plate 021
22	Bearing Plate 022
23	Base

STIRLING ENGINE KIT MATERIALS

You will be equipped with the materials necessary to fabricate a working miniature Stirling engine. Some of the engine parts are supplied already finished (ready for assembly), some of the engine parts are supplied as castings (require further machining), and some of the engine parts are supplied as raw stock (also require further machining). Your kit should include the materials listed below; please see the following page for a list of the tools included in your kit.

PART #	PART NAME	MATERIAL	KIT SIZE
1	Alcohol Burner Cap	Brass	1.06" O.D. x 3/4"
2	Displacer Cylinder	Stainless Steel	1 1/8" O.D. x 3 1/2"
3	Displacer Piston	Stainless Steel	1 1/16" O.D. x 2"
4	Cylinder Plate	Brass Stock	5/8" x 2" x 4"
5	Power Cylinder	Brass	3/4" O.D. x 2"
6	Power Piston	Cold Rolled Steel	5/8" O.D. x 7/8"
7	Gudgeon Block	Aluminum Rod	1/2" O.D. (stock in LMP)
8	Power Connecting Lever	Brass Stock	3/32" x 1/4" x 3"
9	Lever Connector	Brass Stock	1/16 x 1/4 x 2"
10	Lever Shaft	Drill Rod	3/16" O.D.1, 1/8" O.D.2 x 2"
11	Lever 011	Brass Stock	1/16 x 1/4 x 2"
12	Lever 012	Brass Stock	1/16 x 1/4 x 2"
13	Connector Link	Brass H Stock	1/4" x 1/4" x 3/4"
14	Displacer Piston Rod	Drill Rod	1/8" O.D. x 5.14"
15	Transfer Piston Guide	Brass Hex Stock	3/8" HEX (stock in LMP)
16	Crank Pin	Drill Rod	1/8" O.D. x 5/8"
17	Crank Web	Aluminum Rod	1 1/2" O.D.(stock in LMP)
18	Crank Web Shaft	Drill Rod	3/16" O.D. x 2 3/4"
19	Main Bearing Bushings (2)	Brass	3/16" I.D., 5/16" O.D. x 3/8"
20	Flywheel	Brass Casting	3 1/2" O.D.1, 1" O.D.2 x 1"
21	Bearing Plate 21	Aluminum Stock	5/8" x 2" x 3 1/2"
22	Bearing Plate 22	Aluminum Stock	5/8" x 2" x 3 1/2"
23	Base	Zinc/Aluminum Casting	1/2" x 3" x 7"
	16mL Specimen Jar	Glass	1/2" O.D. x 1"
	Wick Material	Canvas	1/2" x 2"
	Precision Dowel Pin	Stainless Steel	1/16" O.D. x 1/4"
	Flathead Socket Head Cap Screw	Steel Alloy	5-40 x 3/8"
	Cup Point Socket Set Screw	Steel Alloy	6-32 x 1/8"
	Cup Point Socket Set Screw	Steel Alloy	5-40 x 1/8"
	Socket Head Cap Screws (6)	Steel Alloy	10-24 x 3/4"
	Socket Head Cap Screws (2)	Steel Alloy	10-32 x 1/2"
	Socket Head Cap Screws (2)	Steel Alloy	10-32 x 5/8"
	Socket Head Cap Screws (2)	Steel Alloy	0-80 x 5/16"
	Socket Head Cap Screw	Steel Alloy	0-80 x 1/4"
	Hex Nuts (3)	Stainless Steel	0-80
	Washers (2)	Stainless Steel	1/4" O.D. x 1/32"
	Name Plate	Brass	3/4" x 3"

(You will be given your name plate and 2 brass screws on Day 10)

STUDENT TOOLS

You will be equipped with a tool box complete with measuring instruments and hand tools. You are expected to keep these in good working condition and to upgrade and replace them as needed throughout your stay at MIT. Subsequent courses in Mechanical Engineering may expect you to have these tools and make assignments presuming you have this equipment..

These following tools were made possible through a generous donation from Ford Motor Company; in addition, other materials have been provided by two local tool companies, GTE Valenite and Starrett Precision Tools. They realize the critical importance of having you understand material processing, measurement, and the way machines are designed and work. These tools will be your personal means to understanding mechanical systems. They are "text books" to assist you in learning about Mechanical Engineering and about standard machining and measurement techniques. Your toolbox should contain the tools listed below.

TOOL	DONATED BY:
Utility Knife	Ford Motor Company
3/16" X 3" Screwdriver	Ford Motor Company
8" Adjustable Wrench	Ford Motor Company
Long Pliers (6") with Cutter	Ford Motor Company
1/4" X 6' Tape Measure	Ford Motor Company
Hex Key Set	Ford Motor Company
Vise Grips (7")	Ford Motor Company
Ball Pein Hammer	Ford Motor Company
2 Point Scribe	Ford Motor Company
Decimal Equivalents and Tap & Drill Sizes Chart	Starrett Precision Tools
Tools & Rules for Precision Measuring	Starrett Precision Tools
Handy Reference Guide	GTE Valenite
Pocket Protector, containing:	GTE Valenite
Ball point pen and mechanical pencil	
Feed-Speed Calculator	
Horsepower Requirements	

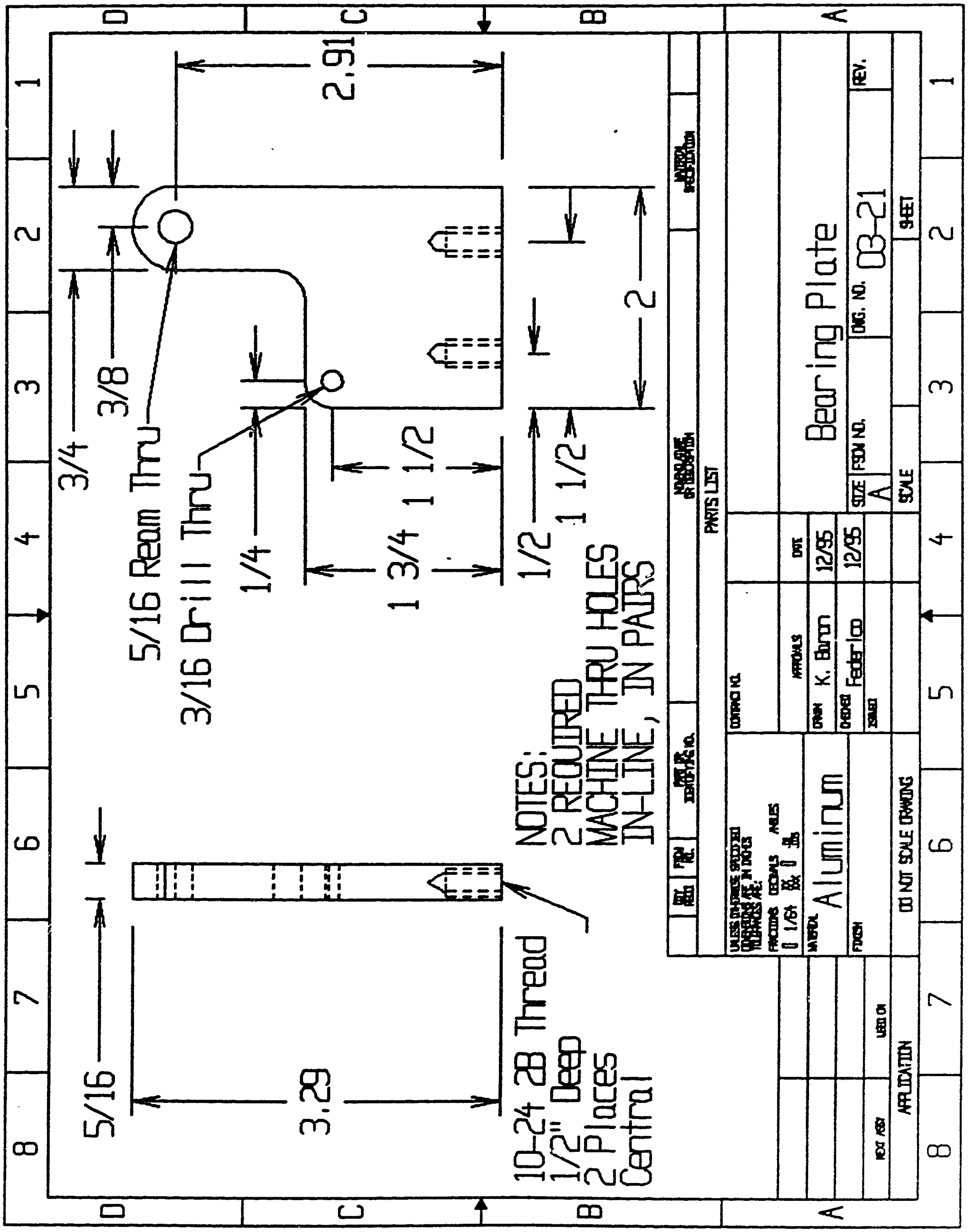
BUILDING 3 (PAPPALARDO LAB) PART DRAWINGS AND PROCESS PLANS

PART DRAWINGS

PROCESS PLANS

Part Name	Part Numbers	Building
Cylinder Plate, Connector Link, and Bearing Plates	004, 013, 021, 022	3
Material	**Start Size**	**Process**
Brass (013, 004) and Aluminum (021, 022)	1/4" X 1/4" X 3/4" (013); 5/16" X 2" X 4" (004) 5/16" X 2" X 3 1/2" (021, 022)	3-A

Op #	Workplaces	Tools	Drawings	Instructions and Parameters	Complete (✓check)
010	Bench	Blue die		Cover area of interest with blue die on all four pieces.	
020		Height gauge		Set height gauge to 1.75"; with the bearing plates in an upright position, scribe a line from the edge to the large hole. Repeat this step for ALL the bearing plates in your group.	
030				Set height gauge to 0.75"; with the bearing plates on their side, scribe a line from the edge to the large hole. Repeat this step for ALL the bearing plates in your group.	
040				Set height gauge to 0.125"; with the connector link lying on its side, scribe a line across its entire length. With the height gauge still set at 0.125", place the connector link upright, and scribe a line perpendicular to the centerline. Rotate link 180°, and scribe another perpendicular line at this end. Repeat this step for ALL the links in your group.	
050		Bearing plate template		Place template on bearing plate, and scribe curved corners on both pieces.	
060		Cylinder plate template		Place template on cylinder plate, and scribe curved corners on the piece.	

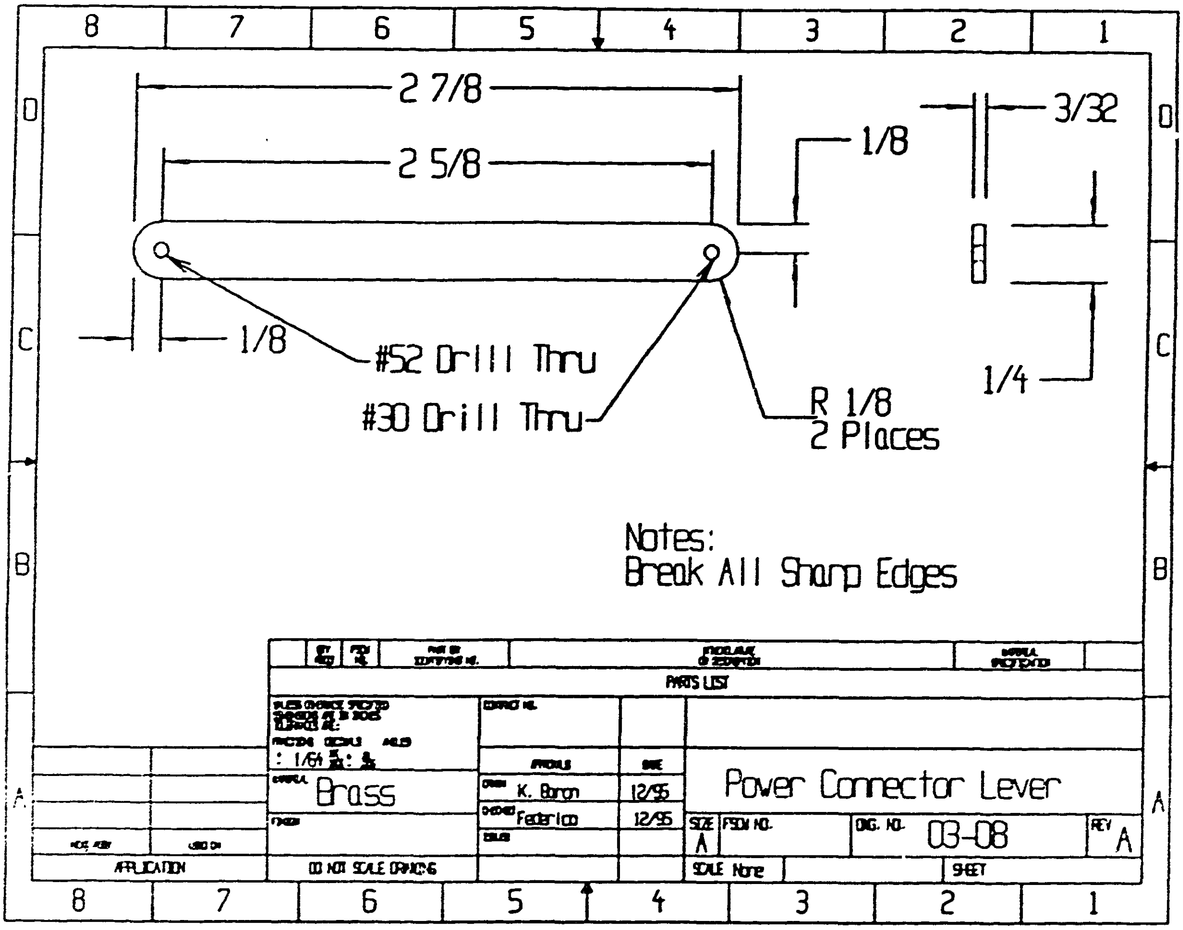

5/16 Ream Thru
3/16 Drill Thru
3/4
3/8
1/4
1 3/4
1 1/2
1/2
1 1/2
2
2.91
5/16
3.29
10-24 2B Thread
1/2" Deep
2 Places
Central
NOTES:
2 REQUIRED
MACHINE THRU HOLES
IN-LINE, IN PAIRS
PARTS LIST
Aluminum
DRAWN K. Baron 12/95
CHECKED Federico 12/95
Bearing Plate
SIZE A
DWG. NO. DB-21
DO NOT SCALE DRAWING
APPLICATION

