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RICE HUSK ENERGY PROJECT
PHASE II FINAL STATUS REPORT

December 1983

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BACKGROUND

Activities of the Rice Husk Energy Project have been organized into three phases, and approval to move from one phase to the next is dependent upon successfully achieving the goals set out for the prior phase. This report reviews the goals for Phase II of the Rice Husk Energy Project, describes activities, achievements and problems encountered during this period, and presents the goals and proposed activities for Phase III of the project.

PHASE II GOALS

The original goals for Phase II are embodied in the GO/NO-GO criteria set out in Table II on page 16a of the grant agreement. These can be stated as follows:

1. To demonstrate that the Stirling power unit can be manufactured in Bangladesh by locally fabricating and operating a Stirling power unit.

2. To up-date estimates of production cost for the final (pre-production) model based upon experience to date with the fabrication of the intermediate model.

3. To demonstrate that the level of skill needed to operate the Stirling power unit is consistent with that available in a typical rural rice mill in Bangladesh.

4. To confirm the advantages of the Stirling power unit in terms of energy utilization and savings through use of a biofuel over conventional fossil fuel based milling systems

5. To evaluate the potential use of the Stirling power unit in conjunction with an alternative rice milling system in which the husk removal and bran removal are carried out in separate operations resulting in different husk and bran characteristics.

In addition, Amendment 4 to the grant agreement specifies that the first intermediate engine would be fabricated locally and operated during Phase II, and that the development of certain manufacturing methods, which were to be accomplished in Phase III, should be completed during Phase II.

PHASE II ACTIVITIES

A. Expansion of Project Workshop

During Phase II the project workshop was shifted to a larger building and was expanded to include two more lathes and a universal milling machine. The lathes were purchased with project funds while the milling machine was shifted to the project workshop from the KWT workshop. This, along with the equipment in the project workshop from Phase I and a steady input of materials, smaller tools, and components and fittings fabricated within the project workshop itself has provided the project with a self sufficient facility which can carry out most of the operations needed to manufacture the Stirling power unit. Developing this facility has taken considerable time and effort; however, the facility has already proven beneficial in the

production of an operating Stirling engine in Phase II, and it is anticipated that Phase III activities will proceed smoothly with the workshop set up and functioning efficiently.

B. Training of Project Workshop and Rice Mill Team

The project team in Narayanganj consists of three workshop personnel (2 machinists and a fitter) and five women rice millers (1 manager and 4 millers). Additional workshop personnel are also seconded from the main KWT workshop as needed. In addition, the women millers carry out a number of workshop-related tasks such as, the daily cleaning and maintenance of machine tools, the preparation and painting of equipment and components, and the maintenance of the project grounds.

C. Test Run of Prototype Stirling Engine

In the first part of Phase II, the prototype developed by Sunpower Inc. in Ohio was shipped by air to Dhaka and set up with a No.4 rice huller. The Prototype did not run for a long period due to wear from metal particles from earlier runs; however, during the several runs it made, it was shown that it could operate a rice huller, and the suitability of the locally made furnace was established. Also experience gained from the operation and repair of the prototype in Dhaka was an invaluable input in the successful modification of the design for local manufacture.

D. Development of Specialized Techniques

In order to fabricate certain components of the Stirling engine, use has been made of some specialized manufacturing methods. While some of these methods are new to Bangladesh, they are within the capabilities of many workshops, and it is expected that local industries may, in fact, benefit in the future by applying these techniques to other products.

1. Explosive Forming

In the Prototype, the stainless steel domes used in making both the displacer and the hot end of the engine were formed from sheet stainless steel, cut out, hydraulically bulged, and welded to reinforcing rings using argon arc welding equipment. For the intermediate model, mechanical pressing using mating dies was explored but found to be very expensive for the short runs expected. As an alternative, the possibility of explosive forming, which had been suggested by Sunpower as a future possibility, was experimented with and eventually settled on as the most effective means for making these components.

2. Furnace Brazing

It is likely that furnace brazing with a protective atmosphere will be used in the fabrication of the hot end of the engine. Information has been collected on this technique, and the necessary gas supply, furnace and retort are in the process of being assembled now. The first spin off of this technique may be for this project itself as it opens up the possibility of making a tube and

shell cooler for the engine by furnace brazing copper tubes to a cast iron sleeve. This may lead to simpler construction and reduce the cost of the engine.

