PD-AAU-016

2.1

SECOND INTERIM REPORT

RICE HUSK ENERGY PROJECT

November 1985

U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT

GRANT NO. 388-0045-07

CONDUCTED BY : THE ASIA FOUNDATION
DHAKA, BANGLADESH

PROJECT FACILITATION : KUMUDINI WELFARE TRUST OF BENGAL
NARAYANGANJ, BANGLADESH

PROTOTYPE ENGINE DESIGN : SUNPOWER, INCORPORATED
ATHENS, OHIO, U.S.A.

TABLE OF CONTENTS

PREFACE

This report presents details of the design and testing of the rice husk fueled Stirling engine that is the focus of this project's activities. The project engine is still being tested and modified and it is anticipated that it will undergo another round of changes during the next few months as performance and durability are improved.

A number of inquiries have been received from groups which are working on Stirling engines or which are considering applications for Stirling engines. An interest has been expressed to have details of the design and performance of the project engine, this report attempts to satisfy this interest and in addition provides some background information on particular issues related to design and fabrication problems that have been encountered during the course of the project.

It is important to understand that the design given in this report has not been fully developed yet and is not yet suitable for manufacture or for operation by inexperienced personnel.

There are a number of inconsistencies and omissions in the design drawings. Because of on-going changes being made in the engine, the time that it takes to make drawings and the limited facilities of the project it is not possible to make a single set of drawings that give accurate details of every component, even as this report is finalized additional design changes are being made in the engine design. This should not detract from the intended purpose of this report to provide information on the configuration of the engine and on the experience gained so far in methods of fabrication and test running.

At the end of the project a final report, similar in format to this one, will be prepared which will give details of the final design which is expected to be suitable for manufacture and routine use. The final report will not dwell on the various design and fabrication avenues that were explored and abandoned but will go into greater detail regarding the procedures used the final design. The final report will be intended more as a guide for manufacturers, though it will also be of interest to research and development groups.

L. Merrick Lockwood
Project Manager

DISCLAIMERS

The engine which is described here is designed to be pressurized with air to 3 to 5 bar while in operation and the heater is designed to operate at a temperature of 650°C. The parts of the engine subjected to high pressures should be hydrostatically tested as discussed in Section III C and suitable precautions observed during operation of this or similar engines. Any production version of this type of engine should incorporate systems to prevent over pressurization and operation at excessively high temperatures.

This design is described here in the hope that it will be of assistance to other groups engaged in Stirling engine research and design. The design is not yet suited for manufacture at this time. Furthermore The United States Agency for International Development, the Asia Foundation, Kumudini Welfare Trust of Bengal and Sunpower, Incorporated accept no responsibility for injury or loss resulting from efforts to duplicate or use the engine described here.

The original prototype engine for this project was designed by Sunpower, Incorporated. The engine that is described here represents the results of two re-design cycles carried out in Bangladesh and continuous modification of individual components. These design changes have been aimed at better adapting the design to local production methods and solving problems that emerged while operating the prototype and subsequent models. In addition the auxiliaries (blower, compressor and cooling water pump) have been designed and/or added to the system in Bangladesh as the prototype relied on electrically powered auxiliaries. It should be understood that because of the extensive changes made to the design in Bangladesh, any problems encountered with this design should not be attributed to the design of the original prototype.

I. SUMMARY

The objective of the Rice Husk Energy Project is to develop the design of a small (5 horsepower) rice husk fueled Stirling engine that will be suitable for manufacture in Bangladesh and for powering small rice mills in rural areas of the country.

The project initially consisted of three phases. In Phase I Sunpower, Incorporated of Athens, Ohio was contracted by the Asia Foundation to design the Stirling engine and make a prototype which was demonstrated at the end of Phase I. In Phases II and III, in Bangladesh, engines were made, tested and modified. Because power and performance targets had not been achieved by May 1985 the project was extended through the addition of Phases A and B. Phase A was scheduled through November 1985 to further test and report on the present (second intermediate) model of the engine. Phase B will extend from December 1985 through May 1986, during this time the engine will go through another re-design cycle to consolidate the many modifications already in use and to resolve some outstanding problems.

This report presents the details of the present design, mainly for the use of other research and development groups that are involved with Stirling engine design and development.

The first part of this report describes the engine and discusses certain aspects of design and production. As this report is intended primarily for research and development groups no details are presented on routine methods of fabrication, though a few unusual methods are discussed. A number of design options that were tried and rejected are presented here as these will be of interest to others who are considering possible modifications that could be incorporated in this or similar designs.

In addition to the description of activities the report there are Appendices which include projections of production costs for the engine, operating data, photographs of the three engines produced so far and detailed design drawings.

II. BACKGROUND

A. THE STIRLING ENGINE

The Stirling or 'hot air' engine was developed in the early part of the 1800's as an alternative to steam power. In the Stirling engine a displacer moves a volume of air within the engine back and forth between a hot space and a cold space. As the air enters the hot part of the engine it expands and the mechanical arrangement is such that this expansion drives the engine's piston through its power stroke. During the remaining part of the cycle the displacer moves the air back to the cold space of the engine where it cools and is compressed by the piston prior to repeating the cycle.

Many of the advantages of the Stirling engine are due to the fact that it is an external combustion engine and that the working gas (air in this case) inside the engine is used over and over again. Because the Stirling engine operates from an external heat source it does not require use of the refined fuels that are necessary for operating internal combustion engines. This opens up the possibility of using renewable sources of energy such as charcoal, wood, rice husk and solar energy as well as the more conventional fossil fuels such as diesel oil, kerosene, natural gas and coal.

Because the fuel is not burned inside the working area of the engine the moving parts are not exposed to corrosive combustion products and consequently wear is significantly reduced. Air does not enter or leave the engine in the operating cycle so there are no complex valves and the engine itself has no carburettor, precision fuel injection equipment or ignition system. The result is a mechanically simple engine design.

The early Stirling engines did however suffer from being very bulky and heavy machines for the amount of power that they produced. Modern materials and design procedures have led to smaller and lighter Stirling engines for a given power output, however designs of the type used in this project still result in an engine that is significantly larger than an internal combustion engine of comparable power. If one considers that a Stirling engine operating on a renewable fuel is equivalent to an internal combustion engine with its own built in refinery, it will be quickly recognized that the larger size is a small price to pay for this versatility.

B. PROJECT OBJECTIVES

The objective of the Rice Husk Energy Project has been to develop and introduce a 5 horsepower engine which utilizes rice husk as its fuel and is suitable for powering a No.4 rice huller. Such a milling system is independent of electricity and diesel fuel supplies. It will provide a savings on fuel to the users as it derives its power from a byproduct of the milling operation and because of its independence of electrical supply lines the engine can be installed anywhere in the country.

A 5 horsepower engine represents the smallest size that is suitable for use with presently available rice milling machinery. There were two important reasons for selecting the smallest engine size as a target for this project. The first reason was to keep the purchase cost of the unit as low as possible so that it would be within the financial means of the largest possible number of entrepreneurs in rural areas of Bangladesh. Secondly, it is felt that a large number of small rice mills widely scattered through the countryside are more suited for rural areas where the production and consumption of rice is also widely scattered. By having many small mills spread throughout the countryside the typical household to mill distance will be small and those living in rural areas could benefit from the economic advantages of machine rice milling without being penalized by high transportation costs associated with long household to mill distances.

C. PROJECT ACTIVITIES

During Phase I (July 1981 to August 1982) Sunpower, Inc. of Athens, Ohio was contracted by the Asia Foundation to develop the design of the project engine and to make a prototype engine to demonstrate the feasibility of a rice husk fueled Stirling engine for providing 5 horsepower. Simultaneously, in Bangladesh the facilities for the project were being set up. Equipment was ordered and an area on the premises of Kumudini Welfare Trust was renovated and prepared to house the project. The facilities that were set up included a workshop, a pilot rice mill and laboratory and office facilities. Phase I concluded with the successful testing of the prototype rice husk fueled Stirling engine during a final Phase I evaluation at Sunpower's facility in Athens, Ohio.

At the beginning of Phase II the prototype engine was shipped to Bangladesh, set up and first run in December 1982. The problems that were encountered in operating the prototype helped in making decisions regarding design modifications in the first intermediate model which was first run in November of 1983. This engine was entirely fabricated in Bangladesh except for the stainless steel heater which was the one used on the prototype that had been made by Sunpower in the U.S.A.

Based on the experience gained in making and running the first intermediate model of the engine a further series of changes were made affecting virtually every component and a new engine was fabricated. This second intermediate model also incorporated, for the first time, an integral engine-powered blower which allowed the furnace to be opearted independently of the electricity supply (both the prototype and th first intermediate model of the engine had relied on an electric blower for supplying the combustion air to the furnace). The second intermediate model ran for the first time on June 18th, 1984.

From August till November of 1984 attention was focused mainly on setting up a brazing furnace which would make it possible to carry out the high temperature (1,100°C) brazing of the heat exchanger elements to the heater head. During the period that the brazing furnace was being constructed and tested a plain heater was fabricated to evaluate the possibility of using this simpler configuration as an attempt at eliminating the need for brazing.

Originally the project was envisioned as being implemented in three phases of one year each. This assumed that the prototype engine would be production ready with only minor adaptations for local manufacture in Bangladesh. The criteria for the prototype engine were; the ability to operate using rice husk as its fuel with a reasonable rate of husk consumption, to produce 5 horse-power of useable power after auxiliaries, and to be manufacturable in Bangladesh. While the prototype engine satisfied all of these requirements the engine had not been tested for extended periods at full power and the auxiliaries (furnace blower, cooling water pump and compressor) had not been integrated with the design. Cooling water was provided to the prototype engine from the city water supply and the blower, compressor and husk feed were electrically operated. Thus more modification and testing was required than had originally been conceived, though in retrospect this kind of activity should have been forseen and it was perhaps overly optimistic to expect a newly developed prototype to be production ready right away.

This additional work has resulted in lengthening of phases and, from June 1985, the extension of the project with a Phase A and Phase B. Phase A, which extends from June through November 1985 was intended to provide time to test the second intermediate model of the engine and prepare this Second Interim Report on the design of the engine. In Phase B, extending from December 1985 through May 1986 the engine design will be modified and a pre-production engine fabricated and demonstrated. At the end of this period a final report will be issued with design information on the latest engine.

III. DESIGN AND FABRICATION OF PROJECT ENGINE

A. DESCRIPTION OF THE PROJECT ENGINE

From the outset of the project priority has been given to arriving at a design of a Stirling engine which not only uses biomass as a fuel but which is also suited for use in rural situations in third world countries and can be manufactured in these countries. Because of these objectives a number of constraints are imposed on the materials and manufacturing methods that can be used, however this is balanced by far less stringent requirements in respect to power to weight ratio and overall size of the unit. This is particularly the case for rice milling where the engine is stationary and portability is not a significant factor.

A target of the project has been to make the Stirling engine with materials and technology that are currently available in the country. This has, for the most part, been possible however in the end it was found necessary to rely on piston rings made of a material (PTFE) that is not presently available in Bangladesh. Most of the bearings used in the project engine have been obtained locally with the exception of one which has been procured specially for the engine. This and other bearings which may contribute to the increased durability of the engine can be ordered through local suppliers.

The project engine uses stainless steel for components exposed to high temperatures and this allows operation with temperatures in the range of 650°C at the heater. The piston and displacer operate in the same cylinder and the movement of the displacer is controlled by means of a bellcrank arrangement that provides for the necessary phasing of displacer movement in respect to piston movement. In order to achieve the required power output of 5 horsepower without resorting to exotic heat resisting materials and high operating pressures the design has gone towards a large displacement, over 7 liters. This has resulted in large moving parts and the operating speed of the engine has been kept low, 720 rpm, in order to avoid balancing problems that would necessitate complicated mechanical solutions.

In the process of adapting the design of the prototype for local manufacture much use has been made of cast iron. The disadvantage of cast iron is that its use tends to increase the weight of components. This is compensated for by the low cost of cast iron, the elimination of the cost and quality control problems associated with welding, and the ease with which cast iron components can be accurately machined to a finished part.

B. DETAILS OF ENGINE COMPONENTS

1. Heater (Fig.3,4,5,6)

The heater is one of the most critical parts of the engine. It must operate under conditions of high temperature and pressure so it is made mostly of 304 stainless steel. In order to get adequate heat exchange surface the original design incorporated external fins and an internal corrugated heat exchanger which were fixed in place by furnace brazing in order to provide adequate thermal contact. Because of the relatively high cost of stainless steel and the sophisticated methods of fabrication employed the heater is the most costly single component and is the most difficult to make. When work on the engine commenced in Bangladesh a number of avenues were pursued in order to try to solve problems of local manufacturability and in an effort to reduce overall costs. Some of these were successful and have been incorporated in the design discussed here while others were not successful and have been abandoned.

The original design for the heater of the engine consists of a welded stainless steel assembly to which both the external and internal heat exchanger elements were furnace brazed. The heater dome was formed by clamping a stainless steel blank to a heavy plate and bulging it to a convex form with hydraulic pressure. This was welded to a machined ring of stainless steel which was in turn welded to the heater can. The shoulder between the heater can and the regenerator housing was a ring cut from half inch thick stainless steel plate and the regenerator housing was welded to a mild steel flange which was drilled so that it could be bolted to the engine body. An internal stainless steel liner separated from the heater can by a corrugated internal heat exchanger and the external heat exchanger fins were tack welded in position and furnace brazed with a nickel based filler to provide the required thermal contact. For the prototype tungsten inert gas (TIG) welding was used for all stainless steel components and the heater was sent out to specialists for furnace brazing.

Several alternative methods of forming the heater dome were tried or considered. Attention was focused initially on spinning a stainless steel blank to form the dome. Early trials of spinning thin stainless steel proved problematic due to the tendency for the metal to harden. While this method is still a possibility it would require heavy duty hydraulically operated equipment and might involve annealing the blank several times, so it was abandoned. The next approach was to try explosive forming and this turned out to be very successful. Using a cast iron die made in the project workshop and locally available fireworks types of explosives, it has been possible to form a piece for the heater which is cut to form the dome and the shoulder for the regenerator housing. In this way the machined attaching ring for the dome and the half inch thick machined piece for the regenerator housing have been eliminated thus saving cost and complexity in fabrication.

As TIG welding equipment and inert gases are not readily available in Bangladesh, all stainless steel welding has been done with conventional arc welding equipment and flux coated stainless steel welding electrodes. These have proven successful in fabricating the heater, it remains to be seen what the life of these joints will be when exposed to the operating temperatures of the engine.

During Phase II, in an effort to avoid the complexity of setting up a brazing furnace, a heater was fabricated which did not require furnace brazing. A grooved inner surface replaced the original corrugated stainless steel sheet used for the internal heat exchanger. This was formed by milling 3 millimeter deep grooves in 1/4 inch stainless steel plate before rolling it to form the heater can. The external heat exchange surface was formed by stainless steel pins which were stud welded to the outside of the heater can. For this purpose a special stud welder was designed and fabricated in the project workshop. The second intermediate engine was first operated with this "welded" heater but the internal clearance for air flow was too small and this put a heavy load on the displacer linkage with the result that the bellcrank eventually collapsed. While this failure was due in part to the inadequate strength of the bellcrank this design was abandoned because of the difficulty of stud welding and groove cutting and because the likelihood was that the pins would burn away at their ends in a relatively short period. Subsequently the furnace brazing facility was built and a locally fabricated, brazed heater was made.

While the brazing facility was under construction a plain heater was made which does not incorporate any special measures such as brazing, welding or grooving to increase the heat exchange surface area, however the heater can was lengthened by 50% to increase the heat exchange area.

Initial comparisons have indicated that the plain heater does not perform as well as the brazed heater but that the difference is not very great, perhaps 10% less. If further testing confirms these initial results it will be possible to use the plain heater and eliminate the need for the furnace brazing which is the only operation in fabricating the project engine which can not be easily done in third world countries.

2. Regenerator

The regenerator material that has been used in the engines up to the present time is a commercially available material made of knitted stainless steel wire. Two approaches have been taken towards the local production of a suitable regenerator material. The first approach has been to procure suitable (0.004 in, diameter) stainless steel wire and arrange to have it knitted locally. Some problems have been encountered with this method, the fine gauge stainless steel wire is not readily available, the price of such fine wire is high, and it has not been a simple as originally thought to have it knitted locally. Because of these problems attention has been concentrated on the second approach which is to generate fine stainless steel turnings on a lathe that will be suitable in thickness and packing qualities to be used as regenerator material. This has the added advantages that the materials cost will be a fraction of that for obtaining the wire and nothing has to be specially imported. It has yet to be determined if the necessary aerodynamic and heat transfer qualities are maintained.

3. Cooler (Fig.8)

In the prototype the body of the engine was an aluminum casting that doubled as the cooler. In order to reduce the size of the aluminum casting the first intermediate model was designed with a cast iron body and a cooler sleeve that was inserted between the body and the cylinder liner. Even with the smaller casting a major problem has been to get aluminum castings that are not porous. The cooler which is presently being used in the engine was machined from the best of about six casting attempts however it still allows some air to leak into the cooling water. Efforts were made to develop a system of gravity diecasting and there is some promise in this approach however there is a strong case for looking at alternative cooler configurations to increase cooler efficiency so further experimentation with gravity diecasting was stopped. Slotting the external grooves and internal fins of the cooler and the other machining operations have not proved to be a problem. If an aluminum cooler were to be used in a final design, consideration would have to be given to problems of corrosion over long periods and how this could be avoided.

4. Cylinder (Fig.9)

The prototype engine incorporated a steel cylinder liner that was finish bored after being shrink fitted in the aluminum body/cooler. The cylinder liner was coated with a PTFE based compound in order to reduce friction and prevent corrosion. Some difficulty was encountered in the prototype with the cylinder going out of round. Because of the changes in the cooler design and in order to facilitate removal and replacement, the cylinder liners for the first and second intermediate model were designed to be made of cast iron. This arrangement solved the problem of replaceability and the cast iron surface is superior to steel in respect to corrosion resistance and friction when no PTFE coating is used.

Problems were encountered in getting non-porous castings for the cylinder liner and after several attempts even the best liner had a small area that leaked slightly. Also, there was still a problem with the liner going oval towards the end in which the displacer runs. This appeared to be due to the relatively thin wall thickness of the cylinder liner, early versions had a 5 mm thick wall in the displacer end. Although the wall thickness in this area was later increased to 7 mm some ovality still developed.

5. Crankcase (Fig.11,12)

The crankcase of the prototype engine was fabricated by welding mild steel parts together to form a crankcase integral with the bearing case. One difficulty that was encountered was that there was no way to inspect the working mechanism of the engine after it had been assembled in order to check alignment, wear, etc. The crankcase of the first intermediate model of the project engine made during Phase II was redesigned to be made from cast iron. This decision reflects the good foundry and machining capabilities, but relatively poor welding skills available in Bangladesh. At the same time an access cover was built into the crankcase opposite the flywheel to allow for easy inspection and to facilitate assembly operations

A problem encountered with the first intermediate model was the excessive shake in the overhung crankcase due in part to the greater mass of some of the reciprocating components. In an effort to locate the crankshaft as close to the foundation as possible so as to reduce the effects of this shake and for a number of other reasons, the crankcase for the second intermediate model of the engine was designed so that the engine could be operated in a vertical position. However, it was subsequently decided not to pursue the idea of vertical orientation for the engine because of the time that would be required to develop a suitable furnace arrangement and the pre-production engine was mounted in a horozontal position for testing with the existing furnace so that test running could proceed. In any redesign of the engine, if the horosontal orientation is maintained the present crankcase would be modified to facilitate attachment directly to the foundation. Alternatively, if a vertical orientation is used the furnace would need to be modified.

Ten bolts attach the crankcase to the body of the engine. The form of the crankcase shown in Figures 11 and 12 does not provide adequate clearance for four of the M10 bolt heads and the pattern and core was modified slightly to solve this problem before casting was undertaken.

6. Bearing Case (Fig.13)

The crankshaft of the prototype engine incorporated a needle bearing, a ball bearing race and a pressure seal made from a filled PTFE material. In the intermediate model two ball bearing races were used with a greased leather pressure seal and the general arrangement was modified to suit the use of cast iron components. The greased leather pressure seal was satisfactory for a period but after a few rounds of disassembly and reassembly it was prone to leaking. In the pre-production engine the design was again changed, this time utilizing two taper roller bearings (30209 and 30210) and a conventional automotive type oil seal in place of the leather pressure seal. This sealing arrangement has worked well so far with no signs of leaking after many short runs over a period of one and a half years and many disassembly cycles.

The taper bearings have worked well with the correct adjustment of play made with a nut and locknut on the crankshaft, somewhat similar to the arrangement on the front wheel of an automobile.

A 3 millimeter diameter O-ring provides a pressure seal between the bearing case and the crankcase. The O-ring is superior to a regular gasket as the axial location can not change as it would with a gasket compressing, or worse yet by using a gasket of the wrong thickness. Another advantage of the O-ring in this application is its tolerance to repeated disassembly and reassembly. As with the crankshaft pressure seal the O-rings used on the crankcase have not had to be replaced over a year and a half of much opening and closing.

7. Crankshaft (Fig.14)

The prototype incorporated a crankshaft fitted with a machined steel counterweight/web. In order to reduce costs and simplify the production operations. Both the intermediate model and the pre-production model of the engine have incorporated built-up crankshafts using mild steel for the crankshaft and the throw and cast iron for the counterweight and the web. In order to provide better balancing the counterweight was made significantly heavier than in the prototype. This arrangement has worked very satisfactorily and is a relatively simple and inexpensive way of producing the crankshaft assembly.

8. Flywheel (Fig.16)

A persistent problem that has been encountered in the project has been a suitable design for keying the flywheel to the crankshaft. Many times puzzling and sometimes alarming noises turned out to result from play between the crankshaft and the flywheel. In order to avoid this problem the first of the locally made engines incorporated a tapered locking hub in the flywheel, however this is somewhat complicated to make. In the design reported here an ordinary keying system has been used. This is satisfactory when the key and slots are machined and appropriate tools are made for installing and removing the flywheel.

9. Displacer (Fig.18,19,20)

The displacer of the prototype used TIG welding for seams and a machined ring between the displacer's dome and can. Three conical internal baffles attached by tabs spot welded to the inside of the displacer can reduced internal heat losses due to radiation and convection.

As with the heater, explosive forming was used to form the dome of the displacer. The same die was conveniently used to form the baffles for the displacer using thinner gauge stainless steel. Explosive forming had the advantage that the draw could be deep enough to form an edge which could be directly spot welded to the displacer can. By using many spot welds the assembly has adequate strength and is leak-proof. Because the baffles are hemispherical in form they provide an important strengthening function in addition to reducing heat losses. This stainless steel assembly is attached to the cast iron displacer base with 24 small (M3) bolts. To avoid air leaks a bead of epoxy cement was placed along the cast iron/stainless steel joint after assembly.

The displacer tube has twice been enlarged from the original design and has been changed to incorporate an internal flexible drive rod that simplifies the method of attachment to the bellcrank. A pressure seal which is located in the crown of the piston and the guide for the displacer tube at the base of the cylinder both incorporate the same carbon/graphite filled PTFE material that is used for the piston and displacer rings. This arrangement has proven satisfactory and has also facilitated assembly and dis-assembly.

The prototype engine was not equipped with a guide for the displacer rod other than where it passed through the piston crown. Based on their operation of the prototype Sunpower recommended the addition of a guide for the displacer rod located at the base of the cylinder. The spider shown in Fig.10 is the result of several changes and now incorporates the same PTFE material as used in the piston rings for the wearing surface of the guide.

10. Piston (Fig.21,22)

The piston of the prototype was machined from an aluminum casting, anodized and sprayed with a PTFE based material to provide a dry lubricated surface. The original concept was to provide for pressure sealing by means of a greased leather ring however this produced too much drag and was replaced with a PTFE tube placed in the ring groove.

A problem with this arrangement is that the wearing surfaces must be kept very clean to avoid wear and when wear does start there is a cascade effect as the first particles of the anodized surface that break loose form an abrasive which break more particles loose. This proved to be a problem with the prototype which was already somewhat worn from earlier testing.

In adapting the design in Bangladesh it was decided to avoid the use of spray-on PTFE material and use rings of impregnated PTFE to serve both as combined wear and compression rings. A carbon-graphite impregnated PTFE material was selected and this has performed satisfactorily.

Other modifications to the piston included provision of a longer skirt to minimize piston slap problems and a two part design that simplifies casting and machining operations. A problem was encounteted in that even a slight mis-alignment in the bore for the wrist pins resulted in the piston being cocked in the cylinder and this resulted in dragging that could become severe as clearances are reduced to avoid leaks. This is due to the arrangement of dual piston links which does not allow the tolerance for slight mis-alignment that pistons with single connecting rods have. In order to solve this problem, the way in which the piston links connect to the crown of the piston has been changed. In the process, the piston crown casting and machining operations have been simplified and the weight of the piston assembly reduced.

The rod seal in the crown of the piston has been modified a number of times to solve problems with both wear and leakage. The prototype used a proprietary steel backed PTFE bearing as a combined wear surface and seal. The first intermediate model used piston ring material to make a lipped seal. Later spring loaded and O-ring backed versions of this configuration were used. These changed reduced but did not eliminate leakage, the most recent seal is a ring machined from 1/8 inch PTFE stock and mounted with an O-ring to activate it. Two of these are used in tandem. This has further improved performance though there is some leakage due to lateral movement of displacer in the cylinder as a result of cylinder ovality. It is expected that this arrangement will be satisfactory in a design where cylinder symmetry is maintained.

11. Rings

Oil is not used in the engine. To reduce friction as the piston and displacer move back and forth in the cylinder, the prototype Stirling engine incorporated a spray-on PTFE based material which was applied to the anodized surface of the aluminum piston and displacer body. Besides requiring the piston and displacer body to be anodized this arrangement demanded skill in the application of the coating of dry lubricant and cleanliness of the engine during operation became critical to avoid the surface from scoring. Based on the reported success of PTFE based piston rings in commercially successful air compressors, it was decided to try this alternative which would eliminate the tricky operations of anodizing and spray application of the dry lubricant. Initial trials with virgin PTFE were satisfactory and subsequently carbon/graphite filled PTFE ring material was ordered. This material has worked well so far and is expected to provide the long term life required for the engine.

12. Linkages (Fig.22,23,24,25)

A recurring problem has been failures in the mechanism linking the displacer to the crankshaft. One of the features of the engine design is that there is no governing mechanism. The design is such that overspeeding is avoided because of the rapid rise of fluid friction as the air (more than 7 liters) is moved back and forth between the hot and cold spaces of the engine. A problem arises when the engine is allowed to run free. In this situation virtually all of the engine's power is passing through the displacer drive linkage which means that it must be constructed to transmit 5 horsepower or more. In the prototype the displacer drive was not designed to withstand the forces of full power free running operation. Adding to this problem were modifications made to the design of the bellcrank in Bangladesh which incorporated an offset bellcrank design. The displacer drive linkage has steadily been improved however it still needs to be more durable and this is one of the areas that will be examined closely in Phase B.

13. Blower (Fig.26,27)

The blower which provides combustion air for the furnace was designed and built into the pre-production engine in Bangladesh during Phase II. The blower operates satisfactorily though the simple design of the impeller could be improved to increase efficiency and reduce noise. (the blower is the only noisy part of the engine). The blower is belted to the engine by means of a jack shaft and rotates 5 times faster than the engine. A large hand operated pulley is used to drive the blower during start up.

14. Compressor

A small built-in air compressor was designed and incorporated in the second intermediate model of the project engine. The first version did not operate satisfactorily and a modification was devised which used a different valving system. This also proved to be unsatisfactory and it was decided to use a small compressor procured from the market which is mounted to the side of the engine and belted to the same jackshaft that drives the blower. This arrangement has worked very well. At some future time consideration may be given to designing a built-in compressor if this would be more economical in respect to production cost.

15. Water Pump

A water pump procured from the local market has been mounted to the side of the engine and driven by belt from the jackshaft to provide cooling water for the engine. The present pump is larger than necessary and later when the cooler design is fixed it will be possible to more closely match the pump to the engine's demands and most likely use a smaller pump.

16. Furnace (Fig.31)

At the beginning of Phase II when the prototype was shipped to Bangladesh, the Sunpower Engineer constructed a furnace at the project site to operate the engine. This furnace consists of a lining of insulating firebricks mounted in a sheetmetal casing and plastered on the inside with fireclay. The furnace was later fitted to a metal cradle to make it mobile and parts have been re-plastered from time to time, however the basic furnace has been used with all three engines and continues to serve satisfactorily, though the heater heats somewhat unevenly. The design of the furnace is an area where there is much potential for innovation and improvement and for a production engine would probably be different in some respects, perhaps utilizing a cast liner. The importance of the work on the engine itself has precluded any plan to modify or improve the furnace within the framework of this project.

17. Husk Feed

The prototype engine used an auger powered by a variable speed electric motor to feed husk from a hopper into the combustion air before it entered the furnace. By placing a venturi ahead of the galvanized iron pipe tee which forms the husk feed access to the airstream, the husk is drawn into the air flow as a result of the negative pressure produced. For the first intermediate model this system was adapted for operation by hand

and worked satisfactorily. In the second intermediate model the design was simplified by eliminating the auger and hopper and directly feeding the husk into the iarstream by hand. This has turned out to be convenient and allows accurate measurement of husk consumption rates bv feeding weighed quantities of husk.

C. PRESSURE TESTING

Before operating the engine, care should be taken to hydrostatically test those parts of the engine that are subjected to the working pressure of the engine. To do this the the heater, body, crankcase, bearing case and blower base were assembled and additional covers used to seal the pivot and crankshaft openings. This assembly was filled with water and all air bled out. The water pressure was raised to twice the maximum operating pressure and maintained for half an hour to insure adequate strength. This is particularly important to check the integrity of the iron castings used in the design.

D. SPECIALIZED PRODUCTION METHODS

A number of specialized production methods were considered for use in fabricating the project engine. Some of these methods were tried and rejected while others proved to be useful and were incorporated in the processes in making the project engine. A number of specialized jig set-ups have been essential to obtain the necessary accuracy in dimensions, position and alignment. Such jigs were devised for use in making the crankcase, crankshaft counterweight and main connecting rod, and a general jigging system used in boring the piston links, swing link bellcrank and bellcrank con-rod. Details of these jigs have been discussed when describing these specific components. Two specialized production methods, explosive forming and furnace brazing, are more involved than the jigging operations and these are described in more detail here.

1. Explosive Forming

In the original prototype the domes of the hot end and the displacer were formed by clamping a disc of stainless steel to a heavy plate and pumping hydraulic fluid between the disc and plate to make the stainless steel bulge. The resulting dome was attached to the "can" of the hot end or displacer by welding to a machined reinforcing ring.

Early in the project it was decided to test out the feasibility of explosively forming these components. After an extensive series of trials with different dies and explosives an effective system has been developed which is now used to produce the dome and baffles for the displacer as well as a single piece from which both the hot end dome and the top of the regenerator housing are cut.

There are a number of advantages in using explosive forming. Because a die is used the pieces that are produced are uniform in shape and very close dimensional tolerances can be maintained. Unlike mechanical or hydraulic pressing which requires precisely machined mating dies of high quality steel, explosive forming requires only one die and this can be made of cast iron. The die for explosive forming can be made in a small workshop for a fraction of the cost of the male and female dies required for a power press and there is no investment in set-up time on the press. This economy is particularly well suited for small scale operations and in research and development where designs and thus dies may have to change after only a few pieces have been formed. Explosive forming also produces a deeper draw than hydraulic bulging. Because the formed pieces can be made with vertical sides the need for a separate reinforcing ring has been eliminated. This has also made it possible to assemble the displacer using spot welding rather than inert gas welding as was done in the prototype.

Ordinarily, explosive forming is carried out using "high" explosives such as T.N.T. which detonate. The explosive reaction in these is triggered by a shock wave or detonation and the advantage for metal forming lies in the very high speed of the resulting pressure wave. In contrast to this, fulminating (burning) explosives such as black powder have a much slower reaction rate and produce a slower pressure wave> The practical result is that a larger charge of the "low" explosive is required to achieve the same result as compared to the high explosive. The problem with high explosives is that they are generally unavailable in Bangladesh where there are virtually no rocks and no need for explosives in quarrying or excavating. On the other hand, local fireworks shops stock a variety of firecrackers, the larger ones verging on being mini bombs. Because of their availability these black powder explosives were used in the forming operations.

The system that proved to be most suitable was to purchase the required size of firecracker from the market, remove the regular fuse, insert an electric fuse in the form of a fine copper wire with suitable leads and the impregnate the firecracker with hot candle wax. A cast iron piece with a suitably machined cavity formed the die and the stainless steel blank was clamped to this with a cast iron ring bolted to the die. An O-ring between the blank and the die prevented air from leaking into the cavity which was evacuated by a vacuum pump connected to the die by 1/4" copper tubing and flare fittings. For limited use a refrigerator compressor with an in line drier to keep moisture out serves as a vacuum pump though its susceptibility to corrosion would make this arrangement unsuitable for anything but limited trials. After the blank has been clamped in position and the die evacuated the explosive is positioned above the blank (at about the center of radius of the curve of the dome), the whole assembly is submerged 1 to 1.5 meters under water and the explosive is discharged by connecting the leads to a 12 volt battery.

To arrive at the correct charge and height above the blank a series of tests should be conducted with a batch of explosives from one source so as to insure as much consistancy as possible in the formulation and wrapping of the explosive. While all this can be somewhat time consuming, it is within the capabilities of small workshops to make the required die and the costs will be a very small fraction of the purchase cost of a set of dies for use with a power press.

2. Furnace Brazing

The external fins and internal corrugated heat exchanger of the heater are brazed in place to provide an adequate path for movement of heat into the engine. Because of the high temperatures involved it is necessary to use a nickel alloy braze filler metal. The hot end is assembled with all welding completed and the filler metal is applied as a powder suspended in a liquid plastic binder which dries soon after application. This binder subsequently vaporizes during the brazing operation.

The assembly to be brazed is placed in a stainless steel container (retort) that is purged with pure dry hydrogen before and during brazing and during cool-down. The hydrogen protects the assembly from oxidizing and acts as a gaseous flux to remove existing oxides.