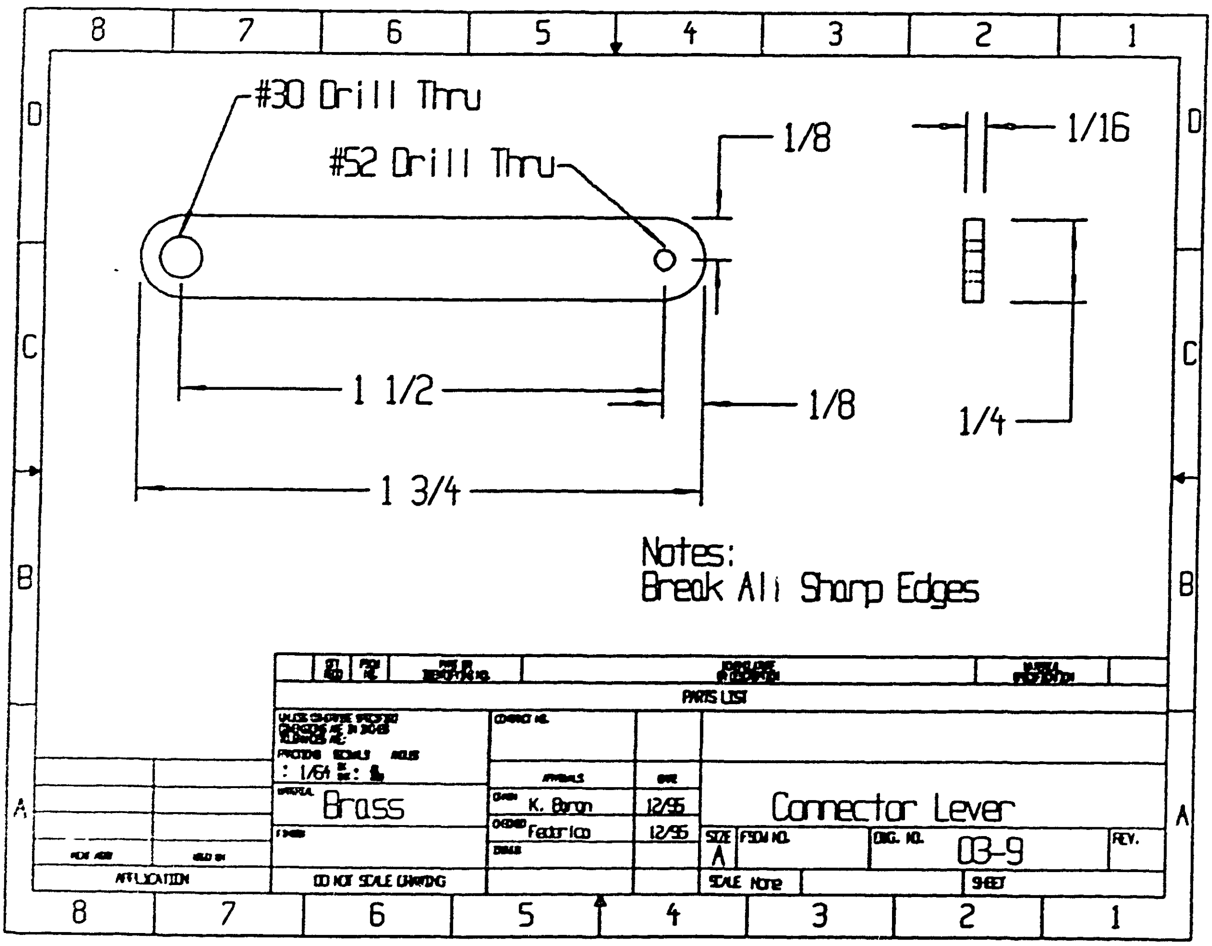
Part Name	Part Numbers	Building
Bearing Plates (page 1)	021, 022	3
Material	**Start Size**	**Process**
Aluminum	5/16" X 2" X 3 1/2"	3-B

Op #	Workplaces	Tools	Drawings	Instructions and Parameters	Complete (✓check)
010	Bench	File		Deburr all edges by hand.	
020	Vertical Mill	Parallel		Place one piece flat on parallel in the mill vise, making sure the parallel does not interfere with the holes.	
030				With the piece against the stop, tighten the vise.	
040		Drill chuck		Place the drill chuck in the mill and tighten draw bar remembering to apply the brake.	
050		5/16" Reamer		Place the 5/16" reamer in the chuck and tighten by hand.	
060				Switch to back gear with gear change levers.	
070				Switch vertical feed to on position.	
080				Set vertical stop.	
090		Digital read out (D.R.O.)		Dial the table location to -2.910, -1.625.	
100				Lock the table in both the x and y directions.	
110				Lower reamer manually to ascertain that the tool lines up with the pre-drilled hole.	
120				Turn the mill on by placing the power switch in 💣 **REVERSE** (move switch *up*).	
130		Coolant and Brush		Using brush, apply coolant to reamer.	
140				Engage vertical feed (vertical feed will switch off after it hits the stop), continuing to apply coolant.	
150				When hole is reamed, turn the mill off (move switch *down*), **being careful 💣 NOT to overshoot and accidentally switch to the FORWARD direction.**	
160				Apply brake to stop rotation of spindle.	
170				Retract reamer by hand after it has come to a complete stop.	
180				Loosen vise, replace piece with fresh stock. Repeat Op #'s 100 - 150 for the second bearing plate.	
190				PARTNER: Repeat Op #'s 110 - 180 with both bearing plates.	

Part Name	**Part Numbers**	**Building**
Bearing Plates (page 2)	021, 022	3
Material	**Start Size**	**Process**
Aluminum	5/16" X 2" X 3 1/2"	3-B

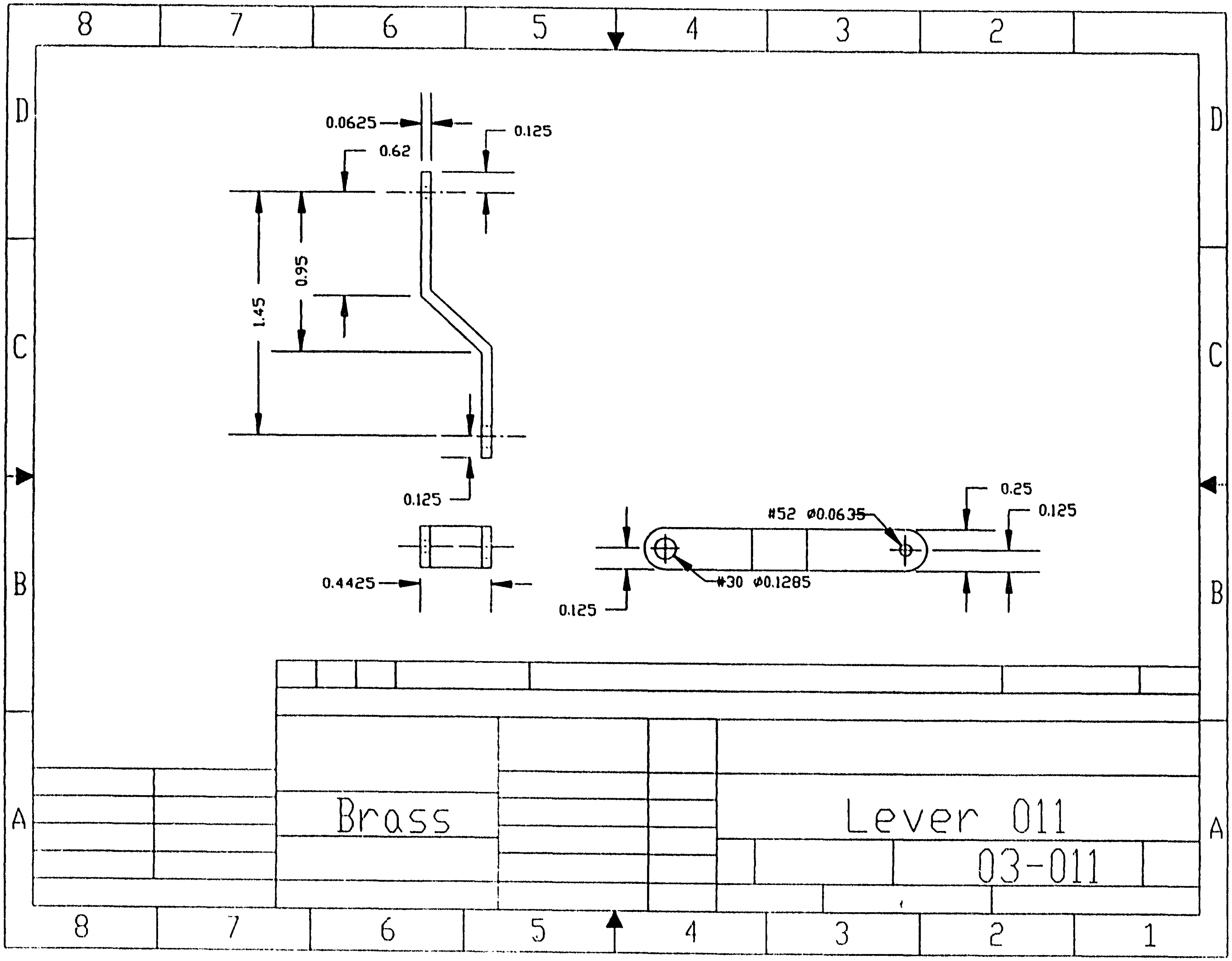
Op #	**Workplaces**	**Tools**	**Drawings**	**Instructions and Parameters**	**Complete (✓check)**
200	Vertical Mill			Loosen chuck by hand and remove reamer.	
210		#10 Drill		Place drill in chuck and tighten by hand.	
220				Switch to forward gear with gear change levers, turn chuck by hand to engage the gear.	
230				Switch vertical feed to the off position.	
240				Unlock the table in both the x and y directions.	
250		D.R.O.		Dial the table location to -1.500, -0.245.	
260				Lock the table in both the x and y directions.	
270				Lower drill manually to ascertain that the tool lines up with the pre-drilled hole.	
280				Turn the mill on by placing the power switch in the ☛ **FORWARD** (move switch *down*).	
290		Brush and Coolant		Lower drill manually and ☛ **PECK DRILL** (lower drill 1/16" into material, raise and brush off chips, repeat until hole is drilled through), applying coolant to drill throughout this step.	
300				When the hole is drilled through, turn the mill off, (move switch *up*), **being careful☛ NOT to overshoot and accidentally switch to the REVERSE direction.**	
310				Apply brake to stop rotation of spindle.	
320				Loosen vise, replace piece with fresh stock. Repeat Op #'s 250 - 300 for the second bearing plate.	
330				PARTNER: Repeat Op #'s 270 - 320 with both bearing plates.	
340		Countersink		Deburr all holes by turning countersink in the hole by hand.	


2 7/8
2 5/8
1/8
3/32
1/8
#52 Drill Thru
#30 Drill Thru
R 1/8
2 Places
1/4
Notes:
Break All Sharp Edges
PARTS LIST
Brass
K. Baron 12/95
Federico 12/95
Power Connector Lever
03-08
A
SCALE None
SHEET
APPLICATION
DO NOT SCALE DRAWING


#30 Drill Thru
#52 Drill Thru
1/8
1/16
1 1/2
1/8
1/4
1 3/4
Notes:
Break All Sharp Edges
PARTS LIST
Brass
K. Baron 12/95
Federico 12/95
Connector Lever
03-9
A
SCALE None
SHEET
APPLICATION
DO NOT SCALE DRAWING

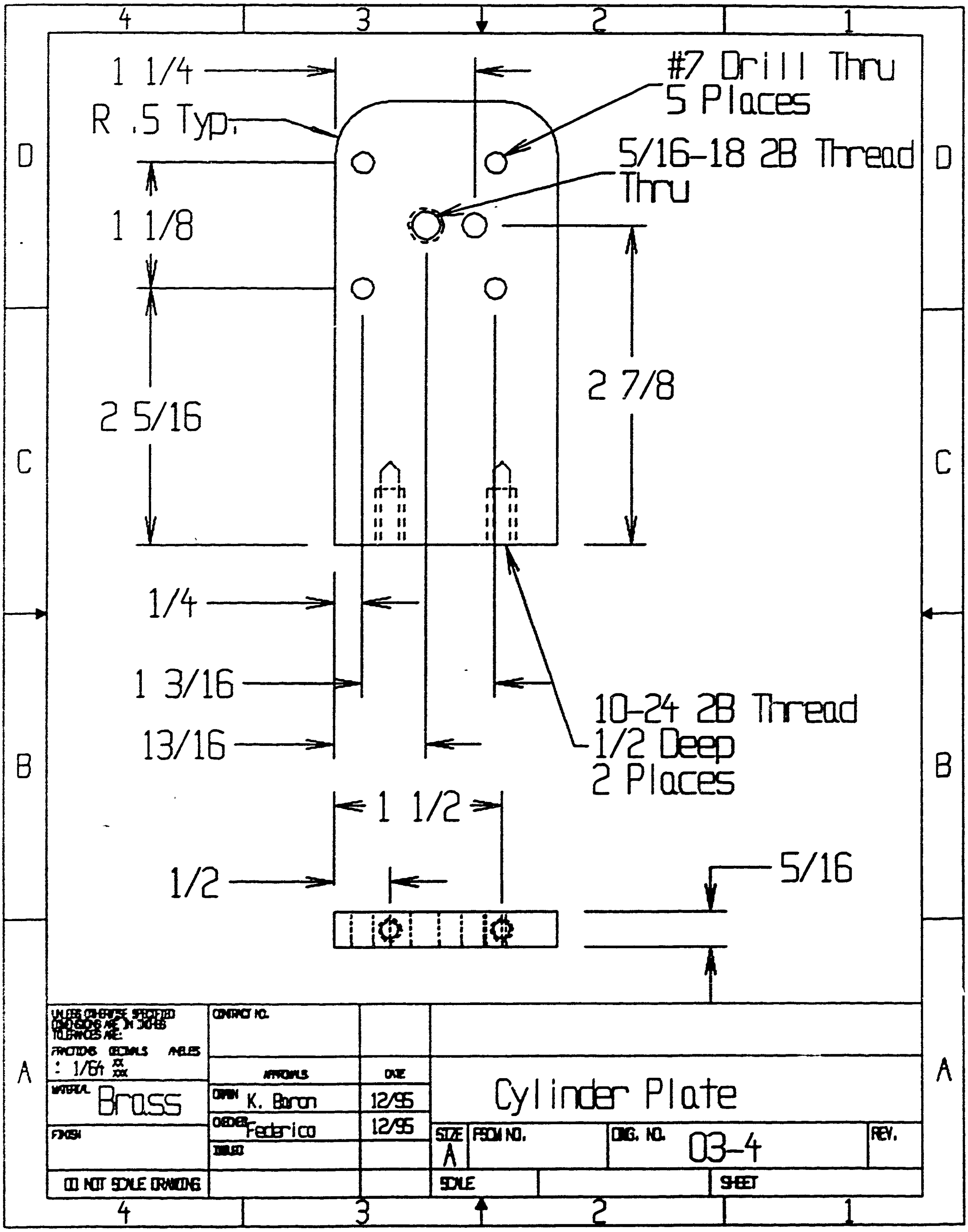
31

32.


0.0625
0.62
0.125
0.95
1.45
0.125
0.4425
0.125
#52 ⌀0.0635
#30 ⌀0.1285
0.25
0.125
Brass
Lever 011
03-011

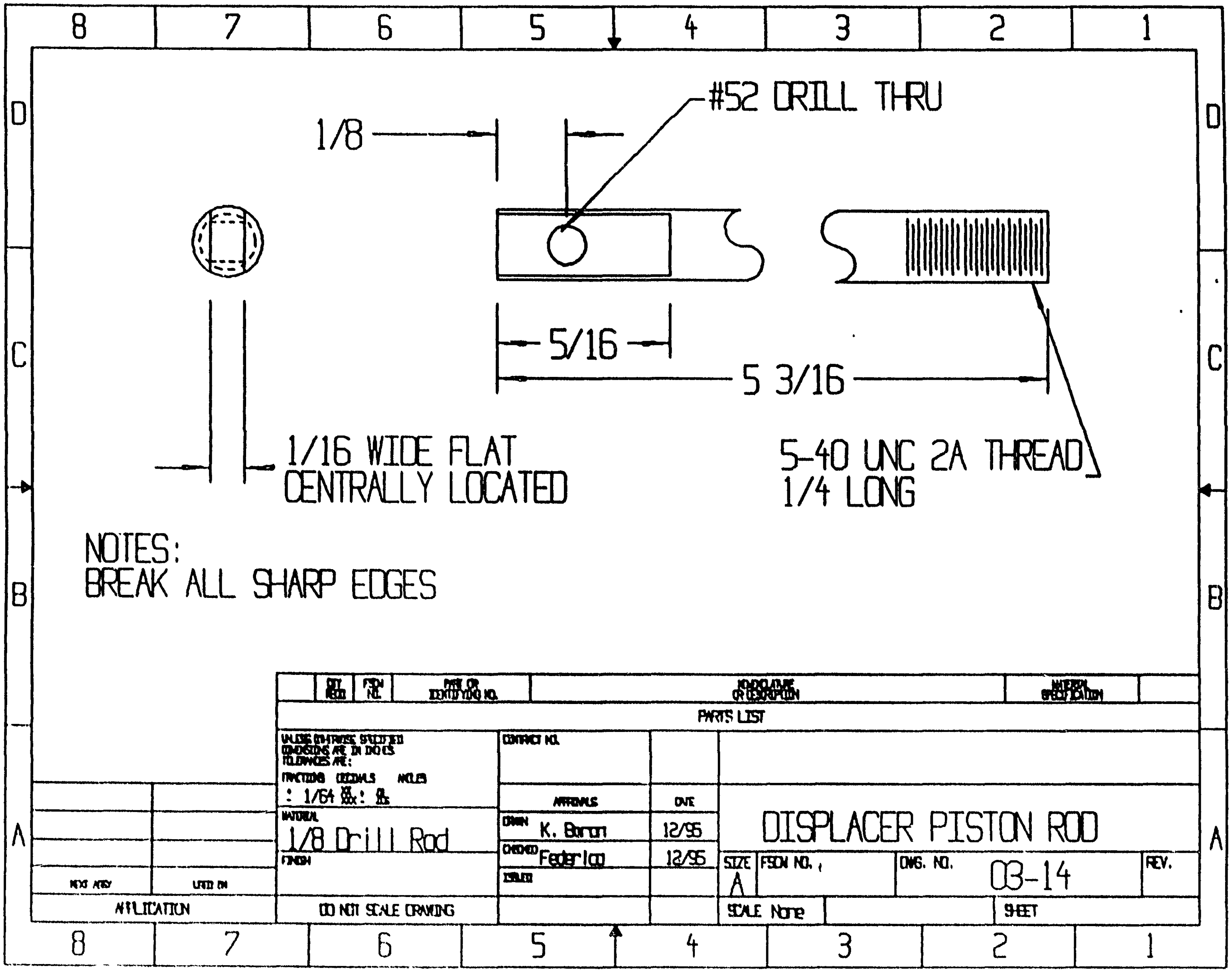
Part Names	**Part Numbers**	**Building**
Power Connecting Lever, Lever Connector, Levers	008, 009, 011, 012	3
Material	**Start Size**	**Process**
Brass	3/32' X 1/4" X 3" (008) 1/16" X 5/16" X 2" (009, 011, 012)	3-C