3. Stud Welding

A possible alternative design for the hot end involves welding many small diameter studs on the outside in place of brazed fins. This would provide an alternative to furnace brazing the external fins and may result in longer life of these elements. A stud welding machine has been designed and made which will permit the welding of small diameter (2-4 mm) studs, closely spaced together. Still remaining to be done is a system to make ceramic ferrules for use with the machine to insure high quality welds.

Local Manufacture of Stirling Engine

In addition to the specialized techniques described above, a wide range of conventional manufacturing procedures were used in order to produce the first of the intermediate models of the Stirling engine. Every component of the engine has been modified in design, either to adapt it to local production methods or to solve problems which emerged during the testing of the prototype.

The biggest single change has been the extensive use of cast iron in the engine. This capitalizes on the availability in Bangladesh of skilled pattern makers and a multitude of foundries with excellent capabilities

in sand casting. The present intermediate model incorporates 12 iron castings and 5 aluminium castings.

Another innovation has been the use of spot welding in the fabrication of the displacer. Considerable time was devoted to making a jig which insures accurate assembly and welding of both the seam of the displacer as well as dome, baffles and body attachment. The use of a cast iron displacer body reduces problems with differential expansion and simplifies attachment of the stainless steel can.

In order to allow for pressurization of the crank case, O-rings were used for static seals. For the one moving seal, at the crankshaft, a die was designed to press a cup-type leather seal. This leather seal has performed satisfactorily and will cost less than the original teflon based material (Rulon).

The piston and displacer designs have been changed from the prototype in that teflon rings are used in place of the spray-on teflon based antifriction coating. Based on reports for dry lubricated air compressors, it is anticipated that this option will provide a long service life in this application and also will enable the simple field replacement of rings rather than the need for re-coating the piston and displacer body.

On the recommendations of Sunpower, a spider was incorporated in the design to provide additional support for the displacer rod. In addition to this, a flexible link working within the displacer

tube was fashioned which provided for a more compact linkage and eliminated one bearing.

The bell crank was changed from aluminium to a riveted assembly of mild steel sheet in an effort to achieve greater strength.

One of the reasons for working extensively with castings was the ease with which these can be accurately machined, using the appropriate jigs and set-ups, and thus insure the correct alignment of moving parts. This proved to be true, as the assembly and fitting of moving parts in the engine went well, and it was relatively easy to get all the parts accurately positioned and moving freely.

The die for explosively forming the stainless steel dome and regenarator collar of the hot end was completed, and two trials were conducted. The second test produced a piece that was not fully formed but which will be useable. The water tank in which the explosives are detonated will be deepened to provide more pressure to form the hot end dome. A gas line is being run to the workshop to use with a brazing furnace. When the brazing furnace is set up, the final steps in fabricating the hot end can be carried out. In the meantime, the intermediate model will be operated using the hot end from the prototype.

F. <u>First running of Locally Manufactured Stirling Engine</u>

The activities mentioned so far have led to the most important achievement of Phase II, which is

the operation of the first locally manufactured Stirling engine in Bangladesh. With the exception of the prototype hot end, all of the components of the intermediate model of the engine were made locally and, as discussed above, represented modification to suit local manufacturing capabilities.

The Sunpower Engineer and the Sunpower Team Leader were on hand before the first run of the engine and commented favourably on the appearance and feel of the engine. They along with everyone else were delighted with the smooth and quiet operation of the engine on its first run, November 21, 1983.

PHASE II PROBLEMS

A technical project of this type is expected to have many unforseen problems, and in fact many small problems arose and have been avoided or solved. The one component which has caused the greatest problem bears mentioning.

The aluminium cooler sleeve initially appeared easy to make. However, early in Phase II it took four months, five attempts at casting in three different foundries, and much machining before the cooler was ready. The final blow came when the engine was ready for its first run on November 3 and the cooler sleeve was found to be porous, resulting in a copious leakage of water from the cooler into the working space of the engine. Attempts to seal the leak with super glue (a whole bottle) failed,

and as a last recourse a crash effort was made to push through the fabrication of a cooler using a cast iron sleeve and copper tubes (tube and shell heat exchanger) so that the engine could be operated before the Phase II evaluation. The second cooler also leaked. In the end, a suggestion by the Sunpower Engineer for sealing the aluminium cooler proved successful, and in short order (and none too late) the engine was running.

