NASA Contractor Report 182210

Development of Free-Piston Stirling Engine Performance and Optimization Codes Based on Martini Simulation Technique

William R. Martini
Martini Engineering
Richland, Washington

September 1989

Prepared for
Lewis Research Center
Under Contract NAS3-22256

National Aeronautics and
Space Administration

(NASA-CR-182210) DEVELOPMENT OF FREE-PISTON STIRLING ENGINE PERFORMANCE AND OPTIMIZATION CODES BASED ON MARTINI SIMULATION TECHNIQUE (Martini Engineering) 269 p CSCL 10B

N90-18326

Unclas
G3/85 0266365

FOREWORD

This is a modified version of the final report written by Dr. W.R. Martini to summarize the work done under NASA Contract NAS3-22256 to develop a free-piston Stirling engine performance and optimization code. The code reported on here is operational. However, it was recognized by Dr. Martini and NASA that the code needed additional development in several areas and also needed validation; only minimal validation of the performance codes (there are several performance code options available), primarily against RE-1000 engine data, was performed under the contract. The "isothermal" performance code option predicted RE-1000 performance close to the values measured at design. The "adiabatic" performance, code option predicted power too large by a factor of almost two; it's possible, considering the minimal "debugging" that was done on this particular option, that a programming error could be responsible for the large error. Since no engines were designed with the code, no information exists concerning its design accuracy.

It had been anticipated that additional development and validation would be carried out under a follow-on contract. However, as a result of Dr. Martini's death the work was never done.

Continued development of Stirling technology during the several years following Dr. Martini's death, means that a potential user of the code would need to carefully evaluate it's assumptions. For example, a free-piston Stirling space engine has been recently constructed which operates at approximately 100 Hz; the Martini code does not account for some effects, such as gas inertia, that become important at higher engine frequencies. Also, the optimization algorithm incorporated in the code is a simple one that was written to expedite the development of the design code's structure; it had been intended that a more powerful and efficient technique would be substituted in the next stage of development.

Dale Hubler of Sverdrup Technology, Inc. (a NASA Lewis Research Center support service contractor) has corrected some problems that a user of the code might encounter. For example, the interactive data input procedure was improved upon and the code was converted to double precision. Dale also disabled (but did not eliminate the coding) of certain graphic features of the code that could be depended upon to work only with a particular graphics board used by Dr. Martini. These and other changes are discussed in certain modified sections of the report.

It has been decided not to expend funds in further development of the Martini design code. However, it is felt that the code might be useful to some in its current stage of development. For example, requests have been received from university students for codes that could be used for class Stirling engine design projects. This fast response code could also be useful to individuals interested in gaining an understanding of Stirling engines by investigating sensitivities of designs to various geometrical changes. Of course, the code could be used as the starting point for development into a design tool for high performance Stirling engines, if sufficient effort were expended in that direction.

A copy of the code on 5 and 1/4 in. floppy disk in high density format can be obtained on request from:

NASA Lewis Research Center
Stirling Technology Branch
Mail Stop 301-2
21000 Brookpark Road
Cleveland, Ohio 44135

Roy Tew
Manager, NASA Contract NAS3-22256

PREFACE

This manual describes a computer program originally written by W.R. Martini to simulate a free piston Stirling engine on the IBM PC. Sverdrup's only contribution to this program and manual has been the following six changes to the original Martini program and the appropriate changes to the manual. Portions of the manual that have been rewritten by Sverdrup are marked by a vertical bar down the side of the page.

(1) The program has been converted to double precision to increase the accuracy of the results. Formerly, when using the program on mainframes the results of power and efficiency often differed from machine to machine (mainframe results were used for comparisons only). Converting the program to double precision brought these results into agreement. Appendix E, J, L, and all sample base cases have been updated to double precision results. Summary results based on these and other cases have been updated wherever possible. Appendix F, K, and M are presented with the single precision results also. The results between versions differ more when the simulated engine is in free piston mode rather than in specified motion mode but the differences are not great. The remainder of the appendices and other examples are left with the results obtained by the single precision version. The increased accuracy comes at the cost of more computer time. Some free motion optimization cases have run overnight on an IBM PC-AT.

(2) The input method was replaced by a more friendly routine which consists of two screens and one instruction line for the user. Each screen displays half of the possible input variables. The user is prompted to choose a variable by name and then to enter a new value. Screen positioning is handled by an assembly language routine and only the chosen variable has its displayed value updated. This method is faster and more flexible than the old. This is IBM-PC assembler and will not work on other machines.

(3) The former input display is now used as a method of recording values of input variables on the printed output. This block of variable values, together with the instructions, would scroll across the screen with each change to a value. The block of numbers gives the input value together with an input variable number. Appendix A show each input variable name together with the number assigned to it. In free piston mode the displacer phase angle (PHASED), the power piston stroke (PPSTR), and the displacer strike (DSPSTR) values on the output are not the values input but the values of the variables at the end of the last case considered.

(4) The capability to optimize the mass of the power piston and the displacer was added.

(5) All executable statements in the graphics subroutines were commented out. Calls to these subroutines now immediately return to the calling program. These subroutines were only useful with a particular graphics board which is not commonly in use. They have been left in the program to assist anyone who wishes to convert this option to be used on another device.

(6) The 17 original source files have been merged into five files (four fortran and one assembler) to simplify changing and moving the files.

Dale Hubler
Sverdrup Technology, Inc.

TABLE OF CONTENTS

1.0 SUMMARY

A FORTRAN computer code is described that could be used to design and optimize a free-displacer, free-piston Stirling engine similar to the RE-1000 engine made by Sunpower. The code contains options for specifying displacer and power piston motion or for allowing these motions to be calculated by a force balance. The engine load may be a dashpot, inertial compressor, hydraulic pump or linear alternator. Cycle analysis may be done by isothermal analysis or adiabatic analysis. Adiabatic analysis may be done using the Martini moving gas node analysis or the Rios second-order Runge-Kutta analysis. Flow loss and heat loss equations are included. Graphical display of engine motions and pressures and temperatures are included. Programming for optimizing up to 15 independent dimensions is included.

Sample performance results are shown for both specified and unconstrained piston motions; these results are shown as generated by each of the two Martini analyses. Two sample optimization searches are shown using specified piston motion isothermal analysis. One is for three adjustable inputs and one is for four. Also, two optimization searches for calculated piston motion are presented for three and for four adjustable inputs. The effect of leakage is evaluated. Suggestions for further work are given.

2.0 INTRODUCTION

Since 1966, the author has been involved in Stirling engine development work and has evolved a method of analysis which has been described in a number of publications (refs. 1-5). Since 1979, Martini Engineering has developed a number of additional computer programs that are more sophisticated than the original isothermal analysis. These involved original methods of taking into account the adiabatic spaces and the partial adiabatic spaces in a Stirling engine. Since essentially all this work was done one government contract or another, there is no proprietary position to protect and the methods of these calculations are freely disclosed in this report.

First, the engine will be described in some detail and then the computer programs will be presented by discussing the flow charts which describe the logic of the main programs and all the subsidiary programs. Next the sample results of some of the base case calculational options are given, both as the output printout as well as a photograph of the graphical output display. Also, the effect of time step size and the time for solution are presented and discussed. Finally, a program users manual is given and current code status and suggestions for further work are discussed. A derivation of the Rios equations and detailed outputs obtained in the time step studies are given in the appendices.

3.0 ENGINE DESCRIPTION

The computer program described in this report is designed to calculate the power output and efficiency of a free displacer, free-power piston Stirling engine similar to the RE-1000 engine built by Sunpower and tested extensively by NASA Lewis Research Center (refs. 7-8). Figure 3.1 show a perspective drawing of the full engine with load. The engine heater tubes are heated by conducting electricity through the tubes themselves. The engine is loaded by dash pot and is water cooled. Figure 3.2 shows a more detailed drawing of the

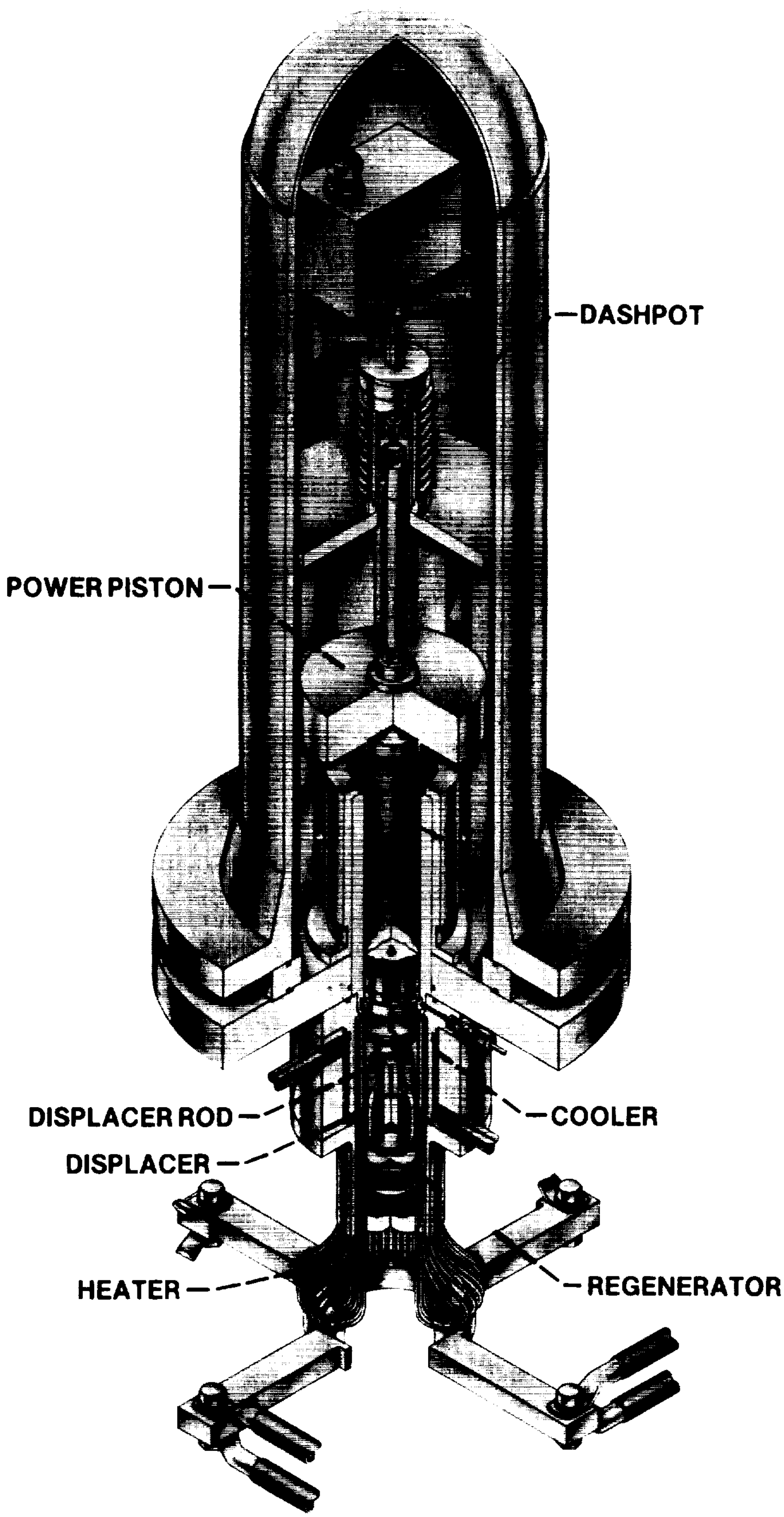

FIGURE 3.1. - DRAWING OF RE-1000 ENGINE (8).

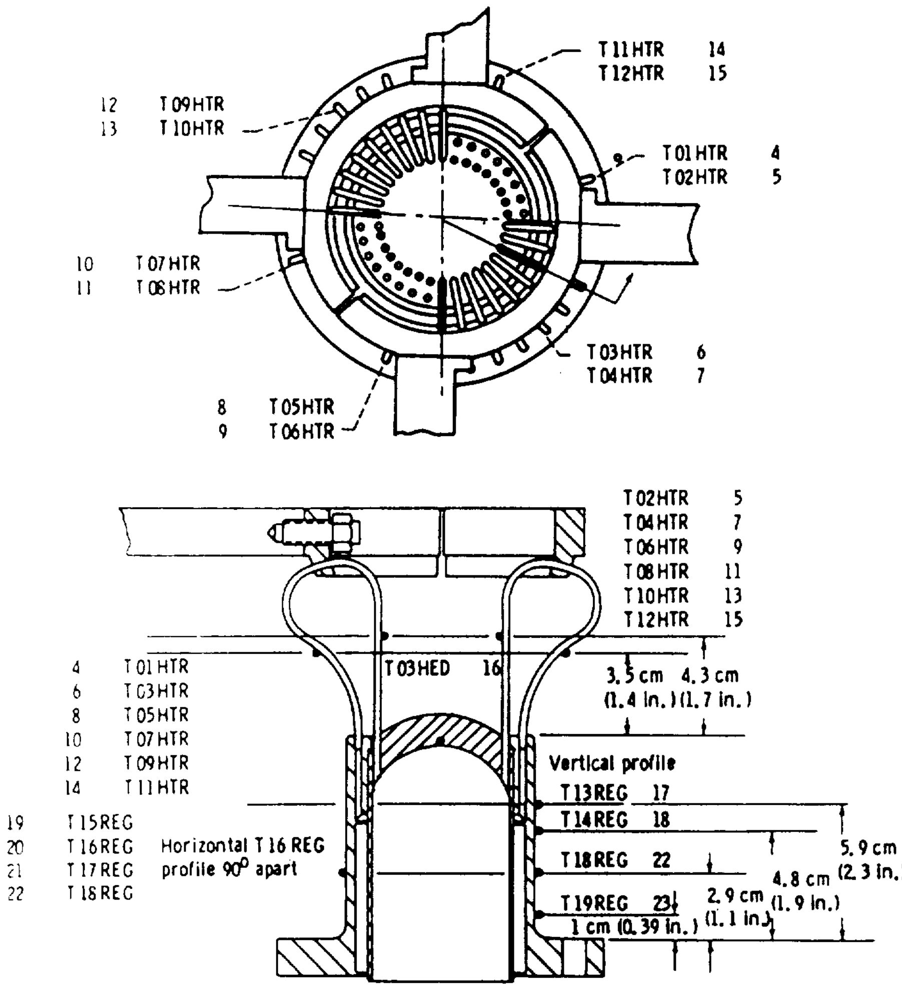

FIGURE 3.2. - RE-1000 HEATER HEAD THERMOCOUPLE LOCATIONS AND HEAT CONDUCTION PATHS (8).

heater and regenerator and part of the cooler to show how the thermal conduction paths between the hot part and the cold part of the engine are currently fabricated.

Figure 3.3 shows some details about the power piston centering ports which are important to consider in the free-piston analysis. These centering ports open up only momentarily at the mid-point of the stroke and the pressure equalization which partially takes place at this time keeps the power piston near the mid-point of its stroke. Note also that the displacer is sprung to the case instead of to the power piston as is sometimes done. Figure 3.4 gives more detail about the displacer rod mounting and communication ports. These communication ports are centering ports and serve the same function for the displacer as is done for the power piston. These four sketches plus the tables of information supplied with the contract statement of work were used to derive the input numbers given in Appendix A. These input numbers give a full description of the engine as far as the computer is concerned.

One thing that is not clear in the four figures given in this section is that the gas cooler is made up of a finned section which is cooled from one side of the fins. We assume that the fin efficiency is 100 percent.

The engine computer program will be described in the next section.

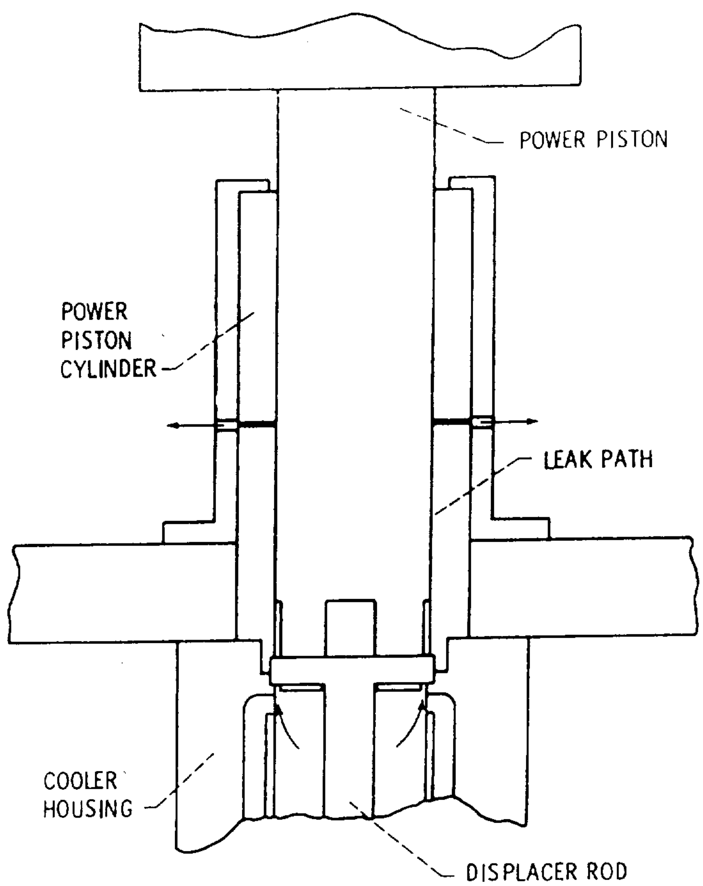

FIGURE 3.3. - POWER PISTON LEAK PATH OF RE-1000 ENGINE.

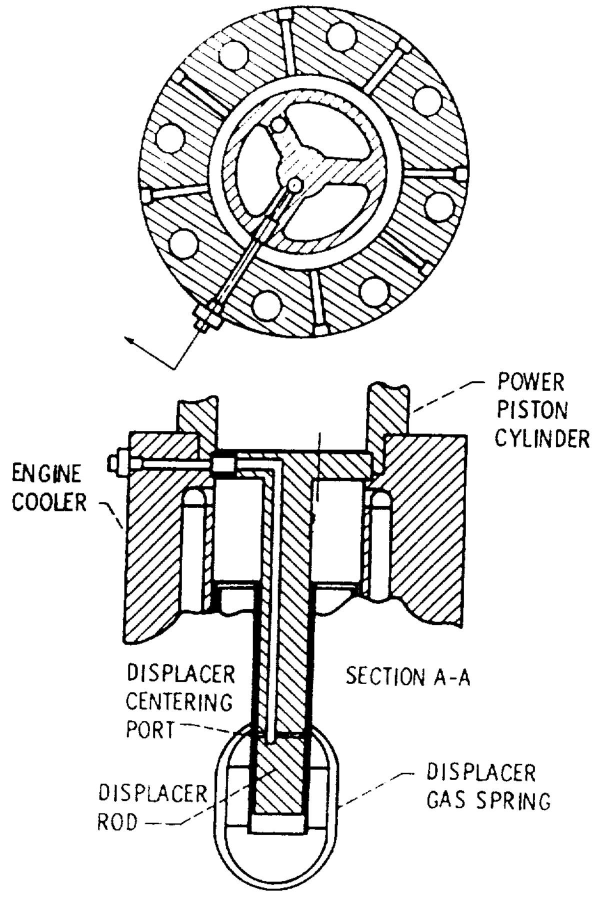

FIGURE 3.4. - DISPLACER ROD MOUNTING AND COMMUNICATION PORTS FOR RE-1000 ENGINE.

4.0 COMPUTER PROGRAM DESCRIPTION

Sections 4.0, 4.1, and 4.2 have been extensively rewritten and all other sections have been changed where appropriate.

The nomenclature for the computer program described in this report is given in Appendices A to C. In Appendix A the input variables are described since they will have to be identified by number and the optimization variables, which are a subset of the input variables, also are identified. The default value for each of the input variables is also shown. Appendix B gives the nomenclature used in the program in alphabetical order along with the units that are used. For a particular variable the units always remain the same. If the units change the variable name changes also. Appendix C contains a variable use table. This compliments the nomenclature list given in Appendix B by identifying the part of the program that the variable is used in. Most variables are in named common so they can be transferred from one subroutine to another. It was found that with the software available, the named common saved much more computer space than use of formal parameters, which we originally tried. This means that sometimes a large common block is introduced into a subroutine when only a few members of that block are actually employed in that subroutine. Nevertheless, it is more economical of computer space when it is all compiled. Also, the table was very useful in writing the program to be certain that all of the variables are defined before they are used and if they are defined in one part of the program and used in another part they are being shared. Also, some variables are used iteratively in subroutines, generated in one pass and used during the next. These must be in a common block. If on each pass they are generated and then used, the variables need only be local variables and their memory location may be freed when the subroutine is exited.

In this chapter the logic of the programming will be explained with the use of flow charts. In most cases the actual equations used are described in the source code to show what is being calculated. Often the source code is commented to give the references where the equations come from.

4.1 Main Program (FPSE)

Figure 4.1 shown the main program flowchart. The program starts by initializing flags. Then the main program calls FPIN, (F1) which will change any of the input variables the user requests it to. This subroutine is described in section 4.2. Next, if graphics are called for,[1] the previous graphic display is removed from the screen and a frame is drawn to start the new display. Also, a cycle counter is reinitialized. We are now at label 350. The main program does some more initializing and then calls subroutine CYCLE (F2) which is the main part of the simulation portion of the program. The simulation portion calculates works, heats, and losses for the particular input values as specified.

---

[1]All graphics subroutines are specifically written to an Orchid board and have been commented out in the current release of this program to avoid compiler errors.

Now comes the decision about whether optimization is called for. This is determined by one of the input values. If optimization is called for the program calls PAOPTI which adjusts the power and controls and records the optimization process. This is explained in Section 4.5. This subroutine first adjusts the power of the engine so it is very close to the target power and then searches through up to 15 of the selected input numbers to find the best values. Once the best values have been selected it is necessary to recalculate the works, heats, and losses for the best ones by going through F2 one more time. If optimization is not called for, or if optimization is called for and optimum values have been found then the control passes to 910 and thence to the subroutine DESOPT which is described in Section 4.4. This prints out the results of the calculations to the printer. Now comes an operator decision about whether to do another case. If the operator decides no, the program stops right there. If the operator decides yes, then it must be tested whether optimization was engaged in. If it was, certain flags have to be reinitialized by starting the program over again and therefore, one cannot go around and find another optimum through the program. Therefore, if the decision is made to continue and optimization is not done the subroutine CLEAR is called, if the graphic option was used, to clear the screen of the last graphic display and control returns to label 300.

4.2 FPIN Input Subroutine

Figure 4.2 shows the flowchart for subroutine FPIN. This subroutine uses arrays to store the input variable names, default values, screen coordinates, and integer flag information. Screen clearing and positioning is handled by an assembly language routine appropriately named SCREEN. The SCREEN routine is described in Section 4.2.1. The subroutine FPIN begins by asking the user if he would like to have the last input case recalled. If the response is no (N) the default values for the input data set are used to initialize all input variables. The screen is then cleared and the first 60 of the input variables and their default values are displayed in three columns on the screen. The user may select any variable by name and enter a new value. This new value must be entered as a real value (i.e., with a decimal point) even though the variable might have an integer value because the new value is read as a real value and later converted to an integer if required. If the user enters "exit" as a variable name the program displays the second half of the input variables as it did the first. If the user enters "exit" on this screen the program will assign all input values, save these values to diskette on drive B, and end the subroutine. The user may enter "prior" as a variable on the second screen if he desires to return to the first screen for additional changes.

Input variable number 45 (NGN) is a special case in the list of input variables. The program initializes the number of gas nodes at 21 and creates additional nodes, up to 200, as required during the simulation. The printed output of input values will display the value of NGN at the end of the run.

4.2.1 Subroutine screen

Description

The screen subroutine is a special purpose subroutine to move the cursor or clear the screen. It is written in assembly language and uses BIOS interrupt 10H to provide some screen facilities.

Calling Format

```
CALL SCREEN (ROW,COL,FUNC)
```

Parameters

Row Integer value containing the row number to which the cursor is to be moved (1 to 24).

Col Integer value containing the column number to which the cursor is to be moved (1 to 80).

Func Integer function code. A value of one will clear the screen, any other value will position the cursor at Row, Col.

Notes

- Row and Col are not checked for range errors. Any value outside the appropriate range will give unpredictable results.

- No values passed are modified.

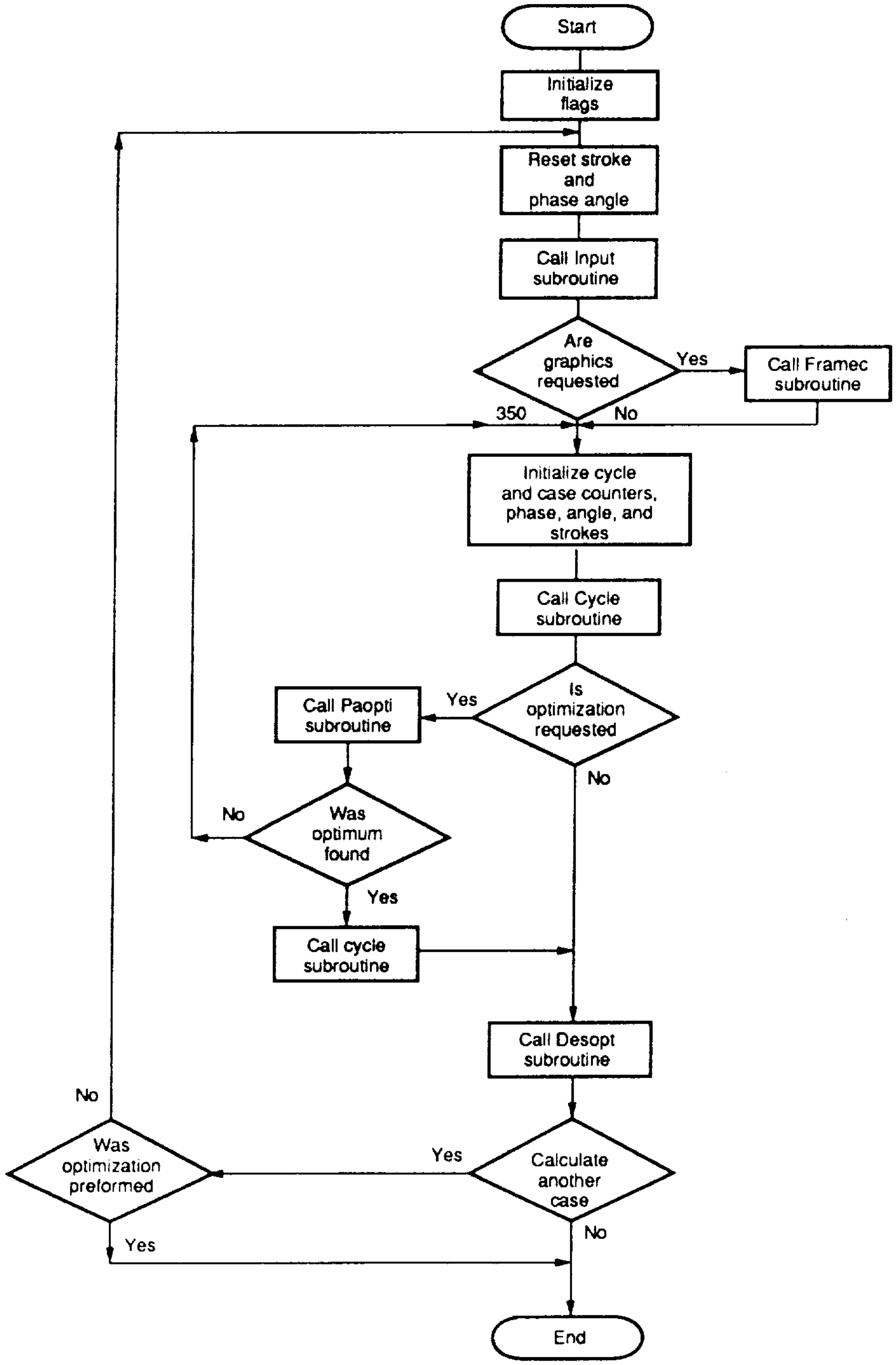

FIGURE 4.1. - MAIN PROGRAM FLOW CHART (FPSE).

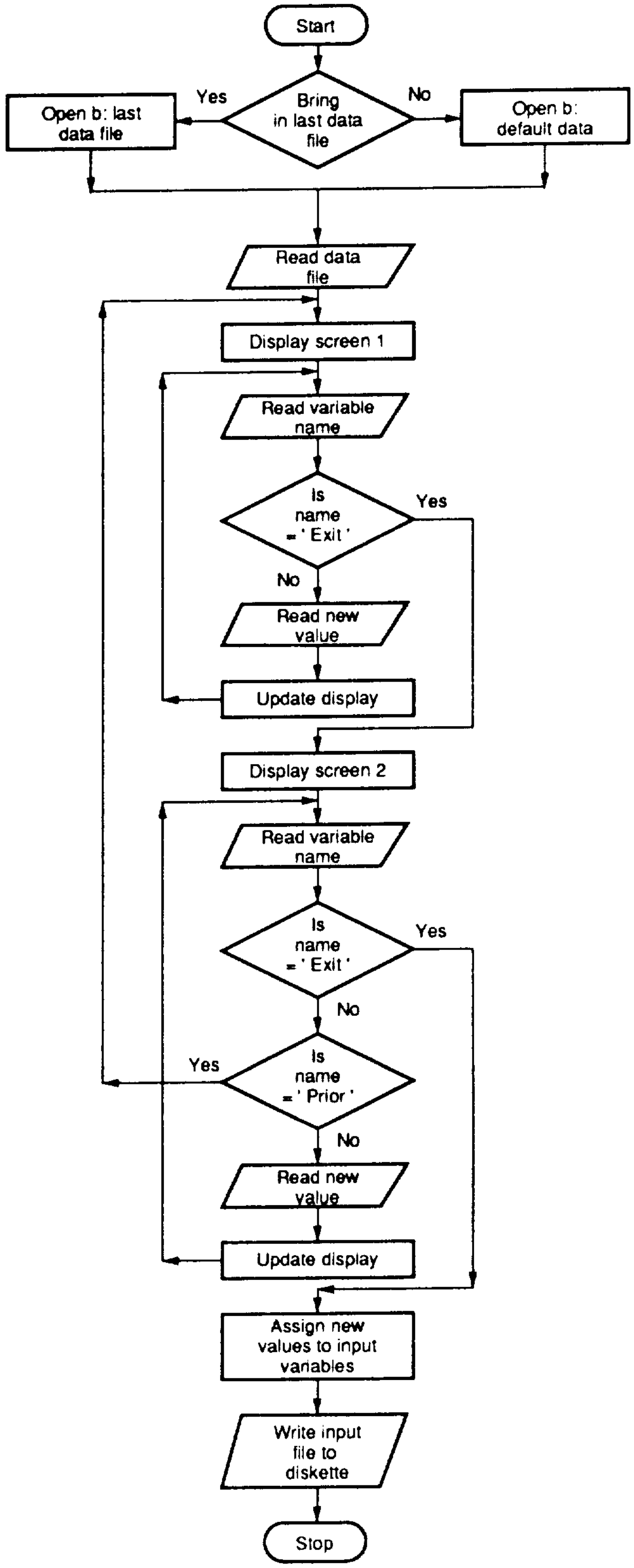

FIGURE 4.2. - FLOW CHART FOR SUBROUTINE FPIN (F1).

4.3 CYCLE Subroutine (F2)

Figure 4.3 shows the flow chart for the CYCLE subroutine. The source code listing is available on floppy diskette (see Foreword). This subroutine is the heart of the computational procedure. It contains much of the computational procedure itself plus it calls eight additional subroutines, F21-F28, for the additional parts of the full computation. The first thing that is done after the subroutine CYCLE is called is the subroutine CONSTS is called. This takes the input values and calculates a large number of intermediate values needed by the rest of the program. These values are placed in INTMED common, which is common to all the subroutines F2-F28 and is the means of passing variables from one to the other. In addition, certain first time flags and accumulators are set at the very beginning which are needed just inside of program F2 or CYCLE. Label 700 is the return point after one cycle is calculated. Then the variables that need to be initialized at the beginning of each cycle are put in. Label 400 is the return point after each time step cycle is calculated. Therefore, the loop starting with label 400 is gone through for each time step.

It was decided that the first time through this calculation, the program should go as if the isothermal specified motion case were selected. This would get the temperatures and motions approximately correct and would be a good start for the other calculations to finish up on. Therefore, the first decision is whether this is the first time or whether we are asking for specified motion or for free motion. If this is the first cycle through the calculation, the subroutine MOVESP is called which calculates the future position of the power piston and the displacer and the volumes that would be represented by this future position based upon specified motion. If free-piston is called for, then MOVEFR is called which does the same thing, but this is based upon a force balance of both the power piston and the displacer and is much more complicated.