Op #	Workplaces	Tools	Drawings	Instructions and Parameters	Complete (✓check)
010	Bench	Lever jig		Place two sets of lever stock in jig; tighten jig wing nuts.	
020	Drill Press	#52 Drill		Place #52 drill bit in drill chuck; tighten with key.	
030				Drill through all eight holes marked #52 on jig; be sure to align drill bit with hole before drilling.	
040		#30 Drill		Replace #52 drill bit with #30 drill bit; tighten drill chuck with key.	
050				Drill through all eight holes marked #30 on jig; be sure to align drill bit with hole before drilling.	
060				Remove #30 drill bit; return drill bits.	
070				Loosen wing nuts and remove levers; separate levers 011 and 012.	
080		Countersink		Deburr ALL holes by turning countersink in the hole by hand.	
090		Bending Jig		Slide one lever 011 into the triangle of 1/8" dowels in the lower half of the bending jig, with the smaller hole of the lever in the triangle.	
100				Place the 3/8" dowel sticking out of the top half of the bending jig in the drill chuck and tighten.	
110				Carefully slide the two halves of the bending jig together, close completely using drill press.	
120				Remove lever 011 from the bending jig.	
130				Repeat OP #'s 090 to 120 with PARTNER's lever 011 and both partners' levers 012.	
140	Beltsander			Round ends of ALL levers carefully.	


1 1/4
R .5 Typ.
#7 Drill Thru
5 Places
5/16-18 2B Thread
Thru
1 1/8
2 5/16
2 7/8
1/4
1 3/16
13/16
10-24 2B Thread
1/2 Deep
2 Places
1 1/2
1/2
5/16
CONTRACT NO.
APPROVALS
DATE
MATERIAL Brass
DRAWN K. Baron 12/95
CHECKED Federico 12/95
ISSUED
FINISH
DO NOT SCALE DRAWING
Cylinder Plate
SIZE A
FSCM NO.
DWG. NO. 03-4
REV.
SCALE
SHEET

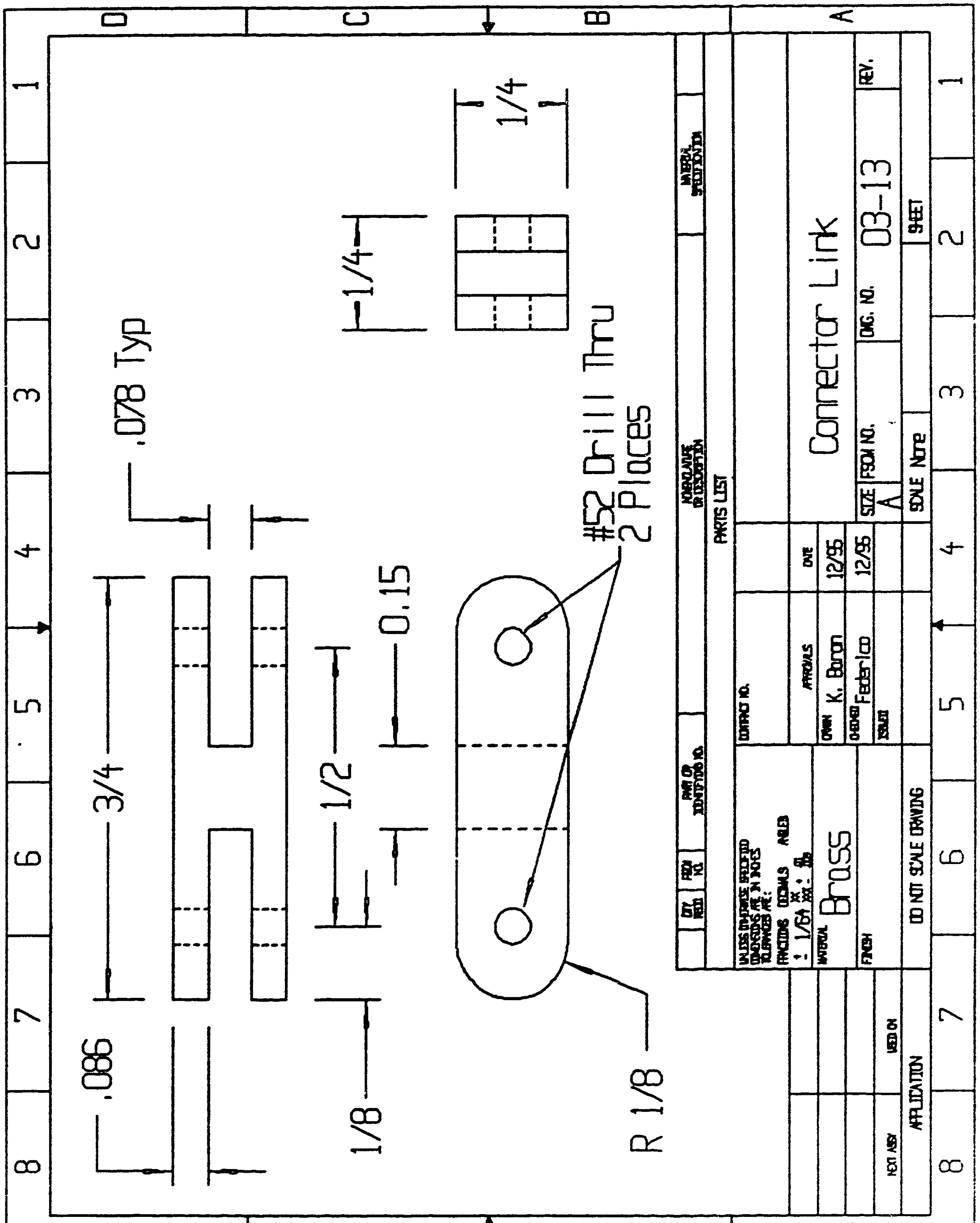
Part Name	**Part Number**	**Building**
Cylinder Plate	004	3
Material	**Start Size**	**Process**
Brass	5/16" X 2" X 4"	3-D

Op #	**Workplaces**	**Tools**	**Drawings**	**Instructions and Parameters**	**Complete (✓check)**
010	Bench	Cylinder plate jig		Place piece in jig; tighten wing nuts.	
020	Drill Press	#7 Drill		Place #7 drill bit in drill chuck; tighten with key.	
030				☞ **PECK DRILL** (lower drill 1/16" into material, raise and brush off chips, repeat until hole is drilled through) through all five holes marked #7 on jig; be sure to align drill bit with hole before drilling.	
040		F Drill (0.257")		Replace #7 drill bit with F drill bit; tighten drill chuck with key.	
050				☞ **PECK DRILL** through the hole marked F on jig; be sure to align drill bit with hole before drilling.	
060				Remove F drill bit; return drill bits.	
070				Loosen wing nuts and remove piece.	
080				PARTNER: Repeat Op #'s 010 - 070	
090	Bench	Countersink		Deburr all holes by turning countersink in the hole by hand.	
100		Vise		Tighten piece (lightly) horizontally in vise.	
110		5/16" - 18 Tap and Tapping block		Place tap through tapping block, align with the F hole and tap through the piece; ☞ ***ADD*** a drop of tapping fluid to tap.	
120				PARTNER: Repeat Op #'s 100 - 110	


#52 DRILL THRU
1/8
5/16
5 3/16
1/16 WIDE FLAT
CENTRALLY LOCATED
5-40 UNC 2A THREAD
1/4 LONG
NOTES:
BREAK ALL SHARP EDGES
PARTS LIST
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:
FRACTIONS DECIMALS ANGLES
± 1/64
MATERIAL
1/8 Drill Rod
FINISH
DO NOT SCALE DRAWING
CONTRACT NO.
APPROVALS
DATE
DRAWN K. Baron 12/95
CHECKED Federico 12/95
ISSUED
DISPLACER PISTON ROD
SIZE A
FSCM NO.
DWG. NO. 03-14
REV.
SCALE None
SHEET
NEXT ASSY
USED ON
APPLICATION

Part Name				Part Number	Building
Displacer Piston Rod				014	3
Material				**Start Size**	**Process**
1/8" Drill Rod				1/8" OD, 5.14" Length	3-E

Op #	Workplaces	Tools	Drawings	Instructions and Parameters	Complete (✓check)
010	Bench	File		Remove burrs from end without thread, file this end face flat.	
020		Blue dye and calipers		Apply blue die to this end of piece, make a mark 0.31" from this end.	
030		Vise		Place piece horizontally in vise, with only the marked distance showing; tighten vise.	
040		File and calipers		File the first flat until remaining material is .094" +0.000, -0.001 thick.	
050				Loosen vise and remove piece.	
060				Holding the first flat against the bench, file the second flat on other side until remaining material is 0.062" +0.000, -0.001 thick.	
070		Blue dye and calipers		Scribe a line on the flat 0.125" from the end of the piece.	
080		Rod jig		Place piece in jig with scribed line facing up; tighten jig.	
090	Drill Press	Center drill		Place center drill in drill chuck; tighten with key.	
100				Carefully align center drill with the center of the scribed line, turn drill on and make the center hole.	
110		#52 Drill		Replace center drill with #52 drill bit; tighten drill chuck with key.	
120				Drill through the piece.	
130		Countersink		Deburr all holes by turning countersink in the hole by hand.	
140	Bench	Blue dye and calipers		Make a mark 0.25" from the end without the thread.	
150		Vise and 5-40 Die		Tighten the piece vertically in the vise so that the mark is visible.Thread to the 0.25" mark using the 5-40 die.	



.086
1/8
R 1/8
3/4
1/2
0.15
.078 Typ
1/4
1/4
#52 Drill Thru
2 Places
PARTS LIST
Brass
K. Bonan
Federico
12/95
12/95
Connector Link
A
03-13
SCALE None
DO NOT SCALE DRAWING
APPLICATION

Part Name	Part Number	Building
Connector Link	013	3
Material	**Start Size**	**Process**
Brass	1/4" X 1/4" X 3/4"	3-F

Op #	Workplaces	Tools	Drawing	Instructions and Parameters	Complete (✓check)
010	Bench	File		Deburr all edges.	
020	Drill Press	Connector link jig		Slide connector link into the jig, with the scribed side facing upwards.	
030		Center drill		Place center drill in drill chuck; tighten with key.	
040				Carefully align center drill with the scribed hole location; turn drill on, and make the center hole. Repeat at the second hole location.	
050				PARTNER: Repeat Op #'s 020 - 040	
060		#52 Drill		Replace center drill with #52 drill bit, carefully align the drill with the center hole.	
070				Drill ☛ ***VERY, VERY CAREFULLY*** through piece, going slowly to avoid collapsing the link. Repeat at the second hole location.	
080				Remove link from jig.	
090				PARTNER: Repeat Op #'s 060 - 080.	
100	Bench	Countersink		Deburr ALL holes by turning countersink in the hole by hand.	
110		File		Round ends of each lever by hand (☛ **DO NOT** use beltsander!).	
120		Sandpaper		Remove internal burrs.	

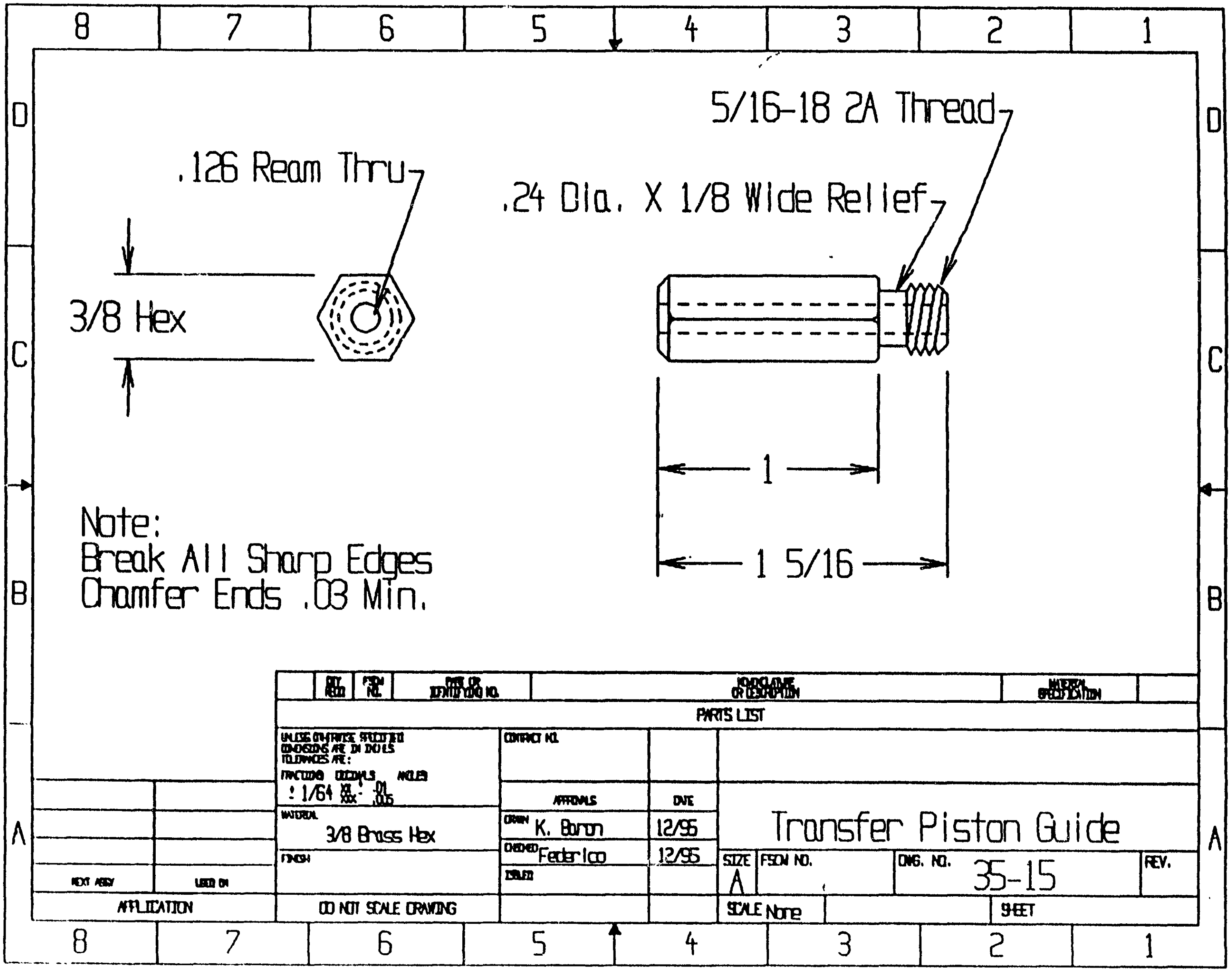
Part Names	Part Numbers	Building
Cylinder Plate and Bearing Plates	004, 020, 021	3
Material	**Start Size**	**Process**
Aluminum (020, 021) and Brass (004)	5/16" X 2" X 4" (004) 5/16" X 2" X 3 1/2" (021, 022)	3-G

Op #	Workplaces	Tools or Part	Drawings	Instructions and Parameters	Complete (✓check)
010	Bandsaw	Cylinder plate		☞ ***VERY, VERY CAREFULLY*** cut the corners of the cylinder plate off, **OUTSIDE** (leave the lines visible on the piece after it has been cut) the scribed radii. Repeat this step for ALL cylinder plates in your group.	
020		Bearing plate		☞ ***VERY, VERY CAREFULLY*** cut the corners of the bearing plate off, **OUTSIDE** the scribed radii. Repeat this step for ALL bearing plates in your group.	
030				☞ ***VERY, VERY CAREFULLY*** cut to the large hole in the bearing plate, **OUTSIDE** the scribed lines on the bearing plate (set the guide to ensure a straight cut). Repeat this step for ALL the bearing plates in your group.	
040	Bench	File		File bearing plate to scribed straight lines by hand.	
050	Beltsander	Cylinder plate, Bearing plates		Round corners of cylinder plate and bearing plates.	