Another task of lesser magnitude proved deceptively simple. This was to cut the piston rings from strips of teflon. Here again a series of methods were tried and failed and ultimately a precision metal jig had to be fabricated to allow accurate cutting of these strips. A one day job had taken three weeks to solve.

RESULTS

With respect to the goals for Phase II which were listed at the beginning of this report, the following results have been achieved.

1. <u>Operation of locally manufactured Stirling engine</u>

   On November 21, 1983, the locally made Stirling power unit was operated for the first time. The furnace was started with a little burning charcoal and subsequently fueled with rice husk only. The engine performed well at a crankcase pressure of about 1 bar (15 lbs/sq.in.) which is below the design pressure of 4 bar (60 lbs/sq.in). The

engine operated a water pump which provided a constant load and good visual indication of power output.

On November 23, 1983, the engine was operated a second time at a demonstration for USAID and USIS personnel. As before, the engine was provided with a load by the water pump, and performance was smooth and quiet.

Auxilliary equipment for the engine consists of a pump to circulate cooling water, a blower for the furnace, and a means of pressurizing the air within the engine. This equipment will be completed within the next few weeks to provide a stand-alone power system.

2. Up-dated estimates of production cost:

While the Stirling engine has the advantage of providing a means to generate mechanical power from inexpensive and renewable biofuel, it is obvious that the purchase cost of the units must be reasonable in order that entreprenuers in rural areas will be willing to purchase them. Because of the very significant savings in energy costs, the initial price of the Stirling engine can be higher than alternative power sources and still remain competitive. The target set for the project engine is a purchase price, when produced in quantity, that does not exceed 150 percent of the cost of a comparable diesel engine. At the beginning of the project the purchase price of a 5 hp diesel engine was about $500 or Tk.10,000 at an exchange rate of Tk 20/$1.00. Currently the price of diesel engines has gone up, but the exchange rate has also changed to Tk 25/$1.00,

with the net result that the dollar value is essentially the same at $500, now equivalent to Tk.12,500.

In order to arrive at an estimate for the eventual cost of the engine when produced in quantity, it is convenient to group engine components into four different classes for costing.

a. Cast iron components with steel shafts, and fasteners such as bolts;

b. Cast aluminium components;

c. Stainless Steel components;

d. Bearings;

To estimate a production cost, including profit, for the cast iron and steel parts of the engine, a number of local manufacturers were visited to see what sorts of equipment are being made locally. Rather than depend on the manufactures' claims regarding production cost and profit, it was decided to identify machinery similar to the Stirling engine with respect to materials used and in the amount of machining and degree of precision, and to identify a cost per weight figure which could be applied to the iron and steel parts of the project engine. The machinery selected for this purpose was a small printing press. The sale cost with respect to weight worked out to be $1.50 per kilogram, and this figure has been used to estimate the sale cost of iron and steel components of the Stirling engine.

Unmachined aluminium castings cost $2.60 per kilogram. In the project engine relatively few parts are made from

aluminium, and this is expected to be further reduced in the pre-production version of the engines. A manufacturer would be able to obtain aluminium castings for substantially less than the $2.60 per kilogram paid in the process of developing a prototype; however, this figure is used on the assumption that it would cover the machining and mark-up on the aluminium parts.

Stainless steel is the most costly material used in the engine, costing $4.80 per kilogram.

A breakdown of engine components according to material categories is shown in Table 1. Weights of components in each category are totaled and multiplied by the appropriate factor to find their contribution to the sale price. To this are added the costs for bearings and the furnace. The total weight of this first intermediate engine is 315 Kg., and the projected selling price is $768.

It should be noted that the weight of this engine, at 315 Kg., is more than twice as heavy as the prototype, which was about 145 Kg. This is due to the shift to cast iron components and the fact that each part has been purposely over-designed. One Phase III activity is to modify the final design in ways to reduce costs, and it is expected that there will be a significant reduction in weight and, consequently, in cost in the final design.