After going through one branch or the other, the calculation comes back together. Based upon the motions that have been calculated, the new bounce space volumes and pressures for the displacer bounce space as well as the power piston bounce space are calculated. Next, the program calls subroutine LEAK which calculates new gas masses in the working gas space and in the displacer bounce space and the power piston bounce space based upon calculated leakages between these different spaces due to the current pressure difference.

Then for each time step the pressure in the working gas and bounce space and the position of the power piston are added up so that at the end of the cycle the average pressure and average power piston position can be calculated.

Next, there is in effect a three way split depending upon whether an isothermal or an adiabatic analysis is desired. If it is an adiabatic analysis, the further decision must be made as whether to use the Martini moving gas node analysis or the Rios analysis. In all three cases the basic thing that is calculated for a particular time step is what the next pressure should be. This is done quite differently in these three different branches.

The calculation then comes back together again and the accumulated work and heat integrals are found. These have to be added to for each time step so that at the end of one cycle, we have the line integral of the total volume versus the pressure to give the basic work output per cycle and the line integral of the hot volume versus the pressure to give the basic heat input per cycle.

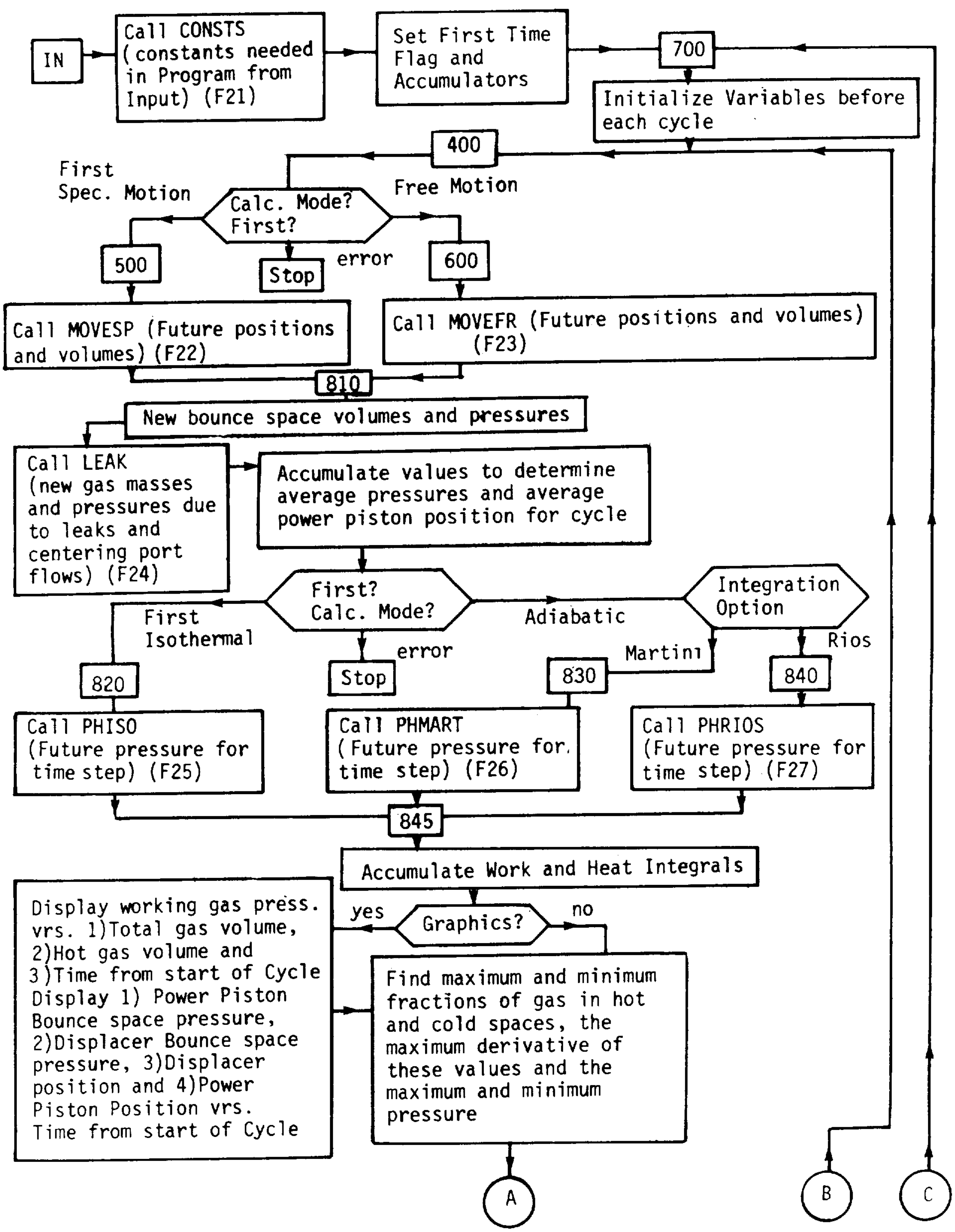

FIGURE 4.3. - FLOW CHART FOR SUBROUTING CYCLE (F2).

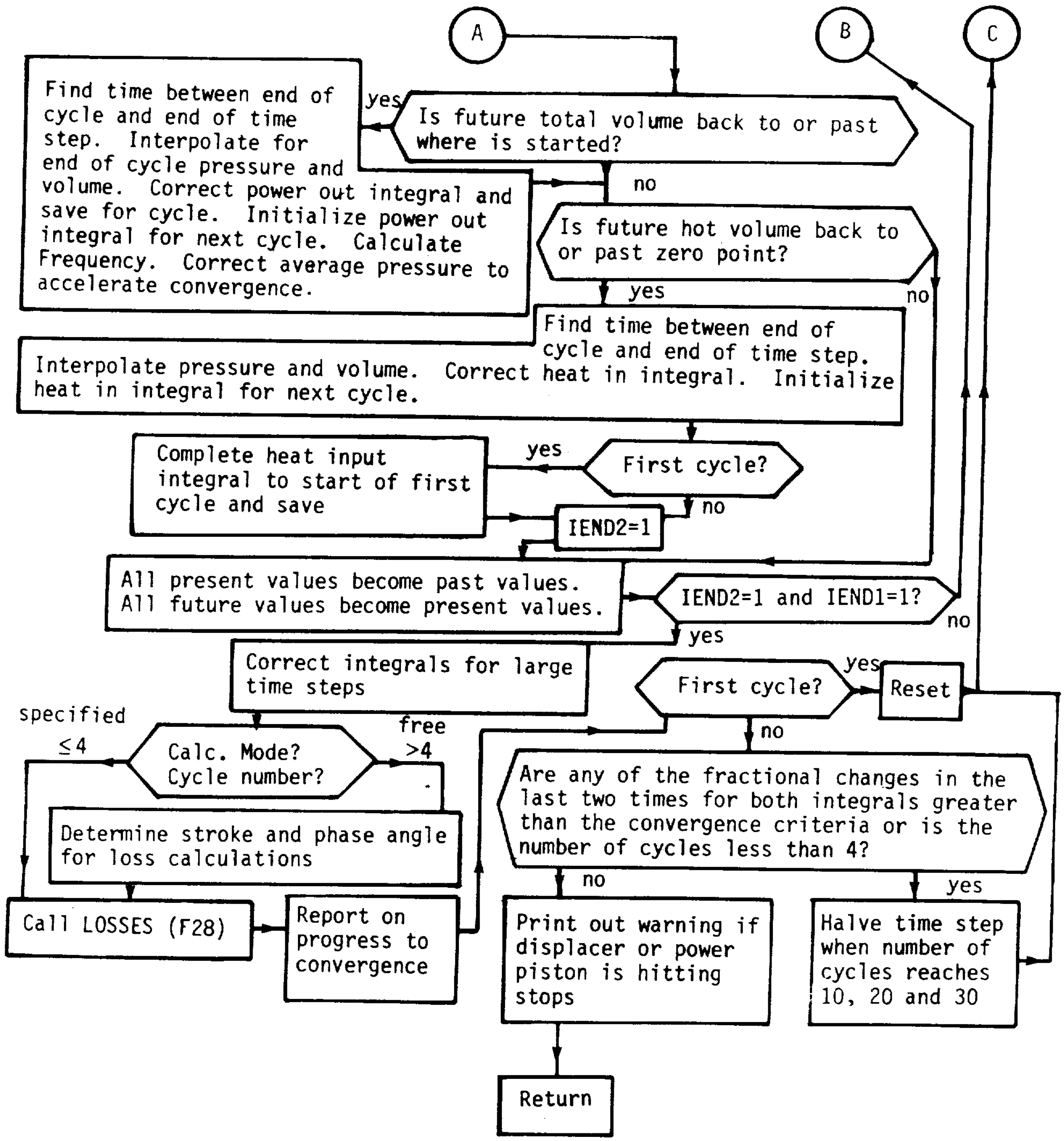

FIGURE 4.3. - CONCLUDED.

If graphics are to be used, then at this point the control splits off to plot segments of seven different line on the screen. This is more fully explained in figure 5.6 of Section 5. Then for all cases the maximum mass fractions of the gas in the hot and cold spaces of the engine and the maximum derivatives of these values are calculated along with the maximum and minimum pressure. Of course, the final values of these are not known until the cycle is completed, but this part finds values as it goes along.

One reason for having an end of cycle test is to integrate a pressure-hot volume curve for exactly one cycle to determine the thermodynamic heat input for one cycle. Another reason is to integrate a pressure total working gas volume curve for exactly one cycle to determine the thermodynamic power output.

For specified motion, the end of cycle test is easy because you know when the cycle will end. You can make it come out to an even number of computational steps. Also both cycles start and end at the same times.

For free motion you do not know ahead of time when the cycle will end. It will always actually end between time steps. Even for small time steps, there is a large error incurred if the end of cycle is not interpolated between time steps. In the free-motion case, the first cycle is always in specified motion just to get the parts moving. In the second cycle, the cycle time for the power piston is usually different than the cycle time for the displacer. As the simulation settles down these two cycle times become the same again. In between, large errors in calculated heat input can occur if the end of cycle is determined by when the power piston finishes its cycle. These errors perturb the way the effective hot and cold working gas temperatures are chosen which feeds back into the pressure-volume curves. These errors, at best, delay convergence and may prevent it. A more serious problem is the choice of an end of cycle test. For some test and for some cases encountered in an optimization search the end of cycle test is never satisfied. The computation hangs up.

The end of the cycle test that was finally found to work and successfully complete an optimization search in the free-piston mode uses a separate end of cycle test for the hot volume and the total volume. At the time the first flag is set, the initial hot volume and the initial total volume are noted. The initial total volume is at the point where the centering ports of the power piston are open. Because of the phase shift, the initial hot volume is near one end of the displacer stroke. Since this extreme hot volume may never be calculated again, at the start the hot volume at which the displacer centering ports are fully open is calculated and used as the end of cycle test for the hot volume. During the first cycle the power piston actually goes through a full cycle, but the displacer goes through about three-quarters of a cycle. Using the trapezoid rule, the first heat input integral is estimated. In all subsequent cycles, the cycle for the displacer, and for the power piston both start and end at midstroke. The cycle times may be different. The power piston cycle time is used to compute frequency.

Now, all present values are made past values and all future values are made present values. In some computer programs large arrays are used so that full information on engine position, pressure, temperatures and so on for the full cycle is available at the end of the cycle for use. For each time step the future values of all these different physical quantities are calculated from present values and sometimes, particularly in the case of the Rios analysis is calculated also from immediate past values. Therefore, for any time step the present, immediate future and immediate past values are the only values that are used and therefore, they are the only ones that are retained. During this part of the program the values are indexed.

After this index, a split is made depending upon whether the end of cycle has been found or not. If not, control returns to label 400 to begin the next time step. If it has been found, we go on to correct the work and heat input integrals for large time increments. This is a correlation developed by Martini (ref. 1) to correct for the smaller line integral which is realized when a relatively small number of time steps are used.

After the free-piston mode has settled down there will be different displacer and power piston strokes and a different phase angle than was input. This program recalculates these.

Next, the subroutine CYCLE calls the subroutine LOSSES which calculates the flow losses and heat losses for the cycle. After exiting LOSSES, the program shows a line in a table which gives the fractional changes in power output and heat input. These can be compared with the convergence criteria in the heading of the table. The operator can judge whether the solution is converging. Also shown in the table are workout and heat input per cycle, the ending pressure and the time step in effect.

The next question asked is, is this the first cycle. If it is, the first cycle flag is changed so it no longer shows the first cycle and the cycle starts over again.

Finally comes the convergence test. As each new value of the heat input and power output integral is determined, the absolute value of the fractional change between the new one and past one is calculated. To pass the convergence test, both these changes must be less than the convergence criteria which is input for two successive times. In addition, at least four cycles must be gone through.

If the convergence test is not met, control passes back to label 700 for another cycle. On the way, the time step is halved after the 10th, 20th and 30th cycle. Experience has shown that when the solution is not converging, reducing the time step helps convergence happen.

If the convergence test is met, warnings are printed out if either the displacer or the power piston hit the end stops. Control then returns to the main program.

4.3.1 CONSTS subroutine (F21). - Figure 4.4 shows the flow chart for subroutine CONSTS. The full source code listing is available per the Foreword. In general, F21 takes the input numbers and from these generates a large number of constants that are used throughout the rest of the subroutine CYCLE. This flow chart enumerates the general headings of these constants and more specific headings are in the source code. After calculating all these constants it calculates the time step in one of two ways whether specified motion or free motion is being called for. It initializes the elapsed time counter. If inertial pump is called for, the initial pressures for this pump are calculated. Finally, for the Martini integration method it calculates the initial gas node properties and then returns to subroutine F2.

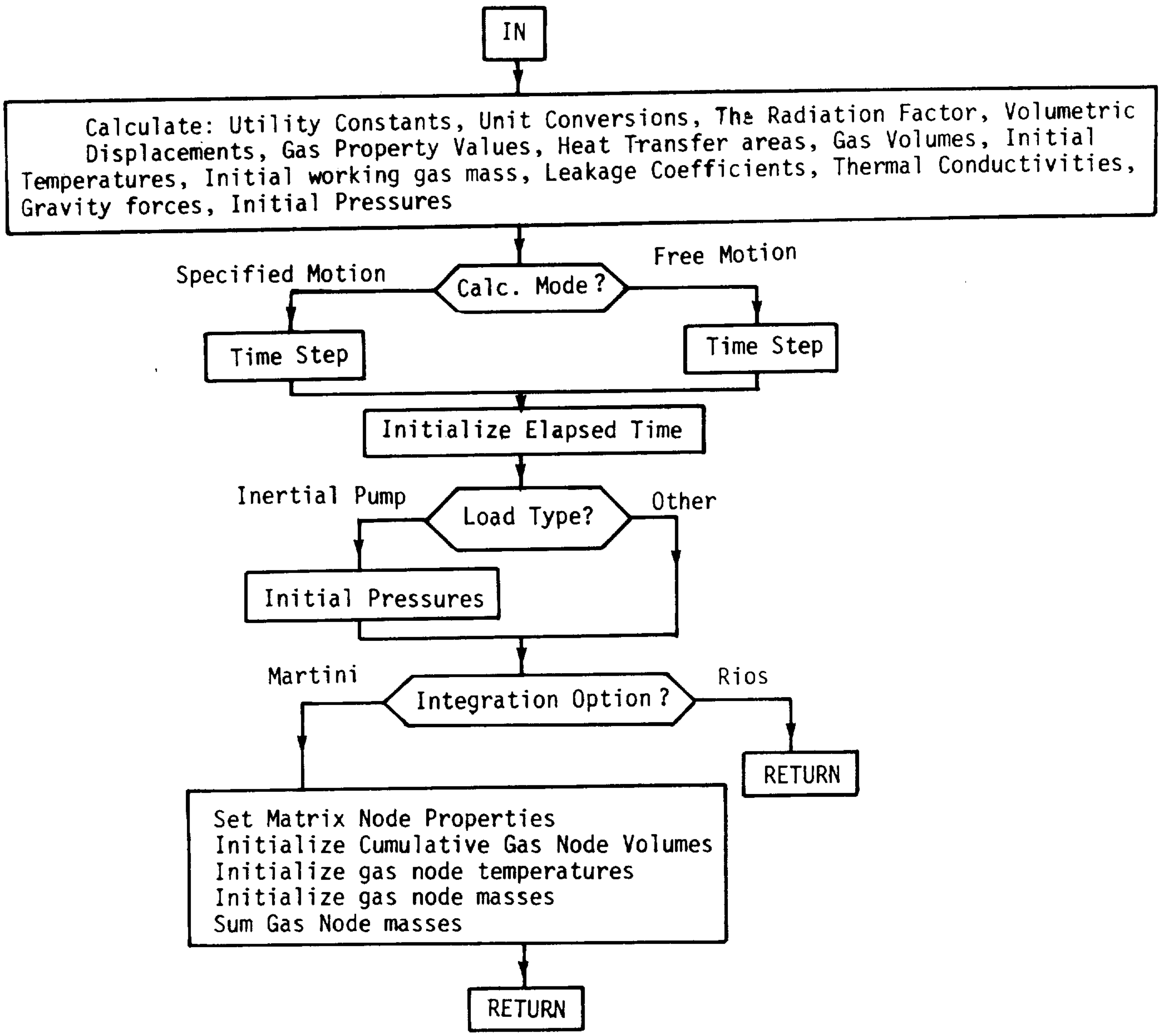

FIGURE 4.4. - FLOW CHART FOR SUBROUTINE CONSTS (F21).

4.3.2 Specified motion subroutine (F22). - The flow chart for the specified motion subroutine MOVESP (F22), is given in figure 4.5. The full source code for this subroutine is available on diskette. Entering this subroutine, the first decision is whether this is the first time step or not. If it is, it initializes the first positions and the first volumes and starts the search for the maximum and the minimum volumes. Then it proceeds on as it does for all other times to index the elapsed time, find the new positions and volumes based upon the formula which is determined by the amount of elapsed time, and searches for the maximum and minimum hot and cold volumes. It then returns to subroutine F2.

4.3.3 Calculated motion subroutine (F23). - The flow chart for this subroutine is shown in figure 4.6. The source code is available on diskette. When this subroutine is called, the first decision is if this is the first time step. If it is, then the search for the maximum and minimum hot and cold volumes is initialized with values that are bound to change. Then the elapsed time is indexed. Next the force balance for the displacer is calculated. The same is true of the power piston, but this is more complicated because the power piston has attached to it one of four different loads. These loads determine one of the forces that are part of the force balance. The load force must be calculated. The power piston force balance is then calculated. In consistent units the time derivative of velocity is equal to the ratio of the net force acting on a body divided by its mass. There are two bodies, the displacer and the power piston. The Adams method is used for integration for better computational stability. This method uses the current ratio plus the last three ratios. These ratios are indexed along. Then the current force per mass ratios are calculated. If this is the start of the second cycle these past ratios do not exist. Therefore, the past ratios are made equal to the current ratio. When this is done the Adams method reduces to the Euler method.

Under some circumstances the use of the Adams method still resulted in computational instability. It was found that because of the lightness of the displacer, this was where the instability started. We found that for a number of time steps before instability could be noticed in the calculated displacer position, the force per mass ratios were alternating in sign with rapidly increasing magnitude. It was found that as soon as this was detected, the instability could be quelled by reducing the time step. After the time step is reduced the Adams method is not strictly correct for four time steps. However, it was found that computational stability was restored.

The Adams method determines the velocity at the end of the next time step. The position of the part at the end of the next time step is calculated from the average velocity for the time step.

Next the new positions are tested to see of they exceed the mechanical stops in the machine. If they do, they are bounced back with a specified bounce coefficient. Then the search for the maximum and minimum hot and cold volumes is done for each time step during the cycle. Finally, the future pressure inside the pumping chambers of the inertial pump is calculated, if inertial pump is called for, and the program return back to subroutine F2.

4.3.4 LEAK subroutine (F24). - The flow chart for subroutine LEAK is shown in figure 4.7. The source code is available on diskette. The first thing this subroutine does is to calculate the leakage for the pressure differences

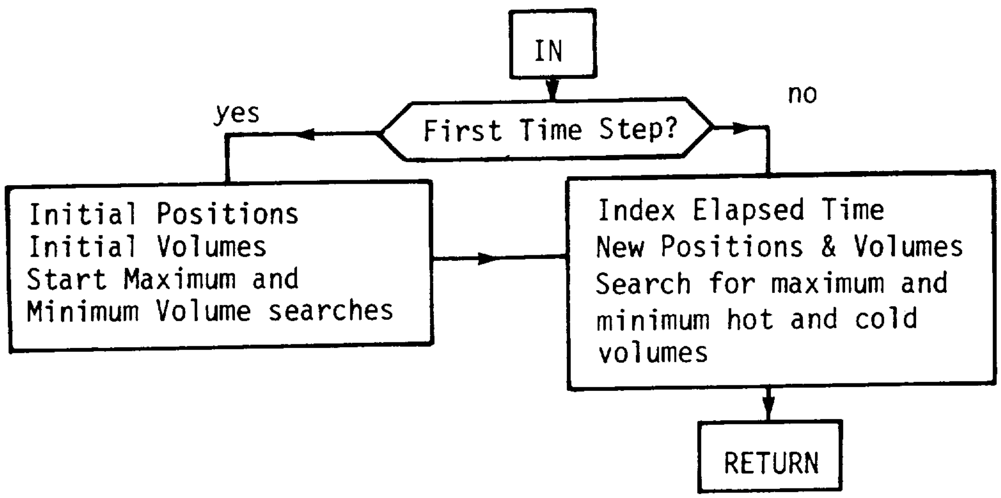

FIGURE 4.5. - FLOW CHART FOR SUBROUTINE MOVESP (F22).

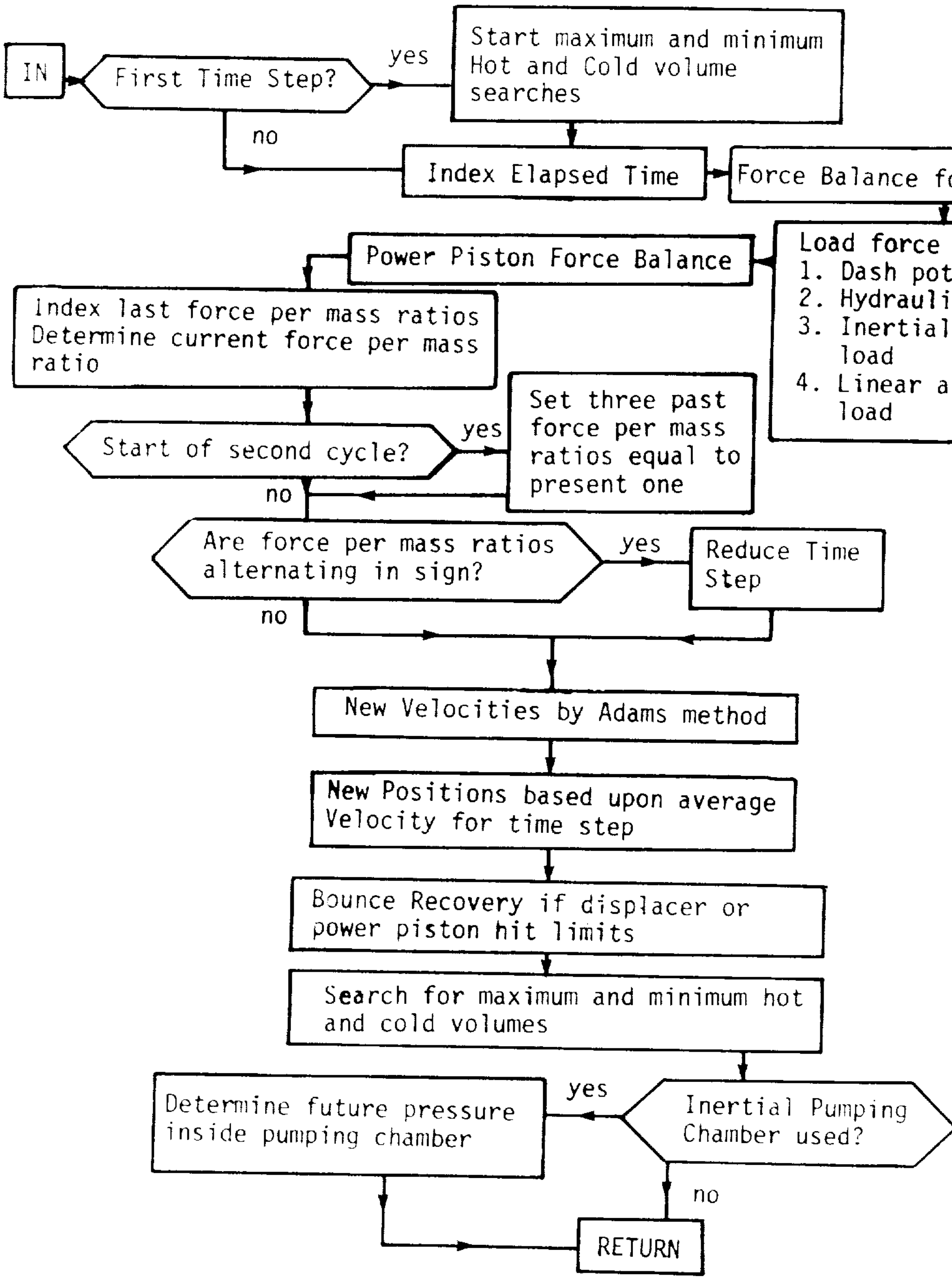

FIGURE 4.6. - FLOW CHART FOR SUBROUTINE MOVEFR (F23).

currently in effect for the displacer rod seal and the power piston seal and for the displacer centering port and the power piston centering port. For these last two leakages, the program deals with five cases. Case 0 is when the centering port is not open at all. Case 1 is when the centering port opens and closes during the time step. Case 2 is when the centering port opens during the time step. Case 3 is when the centering port close during the time step. Case 4 is when the centering port stays open during the time step. All these five cases are needed to determine how long the centering port is open during the time step. This is used along with the flow coefficient and the pressure difference to determine the leakage for the time step. It should be mentioned here that the flow coefficient which is calculated in subroutine F21 is first calculated for the dimensions given in the input numbers and then is adjusted by input number 40 which is the experience factor for the centering ports. The value of 10 now used in Appendix A means that the flow resistance employed is ten times greater than that which was calculated. During the development of the program we tried using the flow resistance as calculated and found that it really disturbed the operation of the engine. There are probably some inertial effects that come into play when the port is open for such a short time. It really should be taken into account in a very detailed evaluation of this procedure. However, since the size and shape of these ports probably have been derived by experience, this experience factor is a good way of taking it into account.

Once these leakages are determined, the change in inventory of the working gas, displacer bounce space and power piston bounce space are determined. In order to fit with the rest of the program the inventories are expressed in MR units, that is the mass of gas in gram moles times the gas constant. The units of these so-called masses are joules per degree Kelvin. Next there is some branching depending upon whether the isothermal or adiabatic calculational mode is used and whether the Martini or Rios method of integration is used. In the isothermal analysis, the change in the gas inventory governs. However, in Martini and the Rios integration method the pressures are important in the continuing integration process. So these have to be changed because of the change in the gas inventory. Also, the mass change that comes out of the cold space are the last gas nodes and this, of course, has to be changed. Finally, in the Martini analysis the change in gas inventory expands or contracts all gas nodes which has an effect on their temperature. For all cases after label 400 the new pressure in the displacer bounce space and power piston bounce space needs to be computed because of leakage. Finally, the control returns back to subroutine F2.

4.3.5 Pressure calculation by using isothermal analysis (F25). - Isothermal analysis is performed by subroutine PHISQ (F25). The flow chart for this subroutine is given in figure 4.8 and the source code is available on diskette. You will note from examination of figure 4.3 that at this point in the calculation there are three branches. This is the first of the branches that will be discussed. There are only nine executable statements in this branch, but the other two branches are much more extensive. No matter which branch is gone through, the result is the same, that is the calculation of the next or future pressure for the time step. In this case the future pressure is calculated by the isothermal assumption which is based upon the future mass, volumes and effective temperatures. This is a single simple equation. If the Rios integration method is used, the future hot space and cold space and working gas inventories need to be calculated so that at the beginning of the second cycle

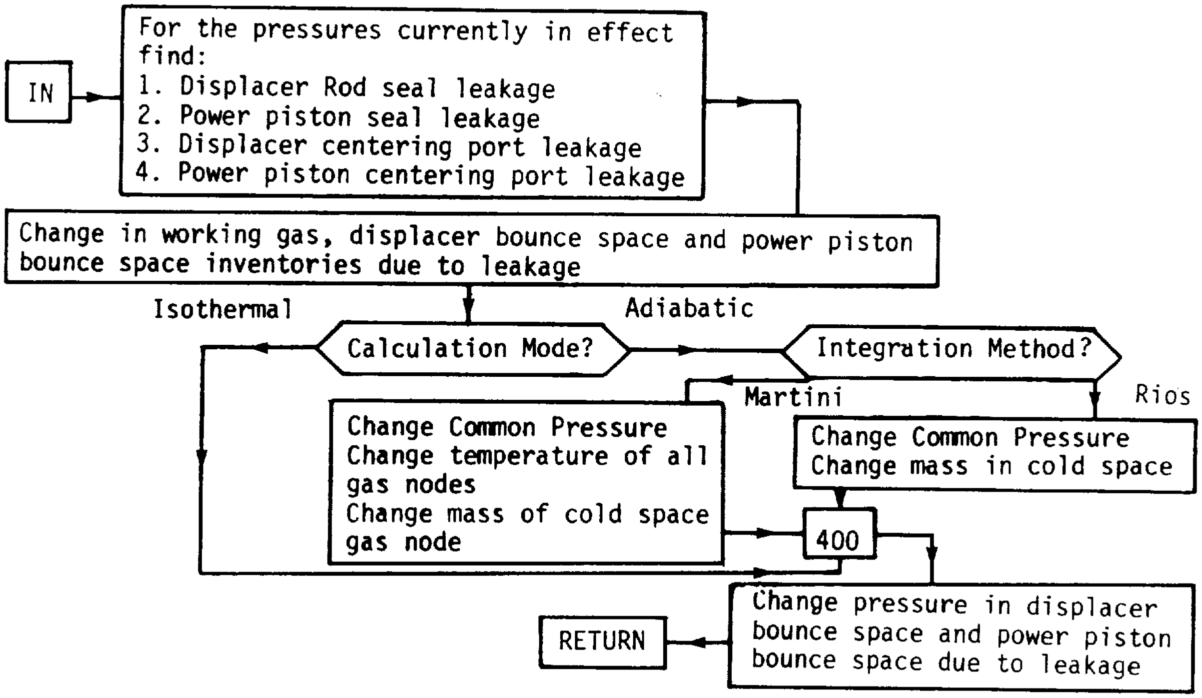

FIGURE 4.7. - FLOW CHART FOR SUBROUTINE LEAK (F24).

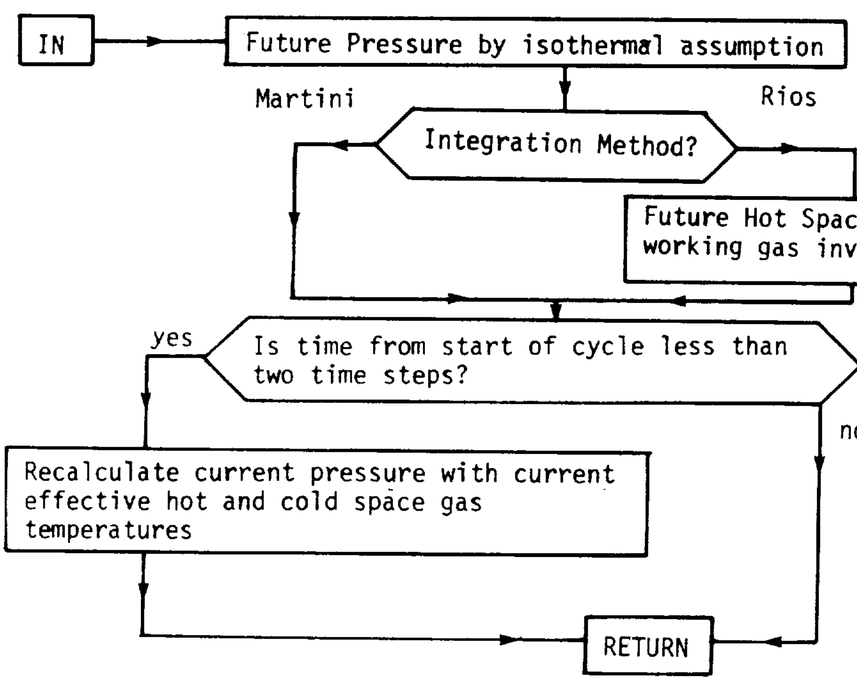

FIGURE 4.8. - FLOW CHART FOR SUBROUTINE PHISO (F25).

when the Rios integration method begins to be used, there are future, present and past hot and cold gas inventories which are needed in the Rios analysis. Also, another embellishment was needed in order to keep from calculating an unrealistically high flow rate. At the end of each cycle there is an adjustment of the effective hot and cold space gas temperature which then are effective for the next cycle. At the first of the iteration procedure this adjustment can be quite drastic and since in the isothermal analysis the pressure depends upon these temperatures as well as upon the gas inventory, the present and future gas pressures would not go together. Therefore, at the beginning of the cycle the present pressure is recalculated based upon the new effective hot and cold space gas temperatures which have just been recalculated. This is the reason for the last part of the flow chart. It solved the problem of making the graphical display look reasonable, and solved the problem of giving a realistic maximum flow rate for the cycle.