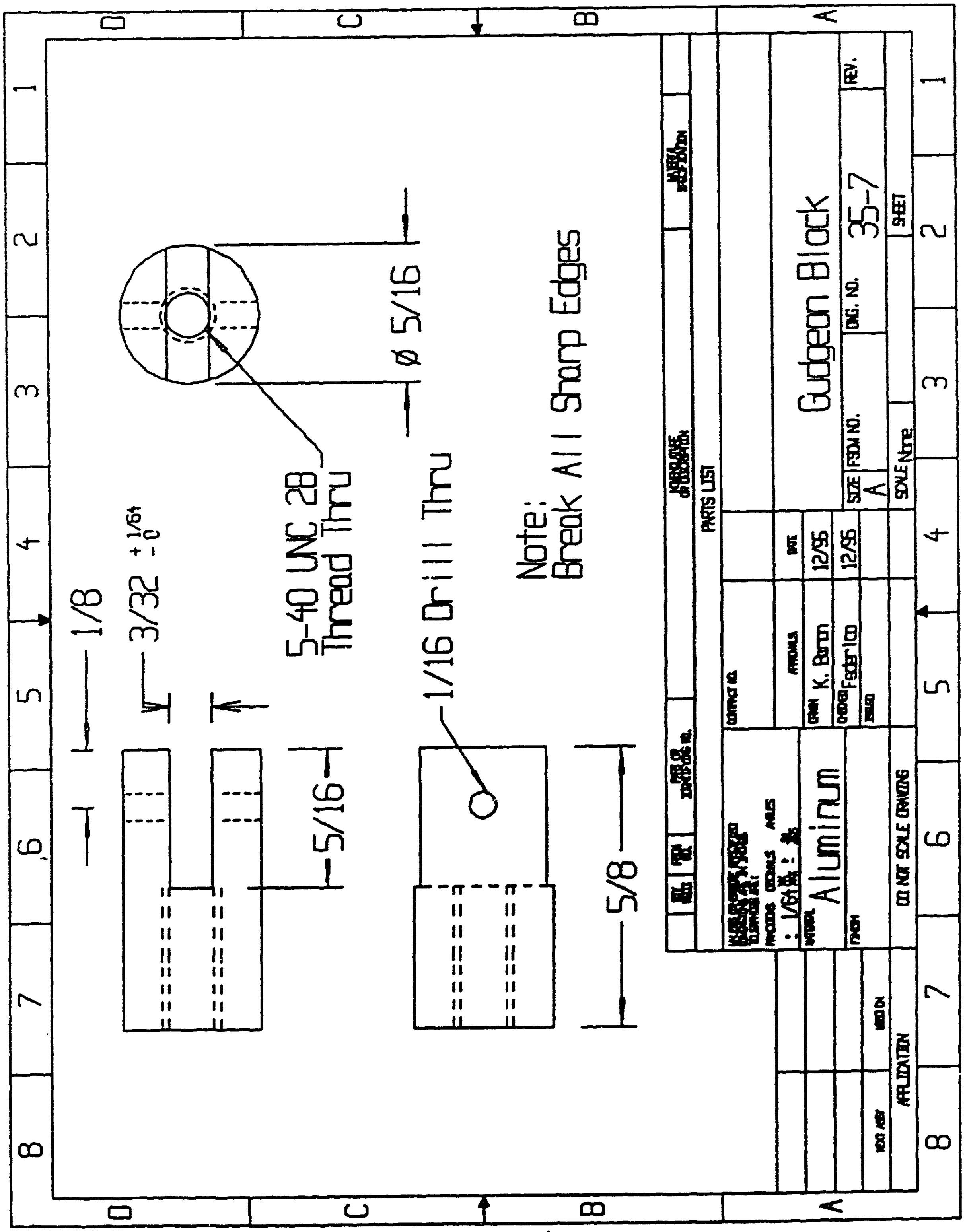
BUILDING 35 (LMP)
PART DRAWINGS AND PROCESS PLANS

PART DRAWINGS

PROCESS PLANS


5/16-18 2A Thread
.126 Ream Thru
.24 Dia. X 1/8 Wide Relief
3/8 Hex
1
1 5/16
Note:
Break All Sharp Edges
Chamfer Ends .03 Min.
PARTS LIST
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE:
FRACTIONS ± 1/64
MATERIAL 3/8 Brass Hex
FINISH
CONTRACT NO.
APPROVALS
DATE
DRAWN K. Baron 12/95
CHECKED Federico 12/95
ISSUED
Transfer Piston Guide
SIZE A
FSCM NO.
DWG. NO. 35-15
REV.
SCALE None
SHEET
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION

Part Name Transfer Piston Guide Bushing				Part Number 014	Building 35
Material Brass Hex Rod				**Start Size** 3/8" Hex Stock	**Process** 35-A
Op #	**Workplaces**	**Tools**	**Drawings**	**Instructions and Parameters**	**Complete (✓check)**
010	Bench	Chuck wrench		Grip stock in 3 jaw chuck, with 2" extending; tighten the chuck jaws securely using chuck wrench.	
020	Lathe			☛ **REMOVE CHUCK WRENCH FROM CHUCK.**	
030				Set spindle speed to 400 RPM; set feed rate to 0.005" per rev.	
040		Cutting tool		Adjust cutting tool for facing.	
050				Turn lathe on and face end to square.	
060				Adjust cutting tool for turning.	
070		Calipers		Turn the hex stock to 0.308" for a length of 5/16".	
080		Center drill		Insert tool in tailstock; drill 60° X 0.125" diameter.	
090		7/64 Drill and Oil		Insert tool; drill through, ☛ **CLEAR CHIPS** at 0.050" intervals, and ☛ **OIL** the drill bit **frequently**.	
100				Reduce the spindle speed to 200 RPM.	
110		0.126 Ream		Insert tool and ream through; clear **chips** and **oil frequently**.	
120		File		File a 45° X 0.08" chamfer on the end.	
130		5/16-18 Die		Cut threads by hand, using the die; use the tailstock as a guide to keep the die square to the centerline.	
140	Bench	Blue die and Height guage		Mark length at 1.312", measuring from the threaded end.	
150	Bandsaw	Hand vise		Place piece in vise, with the threaded end inside and the mark outside; tighten the vise.	
160				☛ **CAREFULLY** cut the piece **outside** of the mark, leaving the mark showing on the piece.	
170	Lathe	Chuck wrench		Grip stock in 3 jaw chuck with mark showing; tighten the chuck jaws securely using chuck wrench.	
180				☛ **REMOVE CHUCK WRENCH FROM CHUCK.**	
190				Increase spindle speed to 400 RPM.	
200				Adjust cutting tool for facing.	
210				Turn lathe on and face end to mark.	
220				*See instructor to check correct fit to 0.125" shaft.	


1/8
3/32 +1/64 -0
5/16
5-40 UNC 2B
Thread Thru
1/16 Drill Thru
ø 5/16
5/8
Note:
Break All Sharp Edges
PARTS LIST
Aluminum
K. Baron
Federico
12/95
12/95
Gudgeon Block
SIZE A
DWG. NO. 35-7
SCALE None
SHEET
REV.
DO NOT SCALE DRAWING
APPLICATION

Part Name Gudgeon Block (page 1)	**Part Number** 007	**Building** 35
Material Aluminum Rod	**Start Size** 1/2" OD Stock	**Process** 35-B

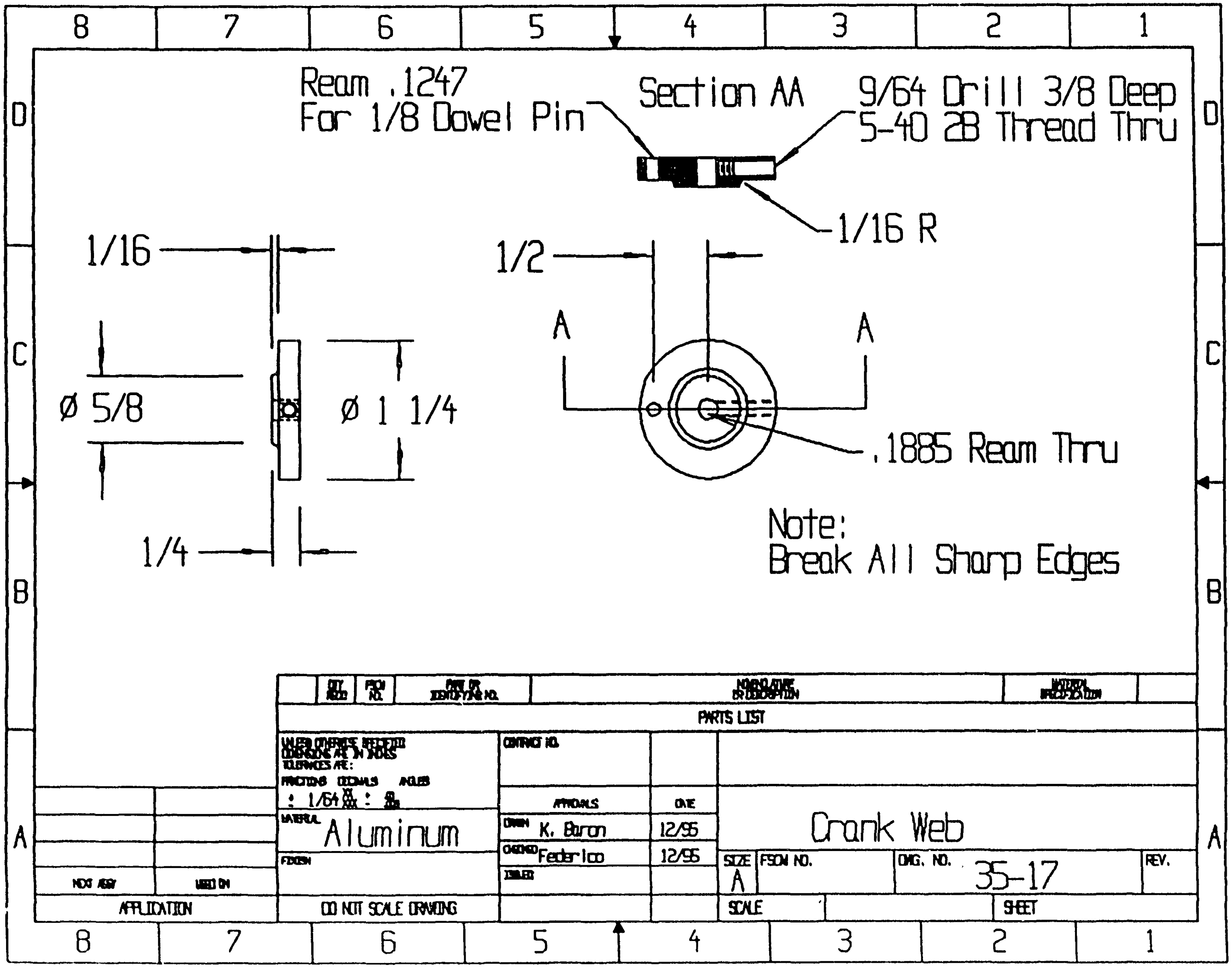
Op #	Workplaces	Tools	Drawings	Instructions and Parameters	Complete (✓check)
010	Lathe	Chuck wrench		Grip stock in 3 jaw chuck, with 1.5" extending; tighten the chuck jaws securely using chuck wrench.	
020				☛ **REMOVE CHUCK WRENCH FROM CHUCK.**	
030				Set spindle speed to 400 RPM; set feed rate to 0.005" per rev.	
040		Cutting tool		Adjust cutting tool for facing.	
050				Turn lathe on and face end to square.	
060				Adjust cutting tool for turning.	
070		Calipers		Turn the outer diameter to 0.375" +0.00, - 0.005 for a length of 0.75".	
080		Center drill		Insert tool in tailstock; center drill 60° X 0.125" diameter.	
090		#38 Drill		Insert tool; drill to a depth of 0.4".	
100	Bandsaw	Hand vise		Place piece in vise, with the machined shoulder outside; tighten the vise.	
110				☛ **CAREFULLY** cut the piece off at the shoulder.	
120	Layout Bench	Blue die and Height guage		Using the height guage, scribe a line 0.625" from the squared (faced on the lathe) end.	
130	Lathe	Chuck wrench		Grip stock in the 3 jaw chuck, with the squared end inside and the scribed line showing; tighten the chuck jaws securely using chuck wrench.	
140				☛ **REMOVE CHUCK WRENCH FROM CHUCK.**	
150				Set spindle speed to 400 RPM, set feed rate to 0.005" per rev.	
160		Cutting tool		Adjust cutting tool for facing.	
170				Turn lathe on and face to the scribed line.	

Part Name Gudgeon Block (page 2)				Part Number 007	Building 35
Material Aluminum Rod				**Start Size** 1/2" OD Stock	**Process** 35-B

Op #	Workplaces	Tools	Drawings	Instructions and Parameters	Complete (✓check)
180	Drill Press	Collet fixture		Locate piece in collet fixture	
190		0.062" Drill		Insert tool and tighten with key.	
200		Cutting oil		Drill through piece. ☞ **USE CUTTING OIL** and **CLEAR CHIPS** frequently.	
210				☞**LEAVE PART IN COLLET FIXTURE.**	
220	Horizontal Mill			Remove drill guide **ONLY** from collet fixture.	
230				Locate collet fixture against stops.	
240				Mill 3/32" slot to a depth of 5/16".	
260	Bench	Die files		Deburr rough edges by hand.	
270		Hand vise		Place piece in vise, with the slot inside and the drilled hole outside; tighten the vise.	
280		5-40 Tap		Cut threads by hand, using the tap.	