3. Suitability of Stirling engine for operation in the field

During Phase I a small rice mill was set up at the project site to enable project personnel to become familiar with all aspects of small scale rice processing and to provide a means of testing the project engine. Since its initial

TABLE 1

ESTIMATED PRODUCTION COST OF ENGINE

Cast Iron & Steel	Wt Kg	Aluminium	Wt Kg	Stainless Steel	Wt Kg	Bearings	Furnace
Body	84	Cooler	18	Hot end	35		
Crankcase	43	Piston & Links	12	Displacer	5		
Bearing Cover and Cover Plate	22						
Cylinder Liner	23						
Flywheel	55						
Counterweight	10						
Displacer Body	4						
Connecting Rod	4						
Weight:	245		30		40	-	
Cost @ $1.50/Kg=$368		@ $2.60/Kg = $78		@ $4.80/Kg = $192		$90	$40

Total Weight:315 Kgs. Total Cost: $768

establishment, this rice milling operation has been run by four women who had previously worked as unskilled laborers for a building contractor. A fifth women, who is educated, manages the mill and keeps records.

To demonstrate that the operation of the Stirling engine will not be too complicated for use in rural areas, the women rice millers have been involved from the beginning with the operation of both the prototype and the intermediate model Stirling engines. In the test runs of the engine, the women entirely managed the operation of the rice husk furnace from the initial firing, through the warm up period, and throughout its operation. Based on the experience of training the women and observing their work with the engine, it can be stated that operation of the Stirling engine is well within the skills available in rural Bangladesh.

4. Comparative advantages in terms of energy costs and maintained

For the Stirling engine to perform successfully in operating a rice mill, its requirement for husk as fuel must be within the amount produced as a by-product during the milling operation. The operation of the prototype engine at the end of Phase I demonstrated a husk consumption rate of 18 Kg. per hour while producing 5 horsepower, as was reported in the First Interim Report. At this power level, a yield of 32 Kg. per hour of husk is expected, as a by-product of the mill, which is more than adequate. The survey on rice

husk utilization also pin-pointed the substantial energy savings that could be realized by using a rice husk fueled Stirling engine to power a rice mill while using the rejected heat from the engine for parboiling operations. The first runs of the locally made intermediate model indicated that the rate of husk consumption was roughly similar to that of the prototype. Detailed tests to determine the rate of husk consumption will be undertaken in Phase III as the performance of the engine is characterized.

5. Alternative rice milling systems

The principle objective of this project is to develop a husk fueled prime mover for use with the traditional steel huller which is widely used throughout the world. It is recognized, however, that there is an interest in modernizing the rice milling sector in order to increase the quality and yield of finished rice and rice milling by-products. An essential feature of this "modernization" of rice milling is to carry out husk removal and bran removal in different machines to provide for better separation of husk and bran. This improves the quality of the finished rice and reduces the energy requirement of the milling operation because the husk is not ground as is the case in the steel huller, and the pure bran, which is mostly free of husk, makes a higher quality animal feed and may open up the possibility of using rice bran directly in human nutrition

With respect to the husk fueled Stirling engine, the important issues vis-a-vis rice mill modernization are:

a. What "modern" rice milling machinery would be suitable for use with the husk fueled Stirling engine ?

b. What effect would the change in husk quality have on the operation of the furnace and the efficiency of the system, in terms of the amount of husk consumed as fuel compared to the amount produced as a by-product of the milling operation ?

Three different rice hulling systems have been evaluated, namely disc, rubber roll and centrifugal.

The efficiency of the disc huller system is dependent on the supply of paddy with uniform kernel length and would not be suitable for use in a custom rice mill where there would be great variation in kernel sizes, not only between batches but within batches.

Rubber roll hullers, while extensively used in some countries , present a problem in regular supply of rubber rolls of adequate quality. Also the price of rubber rolls has risen dramatically in recent years. These drawbacks, along with the high degree of skill needed to operate and maintain a rubber roll huller, makes them unsuitable for rural areas at this time.