As in previous subroutines of this series, control then returns back to subroutine F2.

4.3.6 Pressure calculation by moving gas node analysis (F26). - The flow chart for this subroutine which is called PHMART is given in figure 4.9. The source code listing is available on diskette. This subroutine adapts the Martini version of the moving gas node analysis to this particular application. It does not use it to its full potential since it is used only to predict the next pressure. It does not take advantage of its ability to calculate heat inputs and outputs for the different parts of the machine. In subroutine F21 the working gas space of the engine was divided into 22 different nodes. There are five nodes in the appendix gap space, one node in hot space, five nodes in the heater, five nodes in the regenerator, five nodes in the cooler and one node in the cold space. To get things started each node is given a volume and a temperature. Based upon this volume and temperature, it is given mass. The total working gas mass is then added up and the total of number nodes is added up. As the process continues the number of nodes changes, but can never exceed 200 with the present programming. A check is made to see if any mass is lost during the calculation and it never is. However, between one time step and the next, working gas mass is lost due to leakage as determined by the subroutine LEAK (F24). Starting with the first time step of the second cycle and in each time step thereafter, a ten step process is gone through to compute what the next pressure should be.

In Step 1, based upon total working gas volume change, the new common pressure and new temperatures for each gas node are determined. These new temperatures and the common pressure are determined based upon an adiabatic process. This change in the total volume plus the change in the displacer position causes the positions of these original gas nodes to change relative to the engine itself. Note that the nodes are not tied to the engine, but represent a string of packets of gas that fill the engine working gas space.

In Step 2 the present boundaries between these different packets are determined as measured in volumes from the root of the appendix gap in the hot end of the engine.

In Step 3 the gas nodes are redefined. If a gas node straddles the boundary between the appendix gap and the hot space, the gas node is split into two parts. The part in the hot space is combined with the node already in the hot space and the part in the appendix gap is redefined with a smaller volume and

IN

Step 1. Based upon total working gas volume change determine new common pressure and new temperatures for each gas node based upon an adiabatic process.

Step 2. Determine new positions of current gas nodes based upon the change in Step 1.

Step 3. Split gas nodes that are now part in one part of the engine and part in another.

Step 4. Reinitialize for next time step and consolidate low volume nodes.

Step 5. With no movement of gas nodes, compute new gas temperature for each node based upon temperature difference, and applicable heat transfer coefficient. Keep a running total of the net heat transferred in each part of the engine. Adjust the temperature of the 3 regenerator nodes based upon their heat capacity.

Step 6. Adjust regenerator matrix node temperatures due to metal conduction.

Step 7. New pressure for each gas node due to temperature change due to heat transfer with each node retaining its same volume.

Step 8. Adiabatic pressure equilibration at constant total working gas volume. (Future pressure is calculated at this point.)

Step 9. Adjust nodal gas temperatures due to the pressure changes in Step 8. Adiabatic process.

Step 10. Identify calculated hot and cold space gas temperatures.

RETURN

FIGURE 4.9. - FLOW CHART FOR SUBROUTINE PHMART (F26).

a smaller mass. This same splitting process takes place between the hot space and the heater and between the cooler and the cold space. At the end of step 3 there are a number of nodes in the appendix gap, one node in the hot space, a number of nodes in the heater, regenerator and cooler, and one node in the cold space.

In Step 4 the second gas masses are made the first gas masses and the second gas temperature is made the first gas temperature and the second gas volumes are made the first gas volumes for all nodes. In addition, very small nodes are combined together so that they can be properly calculated. At this point there is an error trap to determine if there are too many nodes. One too many nodes causes the calculation to go crazy.

In Step 5 each gas node is assumed to be stationary and no gas is allowed to move from one node to the next. During the space of time of one time step heat transfer is allowed to happen consistent with the area available for heat transfer and the heat transfer coefficient that applies for that node. A running total is kept of the net heat transfer to or from each part of the engine and the net heat transfer to or from all the gas nodes together. This is powerful information, but it is not used in this calculation because it is incompatible with the rest of the computer program. During this step the regenerator metal nodes are allowed to float. That is, if the temperature of the gas is found to be higher than the temperature of the matrix surrounding it, the temperature of the gas drops and the temperature of the matrix rises, and the amount of heat transfer is recorded. At the end of step 5 each gas node has a different pressure as well as a different temperature.

In Step 6 the temperature of the metal nodes is adjusted to allow for conduction of heat transfer through the matrix. This process must take place at the same time as the heat transfer to or from the gas so that the node temperatures will remain realistic.

In Step 7 we need to normalize the fictitious condition set up by Step 5. That is, each gas node which has been constrained fictitiously to remain at the same volume when the temperatures change and therefore, attain a different pressure, must be allowed to expand or contract so that all gas nodes will end with a common pressure. In Step 5 we calculated the temperature changes. In Step 7 we determine what these pressures are. In Step 8 we perform a pressure equilibration which is simply the solving of one algebraic equation to determine what the pressure would be if each gas node is allowed to expand or contract adiabatically to a single common pressure. This common pressure is the future pressure for the time step.

In Step 9 we adjust the nodal gas temperatures due to the fact that each node either expanded or contracted adiabatically and therefore, changed its gas temperature appropriately. These then are taken into account.

In Step 10 the hot and cold space gas temperatures are identified, since these are needed later on to calculate some of the losses. These temperatures vary widely during the cycle because of the adiabatic character of the analysis. However, they are only used at the end of each cycle for loss calculations as has been mentioned. The loss calculations should really use the information available in this nodal analysis. But since this would be incompatible with the other methods of calculation, it was not done at this time.

After this ten step process the control passes back to subroutine F2.

4.3.7 Pressure calculation by Rios adiabatic analysis (F27). - The flow chart for this subroutine is given in figure 4.10. The source code for this part of the program is available on diskette. The analysis upon which this program is based was first published by P.A. Rios in 1969 (ref. 6). The equations were derived in dimensionless form for a crank operated cooling machine. The program listing in the thesis was illegible, but thanks to the cooperation of Professor Joseph L. Smith of MIT, the author was able to receive a listing of the program and transposed this program for a crank operated heat engine, like the General Motors 4L23 machine. This program was published in the second edition of the Stirling Engine Design Manual (ref. 4). In appendix D of this report the Rios equations have been rederived in a dimensional form which is compatible with the rest of the free-piston Stirling engine program.

According to the flow chart in figure 4.10 at the first of each cycle the choice matrix is defined and constants are calculated which are good for the entire cycle. The choice matrix is simply a programming device for communicating which one of the four paths or cases should be followed through the program. The cases are: (1) mass increasing in both hot and cold spaces; (2) mass decreasing in both hot and cold spaces; (3) mass decreasing in cold space and increasing in hot space; (4) mass increasing in cold space and decreasing in hot space. Some are good for the entire calculation and could have also been calculated in subroutine F21 and transposed over here in a common statement. However, since they are calculated only once each cycle and since the Rios computation requires 360 time steps per cycle to be stable, the time involved is negligible.

Once the initial calculations are out of the way, the program branches into four parts depending upon the case number that is in effect. During the cycle all four cases are used. It does not matter particularly which case you start with, because after each time step the case required for the next time step is determined. Therefore, it quickly gets into the right case. Each case uses a different set of equations to calculate the pressure and the mass change in both the hot and cold part of the machine.

After going through one of these four paths, it comes back together at label 300 and calculates the mass change in both the hot and cold spaces. Based upon this, it goes through a choice matrix calculation to determine the case number which is used in the next time step. This program accumulates a number of arrays that are used for the Rios loss equations. After accumulating these arrays as much as can be done for one time step, it returns control to program F2.

4.3.8 Calculation of losses (F28). - The flow chart for subroutine LOSSES (F28) is given in figure 4.11. The source code for this program is available on diskette. The first thing that happens when we enter this subroutine is to index the cycle number. Then we save the last basic heat input and power output and calculate the next basic heat input and power output. Then if we are doing the adiabatic moving gas node analysis, we set the fractional change of the basic power and the fractional change to the basic heat as the convergence criteria. Note that this is not the convergence criteria that is currently used. It is available for possible future use. Otherwise, we go on and calculate the convergence criteria later. Next we determine the effective flow rates and the fraction of the time that these flow rates act by evaluation of numbers that are calculated as part of F2 during the cycle. Subroutine LOSSES is only entered into after the cycle is over and when the losses for the

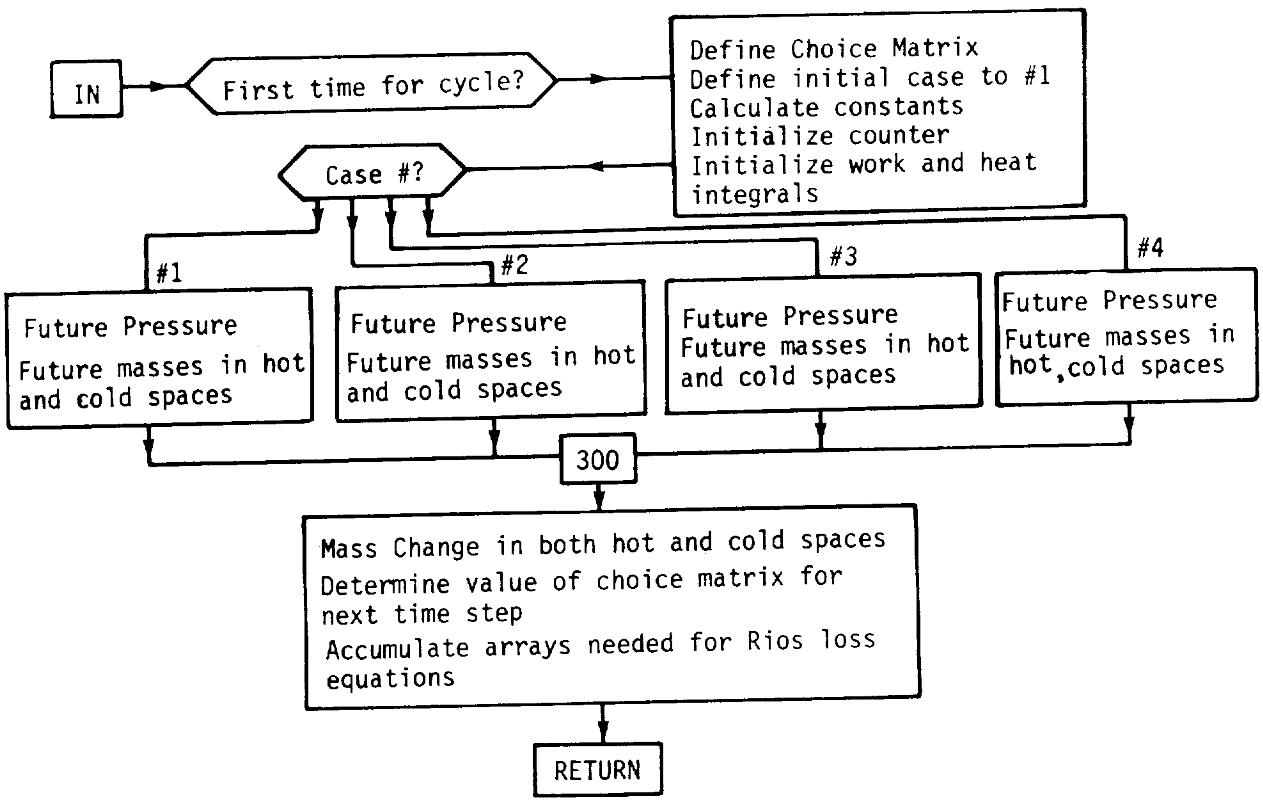

FIGURE 4.10. - FLOW CHART FOR SUBROUTINE PHRIOS (F27).

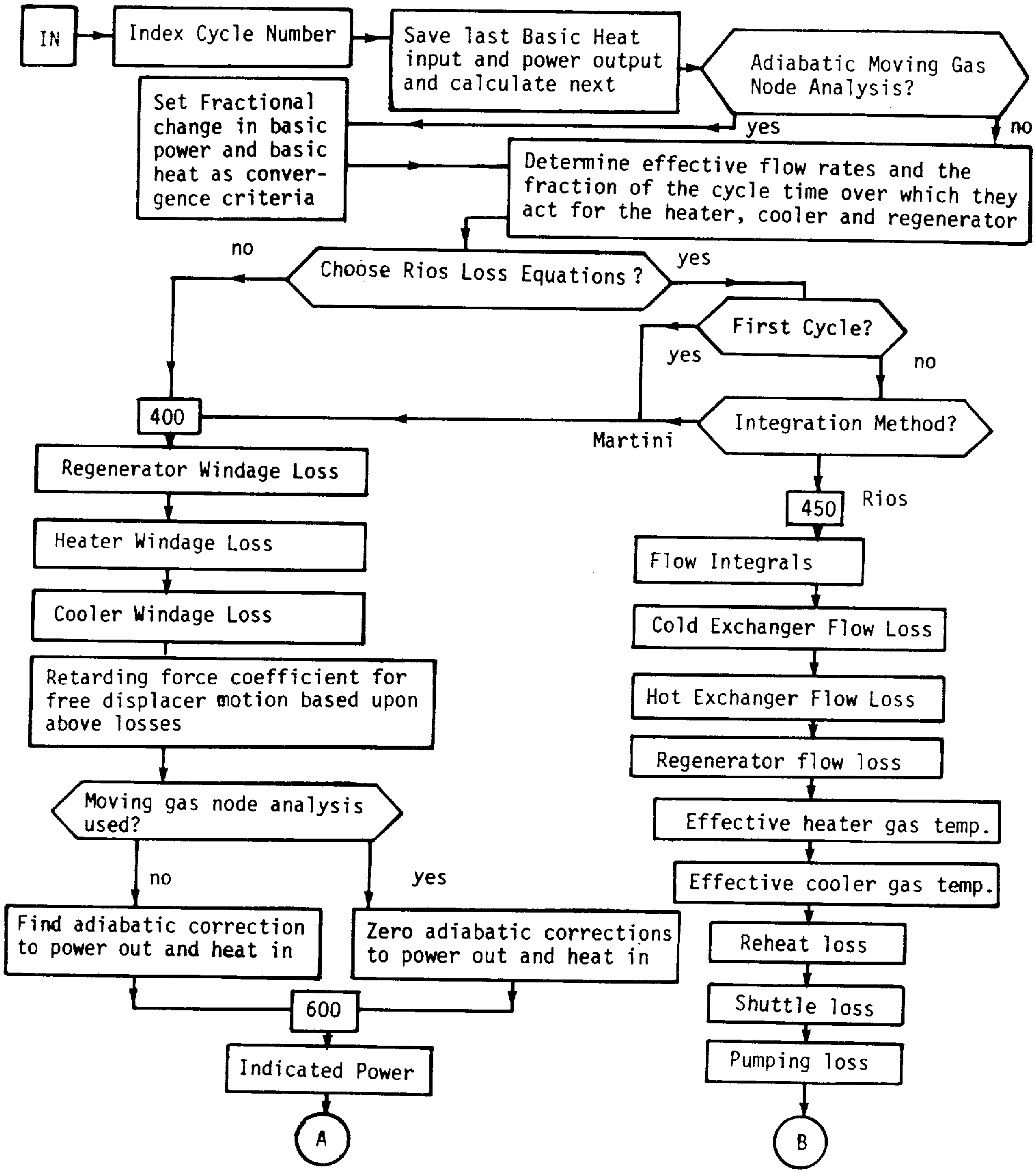

FIGURE 4.11. - FLOW CHART FOR SUBROUTINE LOSSES (F28).

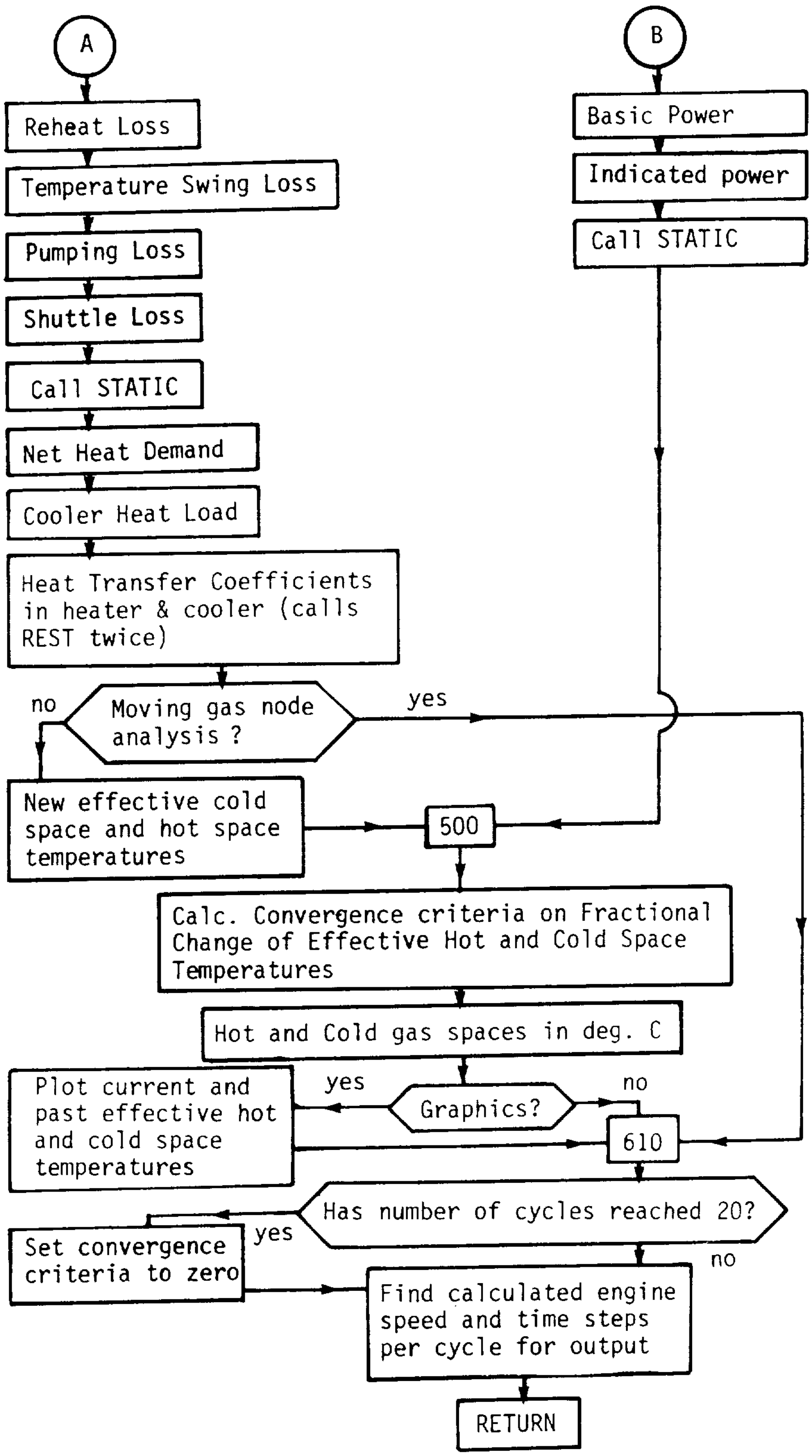

FIGURE 4.11. - CONCLUDED.

cycle are going to be calculated. Now we determine whether the Rios loss equations are to be used. If the inputs specify that they should be used, they will not be used on the first cycle because the Rios integration method is not used on the first cycle. If it is after first cycle, the Rios loss equations can only be used if the Rios integration method is also used to supply information. Therefore, once this is sorted out, there are two main paths through the subroutine, one for the Martini loss equations and one for the Rios loss equations. We will discuss the Martini loss equations first and then the Rios loss equations.

In the Martini loss equations the effective flow rates and cycle times that were calculated in the first part of the subroutine are now used to determined the flow losses or windage losses for the regenerator, heater and cooler. These use standard engineering flow friction equations and are similar to those used in the Stirling Engine Design Manuals (ref. 3 and 4). All of these correlations have been carefully reevaluated to eliminate any discontinuities. Next from these three windage losses plus the area for the displacer a retarding force coefficient is calculated to be used in the free-piston analysis part of the program. It need only be calculated if the free-piston analysis part is invoked, but it is calculated every time. Since this happens only once each cycle, it is not very serious in terms of calculation time.

Next, if the moving gas node analysis is used, no adiabatic correction is needed. Otherwise, the adiabatic correction for the power output and heat input is calculated by a two-dimensional interpolation of the table as explained in references 1 and 2. Control comes back together at label 600. The indicated power is computed, which is the basic power less all the flow losses.

The next four heat losses, the reheat loss, the temperature swing loss, the pumping loss and the shuttle loss, are all calculated in the standard manner using essentially the same equations as have been used in earlier publications. Subroutine STATIC is called for all the static heat losses which are the same on both the Rios leg and the Martini leg of the program.

Therefore, from the basic heat requirement plus all the heat losses and the static heat losses, the heat demands and the cooler heat load can be calculated. These are needed in order to determine what temperature offset there is between the heater temperature and the effective hot space temperature and between the effective cold space temperature and the cooler temperature. Also, at this point the heat transfer coefficients for the heater and cooler are calculated. These are used both to calculated the temperature offsets and to be used in the moving gas node analysis.

Now if the moving gas node analysis is used, a section of the program is skipped. Otherwise, the new effective cold space and hot space temperatures are calculated based upon the heater and cooler demand, the heater and cooler heat transfer coefficient and the heat transfer areas that are calculated earlier in subroutine F21. This now finishes the Martini loss equations side.

In the Rios loss equation side starting with label 450, the Rios method for computing the losses starts out with some flow integrals. This interpretation of what was actually calculated by Rios is based upon a careful reading of this thesis and an evaluation of what was done in the second edition of the Stirling Engine Design Manual. Based upon these flow integrals the cold exchanger, the hot exchanger and regenerator flow losses are computed. The effective heater and effective cooler gas temperatures are computed and the reheat, shuttle and pumping losses are computed in a different way and was done on the Martini analysis even though the names are the same. Based upon this the basic power and indicated power are calculated in the Rios method and then the static heat losses are calculated by calling the same subroutine as before. In the Rios analysis the effective hot space and cold space temperature now refer to the temperature in the heater and cooler only. The Rios analysis does not calculate a temperature for the hot space and the cold space, but assumes that this is an adiabatic region. The procedure does not require calculating this temperature.

Now for both Rios and Martini loss equations the effective hot and cold space temperatures are calculated in degrees centigrade for use in the output program. Then if graphics are called for, a plot is made on the screen of the current and past effective hot and cold spaces temperatures. These plots are useful in that they give an indication of how the solution is converging. Moving gas node analysis does not use these effective temperatures and does not, therefore, render them into degrees centigrade and does not require to have them displayed on the screen. All this is skipped and comes back together at label 610. Finally, we need to determine the calculated engine speed and the time steps per cycle which are needed for the output and are placed in the output common block. After this, the program returns to subroutine F2.

Figure 4.12 shows the flow chart for subroutine STATIC. It is a straight forward subroutine which calculates the static heat losses in the standard way that is found in any engineering test. Many of these are made to depend upon the effective hot and cold space temperature which in the case of the moving gas node analysis is the hot and cold space temperature at the end of the cycle. Possibly in reevaluation some of these loss terms should be calculated based upon metal temperatures instead.

This marks the end of the explanation of the analysis part of the program. Now we move on to the reporting and the optimization of the program.

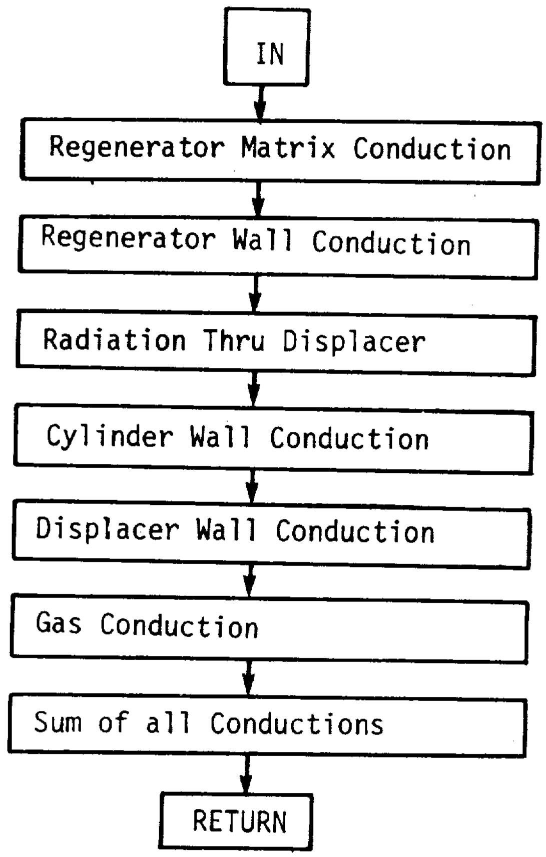

FIGURE 4.12. - FLOW CHART FOR SUBROUTINE STATIC.

4.4 Data Output Subroutine (F3)

Figure 4.13 shows the flow chart for the data output subroutine DESOPT (F3). The source code for this part of the program is available on diskette. As the program is presently designed first all input variable values are printed and then all the outputs to the printer get a final record.

If optimization is called for, the program writes how many cases were tried to find the optimum. It also writes the total input cases which are more because each case must be adjusted to have approximately the target power specified. For the way it is now programmed, the number of input cases is twice the number of variable combinations searched plus one. Next the total number of cycles gone through to find the optimum is given and the number of cycles needed to attain convergence for the last case.

If optimization is not called for, the program simply prints the number of cycles to convergence.

In either case it shows the convergence criteria used. Then it writes a run number and the name of the engine which is the RE-1000. Then depending upon the type of motion it writes specified motion or writes free-piston motion and shows what type of load and load parameters are used. The next thing is a decision on analysis, either isothermal or adiabatic. If it is isothermal, it writes isothermal analysis with corrections. If it is adiabatic, it then determines whether it uses the Martini integration method or the Rios adiabatic analysis and says which one has been used. Then another decision is the loss equations whether the Martini loss equations or the Rios loss equations and it shows which one of those are used. Finally, if the optimizing is called for, it shows the order in which the optimizing is done and the final optimized values. If it is not called for, it says the solution was not optimized. Then it prints out the current operating conditions and the power outputs and heat inputs and returns to the main program.

4.5 Optimization Subroutine (F4)

Figure 4.14 gives the flow chart for the subroutine PAOPTI (F4) which adjusts the power and optimizes after the power is adjusted. The source code for this part of the program is available on diskette. It was found that the indicated power output is almost exactly proportional to the working gas pressure. It was also found that the efficiency is usually a very weak function of pressure. Therefore, in order to speed the search for the optimum, we allowed just two trials for each variable combination. The first trial uses the charge pressure from the last test. The second trial uses a charge pressure calculated assuming the power is directly proportional to pressure.

This subroutine is very simple. It simply asks if the power has been adjusted. If it has not, control goes to F41 for adjustment. If it has, the power adjust flag is reset and control passes to F42 to record and control the optimization process.

4.5.1 Power adjustment subroutine (F41). - Figure 4.15 gives the flow chart for this subroutine. A diskette gives the source code. To start with the decision is made based upon input information how the power is to be adjusted. It can be adjusted by either changing the pressure or changing the

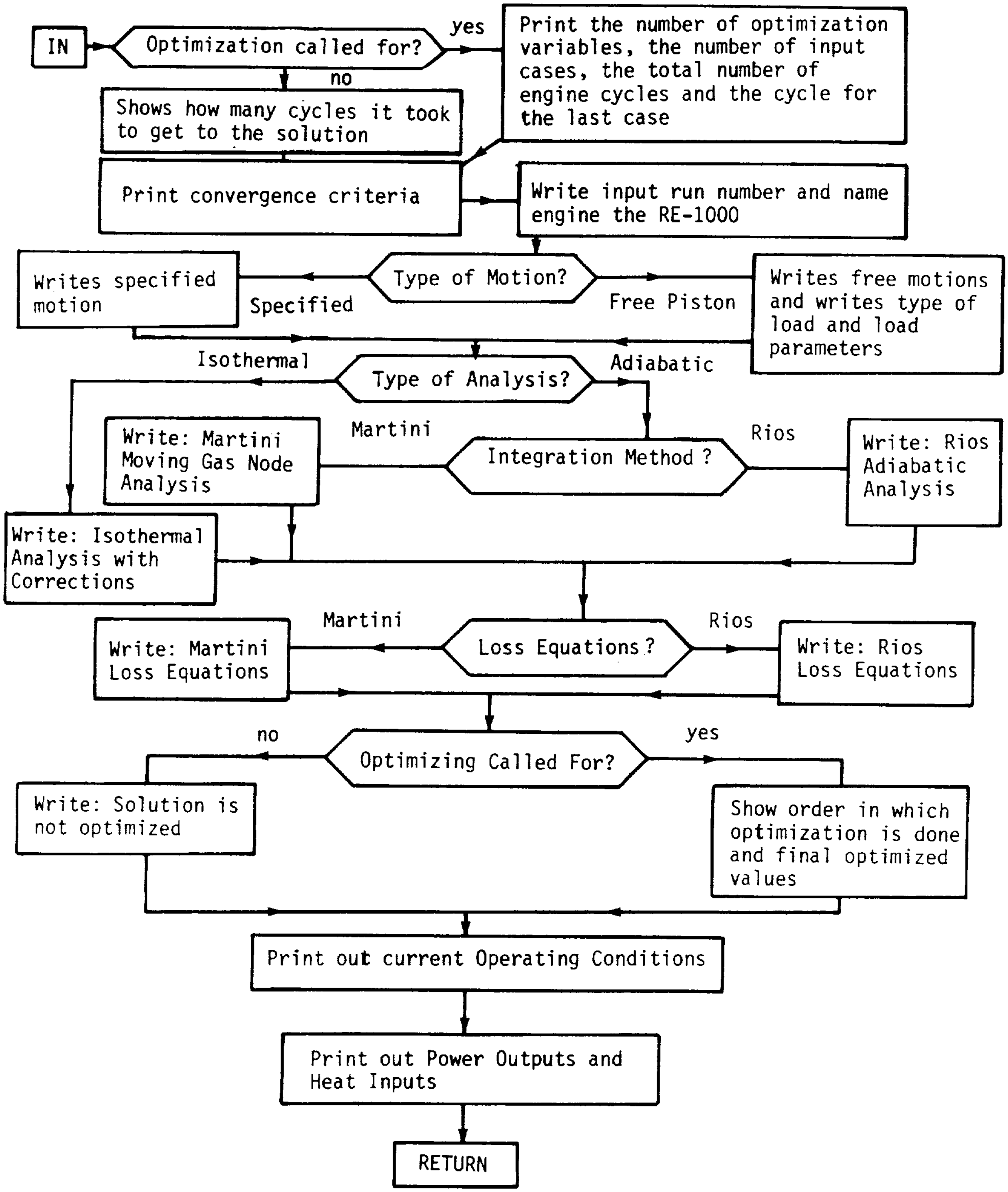

FIGURE 4.13. - FLOW CHART FOR SUBROUTINE DESOPT (F3).

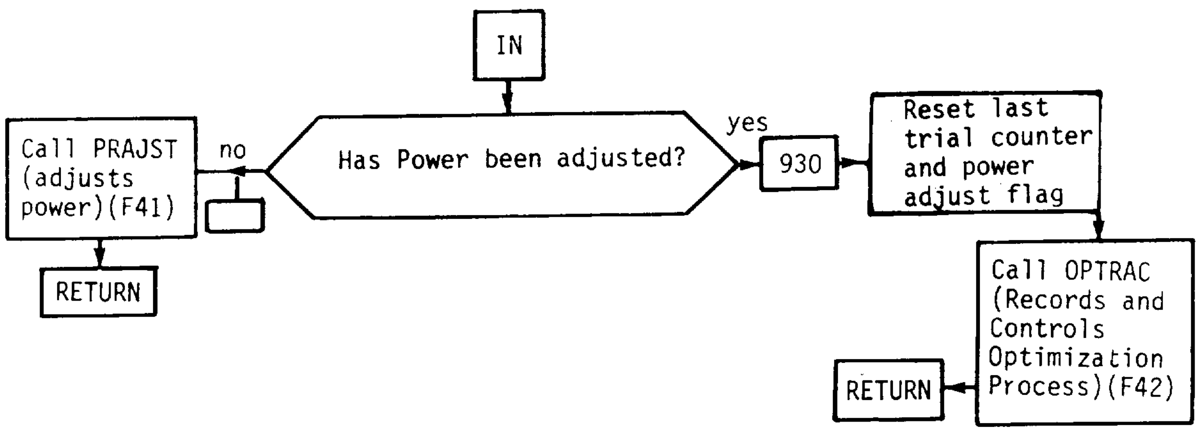

FIGURE 4.14. - FLOW CHART FOR SUBROUTINE PAOPTI (F4).