For the purposes of the project a natural draft gas fired brazing furnace was constructed using locally available insulating and regular refractory bricks. With these arrangements one brazing operation took about 8 hours because of the large size of the furnace and the lower heating rates of the natural draft combustion system.. It was later ascertained that a faster cycle would avoid lingering problems with chromium oxides and would save on hydrogen purging gas. This could be obtained by pre-heating the furnace rather than starting it with the retort on place.

With the use of more sophisticated refractory insulating materials and forced draft burners the size of the furnace could be reduced and a faster brazing cycle obtained.

IV. ENGINE OPERATION AND PERFORMANCE

A. ENGINE OPERATION

To start the engine a small fire is started outside the engine and allowed to burn till there are glowing coals. These coals are placed in the furnace and the blower operated by hand through a large pulley temporarily belted to the jackshaft. At the same time husk is fed into the air stream. The coals ignite the husk and soon the temperature of the furnace is high enough that coals are not necessary. It takes 10 to 15 minutes to achieve the 650°C needed to start and run the engine. In the present system husk is fed manually throughout the operation of the engine. The temperature can be monitored by a thermocouple attached to an analog meter which is marked for the desired operating temperature so that the person feeding husk to the furnace knows when to increase or decrease the feed rate.

B. PERFORMANCE EVALUATION

Measuring power output alone is not a totally satisfactory means for evaluating the performance of the Stirling engine. The power depends upon the temperatures of the heater and the cooler, the working pressure of the air within the engine, and the speed of the engine. In addition, the performance of engine components (heater, cooler, regenerator, etc.) and problems such as frictional losses and poor sealing also can have a profound effect on power output. For example, using only power output to compare the performance of two different heaters, it is necessary to duplicate all the operating conditions and only then compare power readings. It is far more desirable to have a means of evaluating the overall efficiency of the engine for any combination of operating conditions. This is, in fact, possible using the Beale number and one of its associated equations.

William Beale has identified a simple relationship between the power output of a Stirling engine and its speed, swept volume and operating pressure.

Power(Watts) = Beale No. x Pressure (Bar) x Speed (Hz) x Capacity (cc)

The Beale Number is a constant that relates the variables to the predicted power output of the engine in question. Assuming a heater temperature of 650°C and a cooler temperature of 50°C the Beale number is 0.015. The predicted power using this formula and Beale Number would be typical of a reasonably well constructed engine using a moderately sophisticated design. Well made and sophisticated engines could be twice as powerful, simple engines might yield half the predicted power.

A further refinement of the Beale equation includes as variables, the heater temperature and the cooler temperature in degrees Kelvin. In this case the Beale Number is calculated as follows.

Beale No. = 0.034 - 0.052 (cooler temp./ heater temp.)

These equations provide a very useful means for evaluating the performance of the project engine. While the engine is running the pressure, power, speed and temperatures are monitored, then at any given moment the variables can be entered in the Beale equation and a predicted power output calculated. The actual power, which has been recorded at the same time as the other variables, is then figured as a percentage of the predicted power. This percentage provides the means to compare performances of the engine at different times and under different conditions. During a single run if the percentage of the predicted power drops off, one is alerted to look for problems. To produce 5 HP while operating at design conditions the engine must produce 53% of the predicted power.

C. POWER OUTPUT

Much of the testing carried out on the engine has been done using a water pump as the load. A torque indicating hub was designed and built for the water pump and a strobe with digital rpm readout is used to read the torque so that power can be determined. Using this arrangement regular readings of power are made along with records of temperatures during runs where the engine is operating the water pump.

The pulley ratio from the engine to the pump is such that the engine operates at about 600 rpm which is somewhat lower than the design point of 720 rpm. With this arrangement and with reasonable heater temperatures and crankcase pressures it has been possible to get powers in the range of 4 horsepower. When driving the rice huller the engine speed has been higher, in the range of 770 rpm and the power has been more than adequate to operate the huller. By extrapolating the power due to the increased speed it is probable that the engine is driving the rice huller at 5 horsepower.

It is expected that additional power will be achieved after the next series of modifications resolves problems with leaks due to the oval cylinder and improves the performance of the cooler.

D. HUSK REQUIREMENT

In recent trials with the engine operating the rice huller it was found that a milling rate of 216 kg/hour was maintained while the furnace was using husk at the rate of about 20 kg of paddy per hour. With a husk to paddy ratio of 20% the rate of husk production in the milling operation would be about 43 kg/hr. This means that the engine requires less than half of the husk that is produced in the milling operation. Many varieties of rice yield more than 20% of their weight in husk when milled (typically 24% to 26% with some as high as 28% and over) and in these cases well over half of the husk would remain after milling with a Stirling engine powered huller.

V. PRODUCTION COST PROJECTIONS

An important objective of the project is that the Stirling engine should be competetive with diesel engines in respect to manufacturing cost. Because the Stirling engine offers a savings in fuel cost it was felt that a realistic target selling price would be 50% more than the selling price of a comparable diesel engine. In making this comparison it is assumed that the Stirling engine would be manufactured on a scale and with methods comparable to small diesel engines. This would not happen immediately and the cost of the Stirling engine initially would undoubtedly be higher. The local price of a 5 to 6 horsepower diesel engine is about Tk 13,000 (at the rate of Tk30/$1 this is equivalent to $433) so a target selling price for the project engine would be Tk 19,500 ($650).

Appendix A presents a detailed analysis of the costs for materials and finishing that are required for the project engine. These figures are based on the types of operations that have been performed in the project workshop but assume that a number of engines are being produced which result in shorter set-up times for pieces as compared to making only one set of engine components. For large scale production using specialized equipment, as is done generally in diesel engine manufacturing, the costs would be less, however this would depend on large volume outputs which are not likely in the near future.

Page A-1 summarizes the production cost projections showing Tk 17,661 ($589) for materials and Tk 6,648 ($222) for finishing costs. Together these give Tk 24,310 ($810) as manufacturing cost and with a 15% mark-up the selling cost would be Tk 27,956 ($932).

The above prices are higher that the target; however it is likely that some more cost reductions may be realized in the process of re-designing the engine in the next phase. A significant cost savings can be made if the plain heater turns out to be feasible as it would be possible to eliminate the need for furnace brazing which is presently calculated at Tk 1,800 ($60) and this also reduces the amount of stainless steel used in the heater and some other fabrication costs.

Even with these higher costs it is the general feeling of millers and equipment retailers in Bangladesh that if the engine works reliably the advantage of using husk as the fuel could justify as much as a 100% price increase over a diesel engine of comparable power, though this would be difficult to confirm without the hardware in hand.

VI. PRESENT STATUS AND FUTURE ACTIVITIES

In the period from August through November 1985 the engine was run more than twelve times. These runs averaged 45 minutes in length with the longest extending to two hours. Generally the engine was run long enough to reach equilibrium operating conditions and operating data (temperatures, pressures, torque, speed and flow rates) were recorded. Operating data is recorded by hand is analyzed at a later time.

When running the large water pump as a load it is possible to accurately measure power by means of a torque hub on the pump and a digital stroboscopic tachometer. Typically, power output is in the range of 4 horsepower when the engine is running at 600 rpm with a working pressure of 3.5 bar and a heater temperature of 650°C. The speed of the engine is limited by the particular ratio of engine and pump pulley sizes. When operating the rice huller the engine operates at 770 rpm, while the engine would consequently be producing more power it has not been possible to measure power output as the huller is not equiped with a torque indicating mechanism but it is estimated that the engine is running at about 5 horsepower under these conditions and there is more than enough power to drive the huller.

At this time a number of project objectives have been achieved and it has been possible to demonstrate that a rice husk fueled Stirling engine can be fabricated in Bangladesh, however it has not yet been possible to demonstrate the required durability of the engine at full power, and some manufacturing problems have yet to be resolved. For these reasons the engine will go through another (the third) cycle of design evaluation with new drawings and patterns being prepared and a new engine fabricated.

In the process of re-design many components will remain unchanged, some modifications that have already been made in the second intermediate model of the engine will be incorporated into the design in a rational manner, and finally a few changes will be made that were not possible before because they involved altering the basic configuration of the engine.

Many of the parts of the engine and methods of fabrication after undergoing changes and adaptations are now satisfactory and it is not expected that these will need any further modification.

- Explosive forming
    - Heater and displacer domes
    - Displacer baffles

- Displacer
    - Spot welded fabrication
    - Cast iron body

Tube and tube guide

Piston
Two part construction with increased skirt length
Wrist pin arrangement
Piston links

PTFE wear rings

Crankcase
Cast iron consstruction
O-ring seals to bearing case and side cover

Bearing case
Taper roller bearings with double lock nut adjustment for play
Pressure seal

Flywheel and keying system

Crankshaft
Composite cast iron/steel design

Blower design

There are some changes in engine components that can be integrated in the the engine in a better way during a re-design exerise.

The crankcase is presently designed to be mounted vertically. The new design will be arranged for horozontal mounting.

The cylinder design will be changed to avoid the tendency to go oval at its end and to avoid the problem with porous castings.

The present arrangement for driving the auxiliaries will be integrated into the design in a more rational way.

A few parts will be re-designed to solve problems that have emerged during the process of fabricating and operating the first and second intermediate models of the project engine.

It is expected that the cooler will be re-designed to provide for more efficient cooling and solve the present leakage problem.

The displacer drive linkage will be modified so that it can absorb the full load when the engine runs free.

Certain elements of the engine design have been somewhat neglected because of the need to demonstrate the basic engine system operating with satisfactory durability. The furnace in use with the second intermediate engine is the same as used in the prototype and while it works satisfactorily it will certainly be possible to design more efficient and compact versions. Possible directions would be cast refractory linings and more efficient insulation linings. At the present time the engine is being operated with a regenerator composed of a commercially made knitted stainless steel wire. Some work on a regenerator made from carefully generated lathe turnings and on local knitting of stainless steel wire has been carried out but this work was shelved in the interest of solving morer pressing mechanical problems.

In the period from December 1985 to June 1986 the engine will be re-designed and one will be fabricated for testing at the project site. This design will be described in detail in the final report of the project which will also include a more detailed description of manufacturing processes than is being given in this report.

APPENDIX A

PRODUCTION COST PROJECTIONS

PRODUCTION COST SUMMARY

Material costs	Tk	17,661
Finishing costs	Tk	6,648
Total manufacturing cost	Tk	24,310
15% Mark-up	Tk	3,646
Selling price	Tk	27,956

Engine weight w/out furnace 283 Kg.

vb

PRODUCTION COST VARIABLES

MATERIALS	Material Code	Local Cost		Cost/Kg	Total Kg Required	Total Item Cost
Iron castings	Ir-Ca	500	Tk/maund	13	284	3,811
Aluminum castings	Al-Ca	50	Tk/Seer	54	33	1,790
Mild steel shaft	MS-Sf	20	Tk/pound	44	14	625
Mild steel plate	MS-Pl	500	Tk/maund	13	45	602
Stainless steel	St-St	50	Tk/pound	110	27	2,978
Stainless steel scrap	SS-Sc	2,000	Tk/maund	54	6	321
Bearings	Brngs			-	-	1,910
Other materials	MiscM			-	-	5,625
				Total material cost		Tk 17,661

FINISHING	Code	Hourly Rate	Total Hours	Total Item Cost
Large lathe	LgLth	80	8	600
Medium lathe	MdLth	60	12	733
Small lathe	SmLth	40	29	1,147
Milling machine	MiMch	100	4	425
Radial arm drill	RaDrl	50	2	75
Pedistal drill	PeDrl	20	4	83
Boring machine	BoMch	100	1	83
Arc welding	ArWld	50	2	121
Oxy-acetylene welding	OAWld	80	1	47
Spot welding	SpWld	60	1	80
Fitting	Fittg	20	38	770
Other finishing	MiscF	-	-	2,405
		Total finishing cost		Tk 6,648

21

PART NO.	DESCRIPTION	QTY/ ENGINE	MATERIAL TYPE	UNIT WT. (GMS)	UNIT COST	COST/ ENGINE	FINISHING JOB	TIME (MIN)	JOB COST	PART COST	FINISHED COST	WEIGHT (GMS)
	HOT END ASSEMBLY										6,200	28,000
	Heater flange	1	MS-Pl	29,490		395	OAWld	15	20	50		
							MdLth	30	30			
	Regenerator housing	1	St-St	2,900		320	MiscFa		10	14		
							ArWld	5	4			
	Heater can	1	St-St	6,400		705	MiscFa		20	28		
							ArWld	10	8			
	Dome/shoulder piece	1	St-St	5,200		573	MiscFb		200	220		
							MdLth	20	20			
	Inner liner	1	St-St	2,733		301	MiscFa		5	25		
							SpWld	20	20			
	Internal heat exchanger	1	St-St	2,300		254	Fittg	200	67	67		
	External fins	120	St-St	72	8	952	MiscFa		120	120		
	Assembly operations						LgLth	120	160	2,075		
							ArWld	60	50			
							RaDrl	30	25			
							Fittg	120	40			
							MiscFc		1,800			
	Hex bolts, M10x30mm	12	MiscM	27	5	60						324
	Gasket: heater/engine body	1	MiscM			40						300
			(MiscFa Shearing and rolling) (MiscFb Explosive forming) (MiscFc Furnace brazing)									
	REGENERATOR		SS-Sc	6,000		321	SaLth	1,200	800	840	1,161	4,000
							Fittg	120	40			
	ENGINE BODY ASSEMBLY											
	Engine body	1	Ir-Ca	73,050		978	LgLth	60	80	145	1,203	55,700
							RaDrl	30	25			
							Fittg	120	40			
	M10x30 Engine body bolts	10	MiscM	27	5	50						270
	Gasket: engine body/crankcase	1	MiscM			30						200
	COOLER ASSEMBLY										3,351	12,700
	Cooler		Al-Ca	22,000		1,179	MdLth	90	90	2,157		
							MiscFd		2,000			
							Fittg	200	67			
	O-ring, 3mm dia. x1000mm length		MiscM			15						
			(MiscFd Slotting)									
	CYLINDER		Ir-Ca	50,000		670	LgLth	200	267	342	1,011	18,000
							MiMch	45	75			

PART NO.	DESCRIPTION	QTY/ ENGINE	MATERIAL TYPE	UNIT WT. (GMS)	UNIT COST	COST/ ENGINE	FINISHING JOB	TIME	JOB COST	PART COST	FINISHED COST	WEIGHT (GMS)
	SPIDER ASSEMBLY										195	1,500
	Spider	1	Ir-Ca	4,400		59	MdLth	15	15	20		
							PeDrl	5	2			
							Fittg	10	3			
	Rod guide holder	1	Ir-Ca	900		12	SmLth	15	10	12		400
							PeDrl	5	2			
	Rod guide, PTFE	2	MiscM	8	40	80						16
	Hex bolts, M5x15mm	4	MiscM	4	3	12						16
	CRANKCASE	1	Ir-Ca	59,700		800	LgLth	70	93	233	1,033	52,000
							DoMch	50	83			
							RaDrl	20	17			
							Fittg	120	40			
	BEARING CASE ASSEMBLY										868	
	Bearing case	1	Ir-Ca	19,000		254	MdLth	40	40	67		14,073
							PeDrl	20	7			
							Fittg	60	20			
	Outer bearing cap	1	Ir-Ca	900		12	SmLth	30	20	22		341
							PeDrl	5	2			
	Inner bearing cap	1	Ir-Ca	1,800		24	SmLth	30	1	3		353
							PeDrl	5	2			
	Hex bolts, M5x15mm	12	MiscM	4	3	36						48
	Outer bearing 30209	1	Brng			180						464
	Inner bearing, 30210	1	Brng			200						526
	Crankshaft pressure seal	1	MiscM			30						20
	Hex bolts, M10x30mm	6	MiscM	27	5	30						162
	O-ring, 3mm dia x 800mm	1	MiscM			10						
	CRANKSHAFT ASSEMBLY										747	14,700
	Crankshaft	1	MS-Sf	5,930		261	MdLth	90	90	107		
							MiMch	10	17			
	Counterweight/web	1	Ir-Ca	13,300		178	PeDrl	10	3	33		
							Fittg	30	10			
							MdLth	20	20			
	Crank throw	1	MS-Sf	1,306		58	SmLth	15	10	10		
	Lock nut, outer	1	MS-Sf	462		20	SmLth	10	7	7		
	Lock nut, inner	1	MS-Sf	923		41	SmLth	10	7	7		
	Lock washer	1	MiscM	20		5						
	Keys	2	MiscM			20						

PART NO.	DESCRIPTION	QTY/ ENGINE	MATERIAL TYPE	UNIT WT. (GMS)	UNIT COST	COST/ ENGINE	FINISHING JOB	TIME	JOB COST	PART COST	FINISHED COST	WEIGHT (GMS)
	FLYWHEEL ASSEMBLY										800	34,800
	Flywheel	1	Ir-Ca	39,000		522	LgLth RaDrl Fittg	60 10 30	80 8 10	98		
	Main pulley, flat belt	1	Ir-Ca	5,500		74	MdLth PeDrl	15 5	15 2	17		5,000
	Hex bolts, M10x30mm	3	MiscM	27	5	15						81
	Auxilliary pulley	1	Ir-Ca	2,750		37	MdLth PeDrl	20 5	20 2	22		2,500
	Cap screws, M8x20mm	3	MiscM	12	5	15						36
	DISPLACER BODY ASSEMBLY										1,340	7,700
	Displacer dome	1	St-St	906		109	MiscFb			50		
	Displacer baffles	4	St-St	613	68	270	MiscFb		50	200		
	Displacer can	1	St-St	2,256		249						
	Displacer body	1	Ir-Ca	3,500		47	MdLth PeDrl Fittg	30 5 30	30 2 10	42		
	Machine screws, M3x5mm	24	MiscM	1	1	24						24
	Displacer wear ring, PTFE	1	MiscM			250						
	Assembly operations						SpWld Fittg	60 120	60 40	100		
	(MiscFb Explosive forming)											
	DISPLACER TUBE ASSEMBLY										313	1,050
	Displacer tube	1	St-St	1,083		119	MdLth	40	40	40		
	Displacer tube flange	1	MS-Sf	1,012		45	MdLth PeDrl	20 5	27 2	28		
	Displacer tube bush	1	St-St	512		56						
	Cap screws, M5x15mm	8	MiscM	4	3	24						32
	DISPLACER ROD ASSEMBLY										200	500
	Displacer rod	1	MS-Pl	384		5	MiMch	10	17	17		
	Displacer rod base	1	MS-Sf	396		17	SmLth MiMch	15 5	10 8	18		
	Displacer rod bearing holder	1	MS-Sf	703		31	SmLth MiMch	30 5	20 8	28		
	Fabrication						ArWld Fittg	15 20	12 7	19		
	Displacer rod bearing, 396321	1	Brng			60						31
	Displacer rod nuts, M10	2	MiscM	11	2	4						22

PART NO.	DESCRIPTION	QTY/ ENGINE	TYPE	WEIGHT (GMS)	UNIT COST	COST/ ENGINE	JOB	TIME	JOB COST	PART COST	COST	WEIGHT (GMS)
			MATERIAL				FINISHING				FINISHED	
	PISTON ASSEMBLY										1,561	
	Piston skirt	1	Al-Ca	3,000		161	MdLth	30	30	33		1,850
							PeDrl	10	3			
	Cap screws, M4x15mm	12	MiscM	3	5	60						36
	Piston crown	1	Al-Ca	6,500		348	MdLth	40	40	55		2,550
							PeDrl	15	5			
							Fittg	30	10			
	Wrist pin	1	MS-Pl	3,456		46	MdLth	60	60	123		950
							MiMch	30	50			
							MiscFe					
							PeDrl	10	3			
							Fittg	30	10			
	Wrist pin bracket	1	MS-Pl	598		8	SmLth	30	20	46		350
							ArWld	15	12			
							PeDrl	10	3			
							Fittg	30	10			
	Cap screws, M5x25mm	12	MiscM	5								60
	Rod seal holder	1	St-St	678		30	SmLth	20	13	13		100
	O-ring, 2mm dia.x170mm	1	MiscM	3		4						3
	Rod seal, PTFE	1	MiscM	5		22						5
	O-ring, 3mm dia.x 170mm	1	MiscM	5		5						5
	Piston ring, PTFE	1	MiscM	24		60						24
	O-ring, 3mm dia.x 1000mm	1	MiscM	8		20						8
	Wear rings, PTFE	2	MiscM	58	236	526						116
		(MiscFe Hardening & grinding)										

PART NO.	DESCRIPTION	QTY/ ENGINE	TYPE	WEIGHT (GMS)	UNIT COST	COST/ ENGINE	JOB	TIME	JOB COST	PART COST	COST	WEIGHT (GMS)
	PISTON LINKAGE ASSEMBLY										848	
	Piston links	2	MS-Pl	6,160	83	165	MdLth	20	20	77		1,512
							MiMch	30	50			
							Fittg	20	7			
	Needle bearings, 10-1189	4	Brng	72	130	520						288
	Set screws, M8x6mm	4	MiscM	3	5	20						12
	Fiber spacers	4	MiscM	5	8	40	SmLth	10	7	7		20
	Circlip	4	MiscM		5	20						

PART NO.	DESCRIPTION	QTY/ ENGINE	MATERIAL TYPE	MATERIAL UNIT WT. (GMS)	MATERIAL UNIT COST	MATERIAL COST/ ENGINE	FINISHING JOB	FINISHING TIME	FINISHING JOB COST	FINISHING PART COST	FINISHED COST	FINISHED WEIGHT (GMS)
	MAIN CONNECTING ROD ASSEMBLY										737	2,850
	Main connecting rod	1	Ir-Ca	3,900		52	MiMch	90	150	150		
	Piston link pins	2	MiscM		50	100	PeDrl	10	3	10		
							Fittg	20	7			
	Spring pins	2	MiscM		10	20						
	Swing link small end pin	1	St-St	236		26	SmLth	20	13	18		
							Fittg	15	5			
	Con rod main bearing NNF 5007	1	Brng	432		350						432
	Main bearing retaining rings	2	MiscM	40		10						40
	SWING LINK ASSEMBLY										304	
	Swing link	1	MS-Sf	528		23	SmLth	10	7	65		605
			MS-Pl	404		5	MdLth	15	15			
							MiMch	10	17			
							ArWld	20	17			
							Fittg	30	10			
	Small end bearing, F-2-4650	1	Brng	23		50						23
	Large end bearings, 2018-3	2	Brng	56	80	160						112
	SWING LINK PIVOT ASSEMBLY										101	247
	Pivot	1	St-St	317		35	SmLth	15	10	10		
	Spacers	2	MS-Sf	158	7	14	SmLth	15	10	10		
	Pivot gaskets	2	MiscM		2	4						
	Pivot washers	2	St-St	51	6	11	SmLth	10	7	7		
	Pivot nuts	2	MiscM	11	5	10						22

37

PART NO.	DESCRIPTION	QTY/ ENGINE	MATERIAL TYPE	UNIT WT. (GMS)	UNIT COST	COST/ ENGINE	FINISHING JOB	TIME	JOB COST	PART COST	FINISHED COST	WEIGHT (GMS)
	BELLCRANK ASSEMBLY										486	2,250
	Main pivot	1	MS-Sf	1,179		52	SmLth	20	13	13		
	Bellcrank webs	2	MS-Pl	1,200	16	32	PeDrl Fittg MdLth	10 120 20	3 40 20	63		
	Disp. con rod pivot	1	MS-Sf	198		9	SmLth	15	10	10		
	Reinforcing plates	3	MS-Pl	144	2	6	Fittg	60	20	20		
	B.C. pivot bearings	2	Brng	56	100	200						112
	B.C. bearing outer spacer	1	MS-Sf	257		11				8		
	B.C. bearing inner spacer	1	MS-Sf	106		5				8		
	Set screw, M5x8mm	1	MiscM			10						
	Assembly operations						ArWld MdLth Fittg	20 15 20	17 15 7	38		
	BELLCRANK PIVOT ASSEMBLY										172	294
	B.C. pivot	1	St-St	500		64	SmLth	15	10	10		
	B.C. pivot spacers	2	MS-Sf	240	11	21	SmLth	20	13	13		
	B.C. pivot gaskets	2	MiscM		2	4	Fittg	15	38	38		
	B.C. pivot washers	2	St-St	100	11	22	SmLth	15	10	10		
	B.C. pivot nuts	2	MiscM	11	5	10						
	BELLCRANK CON-ROD ASSEMBLY										399	
	Bellcrank con-rod	1	MS-Pl	1,760		24	SmLth MiMch	40 20	27 33	60		698
	Bearing (B.C.R./crank throw)	1	Brng	240		150						240
	Bearing (B.C.R./bellcrank)	1	Brng	240		150						240
	Bearing retaining rings	3	MiscM	4	5	15						12

PART NO.	DESCRIPTION	QTY/ ENGINE	MATERIAL TYPE	UNIT WT. (GMS)	UNIT COST	COST/ ENGINE	FINISHING JOB	TIME	JOB COST	PART COST	FINISHED COST	WEIGHT (GMS)
	SIDE COVER ASSEMBLY										223	8,712
	Side cover	1	Ir-Ca	10,300		138	MdLth PeDrl	40 15	40 5	45		
	Hex bolts, M10x30mm	6	MiscM	27	5	30						162
	O-ring, 3mm dia.x800mm	1	MiscM			10						
	BLOWER SHAFT ASSEMBLY										210	
	Blower shaft	1	MS-Sf	900		40	SmLth	40	27	27		650
	B.S. bearing cover	1	MS-Sf	220		10	SmLth PeDrl	15 5	10 2	12		175
	Hex bolts, M4x15mm	4	MiscM	3	3	12						12
	Bearing, Lg. 6204/ZZ	1	Brng	106		50						106
	Bearing, Sm. 6203/ZZ	1	Brng	63		40						63
	Bearing shaft spacer	1	Ms-Sf	200		10	SmLth	15	10	10		
	BLOWER IMPELLER ASSEMBLY										253	
	Impeller disk	1	MS-Pl	800		11	MdLth PeDrl	40 15	40 5	45		
	Impeller vanes	6	MiscM		10	60	Fittg PeDrl	180 15	60 5	65		
	Hex bolts, M4x10mm	15	MiscM	3	4	60						45
	Hex nuts, M4	12	MiscM	1	1	12						12
	BLOWER BASE ASSEMBLY										146	
	Blower base	1	MS-Pl	900		12	Fittg PeDrl	180 15	60 5	65		850
	Blower base spacers	3	MS-Sf	15	1	2	SmLth OAWld	60 20	40 27	67		45

PART NO.	DESCRIPTION	QTY/ ENGINE	MATERIAL TYPE	UNIT WT. (GMS)	UNIT COST	COST/ ENGINE	FINISHING JOB	TIME	JOB COST	PART COST	FINISHED COST	WEIGHT (GMS)
	BLOWER COVER ASSEMBLY										204	
	Blower cover	1	Al-Ca	1,900		102	MdLth PeDrl Fittg	20 20 20	20 7 7	33		
	Hex bolts, M4x10mm	7	MiscM	3	4	28						21
	Inlet screen	1	MiscM			15						
	Inlet screen retainer	1	MiscM				SmLth PeDrl	10 5	7 2	8		101
	Cap screws, M4x10mm	6	MiscM	2	3	18						8
	WATER PUMP	1	MiscM			500					500	
	COMPRESSOR	1	MiscM			1,200					1,200	
	FURNACE	1	MiscM			2,000					2,000	

APPENDIX B

SAMPLE ENGINE RUN DATA SHEET

Notes on Engine Run Data Sheet

1. Location of thermocouples for temperature measurement

   DI - Brased inside heater
   HA - Working air at hot end of heater
   RH - Working air at heater side of regenerator
   RC - Working air at cooler side of regenerator
   CA - Working air entering cylinder from cooler

   H/R - Difference between HA and RH
   R/R - Difference between RH and RC
   R/C - Difference between RC and CA

2. % of Pred. under POWER is the percentage of the predicted power (using the Beale formula) that is being achieved.

3. Pressure curves.

   The pressure curves following the data sheet show the pressure of the working space and the pressure in the crankcase during one cycle.

   The working space curve is the higher of the two during the first ninty degrees of travel after piston top dead center.

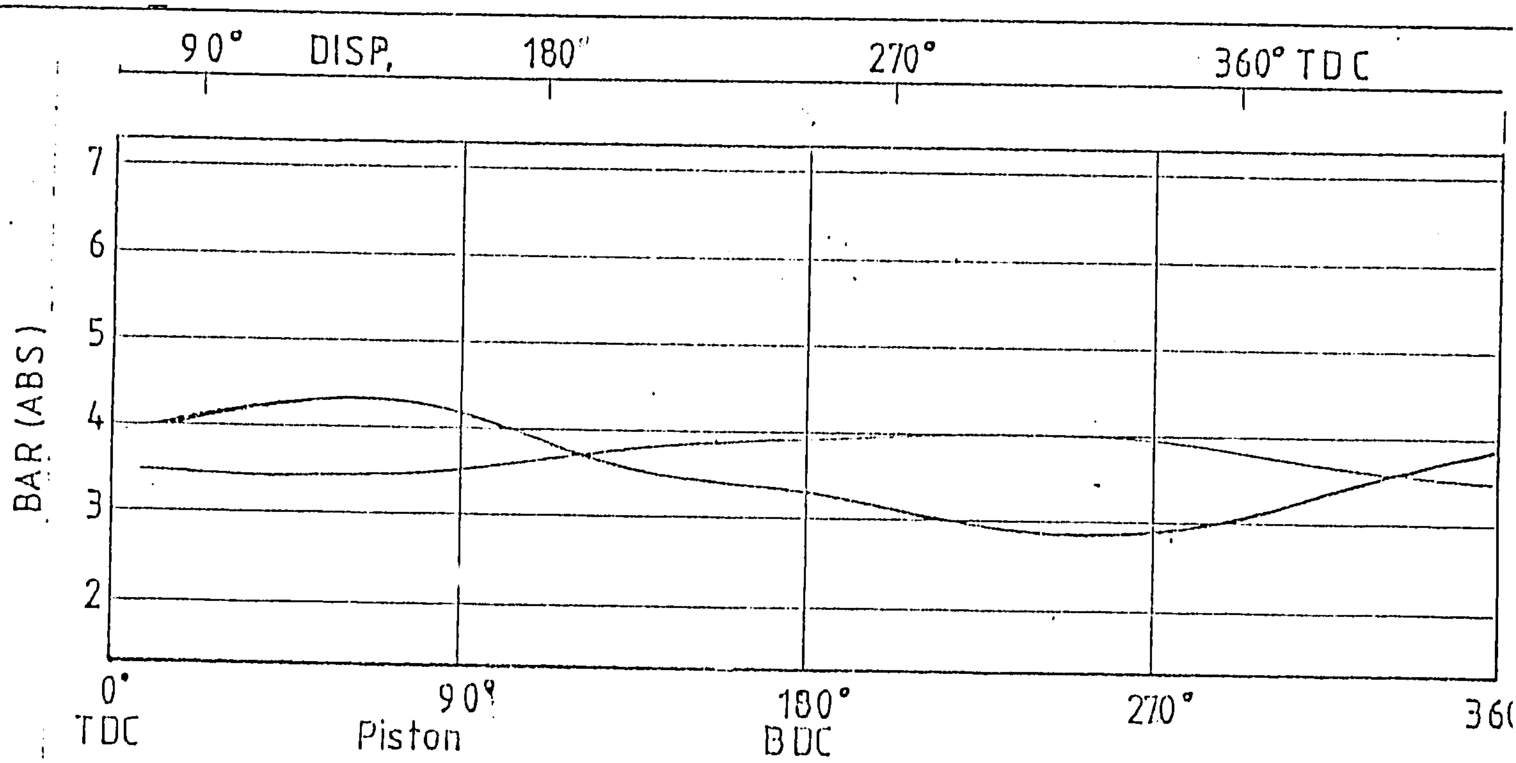
DATE: Oct.26, 1985 RUN: PAGE: 1 of 1 Using brazed head

TIME	TEMPERATURE: DOME DI	WORKING GAS: HA	RH	RHb	RHc	RC	CA	DELTA Ts: H/R	R/R	R/C	FLUE GAS: IN	OUT	AIR FLOW m3/sec	COOLING WATER: TEMP IN	TEMP OUT	Ltr/Min	KW OUT	AIR PRES BAR (ga)	RPM: ENG	PUMP	POWER: TORQ Kg	HP	% of Pred	HUSK Kg/hr
09:13		Charcoal in, hand blower started																0						
09:22	650	Started with blower and compressor																						20
09:25	598	Stopped to belt up big pump																1						13
09:30	634	491	476			95	75	15	301	20				28	33	21	7.3	2.2	551	1185	3	2.4	53%	17
09:35	652	475	465			105	90	10	360	15				28	37	21	13.2	3	605	1300	3.7	3.3	52%	22
09:40	606	454	449			111	96	5	338	15				28	38	21	14.6	3.7	608	1308	4	3.6	51%	18
09:45	619	472	463			112	97	9	351	15				28	39	21	16.1	3.4	606	1303	4	3.6	54%	24
09:46		Husk feed off 0.4 liters/min air leak into cooling water																						
		Re-set PIDC on pressure recorder																						
09:58	570	Re-started																.7						
10:00	529	456	451			101	75	5	350	26				28	32	21	5.9	1.7	463	995	3	2.1	73%	11
10:05	622	482	475			107	89	7	368	18				28	36	21	11.7	3.4	591	1271	3.9	3.4	52%	18
10:10	625	477	467			109	91	10	358	18				27	37	21	14.6	3.5	599	1287	3.8	3.4	49%	17
10:15	628	478	470			109	92	8	361	17				27	37	21	14.6	3.1	600	1290	3.9	3.5	55%	19
		Husk feed off, engine allowed to run down																						
10:32	281	244	246			70	55	-2	176	15				27	29	21	2.9	1	200					
10:35	275	237	238			64	53	-1	174	11				27	29	21	2.9	1	160					
10:40	260	225	227			60	50	-2	167	10				27	28	21	1.5	.7						
10:42	260	Engine stopped																						