After considering the advantages and disadvantages of each system, it has been decided to test the Stirling engine using a centrifugal huller in conjunction with the existing No.4 huller functioning as a polisher for bran removal. Centrifugal hullers for small mills are available from India where they have been in use for a number of years. The centrifugal huller also has the

advantage of being relatively easy to operate and can easily be reproduced locally if there is an interest in modernizing small rural rice mills in Bangladesh.

Two manufacturers of centrifugal rice hullers (Navinchandra and Krishna) have been located in India. After comparing the two different models, one will be purchased and, along with a supply of spare parts, shipped to Narayanganj to be set up and tested with the Stirling engine.

PROPOSED SCHEDULE OF ACTIVITIES FOR PHASE III

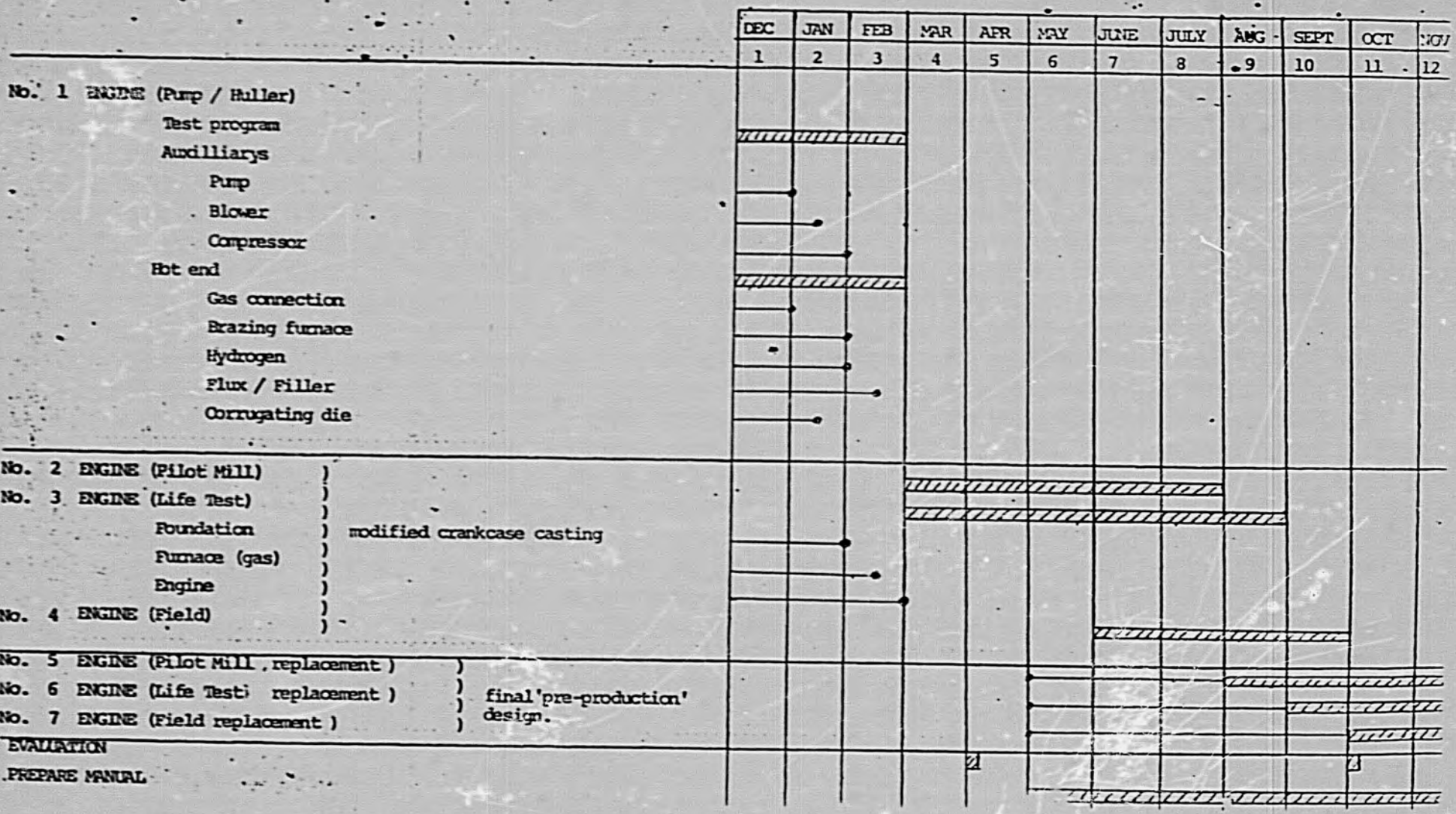
During Phase III a series of engines will be made and tested in order to arrive at the final design. There will be three test set-ups, the first being a Stirling engine powered rice huller at the project site (the present position of the first intermediate model). The second test set-up will be a Stirling engine fired with natural gas and operating a water pump. This will also be at the project site and will facilitate building up operating time without having to worry about a constant supply of rice.