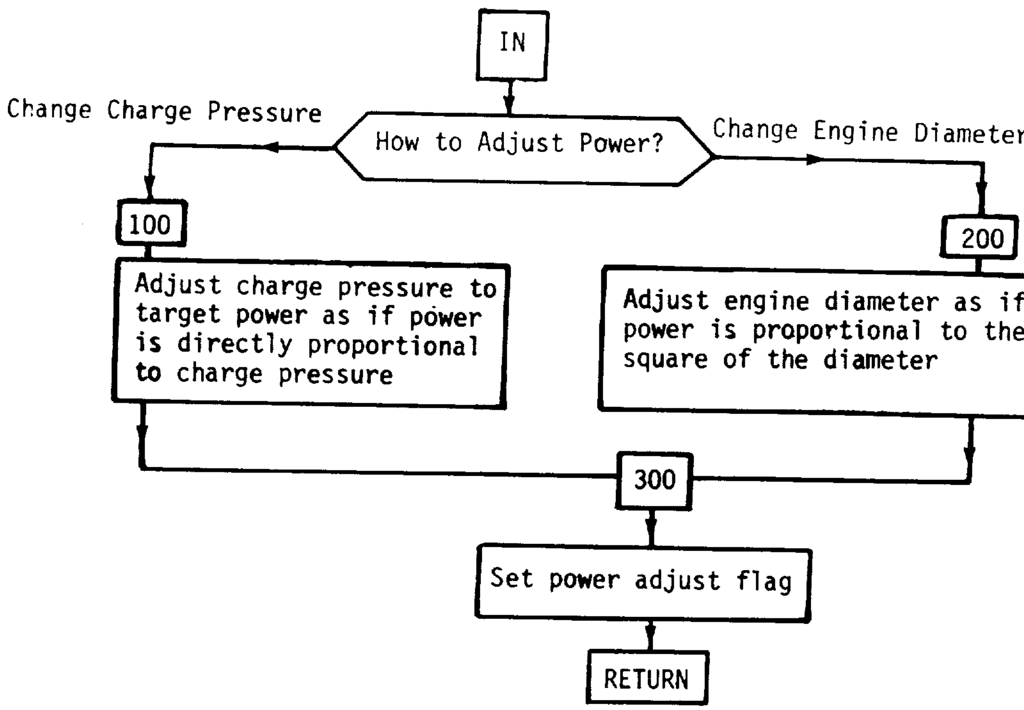

FIGURE 4.15. - FLOW CHART FOR SUBROUTINE PRAJST (F41).

engine diameter. If it is to be changed by the engine diameter, the engine diameter is changed as though the power is proportional to the square of the diameter. If it is changed by the charge pressure, the charge pressure is changed as though the power is proportional to the engine charge pressure.

Control then comes back to label 300. The power adjust flag is set and control passes back to F4.

One of the aspects of this calculation procedure that was not realized fully at first is that the calculation can be repeatable and that for each pressure the power output and heat input can appear to be converging very well. But, a graph of power output versus charge pressure can still be quite irregular -- so can the efficiency-pressure curve. Only when a combination of time step size and convergence criteria can be found that will result in regular curves can a optimization search can be undertaken with confidence.

4.5.2 Optimization recording and controlling subroutine (F42). - Figure 4.16 shows the flow chart of this subroutine. The source code listing can obtained on diskette. On entering this subroutine the first thing that is done is calculate an engine efficiency and index the trial counter. Then the question is asked, is this the first time this subroutine has been entered. If the answer is yes, there are a great number of things that need to be done to set up this subroutine for further use. The first thing is to reset the first time flag so that we will never do this again without starting the program all over. There are 21 input values identified in appendix A as also optimizable values and given an optimization number which goes from one to 21. The way the program is set up now only these 21 values can be adjusted in an optimization routine. As many as 15 of these variables can be adjusted at one time. Some of these variables are real numbers and some are integers. They are transposed into a trial array which is a real number array 21 places long. Then the table heading is displayed and the best choice and best efficiency variables are initialized. Also, the short cut flag is initialized to no short cut. All the elements of a choice matrix are set to one. Then the first line of the data is printed. This is the base case that the optimizing program started with. Then the maximum choice number is calculated which is three raised to the power of the number of choices that are going to be considered. For instance, if three choices are being considered, it is three to the third, or 27; if four, it's three to the fourth or 81. Finally, the current trial array is also saved as an original trial array. The original trial array is sometimes called the base case.

Basically, the program tests all combinations of the adjustable variables around the base case either greater of less than in all combinations. For instance, table 4.1 shows the progression of choice matrices used if there are three adjustable inputs and number 13 is the first choice, number 15 is the second choice, and number 14 is the third choice. The first row in table 4.1 is the base case choice matrix. Note that all the values are 1.0. For this particular case, all the choice matrix numbers except 13, 14, and 15 are always one. The program is set up so that any of the 19 adjustable values can be chosen in any order up to a total of 15. Note that the second row in table 4.1 gives the second choice matrix. It is all 1.0 except for number 13. The third choice matrix is all 1.0 except for number 13 which is 0.9 Note that as the program applies this choice matrix to the 21 adjustable inputs, it systematically tests the three that in this case were chosen for adjustment both 10 percent higher and 10 percent lower in all possible combinations.

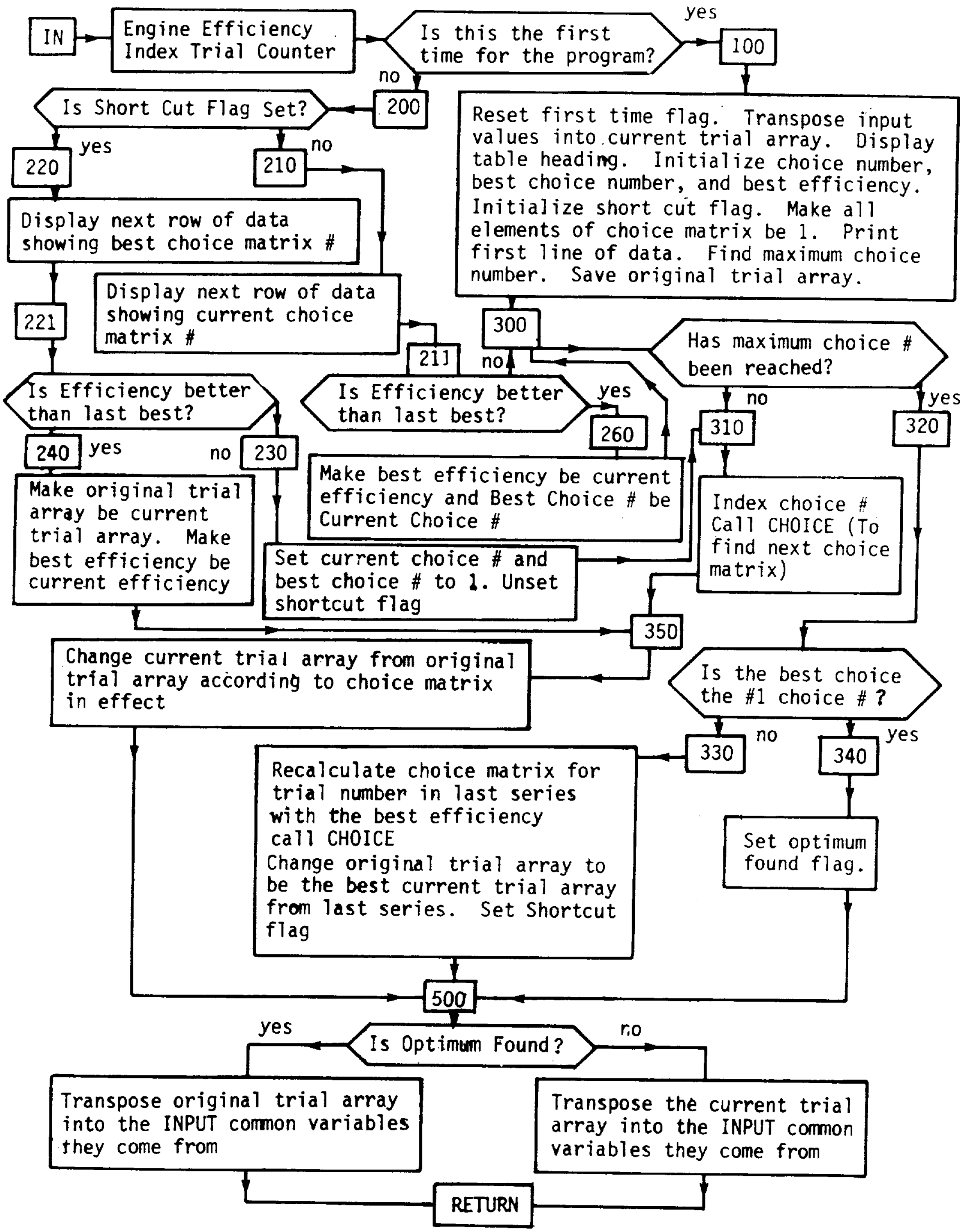

FIGURE 4.16. - FLOW CHART FOR SUBROUTINE OPTRAC (F41).

TABLE 4.1
CHOICE MATRIX VALUES FOR BASE CASE
3 OF ADJUSTABLE INPUTS

Choice # NCH	CHMTX(1)-CHMTX(12)	CHMTX(13)	CHMTX(14)	CHMTX(15)	CHMTX(16)-CHMTX(19)
1	1.0	1.0	1.0	1.0	1.0
2	1.0	1.1	1.0	1.0	1.0
3	1.0	0.9	1.0	1.0	1.0
4	1.0	1.0	1.0	1.1	1.0
5	1.0	1.1	1.0	1.1	1.0
6	1.0	0.9	1.0	1.1	1.0
7	1.0	1.0	1.0	0.9	1.0
8	1.0	1.1	1.0	0.9	1.0
9	1.0	0.9	1.0	0.9	1.0
10	1.0	1.0	1.1	1.0	1.0
11	1.0	1.1	1.1	1.0	1.0
12	1.0	0.9	1.1	1.0	1.0
13	1.0	1.0	1.1	1.1	1.0
14	1.0	1.1	1.1	1.1	1.0
15	1.0	0.9	1.1	1.1	1.0
16	1.0	1.0	1.1	0.9	1.0
17	1.0	1.1	1.1	0.9	1.0
18	1.0	0.9	1.1	0.9	1.0
19	1.0	1.0	0.9	1.0	1.0
20	1.0	1.1	0.9	1.0	1.0
21	1.0	0.9	0.9	1.0	1.0
22	1.0	1.0	0.9	1.1	1.0
23	1.0	1.1	0.9	1.1	1.0
24	1.0	0.1	0.9	1.1	1.0
25	1.0	1.0	0.9	0.9	1.0
26	1.0	1.1	0.9	0.9	1.0
27	1.0	0.9	0.9	0.9	1.0

Since each one of these trials have very close to the same power output, the question is, which one has the best efficiency. All combinations are tried and the best efficiency combination is noted. This best efficiency combination is now made the original trial array and a short cut flag is set so that the choice matrix which was found to be best defines a particular direction of motion from the base case to the optimum. This direction is used as many times as it will produce better efficiency. Then the program goes back to a normal search through all possible choices. An optimum is found when the subroutine has gone through all possible choices and has found that the best one is still the first one, that is, no change. Now with this as a general discussion we will then go back to talking through the flow chart.

If this is not the first time through the program, the control goes to label 200 and the question that is asked is, "Is the short cut flag set?" If it is, it means that the case that has just been calculated and adjusted for the right power output will be displayed with the choice number being the last choice number. If the short cut flag is not set, the display of the last calculated results would be shown with the current choice matrix number. If the short cut flag is set, the question is asked at label 221, "Is efficiency better than the last best efficiency?" If it is, we are on the short cut path and we make the original trial array values to be the current trial array values and make the best efficiency be the current efficiency and go on to label 350. We also save the charge pressure to use for the last calculation in case this should turn out to be the optimum choice.

If the short cut flag is set, but the efficiency is not better than the last best, then going to label 230, we start the search over by setting the current choice number and the best choice number to one and reset the short cut flag and go to label 310.

If the short cut flag is not set, then after displaying the results the question is asked again "Is efficiency better that the last best?" If it is, we make the best efficiency be the current efficiency and the best choice number be the current choice number and save the charge pressure and go on to label 300, which is where the control comes in if this is the first time through the program. At this point the question is asked "Has the maximum choice number been reached?" If the answer is no, control passes to label 310 and the choice number is indexed to the next choice number. The subroutine CHOICE is called to find the next choice matrix based upon this choice number and other input values such as the number of optimization values that are being chosen and what order these optimizable values are being tested. Figure 4.19 gives the flow chart for this subroutine. Control then passes to label 350.

However, if the maximum choice number has been reached, control passes to label 320 and the question is asked "Is the best choice number the number one choice number?" If it is, this is an indication that the optimum value has been found and the optimum flag is set and control passes to label 500.

From label 350 we have a choice matrix that is in effect. Either it is the short cut choice matrix or the choice matrix that has just been calculated and we need to multiply this choice matrix by the original trial array to get the next current trial array to go back into the design program. This is done and control passes to label 500.

If the maximum choice number has been reached, but the choice number with the best efficiency is not the number one choice number, we must recalculate the choice matrix for the trial number which has been saved to indicate which of all the many choice matrices that were calculated creates the best efficiency when applied to the original trial array. This choice matrix is recreated by calling subroutine CHOICE. Once this choice matrix has been recalculated, the original trial array is changed to be the best current trial array from the last series and the short cut flag is set to determine the way the control passes in the next time through this program. Control then moves to label 500.

At label 500, the question is asked "Has the optimum been found?" If it is, the original trial array is transposed into the input common variables that they come from and the saved charge pressure is transposed into the input charge pressure and the program returns. If the optimum is not found, the current trial array is transposed into the input common variable that they come from. However, some of them will have been changed from the original transposition at the beginning of this subroutine. After either one of these transpositions the control is passed back into the subroutine F4.

Figure 4.17 shows the flow chart for subroutine CHOICE. Subroutine CHOICE is called at two different points in the OPTRAC (F42) subroutine. This subroutine is designed to change the choice matrix which is 19 columns long, as shown in table 4.1, to an array depending upon what optimization number are chosen, how many are chosen and the percent change used in the optimization search. For the base case given in appendix A, the first optimization number to be searched is 13, followed by 15 and 14. These are to be changed by 10 percent. Table 4.1 shows the choice matrix values for these 27 choices. Note that the choice matrix column one to column 12 is one and from 16 to 19 is one at all times. The only changes, of course, are 13, 14, and 15. This periodic relationship between the choice number and the choice matrix values is calculated in subroutine CHOICE which then calls the subroutine ADJST. For the base case subroutine CHOICE calls ADJST just times and then returns. It may call it up to 15 times and till work properly.

Figure 4.18 shows the flow chart for subroutine ADJST. The first time ADJST is called, J = 1 and it returns the value for CHMTX (ref. 13). The second time ADJST is called J = 2 and it returns for CHMTX (ref. 15). The third time ADJST is called J = 3 and it returns values for CHMTX (ref. 14). This subroutine has been checked and does produce the periodic values given in table 4.1. It is expandable to give any number desired. For a large number of adjustable inputs, it would be impossible to store the choice matrices precalculated in the computer. It is necessary to calculate them each time they are used.

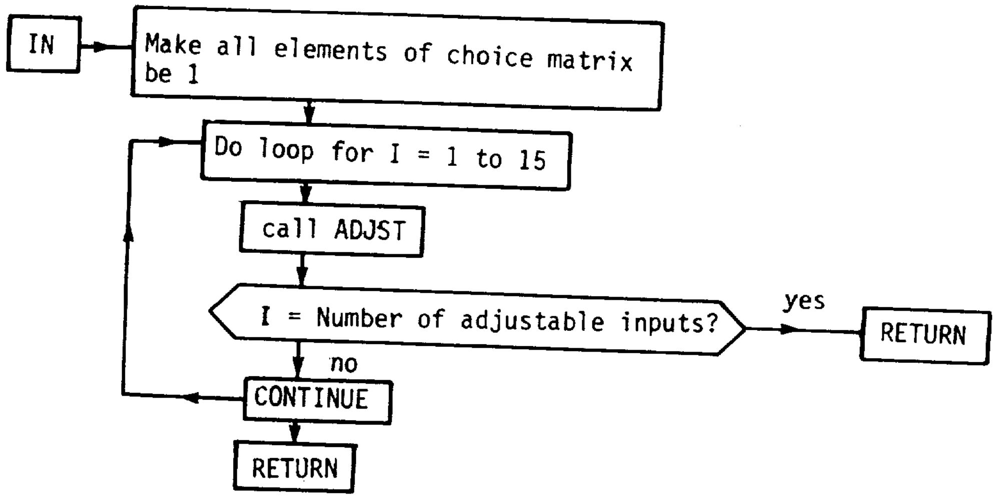

FIGURE 4.17. - FLOW CHART FOR SUBROUTINE CHOICE.

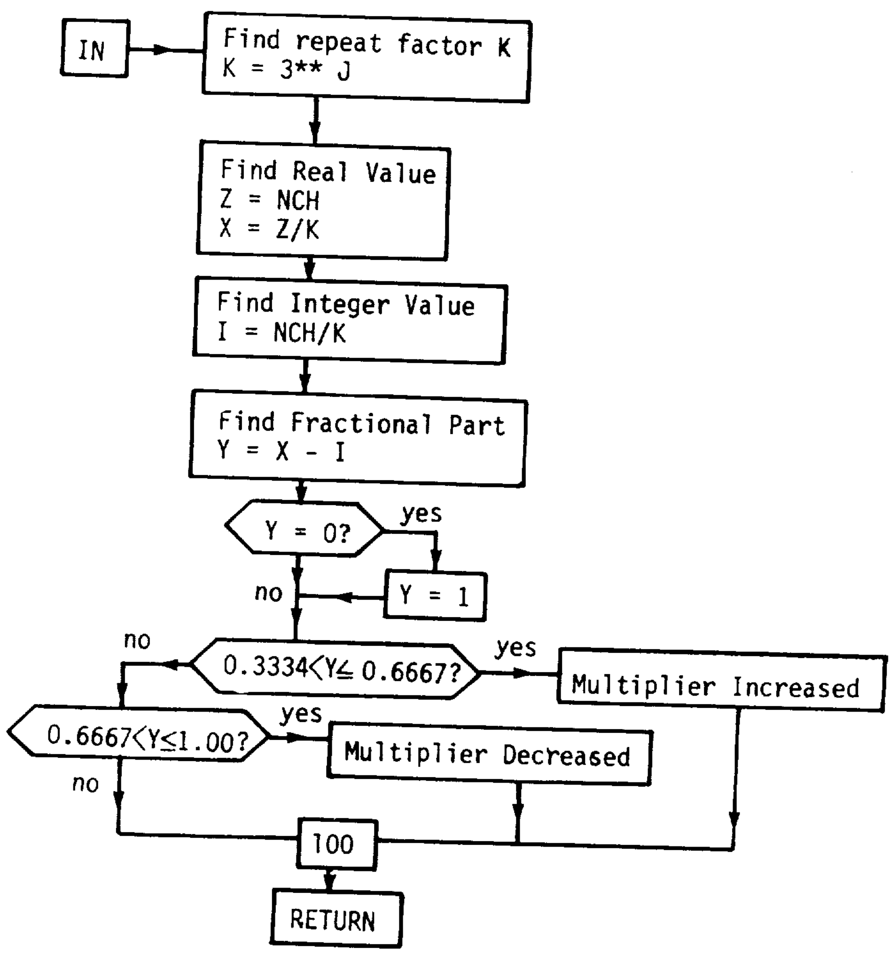

FIGURE 4.18. - FLOW CHART FOR SUBROUTINE ADJST.

5.0 SAMPLE RESULTS

It was found by experience that time step size was all important, particularly when the calculated motion options were being exercised. It was found that solutions could be rapidly convergent but still give erroneous results. A number of trials were done which showed that only when the time steps were small enough did the effect of pressure on the solution make reasonable sense. Therefore, the effect of time step size and convergence criteria on the solution will be presented first. Next, the results of sample base cases will be given. Finally, the results of optimization searches will be presented.

5.1 Effect of Time Step and Convergence Criteria

Two separated investigations were made into the effect of time step and convergence criteria on the results. The first used isothermal analysis with corrections and employed a linear alternator with a load constant of 0.040 $N/(cm/sec)^2$. The second employed the Martini moving gas node analysis (adiabatic analysis) and employed a linear alternator with a load constant of 0.02 $N/(cm/sec)^2$.

5.1.1 Isothermal analysis. - To review, two solution parameters affect the answers that are obtained for a given case, one is the convergence criteria and the other is the time step.

The convergence criteria is the fraction that both the heat input and the power output integral changes from one cycle to the next. For the convergence criteria to be satisfied, this change for both the heat input and the power output integral must be less than the convergence criteria for two successive cycles.

The time step is simply the time interval used to calculate the solution. The smaller the time interval, up to a point, the more accurate the solution and also the more time consuming the calculation becomes.

It was observed that the convergence criteria and the time step were related. A large time step caused considerable variability from one time step to the next. Therefore, a tight convergence criteria would never be met except by accident.

5.1.1.1 Effect of convergence criteria: Table 5.1 summarizes the results of a series of calculations to determine the best convergence criteria. The full computer output is given in appendix E. These results are from the double precision version. The series was all run at 66 Bar pressure and an initial time step of 0.1 msec, which resulted in 415 time steps per cycle. Note that as the convergence criteria get tighter the cycles to solution get longer. However, the frequency of operation is not changed, and the indicated efficiency is hardly changed. The only change of note is in the indicated power. However, in order to save computer time, a convergence criteria of 0.005 was picked in order to get good accuracy with reasonable calculation time.

5.1.1.2 Interaction of Convergence Criteria and Time Step: Table 5.2 shows how the time step and the convergence criteria relate to number of cycles it takes to convergence. Note that at even the smallest time step tested it

TABLE 5.1
EFFECT OF CONVERGENCE CRITERIA
SUNPOWER RE-1000 ENGINE FREE MOTION -
LINEAR ALTERNATOR
Load Constant = 0.040 $N/(cm/sec)^2$

Isothermal Analysis
66 Bar Charge Pressure
0.1 msec time step
(See Appendix E for full output)

Convergence criteria	Cycles to Solution	Indicated Power, W	Indicated Efficiency, %	Calc. freq., Hz
0.001	10	719.05	28.14	24.08
0.005	13	728.0	28 27	24.07
0.002	23	744.51	28.43	24.07
0.001	30	750.44	28.48	24.06
0.0005	39	754.90	28.54	24.06

Table 5.2

RELATIONSHIP BETWEEN CONVERGENCE CRITERIA AND TIME STEP

Convergence Criteria	Cycles to convergence at time step of: 0.1 msec	0.2 msec	0.5 msec	1.0 msec
0.01	11			
0.005	12-13(3)	11-13(1)	12-39(2)	no conv.
0.002	23			
0.001	33			
0.0005	41			
0.0002	no conv.			

(1) Various charge pressures (See Appendix W)
(2) Various charge pressures (See Appendix X)
(3) Various charge pressures (See Appendix Y)

is possible to set the convergence criteria so tight that the criteria would never be satisfied. This indicates the variability gets smaller from cycle to cycle as the calculation progresses but there is an inherent variability that remains which is reduced only by reducing the size of the time step.

Going the other direction in table 5.2 at a convergence criteria of 0.005 there is a time step, in this case 1.0 msec, in which the inherent variability was so large from cycle to cycle that there was practically no chance that the convergence criteria would be satisfied. In this case, the heat input integral was calculated for 167 cycles. After the first 10 cycles, there was no noticeable convergence. The change in power output integral was roughly cycling from 0.000 to 0.036. The change in heat input varying randomly from 0.050 to 0.170. Therefore, there was no way for two successive changes in these two integrals to be less than 0.005.

Table 5.2 shows that the cases calculated at a convergence criteria of 0.005 showed a larger variability in the number of cycles to convergence. As the time step increased, the maximum number of cycles increased but the minimum remained nearly the same. This indicates again the chance nature of satisfying the convergence criteria. The full printout for the cases that are summarized in table 5.2 are included in appendices W, X and Y. They were calculated to determine how the power output and efficiency change with charge pressure.

Table 5.3 summarizes how the calculated power output and efficiency varies with charge pressure over a wide range. Appendix W gives the full computer printout. It is surprising that the same engine works over such a wide range of charge pressures. Table 5.3 was done for a time step of 0.2 msec.

Table 5.4 was done for the same case and for a limited range of pressures only with 0.5 msec as the time step.

Table 5.5 was also done for the same case and for a limited range of pressures only with 0.1 msec as the time step.

Figure 5.1 graphs the information given in table 5.3 over the full range. Note that the calculated power is very nearly proportional to charge pressure, especially in the range of normal operating pressure. Also, note that the efficiency in the normal operating range of 60 to 70 bar is not a strong function of frequency. Therefore, it was concluded that in choosing between engine designs to find the optimum one need not find the exact pressure that will give the target power in order to choose between competing designs on the basis of efficiency.

Figure 5.2 compares tables 5.3, 5.4 and 5.5 over a limited pressure range of 66 to 72 bar and on an expanded scale so that the difference between the results can be noted more clearly. Note that as expected, the 0.1 msec time step gave the most regular results but they were not perfect. The 0.2 msec time step was not quite as good but still acceptable. The 0.5 msec time step gave results that can be quite misleading. Also note, as was observed in table 5.1, that the frequency is easiest to calculated correctly, next comes efficiency, and finally, the most difficult, indicated power.

5.1.2 Adiabatic analysis. - The adiabatic analysis available in the program is the Martini moving gas node analysis. This analysis predicts the next pressure without making adjustments in the effective constant hot space and cold space gas temperatures at the end of each cycle. Therefore, progress toward convergence is smoother. Therefore, it was felt that a longer time step of 1 msec would be satisfactory. At this time step and a convergence criteria of 0.005, the allowable number of gas nodes of 200 was exceeded after 19 cycles. Therefore, the series was done at a convergence criteria of 0.01. The computer outputs for this series are given in appendix Z. The power output, efficiency and frequency are plotted in figure 5.3. Note that, as usual, the calculation of frequency is very regular but the calculation of indicated power and efficiency is somewhat irregular particularly when calculations are made for closely spaced pressures. It should be noted that some runs given in appendix Z did not finish at a time step of 1 msec. Sometimes the number of cycles exceeded 10 and the time step was automatically halved. Sometimes calculational instability was detected by the program and the time step was halved one or two times. Nevertheless, the convergence criteria of 0.01 was retained.

Since this series was not regular, another series of calculations was run with a convergence criteria of 0.005 and an initial time step of 0.25 msec. The full computer output for this series of calculations is given in appendix AA. It was not necessary to change from this initial value since convergence was found in from seven to nine cycles. Figure 5.4 compares the results from appendix AA and Z plotted on an expanded scale for pressures from 70 to 82 bar. As usual, the frequency is calculated accurately either way. However, only the calculation series with 0.005 convergence criteria and 0.25 msec time step makes sense as far as calculating power. Therefore, the results given in appendix Z must be considered seriously in error.

5.1.3 Conclusion on time step and convergence criteria. - In employing the computer program described in this report in the calculated motion mode, one should graph the calculated powers versus charge pressure over a short range to see that this power is regular and approximately proportional to charge pressure. If not, a smaller time step or a smaller convergence criteria or both should be used until such a regular relationship is obtained.

Table 5.3

SUMMARY OF COMPUTED RESULTS
RE-1000 ENGINE

Time Step = 0.2 msec
Convergence Criteria = 0.005
Heater Temperature = 600 C
Cooler Temperature = 40 C

Free Motions - Linear Alternator
Load Constant = 0.040 N/(cm/sec)**2

Isothermal Analysis with Corrections
(Full printout in Appendix W)

Charge Pressure Bar	Indicated Power, W	Indicated Efficiency, %	Calculated Frequency, Hz
10.00	69.43	9.97	9.46
20.00	199.40	18.96	13.50
30.00	318.40	22.79	16.40
40.00	428.70	25.47	18.86
50.00	540.33	27.12	21.03
60.00	657.10	27.96	23.00
66.00	723.51	28.23	24.10
67.00	733.31	28.26	24.29
68.00	742.31	28.25	24.46
69.00	754.88	28.29	24.64
70.00	761.03	28.31	24.81
71.00	773.44	28.34	24.99
72.00	783.68	28.33	25.16

Table 5.4

SUMMARY OF COMPUTED RESULTS
RE-1000 ENGINE

Time Step = 0.5 msec
Convergence Criteria = 0.005
Heater Temperature = 600 C
Cooler Temperature = 40 C

Free Motions - Linear Alternator
Load Constant = 0.040 N/(cm/sec)**2

Isothermal Analysis with Corrections
(Full printout in Appendix X)

Charge Pressure Bar	Indicated Power, W	Indicated Efficiency, %	Calculated Frequency, Hz
66.00	711.72	28.25	24.18
67.00	750.97	28.29	24.34
68.00	749.05	28.27	24.53
69.00	749.70	28.14	24.70
70.00	758.76	28.16	24.90
71.00	765.12	28.23	25.07
71.50	787.16	28.38	25.17
72.00	781.90	28.28	25.23

Table 5.5

SUMMARY OF COMPUTED RESULTS
RE-1000 ENGINE

Time Step = 0.1 msec
Convergence Criteria = 0.005
Heater Temperature = 600 C
Cooler Temperature = 40 C

Free Motions - Linear Alternator
Load Constant = 0.040 N/(cm/sec)**2

Isothermal Analysis with Corrections
(Full printout in Appendix Y)

Charge Pressure Bar	Indicated Power, W	Indicated Efficiency, %	Calculated Frequency, Hz
67.00	736.20	28.29	24.26
68.00	744.65	28.30	24.44
69.00	755.28	28.32	24.62
70.00	767.57	28.35	24.79
71.00	776.14	28.37	24.97
72.00	788.89	28.42	25.14

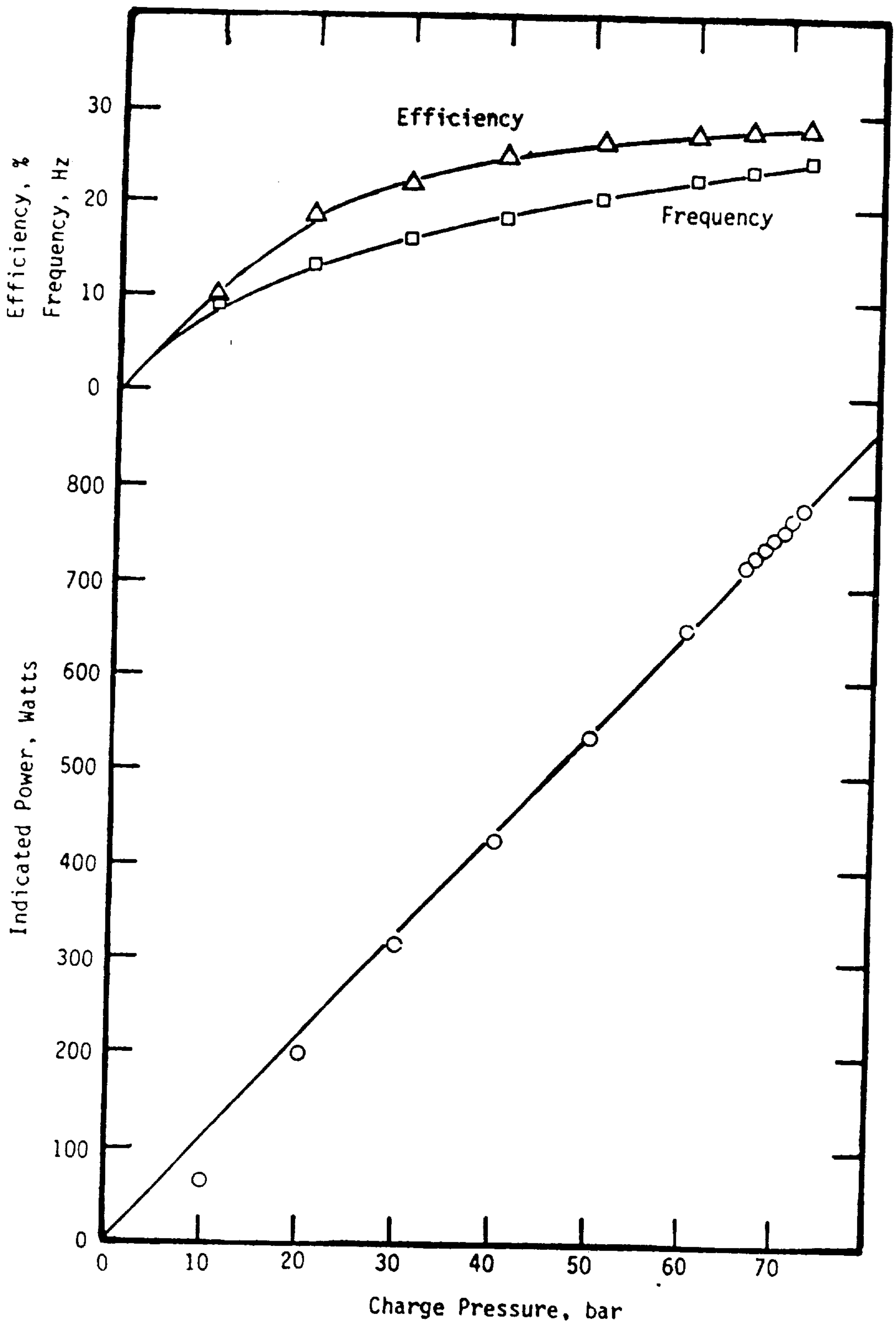

FIGURE 5.1. - EFFECT OF PRESSURE ON CALCULATED FREE-PISTON ENGINE GENERATOR OPERATION. TIME STEP, 0.2 MSEC; CONVERGENCE CRITERIA, 0.005. (SEE TABLE 5.3.)