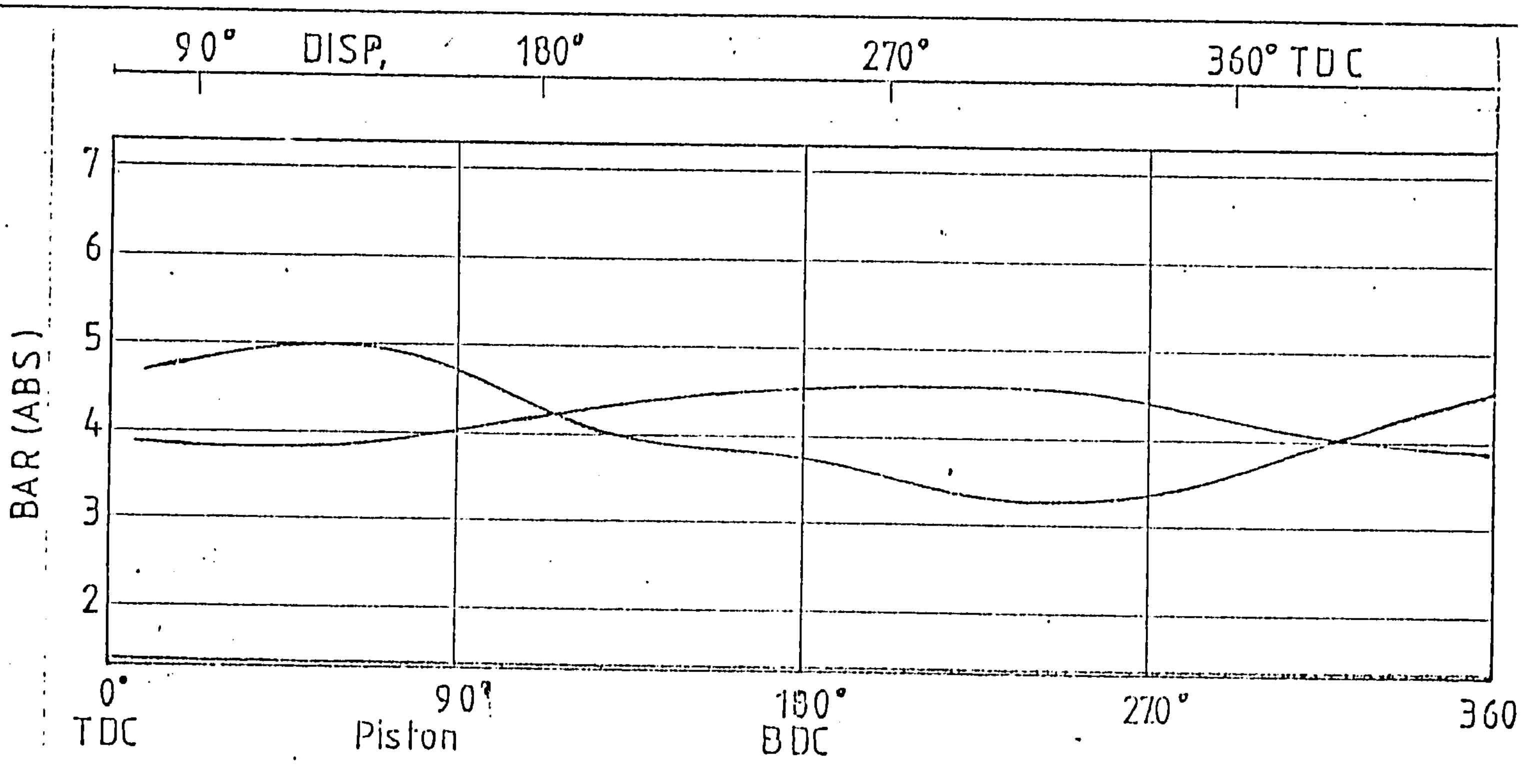
PRESSURE VARIATIONS IN WORKING SPACE AND CRANKCASE

DATE: Oct.26. 1985
RUN :

TIME: 09:30



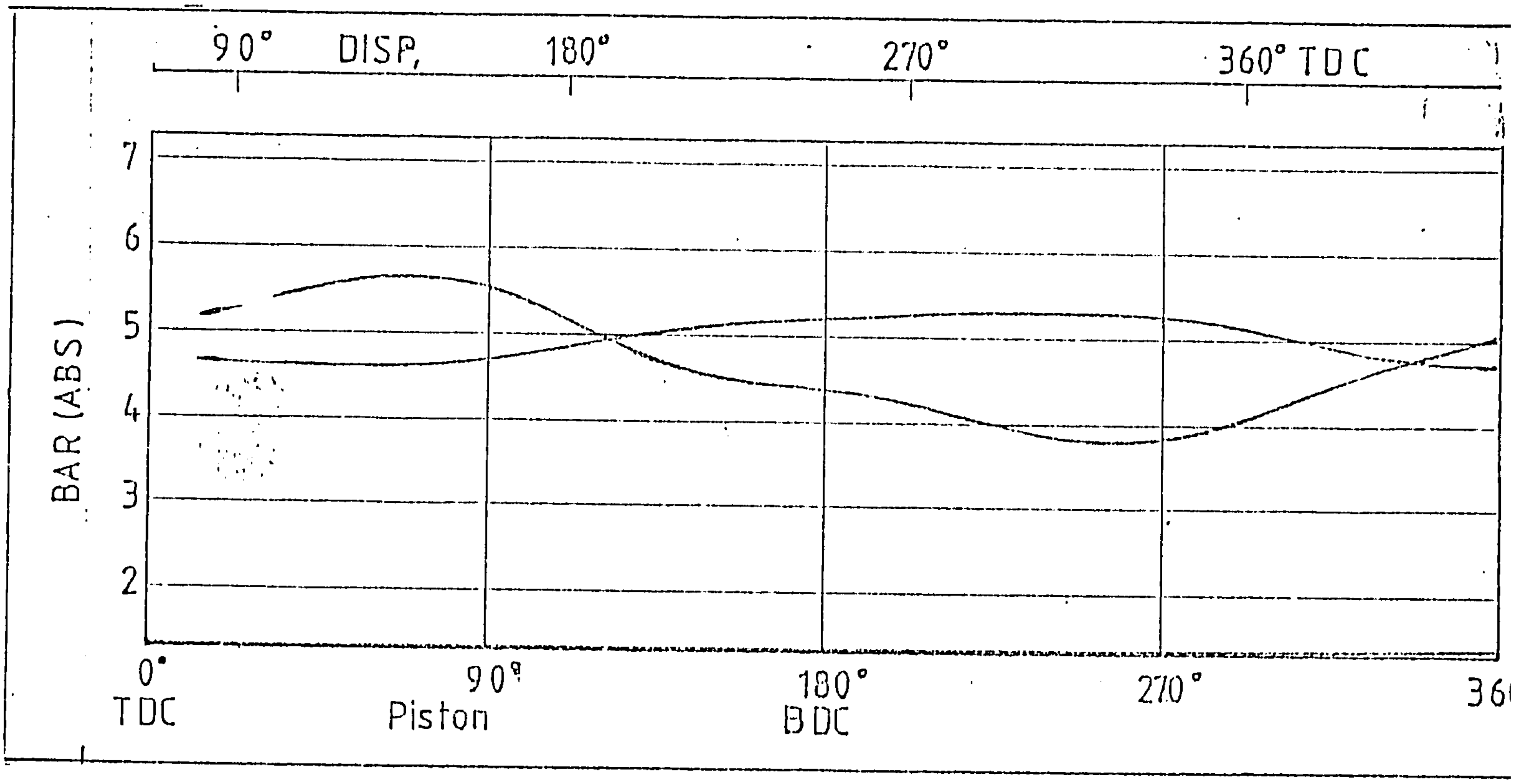
TIME: 09:35



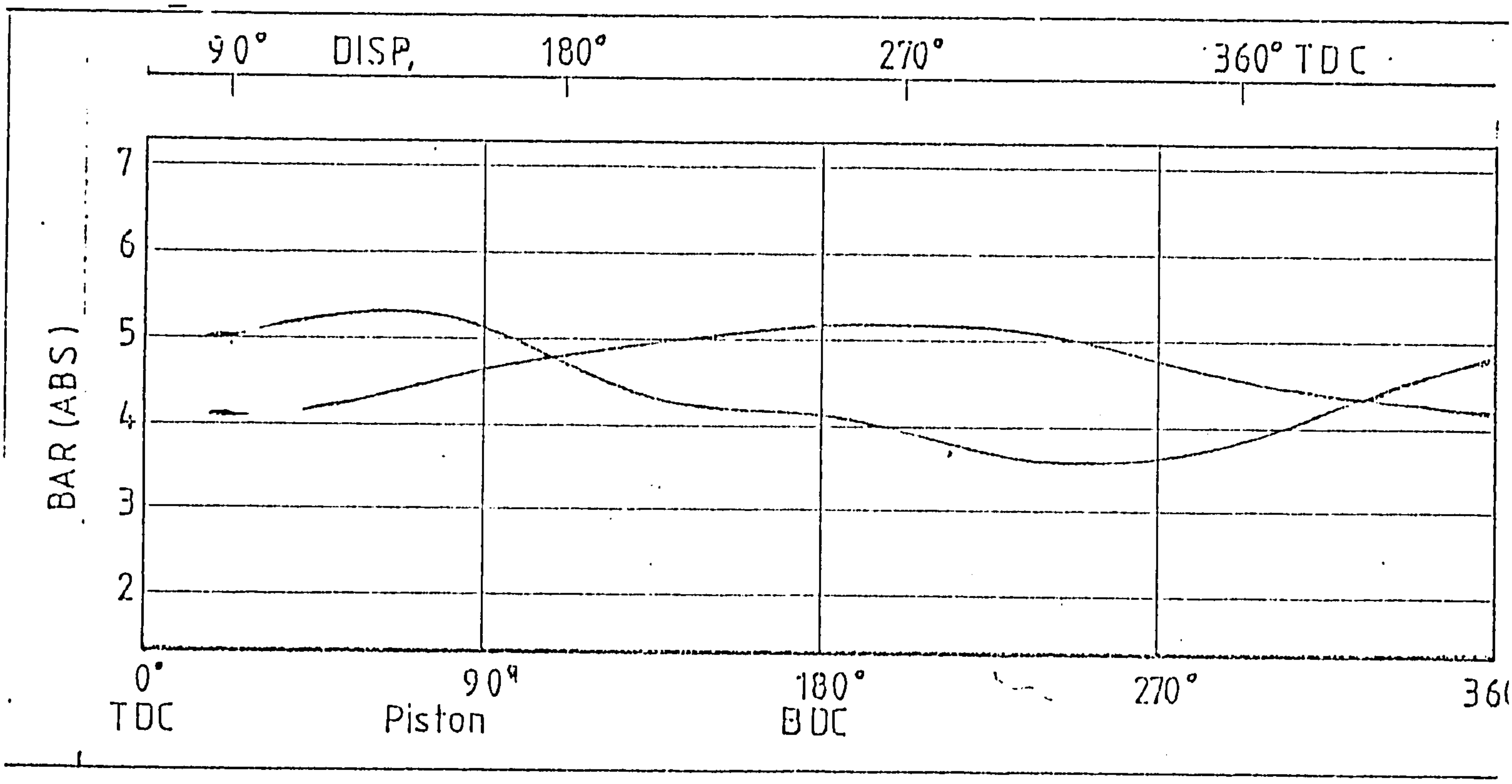
PRESSURE VARIATIONS IN WORKING SPACE AND CRANKCASE

DATE: Oct.26. 1985
RUN :

TIME: 09:40



TIME: 09:45

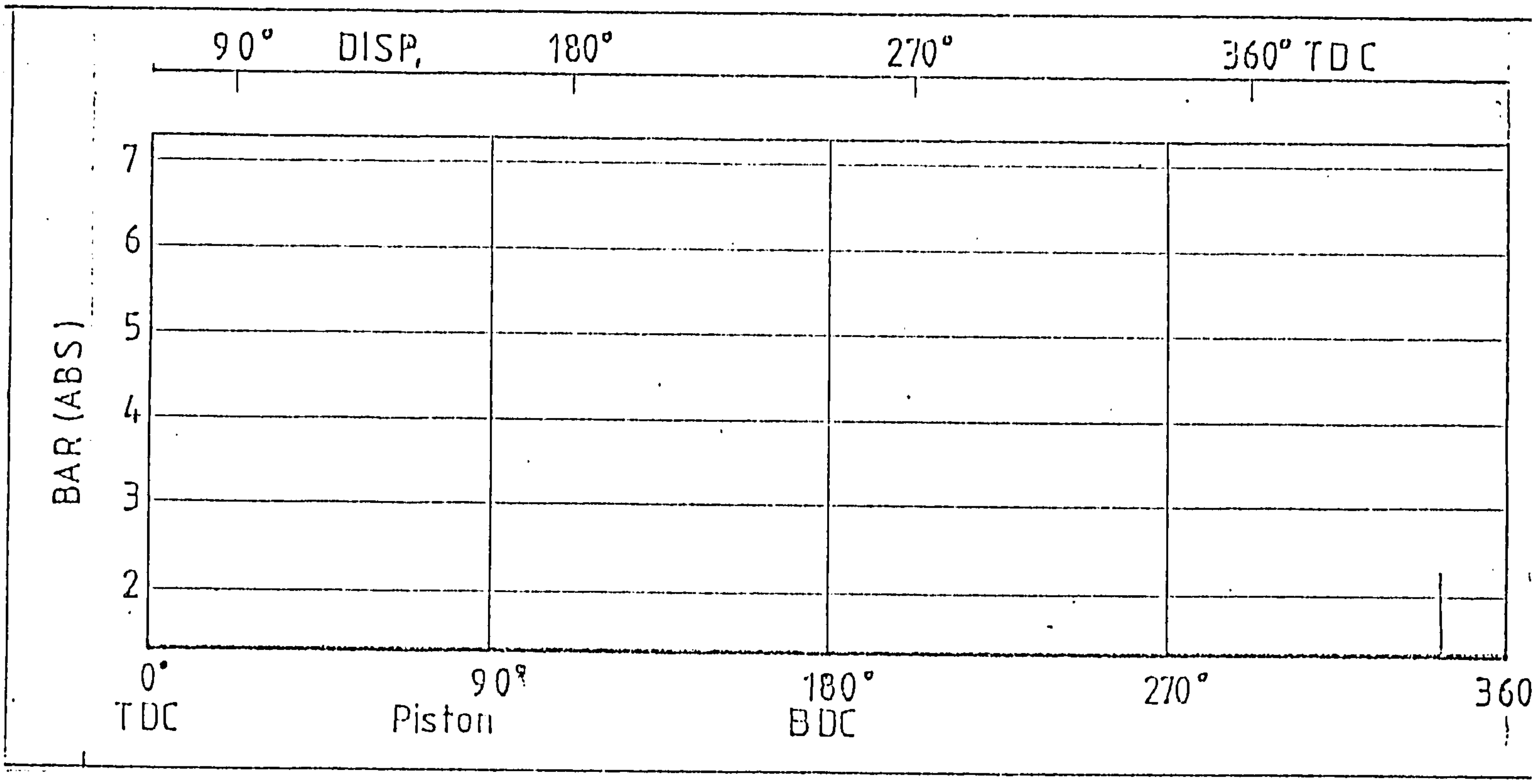


40

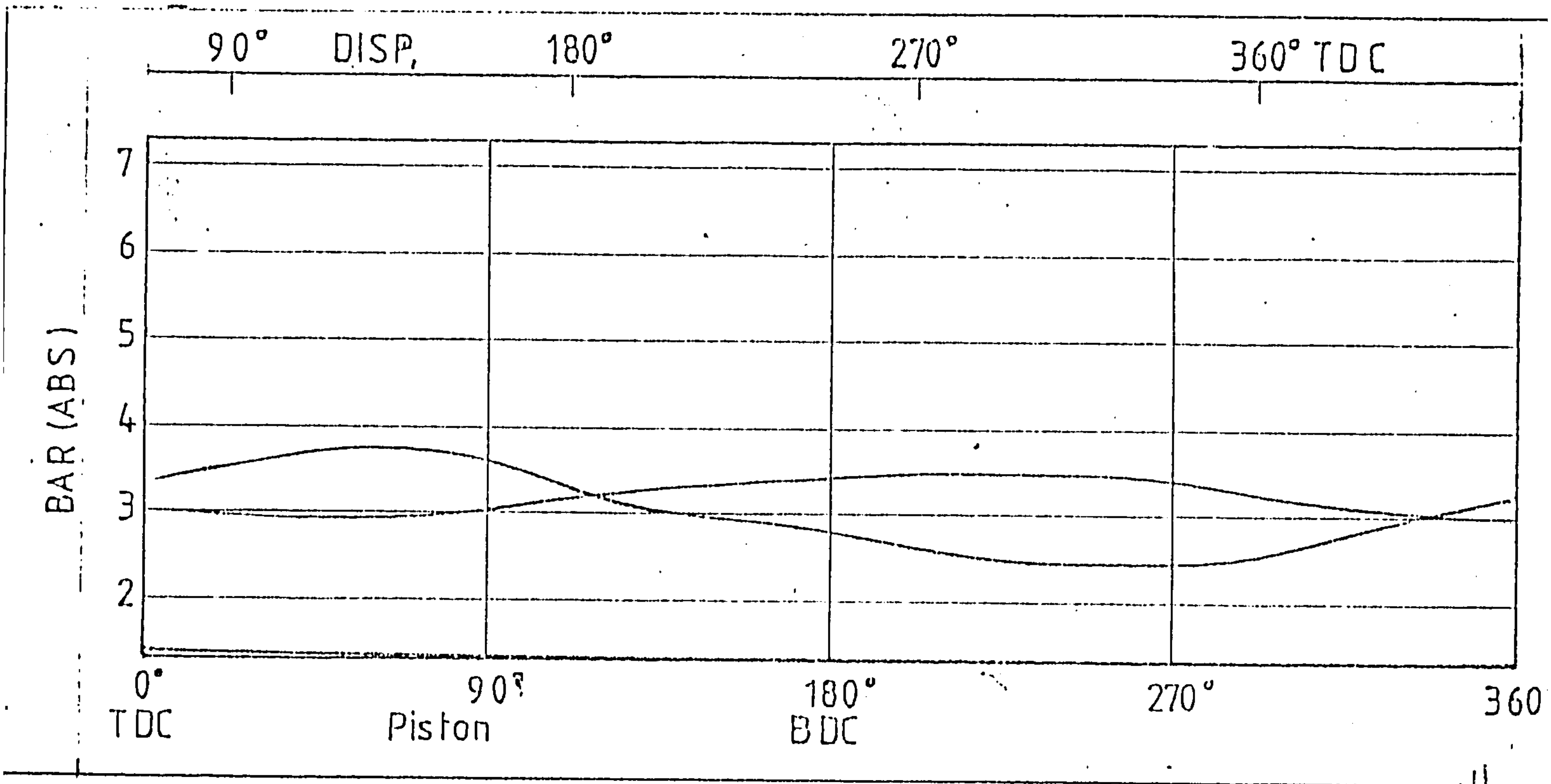
PRESSURE VARIATIONS IN WORKING SPACE AND CRANKCASE

DATE: Oct.26. 1985
RUN :

TIME: 09:46 Piston TDC before correcting



TIME: 10:00

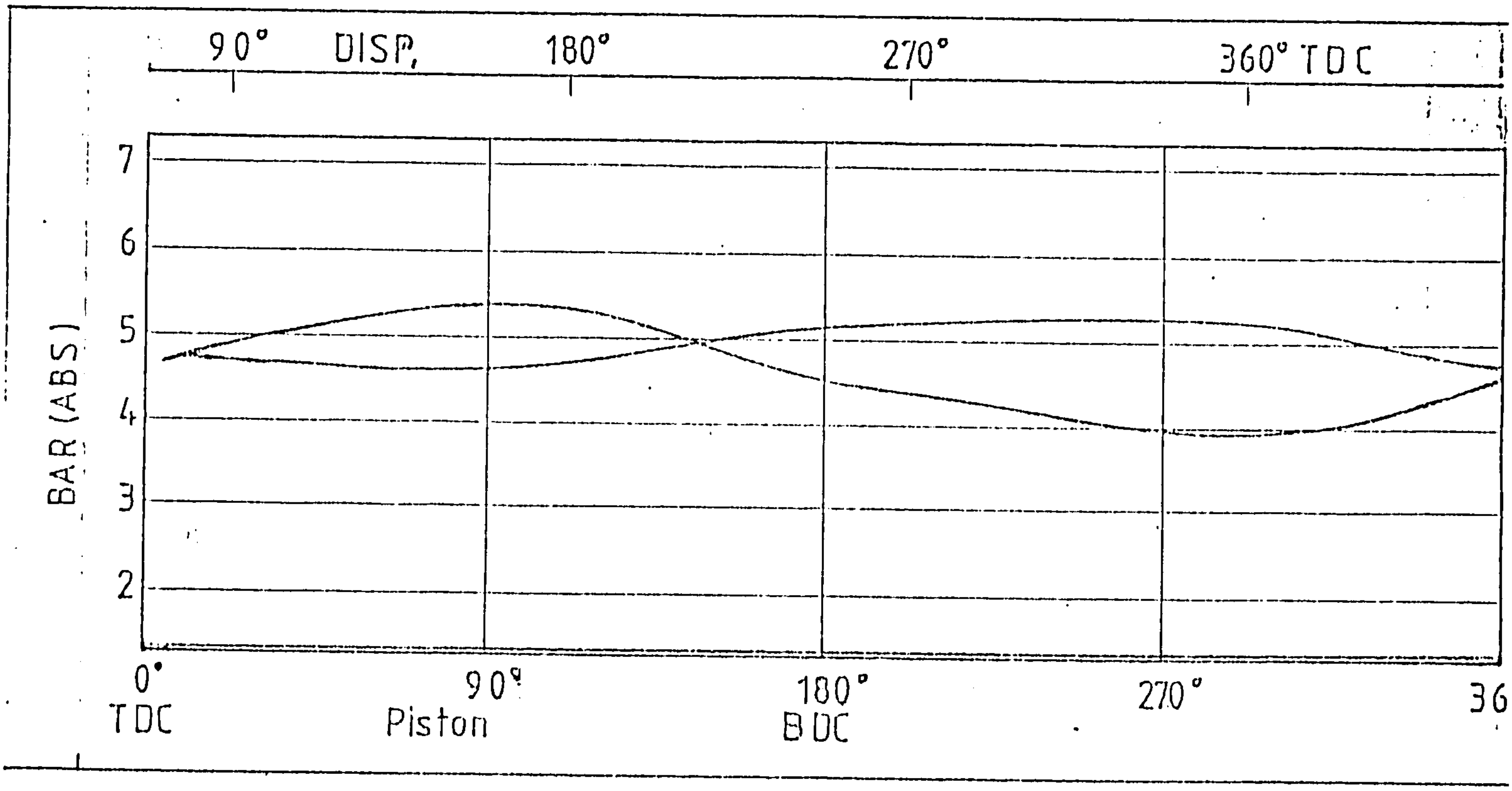


41

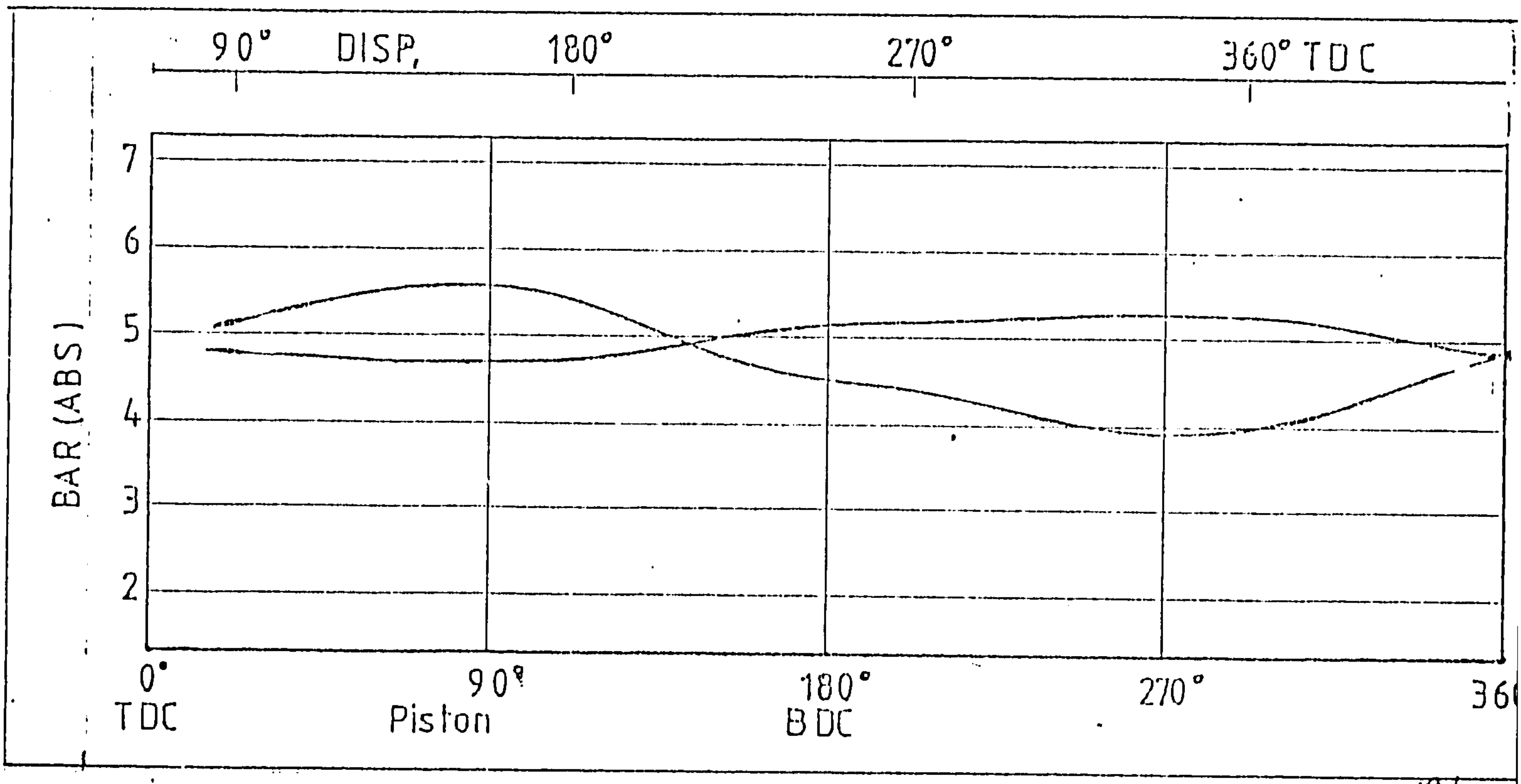
PRESSURE VARIATIONS IN WORKING SPACE AND CRANKCASE

DATE: Oct.26. 1985
RUN :

TIME: 10:05



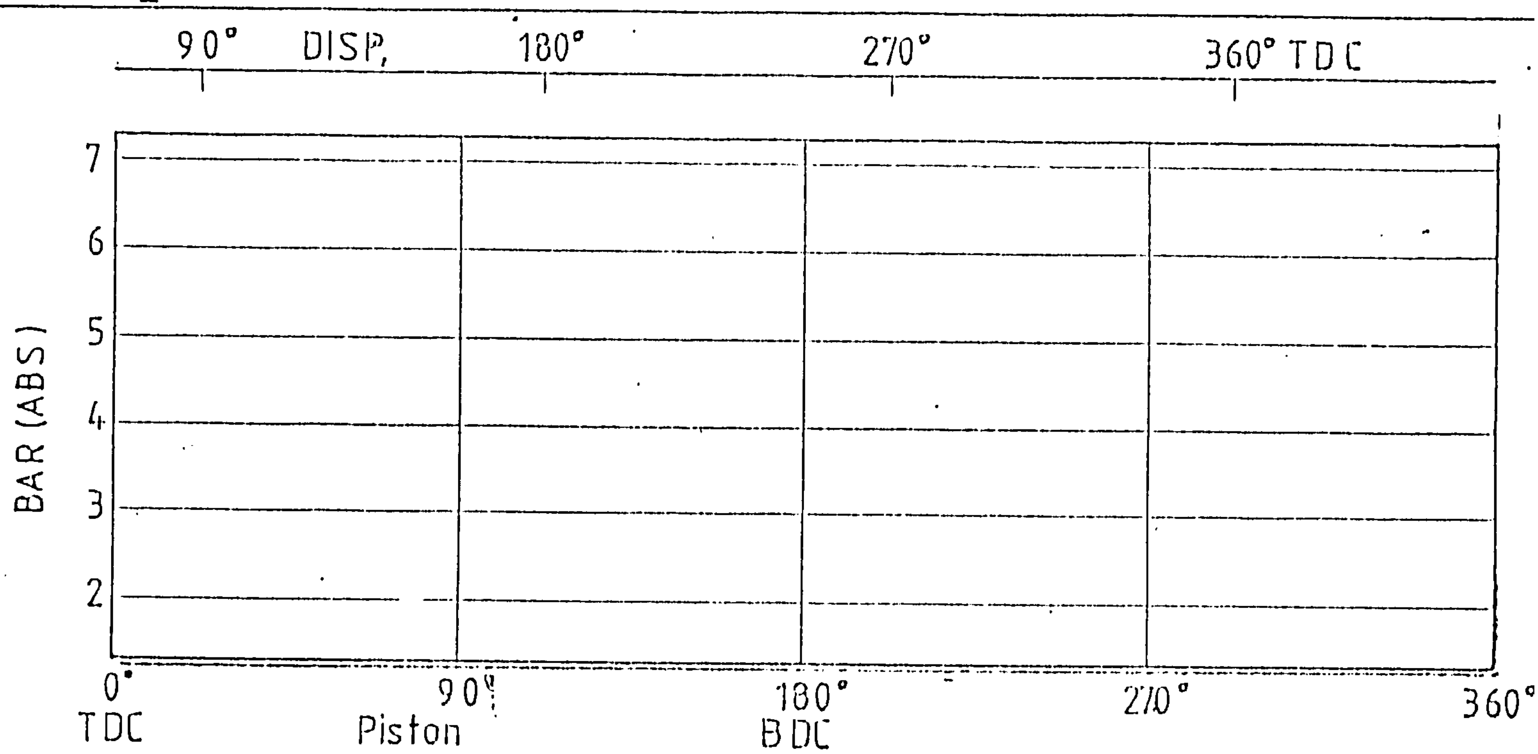
TIME: 10:10



PRESSURE VARIATIONS IN WORKING SPACE AND CRANKCASE

DATE: Oct.26. 1985
RUN :

TIME: 10:48 Piston TDC calibration check



TIME:

H3

APPENDIX C

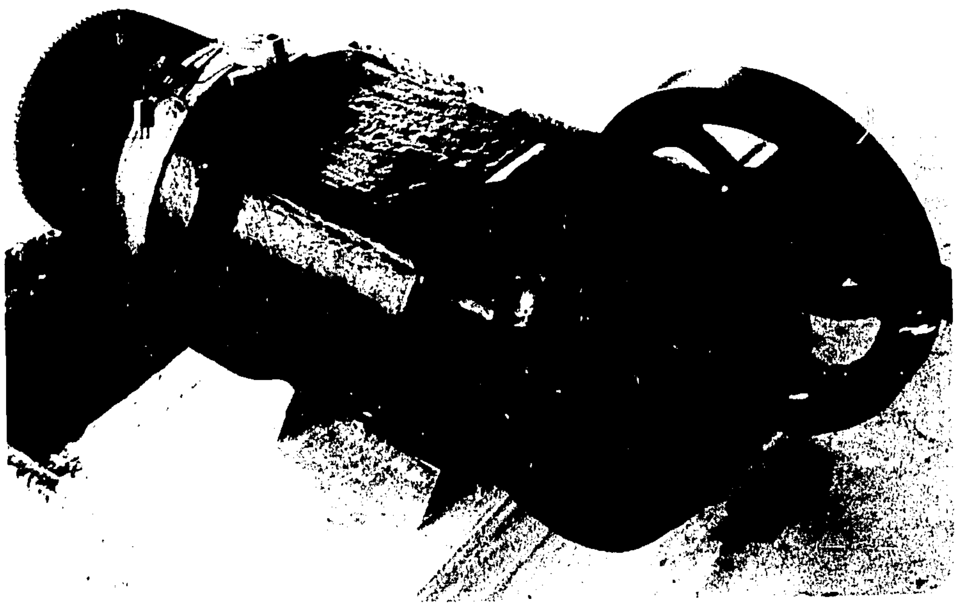
PHOTOGRAPHS

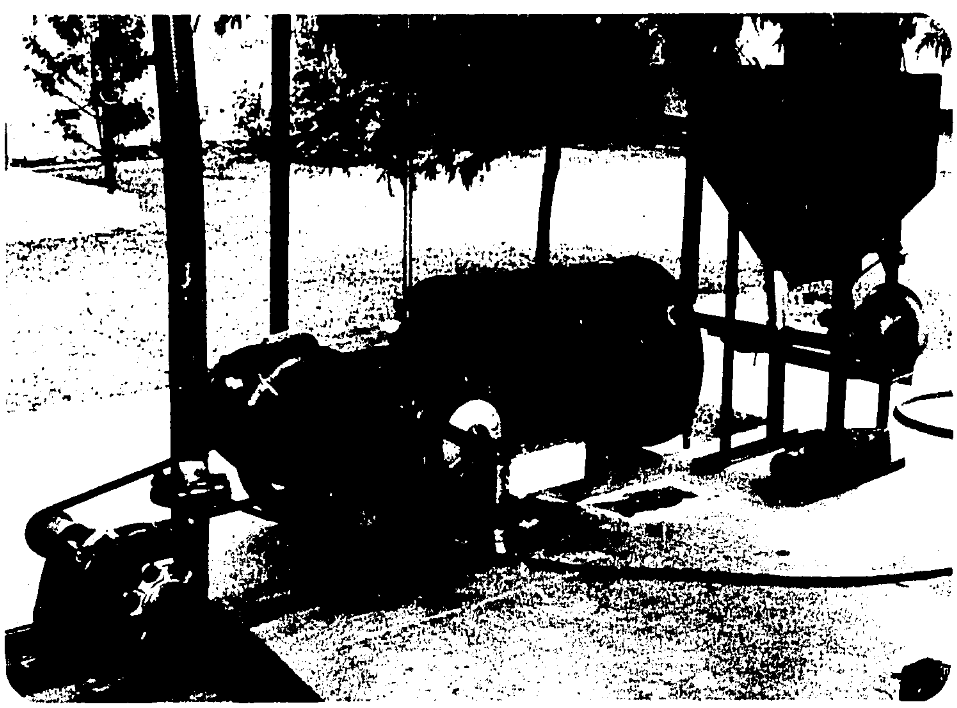
Photograph No.1

Prototype set up for testing
in Bangladesh

Photograph No.2

Displacer, piston and linkage
of prototype engine





Photograph No.3

First intermediate model

Photograph No.4

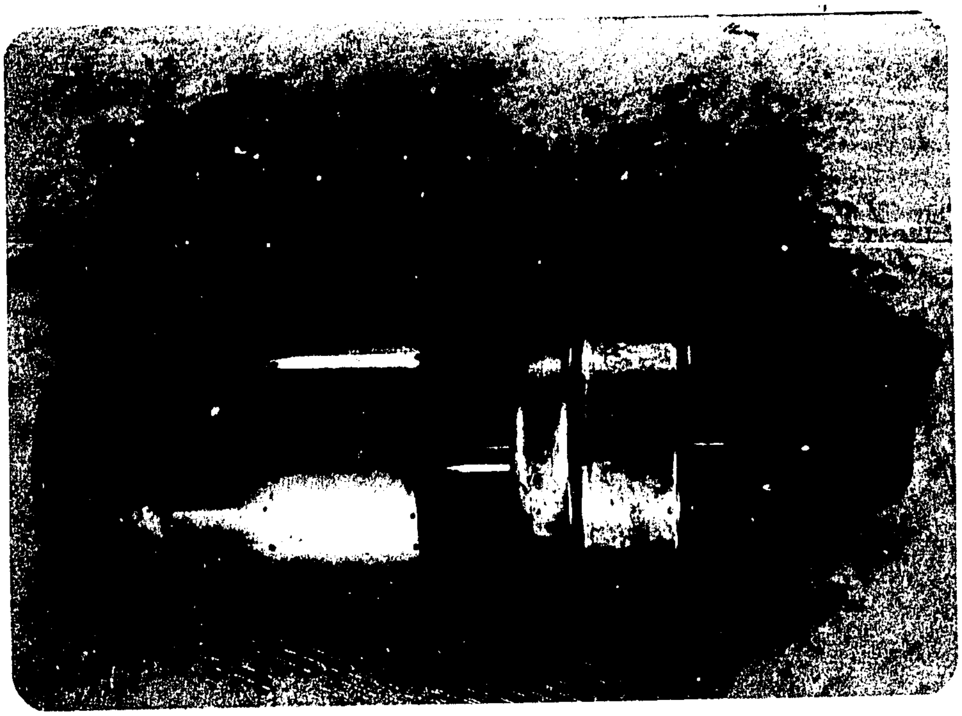
First intermediate model belted to large water pump for loading. The elements of a blower and water pump are at the side but these designs were never used.