The third test set-up will be a Stirling powered rice mill in a rural area near to Narayanganj to demonstrate the suitability of the system as well as to get feedback on customer acceptance. It is anticipated that engines similar to the first intermediate model will be evaluated at each of these sites and that these will subsequently be replaced by "pre-production" models based on further changes in the design resulting from experience gained in the earlier field testing operation.

The following chart outlines the activities to be undertaken during Phase III showing the time expected to

accomplish each task.

Performance levels have been set as follows. Before an engine is placed outside the project site for field testing, 30 hours of operation with at least 5 start-up procedures must be demonstrated by the women millers without assistance from the project's engineering staff. The final performance target for the project is to demonstrate the potential for 600 hours of operation with village level operation and maintenance (VLOM). This capability will be demonstrated by operation of the life test engine at the project site to establish life of components and by operation of the field test unit to confirm the design's suitability for use with a rice huller and customer acceptance.


DEC 1
JAN 2
FEB 3
MAR 4
APR 5
MAY 6
JUNE 7
JULY 8
AUG 9
SEPT 10
OCT 11
NOV 12
No. 1 ENGINE (Pump / Huller)
Test program
Auxilliarys
Pump
Blower
Compressor
Hot end
Gas connection
Brazing furnace
Hydrogen
Flux / Filler
Corrugating die
No. 2 ENGINE (Pilot Mill)
No. 3 ENGINE (Life Test)
Foundation
Furnace (gas)
Engine
No. 4 ENGINE (Field)
modified crankcase casting
No. 5 ENGINE (Pilot Mill , replacement)
No. 6 ENGINE (Life Test replacement)
No. 7 ENGINE (Field replacement)
final 'pre-production' design.
EVALUATION
PREPARE MANUAL