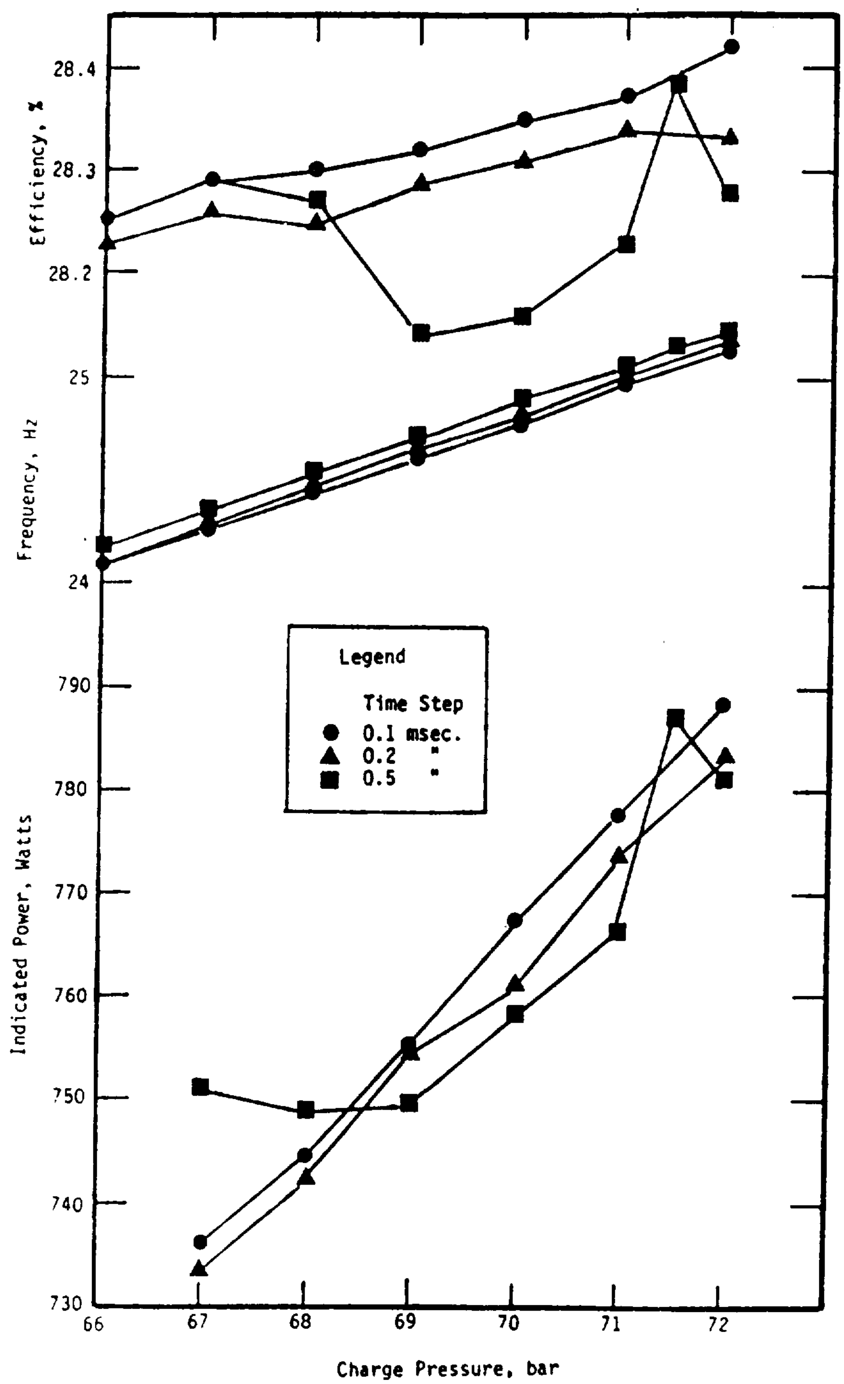

FIGURE 5.2. - COMPARISON OF FREQUENCY EFFICIENCY AND INDICATED POWER FOR DIFFERENT TIME STEPS. (ISOTHERMAL ANALYSIS.)

FIGURE 5.3

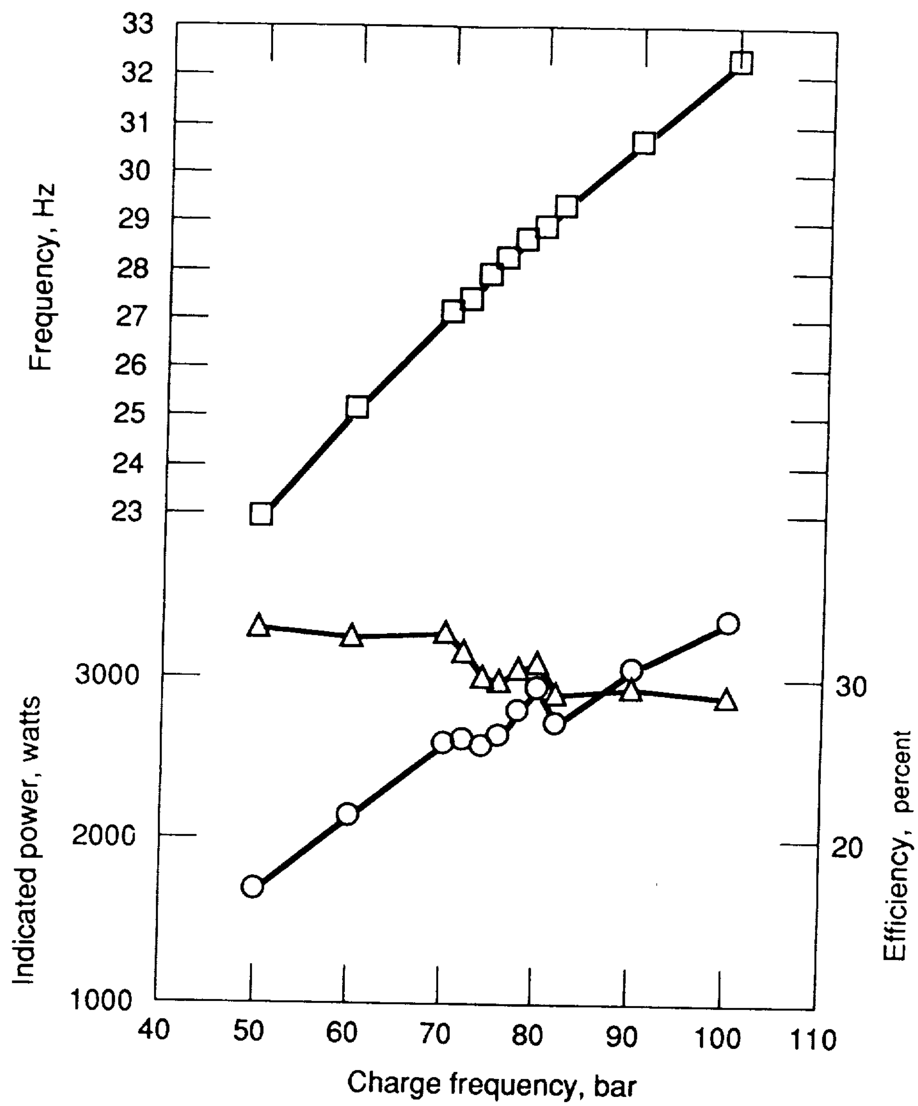

FIGURE 5.3 - EFFECT OF PRESSURE ON INDICATED POWER, EFFICIENCY, AND FREQUENCY. INITIAL TIME STEP, 1 MSEC; CONVERGENCE CRITERIA, 0.01. (ADIABATIC ANALYSIS.)

FIGURE 5.4

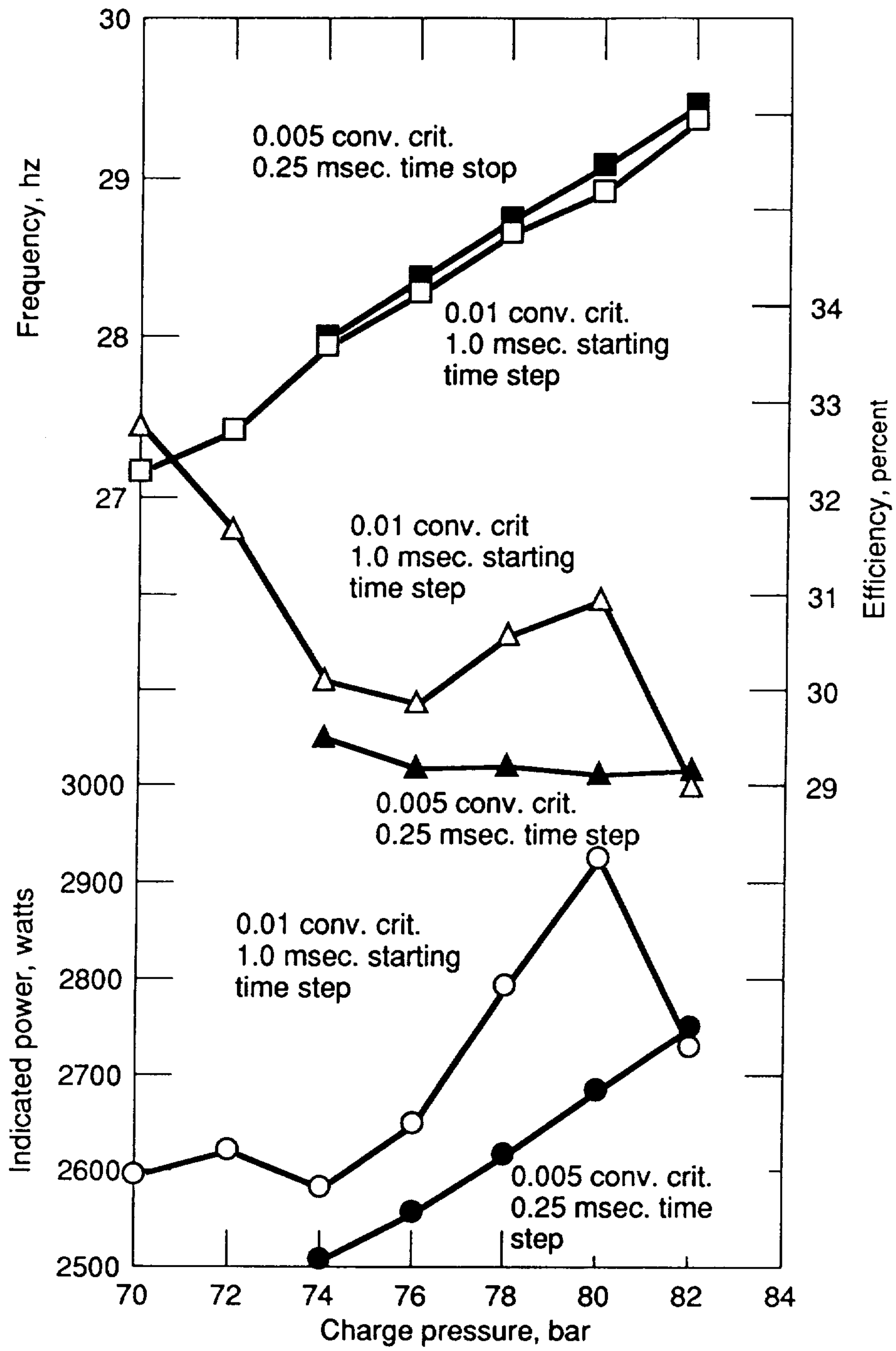

FIGURE 5.4 - COMPARISON OF FREQUENCY, EFFICIENCY, AND POWER FOR DIFFERENT TIME STEPS AND CONVERGENCE CRITERIA. (ADIABATIC ANALYSIS.)

5.2 Sample Base Cases

The engine dimensions and operating conditions for all the sample cases are given in appendix A except as specifically stated in each one of the base cases. It was found that in producing these base cases, it was extremely helpful to pay close attention to the graphical display because it was much easier to determine whether the solution was going awry by watching the display than by looking at diagnostic printouts, although these were also very useful in certain cases. All results demonstrated in these base cases were generated by the double precision version of the program.

5.2.1 Specific motion isothermal analysis. - This is the analysis one gets if no change is made at all in the base case program with the exception of adding graphical output if the computer has the capability for this. Table 5.6 shows the printout that is obtained when this is done. Note that the run number is one of the input values that can be changed and is for the convenience of the user. The different options of the program are specified in the heading so that one can see at a glance what choices have been made. All the dimensions of the RE-1000 engine are printed on the output. Note that the operating conditions are given first. These are all things that can be changeable in the engine without rebuilding it. The power piston stroke and displacer piston stroke are input numbers. They do not necessarily represent the actual strokes of the parts unless the specified motion option is chosen which it is in this case.

The reader is referred to section 4 for a detailed explanation of how these different values are calculated under the different circumstances. In this section will be explained the significance that each one of these values given in table 5.6 and succeeding tables that follow is supposed to represent. There is a basic power and a basic heat requirement that are required if the engine were perfect. Since the engine is not perfect, a number of corrections have to be made to the basic power as well as the basic heat requirement to obtain the predicted value for the power output and efficiency. In this case of isothermal analysis and specified motion we know ahead of time how the displacer and the power piston move. In the isothermal analysis we assume we know what an effective temperature will be for the hot space and the heater gas and for the cold space and cooler gas. Therefore, we can determine the pressure during the cycle. The line integral of the total volume versus this pressure times the frequency is the basic power output for the cycle. The line integral of the hot volume versus the pressure times the frequency is the basic heat input.

Then, according to references 1 and 2, Martini Engineering has worked out a method of relating the basic power output and the basic heat input calculated by isothermal analysis to the basic power output and heat input for an adiabatic hot space and cold space which would be more time consuming to compute. There is a functional relationship between both the isothermal work and the adiabatic work and between the isothermal heat input and the adiabatic heat input. Therefore, a correction is applied by a two-dimensional interpolation in a data table which is part of the computer program.

Also, on the power output side an estimate is made of the flow losses through the heater, regenerator, and cooler, and these are subtracted from the basic power to give the indicated power. In the case of a free piston Stirling

Table 5.6

COMPUTED RESULTS FOR SPECIFIED MOTION,
ISOTHERMAL ANALYSIS

(Base Case Dimensions from Appendix A)

CONVERGENCE CRITERIA IS: .00050

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	41.2037	64.3800	7.0134	1.4029
2	.58796	.67810	38.4287	64.0719	7.0389	1.4029
3	.06735	.00479	34.1658	52.8642	7.0413	1.4029
4	.11093	.17492	36.6826	60.2570	7.0386	1.4029
5	.07366	.13984	37.5514	63.1660	7.0401	1.4029
6	.02369	.04828	36.7339	60.9168	7.0409	1.4029
7	.02177	.03561	36.7083	60.7805	7.0405	1.4029
8	.00070	.00224	36.9490	61.4834	7.0404	1.4029
9	.00656	.01156	36.9033	61.3747	7.0405	1.4029
10	.00124	.00177	36.8478	61.2095	7.0405	1.4029
11	.00150	.00269	36.8837	61.1748	6.9675	.7015
12	.00097	.00057	36.8409	61.0046	6.9724	.7015
13	.00116	.00278	36.9408	61.4092	6.9720	.7015
14	.00271	.00663	36.9221	61.3223	6.9720	.7015
15	.00051	.00142	36.8970	61.1995	6.9720	.7015
16	.00068	.00200	36.9086	61.2475	6.9719	.7015
17	.00031	.00078	36.9132	61.2702	6.9719	.7015
18	.00012	.00037	36.9085	61.2494	6.9719	.7015

CURRENT OPERATING CONDITIONS ARE:

01=	72.000	02=	2	03=	600.000	04=	40.000	05=	49.600
06=	2.700	07=	2.600	08=	0	09=	1	10=	1.000
11=	0	12=	.000	13=	1.000	14=	1	15=	1
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	22	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0000	76=	1.0000	77=	3.0000	78=	1.0000	79=	4.0000
80=	20.0000	81=	.0100	82=	.1000	83=	.0005	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0	116=	0	117=	0	118=	0	119=	0
120=	0								

Table 5.6 Concluded

```
 ENTERED PRINT ROUTINE AFTER    18 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN      .0005
                   RUN#  1   FOR
                   SUNPOWER RE1000 ENGINE
                   SPECIFIED MOTIONS
                   ISOTHERMAL ANALYSIS WITH CORRECTIONS
                   MARTINI LOSS EQUATIONS
                   SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =     29.70      CHRG. PRESS., BAR   =     72.00
HEAT IN, DEG C =    600.00      HEAT OUT, DEG. C    =     40.00
W. GAS 1=H2,2=HE,3=AIR 2        PHASE ANG. DEGREES =     49.60
POWER P.STR,CM =      2.70      DISPL. STROKE, CM   =      2.60
CALC.FREQ., HZ =     29.70      TIME STEPS/CYCLE    =     48.00

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                     HEAT REQUIREMENT, WATTS
  BASIC               1096.1822   BASIC                   1819.1067
  ADIABATIC CORR.      -50.6575   ADIABATIC CORR.           92.1976
  HEATER FLOW LOSS     -80.6737   REHEAT                   610.9303
  REGEN.FLOW LOSS      -84.0998   SHUTTLE                  104.7203
  COOLER FLOW LOSS      -3.4007   PUMPING                    5.9110
  INDICATED            877.3505   TEMP. SWING                1.0149
                                  CYL. WALL COND.          193.2727
                                  DISPLCR WALL COND.        33.7666
--------------------------------  REGEN. WALL COND.         60.9939
INDICATED EFFICIENCY, %  31.17    CYL. GAS COND.             6.0904
                                  REGEN. MTX. COND.          4.5869
--------------------------------  RAD.INSIDE DISPL.          4.7596
EXP.SP.EFFECT.TEMP.,C   574.73    FLOW FRIC. CREDIT       -122.7236
COMP.SP.EFFECT.TEMP.,C   57.46    TOTAL HEAT TO ENG.      2814.6273
```

engine the mechanical losses are considered negligible and are not considered. Therefore, the indicated power is the power applied to the load.

On the heat input side the reheat loss is simply the extra heat that must be added each cycle to bring the working gas entering the hot space back to hot space temperature. A better regenerator can reduce reheat loss. The shuttle loss is the loss suffered as heat is transferred across the displacer gap as it moves back and forth. Increasing the gap or increasing the length of the displacer with reference to its stroke can reduce this loss. Pumping loss is the loss incurred by packing hot gas into this appendix gap around the displacer and then bringing back somewhat colder gas because of the heat transfer into this gap. Pumping loss can be decreased by decreasing this gas thickness. Therefore, there is a trade off between shuttle loss and pumping loss. Temperature swing loss is the additional loss incurred due to the fact that the regenerator matrix has heat capacity. This is a correction to the reheat loss which assumes that the regenerator matrix has infinite heat capacity. The different steady state conduction terms are then itemized. These are the cylinder wall conduction, the hot cap wall conduction, the regenerator wall conduction, the cylinder gas conduction, the regenerator matrix conduction, and the radiation inside the displacer. Also, since the flow losses in the heater and half of them in the regenerator are converted to heat, there is a credit for this giving a total heat requirement for the engine. Also, shown in table 5.6 is the expansion space effective temperature and the compression space effective temperature which were obtained by an iterative procedure such that the temperature difference between the heat source metal temperature and the effective expansion space gas temperature was adequate to transfer heat through the heater considering that the temperature difference is effective during the time the gas moves. The same calculation is made for the cold side so that the temperature offset is adequate to transfer heat that is needed to be transferred through the cooler.

This procedure has been used by Martini and has been published in a number of places (refs. 1-5).

Figure 5.5 gives a graphical output for this case. Figure 5.6 gives an explanation of what is meant by this graphical output. Seven curves are plotted for each cycle. These curves are superimposed upon each other until a convergence is reached. The most important is the total volume pressure curve or indicator diagram. This is shown as a pickle-shaped diagram on the right hand side of the display. There is a lighter curve above and a heavier curve below. The lighter curve is the first cycle in which it was assumed that the beginning pressure is the charge pressure. Since this created a higher than desired average pressure for the working gas space, the pressure was adjusted for the second cycle so that the average pressure in the working gas space would be equal to the charge pressure.

As explained in figure 5.6 there are three curves that involve this pressure. One plots the total volume versus the working gas pressure to give a closed curve proportional to the power output. Another curve plots the hot volume versus the working gas pressure to give a closed curve with an area proportional to the heat input. Finally, there are three curves that show how the working gas, displacer bounce and power piston bounce pressure vary with time during the cycle.

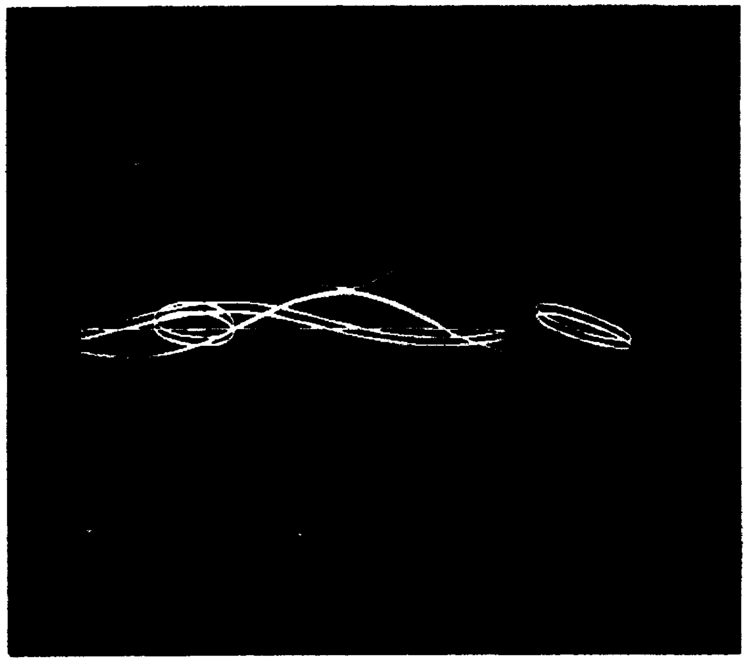

FIGURE 5.5. - GRAPHICAL OUTPUT FOR SPECIFIED MOTION. (ISOTHERMAL ANALYSIS.) (SEE FIG. 5.6 FOR EXPLANATION OF CURVES.)

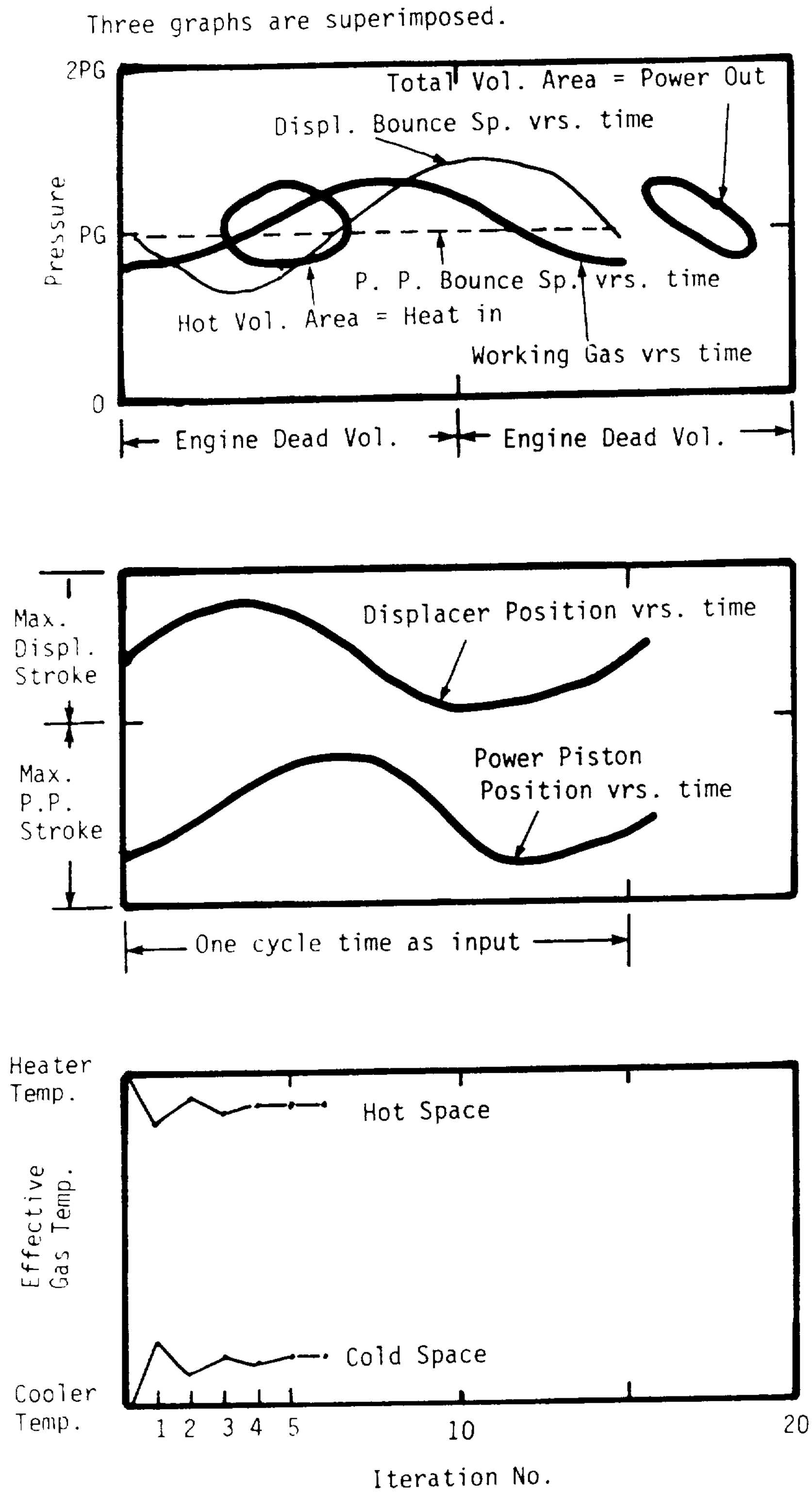

FIGURE 5.6. - GRAPHICAL OUTPUT FOR CALCULATED MOTION, LINEAR ALTERNATOR LOAD. (ISOTHERMAL ANALYSIS.)

Also shown in figure 5.5 are the positions of the displacer and the power piston for one cycle. Since this is a specified position case, these positions do not change from cycle to cycle and they are assumed to be sinusoidal. The frequency, the amplitude and the phase angle that are given are used to plot these curves. Finally, as is common in isothermal analysis, the effective hot space and cold space temperatures are adjusted. The curves as explained in the third part of figure 5.6 show how these adjustments take place. Most of the adjustment is in the second cycle and after that, very minor adjustments are needed and after 17 cycles the solution meets the very tight convergence criteria and the solution ends.

<u>5.2.2. Free-piston motion with linear generator and isothermal analysis</u>. - In the free-piston motion the specified motion of the displacer and the power piston is replaced with a force balance which takes into account all the forces acting upon the displacer and power piston at a particular time and, knowing its current velocity and mass, predict the velocity for the next time step and therefore, the position of the power piston and the displacer for the next time step. Also, the history of the last three time steps are used in the Adams method of integration.

This case is different from the base case by making the following changes:

Number 10 Time step to 0.1 msec
Number 14 Engine load to four
Number 15 Method of calculation from one to two
Number 75 Alternator load parameter to 0.04
Number 83 Convergence criteria from 0.0005 to 0.005

These changes were made because the calculation series given in table 5.1 and appendix Y showed that this is a stable operating point. Table 5.7 shows the computed results for this final version of the computer program. Appendix Y was done with an earlier version which did not have the final aids to convergence added. For these conditions and 72 bar charge pressure, the solution in appendix Y required 13 cycles. This final solution for the same time step and convergence criteria required 11 cycles. The results are almost identical as far as power output, frequency and efficiency are concerned. The changes in power output and heat input from cycle to cycle are less drastic at first, but in this case the solution at 0.1 msec time step does not usually allow the fractional change in both integrals to be less than 0.005 for two successive times. After going to a time step of 0.05 msec, the calculation settled down enough to meet the criteria.

There should be no reason that tables 5.6 and 5.7 should give the same results since the frequencies and strokes are quite different.

Figure 5.6(a) shown the graphical output for this case. Note that the new lower frequency is found after three cycles. The rest of the time was taken to settle the solution. Thirteen curves are drawn, but after the first few the rest are essentially repeats as far as the graphical output is concerned. Note also that it takes only about three cycles to change the phase angle.