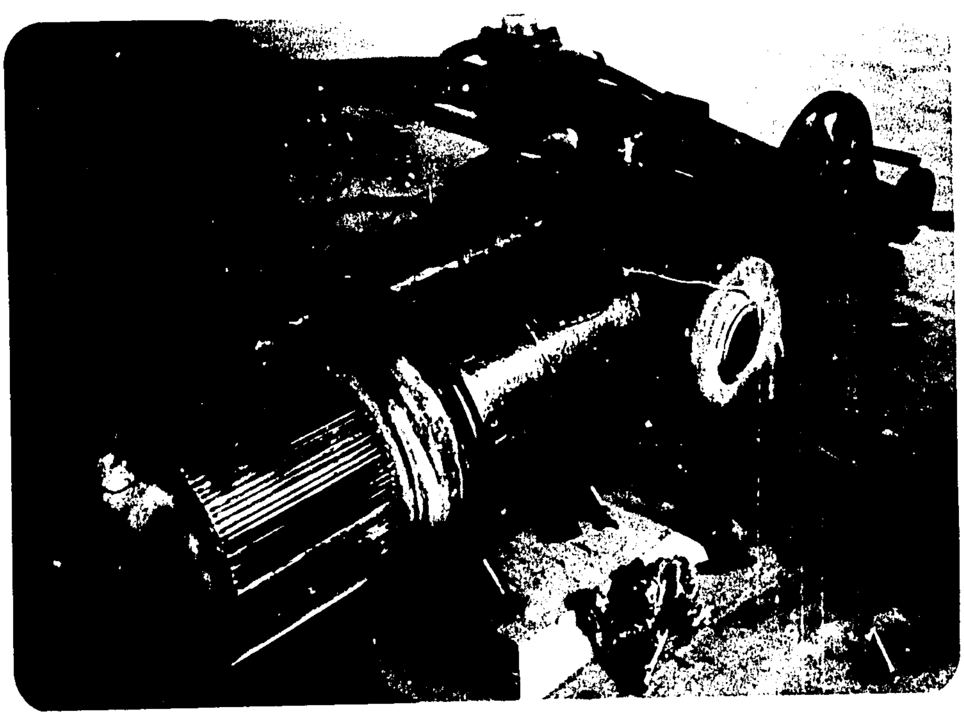
Photograph No.5

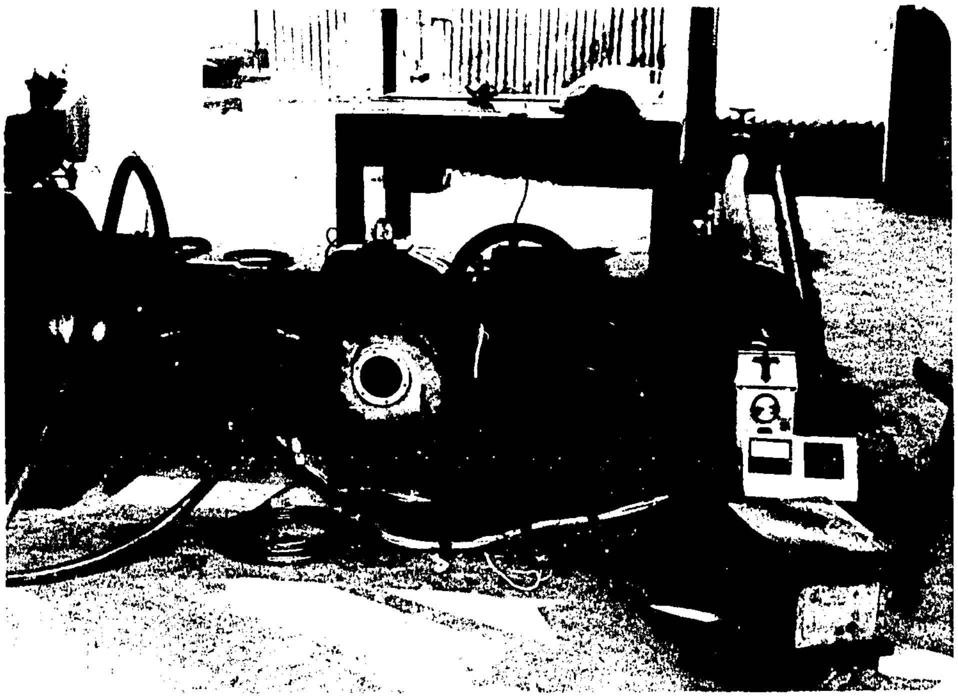
Displacer, piston and linkage of the first intermediate model. The compressor piston on the bellcrank was part of a design for a built-in compressor that was not successful

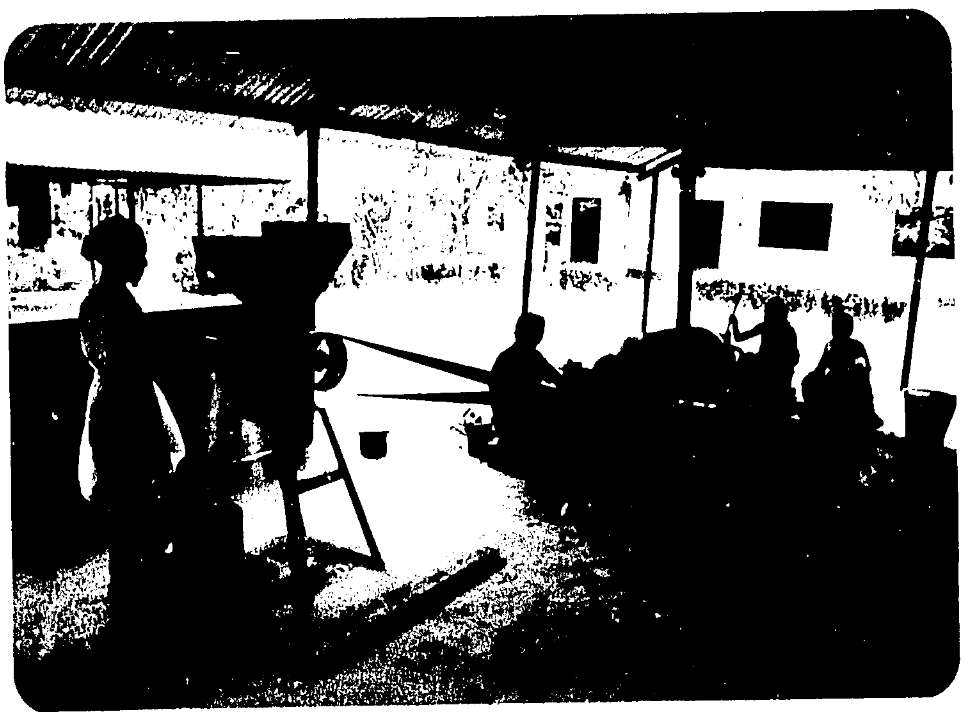
Photograph No.6

The second intermediate model with the locally brazed heater.









Photograph No.7

The second intermediate model with the external compressor belted to the jack shaft

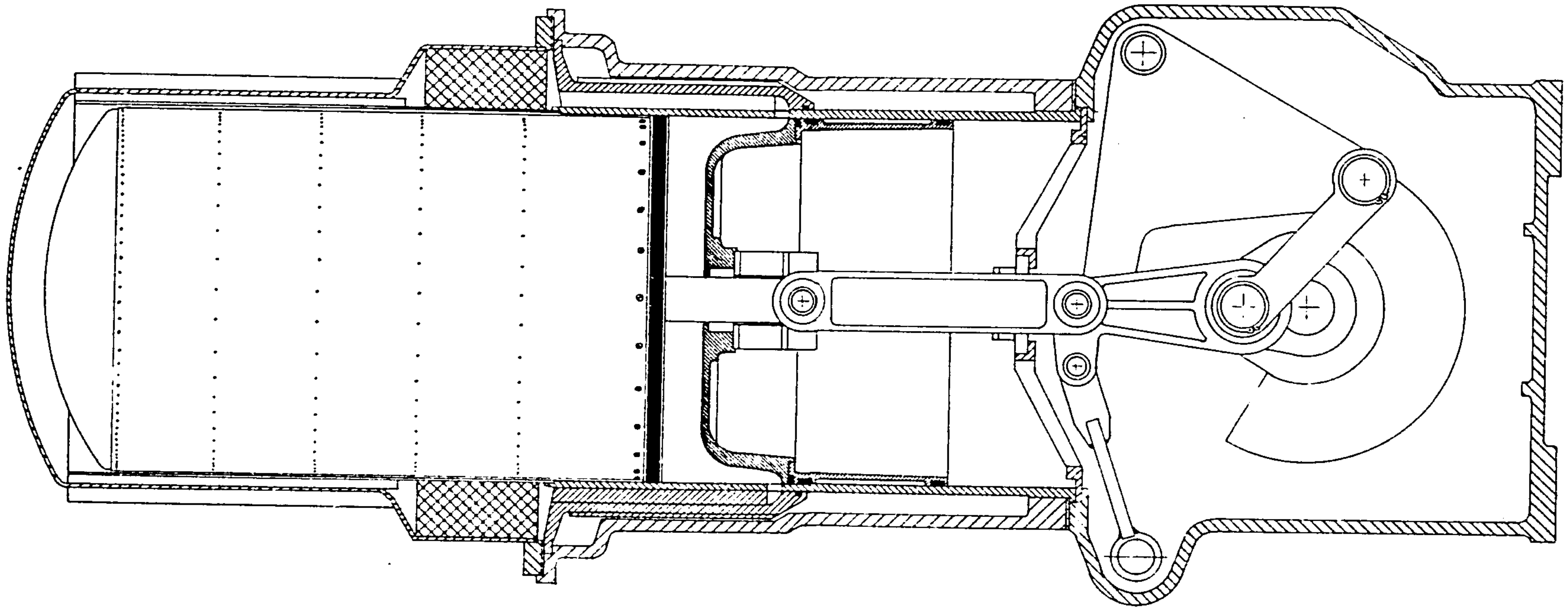
Photograph No.8

Operating the No.4 rice huller with the second intermediate model

APPENDIX D

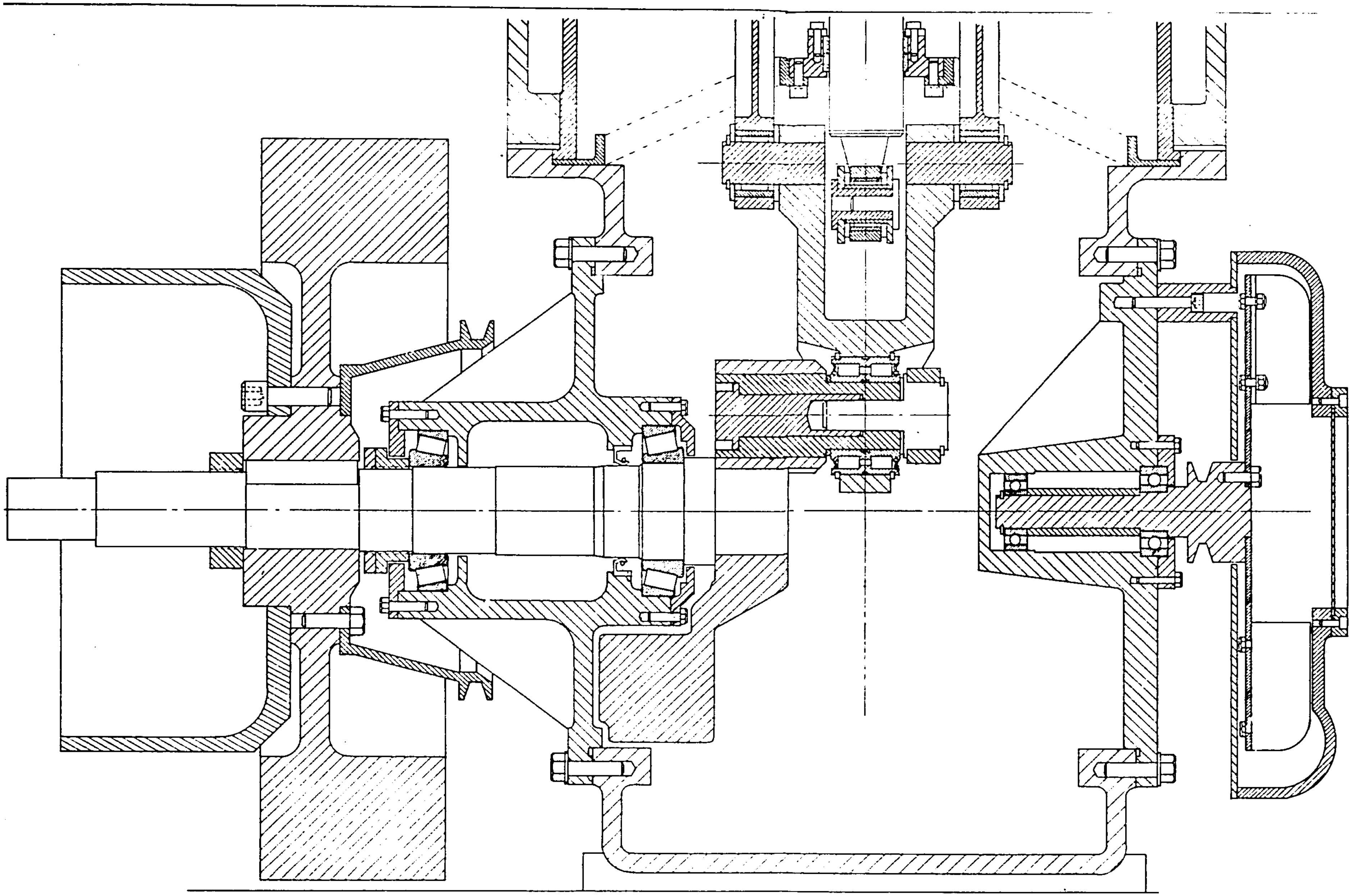
DESIGN DRAWINGS

INDEX TO DESIGN DRAWINGS



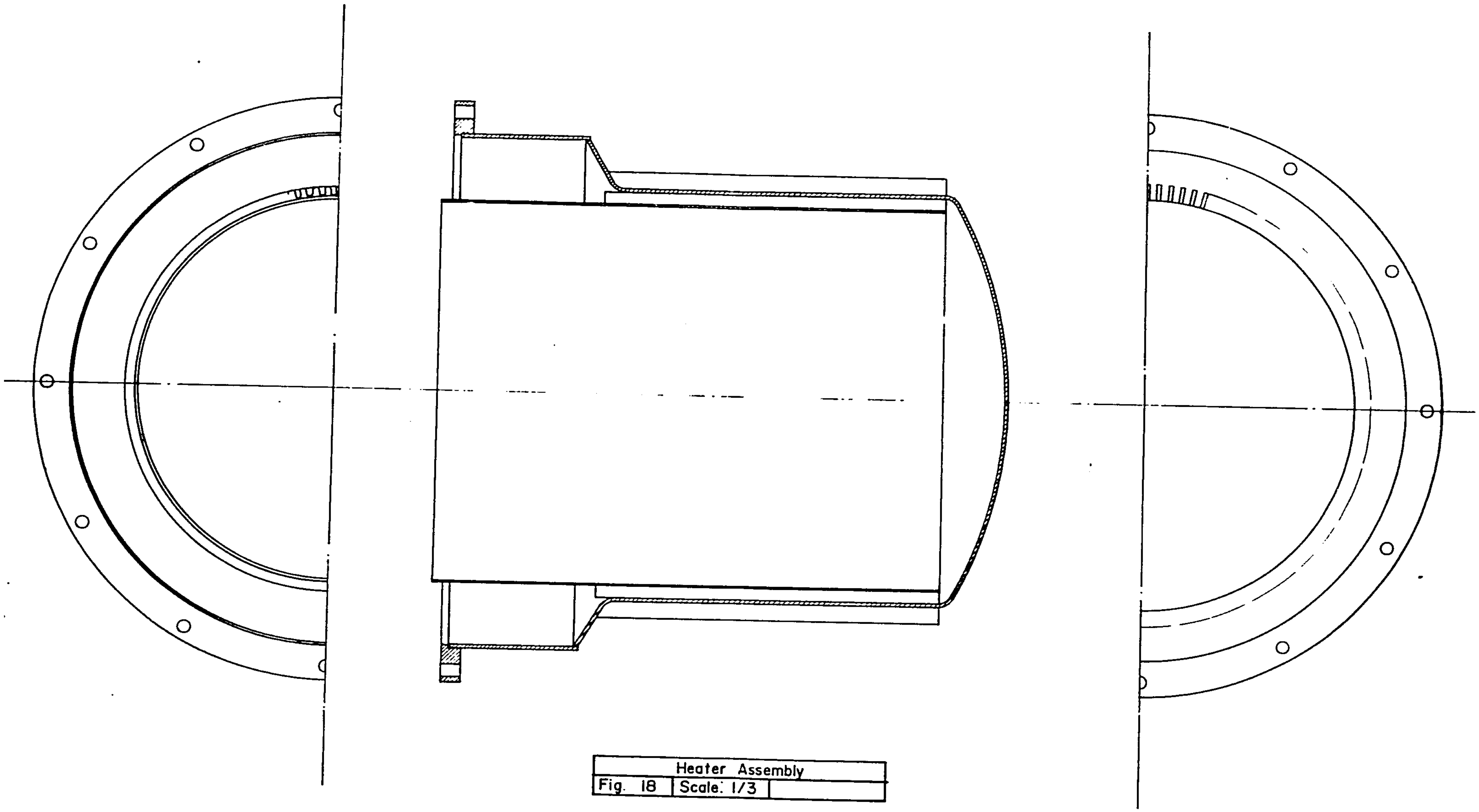
Engine Assembly		
Fig. 1	Scale 1/4	

RICE HUSK ENERGY PROJECT	Page
Second Intermediate Model	



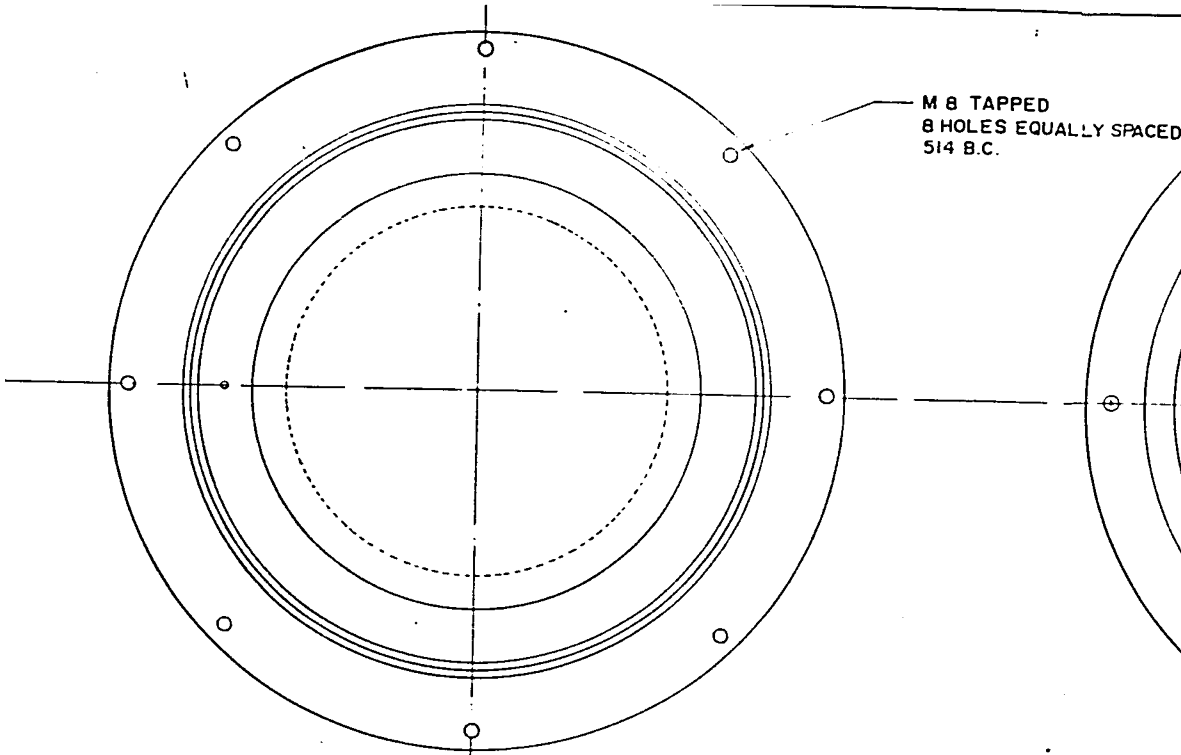
Crankcase Assembly		
Fig. 2	Scale: 1/2	

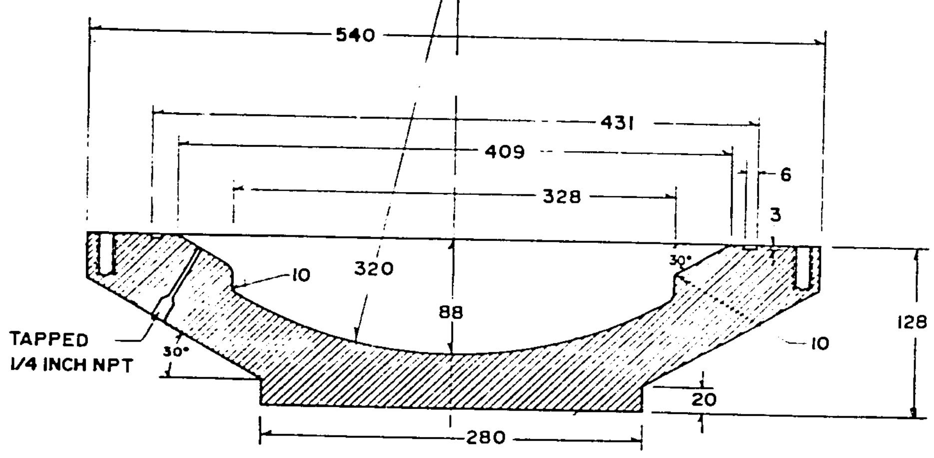
RICE HUSK ENERGY PROJECT	Page
Second Intermediate Model	2



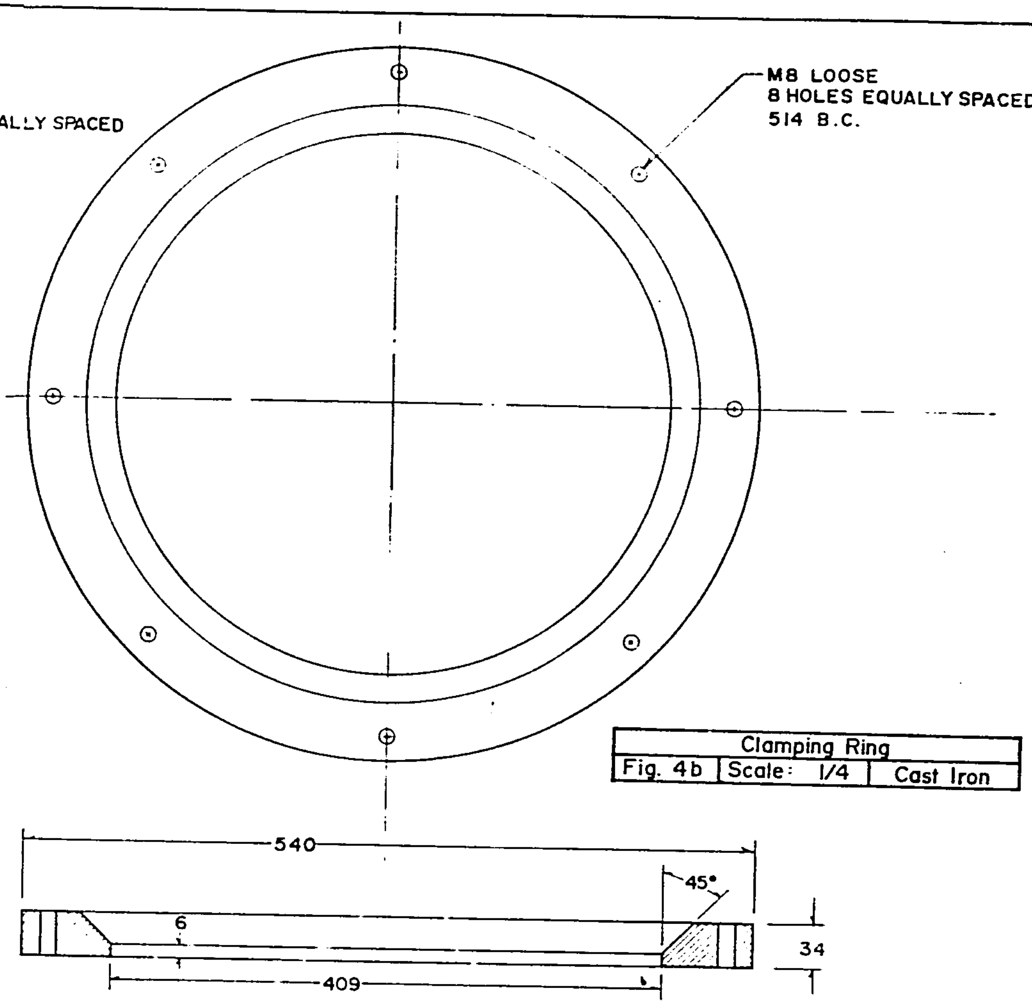
Heater Assembly		
Fig. 18	Scale: 1/3	

RICE HUSK ENERGY PROJECT	Page
Second Intermediate Model	3

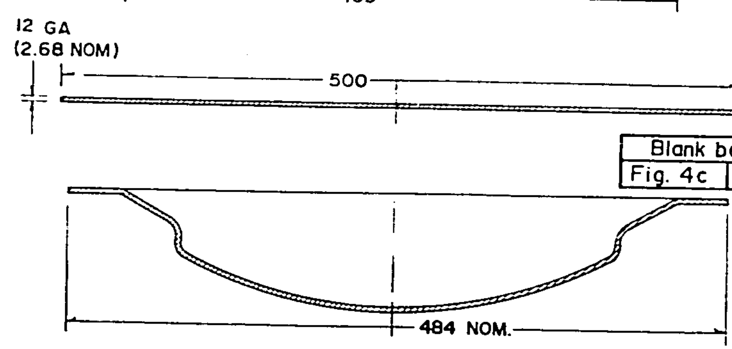




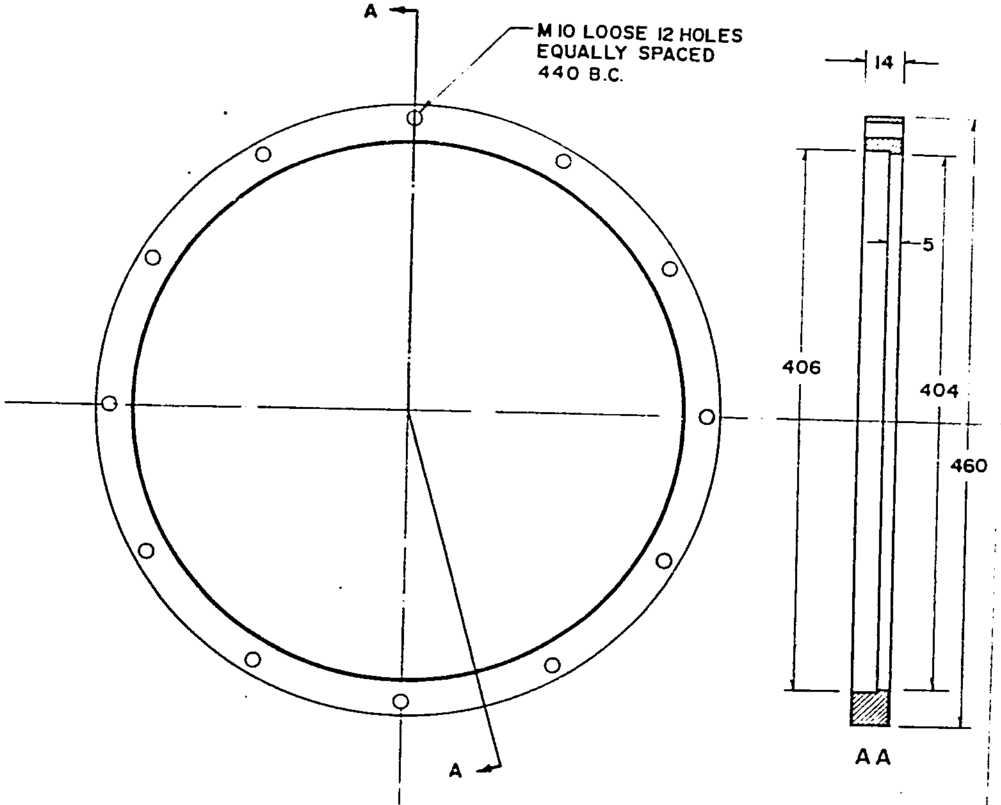
Die For Heater Dome		
Fig. 4a	Scale: 1/4	Cast Iron



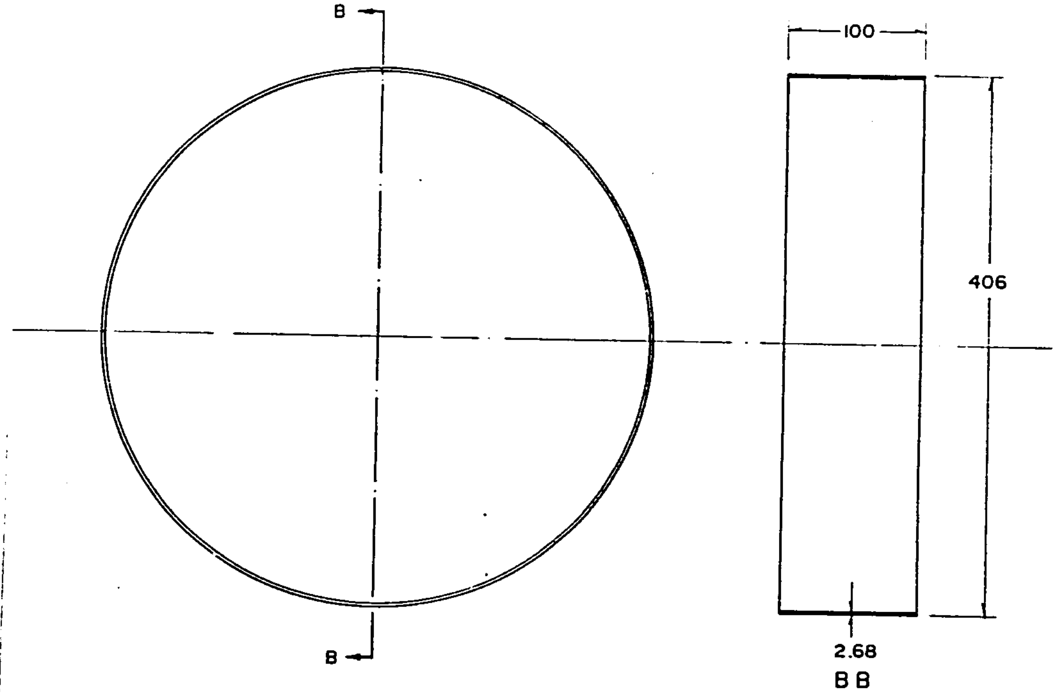
Clamping Ring		
Fig. 4b	Scale: 1/4	Cast Iron



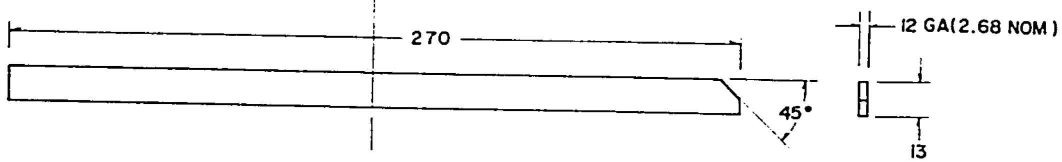
Blank before and after Forming		
Fig. 4c	Scale: 1/4	304 SS.