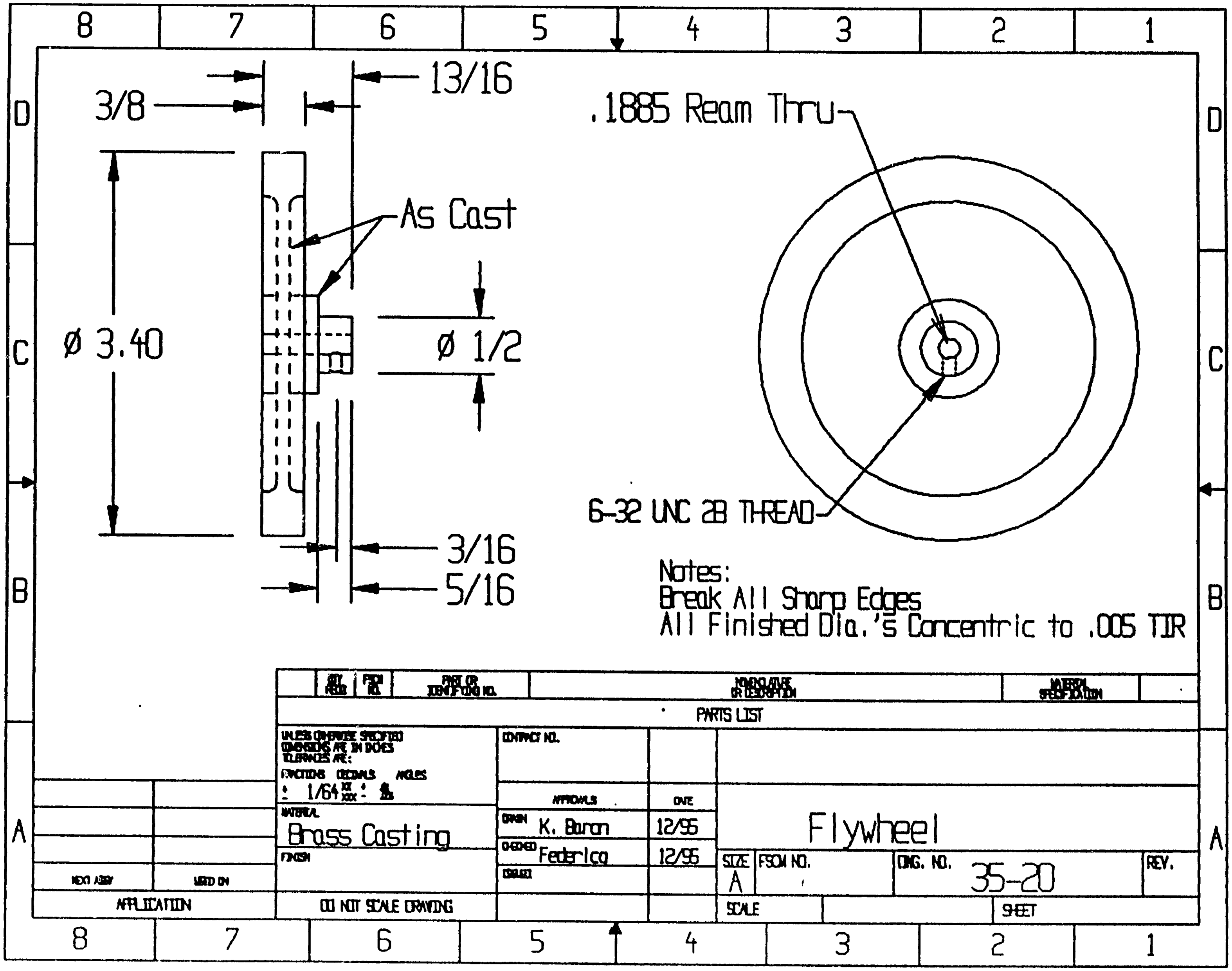
Part Name	Part Number	Building
Crank Web (page 1)	017	35
Material	**Start Size**	**Process**
Aluminum Rod	1.5" OD Stock	35-C

Op #	Workplaces	Tools	Drawings	Instructions and Parameters	Complete (✓check)
010	Lathe	Chuck wrench		Grip stock in 3 jaw chuck, with 2" extending; tighten the chuck jaws securely using chuck wrench.	
020				💣 **REMOVE CHUCK WRENCH FROM CHUCK.**	
030				Set spindle speed to 400 RPM; set feed rate to 0.005" per rev.	
040		Cutting tool		Adjust cutting tool for facing.	
050				Turn lathe on and face end to square.	
060				Adjust cutting tool for turning.	
070		Calipers		Turn the outer diameter to 1.25" for a length of 0.35"	
080		Micrometer stop		With the cutting tool at end of the piece, set the stop offset 0.062" from the carriage.	
090				Turn the diameter to 5/8" for a length of 1/16" (to the stop).	
100		Center drill		Insert tool in tailstock; drill 60° X 0.125" diameter.	
110		11/64" Drill, Oil		Insert tool; drill to a depth of 5/16", 💣 **CLEAR CHIPS** and 💣 **OIL** the drill bit **frequently**.	
120		0.1885 Ream		Ream through drilled hole; clear **chips** and **oil frequently**.	
130	Layout Bench	Blue die and Height guage		Using the height guage, scribe a line 0.25" from the squared end.	
140	Bandsaw	Hand vise		Place the piece in vise, with the scribed line outside; tighten the vise.	
150				💣 **CAREFULLY** cut the piece **outside** of the mark, leaving the mark on the piece.	


Ream .1247
For 1/8 Dowel Pin
Section AA
9/64 Drill 3/8 Deep
5-40 2B Thread Thru
1/16 R
1/16
1/2
A
A
Ø 5/8
Ø 1 1/4
.1885 Ream Thru
1/4
Note:
Break All Sharp Edges
PARTS LIST
CONTRACT NO.
APPROVALS
DATE
MATERIAL Aluminum
DRAWN K. Baron 12/95
CHECKED Federico 12/95
Crank Web
SIZE A
FSCM NO.
DWG. NO. 35-17
REV.
SCALE
SHEET
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING

Part Name	Part Number	Building
Crank Web (page 2)	017	35
Material	**Start Size**	**Process**
Aluminum Rod	1.5" OD Stock	35-C

Op #	Workplaces	Tools	Drawings	Instructions and Parameters	Complete (✓check)
160	Lathe	1 1/4" Collet		Grip stock in collet, with cut end extending and the mark outside; tighten the collet securely.	
170				Set spindle speed to 400 RPM; set feed rate to 0.005" per rev.	
180		Cutting tool		Adjust cutting tool for facing.	
190				Turn lathe on and face end to square.	
200		Calipers		Check size.	
210		C.Web jig		Place piece in the jig and close tightly.	
220	Drill Press	0.120" Drill		Insert drill bit and tighten with key.	
230				Drill through the piece (on the face of the piece; for the press fit of the crank pin).	
240		0.1247" Ream		Insert ream; ream through the drilled hole.	
250		9/64" Drill		Insert drill bit; drill to a depth of 3/8" (on the side of piece; for the set screw).	
260		#38 Drill		Insert drill bit; drill to the center hole (in the 9/64" hole).	
270		5-40 Tap		Cut threads by hand, using tap; make sure the tap is perpendicular to the part.	
280		Countersink and File		Deburr all holes and sharp corners.	



3/8
13/16
.1885 Ream Thru
As Cast
ø 3.40
ø 1/2
6-32 UNC 2B THREAD
3/16
5/16
Notes:
Break All Sharp Edges
All Finished Dia.'s Concentric to .005 TIR
PARTS LIST
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE:
MATERIAL
Brass Casting
FINISH
DRAWN K. Baron 12/95
CHECKED Federico 12/95
Flywheel
SIZE A
DWG. NO. 35-20
REV.
SCALE
SHEET
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING

Part Name				Part Number	Building
Flywheel (page 1)				019	35
Material				**Start Size**	**Process**
Brass Casting				3 1/2" OD1, 1" OD2 X 1" Length	35-D

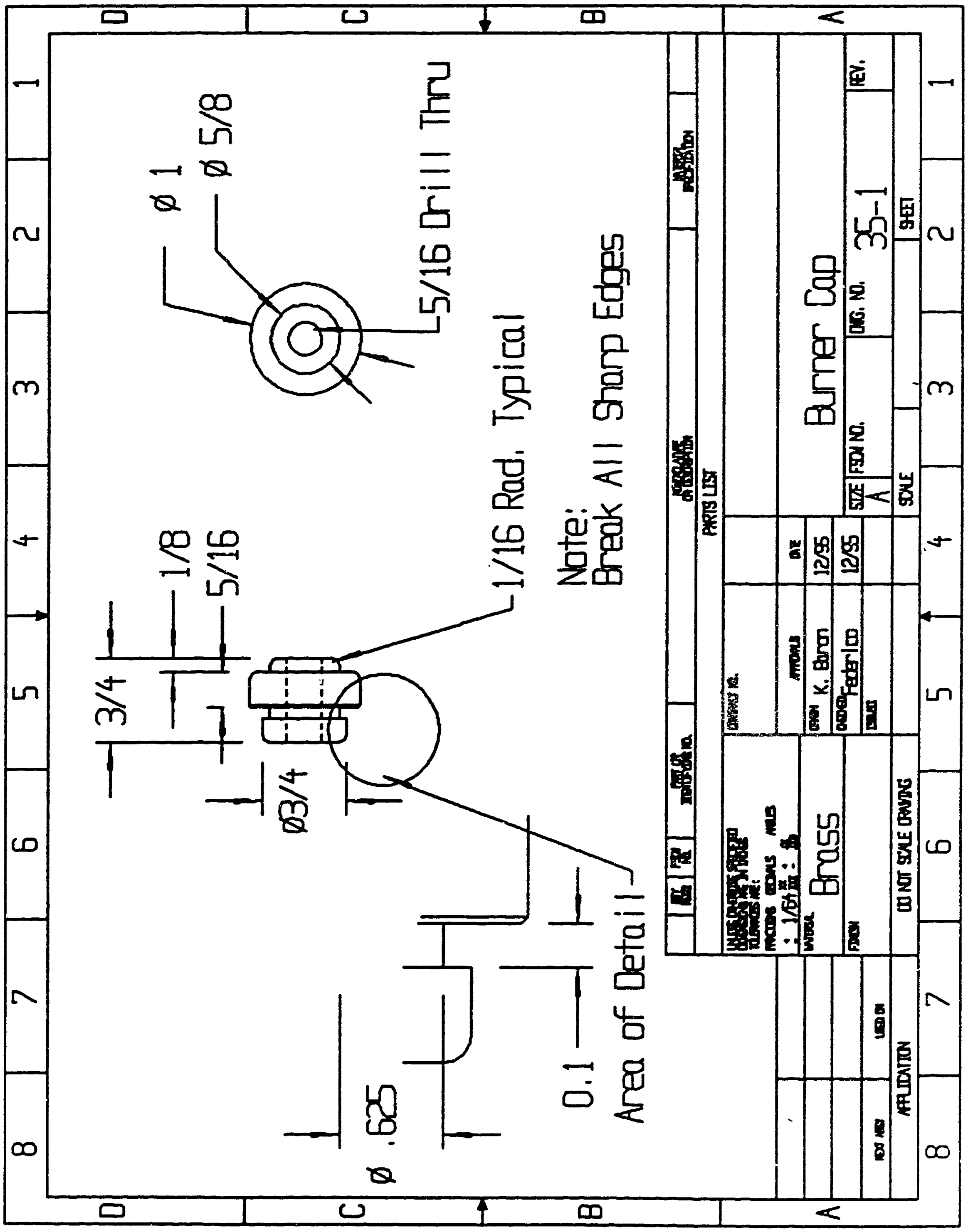
Op #	Workplaces	Tools	Drawings	Instructions and Parameters	Complete (✓check)
010	Lathe	Chuck wrench		Grip casting in 3 jaw chuck, with the small diameter (OD2) inside; using the tailstock, apply light pressure to hold the casting square to the chuck jaws, and then tighten the chuck jaws securely using chuck wrench.	
020				**REMOVE CHUCK WRENCH FROM CHUCK**	
030				Set surface speed to 600 RPM, set feed rate to 0.0037" per rev.	
040		Cutting tool		Adjust cutting tool for facing.	
050				Turn lathe on and face large rim (not indentation) clean.	
060				Adjust cutting tool for turning.	
070		Calipers		Turn large diameter (OD1) to 3.400 for the entire length of OD1, taking 0.03" passes.	
080		#2 Center drill		Insert tool in tailstock; drill to create conical starting hole.	
090		5/32" Drill		Insert tool; drill through piece. Withdraw drill every 1/8" to clear chips and oil frequently.	
100		0.1885" Ream		Insert tool; ream through piece. Withdraw reamer every 1/8" to remove chips.	
110		Countersink		Deburr holes by turning countersink in the hole by hand.	

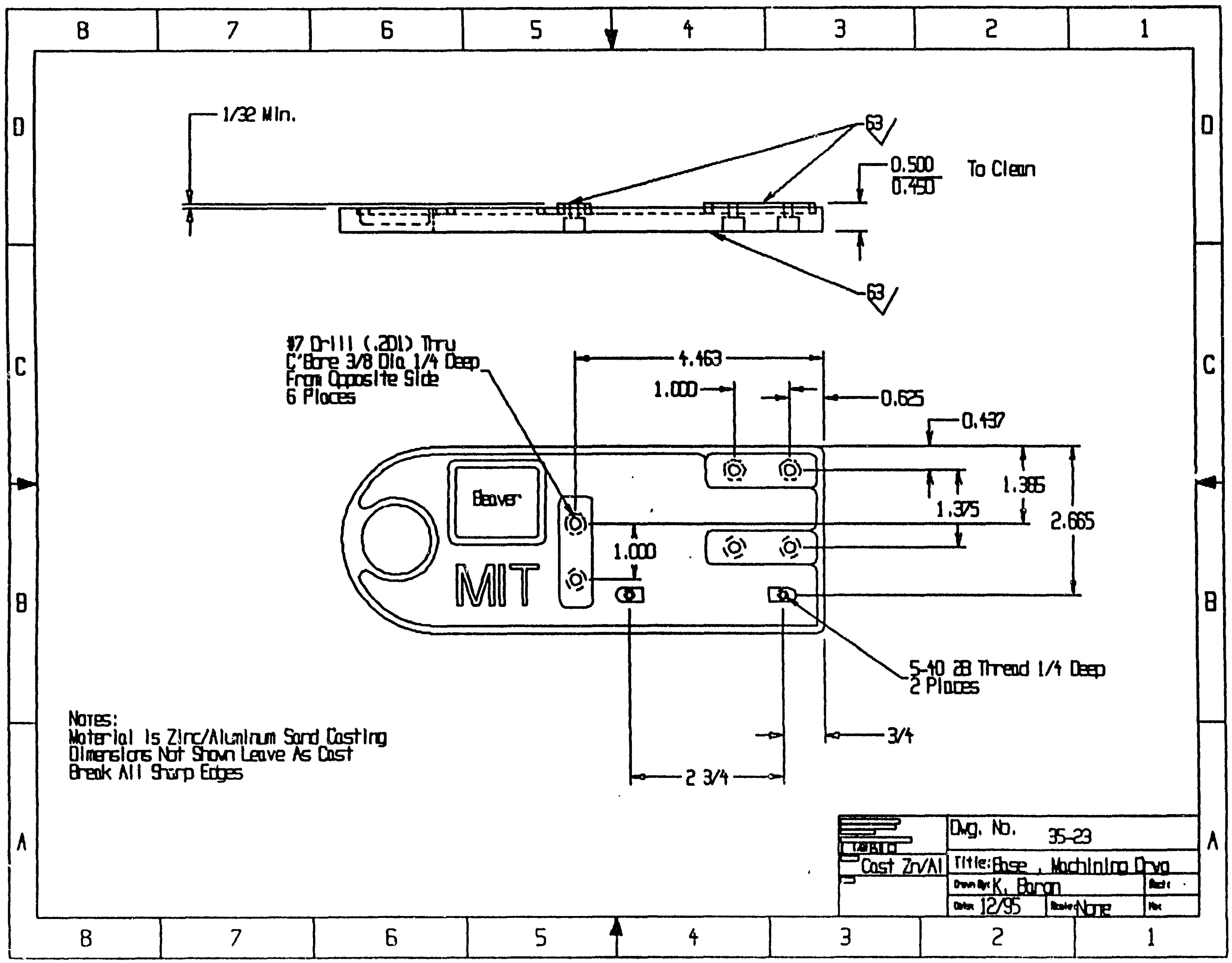
Part Name	Part Number	Building
Flywheel (page 2)	019	35
Material	**Start Size**	**Process**
Brass Casting	3 1/2" OD1, 1" OD2 X 1" Length	35-D

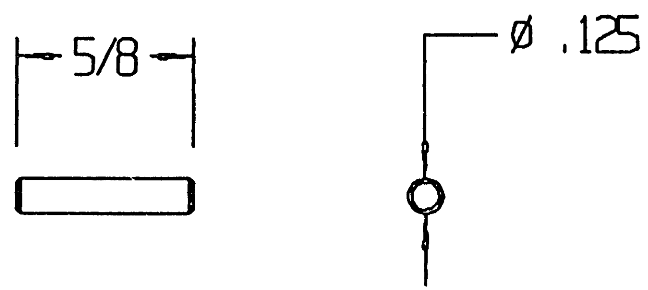
Op #	Workplaces	Tools	Drawings	Instructions and Parameters	Complete (✓check)
120	Lathe	Chuck wrench		Grip casting in soft jaws, with the machined face in (clean the chuck jaws first), gripping the outer diameter (OD1); tighten securely using chuck wrench.	
130				☛ **REMOVE CHUCK WRENCH FROM CHUCK**	
140				Set surface speed to 600 RPM, set feed rate to 0.0037" per rev.	
150		Cutting tool		Adjust cutting tool for facing.	
160				Turn lathe on and face large rim (not indentation) until the large diameter is 3/8" wide; set the carriage stop	
170				when done.	
180		7/16" Spacer		With the 7/16" spacer beween the stop and the carriage, face the small diameter until the overall length of the entire flywheel is 13/16"; remove the 7/16" spacer	
190				Adjust cutting tool for turning.	
200		1/8" Spacer		With the 1/8" spacer between the stop and the carriage, turn the small diameter to 0.500" +0.000, -0.005 for a length of 5/16" (the tolerance must be held in order for the flywheel to fit into the drill jig).	
210		File		Deburr sharp corners.	
220	Drill Press	Drill jig Hand vise		Place jig over the small diameter and put the piece and jig in the vise (make sure there are no chips in the vise or the jig); tighten vise.	
230		#36 Drill		Insert tool and tighten with key	
240	Bench			Drill through **ONE** wall of the small diameter.	
250		Long #2 center drill		Insert tool; chamfer the drilled hole.	
260		6-32 Tap		Cut threads by hand, using tap; make sure the tap is perpendicular to the part.	