Table 5.7

RESULTS FOR CALCULATED MOTION AND
LINEAR ALTERNATOR LOAD - ISOTHERMAL ANALYSIS

CONVERGENCE CRITERIA IS: .00500

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	41.2171	64.2647	6.8745	.1000
2	.58783	.67868	47.6599	63.7569	7.0252	.1000
3	.15631	.00790	34.1322	57.6921	6.8714	.1000
4	.28384	.09512	39.9877	65.9273	6.8900	.1000
5	.17156	.14274	39.9027	66.3738	6.8695	.1000
6	.00213	.00677	40.2669	66.9577	6.8617	.1000
7	.00913	.00880	40.6012	67.3663	6.8401	.1000
8	.00830	.00610	41.0302	68.1034	6.8336	.1000
9	.01057	.01094	41.2292	68.4511	6.8277	.1000
10	.00485	.00511	41.3839	68.7004	6.8109	.1000
11	.00375	.00364	41.5762	68.9781	6.8052	.0500

CURRENT OPERATING CONDITIONS ARE:

01=	72.000	02=	2	03=	600.000	04=	40.000	05=	92.229
06=	2.221	07=	2.723	08=	0	09=	1	10=	.100
11=	0	12=	.000	13=	1.000	14=	4	15=	2
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	22	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0400	76=	1.0000	77=	3.0000	78=	1.0000	79=	4.0000
80=	20.0000	81=	.0100	82=	.1000	83=	.0050	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0	116=	0	117=	0	118=	0	119=	0
120=	0								

Table 5.7 Concluded

```
 ENTERED PRINT ROUTINE AFTER     11 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN       .0050
                    RUN#  1   FOR
                    SUNPOWER RE1000 ENGINE
                    FREE MOTIONS -- LINEAR ALTERNATOR
                         LOAD CONSTANT =     .040 N/(CM/SEC)**2.
                    ISOTHERMAL ANALYSIS WITH CORRECTIONS
                    MARTINI LOSS EQUATIONS
                    SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70       CHRG. PRESS., BAR   =     72.00
HEAT IN, DEG C =     600.00       HEAT OUT, DEG. C    =     40.00
W. GAS 1=H2,2=HE,3=AIR 2          PHASE ANG. DEGREES  =     92.23
POWER P.STR,CM =       2.22       DISPL. STROKE, CM   =      2.72
CALC.FREQ., HZ =      25.13       TIME STEPS/CYCLE    =    795.71

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                      HEAT REQUIREMENT, WATTS
  BASIC                1045.0108    BASIC                   1733.7518
  ADIABATIC CORR.       -45.9296    ADIABATIC CORR.           88.1723
  HEATER FLOW LOSS      -92.2179    REHEAT                   666.2807
  REGEN.FLOW LOSS      -115.0524    SHUTTLE                  116.1903
  COOLER FLOW LOSS       -5.8318    PUMPING                    9.1725
  INDICATED             785.9791    TEMP. SWING                1.3352
                                    CYL. WALL COND.          195.5516
                                    DISPLCR WALL COND.        34.1648
--------------------------------    REGEN. WALL COND.         61.7131
INDICATED EFFICIENCY, %  28.35      CYL. GAS COND.             6.1623
                                    REGEN. MTX. COND.          4.6409
--------------------------------    RAD.INSIDE DISPL.          4.7975
EXP.SP.EFFECT.TEMP.,C   576.06      FLOW FRIC. CREDIT       -149.7441
COMP.SP.EFFECT.TEMP.,C   52.73      TOTAL HEAT TO ENG.      2772.1888
```

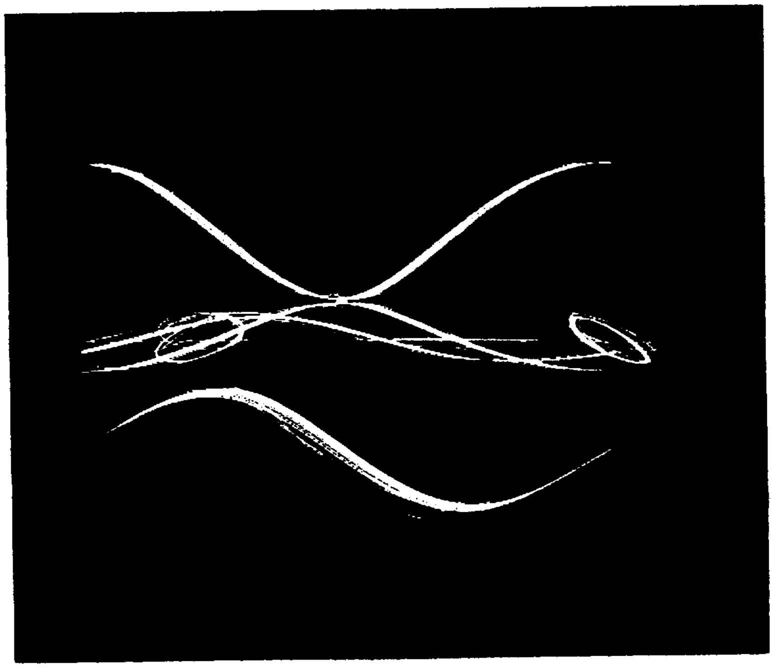

FIGURE 5.6(a)

Table 5.8

RESULTS FOR FREE-PISTON MOTION AND
INERTIAL COMPRESSOR LOAD - ISOTHERMAL ANALYSIS

CONVERGENCE CRITERIA IS: .00500

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	41.2171	64.2647	6.8745	.1000
2	.58783	.67868	35.0681	53.5180	7.0958	.1000
3	.14918	.16723	39.2237	55.8193	7.0217	.1000
4	.11850	.04300	55.1115	86.9361	6.9616	.1000
5	.40506	.55746	61.8815	100.9092	6.9491	.1000
6	.12284	.16073	63.8623	106.5299	6.9579	.1000
7	.03201	.05570	63.4483	106.4051	6.9732	.1000
8	.00648	.00117	63.0399	105.2241	6.9697	.1000
9	.00644	.01110	63.5025	105.9676	6.9590	.1000
10	.00734	.00707	63.7454	106.5145	6.9664	.1000
11	.00382	.00516	63.8477	106.7131	6.9547	.0500
12	.00161	.00186	63.8920	106.7274	6.9521	.0500

CURRENT OPERATING CONDITIONS ARE:

01=	72.000	02=	2	03=	600.000	04=	40.000	05=	69.724
06=	3.585	07=	2.796	08=	0	09=	1	10=	.100
11=	0	12=	.000	13=	1.000	14=	3	15=	2
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	22	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0400	76=	1.0000	77=	3.0000	78=	1.0000	79=	.5000
80=	5.0000	81=	1.0000	82=	.1000	83=	.0050	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0	116=	0	117=	0	118=	0	119=	0
120=	0								

Table 5.8 Concluded

```
 ENTERED PRINT ROUTINE AFTER    12 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN      .0050
                   RUN#  1   FOR
                   SUNPOWER RE1000 ENGINE
                   FREE MOTIONS -- INERTIAL COMPRESSOR
                        INLET PRESSURE OF PUMPED GAS=   1.00 BAR.
                        OUTLET PRESSURE OF PUMPED GAS=   5.00 BAR.
                        AREA OF LOAD PISTON=     .500 CM**2.
                        END CLEARANCE IN PUMP=    1.000 CM.
                   ISOTHERMAL ANALYSIS WITH CORRECTIONS
                   MARTINI LOSS EQUATIONS
                   SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =       29.70        CHRG. PRESS., BAR  =      72.00
HEAT IN, DEG C =      600.00        HEAT OUT, DEG. C   =      40.00
W. GAS 1=H2,2=HE,3=AIR 2            PHASE ANG. DEGREES =      69.72
POWER P.STR,CM =        3.59        DISPL. STROKE, CM  =       2.80
CALC.FREQ., HZ =       30.62        TIME STEPS/CYCLE   =     653.15

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                        HEAT REQUIREMENT, WATTS
  BASIC                 1956.4315     BASIC                     3268.0914
  ADIABATIC CORR.       -115.9755     ADIABATIC CORR.            201.7725
  HEATER FLOW LOSS      -169.1202     REHEAT                     876.8796
  REGEN.FLOW LOSS       -192.3061     SHUTTLE                    118.8972
  COOLER FLOW LOSS       -10.1656     PUMPING                     12.7575
  INDICATED             1468.8642     TEMP. SWING                  2.1328
                                      CYL. WALL COND.            189.7416
                                      DISPLCR WALL COND.          33.1497
--------------------------------      REGEN. WALL COND.           59.8795
INDICATED EFFICIENCY, %   32.55       CYL. GAS COND.               5.9792
                                      REGEN. MTX. COND.            4.5031
--------------------------------      RAD.INSIDE DISPL.            4.5325
EXP.SP.EFFECT.TEMP.,C   564.63        FLOW FRIC. CREDIT         -265.2732
COMP.SP.EFFECT.TEMP.,C   56.81        TOTAL HEAT TO ENG.        4513.0435
```

5.2.3 Free-piston motion, inertial compressor, isothermal analysis. - To calculate this case, the following input values were changed from the previous case.

Number 14 Engine load from four to three
Number 78 Inlet pressure of pumped gas to 1.00 bar
Number 79 Areas of load piston = 0.5 cu^2
Number 80 Outlet pressure of pumped gas to 5.00 bar
Number 81 End clearance in pump = 1 cm

The results of this calculation are shown in table 5.8. The graphical output is shown in figure 5.7.

In this case the power piston of the engine is attached to a gas compressor that is double acting and has inlet and output valves on each end. The effect of the area of the connecting rod is ignored. The gas in the pumping gas spaces is assumed to act as if it were adiabatic as far as the compression and expansion effects are concerned. One must specify the inlet and outlet pressure of the gas, the area of the load piston and the end clearance in the pump which is the distance between the piston and the end of the pumping chamber when the power piston is at its stop on either end. All these values affect how the displacer and power piston move. Note that at the end of each cycle the effective temperature of the gas in the hot space and the cold space of the engine is adjusted as is usually done in the isothermal analysis so the temperature between the metal and gas is adequate to transfer the heat that is required by the engine. The graphical presentation of the data as well as the work output and heat inputs in table 5.8 shows that about four or five cycles are needed to steady out the work and the frequency. After this they become quite stable and the operation is stable within some narrow bounds. As in the last case, adequate stability to meet the convergence criteria only when the time step is halved after 10 cycles. Only two more cycles are needed to meet convergence criteria.

5.2.4 Specified motion and moving gas node analysis. - To calculate this case the following input values are changed from the previous case:

Number 15 Calculation option from two to three

In this analysis, the concept of an effective hot space and cold space temperature is not used. In its place a large number of gas nodes are assumed to move back forth through the working gas space. Each one of these gas nodes represents a specific quantity of gas which is followed through the cycle. However, in the expansion and the compression space the gas nodes are redefined so that there is one homogenized gas node for the expansion space and another one for the compression space. Otherwise, there is no flow between one gas node and the next. Table 5.9 shows the results of this sample case. This solution is not disturbed each cycle by the picking of a different effective hot and cold space temperature. The hot space and cold space temperatures change smoothly during the cycle and fairly quickly attain a steady state operation. That is, they cycle through the same temperatures each cycle. Table 5.9 shows how these works approached a steady state and shows that the results with this type of analysis are reasonable.

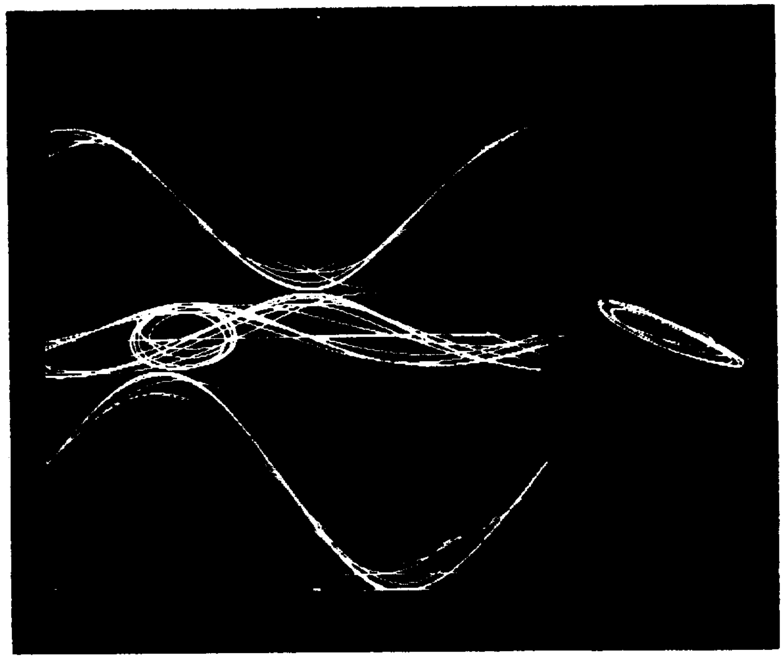

FIGURE 5.7. - GRAPHICAL OUTPUT FOR FREE-PISTON MOTION INERTIAL COMPRESSOR LOAD. (ISOTHERMAL ANALYSIS.)

Table 5.10 compares two calculations of the same engine under the same conditions. The adiabatic analysis predicts 35 percent more power and 10 percent more efficiency than the isothermal analysis. The adiabatic analysis should be more accurate since it is much closer to the true way the engine operates. However, the isothermal analysis has been shown to agree with the General Motors data on their 4L23 engine to within ±10 percent (refs. 1 and 2). It will be interesting to see how these two agree with test results on the RE-1000 engine (ref. 7).

Since in the moving gas node analysis the hot and cold spaces are adiabatic, there is no need for an adiabatic correction. Therefore, this has been set to zero. Otherwise, all the other losses are calculated in the same way as previously. Figure 5.8 shows that the graphical output is very well behaved. The work diagram is slightly more tipped (as you would expect) because of the adiabatic character of the hot and cold spaces.

5.2.5 Specified motion and Rios adiabatic analysis. - In order to do this case the following changes are made from the last case:

Number 32 Integration option from zero to one
Number 46 Number of time steps per cycle from 24 to 360

With the aid of the Rios thesis (ref. 6) and the program given in the Second Edition of the Stirling Engine Design Manual (ref. 4), the Rios analysis was adapted to the free-piston environment. One important change was that the hot and cold spaces do not go to zero once each cycle like they did in the original Rios analysis. Therefore, they cannot be reinitialized like Rios did once each cycle. The problem is that the Rios algorithm in which central difference is used is computationally unstable. However, by using small time steps and initializing once each cycle, Rios could use this effectively. However, since our hot and cold spaces do not go to zero because this is a free-piston machine, the reinitialization cannot take place and the instability of the solution builds up to unuseful proportions after about two cycles. Figure 5.9 shows how this happens. Every other time step is either higher or lower than it should be. Eventually, the line becomes so broad as to be useless. For specified motion it might be possible to redefine the hot and cold volume so that they would go to zero each cycle and to reinitialize the integrals. However, this would not work for the calculated motion case.

Table 5.11 shows how the work output and heat input integrals began to be calculated for the Rios method. These figures were calculated by the single precision version of the program. The double precision version could not complete more than one cycle. These work and heat input integrals should be the same as the moving gas node analysis integrals since the assumptions are the same. Note the comparison on table 5.12. Note that the Rios work output is much larger than any of the others. It was not determined why this is so.

5.2.6 Calculated motion, linear alternator load and moving gas node, adiabatic analysis. - To do this case from the last one, the following changes were made:

Number 10 Time step from 0.1 to 0.25
Number 14 Engine load from three to four
Number 15 Method of calculation from three to four
Number 32 Integration option from one to zero

Table 5.9

RESULTS OF SPECIFIED MOTION AND
MOVING GAS NODE ANALYSIS

CONVERGENCE CRITERIA IS: .00500

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	40.9903	64.2182	7.0150	1.4029
2	.59010	.67891	43.4757	70.4939	7.0120	1.4029
3	.06063	.09772	45.3251	80.8912	7.0086	1.4029
4	.04254	.14749	45.7091	81.6915	7.0103	1.4029
5	.00847	.00989	45.5983	81.4233	7.0103	1.4029
6	.00242	.00328	45.6074	81.4137	7.0105	1.4029

CURRENT OPERATING CONDITIONS ARE:

01=	72.000	02=	2	03=	600.000	04=	40.000	05=	49.600
06=	2.700	07=	2.600	08=	0	09=	1	10=	.100
11=	0	12=	.000	13=	1.000	14=	3	15=	3
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	36	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0400	76=	1.0000	77=	3.0000	78=	1.0000	79=	.5000
80=	5.0000	81=	1.0000	82=	.1000	83=	.0050	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0	116=	0	117=	0	118=	0	119=	0
120=	0								

Table 5.9 Concluded

```
 ENTERED PRINT ROUTINE AFTER     6 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN       .0050
                   RUN#  1   FOR
                   SUNPOWER RE1000 ENGINE
                   SPECIFIED MOTIONS
                   MARTINI MOVING GAS NODE ANALYSIS
                   MARTINI LOSS EQUATIONS
                   SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70      CHRG. PRESS., BAR   =     72.00
HEAT IN, DEG C =     600.00      HEAT OUT, DEG. C    =     40.00
W. GAS 1=H2,2=HE,3=AIR 2         PHASE ANG. DEGREES  =     49.60
POWER P.STR,CM =       2.70      DISPL. STROKE, CM   =      2.60
CALC.FREQ., HZ =      29.70      TIME STEPS/CYCLE    =     24.00

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                     HEAT REQUIREMENT, WATTS
  BASIC               1354.5408    BASIC                    2417.9862
  ADIABATIC CORR.         .0000    ADIABATIC CORR.              .0000
  HEATER FLOW LOSS     -74.2184    REHEAT                    724.2311
  REGEN.FLOW LOSS     -102.5136    SHUTTLE                   107.3639
  COOLER FLOW LOSS      -5.4981    PUMPING                    10.2203
  INDICATED           1172.3106    TEMP. SWING                 1.4415
                                   CYL. WALL COND.           198.1517
                                   DISPLCR WALL COND.         34.6191
--------------------------------   REGEN. WALL COND.          62.5336
INDICATED EFFICIENCY, %  34.01     CYL. GAS COND.              6.2442
                                   REGEN. MTX. COND.           4.7026
--------------------------------   RAD.INSIDE DISPL.           4.6421
                                   FLOW FRIC. CREDIT        -125.4752
                                   TOTAL HEAT TO ENG.       3446.6611
```

TABLE 5.10

COMPARISON OF ISOTHERMAL AND
ADIABATIC METHODS OF ANALYSIS
RE-1000 ENGINE

	Isothermal	Adiabatic
Charge pressure, bar	72.00	72.00
Heat in, C	600.00	600.00
Heat out, C	40.00	40.00
Phase angle, deg.	49.6	49.6
Power piston, Str, cm	2.70	2.70
Displacer stroke, cm	2.60	2.60
Gas	Helium	Helium
Frequency	29.7	29.7
Reference	Table 5.6	Table 5.9
Cycles to convergence	18	6
Convergence criteria	0.0005	0.005
Time steps/cycle	48	24
Indicated power, watts	877.35	1172.3
Indicated efficiency	31.17	34.01

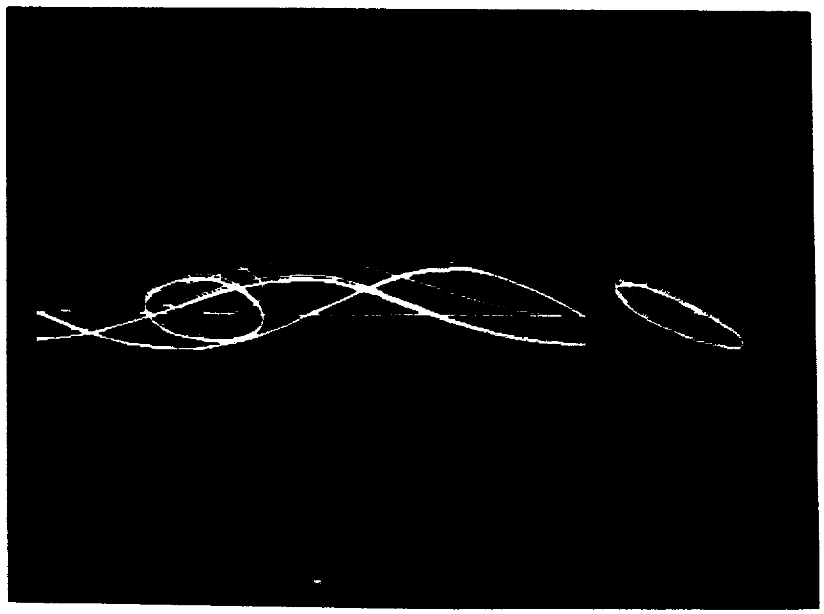

FIGURE 5.8. - GRAPHICAL OUTPUT FOR SPECIFIED MOTION AND MOVING GAS NODE ANALYSIS.

Table 5.13 shows the results of this calculation. Figure 5.10 shows the graphical output. This sample output calculates the same case as was done with isothermal analysis. Table 5.14 compares the main results from these two cases. Note that the results are fairly close except for the power output. The adiabatic analysis seems to consistently predict higher power than the isothermal analysis. This observation is confirmed by comparing the size of the heat input and power curves in figure 5.10 compared with figure 5.6.

5.2.7 Calculated motion, inertial compressor, and moving gas node, adiabatic analysis. - To do this case from the last one, the following changes were made in the input:

Number 14 Engine load from four to three

Table 5.15 gives the printed results and figure 5.11 gives the graphical results. As always, the first cycle is isothermal, specified motion just to get the part moving. Then it takes five cycles to transition to approximately the steady state operating condition for calculated motion. Then it takes another three cycles of steady state operation to satisfy the convergence criteria. After the natural transition has occurred, mathematical convergence comes quickly.

Table 5.16 compares the results of two calculations for the same engine and inertial compressor. The isothermal analysis was done with a correction for the adiabatic effect. The adiabatic analysis is a nodal analysis in which the adiabatic nature of the hot and cold spaces is taken into account during the calculation. The main outputs are fairly close except for power. The adiabatic analysis predicts twice as much power as the isothermal analysis. It will be interesting to find out if either one agrees with tests.

5.2.8. Conclusion on sample base cases. - The computer program calculates accurately converged results for all four methods of calculation. The Martini moving gas node method of adiabatic analysis is operational but consistently predicts larger powers than the isothermal analysis. The Rios analysis has an inherent calculational instability which prevents a complete solution.

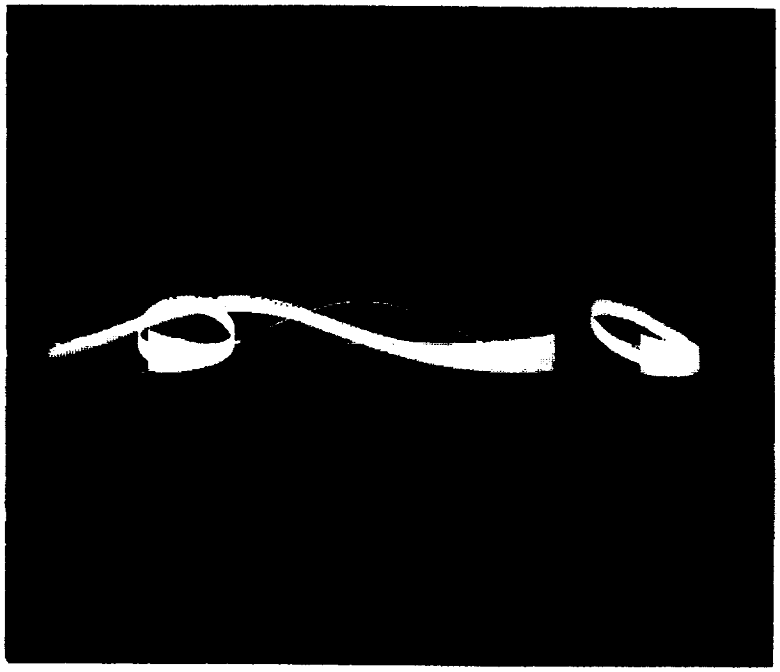

FIGURE 5.9. - GRAPHICAL OUTPUT FOR SPECIFIED MOTION AND RIOS ADIABATIC ANALYSIS.

TABLE 5.11
PARTIAL RESULTS FOR SPECIFIED MOTION
AND RIOS ADIABATIC ANALYSIS

Convergence criteria is: 0.00500

Cycle Numb.	Change power, out	Change heat, in	Work out, Joules	Heat in, Joules	End pressure, MPa	Time step, msec
1	0.00000	0.00000	41.2054	64.2541	6.8808	0.0935
2	.58795	.67873	58.2716	84.6213	7.0516	
3	.41417	.31698	61.0769	82.0306	6.9603	
4	.04814	.03061	60.1012	78.1137	7.1011	↓

TABLE 5.12
COMPARISON OF WORK OUTPUTS AND HEAT INPUTS
FOR THREE METHODS OF CALCULATION

Specified Motion	Work out Joules	Heat in Joules	References
Adiabatic analysis moving gas node	46	81	Table 5.9
Adiabatic analysis Rios	60	78	Table 5.11
Isothermal analysis and correction	36.9	61.2	Table 5.6

Table 5.13

RESULTS FOR CALCULATED MOTION, LINEAR ALTERNATOR LOAD
AND MOVING GAS NODE (ADIABATIC) ANALYSIS

CONVERGENCE CRITERIA IS: .00500

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	41.1863	64.2555	6.8796	.2500
2	.58814	.67872	55.9928	83.0952	6.6469	.2500
3	.35950	.29320	64.8097	115.4784	6.5569	.2500
4	.15747	.38971	75.1691	134.8363	6.5023	.2500
5	.15984	.16763	79.2829	142.7712	6.4827	.2500
6	.05473	.05885	80.4267	145.0904	6.4620	.2500
7	.01443	.01624	80.8724	145.8399	6.4894	.2500
8	.00554	.00517	81.2056	146.1244	6.4643	.2500
9	.00412	.00195	81.3618	146.5427	6.4407	.2500

CURRENT OPERATING CONDITIONS ARE:

01=	72.000	02=	2	03=	600.000	04=	40.000	05=	77.605
06=	2.652	07=	3.561	08=	0	09=	1	10=	.250
11=	0	12=	.000	13=	1.000	14=	4	15=	4
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	124	46=	360	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0400	76=	1.0000	77=	3.0000	78=	1.0000	79=	.5000
80=	5.0000	81=	1.0000	82=	.1000	83=	.0050	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0	116=	0	117=	0	118=	0	119=	0
120=	0								

Table 5.13 Concluded

```
ENTERED PRINT ROUTINE AFTER      9 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN       .0050
                    RUN#  1   FOR
                    SUNPOWER RE1000 ENGINE
                    FREE MOTIONS -- LINEAR ALTERNATOR
                        LOAD CONSTANT =     .040 N/(CM/SEC)**2.
                    MARTINI MOVING GAS NODE ANALYSIS
                    MARTINI LOSS EQUATIONS
                    SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70      CHRG. PRESS., BAR    =     72.00
HEAT IN, DEG C =     600.00      HEAT OUT, DEG. C     =     40.00
W. GAS 1=H2,2=HE,3=AIR 2         PHASE ANG. DEGREES   =     77.61
POWER P.STR,CM =       2.65      DISPL. STROKE, CM    =      3.56
CALC.FREQ., HZ =      26.95      TIME STEPS/CYCLE     =    148.44

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                      HEAT REQUIREMENT, WATTS
  BASIC               2192.3912     BASIC                  3948.7687
  ADIABATIC CORR.         .0000     ADIABATIC CORR.            .0000
  HEATER FLOW LOSS    -208.4823     REHEAT                 1196.5663
  REGEN.FLOW LOSS     -351.5405     SHUTTLE                 193.5243
  COOLER FLOW LOSS     -27.5087     PUMPING                  17.8827
  INDICATED           1604.8597     TEMP. SWING               4.3889
                                    CYL. WALL COND.         190.3624
                                    DISPLCR WALL COND.       33.2582
--------------------------------    REGEN. WALL COND.        60.0754
INDICATED EFFICIENCY, %  30.42      CYL. GAS COND.            5.9987
                                    REGEN. MTX. COND.         4.5178
--------------------------------    RAD.INSIDE DISPL.         3.9868
                                    FLOW FRIC. CREDIT      -384.2526
                                    TOTAL HEAT TO ENG.     5275.0776
```

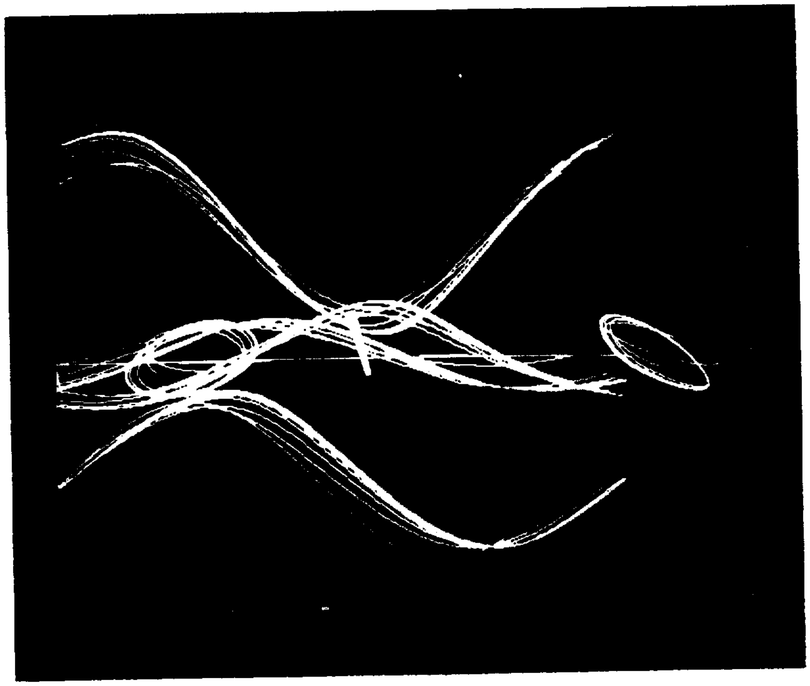

FIGURE 5.10. - GRAPHICAL OUTPUT FOR CALCULATED MOTION, LINEAR ALTERNATOR LOAD AND MOVING GAS NODE. (ADIABATIC ANALYSIS.)

TABLE 5.14
COMPARISON OF CALCULATED RESULTS FOR AN ISOTHERMAL AND MOVING GAS NODE, ADIABATIC, ANALYSIS OF A CALCULATED MOTION LINEAR ALTERNATOR

Calculated motion	Isothermal	Adiabatic
Reference	Table 5.7	Table 5.13
Load constant, $N/(cm/sec)^2$	0.040	0.040
Charge pressure, bar	72.00	72.00
Time step, msec	0.1	0.25
Convergence criteria	0.005	0.005
Power piston, Str., cm	2.22	2.65
Displacer, Str., cm	2.72	3.56
Calc. frequency, Hz	25.13	26.95
Indicated power, W	785.98	1604.86
Indicated eff., percent	28.35	30.42
Cycles to convergence	13	9

Table 5.15

RESULTS FOR CALCULATED MOTION, INERTIAL COMPRESSOR LOAD, AND MOVING GAS NODE, ADIABATIC ANALYSIS

CONVERGENCE CRITERIA IS: .00500

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	41.1863	64.2555	6.8796	.2500
2	.58814	.67872	41.9359	67.0226	6.9231	.2500
3	.01820	.04306	63.1770	104.1761	6.7206	.2500
4	.50651	.55434	103.9885	185.0017	6.6209	.2500
5	.64599	.77586	122.2075	226.8067	6.6092	.2500
6	.17520	.22597	126.7057	233.9285	6.5661	.2500
7	.03681	.03140	127.9249	236.6349	6.5991	.2500
8	.00962	.01157	127.8781	237.3906	6.5596	.2500
9	.00037	.00319	127.6354	236.7590	6.5938	.2500

CURRENT OPERATING CONDITIONS ARE:

01=	72.000	02=	2	03=	600.000	04=	40.000	05=	55.478
06=	4.198	07=	3.814	08=	0	09=	1	10=	.250
11=	0	12=	.000	13=	1.000	14=	3	15=	4
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	116	46=	360	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0400	76=	1.0000	77=	3.0000	78=	1.0000	79=	.5000
80=	5.0000	81=	1.0000	82=	.1000	83=	.0050	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0	116=	0	117=	0	118=	0	119=	0
120=	0								

Table 5.15 Concluded

```
 ENTERED PRINT ROUTINE AFTER      9 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN       .0050
                   RUN#  1   FOR
                   SUNPOWER RE1000 ENGINE
                   FREE MOTIONS -- INERTIAL COMPRESSOR
                        INLET PRESSURE OF PUMPED GAS=   1.00 BAR.
                        OUTLET PRESSURE OF PUMPED GAS=   5.00 BAR.
                        AREA OF LOAD PISTON=       .500 CM**2.
                        END CLEARANCE IN PUMP=     1.000 CM.
                   MARTINI MOVING GAS NODE ANALYSIS
                   MARTINI LOSS EQUATIONS
                   SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70       CHRG. PRESS., BAR  =     72.00
HEAT IN, DEG C =     600.00       HEAT OUT, DEG. C   =     40.00
W. GAS 1=H2,2=HE,3=AIR 2          PHASE ANG. DEGREES =     55.48
POWER P.STR,CM =       4.20       DISPL. STROKE, CM  =      3.81
CALC.FREQ., HZ =      31.61       TIME STEPS/CYCLE   =    126.54

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                      HEAT REQUIREMENT, WATTS
  BASIC                4034.7092    BASIC                    7484.2374
  ADIABATIC CORR.          .0000    ADIABATIC CORR.              .0000
  HEATER FLOW LOSS     -443.6864    REHEAT                   1752.0629
  REGEN.FLOW LOSS      -710.7298    SHUTTLE                   214.7223
  COOLER FLOW LOSS      -61.9715    PUMPING                    28.7088
  INDICATED            2818.3215    TEMP. SWING                 9.1490
                                    CYL. WALL COND.           184.1234
                                    DISPLCR WALL COND.         32.1682
--------------------------------    REGEN. WALL COND.          58.1065
INDICATED EFFICIENCY, %  31.39      CYL. GAS COND.              5.8021
                                    REGEN. MTX. COND.           4.3697
--------------------------------    RAD.INSIDE DISPL.           3.7482
                                    FLOW FRIC. CREDIT        -799.0513
                                    TOTAL HEAT TO ENG.       8978.1474
```

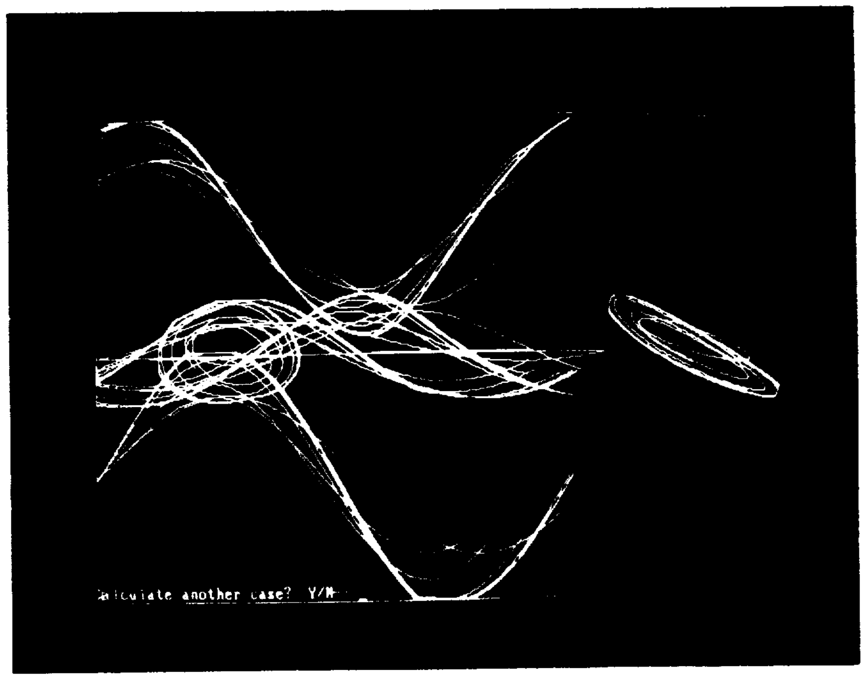

FIGURE 5.11. - GRAPHICAL OUTPUT FOR CALCULATED MOTION INERTIAL COMPRESSOR LOAD AND MOVING GAS NODE. (ADIABATIC ANALYSIS.)