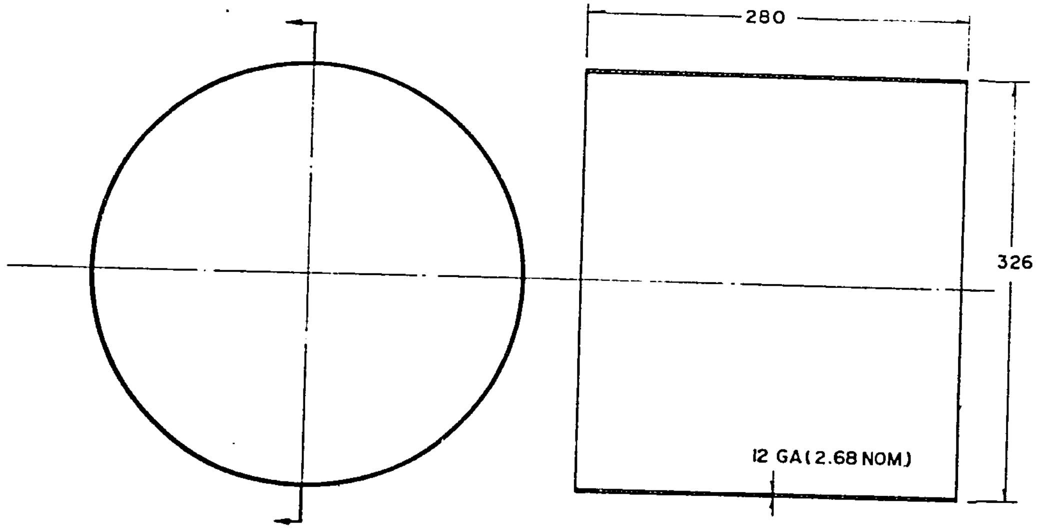
Heater Flange		
Fig. 5a	Scale: 1/4	Mild Steel



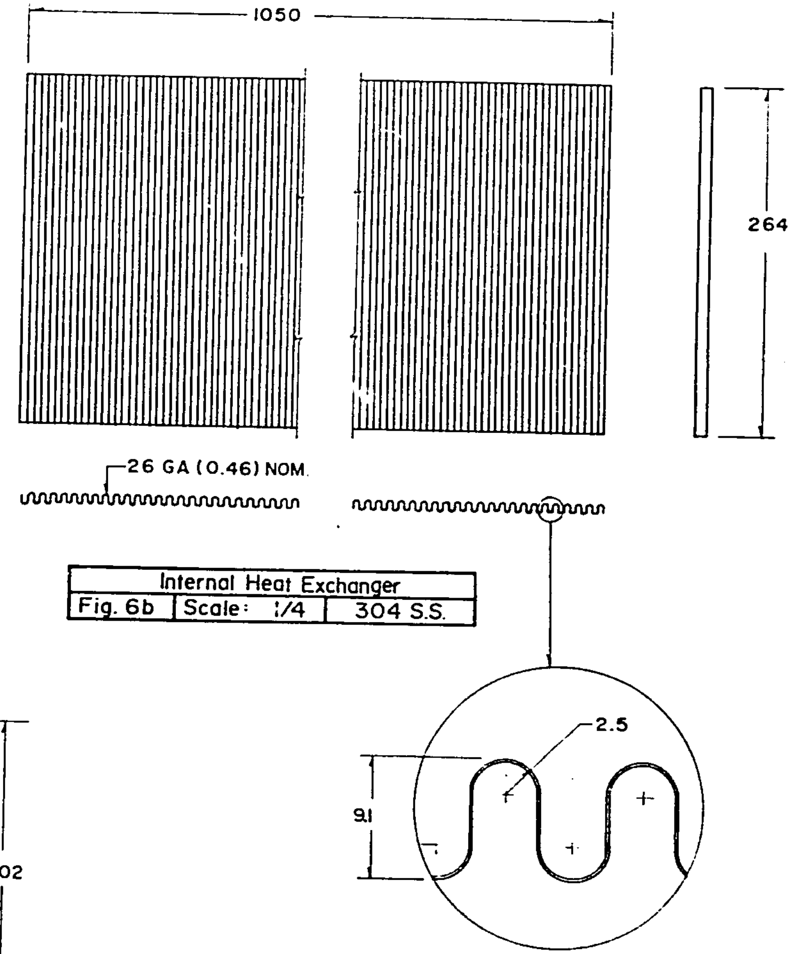
Heater Regenerator Housing		
Fig. 5b	Scale: 1/4	304 S.S.



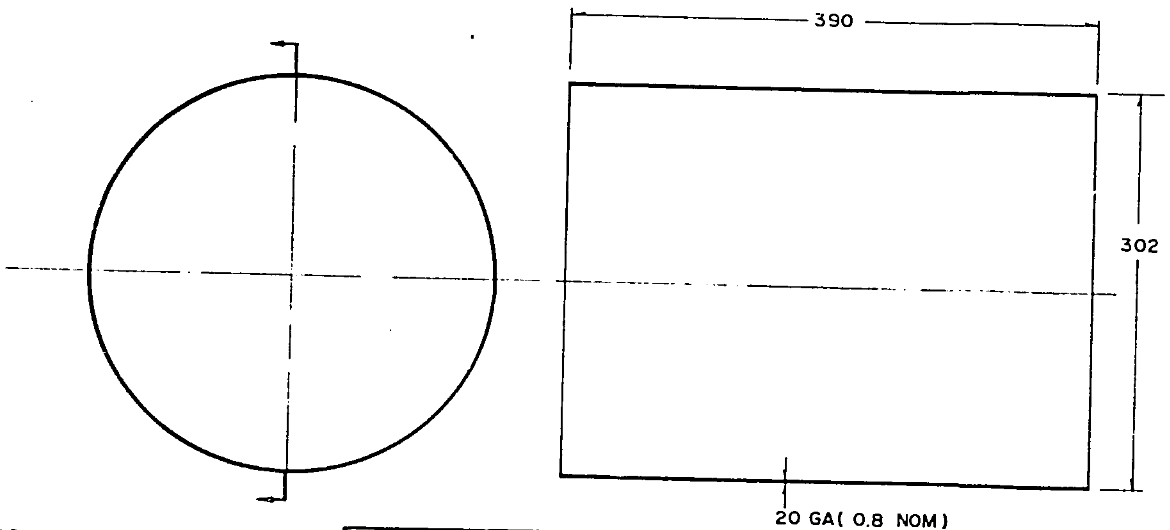
External Heater Fin		
Fig. 5c	Scale: 1/2	304 S.S.



Heater Can		
Fig. 6a	Scale: 1/4	304 S.S.

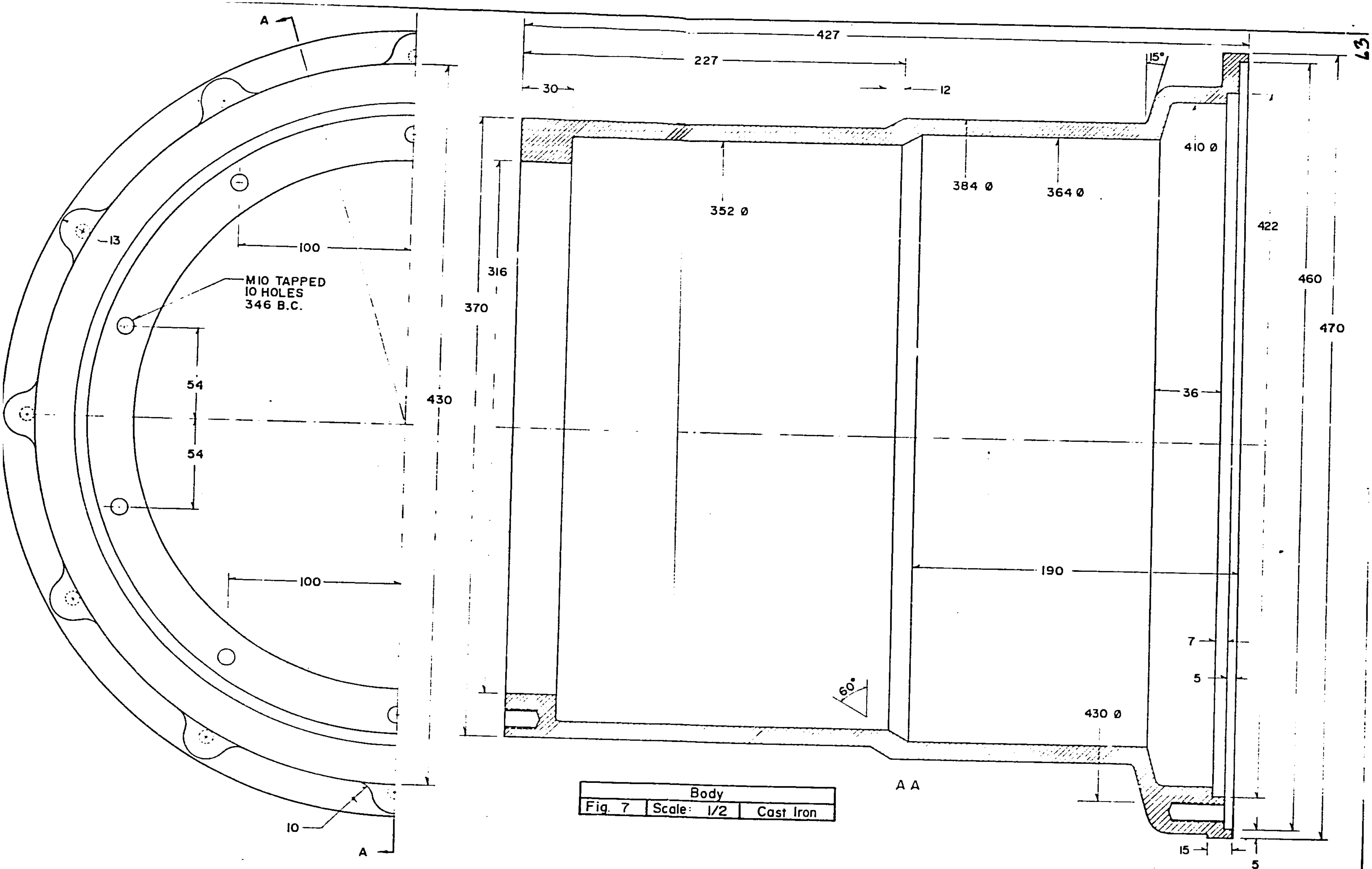


Internal Heat Exchanger		
Fig. 6b	Scale: 1/4	304 S.S.



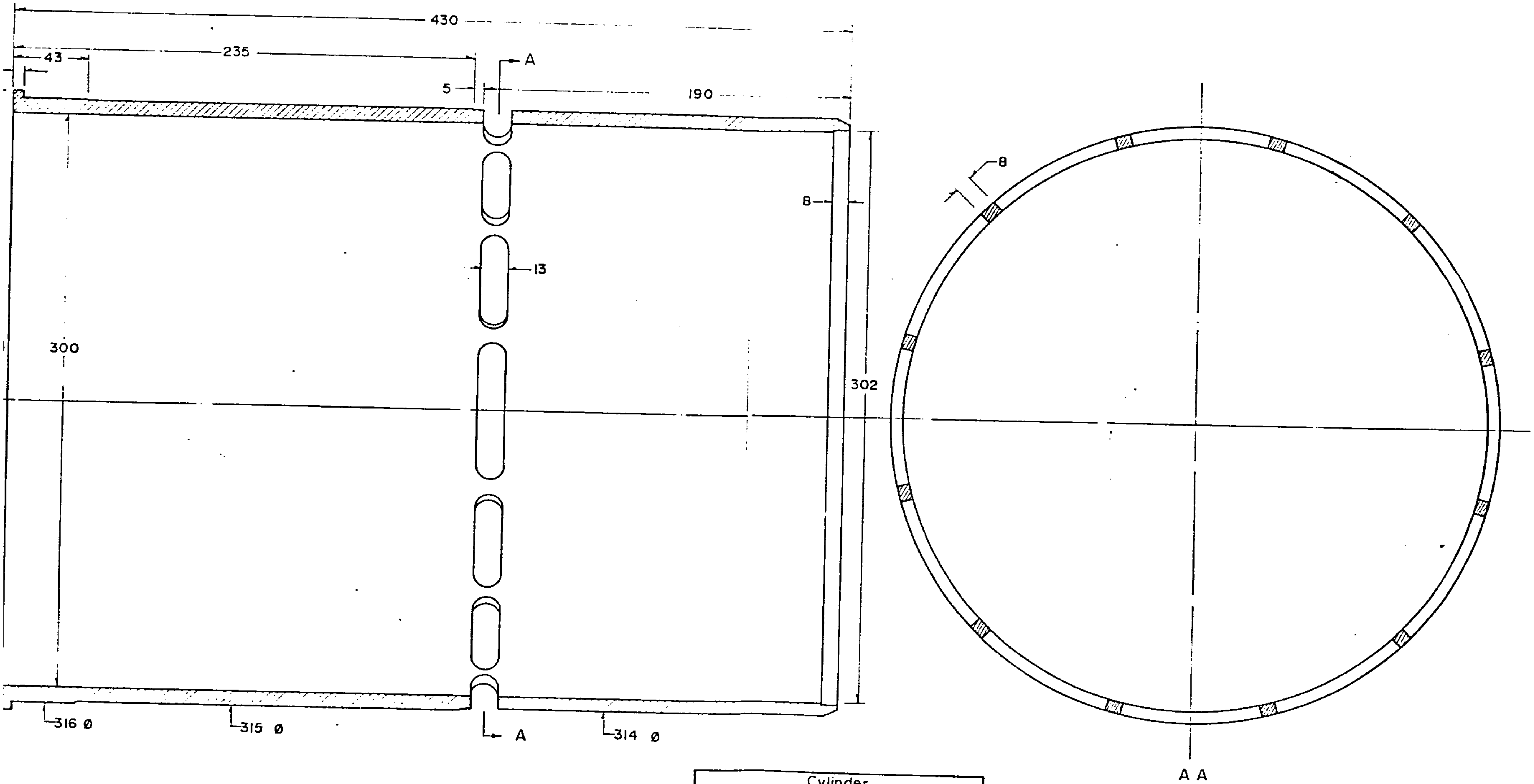
Internal Liner		
Fig. 6c	Scale: 1/4	304 S.S.

RICE HUSK ENERGY PROJECT	Page
Second Intermediate Model	6



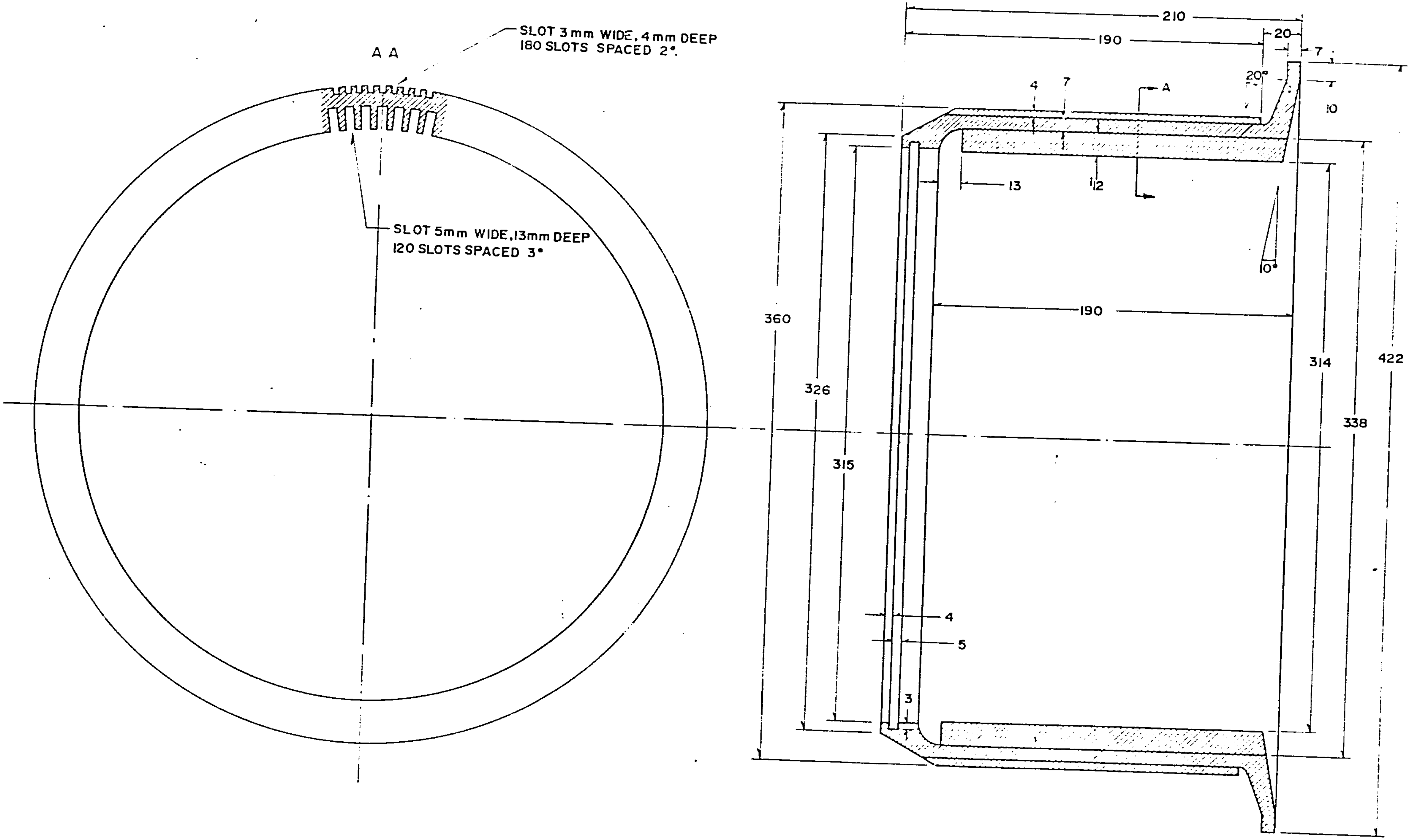
Body		
Fig. 7	Scale: 1/2	Cast Iron

RICE HUSK ENERGY PROJECT	Page
Second Intermediate Model	7



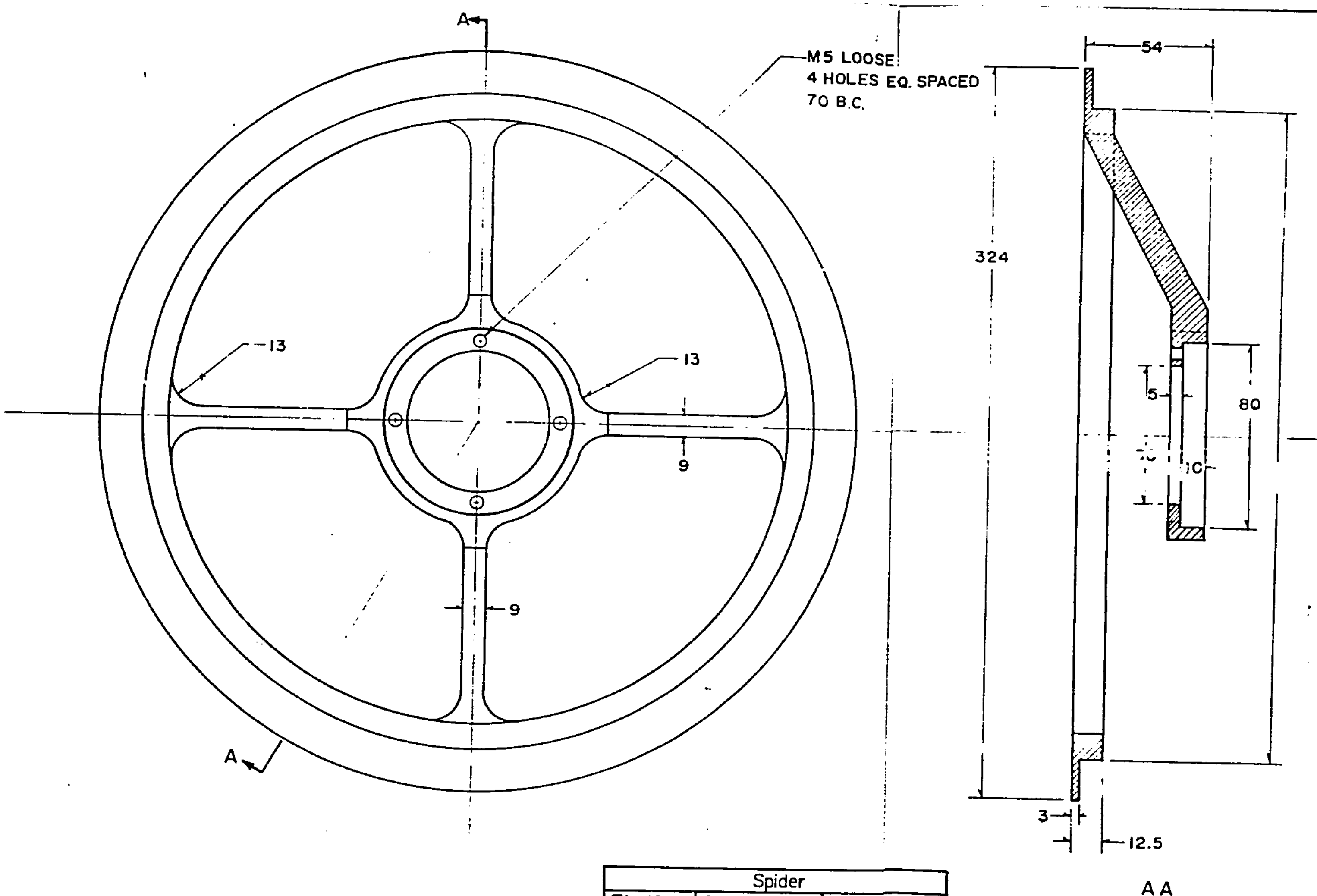
Cylinder		
Fig. 9	Scale 1/2	Cast Iron

RICE HUSK ENERGY PROJECT	Page
Second Intermediate Model	9

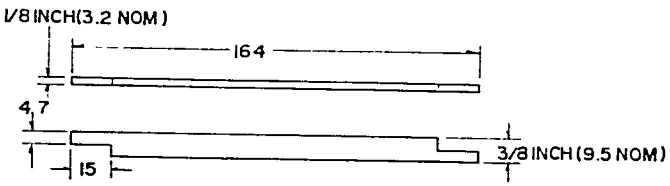


Cooler		
Fig. 8	Scale: 1/2	Cast Alum.

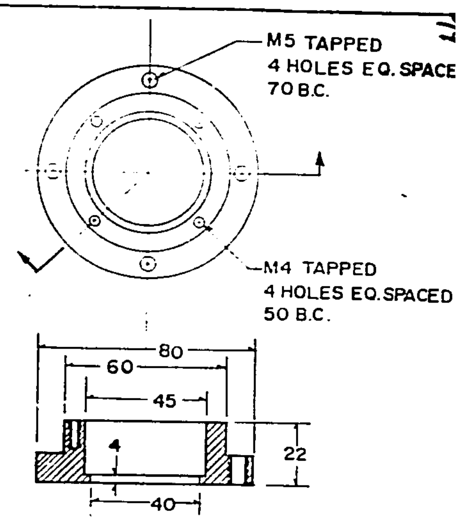
RICE HUSK ENERGY PROJECT — Page
Second Intermediate Model — 8



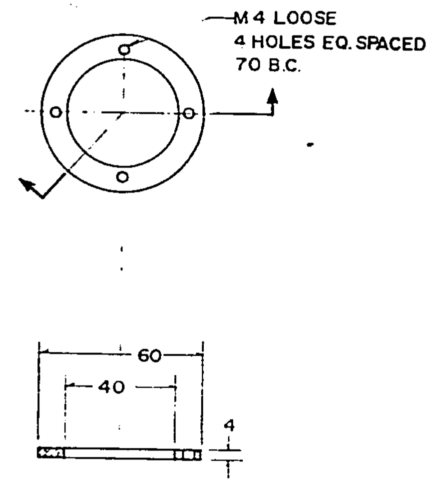
Spider		
Fig. 10 a	Scale: 1/2	Cast Iron



Tube Guide		
Fig 10b	Scale: 1/2	PTFE Alloy

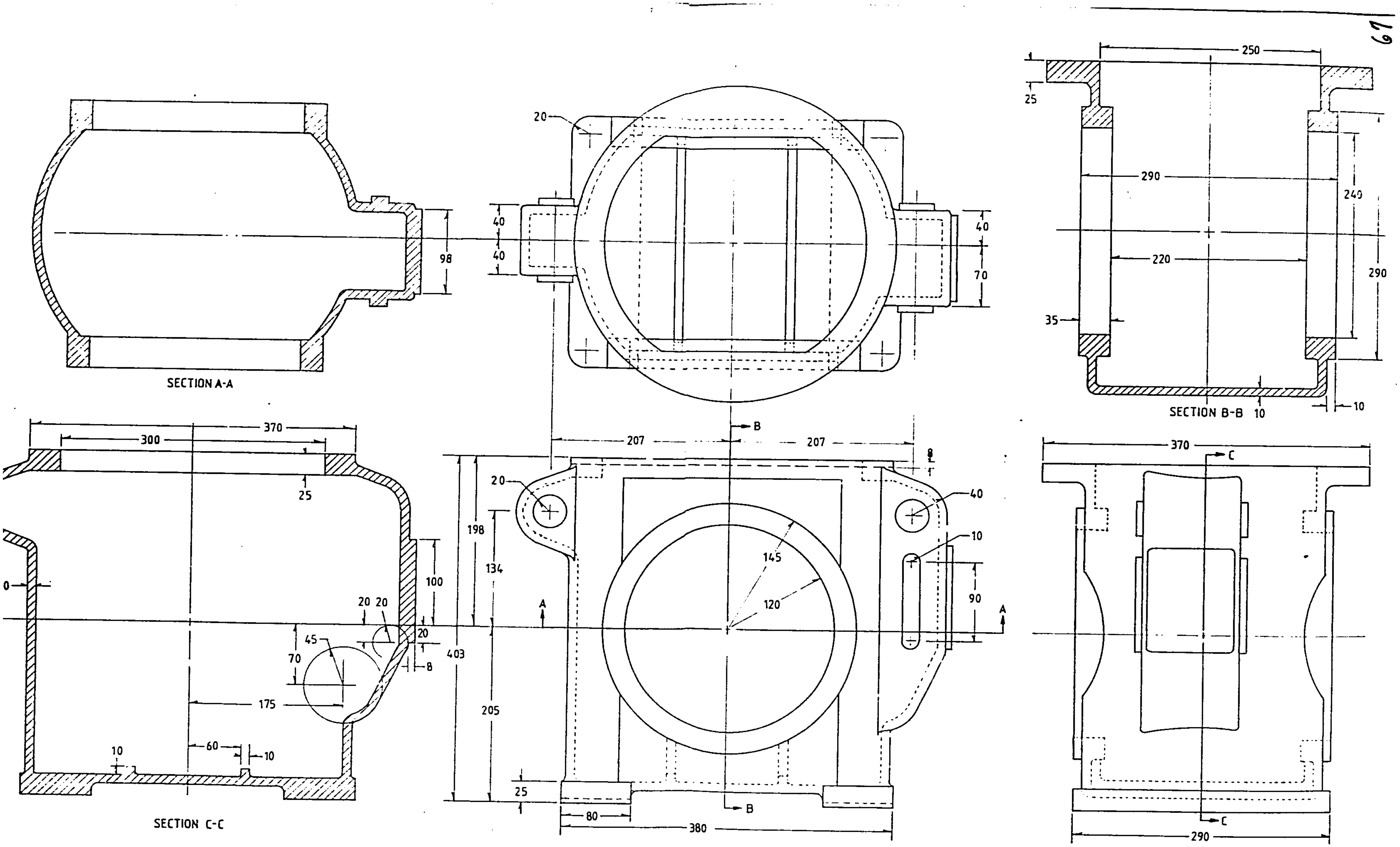


Tube Guide Holder		
Fig 10c	Scale: 1/2	Mild Steel



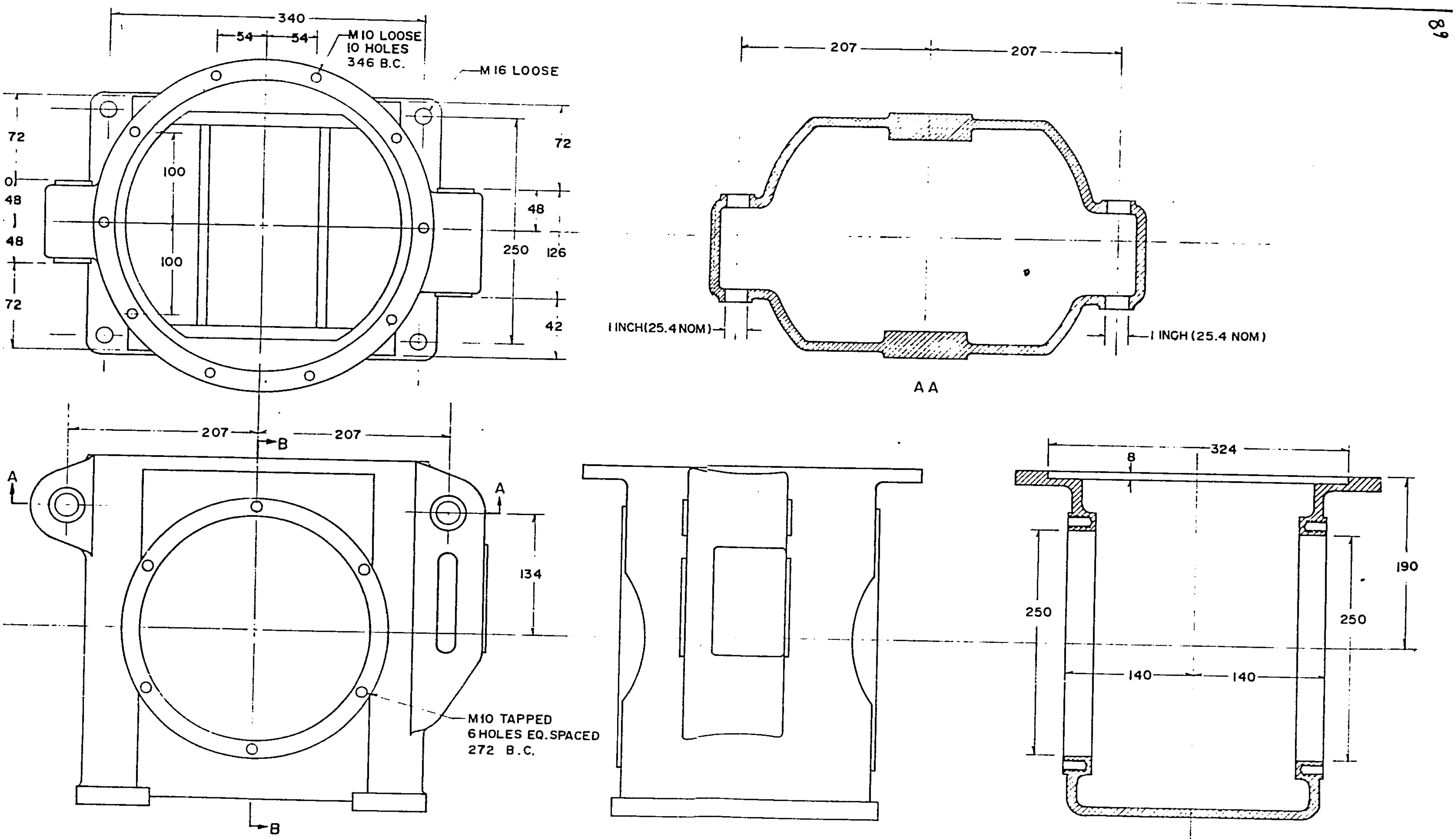
Tube Guide Retainer		
Fig. 10d	Scale: 1/2	Mild Steel

RICE HUSK ENERGY PROJECT	Page
Second Intermediate Model	10



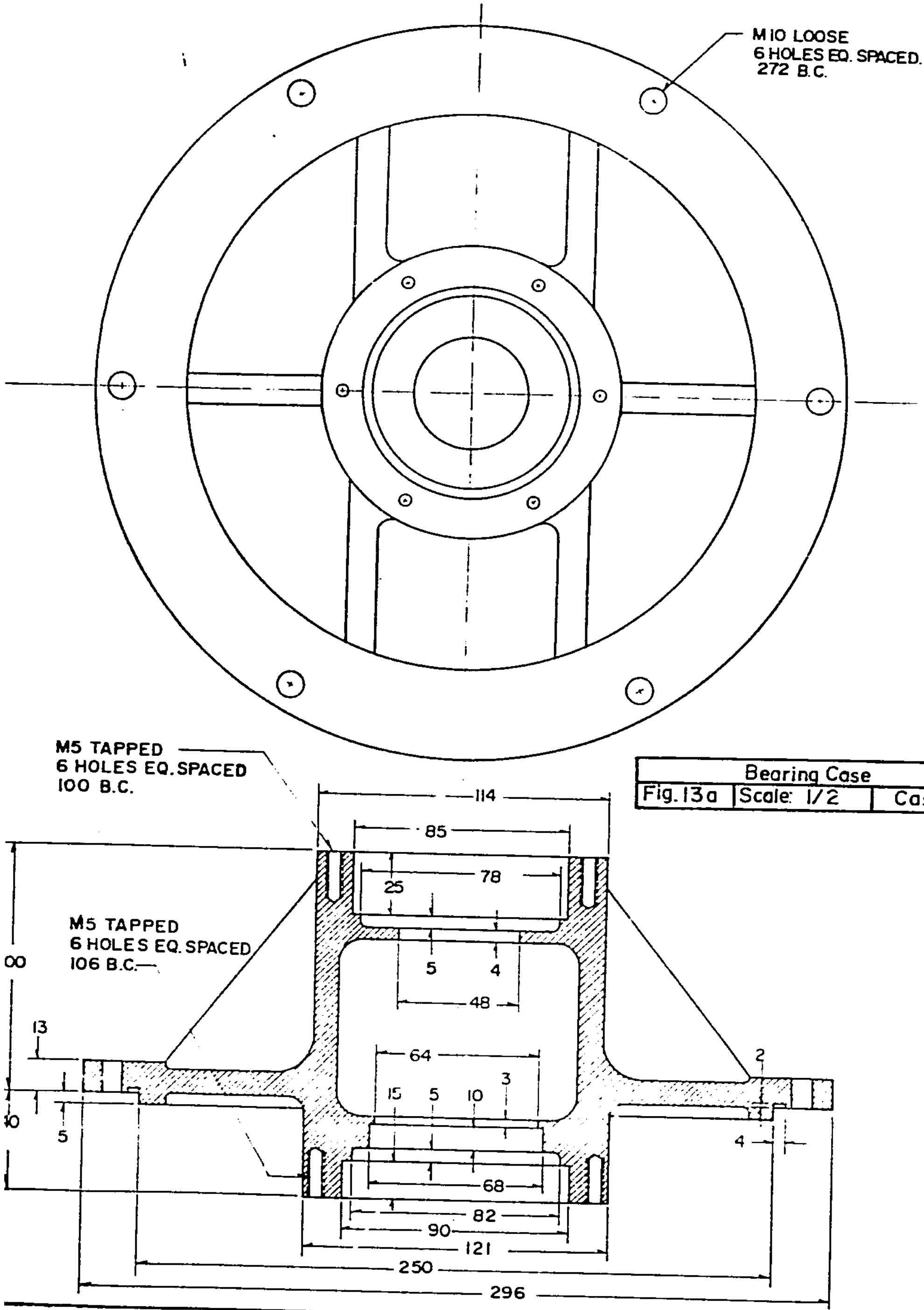
Crankcase Casting		
Fig. II	Scale: 1/4	Cast Iron