DRAWINGS OF SUPPLIED PARTS

PART DRAWINGS


Ø 1
Ø 5/8
5/16 Drill Thru
1/16 Rad. Typical
Note:
Break All Sharp Edges
3/4
1/8
5/16
Ø3/4
Ø .625
0.1
Area of Detail
PARTS LIST
Brass
K. Baron
12/95
Federico
12/95
Burner Cap
SIZE
A
DWG. NO.
35-1
SCALE
SHEET
REV.
DO NOT SCALE DRAWING
APPLICATION


1/32 Min.
63
0.500
0.450
To Clean
63
#7 Drill (.201) Thru
C'Bore 3/8 Dia 1/4 Deep
From Opposite Side
6 Places
4.463
1.000
0.625
0.437
1.385
1.375
2.665
1.000
Beaver
MIT
5-40 28 Thread 1/4 Deep
2 Places
3/4
2 3/4
Notes:
Material Is Zinc/Aluminum Sand Casting
Dimensions Not Shown Leave As Cast
Break All Sharp Edges
Cast Zn/Al
Dwg. No. 35-23
Title: Base , Machining Drwg
Drawn By: K. Baron
Date: 12/95
Scale: None



Notes:
Break All Sharp Edges

QTY REQD	FSCM NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION

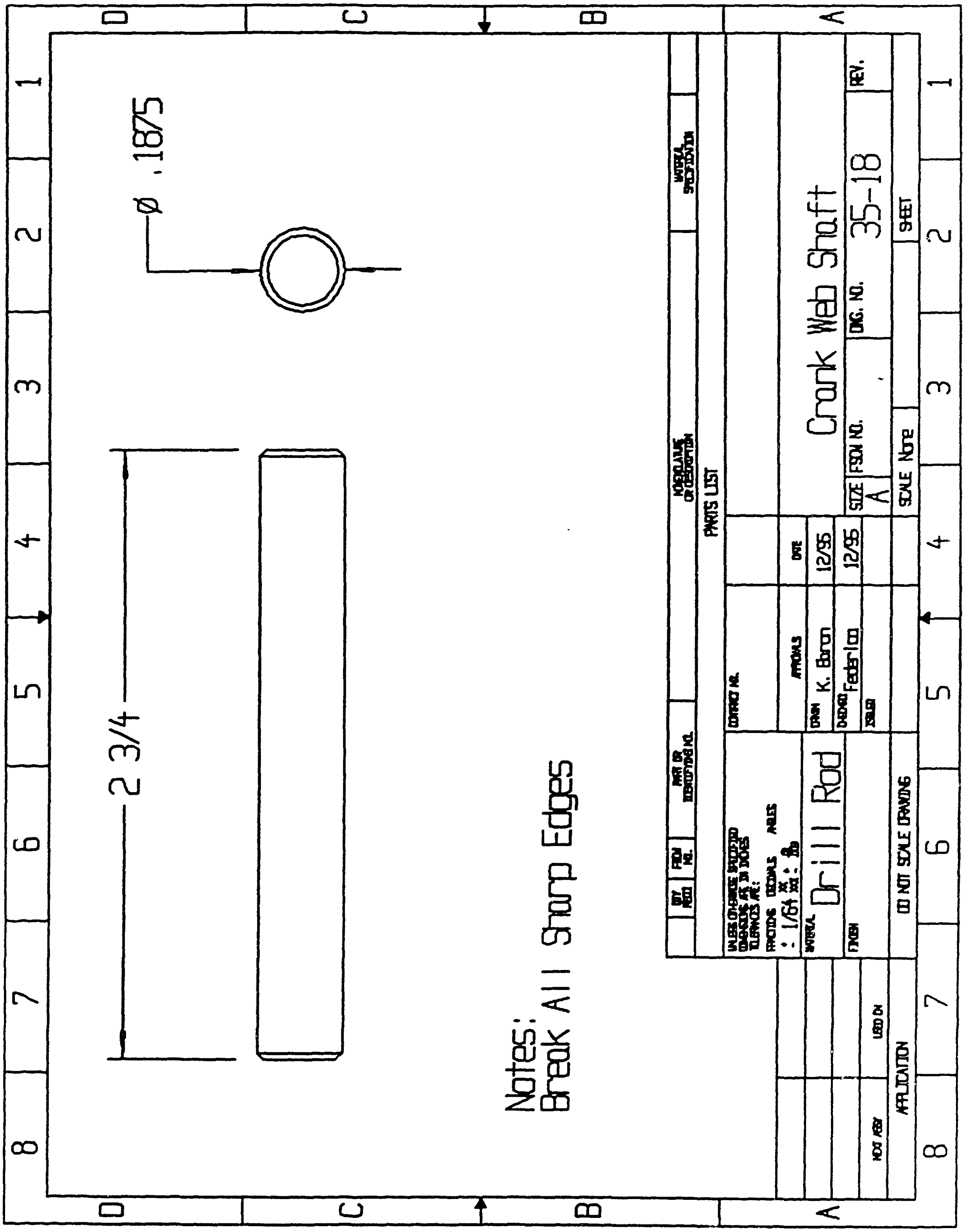
PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE: FRACTIONS ± 1/64 DECIMALS .XX ± .01 .XXX ± .005 ANGLES	CONTRACT NO.
MATERIAL Drill Rod	APPROVALS / DATE
	DRAWN K. Boron 12/95
FINISH	CHECKED Federico 12/95
	ISSUED
DO NOT SCALE DRAWING	

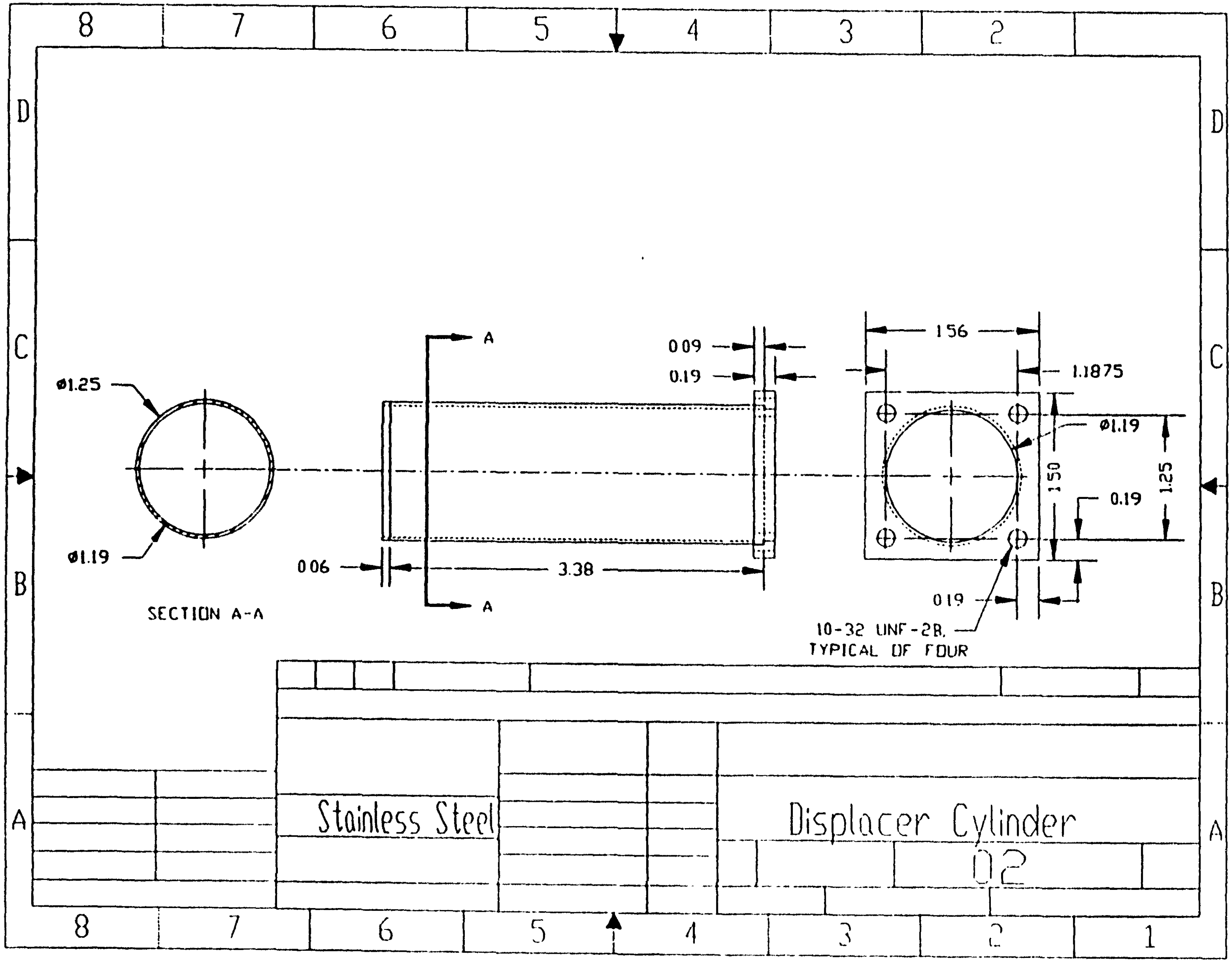
Crank Pin

SIZE	FSCM NO.	DWG. NO.	REV.
A		35-16	
SCALE None		SHEET	

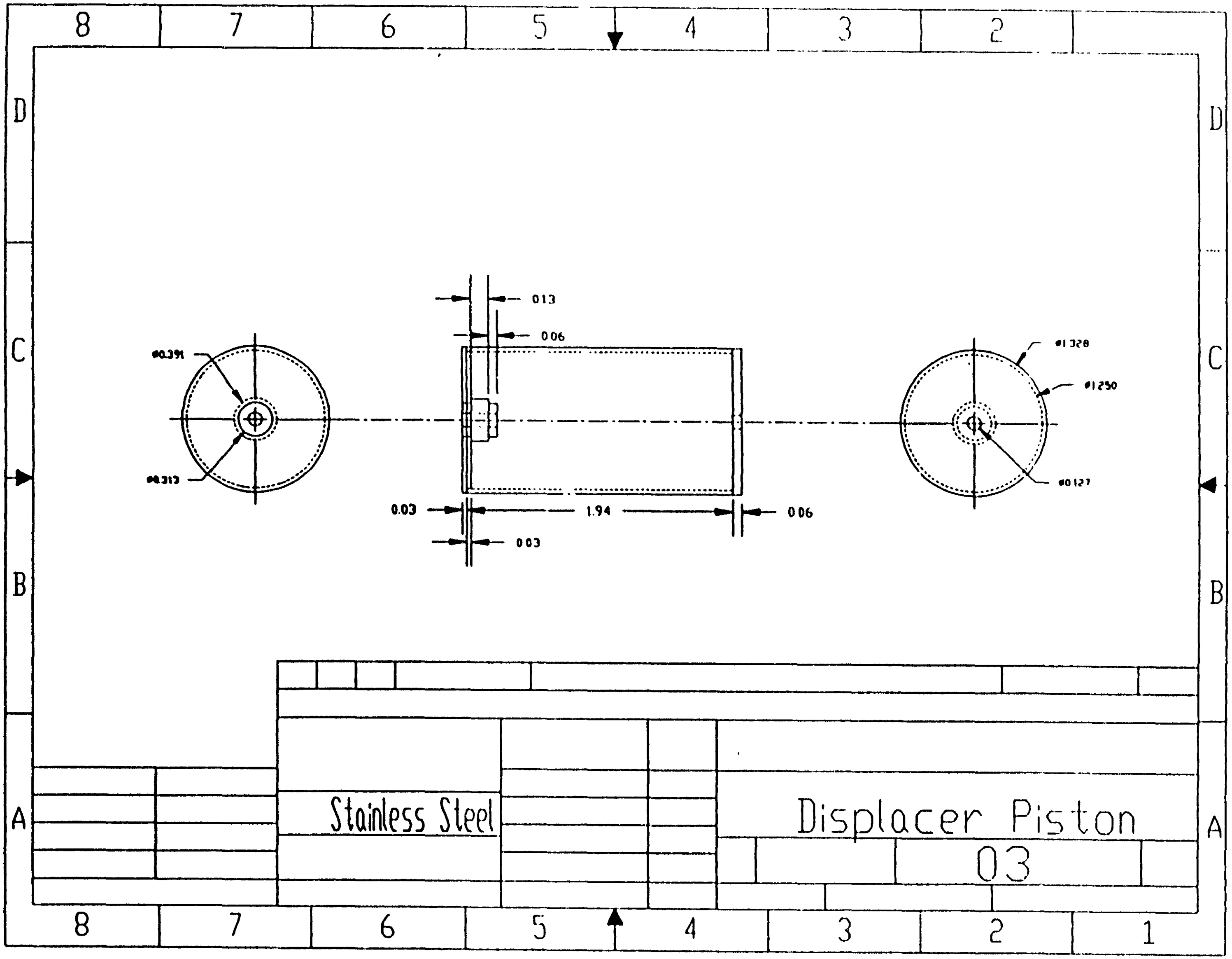
NEXT ASSY	USED ON
APPLICATION	

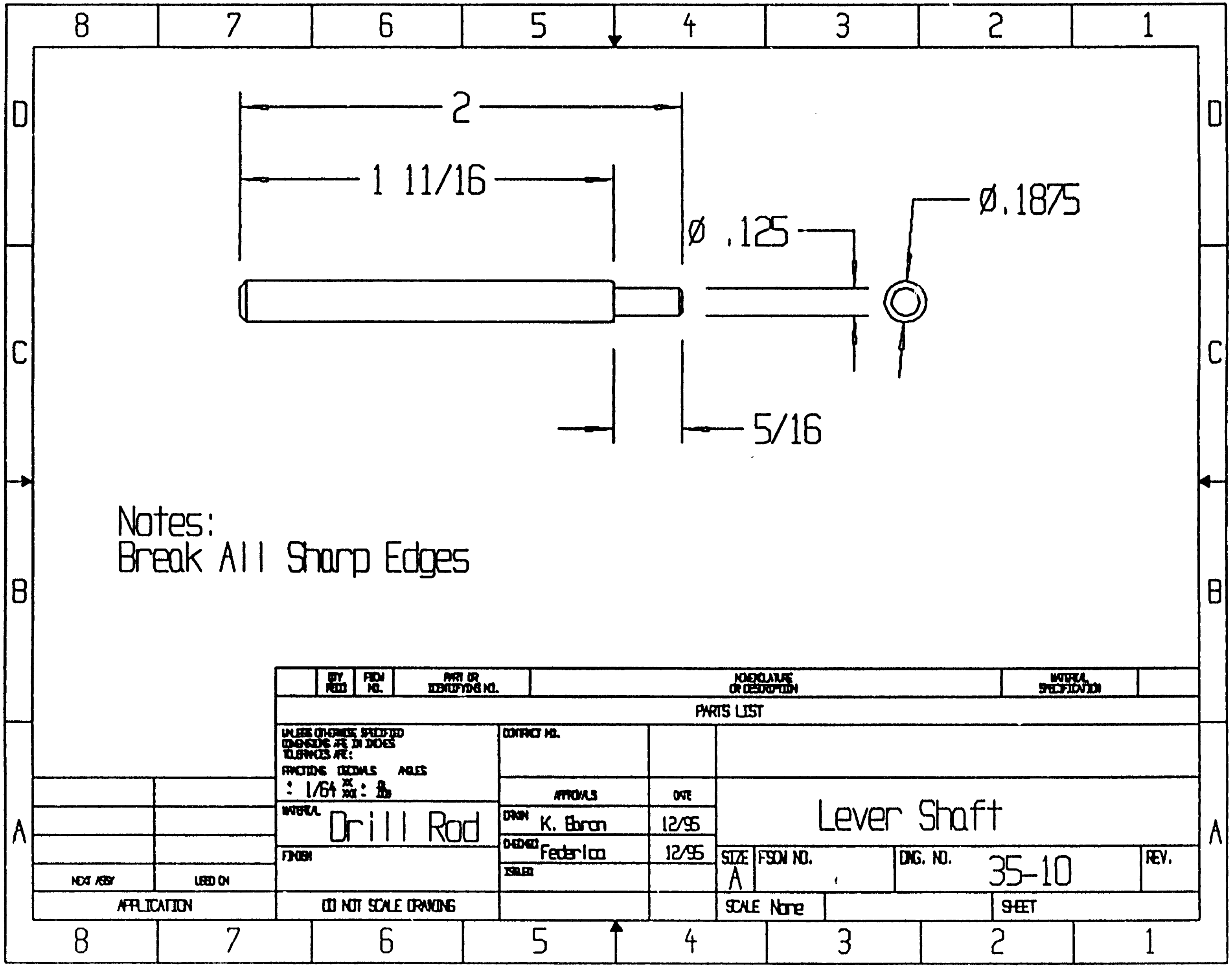

Ø .1875
2 3/4
Notes:
Break All Sharp Edges
PARTS LIST
Drill Rod
K. Baron
Federlco
12/95
12/95
Crank Web Shaft
SIZE A
DWG. NO. 35-18
REV.
SCALE None
SHEET
DO NOT SCALE DRAWING
APPLICATION
NEXT ASSY
USED ON