TABLE 5.16
COMPARISON OF CALCULATED RESULTS FOR AN ISOTHERMAL AND A MOVING GAS NODE, ADIABATIC ANALYSIS OF AN INERTIAL COMPRESSOR OPERATING WITH CALCULATED MOTION

	Isothermal	Adaibatic
Reference table	5.8	5.15
Inputs		
Convergence Criteria	0.005	0.005
Time step, msec	.05	.25
Cycles to convergence	12	9
Inlet pressure of pumped gas, bar	1.00	1.00
Outlet pressure of pumped, gas	5.00	5.00
Area of load piston, cm^2	0.5	0.5
End of clearance in pump, cm	1.0	1.0
Outputs		
Calculated frequency, Hz	30.62	31.61
Indicated power, watts	1469	2818
Efficiency	32.55	31.39

5.3 Optimization Searches

The ability of this program to conduct a search for the optimum design is one of the reasons for developing the program. Experience has shown that the calculation of each case must be solidly done. It must be done at a small enough time step and a tight enough convergence so that the solution will be accurate (see Section 5.1) The program must have provisions to adjust the time step so that a proper solution would be found for every case. The results of four searches will be presented:

(1) Specified motion, isothermal analysis, three adjustable inputs
(2) Specified motion, isothermal analysis, four adjustable inputs
(3) Calculated motion, linear alternator, isothermal analysis, three adjustable inputs
(4) Calculated motion, linear alternator, isothermal analysis, four adjustable inputs

5.3.1 Specified motion, three adjustable inputs. - In this sample search, three properties of the regenerator were adjusted. The goal was to find the best efficiency with the engine power near 1 kW. To do this case, the following inputs need to be changed or checked:

Number 15	Method of calculation to 1
Number 16	Optimization option to 1
Number 17	Number of adjustable variables to 3
Number 18	Target power, watts to 1000
Number 19	Percent change in optimization to 10
Number 46	Number of time steps per cycle to 24
Number 83	Convergence criteria to 0.005
Number 101	First optimizable variable to 13
Number 102	Second optimizable variable to 15
Number 103	Third optimizable variable to 14

Table 5.17 shows the first part of the search table. For this case, the choice matrix is as shown in table 4.1. There are 27 choice matrices to test to see which gives the best efficiency. The first time the choice matrix is applied to change the three selected inputs the charge pressure for the last case is used. A case is run which results in a particular power. The charge pressure is then adjusted to give the target power by assuming that the power is proportional to charge pressure. The results of the second try for each of the 27 change matrix numbers is printed in table 5.17. Note that the power is usually within 1 percent of the target power. Considering that the efficiency is usually not a strong function of pressure or power (see figs. 5.1, 5.2, and 5.4), this accuracy in hitting the target power is more than adequate. Note that the first column in table 5.17 shows that trial number. The second column shows the choice matrix number which goes from 1 to 27. The third column shows the choice matrix number that results in the best efficiency for a particular search. The fourth column gives the cylinder diameter. One has a choice of adjusting either the cylinder diameter or the average pressure to get the target power. This test was done by changing the pressure. The fifth column shows these average pressures. The sixth column shows the powers which should be close to the target power of 1000 W. The seventh column gives the efficiency for each case calculated. The eighth column gives the best efficiency

Table 5.17

FIRST PART OF OPTIMUM SEARCH TABLE
SPECIFIED MOTION - THREE VARIABLES

SEARCH FOR OPTIMUM

The number of active optimization numbers is: 3
The order in which the optimization numbers are tested is:
13 15 14 0 0 0 0 0 0 0 0 0 0 0 0

Trial Num.	Ch.Mx.#	Best#	Cyl.D.cm	Pavg.Bar	Pwr.W	Eff. %	Bst.Eff.%
1	1	1	5.718	81.96	1010.48	31.63	31.63
2	2	1	5.718	80.89	999.09	31.91	31.63
3	3	2	5.718	81.77	1000.88	31.18	31.91
4	4	2	5.718	80.22	998.83	27.34	31.91
5	5	2	5.718	80.64	1000.31	27.50	31.91
6	6	2	5.718	80.14	999.60	27.12	31.91
7	7	2	5.718	84.68	1005.42	33.24	31.91
8	8	7	5.718	83.15	998.43	33.74	33.24
9	9	8	5.718	86.13	1003.82	32.53	33.74
10	10	8	5.718	80.27	995.21	30.81	33.74
11	11	8	5.718	80.56	1000.24	31.10	33.74
12	12	8	5.718	81.04	1000.46	30.45	33.74
13	13	8	5.718	80.31	999.46	26.16	33.74
14	14	8	5.718	80.74	1000.31	26.29	33.74
15	15	8	5.718	80.11	999.50	25.96	33.74
16	16	8	5.718	83.30	1003.56	32.88	33.74
17	17	8	5.718	82.17	998.90	33.33	33.74
18	18	8	5.718	84.50	1002.80	32.26	33.74
19	19	8	5.718	81.75	997.44	32.33	33.74
20	20	8	5.718	81.57	999.83	32.70	33.74
21	21	8	5.718	82.79	1001.29	31.85	33.74
22	22	8	5.718	80.24	998.06	28.57	33.74
23	23	8	5.718	80.64	1000.30	28.75	33.74
24	24	8	5.718	80.33	999.73	28.32	33.74
25	25	8	5.718	86.56	1008.06	33.48	33.74
26	26	8	5.718	84.46	997.73	34.05	33.74
27	27	26	5.718	88.33	1005.35	32.66	34.05
28	26	26	5.718	89.89	1001.56	34.46	34.05
29	26	26	5.718	97.95	1010.48	33.71	34.46
30	2	1	5.718	87.26	991.94	35.15	34.46
31	3	2	5.718	93.42	1009.66	33.49	35.15

so far. Note that the program always goes through all 27 cases for each search. In the first search, it finds the second choice matrix results in a better efficiency than the first. Then the seventh is better than the second. Then the eighth is better than the seventh. Finally the 26th choice matrix is better than the eighth. The 26th choice matrix is a set of multipliers to multiply the base case values of all the optimizable input values to get a trial set (see table 4.1 and appendix A). After trial number 27, the program multiplies choice matrix number 26 by the base case values to get a new set of base case values. The program then applies the 26 choice matrix another time to multiply the base values by to get the trial number 28. This was found to result in a better efficiency. This is a shortcut procedure. We have found by experience that if we had started the search over with choice matrix number 1, we still would have found number 26 to be the best.

Since the shortcut worked once, we try it again. This time (trial number 29) it does not result in a higher efficiency. Therefore, trial number 28 is taken as the base case choice matrix number 1, for the next full search of all possibilities around the new base case.

In table 5.18, the end of this search table is shown. Note that at trial number 212 the test efficiency of 37.34 percent with a pressure of 94.74 bar is found. This is choice matrix number 19. Applying this choice matrix once more in trial number 221 does not result in a better efficiency. After trial number 220, a new base case input value set is calculated from the old set by multiplying by choice matrix number 19. This new base case was found to be better than any combination, up or down of the three adjustable variables (27 possibilities). Therefore, the optimum value has been found. The final values for he adjustable inputs and the itemized losses are shown in table 5.19. Table 5.20 summarizes and identifies the beginning and ending values. Note that the optimization search increases efficiency by 5.6 percentage points by tripling the radial thickness of the regenerator to allow a much larger flow area, reducing the porosity somewhat and halving the wire diameter.

It should be mentioned that the best efficiency of 37.37 percent found in table 5.18 does not get duplicated in table 5.19 when the best case is recalculated. The reason for this is the pressure for the best case was not saved and reentered. This was done in the calculated motion optimizing sessions.

5.3.2 Specified motion - four adjustable inputs. - To do this case the following inputs need to be changed or checked over the last one:

Number 17 Number of adjustable variables to 4
Number 104 Fourth optimizable variable to 12

Table 5.21 shows the first and last part of the optimization search table. It works the same as the previous case except there are 81 choice matrices to search through instead of 27.

Table 5.22 shows the optimized results for this case. Table 5.23 shows how these four variables changed due to optimization. All other variables are made to be the same. Only the pressure changes to adjust the power to near the target power. Note that 6.8 percentage points are gained by increasing the radial thickness (flow area) by a factor of four and decreasing the regenerator length by a factor of five and by decreasing the wire diameter by a factor of six. At this point, nothing is said about how the pressure vessel for the

Table 5.18

LAST PART OF OPTIMUM SEARCH TABLE
SPECIFIED - THREE VARIABLES

212	19	1	5.718	94.74	1002.78	37.37	37.34
213	20	19	5.718	96.59	1001.61	37.35	37.37
214	21	19	5.718	92.43	995.64	37.27	37.37
215	22	19	5.718	93.24	1000.44	37.05	37.37
216	23	19	5.718	95.82	1001.29	36.91	37.37
217	24	19	5.718	90.62	996.96	37.14	37.37
218	25	19	5.718	99.10	1014.42	36.77	37.37
219	26	19	5.718	99.09	999.98	36.80	37.37
220	27	19	5.718	96.68	995.81	36.36	37.37
221	19	19	5.718	96.23	999.48	37.24	37.37
222	2	1	5.718	96.46	1000.20	37.34	37.37
223	3	1	5.718	92.45	995.78	37.27	37.37
224	4	1	5.718	93.24	1000.44	37.05	37.37
225	5	1	5.718	95.82	1001.29	36.91	37.37
226	6	1	5.718	90.62	996.96	37.14	37.37
227	7	1	5.718	99.10	1014.42	36.77	37.37
228	8	1	5.718	99.09	999.98	36.80	37.37
229	9	1	5.718	96.68	995.81	36.36	37.37
230	10	1	5.718	92.94	997.06	37.32	37.37
231	11	1	5.718	95.42	1001.85	37.29	37.37
232	12	1	5.718	91.04	996.12	37.31	37.37
233	13	1	5.718	92.60	1000.73	36.73	37.37
234	14	1	5.718	95.19	1001.10	36.56	37.37
235	15	1	5.718	89.92	997.42	36.85	37.37
236	16	1	5.718	96.41	1009.30	37.03	37.37
237	17	1	5.718	97.09	1000.82	37.06	37.37
238	18	1	5.718	94.17	995.68	36.75	37.37
239	19	1	5.718	96.51	1002.75	37.26	37.37
240	20	1	5.718	98.24	1001.79	37.29	37.37
241	21	1	5.718	94.34	995.11	37.09	37.37
242	22	1	5.718	94.11	999.85	37.30	37.37
243	23	1	5.718	96.69	1001.55	37.20	37.37
244	24	1	5.718	91.60	996.40	37.34	37.37
245	25	1	5.718	102.91	1023.16	36.36	37.37
246	26	1	5.718	101.74	998.07	36.36	37.37
247	27	1	5.718	100.13	996.68	35.79	37.37

CURRENT OPERATING CONDITIONS ARE:

01=	94.741	02=	2	03=	600.000	04=	40.000	05=	49.600
06=	2.700	07=	2.600	08=	0	09=	1	10=	1.000
11=	0	12=	.000	13=	1.000	14=	1	15=	1
16=	1	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	22	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	1.5521	64=	46.7727
65=	66.9506	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0000	76=	1.0000	77=	3.0000	78=	1.0000	79=	4.0000
80=	20.0000	81=	.0100	82=	.1000	83=	.0050	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0

Table 5.19

```
 ENTERED PRINT ROUTINE AFTER    247 OPT. VARIABLE COMBINATIONS
                               495 TOTAL INPUT CASES
                              4114 TOTAL CYCLES
NUMBER OF CYCLES FOR LAST CASE WAS      8
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN      .0050
                   RUN#  1    FOR
                   SUNPOWER RE1000 ENGINE
                   SPECIFIED MOTIONS
                   ISOTHERMAL ANALYSIS WITH CORRECTIONS
                   MARTINI LOSS EQUATIONS

THE ORDER IN WHICH THE OPTIMIZATION NUMBERS ARE TESTED IS:
 13  15  14   0   0   0   0   0   0   0   0   0   0   0   0

FINAL VALUES FOR CHANGABLE INPUT BY OPTIMIZATION #
         OPTIMIZATION #         VALUE
              13                1.5521
              15               66.9506
              14               46.7727

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70       CHRG. PRESS., BAR  =      94.74
HEAT IN, DEG C =     600.00       HEAT OUT, DEG. C   =      40.00
W. GAS 1=H2,2=HE,3=AIR 2          PHASE ANG. DEGREES =      49.60
POWER P.STR,CM =       2.70       DISPL. STROKE, CM  =       2.60
CALC.FREQ., HZ =      29.70       TIME STEPS/CYCLE   =      24.00

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                      HEAT REQUIREMENT, WATTS
  BASIC                1252.2024    BASIC                  2041.1550
  ADIABATIC CORR.       -52.0053    ADIABATIC CORR.         104.1847
  HEATER FLOW LOSS      -97.4405    REHEAT                  185.5717
  REGEN.FLOW LOSS       -94.4209    SHUTTLE                 107.6520
  COOLER FLOW LOSS       -5.5529    PUMPING                   7.2932
  INDICATED            1002.7828    TEMP. SWING                .1843
                                    CYL. WALL COND.         254.6543
                                    DISPLCR WALL COND.       34.7119
--------------------------------    REGEN. WALL COND.        62.7014
INDICATED EFFICIENCY, %  37.37      CYL. GAS COND.            6.2609
                                    REGEN. MTX. COND.        18.7517
--------------------------------    RAD.INSIDE DISPL.         4.9054
EXP.SP.EFFECT.TEMP.,C   580.49      FLOW FRIC. CREDIT      -144.6510
COMP.SP.EFFECT.TEMP.,C   48.78      TOTAL HEAT TO ENG.     2683.3756
```

TABLE 5.20
RESULTS OF OPTIMIZATION SPECIFIED MOTION - THREE VARIABLES

Optimization number	Identity	Units	Original values	Final values
13	Radial thickness of regenerator	cm	0.554	1.5521
15	Porosity of matrix	%	75.9	66.9506
14	Diameter of wire in matrix	Microns	88.9	46.7727
	Efficiency	%	31.63	37.37

Table 5.21

FIRST AND LAST PART OF OPTIMUM SEARCH TABLE
SPECIFIED MOTION - FOUR ADJUSTABLE VARIABLES
SEARCH FOR OPTIMUM

The number of active optimization numbers is: 4
The order in which the optimization numbers are tested is:
13 15 14 12 0 0 0 0 0 0 0 0 0 0 0

Trial Num.	Ch.Mx.#	Best#	Cyl.D.cm	Pavg.Bar	Pwr.W	Eff. %	Bst.Eff.%
1	1	1	5.718	81.96	1010.48	31.63	31.63
2	2	1	5.718	80.89	999.09	31.91	31.63
3	3	2	5.718	81.77	1000.88	31.18	31.91
4	4	2	5.718	80.22	998.83	27.34	31.91
5	5	2	5.718	80.64	1000.31	27.50	31.91
6	6	2	5.718	80.14	999.60	27.12	31.91
7	7	2	5.718	84.68	1005.42	33.24	31.91
8	8	7	5.718	83.15	998.43	33.74	33.24
9	9	8	5.718	86.13	1003.82	32.53	33.74
10	10	8	5.718	80.27	995.21	30.81	33.74
11	11	8	5.718	80.56	1000.24	31.10	33.74
12	12	8	5.718	81.04	1000.46	30.45	33.74
13	13	8	5.718	80.31	999.46	26.16	33.74
14	14	8	5.718	80.74	1000.31	26.29	33.74
15	15	8	5.718	80.11	999.50	25.96	33.74
16	16	8	5.718	83.30	1003.56	32.88	33.74
17	17	8	5.718	82.17	998.90	33.33	33.74
18	18	8	5.718	84.50	1002.80	32.26	33.74
19	19	8	5.718	81.75	997.44	32.33	33.74
20	20	8	5.718	81.57	999.83	32.70	33.74
21	21	8	5.718	82.79	1001.29	31.85	33.74
22	22	8	5.718	80.24	998.06	28.57	33.74
23	23	8	5.718	80.64	1000.30	28.75	33.74
24	24	8	5.718	80.33	999.73	28.32	33.74
25	25	8	5.718	86.56	1008.06	33.48	33.74
26	26	8	5.718	84.46	997.73	34.05	33.74
27	27	26	5.718	88.33	1005.35	32.66	34.05
28	28	26	5.718	82.12	994.63	31.79	34.05
29	29	26	5.718	82.31	1000.16	32.14	34.05
30	30	26	5.718	83.21	1000.92	31.35	34.05
31	31	26	5.718	81.16	998.48	27.78	34.05
32	32	26	5.718	81.64	1000.35	27.93	34.05
963	63	1	5.718	79.65	1001.92	37.68	38.42
964	64	1	5.718	75.15	994.86	38.30	38.42
965	65	1	5.718	75.96	1000.94	38.29	38.42
966	66	1	5.718	75.23	999.07	38.32	38.42
967	67	1	5.718	74.55	999.38	37.44	38.42
968	68	1	5.718	75.29	1000.66	37.34	38.42
969	69	1	5.718	73.93	998.71	37.53	38.42
970	70	1	5.718	78.39	1007.91	38.14	38.42
971	71	1	5.718	77.71	998.94	38.13	38.42
972	72	1	5.718	78.21	1000.92	37.92	38.42
973	73	1	5.718	76.74	997.92	38.40	38.42
974	74	1	5.718	77.14	1000.55	38.41	38.42
975	75	1	5.718	76.84	999.54	38.33	38.42
976	76	1	5.718	74.96	998.12	38.10	38.42
977	77	1	5.718	75.72	1000.75	38.02	38.42
978	78	1	5.718	74.52	998.71	38.17	38.42
979	79	1	5.718	81.81	1016.50	37.72	38.42
980	80	1	5.718	80.05	996.67	37.70	38.42
981	81	1	5.718	81.63	1003.67	37.31	38.42

Table 5.22

PRINTOUT OF OPTIMIZED DESIGN
SPECIFIED MOTION - FOUR ADJUSTABLE VARIABLES

CURRENT OPERATING CONDITIONS ARE:

01=	77.170	02=	2	03=	600.000	04=	40.000	05=	49.600
06=	2.700	07=	2.600	08=	0	09=	1	10=	1.000
11=	0	12=	.000	13=	1.000	14=	1	15=	1
16=	1	17=	4	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	22	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	1.3272	63=	2.0247	64=	14.8260
65=	73.6457	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0000	76=	1.0000	77=	3.0000	78=	1.0000	79=	4.0000
80=	20.0000	81=	.0100	82=	.1000	83=	.0050	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	12
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0								

```
ENTERED PRINT ROUTINE AFTER    981 OPT. VARIABLE COMBINATIONS
                              1963 TOTAL INPUT CASES
                             17854 TOTAL CYCLES
NUMBER OF CYCLES FOR LAST CASE WAS    10
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN       .0050
                   RUN#  1    FOR
                   SUNPOWER RE1000 ENGINE
                   SPECIFIED MOTIONS
                   ISOTHERMAL ANALYSIS WITH CORRECTIONS
                   MARTINI LOSS EQUATIONS

THE ORDER IN WHICH THE OPTIMIZATION NUMBERS ARE TESTED IS:
 13  15  14  12   0   0   0   0   0   0   0   0   0   0   0

FINAL VALUES FOR CHANGABLE INPUT BY OPTIMIZATION #
         OPTIMIZATION #          VALUE
              13                2.0247
              15               73.6457
              14               14.8260
              12                1.3272

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70        CHRG. PRESS., BAR   =      77.17
HEAT IN, DEG C =     600.00        HEAT OUT, DEG. C    =      40.00
W. GAS 1=H2,2=HE,3=AIR 2           PHASE ANG. DEGREES  =      49.60
POWER P.STR,CM =       2.70        DISPL. STROKE, CM   =       2.60
CALC.FREQ., HZ =      29.70        TIME STEPS/CYCLE    =      24.00

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                       HEAT REQUIREMENT, WATTS
  BASIC                1201.0909     BASIC                     1974.8192
  ADIABATIC CORR.       -52.5440     ADIABATIC CORR.            100.4631
  HEATER FLOW LOSS      -84.1675     REHEAT                     122.0498
  REGEN.FLOW LOSS       -60.3180     SHUTTLE                    106.2553
  COOLER FLOW LOSS       -3.5367     PUMPING                      6.8512
  INDICATED            1000.5247     TEMP. SWING                  1.1423
                                     CYL. WALL COND.            277.2513
                                     DISPLCR WALL COND.          34.2616
--------------------------------     REGEN. WALL COND.           61.8880
INDICATED EFFICIENCY, %  38.42       CYL. GAS COND.               6.1797
                                     REGEN. MTX. COND.           22.2208
--------------------------------     RAD.INSIDE DISPL.            4.8352
EXP.SP.EFFECT.TEMP.,C   577.75       FLOW FRIC. CREDIT         -114.3265
COMP.SP.EFFECT.TEMP.,C   52.87       TOTAL HEAT TO ENG.        2603.8910
```

 C-2

TABLE 5.23
RESULTS OF OPTIMIZATION SPECIFIED MOTION - FOUR VARIABLES

Optimization number	Identity	Units	Original values	Final values
13	Radial thickness of regenerator	cm	0.554	2.0247
15	Porosity of matrix	%	75.9	73.6457
14	Diameter of wire in matrix	Microns	88.9	14.826
12	Regenerator length in direction of flow	cm	6.446	1.3272
	Efficiency	%	31.63	38.42

engine could be designed or whether such fine wire is practical (15 μm = 0.0006 in.). Fully completed optimization programs should have practical limitations set based upon engine design and availability of materials.

In comparison of tables 5.20 and 5.23, one sees that simply by including the length of the regenerator, we optimize to quite a different looking engine but gain very little in efficiency. One needs to combine optimization searches with common sense.

5.3.3 Calculated motion - three adjustable inputs. - To do this case the following inputs need to be checked or changed over the last one:

Number 10 Time step to 0.2 msec
Number 14 Engine load to four
Number 15 Method of calculation to two
Number 17 Number of adjustable variables to three
Number 75 Alternator constant to 0.02 $N/(cm/sec)^2$

Table 5.24 shows the first and last part of the optimization search table. The important difference to note here is target power can be missed by ±20 percent instead of about ±1 percent specified motion case. This is contrary to tests shown in figures 5.1 and 5.2 where indicated power is nearly exactly proportional to charge pressure for the same mode of calculation, calculated motion and linear generator. The variation is almost too large.

Table 5.25 shows the optimized results for this case with a list of itemized losses.

Table 5.26 shows how these three adjustable inputs change as the optimum is searched. Note that the search predicts a 6.0 percentage point increase in efficiency by increasing the radial thickness by 66 percent, decreasing the porosity and increasing the wire diameter. These last two trends are opposite those found in the last two optimization searches. (The final porosity is not easy to attain--close packed spheres have 40 percent porosity.) We need a flow loss equation that will take this into account.

5.3.4 Calculated motion - four adjustable inputs. - To do this case the following inputs need to be changed:

Number 10 Time step to 0.1 msec
Number 17 Number of optimizable variables to four
Number 104 Fourth optimizable variable to be variable number 12

Table 5.27 shows the first and last part of the optimum search table. The same wide variation in powers is noted. The original example as calculated by W. Martini was done with a time step of 0.25 msec. W. Martini modified the program to calculate a more consistent target power but he could only get the simulation to run for 37 trials. When the program was converted to double precision this case would stop working on the 187th trial. It was necessary to decrease the time step to 0.1 msec to allow the program to complete and output results. Table 5.28 shows these results. Table 5.29 shows the initial and final values for the four optimized variables.

Table 5.24

FIRST AND LAST PART OF OPTIMUM SEARCH TABLE
CALCULATED MOTION - THREE ADJUSTABLE VARIABLES

SEARCH FOR OPTIMUM

The number of active optimization numbers is: 3
The order in which the optimization numbers are tested is:
13 15 14 0 0 0 0 0 0 0 0 0 0 0 0

Trial Num.	Ch.Mx.#	Best#	Cyl.D.cm	Pavg.Bar	Pwr.W	Eff. %	Bst.Eff.%
1	1	1	5.718	48.48	1013.62	29.36	29.36
2	2	1	5.718	46.80	988.46	29.31	29.36
3	3	1	5.718	51.67	1036.02	29.41	29.36
4	4	3	5.718	44.12	956.32	25.77	29.41
5	5	3	5.718	45.76	1001.19	25.89	29.41
6	6	3	5.718	45.44	982.90	25.70	29.41
7	7	3	5.718	68.89	1051.69	32.35	29.41
8	8	7	5.718	58.75	1016.07	31.88	32.35
9	9	7	5.718	76.49	992.56	32.24	32.35
125	14	1	5.718	61.17	993.15	33.83	35.47
126	15	1	5.718	83.73	1040.76	34.79	35.47
127	16	1	5.718	152.32	1321.23	35.42	35.47
128	17	1	5.718	99.70	923.40	34.83	35.47
129	18	1	5.718	154.00	1132.57	34.91	35.47
130	19	1	5.718	120.18	1030.85	35.28	35.47
131	20	1	5.718	102.49	909.17	34.73	35.47
132	21	1	5.718	159.78	1121.92	34.83	35.47
133	22	1	5.718	98.55	1090.72	35.39	35.47
134	23	1	5.718	79.18	928.39	34.72	35.47
135	24	1	5.718	118.74	1099.40	35.22	35.47
136	25	1	5.718	204.75	1283.77	34.71	35.47
137	26	1	5.718	135.86	900.69	34.32	35.47
138	27	1	5.718	222.62	1143.86	33.88	35.47

Table 5.25

PRINTOUT OF OPTIMIZED DESIGN
CALCULATED MOTION - THREE ADJUSTABLE INPUTS

CURRENT OPERATING CONDITIONS ARE:

01=	109.221	02=	2	03=	600.000	04=	40.000	05=	88.648
06=	2.616	07=	1.885	08=	0	09=	0	10=	.200
11=	0	12=	.000	13=	1.000	14=	4	15=	2
16=	1	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	22	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.8761	64=	94.8855
65=	44.8182	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0200	76=	1.0000	77=	3.0000	78=	1.0000	79=	4.0000
80=	20.0000	81=	.0100	82=	.1000	83=	.0050	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0								

Table 5.25 Concluded

```
 ENTERED PRINT ROUTINE AFTER    138 OPT. VARIABLE COMBINATIONS
                               277 TOTAL INPUT CASES
                              2363 TOTAL CYCLES
NUMBER OF CYCLES FOR LAST CASE WAS      6
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN       .0050
                   RUN#  0    FOR
                   SUNPOWER RE1000 ENGINE
                   FREE MOTIONS -- LINEAR ALTERNATOR
                        LOAD CONSTANT =     .020 N/(CM/SEC)**2.
                   ISOTHERMAL ANALYSIS WITH CORRECTIONS
                   MARTINI LOSS EQUATIONS

THE ORDER IN WHICH THE OPTIMIZATION NUMBERS ARE TESTED IS:
 13  15  14   0   0   0   0   0   0   0   0   0   0   0   0

FINAL VALUES FOR CHANGABLE INPUT BY OPTIMIZATION #
         OPTIMIZATION #        VALUE
              13                .8761
              15              44.8182
              14              94.8855

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70       CHRG. PRESS., BAR    =    109.22
HEAT IN, DEG C =     600.00       HEAT OUT, DEG. C     =     40.00
W. GAS 1=H2,2=HE,3=AIR 2          PHASE ANG. DEGREES =      88.65
POWER P.STR,CM =       2.62       DISPL. STROKE, CM    =      1.89
CALC.FREQ., HZ =      30.57       TIME STEPS/CYCLE     =    163.54

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                      HEAT REQUIREMENT, WATTS
  BASIC                1553.5208    BASIC                   2568.2358
  ADIABATIC CORR.       -65.8808    ADIABATIC CORR.          130.9153
  HEATER FLOW LOSS      -89.8186    REHEAT                   235.7924
  REGEN.FLOW LOSS      -285.0101    SHUTTLE                   56.1540
  COOLER FLOW LOSS       -6.9309    PUMPING                   19.1353
  INDICATED            1105.8803    TEMP. SWING                 .2201
                                    CYL. WALL COND.          215.4641
                                    DISPLCR WALL COND.        34.4467
--------------------------------    REGEN. WALL COND.         62.2223
INDICATED EFFICIENCY, %  35.47      CYL. GAS COND.             6.2131
                                    REGEN. MTX. COND.         16.3832
--------------------------------    RAD.INSIDE DISPL.          4.8287
EXP.SP.EFFECT.TEMP.,C   577.81      FLOW FRIC. CREDIT       -232.3236
COMP.SP.EFFECT.TEMP.,C   49.23      TOTAL HEAT TO ENG.      3117.6875
```

TABLE 5.26
RESULTS OF OPTIMIZATION CALCULATED MOTION - THREE VARIABLES
[Linear alternator load]

Optimization number	Identity	Units	Original values	Final values
13	Radial thickness of regenerator	cm	0.544	.8761
15	Porosity of matrix	%	75.9	44.8182
14	Diameter of wire in matrix	Microns	88.9	94.8855
	Efficiency	%	29.36	35.47

Table 5.27

SEARCH FOR OPTIMUM

The number of active optimization numbers is: 4
The order in which the optimization numbers are tested is:
13 15 14 12 0 0 0 0 0 0 0 0 0 0 0

Trial Num.	Ch.Mx.#	Best#	Cyl.D.cm	Pavg.Bar	Pwr.W	Eff. %	Bst.Eff.%
1	1	1	5.718	48.39	1011.34	29.36	29.36
2	2	1	5.718	46.81	985.36	29.30	29.36
3	3	1	5.718	51.67	1036.06	29.43	29.36
4	4	3	5.718	44.07	951.82	25.75	29.43
5	5	3	5.718	46.24	1021.47	25.91	29.43
6	6	3	5.718	45.86	996.42	25.71	29.43
7	7	3	5.718	68.55	1049.10	32.37	29.43
8	8	7	5.718	58.63	1015.50	31.88	32.37
9	9	7	5.718	76.38	993.29	32.29	32.37
10	10	7	5.718	45.23	948.25	28.48	32.37
11	11	7	5.718	47.28	1020.72	28.77	32.37
12	12	7	5.718	48.65	1005.15	28.60	32.37
13	13	7	5.718	44.57	972.91	24.83	32.37
14	14	7	5.718	45.32	996.39	24.92	32.37
15	15	7	5.718	45.91	1005.99	24.76	32.37
16	16	7	5.718	59.00	1000.85	31.36	32.37
17	17	7	5.718	52.66	998.93	30.87	32.37
18	18	7	5.718	69.29	1028.81	31.76	32.37
19	19	7	5.718	51.93	1030.18	30.07	32.37
20	20	7	5.718	47.43	975.34	29.90	32.37
21	21	7	5.718	56.32	1011.03	30.40	32.37
22	22	7	5.718	43.53	924.33	26.63	32.37
23	23	7	5.718	46.87	1028.88	26.88	32.37
24	24	7	5.718	46.19	993.06	26.70	32.37
25	25	7	5.718	78.60	1041.86	33.01	32.37
26	26	25	5.718	66.67	1031.16	32.86	33.01
27	27	25	5.718	86.36	985.19	32.90	33.01
28	28	25	5.718	53.35	1070.29	29.75	33.01
29	29	25	5.718	47.44	960.11	29.44	33.01
30	30	25	5.718	55.03	1007.51	29.84	33.01
31	31	25	5.718	44.66	943.07	26.09	33.01
32	32	25	5.718	47.32	1022.78	26.21	33.01
33	33	25	5.718	46.73	998.69	26.13	33.01
34	34	25	5.718	74.17	1029.71	32.56	33.01
394	67	1	5.718	67.20	1085.00	34.46	36.21
395	68	1	5.718	54.54	860.80	32.83	36.21
396	69	1	5.718	97.13	1316.34	35.40	36.21
397	70	1	5.718	108.62	1085.11	35.85	36.21
398	71	1	5.718	85.64	832.11	34.64	36.21
399	72	1	5.718	156.57	1350.12	35.75	36.21
400	73	1	5.718	104.08	899.61	35.37	36.21
401	74	1	5.718	98.47	962.64	35.67	36.21
402	75	1	5.718	151.67	1242.72	35.94	36.21
403	76	1	5.718	86.35	981.96	35.41	36.21
404	77	1	5.718	75.33	888.52	34.72	36.21
405	78	1	5.718	123.22	1273.33	36.20	36.21
406	79	1	5.718	164.40	1256.85	36.11	36.21
407	80	1	5.718	111.92	754.10	34.38	36.21
408	81	1	5.718	234.62	1416.26	34.95	36.21

Table 5.28

```
1 ENTERED PRINT ROUTINE AFTER   408 OPT. VARIABLE COMBINATIONS
                                817 TOTAL INPUT CASES
                               7183 TOTAL CYCLES
 NUMBER OF CYCLES FOR LAST CASE WAS      7     ,
 FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
 IN AND POWER OUT HAS BEEN LESS THAN       .0050
                       RUN#  1    FOR
                       SUNPOWER RE1000 ENGINE
                       FREE MOTIONS -- LINEAR ALTERNATOR
                           LOAD CONSTANT =     .020 N/(CM/SEC)**2.
                       ISOTHERMAL ANALYSIS WITH CORRECTIONS
                       MARTINI LOSS EQUATIONS

 THE ORDER IN WHICH THE OPTIMIZATION NUMBERS ARE TESTED IS:
  13   15   14   12    0    0    0    0    0    0    0    0    0    0    0

 FINAL VALUES FOR CHANGABLE INPUT BY OPTIMIZATION #
       OPTIMIZATION #        VALUE
             13               .7965
             15             36.3027
             14            115.9712
             12              4.6056

 OPERATING CONDITIONS ARE:
 SPEC.FREQ., HZ =      29.70     CHRG. PRESS., BAR  =     114.19
 HEAT IN, DEG C =     600.00     HEAT OUT, DEG. C   =      40.00
 W. GAS 1=H2,2=HE,3=AIR 2        PHASE ANG. DEGREES =      85.69
 POWER P.STR,CM =       2.55     DISPL. STROKE, CM  =       1.78
 CALC.FREQ., HZ =      31.75     TIME STEPS/CYCLE   =     314.91

 COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
 POWER, WATTS                     HEAT REQUIREMENT, WATTS
   BASIC              1621.7096     BASIC                    2686.5611
   ADIABATIC CORR.     -70.1346     ADIABATIC CORR.           138.3823
   HEATER FLOW LOSS    -89.4897     REHEAT                    287.6481
   REGEN.FLOW LOSS    -261.6603     SHUTTLE                    50.0445
   COOLER FLOW LOSS     -5.3216     PUMPING                    20.6800
   INDICATED          1195.1034     TEMP. SWING                  .2828
                                    CYL. WALL COND.           210.6503
                                    DISPLCR WALL COND.         34.3773
---------------------------------   REGEN. WALL COND.          62.0969
 INDICATED EFFICIENCY, %   36.21    CYL. GAS COND.              6.2006
                                    REGEN. MTX. COND.          18.9148
---------------------------------   RAD.INSIDE DISPL.           4.8199
 EXP.SP.EFFECT.TEMP.,C   576.90     FLOW FRIC. CREDIT        -220.3199
 COMP.SP.EFFECT.TEMP.,C   50.30     TOTAL HEAT TO ENG.       3300.3387

1
```

TABLE 5.29 - RESULTS OF OPTIMIZATION CALCULATED MOTION - FOUR ADJUSTABLE INPUTS

[Linear Alternator Load]

Optimization number	Identity	Units	Original values	Final values
13	Radial thickness of regenerator	cm	0.554	0.7965
15	Porosity of matrix	%	75.9	36.303
14	Diameter of wire in matrix	Microns	88.9	115.97
12	Length of regenerator	cm	6.446	4.606
	Efficiency	%	29.70	36.21

5.3.5 Comments on optimization searches. - The program can do optimization searches for both specified motion and calculated motion options as required by contract. However, the program still needs to be improved in a number of respects to be of practical use in Stirling engine design. Suggestions for improvements are discussed below.