RICE HUSK ENERGY PROJECT	Page
Second Intermediate Model	11

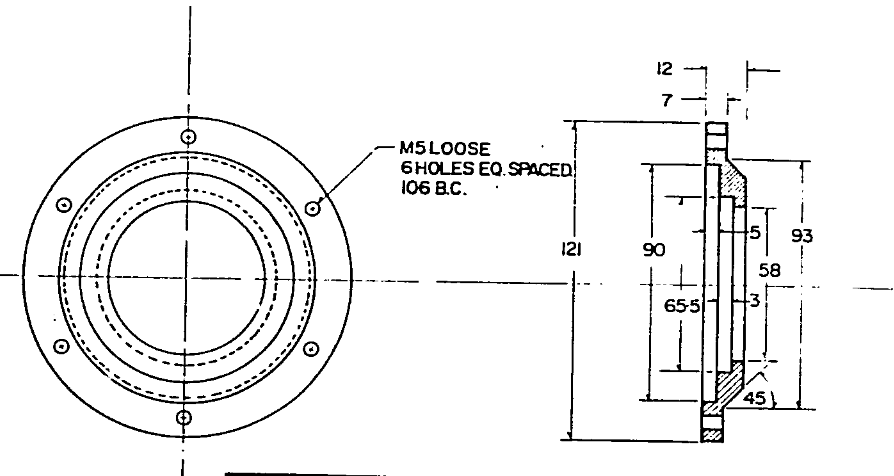


Crankcase Machining Dimensions		
Fig. 12	Scale: 1/4	Cast Iron

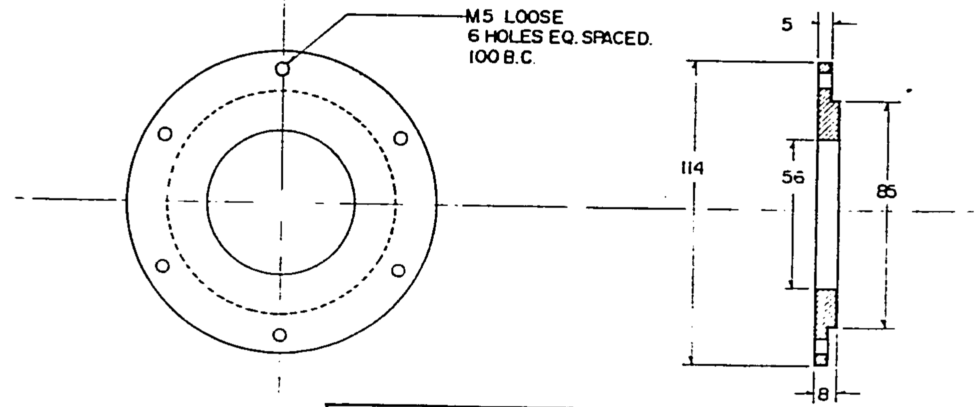
RICE HUSK ENERGY PROJECT	Page
Second Intermediate Model	12



Bearing Case		
Fig. 13a	Scale: 1/2	Cast Iron

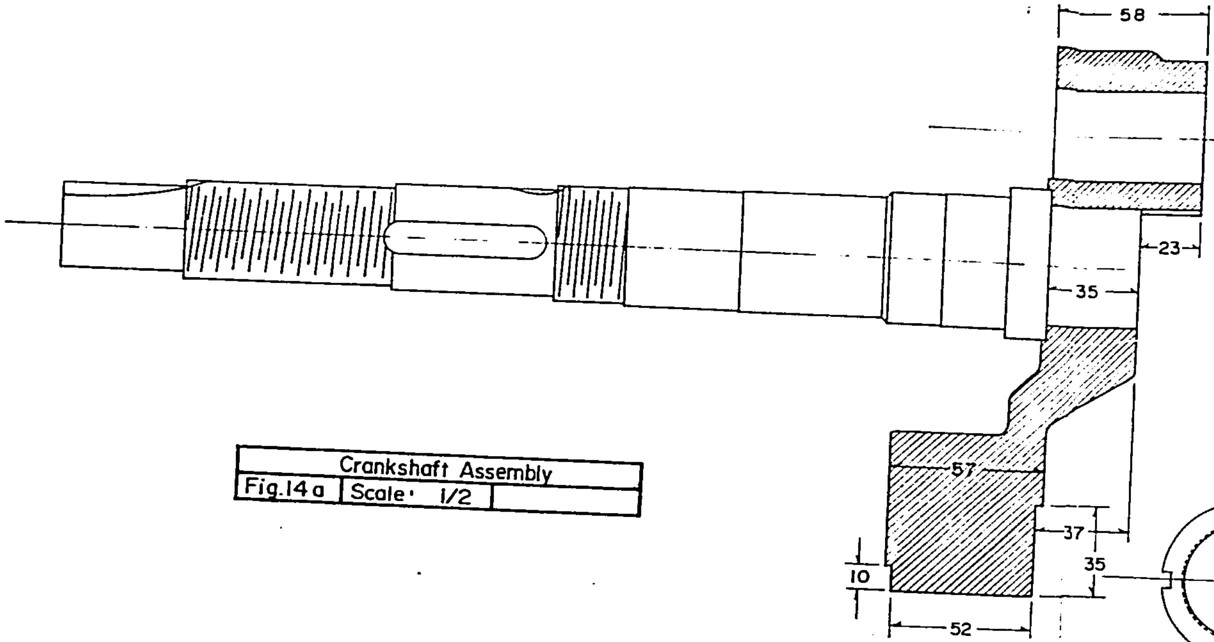


Inner Bearing Cap		
Fig. 13b	Scale: 1/2	Cast Iron

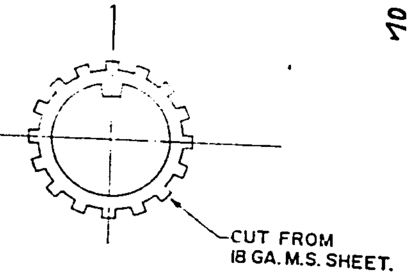


Outer Bearing Cap		
Fig. 13c	Scale: 1/2	Cast Iron

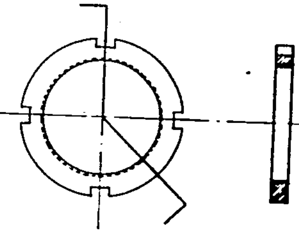
RICE HUSK ENERGY PROJECT	Page
Second Intermediate Model	13



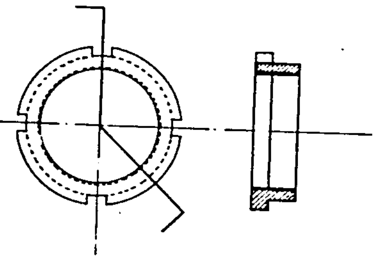
Crankshaft Assembly		
Fig. 14 a	Scale : 1/2	



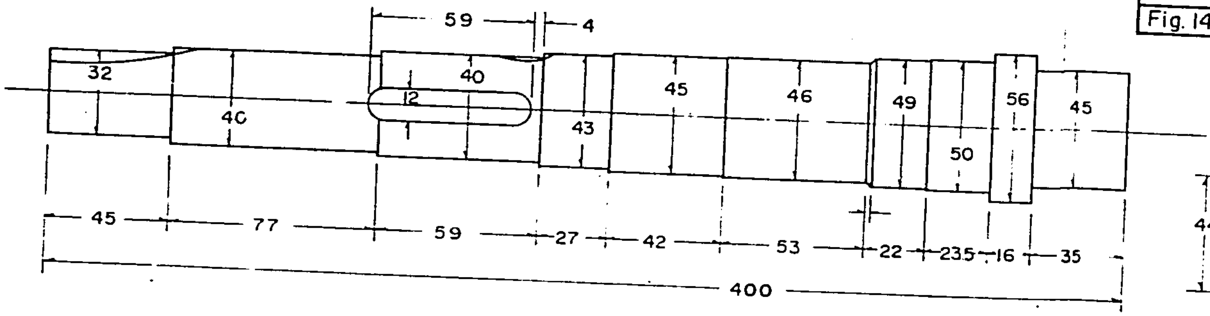
Lockwasher		
Fig. 14 c	Scale : 1/2	Mild Steel



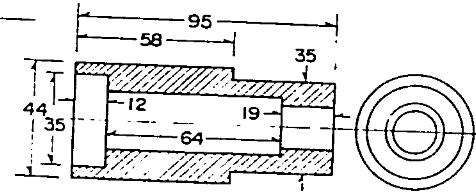
Outside Locknut		
Fig. 14 d	Scale : 1/2	Mild Steel



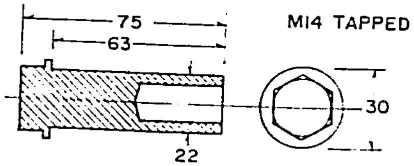
Inside Locknut		
Fig. 14 e	Scale : 1/2	Mild Steel



Crankshaft		
Fig. 14 b	Scale : 1/2	Mild Steel

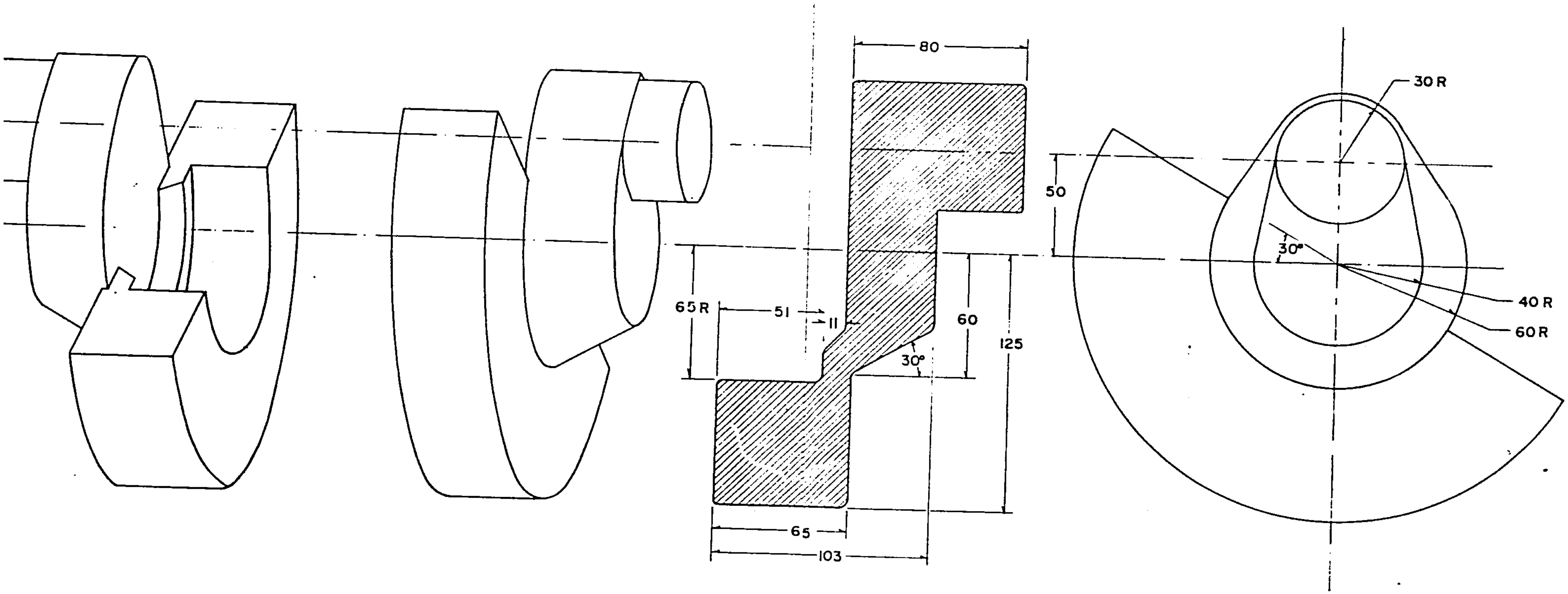


Crank Throw		
Fig. 14 f	Scale : 1/2	Mild Steel

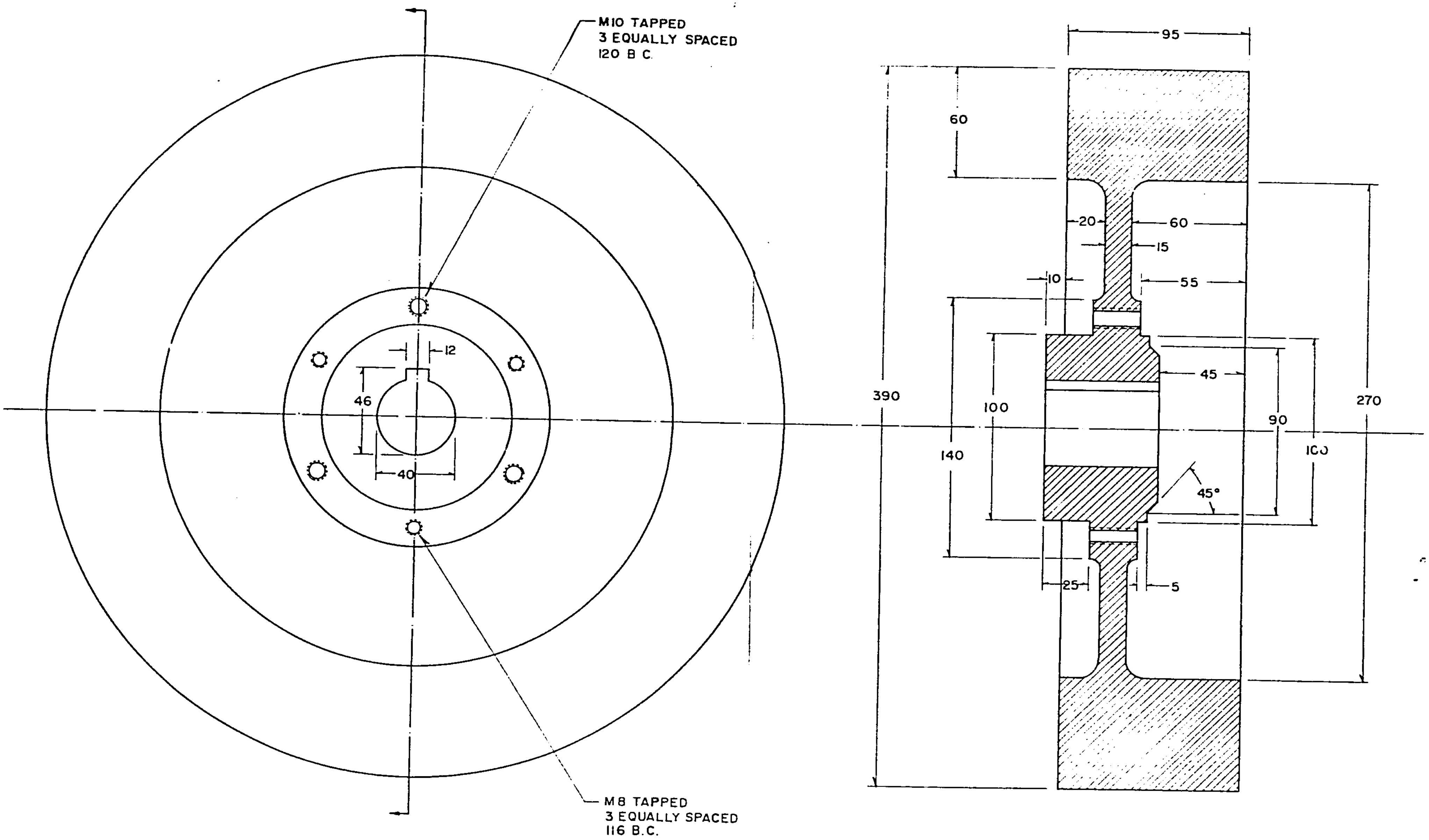


Locking Bolt		
Fig. 14 g	Scale : 1/2	Mild Steel

RICE HUSK ENERGY PROJECT	Page
Second Intermediate Model	14

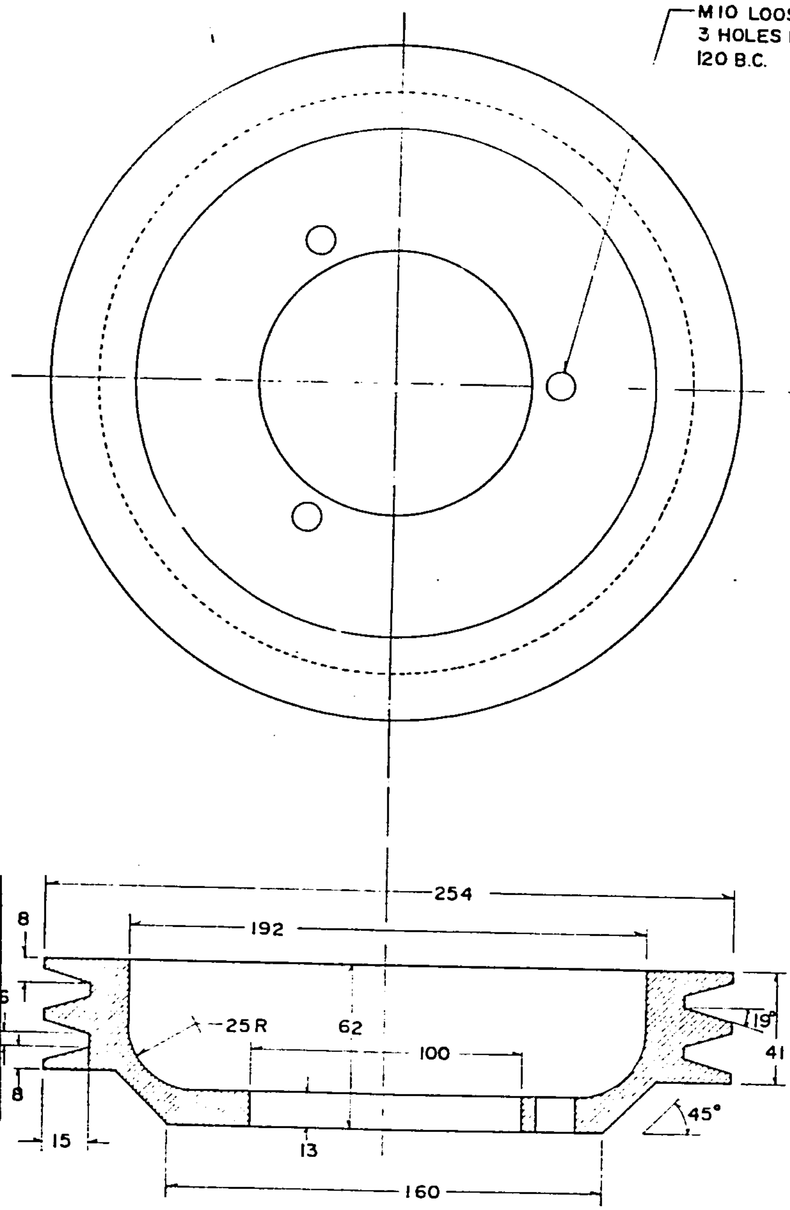


Crankshaft Counterweight Casting		
Fig. 15	Scale : 1/2	Cast Iron

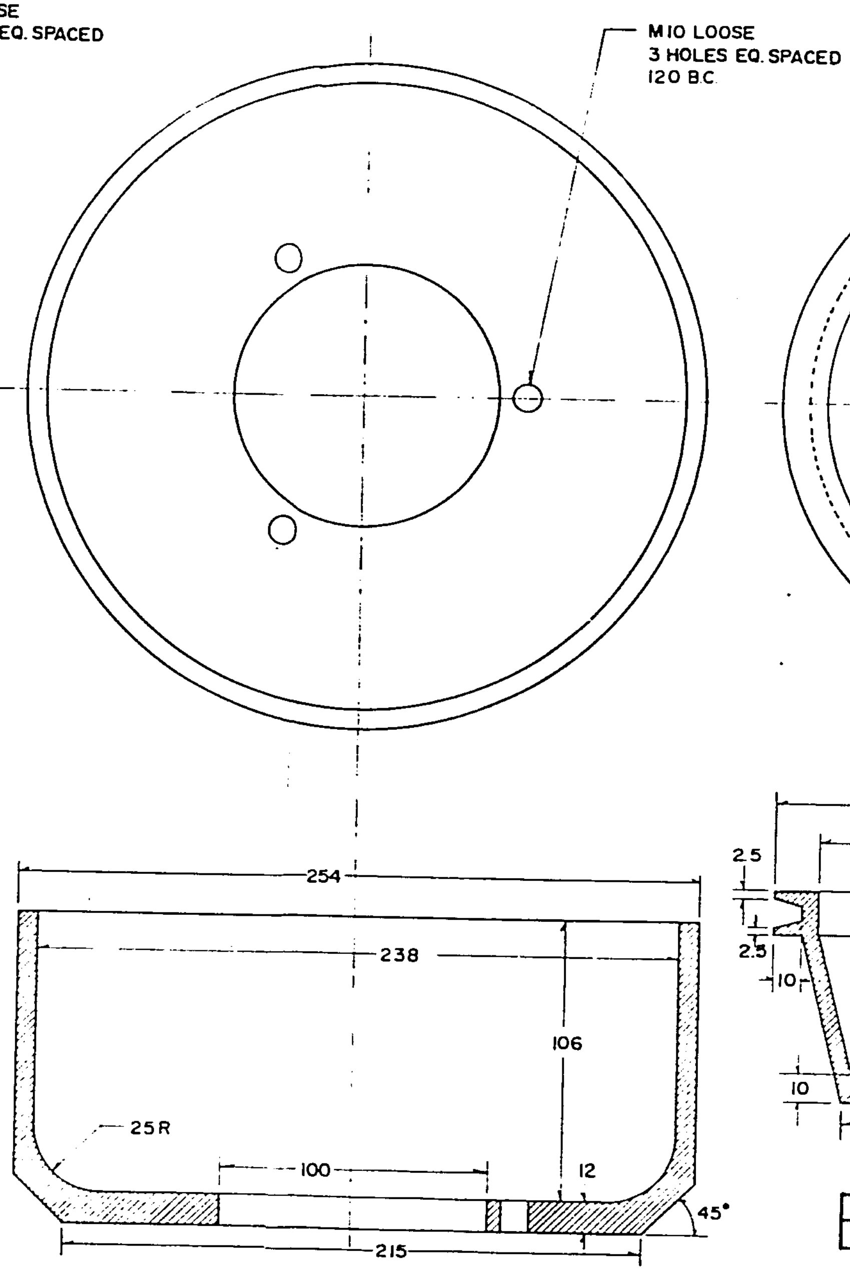


Flywheel		
Fig. 16	Scale: 1/2	Cast Iron

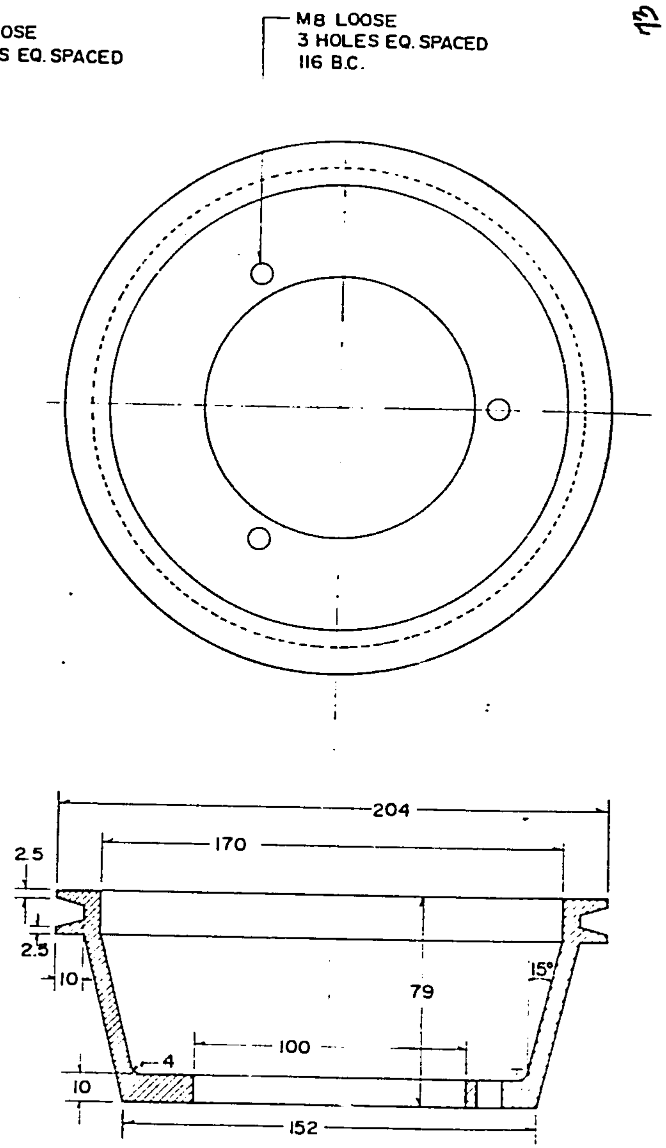
RICE HUSK ENERGY PROJECT	Page
Second Intermediate Model	16



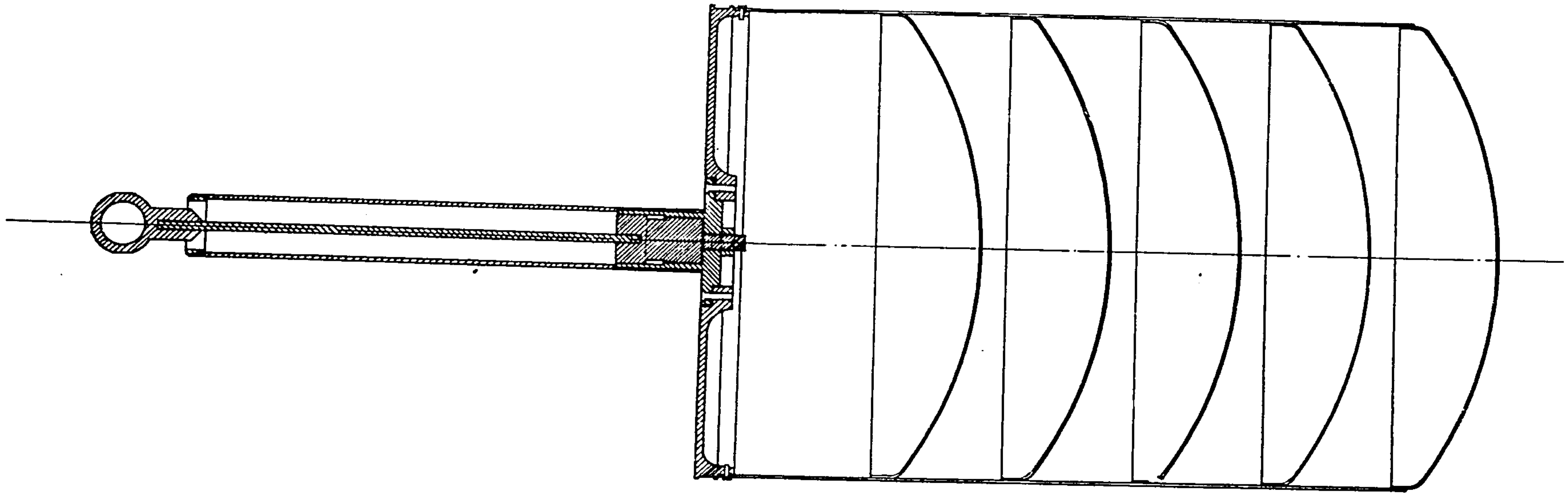
V-Belt Pulley		
Fig. 17 a	Scale: 1/2	Cast Iron



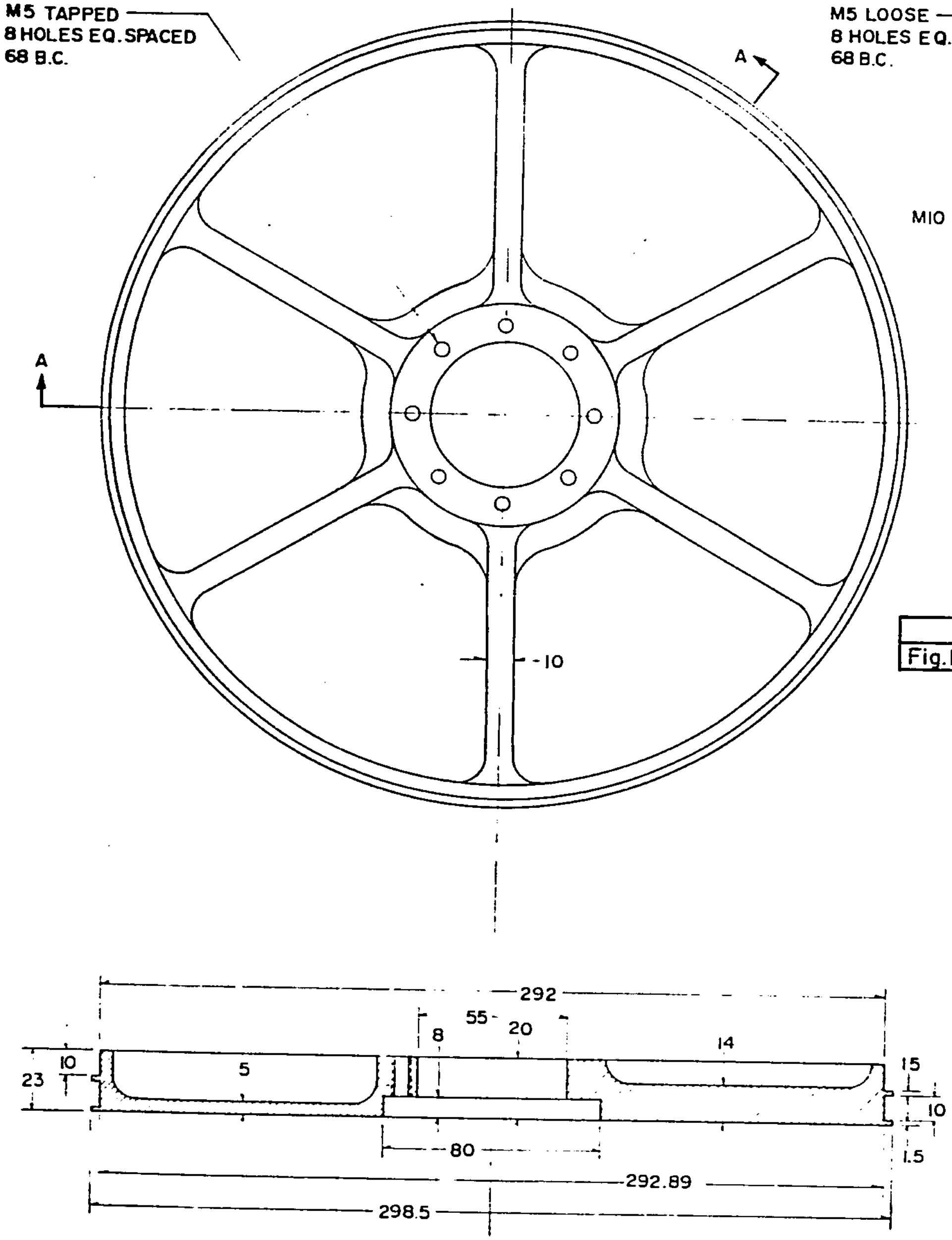
Flat Belt Pulley		
Fig. 17 b	Scale: 1/2	Cast Iron



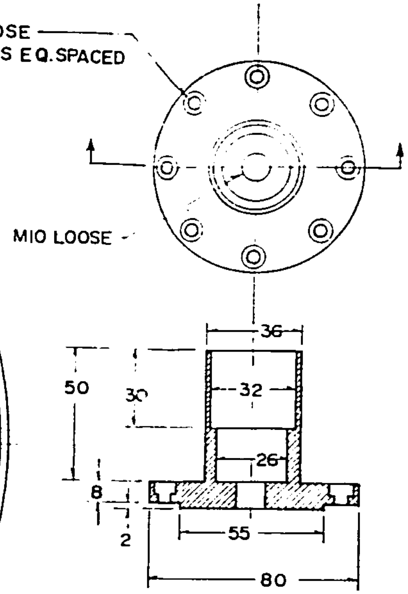
Auxilliary Pulley		
Fig. 17 c	Scale: 1/2	Cast Iron