53

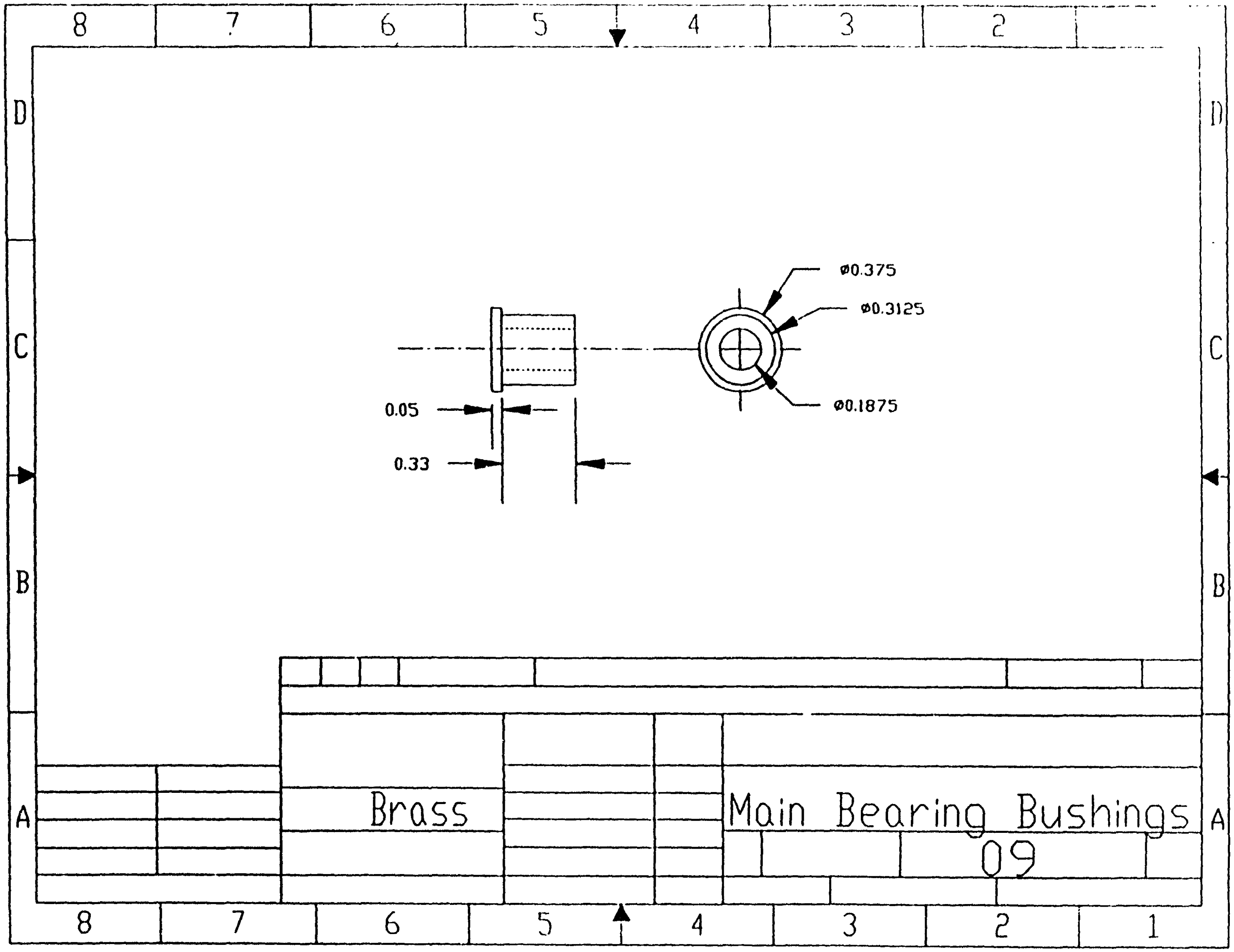


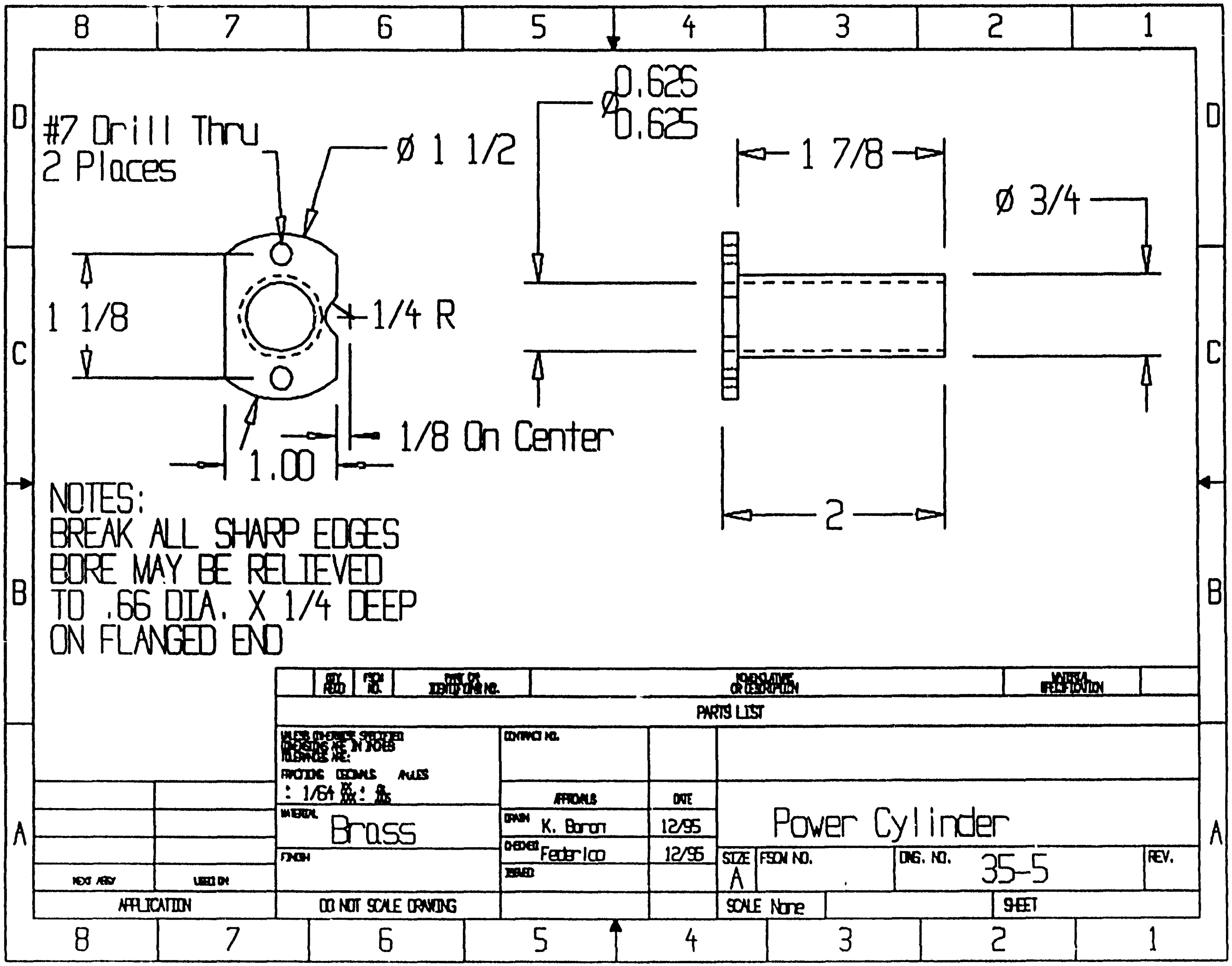
8
7
6
5
4
3
2
1
D
C
B
A
ø1.25
ø1.19
SECTION A-A
A
A
0.06
3.38
0.09
0.19
1.56
1.1875
ø1.19
1.50
1.25
0.19
0.19
10-32 UNF-2B,
TYPICAL OF FOUR
Stainless Steel
Displacer Cylinder
02

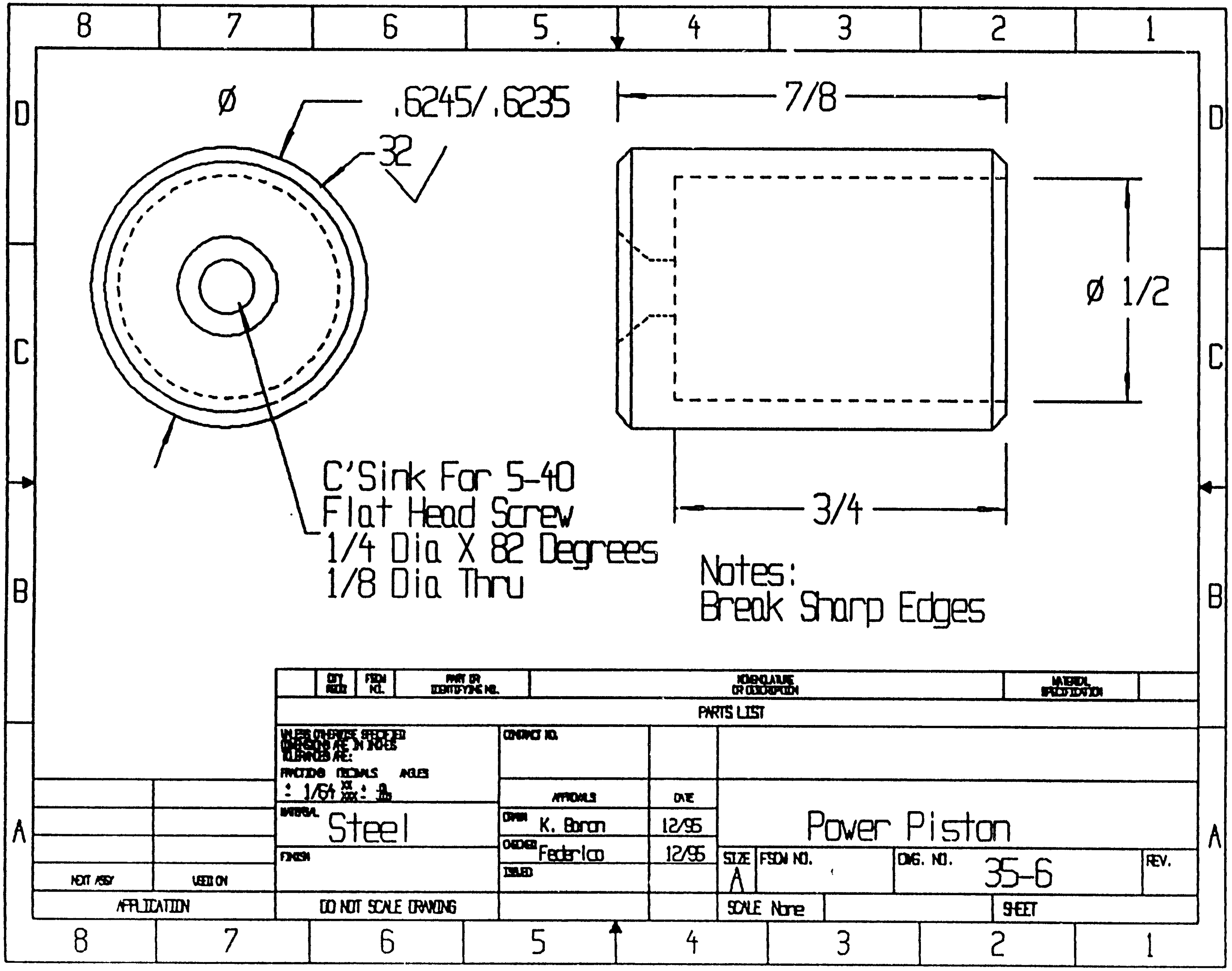

ø0.391
ø0.313
0.13
0.06
0.03
1.94
0.06
0.03
ø1.328
ø1.250
ø0.127
Stainless Steel
Displacer Piston
03



2
1 11/16
Ø .125
Ø.1875
5/16
Notes:
Break All Sharp Edges
QTY REQD
FSCM NO.
PART OR IDENTIFYING NO.
NOMENCLATURE OR DESCRIPTION
MATERIAL SPECIFICATION
PARTS LIST
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE:
FRACTIONS DECIMALS ANGLES
± 1/64
CONTRACT NO.
APPROVALS
DATE
DRAWN K. Baron 12/95
CHECKED Federico 12/95
ISSUED
MATERIAL Drill Rod
FINISH
Lever Shaft
SIZE A
FSCM NO.
DWG. NO. 35-10
REV.
SCALE None
SHEET
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING


Ø0.375
Ø0.3125
Ø0.1875
0.05
0.33
Brass
Main Bearing Bushings
09


#7 Drill Thru
2 Places
Ø 1 1/2
Ø 0.625 0.625
1 7/8
Ø 3/4
1 1/8
1/4 R
1/8 On Center
1.00
2
NOTES:
BREAK ALL SHARP EDGES
BORE MAY BE RELIEVED
TO .66 DIA. X 1/4 DEEP
ON FLANGED END
PARTS LIST
Brass
K. Baron 12/95
Federico 12/95
Power Cylinder
SIZE A
DWG. NO. 35-5
SCALE None
APPLICATION
DO NOT SCALE DRAWING


Ø .6245/.6235
32
7/8
Ø 1/2
3/4
C'Sink For 5-40
Flat Head Screw
1/4 Dia X 82 Degrees
1/8 Dia Thru
Notes:
Break Sharp Edges
PARTS LIST
MATERIAL Steel
DRAWN K. Boron 12/95
CHECKED Federico 12/95
Power Piston
SIZE A
DWG. NO. 35-6
SCALE None
SHEET
REV.
DO NOT SCALE DRAWING
APPLICATION
NEXT ASSY
USED ON

ENGINE ASSEMBLY

PRE-ASSEMBLY

1. Use a file to clean all sharp edges and burrs from your parts. Burrs can increase the friction in your engine, preventing it from running.

FLYWHEEL ASSEMBLY

Bearing Plate Assembly

1. Press fit main bearing bushings into bearing plates.
2. Push crank web shaft through bearings to align bearing plates while bolting them to the base.
3. Bolt bearing plates to the base so that the bearings are near the edge and the ends of the bushings are facing *inward.*
4. Test fit crank web shaft in bearings and, ONLY IF NECESSARY, line ream bearings with a 0.1885" reamer to allow the crank web shaft to rotate freely.
5. Test fit lever shaft in bearing plates and, ONLY IF NECESSARY, line ream bearing plates with a 0.1885" reamer to allow the lever shaft to rotate freely.