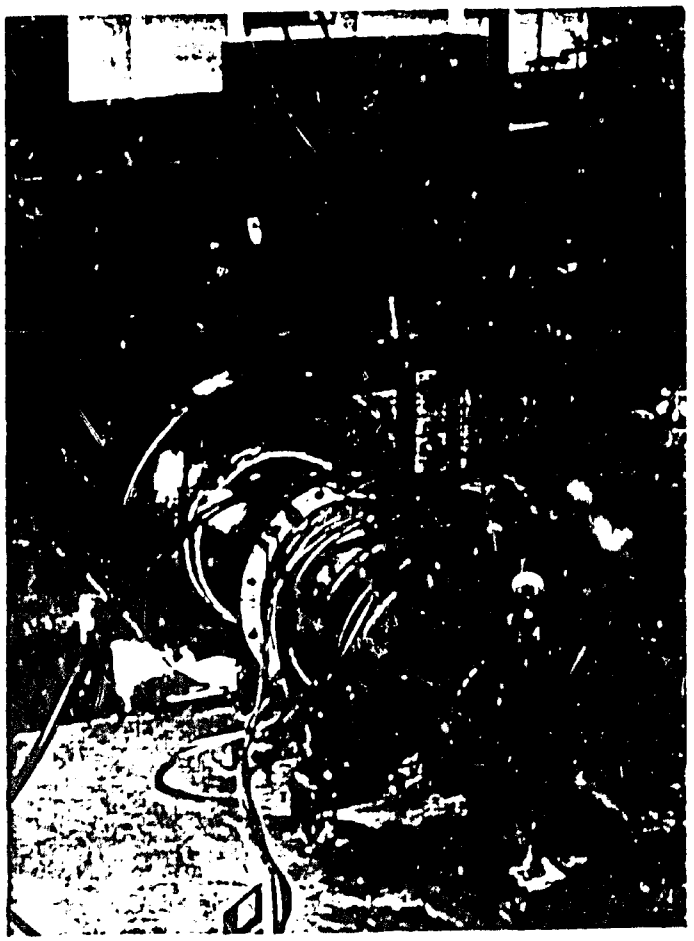


Figure 1 - Prototype rice husk fueled Stirling engine

PROTOTYPE RICE HUSK FUELED
STIRLING ENGINE

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Designed and fabricated by Sunpower, Inc. during Phase I of the project, the prototype 4 kW Stirling engine was shipped by air to Dhaka in Phase II where it was equipped with a locally made furnace and used to power a No.4 rice huller. Figure 1 is a close-up of the engine and Figure 2 shows the Stirling engine running the rice huller. Rice husk is fed by a manually operated auger and drops from the hopper into the airstream being blown into the furnace. The electric blower will ultimately be replaced by an engine driven blower, resulting in a stand-alone unit.