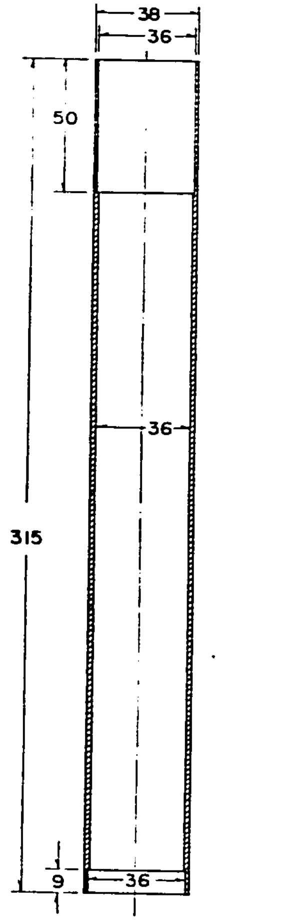
Displacer Assembly		
Fig. 18	Scale: 1/3	



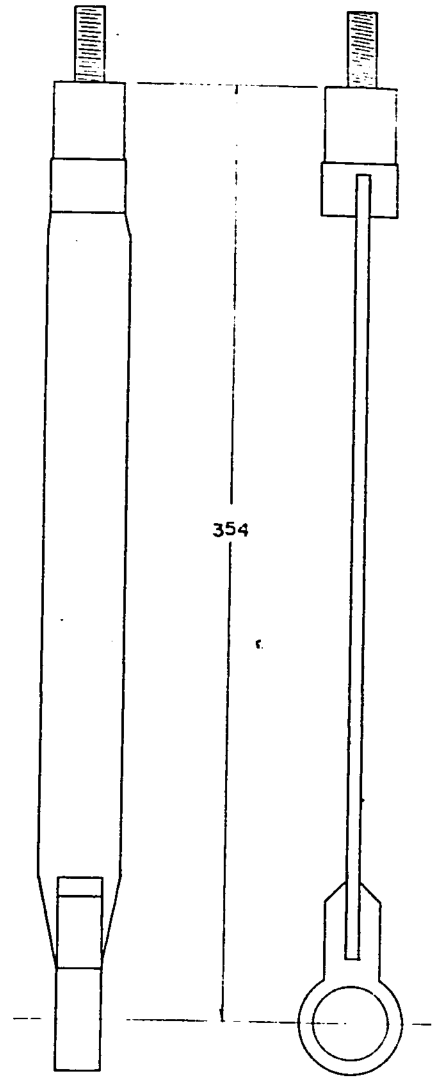
Displacer Body		
Fig. 19 a	Scale: 1/2	Cast [illegible]

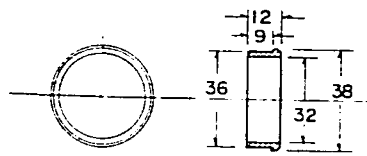


Displacer Tube Flange		
Fig. 19b	Scale: 1/2	Mild Steel



Displacer Tube		
Fig. 19c	Scale: 1/2	304 S.S

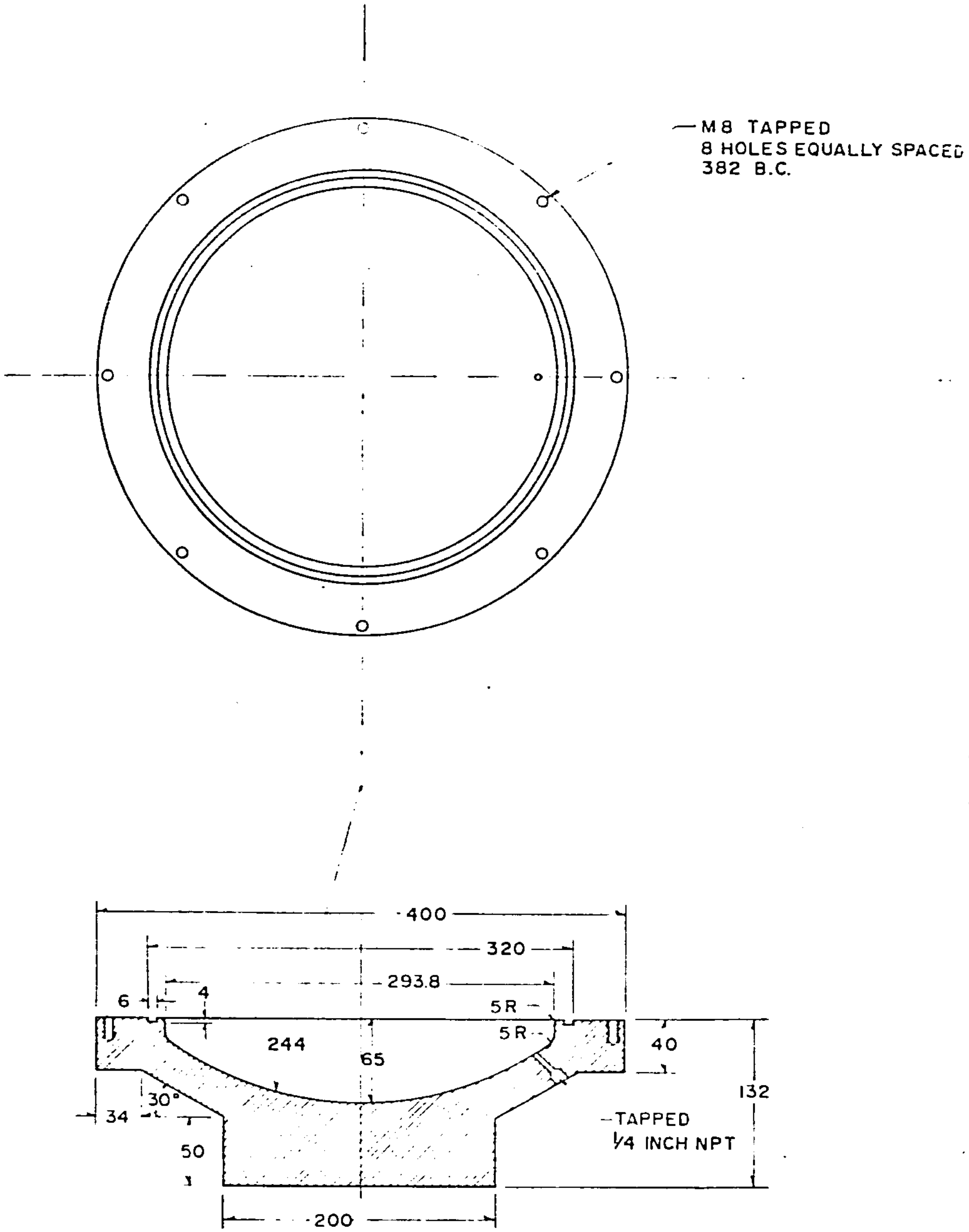




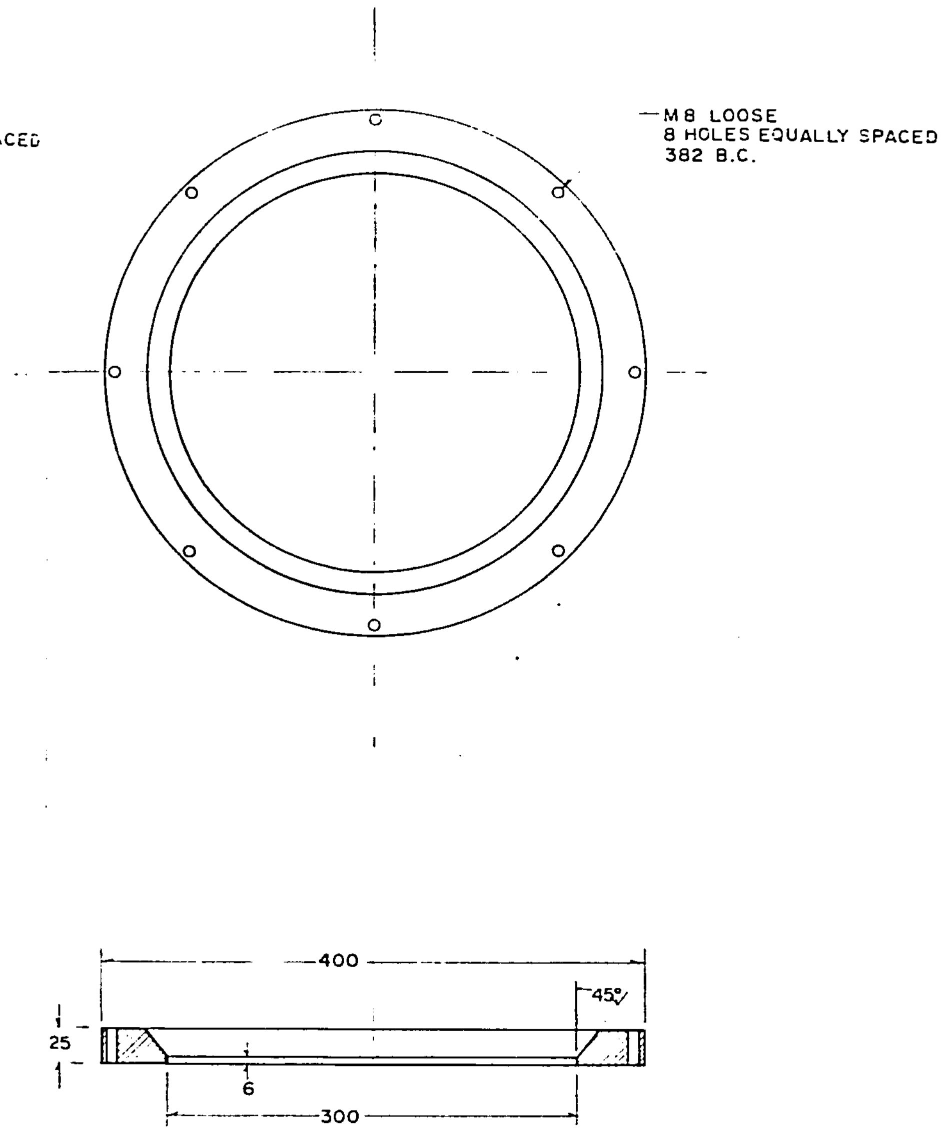
Displacer Tube Ring		
Fig. 19e	Scale: 1/2	Brass

Displacer Rod		
Fig. 19d	Scale: 1/2	Mild Steel

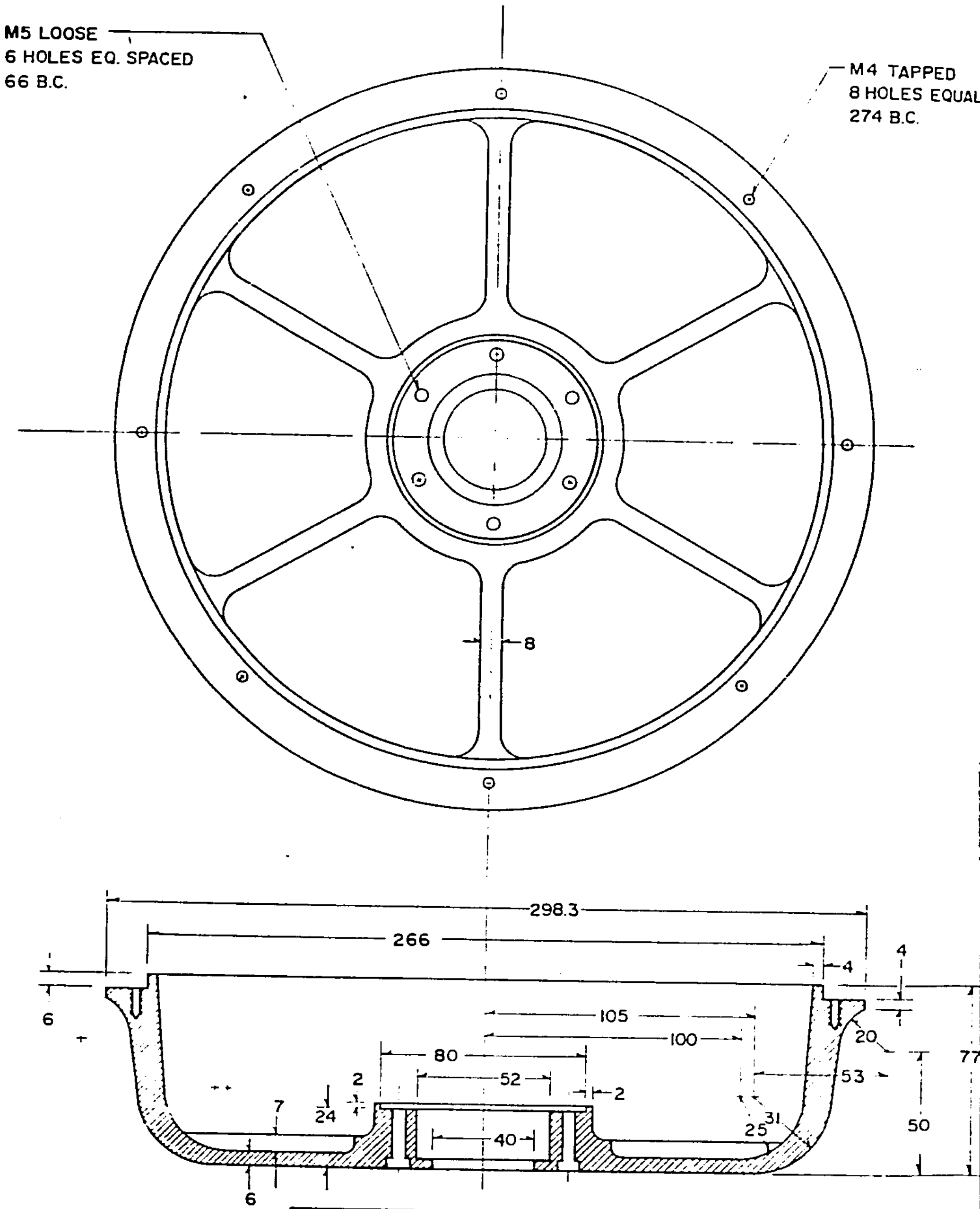
RICE HUSK ENERGY PROJECT	Page
Second Intermediate Model	19



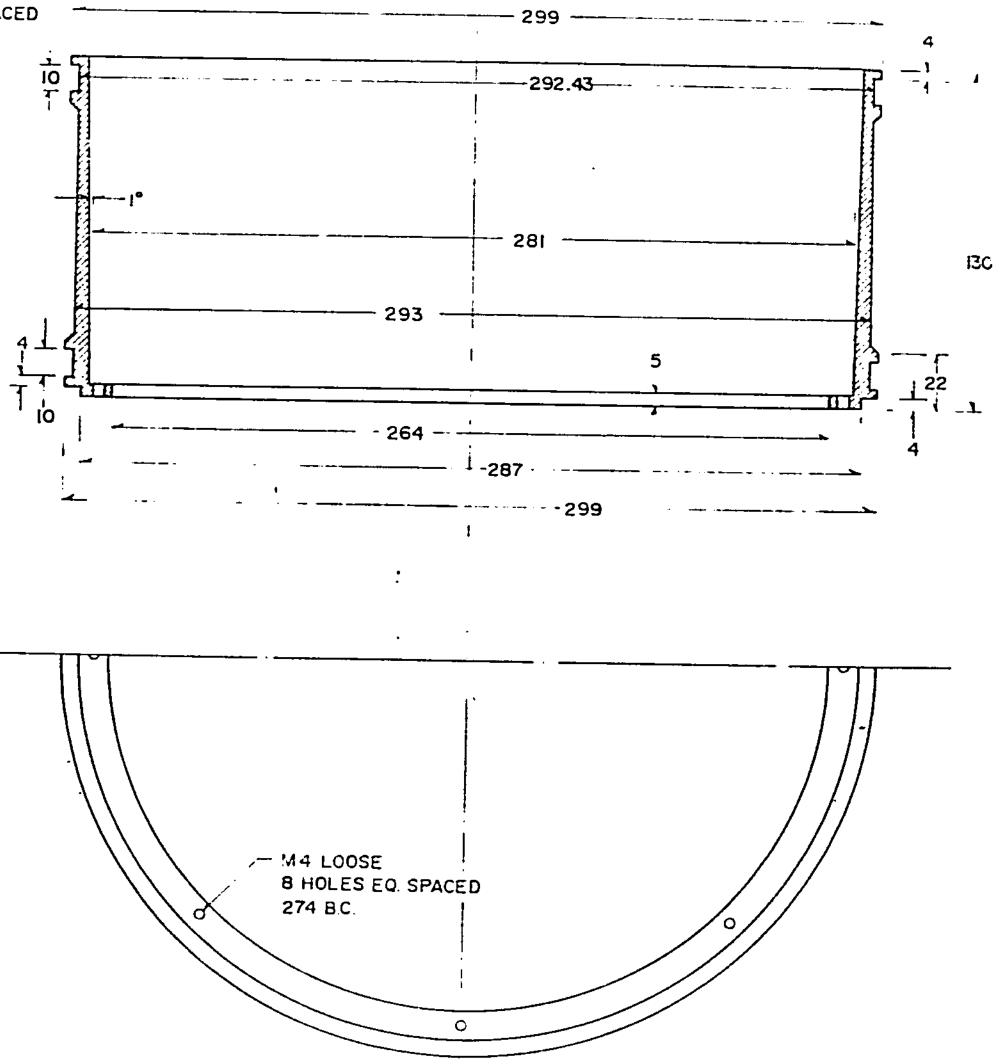
Die for Displacer Dome
Fig. 20a | Scale 1/4 | Cast Iron



Clamping Ring
Fig. 20b | Scale 1/4 | Cast Iron

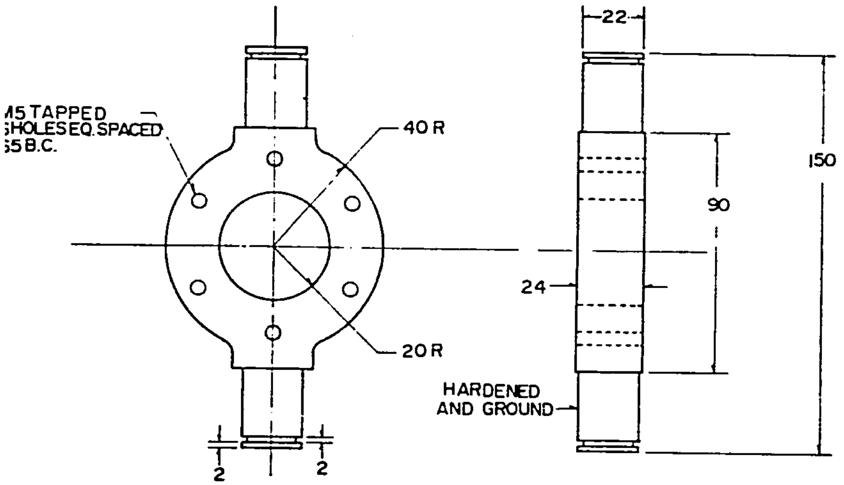


Piston Crown		
Fig. 21 a	Scale: 1/2	Cast Alum.

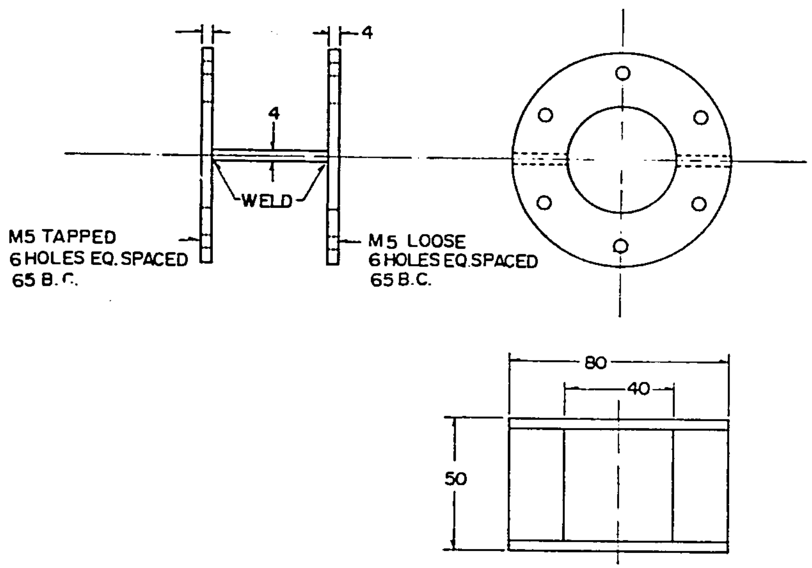


Piston Skirt		
Fig. 21 b	Scale: 1/2	Cast Alum.

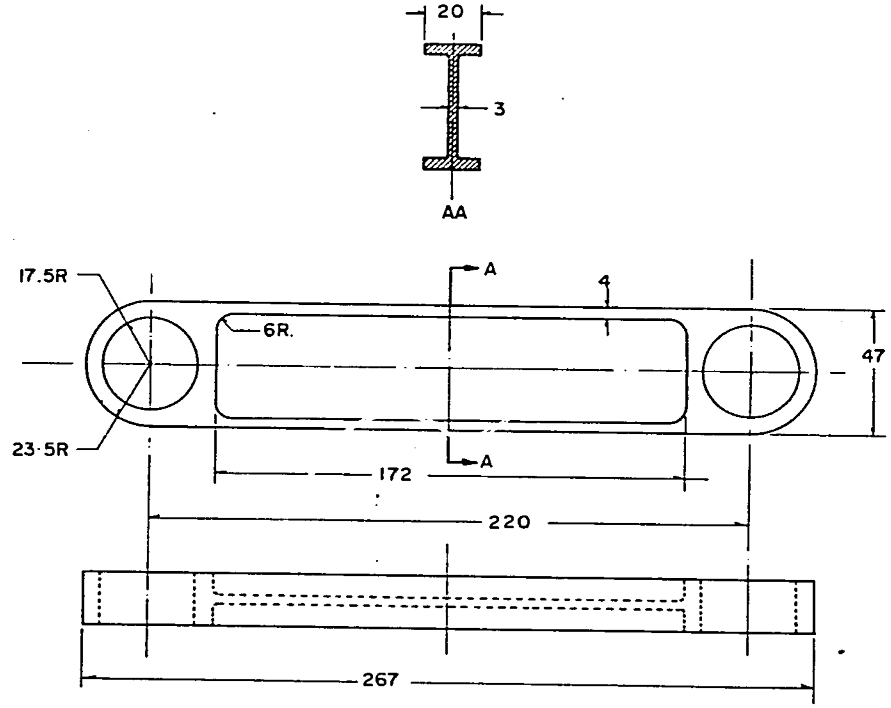
RICE HUSK ENERGY PROJECT	Page
Second Intermediate Model	21



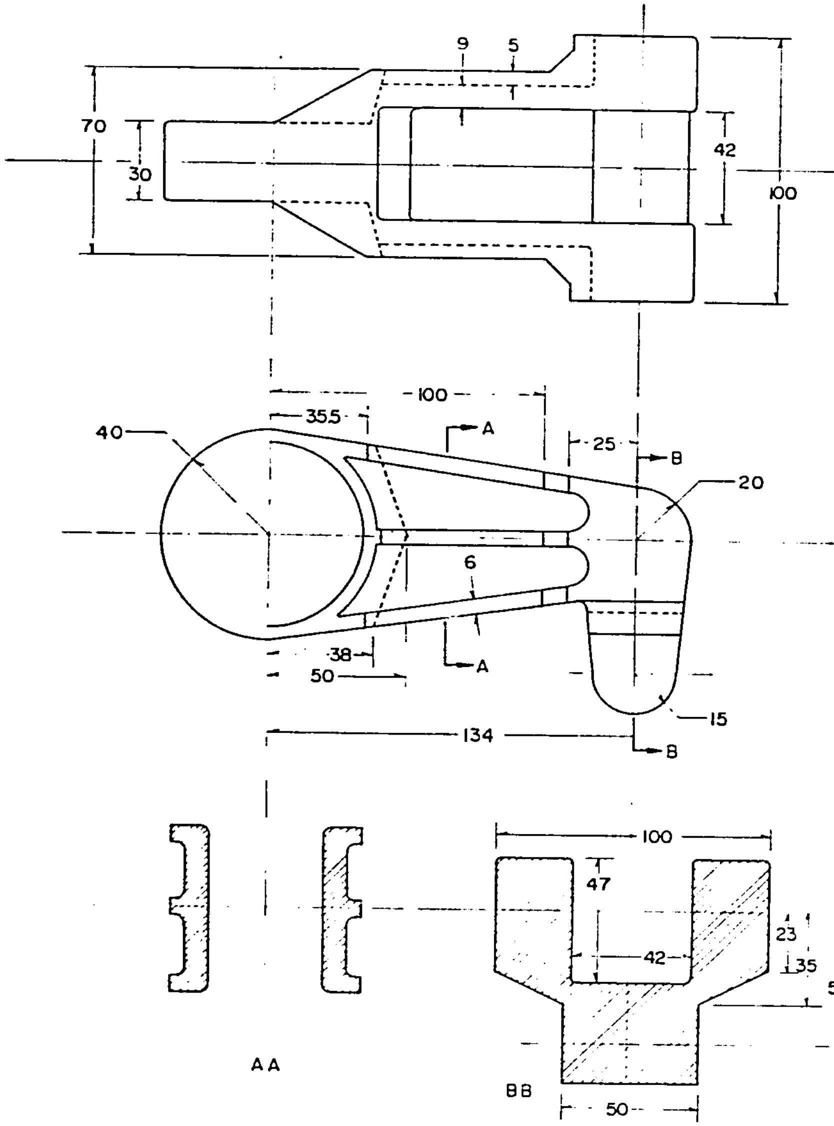
Wrist Pin		
Fig.22a	Scale: 1/2	Mild Steel



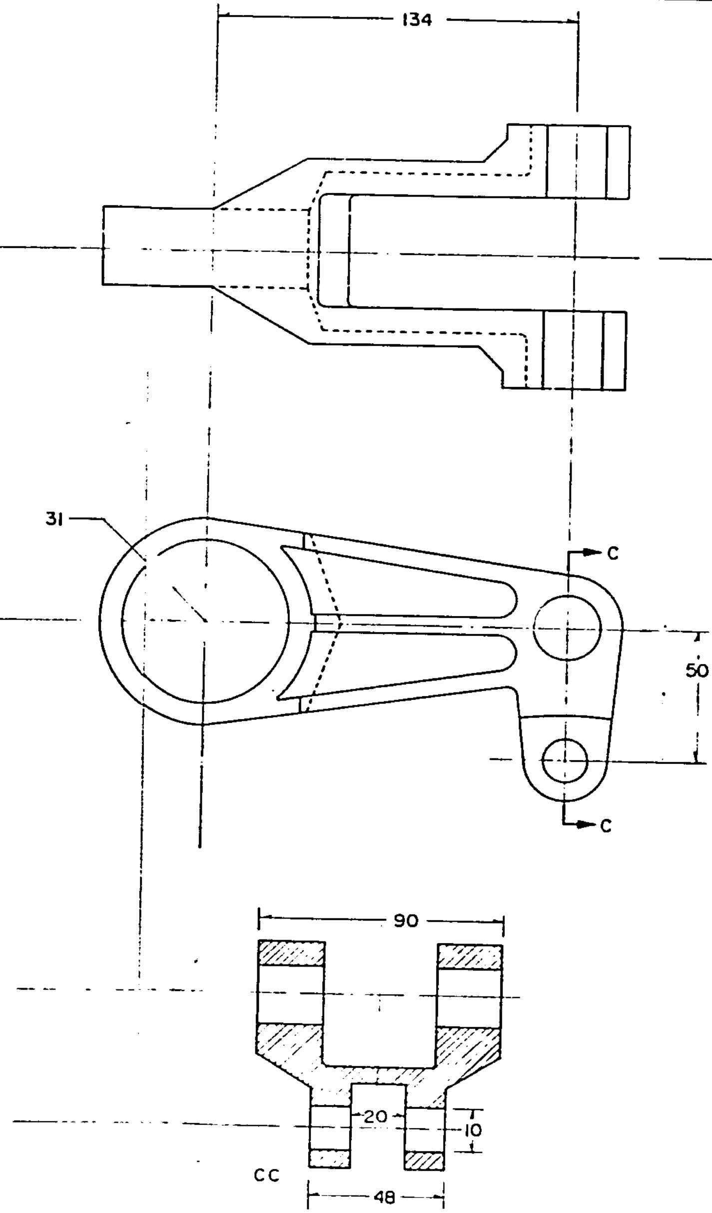
Wrist Pin Bracket		
Fig.22b	Scale: 1/2	Mild Steel.



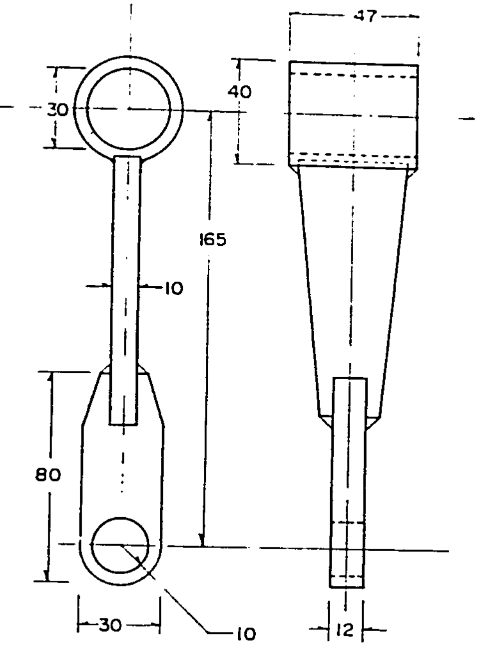
Piston Link		
Fig.22c	Scale: 1/2	Mild Steel



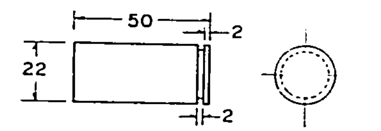
Main Connecting Rod Casting		
Fig. 23a	Scale: 1/2	Cast Iron



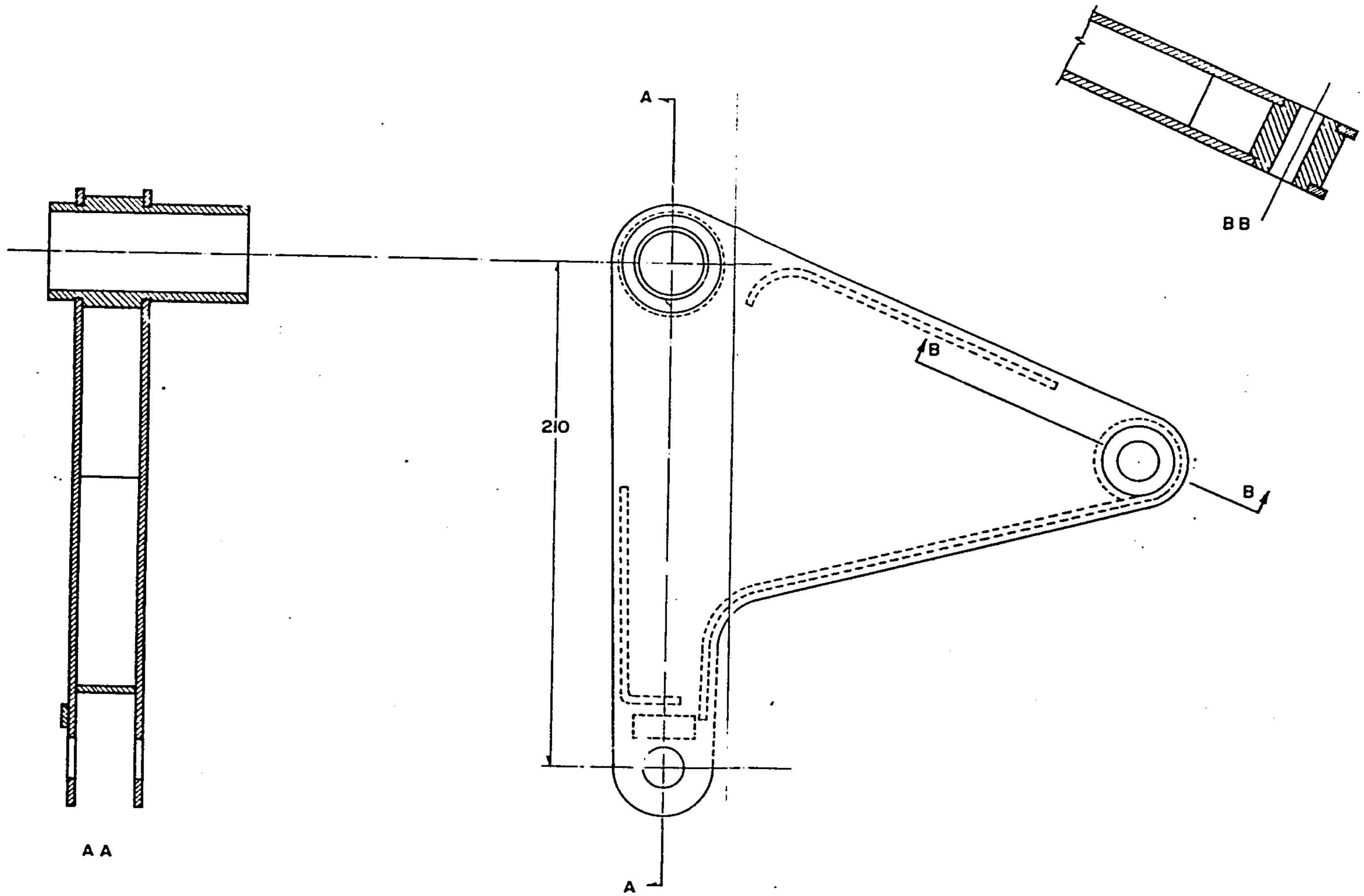
Main Connecting Rod as Machined		
Fig. 23b	Scale: 1/2	Cast Iron