Crank Web Assembly

1. Press fit the crank pin into the crank web. If the hole in the crank web is too large, use a small amount of super glue to hold the crank pin in the crank web.
2. Push the crank web onto the crank web shaft such that the end of the shaft is flush with the crank pin side of the crank web and tighten the set screw to hold the crank web in place.
3. Install the flywheel between the bearing plates on the crank web shaft such that the crank web is on the power cylinder side of the bearing plates.
4. Tighten the set screw to hold the flywheel to the crank web shaft.

CYLINDER PLATE ASSEMBLY

Guide Bushing Assembly

1. Place a *small* amount of RTV on the threads of the transfer piston guide bushing and screw the bushing into the cylinder plate.

Displacer Piston Assembly

1. Screw the displacer piston onto the displacer piston rod
2. Push the displacer piston rod into the transfer piston guide bushing with the displacer piston on the opposite side of the cylinder plate from the guide bushing. The displacer piston shaft should move freely in the guide bushing.
3. Clean the power cylinder with alcohol to remove ***all*** traces of oil inside the cylinder.
   Note - you must ***NOT*** have any trace of oil in the power cylinder or on the power piston otherwise your engine will not run.
4. Coat the base of the displacer cylinder and the power piston cylinder with a *thin* coat of RTV and bolt them in place on the cylinder plate.

Power Piston Assembly

1. Fasten the gudgeon block to the power connecting lever with the 1/16" dowel pin.
2. Clean the power piston with alcohol to remove ***all*** traces of oil.
3. Place a ***small*** amount of Loctite on the end of the gudgeon block and in the threads of the gudgeon block and screw assembly to the power piston.
4. Push the power piston into the power cylinder.

Cylinder Plate Installation

1. Place the 1/32" washer and then the free end of the power connecting lever on the crank pin.and loosely bolt the cylinder plate to the base.
2. Align the cylinder plate so that the flywheel can rotate without the power piston link rubbing against the crank web and tighten the cylinder plate bolts.

LEVERS AND DISPLACER PISTON ROD ASSEMBLY

1. Place the lever shaft in the bearing plates.
2. Using solder, tin the end with the big hole on both lever 011 and lever 012.
3. Fasten the displacer piston rod to the connector link using a 0-80 X 5/16" screw and nut. Place a drop of Loctite on the nut to prevent ioosening.
4. Put the other 1/32" washer outside the power connecting lever and then place the lever connector on the crank pin.
5. Place lever 011 on the lever shaft and fasten its other end to the connector link using a 0-80 X 5/16" screw and nut. Place a drop of Loctite on the nut to prevent loosening.
6. Place lever 012 on the lever shaft and fasten to the lever connector using a 0-80 X 1/4" screw and nut. Do not overtighten (the levers must rotate with respect to each other), but do place a drop of Loctite on the nut to prevent loosening.
7. Rotate the crank web so that the crank pin is at 6 o'clock and pull the displacer piston until it touches the cylinder plate, and then back it off by an **ITTY BITTY** fraction. While maintaining this position, heat levers 011 and 012 at the lever shaft so that they solder together.
8. Test to make sure the flywheel rotates freely.

BURNER ASSEMBLY

1. Place the o-ring in the groove on the alcohol burner cap.
2. Roll the wick material and push it up through the burner cap, leaving about 1/8" exposed for lighting.
3. Place the burner cap on the glass bottle and place the bottle on the base.

FINAL ASSEMBLY

1. Clean the botom of the base with alcohol and stick the three small pads on the bottom - one to the left and two to the right.
2. Screw your name plate onto the base with the two brass screws.

TROUBLESHOOTING - IF YOUR ENGINE DOES NOT RUN

Let your engine cool.

Make sure that it is assembled correctly and that there is very little friction in the moving parts. These engines do not have a lot of power. Even a small amount of friction will prevent them from running. The major sources of friction are: the transfer piston guide bushing, the lever shaft, and the connector link and levers,.

Make sure the displacer piston rod travels easily through the transfer piston guide bushing and oil as necessary.

Make sure the levers do not bind inside the connector link and bend the levers if necessary.

Make sure the lever shaft rotates smoothly and oil as necessary.

Make sure there is no oil or dirt in the power cylinder. **Do *NOT* get *ANY* oil in the power piston cylinder.** Your engine will not run if there is any oil in the power cylinder. Wash the piston and cylinder with alcohol as needed.

Make sure the heat transfer piston does not "bottom out" (hit the cylinder plate) as the flywheel rotates. You can adjust this by heating the soldered link joint and moving the links relative to each other.

Make sure the heat transfer cylinder and power cylinder do not leak air. You can test this by wetting the RTV'd joints and spinning the flywheel. You will see very small bubbles if there is a leak.

Try your engine again, letting it warm up thoroughly before attempting to run it again.

ENGINE MAINTENANCE

GENERAL MAINTENANCE

Periodically check all screws and links to make sure they are tight. Loctite can be used to help prevent these parts from working their way loose.

You should oil the moving parts of your engine occasionally. ***Never***, however, oil the power piston unless you do not plan on running your engine in the near future.

Many people prefer the hue that brass takes on as it oxidizes. If you want to keep your engine looking shiny, however, you can periodically polish it with a good metal polish. Do not coat your engine with lacquer to prevent oxidation. The lacquer could burn and will inhibit heat transfer, degrading engine performance.

You occasionally may have to remove the power piston from your engine and clean the piston and cylinder. The power piston is made of steel and will rust. If rust forms, remove it from the power cylinder and clean the rust from it with fine sandpaper or steel wool. Do **NOT** oil the power piston unless you do not plan on running your engine.

STORAGE

If you plan on storing your engine for a long period without using it, you may want to coat the power piston with a light oil such as WD-40 to prevent rust. All traces of this oil should be removed with alcohol from both the power piston and the cylinder before attempting to run your engine again. If rust does form on your engine, it can be removed with fine sandpaper or steel wool. ***Never*** store your engine with alcohol in it.

7. CONCLUSIONS

The intent in the machine shop instruction was to provide the students with an introduction to machining and safety issues. Nearly all students were able to build running Stirling engines by the end of the class, and the three remaining engines needed only a little more time to be coaxed into running.

The information provided in this thesis is meant as a documentation of the first *iteration* of 2.670, so that it can be built upon year after year. With two weeks and eighty mechanical engineers (twice!), there are limitless possiblities to the machining project. There is no uncertainty in the author's mind that the project will evolve year after year, (but always with the original goals of elementary instruction in mind).

The first year of 2.670 went extraordinarily well, due to the efforts of many, many people. The class got off to a snowy start, early in the morning on Monday, January 8, 1996, the first day of I.A.P. Nearly two-thirds of the class showed up, despite the inclement weather, and in spite of this potentially ominous sign, the students seemed to enjoy the class immensely, appreciating the chance to take a hands-on introductory class during I.A.P. And it is perhaps safe to say that the instructors enjoyed it even more!

APPENDIX 1

In order to ensure that all students were aware of the registration process, all undergraduate Mechanical Engineering Advisors were sent the memo shown on page 113, and all sophomore students received the memo on page 114 and the World Wide Web instructions on page 115.

IMPORTANT

To: Mechanical Engineering Advisors
From: Doug Hart (dphart@mit.edu; x32178)
Kevin Otto (knotto@mit.edu; x38199)
Date: Monday, August 28, 1995
Re: Registration for **2.670: M.E. Tools**

2.670: M.E. Tools is a new requirement and a prerequisite for 2.007 (2.70) under the revised Mechanical Engineering curriculum. It is intended for sophomores and will only be offered during IAP. There will be two sessions; both sessions will meet from 8 am to 5 pm, Monday through Friday. Session 1 will meet Jan. 8 - Jan. 19 (first two weeks of IAP) and Session 2 will meet Jan. 22 - Feb. 2 (second two weeks of IAP).

Registration and session assignments will be carried out using a form on the World Wide Web. The form should be submitted between 8 am on Tuesday, September 5, 1995 (Registration Day) and 11:59 pm on Sunday, September 10. We will ignore all submissions made before Sept. 5 and if the form is not submitted by 11:59 pm on Sept. 10, the student will not be able to take this course (with very few exceptions).

There are information pages regarding registration for 2.670 in the packets for your sophomore advisees. Please alert your advisees to these pages and emphasize that they must register using the World Wide Web by 11:59 pm on Sunday, September 10. Extra copies are available in the Mechanical Engineering Undergraduate Office, Room 3-154.

Thank you!

Doug Hart   Kevin Otto

IMPORTANT

To: Mechanical Engineering Undergraduates
From: The 2.670 Administration
Date: Monday August 28, 1995
Re: Registration for **2.670: M.E. Tools**

2.670: M.E. Tools is a new requirement and is a prerequisite for 2.007 under the revised Mechanical Engineering curriculum and is intended for sophomores. Introductory machine shop techniques and introductory computer programs will be taught. It will only be offered during IAP; the two sessions will both meet from 8 am to 5 pm, Monday through Friday. Session 1 will meet Jan. 8 - Jan. 19 (first two weeks of IAP) and Session 2 will meet Jan. 22 - Feb. 2 (second two weeks of IAP). Each session can accomodate no more than 80 students.

Registration and session assignments will be carried out using a form on the World Wide Web. **Please submit the form between 8 am on Tuesday, September 5, 1995 (Registration Day) and 11:59 pm on Sunday, September 10.** Section assignments will be made on a first come, first serve basis. We will ignore all submissions made before Sept. 5 and if the form is not submitted by 11:59 pm on Sept. 10, you will not be able to take this course (with very few exceptions).

The URL for the 2.670 homepage is "**`http://me.mit.edu/2.670/`**". The link for the registration form is on this page. The attached sheet explains how to start Mosaic and how to find this homepage. **The section assignments will be available over the World Wide Web by 8 am, Monday, September 18, 1995.** You will then be notified by email of your section assignment.

If you have any questions, please send email to 2.670adm@mit.edu. Extra copies of this memo are available in the Mechanical Engineering Undergraduate Office, Room 3-154.

Thank you!

The 2.670 Administration

2.670 World Wide Web Information:

An Athena account is very neccessary for 2.670. If you do not have an account, go to any Athena workstation and click on "Register for an Account" (your account should become active overnight). If you have any problems or questions, stop by the User Accounts Office, in room 11-124. (behind the "Fishbowl" cluster). To fill out the registration form you will need to use the World Wide Web. Athena workstations have "Mosaic", which is a World Wide Web "browser". A browser is a program which allows you to see the information which is available over the World Wide Web.

In order to start Mosaic, log in at any Athena workstation and do one of the following:

a)Type "add sipb; Mosaic &" at your xterm prompt.
Example: `athena% add sipb; Mosaic &`

b)Use the dash bar at the top of your screen.
Example: Click on "`Communication`", then click on "`World Wide Web`", then click on either "`Mosaic - MIT Home Page`" or "`Mosaic - default Home Page`". A window will pop up in the center of your screen asking you to verify that you wish to start Mosaic - click "`Yes`".

Once you have the Mosaic window, click on the "`Open...`" button at the bottom of the window. A new window will pop up which says "`URL To Open:`". Make sure the mouse arrow is directly over the long rectangular box (the cursor in the box will be black and flashing instead of dotted gray) and type "**`http://me.mit.edu/2.670/`**" (don't type the quotation marks). This will take you to the 2.670 homepage. You can "surf the web" by clicking on blue words - these are called links and take you to other pages. You can always retrace your steps by clicking on the "`Back`" button at the bottom of the Mosaic window. Look for the link that says "`Class Registration`" and click on it.

Read through the information at the top of the page and use the scroll bar on the right side of the window to scroll down to the form. If you would like, you can request to be in the same section as a friend. Fill out the fields and click on the "`Submit Registration`" button down at the bottom of the page. You may resubmit the form if you wish, but we will only look at the last form you turn in. **If you have a *valid* reason why you would be unable to attend either of the sessions, you must explain why in the "`Other`" field at the bottom of the form.** Only university related reasons will be considered.

The section assignments will be available on the World Wide Web (look for the "`Section Assignments`" link from the 2.670 homepage) by 8 am on Oct. 9, 1995. You will also be notified by email of your section assignment.

If you have any questions or problems, please send email to 2.670adm@mit.edu.

APPENDIX 2

In order to elicit specific responses on the different parts of the class, as well as to attempt to determine the level of competency of the students both before and after the class, the survey found on pages 117-119 was distributed along with the Pi Tau Sigma Evaluations on the last day of class (the results of the survey are discussed in Section *5. Surveys*).

2.670 SESSION 1 EVALUATION

Hi! As the first set of students ever to take 2.670, we'd appreciate your input on the class. Your response is completely anonymous and will not be read until grades have been assigned. If you already answered any of these questions on the PTS Evaluation form, you do not have to repeat your answer here. Thank you!!

Machine Shop

1. Please rate your familiarity with machining *before and after* the class.

BEFORE 1----------------2----------------3----------------4----------------5

What's a drill press? — I could build a Boeing 747 with my own two hands!

AFTER 1----------------2----------------3----------------4----------------5

2. **Pappalardo Lab** - Please comment on your three days in the Pappalardo Lab. In particular, what did you learn? Was it useful? Was the pace too fast/too slow? What should we add/remove next year?

3. **L.M.P.** - Please comment on your three days in the L.M.P. In particular, what did you learn? Was it useful? Was the pace too fast/too slow? What should we add/remove next year?

Computer Lab

4. XESS

a) Please rate your familiarity with XESS *before and after* the class.

BEFORE 1----------------2----------------3----------------4----------------5

What's a cell? — I used XESS to analyze the velocity of the air flow around the wings of my 747!

AFTER 1----------------2----------------3----------------4----------------5

b) Please comment on the XESS instruction and homework. In particular, what did you learn? Was it useful? Was the pace too fast/too slow? What should we add/remove next year?

5. Matlab

a) Please rate your familiarity with Matlab *before and after* the class.

BEFORE 1---------------2---------------3---------------4---------------5

What's a matrix? I used Matlab to graph the air speed of my 747 vs. the total passenger weight!

AFTER 1---------------2---------------3---------------4---------------5

b) Please comment on the Matlab instruction and homework. In particular, what did you learn? Was it useful? Was the pace too fast/too slow? What should we add/remove next year?

6. Pro/Engineer

a) Please rate your familiarity with Pro/Engineer *before and after* the class.

BEFORE 1---------------2---------------3---------------4---------------5

What's CAD stand for? I did a Pro/Engineer model of my 747!

AFTER 1---------------2---------------3---------------4---------------5

b) Please comment on the Pro/Engineer instruction and homework. In particular, what did you learn? Was it useful? Was the pace too fast/too slow? What should we add/remove next year?

Safety

7. Please comment on the safety instruction and on the safety in the machine shop. Was the instruction adequate/inadequate? Did you have a safe working environment in the machine shop?

The Schedule

8. Please comment on the schedule. Was it helpful for learning the material? Was it confusing? How should we modify it?

The Stirling Engine

9. Please comment on the Stirling Engine project. Was it a good learning tool for the machine shop? For the computer lab? How should we modify it?

The Web Pages

10. How often did you refer to the web pages? Which pages did you find particularly useful? Which pages should we definitely keep next year? What should we add?

The Green Handout

11. Process Plans - How often did you refer to the process plans? Did you find them useful? Confusing? How should we modify them next year?

12. Other - Did you use the rest of the pages in your handout? Which ones were particularly useful? Which ones did you ignore? What should we add or remove next year?

Other

13. Please comment on any other aspect of the class. What did you like most/least about the class? What should definitely be kept/added/removed in/to/from the class for next year?

REFERENCES

[1] Galendez, Liv C., *Development of an Introductory Hands-on Machine and Computer Analysis Course*, ©1996

[2] Photographs courtesy of Kevin Otto

[3] Senft, James, *Ringbom Stirling Engines*, p.11, Oxford University Press, New York, ©1993

[4] Pro/Engineer rendering of the Stirling Engine courtesy of Phil Houdek

[5] Smith, Robert H. (M.I.T.), *Textbook of Advanced Machine Work*, p. 519, Industrial Education Book Company, Boston, USA, ©1930

Also:

West, C.D., *Principles and Applications of Stirling Engines* Van Nostrand Rein Hold Co., New York, ©1986

THESIS PROCESSING SLIP

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