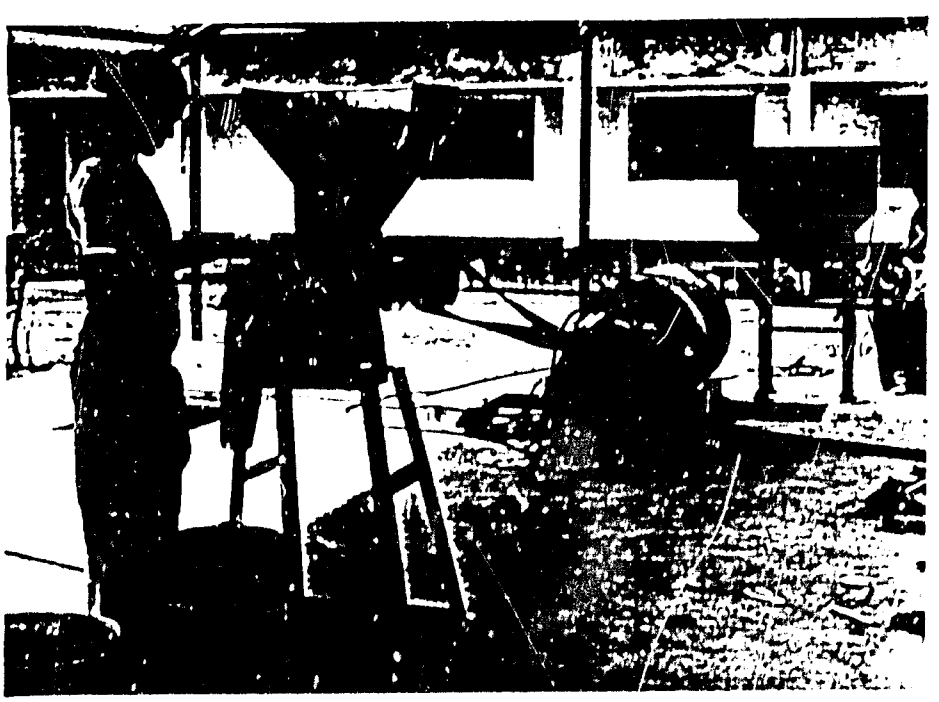


Figure 2 - Operating a No.4 rice huller with the prototype Stirling engine

.FIRST INTERMEDIATE MODEL RICE HUSK FUELED STIRLING ENGINE

December 1983

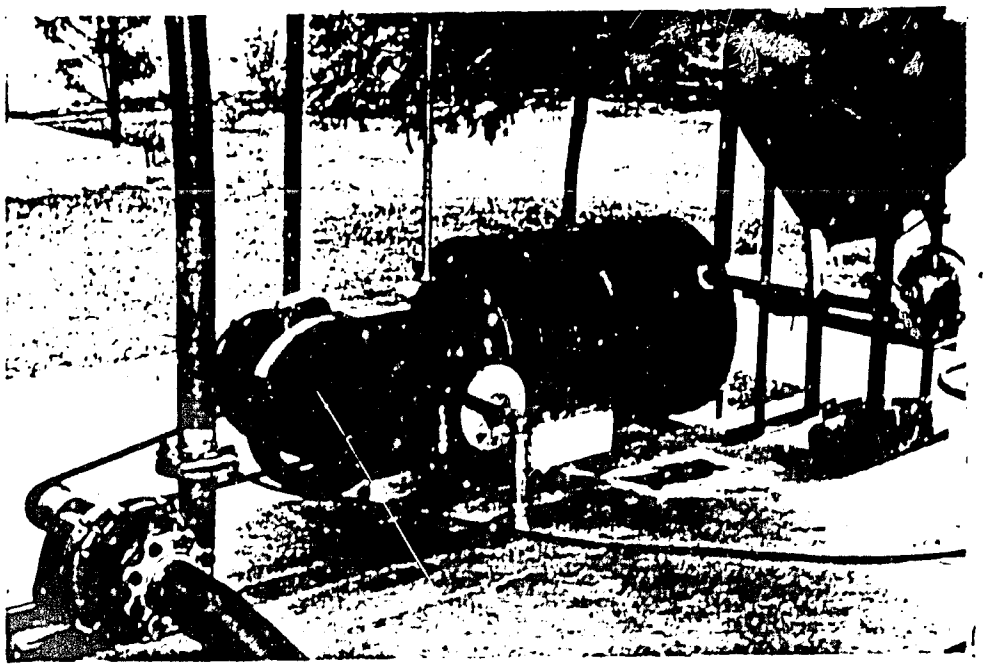
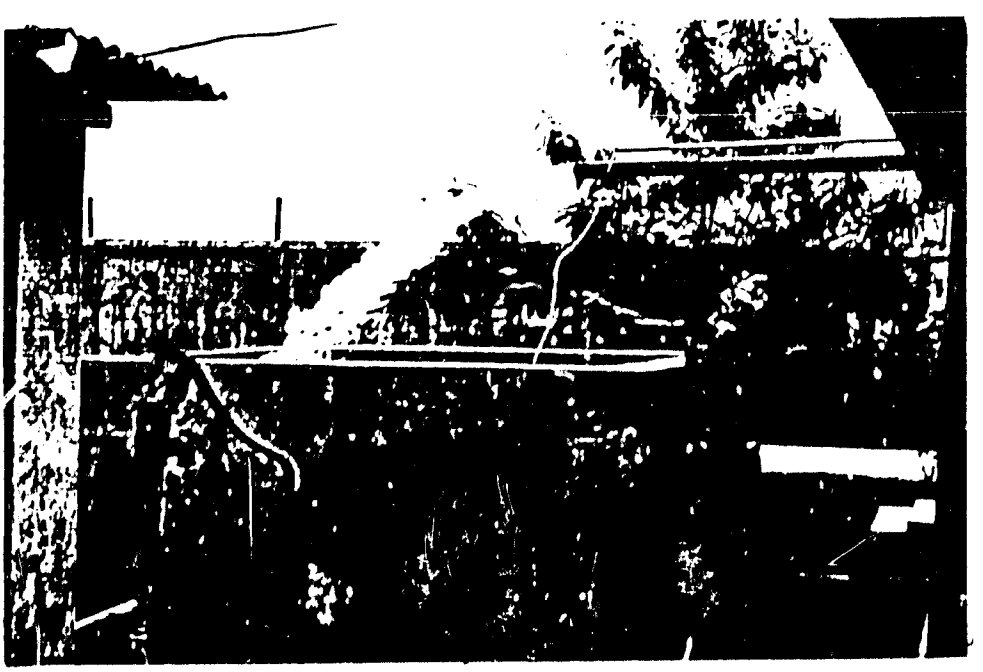


Figure 3

Intermediate model rice husk fueled Stirling engine attached to a water pump for preliminary testing

.The design of this first locally made Stirling engine has been changed in many details to adapt to local manufacturing requirements, while maintaining most of the features of the prototype in respect to heat exchangers and linkage geometry. The engine driven blower and pump for circulating cooling water can be seen to the right of the flywheel in Figure 3 and will replace the electric blower on the right. Preliminary testing has been carried out with a water pump. The output of the pump while being driven by the husk fueled Stirling engine can be seen in Figure 4.

Water flow from pump driven by the rice husk fueled Stirling engine