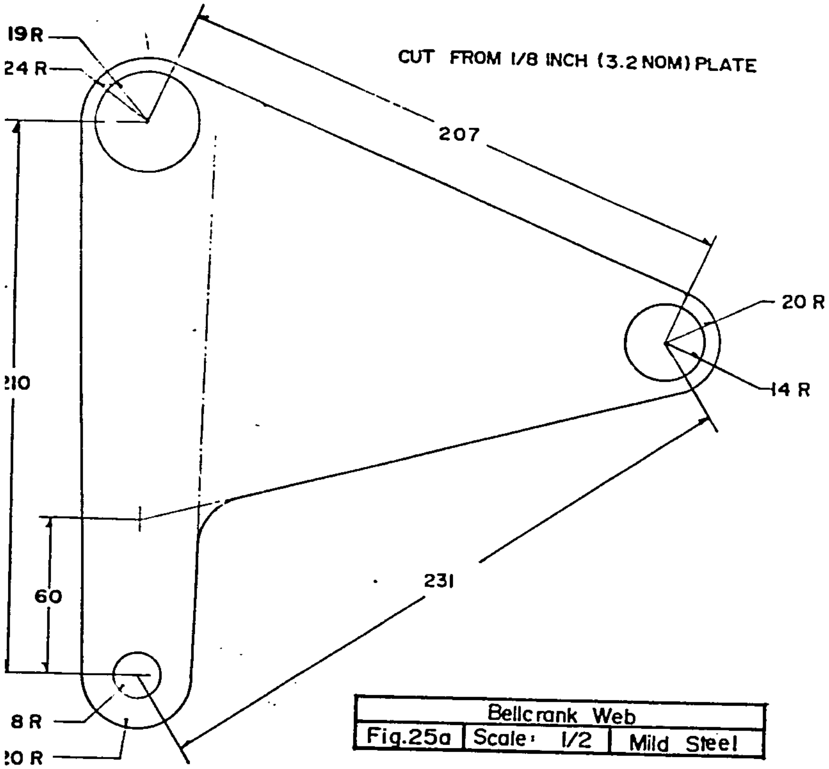
Swing Link		
Fig. 23c	Scale: 1/2	Mild Steel



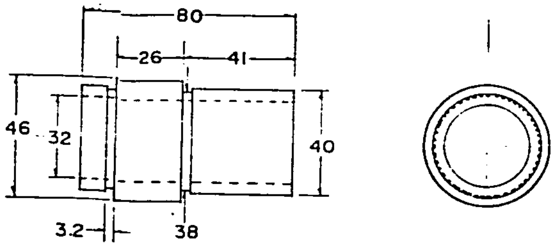
Main Connecting Rod Pin		
Fig. 23d	Scale: 1/2	Hardened Steel



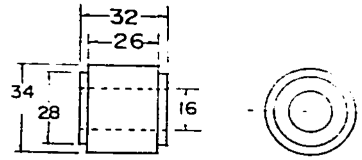
Bellcrank Assembly		
Fig. 24	Scale: 1/2	



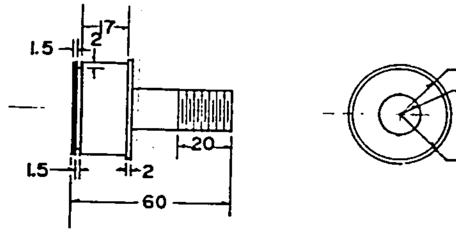
Bellcrank Web		
Fig.25a	Scale: 1/2	Mild Steel



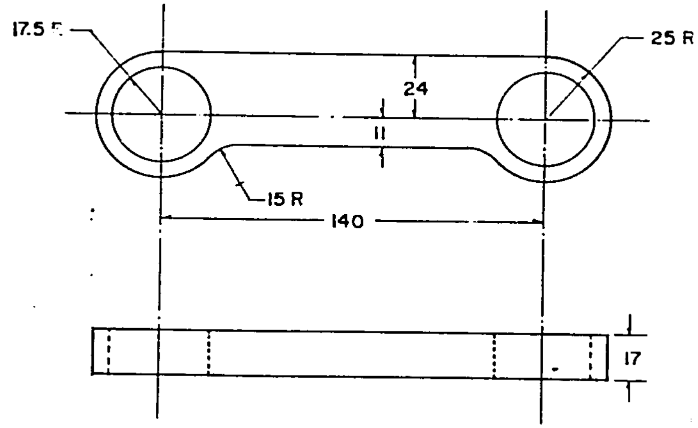
Main Pivot		
Fig.25b	Scale: 1/2	Mild Steel



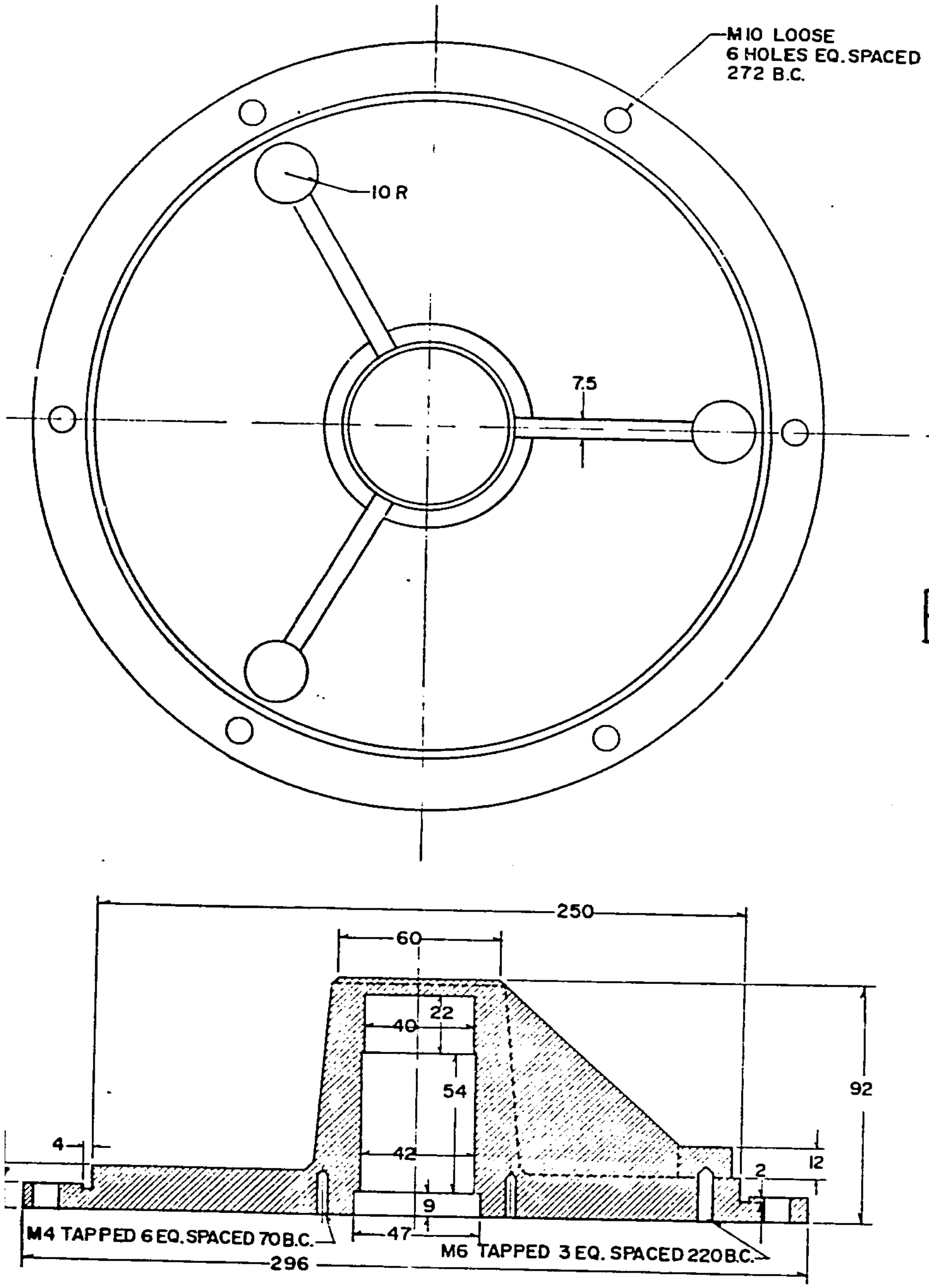
Con Rod Pivot		
Fig. 25c	Scale: 1/2	Mild Steel



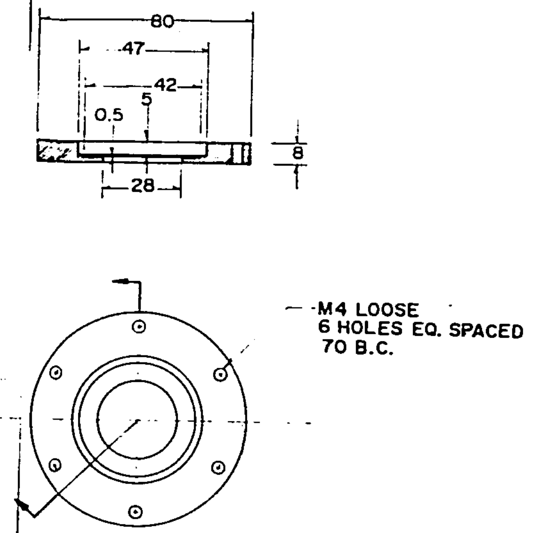
Bellcrank/Conrod Bearing		
Fig. 25d	Scale: 1/2	



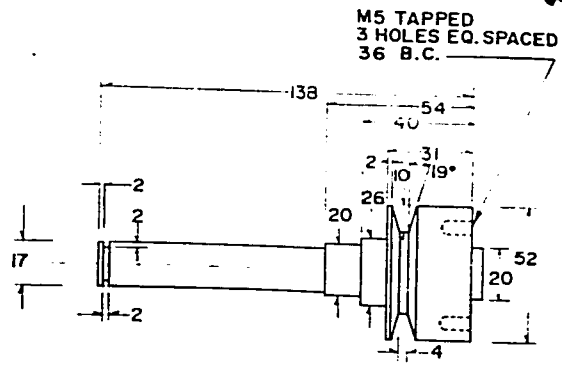
Bellcrank Con Rod		
Fig. 25e	Scale: 1/2	Mild Steel



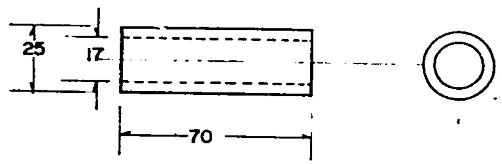
Side Cover		
Fig. 26a	Scale 1/2	Cast Iron



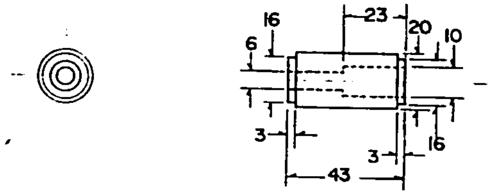
Blower Bearing Cover		
Fig. 26b	Scale. 1/2	Mild Steel



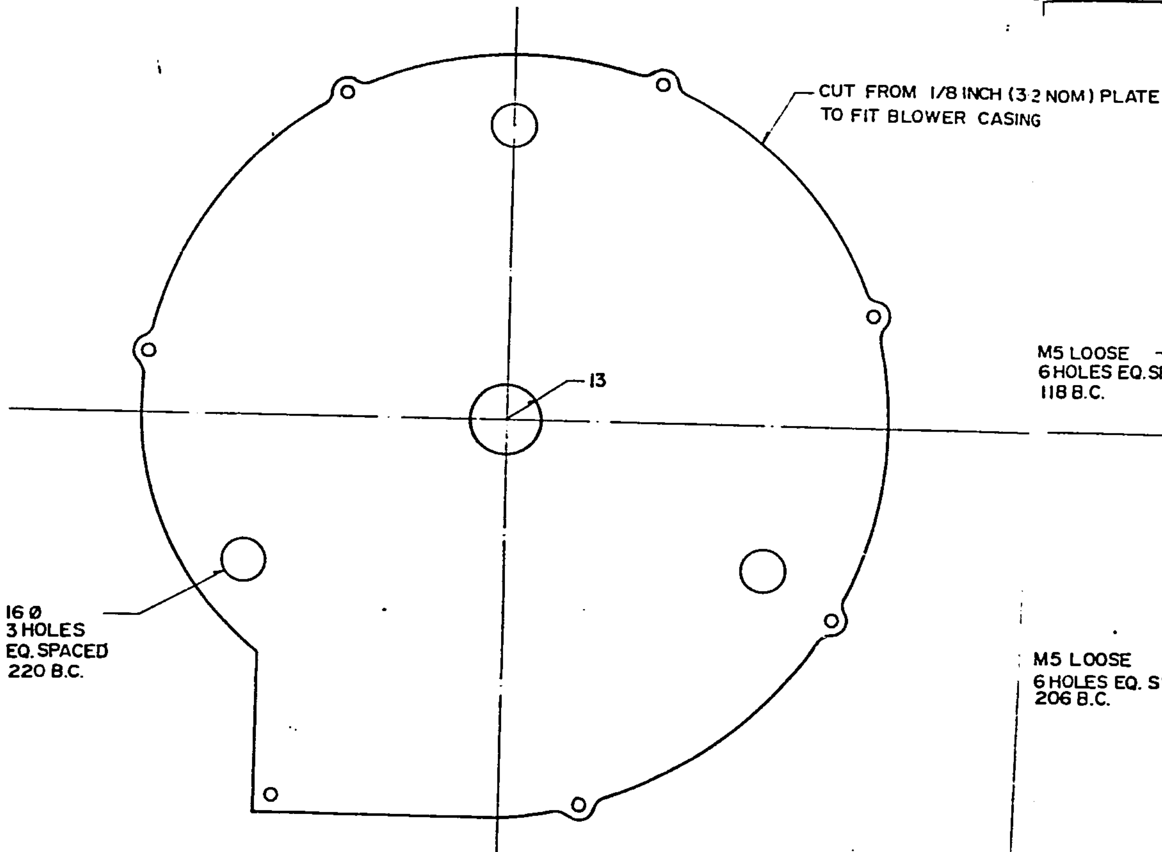
Blower Shaft		
Fig. 26c	Scale 1/2	Mild Steel



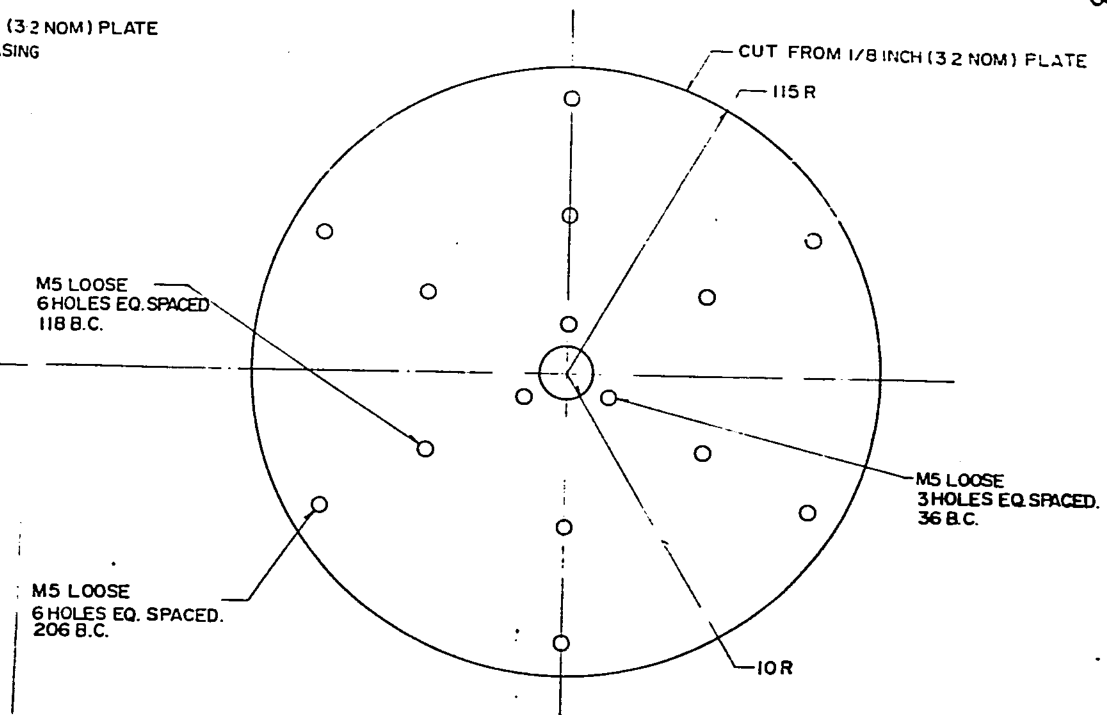
Blower Bearing Spacer		
Fig. 26d	Scale. 1/2	Mild Steel



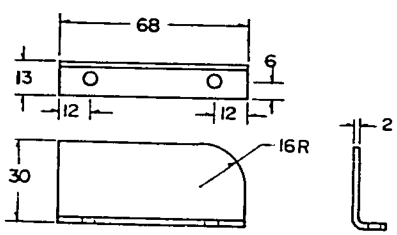
Blower Base Spacer		
Fig. 26 e	Scale 1/2	Mild Steel



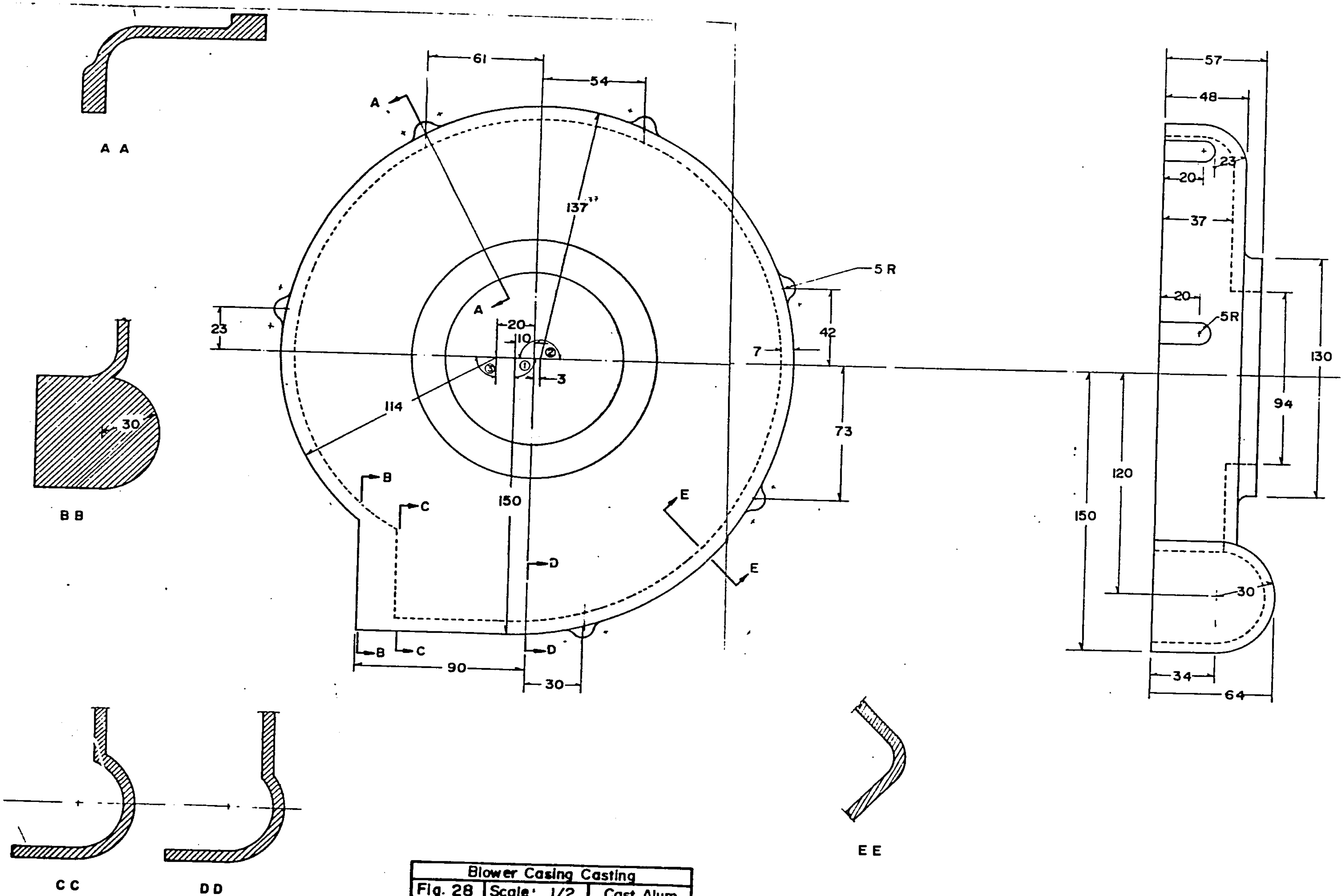
Blower Base		
Fig. 27a	Scale: 1/2	Mild Steel



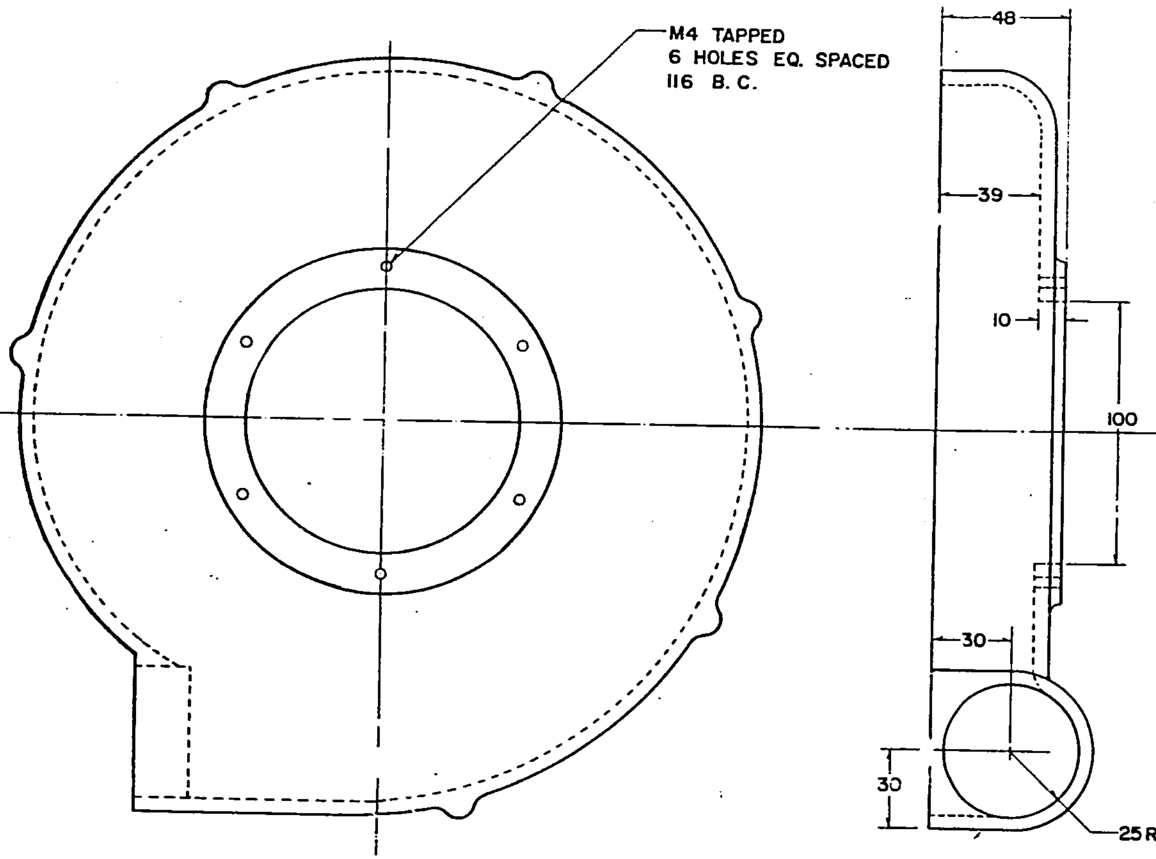
Impeller Rotor		
Fig. 27b	Scale: 1/2	Mild Steel



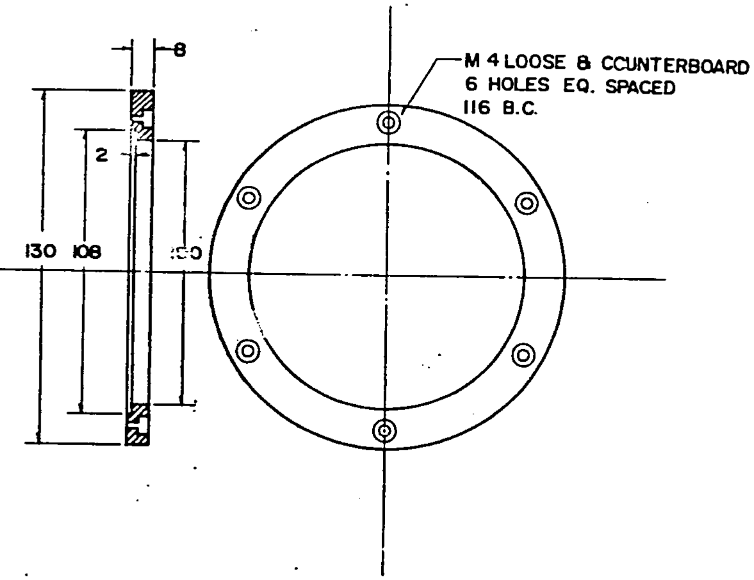
Impeller Blade		
Fig. 27c	Scale: 1/2	Aluminum



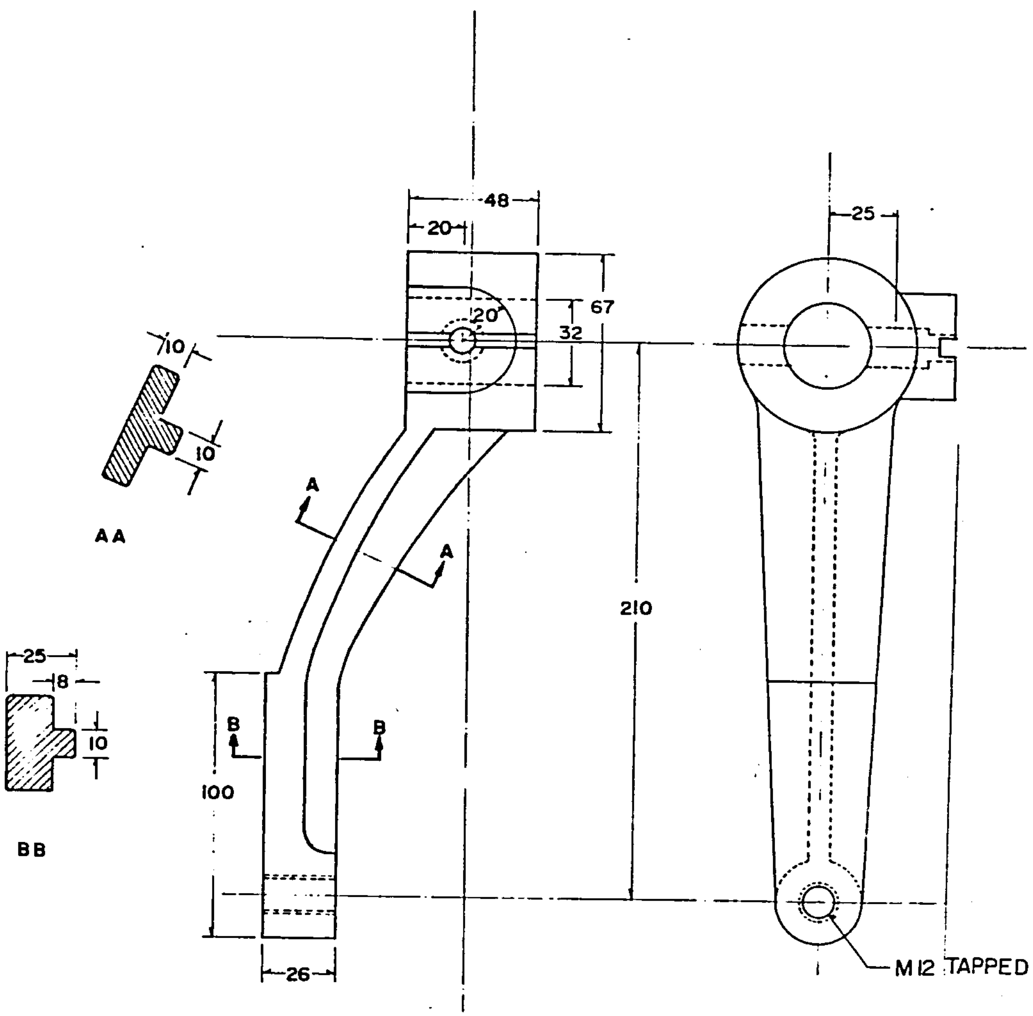
Blower Casing Casting		
Fig. 28	Scale: 1/2	Cast Alum



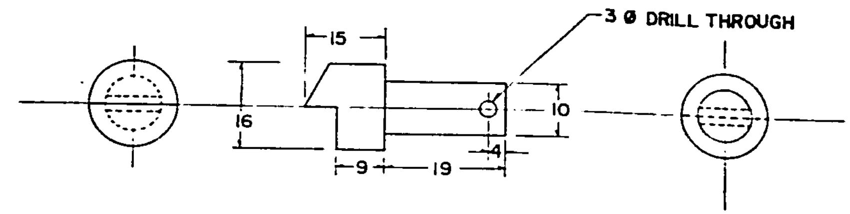
Blower Casing Finishing Dimensions		
Fig. 29a	Scale: 1/2	Cast Alum.



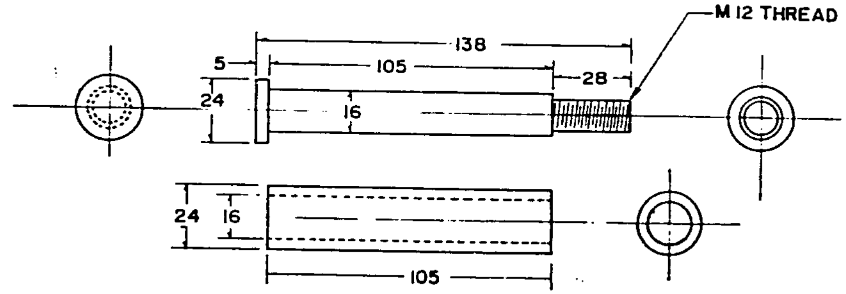
Inlet Screen Retainer		
Fig. 296	Scale: 1/2	Aluminum



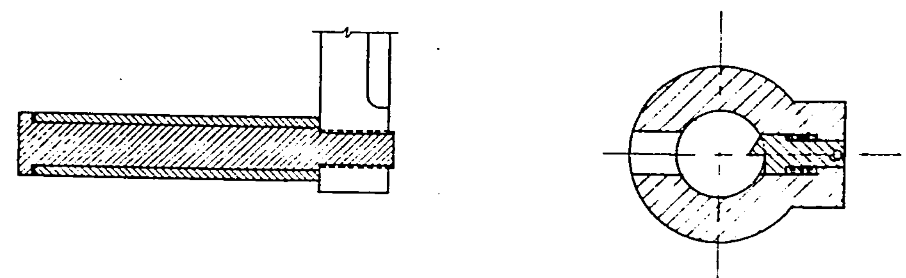
Starting Handle		
Fig. 30a	Scale: 1/2	Cast Iron



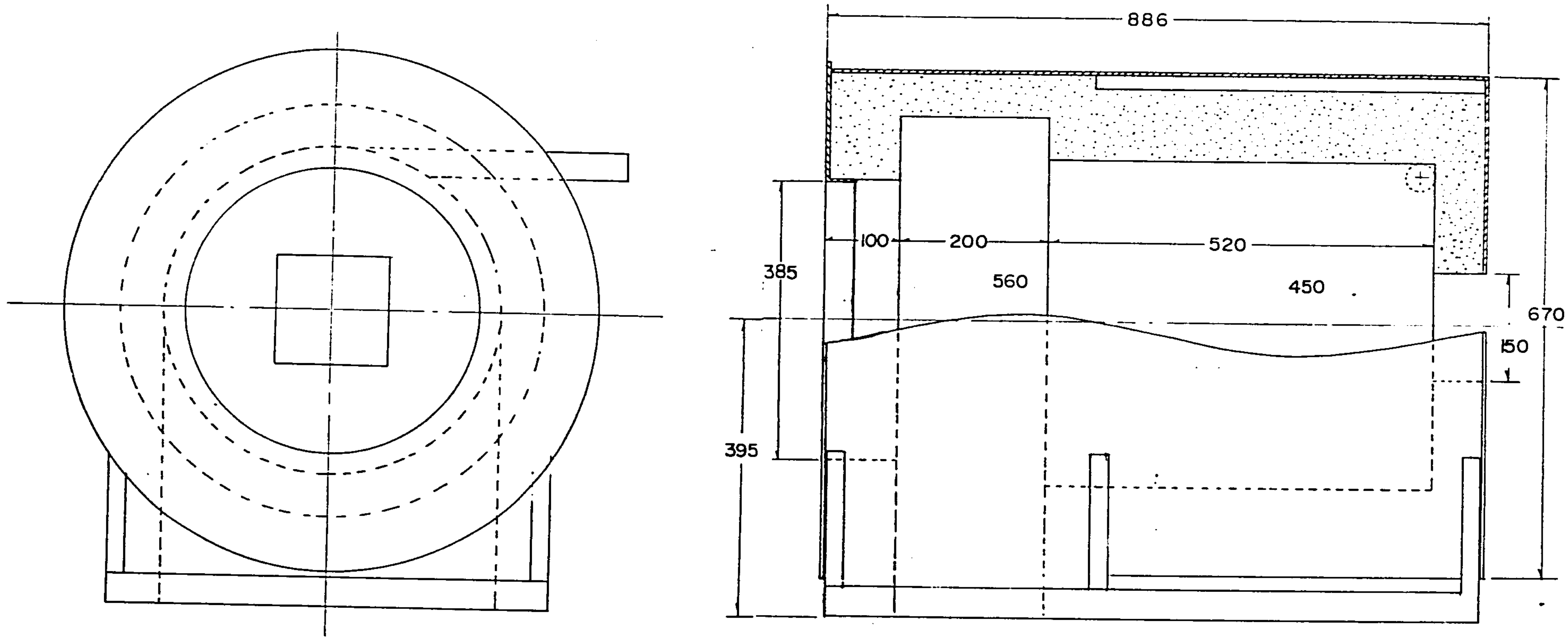
Starting Handle Pawl		
Fig. 30b	Scale: 1/1	Carbon Steel



Starting Handle Pivot & Sleeve		
Fig. 30c	Scale: 1/2	Mild Steel



Starting Handle Assembly Details		
Fig. 30d	Scale: 1/2	



Furnace		
Fig. 31	Scale 1/6	