5.3.5.1 Closer approach to constant power: The provision of having just two cases per trial number, with the first case used to set the charge pressure for the second, works well for specified motion but poorly for calculated motion. A second method needs to be added in order to zero in on the target power efficiently. The target power cannot be obtained exactly because of the jitter in the solution. Figure 5.12 shows the results of some calculations aimed at finding the exact pressure that will give exactly 1000 W of power. Note that when the scale is greatly expanded, and when enough trials are made, one can see that even with a fairly small time step and an apparently tight convergence, there is still some jitter in the solution. One must make the window around the target power large enough so that the solution can find it.

Table 5.30 compares the results plotted in Figure 5.12. Note the very high value calculated with 11 cycles and the low values calculated with 7 cycles. Apparently, there needs to be more cycles and a closer approach to steady state.

A new series was done with a convergence criteria of 0.001 instead of 0.005. This series is summarized in table 5.31 and graphed in figure 5.13. Note the jitter is gone but it makes a lot of difference whether 24 or 25 cycles are used to find the solution. The convergence criteria still is not tight enough.

These observations substantiate the data given in table 5.1. Most runs in Section 5 were done at a convergence criteria of 0.005 knowing that the power would be calculated low but the computation time would be small.

The effect of an even smaller convergence criteria will be discussed in Section 5.4.

5.3.5.2 Provision for no solution: In the calculated motion mode some cases will stop operating or after a few cycles never complete the next cycle. Provisions must be added to the program to stop such cases and ignore them in searching for the optimum.

5.3.5.3 Limitation on porosity: The heat transfer and flow loss equations need to be improved to adequately take into account the porosity of the matrix and make it impossible to choose unreasonable matrix porosities.

5.3.5.4 Limitation on dimensions: In the limited experience so far obtained with optimization searches, an "optimum" design was found to have a regenerator with a very large face area and a very short flow path. It would be difficult to enclose such a regenerator. As the optimization search is extended to other parts of the engine similar difficulties may arise. These mechanical constraints need to be written into the program.

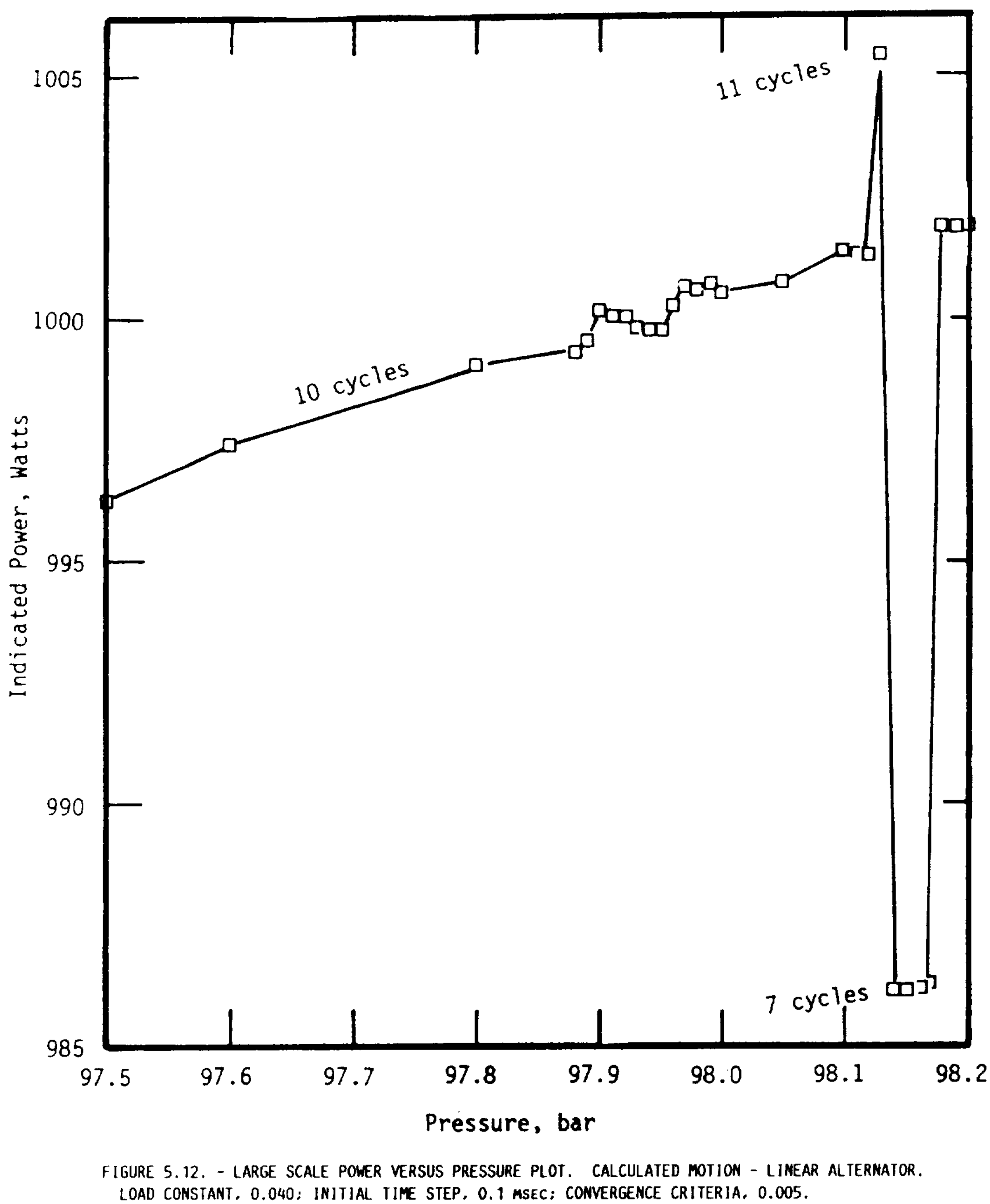

FIGURE 5.12. - LARGE SCALE POWER VERSUS PRESSURE PLOT. CALCULATED MOTION - LINEAR ALTERNATOR. LOAD CONSTANT, 0.040; INITIAL TIME STEP, 0.1 MSEC; CONVERGENCE CRITERIA, 0.005.

Table 5.30

EFFECT OF PRESSURE ON COMPUTED RESULTS
CALCULATED MOTION - LINEAR ALTERNATOR
Load Constant = 0.040 N/(cm/sec)^2,
Initial Time Step = 0.1 msec,
Convergence Criteria = 0.005

Pressure Bar	Indicated Power Watts	# Cycle to Solution	Indicated Efficiency	Calculated Freq. Hz	Final Time msec
97.50	999.3268	10	27.81	29.22	0.1
97.60	997.3368	10	27.82	29.23	0.1
97.80	999.0834	10	27.82	29.26	0.1
97.88	999.3170	10	27.80	29.28	0.1
97.89	999.6638	10	27.82	29.27	0.1
97.90	1000.2170	10	27.81	29.27	0.1
97.91	1000.1320	10	27.81	29.28	0.1
97.92	1000.1190	10	27.81	29.28	0.1
97.93	999.8864	10	27.80	29.28	0.1
97.94	999.8163	10	27.81	29.29	0.1
97.95	999.8077	10	27.79	29.29	0.1
97.96	1000.3810	10	27.82	29.29	0.1
97.97	1000.7230	10	27.81	29.29	0.1
97.98	1000.6570	10	27.81	29.29	0.1
97.99	1000.7170	10	27.80	29.29	0.1
98.00	1000.6160	10	27.81	29.29	0.1
98.05	1000.8140	10	27.80	29.30	0.1
98.10	1001.3980	10	27.80	29.31	0.1
98.11	1001.3400	10	27.80	29.31	0.1
98.12	1001.3660	10	27.80	29.31	0.1
98.13	1005.4270	11	27.85	29.30	0.1
98.14	986.2051	7	27.70	29.36	0.1
98.15	986.2258	7	27.69	29.36	0.1
98.16	986.2603	7	27.69	29.37	0.1
98.17	986.3230	7	27.68	29.37	0.1
98.18	1001.9550	10	27.79	29.32	0.1
98.19	1001.9790	10	27.79	29.32	0.1
98.20	1001.9090	10	27.79	29.32	0.1

Table 5.31

EFFECT OF PRESSURE ON COMPUTED RESULTS
(Same Case as Table 5.34 except
Convergence Criteria = 0.001

Pressure Bar	Indicated Power Watts	# Cycle to Solution	Indicated Efficiency	Calculated Freq. Hz	Final Time msec
94.80	998.4567	24	28.10	28.78	0.025
94.90	999.3182	24	28.10	28.80	0.025
94.96	999.7576	24	28.10	28.81	0.025
94.97	999.9558	24	28.10	28.81	0.025
94.98	1000.7030	25	28.10	28.81	0.025
94.99	1000.0710	24	28.10	28.81	0.025
95.00	1000.1530	24	28.10	28.81	0.025
95.01	1000.8860	25	28.10	28.81	0.025
95.02	1000.3180	24	28.09	28.82	0.025
95.03	1000.3940	24	28.09	28.82	0.025
95.04	1001.2340	25	28.10	28.82	0.025
95.05	1000.5580	24	28.10	28.82	0.025
95.06	1000.7570	24	28.09	28.82	0.025
95.07	1001.4760	25	28.10	28.82	0.025
95.08	1000.8580	24	28.09	28.82	0.025
95.09	1001.6090	25	28.10	28.83	0.025
95.10	1001.0080	24	28.10	28.83	0.025
95.20	1002.4990	25	28.09	28.84	0.025

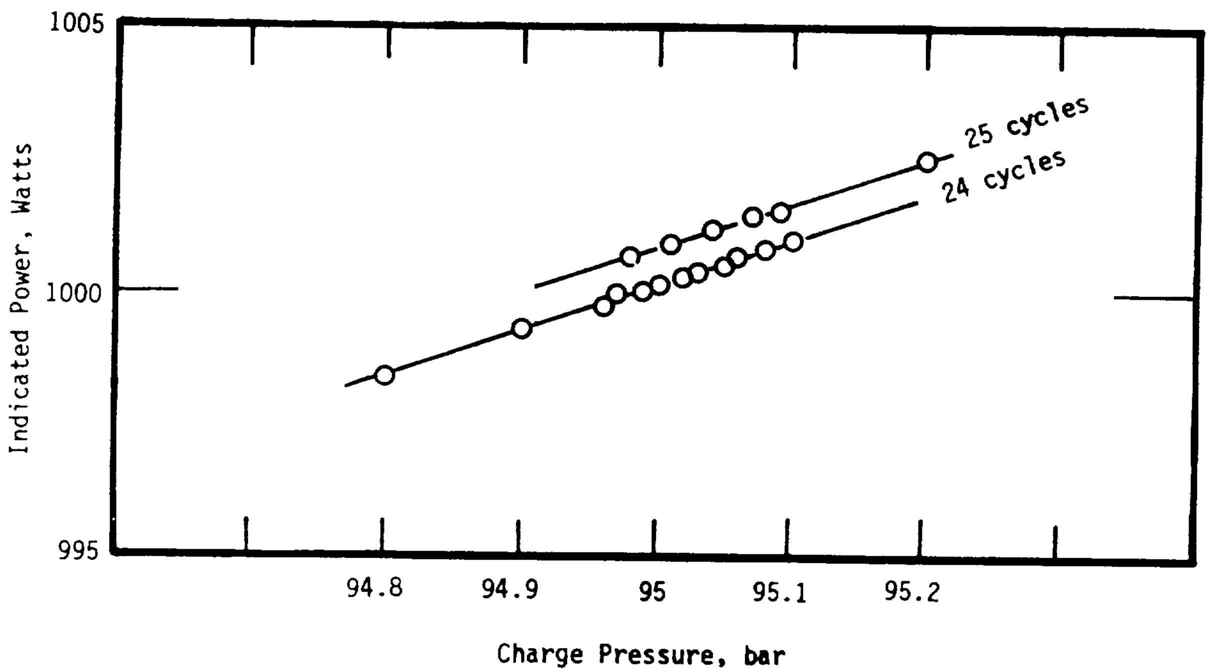

FIGURE 5.13. - LARGE SCALE POWER VERSUS PRESSURE PLOT. (SAME CASE AS FIG. 5.12 EXCEPT CONVERGENCE CRITERIA, 0.001.)

5.4 Effect of Leakage

In Section 5.3.5.1, we found it takes a very long time to reach a steady operating point. In investigating this property of the computer program, some interesting observations were made concerning leakage.

In the standard program, the following adjustments are made in the working gas inventory:

(1) Arbitrary adjustment at the end of each cycle to make average working gas pressure and average bounce space pressure equal
(2) Leakage through displacer centering port
(3) Leakage through power piston centering port
(4) Leakage through displacer rod seal

5. Leakage through power piston seal

Tests were run to separate some of these effects. The results of tests are summarized in table 5.32 and in figure 5.14.

We found that the pressure adjustment by itself was adding gas to the working gas at a constant rate. This adjustment was cut back just for this test to be only the first four cycles when it is really needed. With this feed removed, the normal seal leakage and centering port leakage settles out quicker and at a lower power.

Keeping the pressure adjustment cut back to the first four cycles, we investigated what part of the leakage was having an effect. When the seal leakage was stopped and the centering port leakage was allowed to remain the power increased. This needs to be looked into thoroughly because this centering port should draw off power. We found that when the centering port leakage was made large, that the engine pressures were adjusted the right way. With the centering ports plugged and the seal leakage at normal values, the power drops as expected. The reason for the peculiar shape of this curve is not understood.

5.5 Computer Time

Converting this program to double precision has increased the computer time required to run the program. Some optimization cases can easily run overnight on an IBM PC/AT. The cases in appendix J were timed to see how much difference in the two versions there is. The single precision version required approximately 20 min to calculate results for these 11 cases and the double precision version took over 50 min for the same 11 cases.

The differences can accumulate rapidly in an optimization problem. Example 5.3.1 takes 44 min to run nearly 500 cases with the double precision version. The single precision version only requires 33 min. Example 5.3.2 required 3 hr to run 1963 total cases with the double precision version. The single precision version ran 1343 cases in 1 hr 40 min. These are all cases which are centered around the base set of conditions. Choosing other options such as the Rios loss equation method for calculating losses can increase the necessary calculation time even more. The base optimization examples were run with the Rios loss equation method and the results using this method are identical to the documented results.

Table 5. 32

EFFECT OF LEAKAGE
95 BAR CHARGE PRESSURE
CALCULATED MOTION - LINEAR GENERATOR
Load Constant, 0.04 N/(cm/sec**2
Convergence Criteria = 0.0001

	Input No.							
Cycles for Pressure Adjust	No.33 F.F. Clear Micron	No.35 D.Rod Clear Micron	No.40 Center Prt.exp. Factors	Cycles to Conv.	Indicated Power Out Watts	Indicated Efficiency %	Calculated Frequency Hz	Final Time Step,msec
Every	33	25.4	10	45	1006.8140	28.16	28.80	0.0125
Every	0.0	0.0	999		did not converge			0.0125
First 4	0.0	0.0	999	15	984.5011	28.44	28.56	0.05
First 4	33	25.4	10	35	990.2820	27.99	28.80	0.0125
First 4	33	25.4	999	31	942.1617	28.06	28.67	0.0125
First 4	0.0	0.0	10	37	1036.3780	28.40	28.70	0.0125

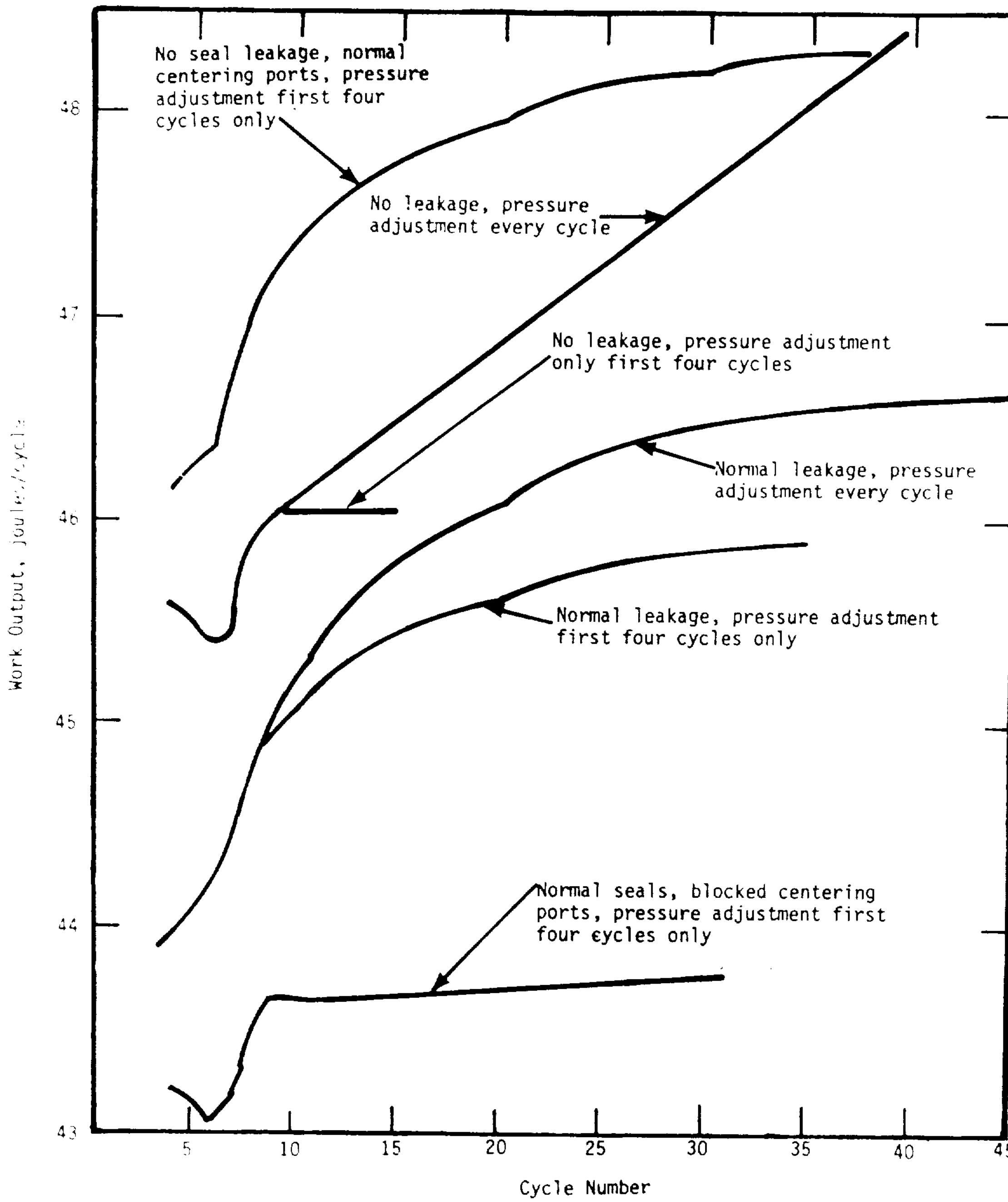

FIGURE 5.14. - EFFECT OF LEAKAGE.

6.0 PROGRAM USERS MANUAL

This program was developed on an IBM personal computer with two double density disk drives, drives A and B, and additional memory. Each diskette drive had a capacity of 315 Kb. The memory was rated at 384 Kb and in addition there was a ram disk (C) which acts as a third rapid access disk drive with a capacity of 251 Kb. The configuration described above worked for the FPSE program which was compiled on it.

In addition to the added memory that this particular IBM personal computer had there was a graphics package which allowed high resolution graphics to be displayed on the IBM monochrome personal computer display. This particular graphics package provided 350 lines by 720 columns. The package was obtained from Orchid Technology, 47790 Westinghouse Drive, Fremont, California 94539. The package included a plug-in board and software for a number of different computer languages which allows the graphics capability to be used very conveniently. This graphics package may not be available now but it is the one that Martini Engineering used. This users manual is exact for the type of computer described above. It would, of course, have to be adapted for other computers, but much of the way of doing things should remain the same.

Sverdrup Technology's IBM PC's are typically equipped with a hard drive and do not have the disk storage limits W. Martini had. This has given us the option of using larger files without running out of space while compiling. The files have been combined as follows:

F1.FOR contains FPSE.FOR and FPIN.FOR
FPIN.FOR replaces F1.FOR, F11.FOR, and F12.FOR
F2A.FOR contains F2.FOR and F21.FOR
F2B.FOR contains F22.FOR through F28.FOR
F3.FOR contains F3.FOR, F4.FOR, F41.FOR, and F42.FOR

Together with SCREEN.ASM these four files contain the 17 source members Martini used with his dual diskette drive system. These programs are distributed on 2 DS-DD diskettes. The source diskette contains the previously mentioned 5 source files, the default input data table, and the SCREEN object and listing files. The program diskette contains an executable version with 2 input files. Initially both files are identical but the program uses INPUT.TBL to store the last case simulated and so this file will change whenever the program is run. MAKE BACKUP COPIES OF BOTH DISKETTES. This program will run on a monochrome, color, or enhanced graphics display, provided the user includes the command 'DEVICE=ANSI.SYS' in the file CONFIG.SYS in his root directory.

First the method of using the compiled program will be described and then the method of modifying the source codes and recompiling will be described.

6.1 Using the Compiled FPSE.EXE

To use this compiled program all one needs is an IBM compatible PC that can read the file from a 5-1/4 in. diskette. Once the computer is on and ready for operation, put the program diskette in the B disk drive. Do a directory of the diskette and you will find three files. One file is FPSE.EXE with a size of 209054 bytes. The other files are INPUT.TBL and DEFLT.TBL and they have a size of 3000 bytes. The file FPSE.EXE contains the executable code. The other two files are the data. The program expects to find the data file on drive B. On a PC with only one floppy diskette drive the program will run from drive A. It is also possible to change the drive designation by modifying the source code in FPSE.FOR. To start the program type B:FPSE and hit the return key. After the program loads into memory it will ask the question 'Bring in last file for more modification?'. If the user answers 'NO' then the default data for the RE-1000 engine will be displayed. If the answer is 'YES' then the last case simulated is displayed on the screen. The user then proceeds to name the variable they wish to change and assign a new value to it. The screen is updated with this new value. When all changes have been made the user enters 'EXIT' and the simulation begins. After the computer is finished with the particular case the program asks the user whether they would like to calculate another case. If the answer is 'Y' the display will be erased and the input table redisplayed. If the answer is 'N' or if optimization was done as part of the last case then the program must be restarted as described in this section.

6.2 Changing Source Code and Recompiling*

For those users who plan to transfer the computer program described in this report to a mainframe computer, this section will be of no interest. However, for those users who will be using this computer program on something like an IBM personal computer, this section is written. It is assumed that the user has some sort of editor program which can take the source code files available on disk and make whatever modifications the user wants to make to them. Then the user must recompile the files that have been changed to produce object codes and then link these object codes into one executable code similar to the one that was furnished with the report. The author has used both the IBM FORTRAN and the Microsoft FORTRAN to develop this program. The author found that the IBM FORTRAN had a number of problems with it that could not be resolved by contacting the vendor. IBM supports their FORTRAN program by requiring the vendor to understand what the problem is and to call in and obtain an answer. Since it is a very rare vendor salesman who has ever used FORTRAN of any description this method of support breaks down very quickly. The author has found that the Microsoft FORTRAN works very well in almost all instances and is well supported by Microsoft of Bellevue, Washington. Both FORTRAN's were written by Microsoft and operate in the same way. Both compilers are for FORTRAN 77 with some restrictions. As of this time they are the only ones known that will compile large programs on the IBM personal computer or compatible computers for any type of FORTRAN.

Another FORTRAN is available for the IBM-PC and many other microcomputers. It is sold by Supersoft. On a sample program that was felt to give a typical mix of instructions, Supersoft claims the following performance in comparison:

	Time, sec	Size, EXE file
IBM PC FORTRAN	158.1	40 192
Supersoft FORTRAN	78.9	21 760

*These instructions are written for a two-drive machine with drive C being a ram disk.

However, they state that the current compiler allows only 64 K of code space and 64 K of data space. By a phone call of Supersoft in March 1983, we found that they expected to have chaining in September 1983. True large programs would be much later.

Since it is possible that a number of readers of this report will use the same or similar equipment to what the author used, the system that the author found to be efficient for compiling this size program will be described in the following paragraphs.

Both the Microsoft and IBM FORTRAN compilers have a limit of 64 K of memory in compiling any one module of a large program. Then any number of modules can be linked together to form a single executable file and the limit here is only in the size of the main memory. The FPSE program was written, edited and compiled in 17 different modules, when divided into the major sub-routes. Experience has shown that to maintain such a program, it is better to have an even larger number of modules than the 17 that it is presently divided into. The reason for this is that the smaller modules take less time to recompile and the subsequent linking operation is about the same no matter how many modules there are, as long as the total length is the same. We found that the use of common blocks to transfer data from one program module to another was much more saving of computer memory than was the use of formal parameters. If a given size program module runs out of memory at compile time, the only thing that can be done is to subdivide it into two or more smaller pieces. In putting the full program together this subdivision was carried to ridiculous lengths as it seemed at the time without getting to a program which would compile without running out of memory. At that time we switched over from formal parameters to named common blocks at the suggestion of the Microsoft technical support people, and the problem went away. Some of the program modules which had not been broken up at this time were still very large but were compilable by the use of common blocks. At least in the microcomputer environment the use of named common blocks appears to be much more saving of memory than the use of formal parameters. However, both will work and can be used.

There are many different ways of using the FORTRAN software to produce an executable code. If there were enough disk space, it would be possible to design a batch file to go all the way from a collection of source files to an executable file. This might be possible for a microcomputer with a hard disk. It would also certainly be possible for a programmer operating with a mainframe computer. However, using the IBM personal computer at the most basic level there is a lot of constant attention and changing of disks in order to go from a source file to an executable file. For the size program that was produced in this contract, the following method was found to be about the best. This method used two batch files. One batch file was used to take the source code and produce an object file more or less automatically. Another batch file was used to gather up all the object files and make one single executable file. The use of these two batch files will now be further explained.

Table 6.2 Batch File for Compiling FORTRAN Programs.

```
REM CP COMPILES USING FOR1 AND FOR2 AND STORES OBJECT FILE ON A DISK
COPY CP.BAT C:
COPY %1.FOR C:
C:
PAUSE --INSERT FORTRAN A: DISK IN DRIVE "B" AND OBJ. FILES DISK IN DRIVE "A".
B:FOR1 %1,A:,CON,NUL;
B:FOR2
ERASE %1.FOR
REM -- REMOVE OBJECT FILES DISK AND INSERT SOURCE FILE AND EDIT IN "A".
A:
```

Table 6.3 Record of Console Displays During Compilation.

```
A>CP FPSE

A>REM CP COMPILES USING FOR1 AND FOR2 AND STORES OBJECT FILE ON A DISK

A>COPY CP.BAT C:
        1 File(s) copied
A>COPY FPSE.FOR C:
        1 File(s) copied
A>C:

C>PAUSE --INSERT FORTRAN A: DISK IN DRIVE "B" AND OBJ. FILES DISK IN DRIVE "A".
Strike a key when ready . . .
C>B:FOR1 FPSE,A:,CON,NUL;
Microsoft FORTRAN77 V3.10 05/03/83
```

(This part is given in Appendix D.)

```
C>ERASE FPSE.FOR

C>REM -- REMOVE OBJECT FILES DISK AND INSERT SOURCE FILE AND EDIT IN "A".

C>A:
```

The batch file that is used to convert a single source file written in FORTRAN into an object file is given in table 6.2. To use this batch file you need one or more disks that contain the source code files and possibly the editor program that is used. These source code disks should each have a copy of CP.BAT on them. Also, you need another disk with copies of the first and second compilation code that is used by either IBM FORTRAN or Microsoft FORTRAN. The first pass should be labeled FOR1.EXE and the second pass should be labeled FOR2.EXE. A copy of CP.BAT should also be on this disk. From the disk operating system prompt (A>) type in CP, a space, then the name of the file without the .FOR subscript (for instance, FPSE). Hit return. See the first line of table 6.3. The first thing that shows is the remark line to show what kind of a program you have. After this, it copies the CP.BAT and the subject source file to the C disk. Check to see that both files get copied. By using the C disk as well as the A and B disks it is possible to do a compilation without additional supervision from the operator. Next the control passes to the C disk and there is a pause in order to carry out the instructions given. Put a formatted disk that is to accept all the object files into the A drive and the disk that contains the FOR1 and FOR2 in the B drive. When this is done, it says strike any key. The rest of the compilation is now automatic. A listing of the source code with line numbers and with errors highlighted, if there are any, and a listing of all the variables used in alphabetical order is displayed on the screen and can be printed out by using the control P code to make the printer print what is displayed on the screen. The listings given in the appendices D to T* were all done by this method. It is very convenient because one can watch the compilation proceed and determine what errors there are even before compilation is finished. If there are no errors, the object file will be created and have the same prefix as the source file but the suffix will be .OBJ.

In this way each one of the modules of the full program can be compiled and the object files stored on a single disk. Of course, any compile time errors must be noted and corrections made before the linking can be undertaken. Table 6.3 is a record of what appears on the screen during a typical compilation section for file FPSE.FOR.

At the end of the printout the batch file concludes by erasing the source file (in this case, FPSE.FOR) from the C disk and presenting the instruction, "Remove the object files disk and insert source file and edit in A." This is a convenient way of doing it because disk B can continue to have the compilation software on it. This software with two programs takes up most of the disk so additional programs of any magnitude cannot be added to an ordinary double density disk for the IBM PC OR PC compatible machines.

Batch files also work well for linking all the programs together. Table 6.4 shows a listing of a batch file that does this and table 6.5 shows the messages that are recorded on the console when this is undertaken. To start with, the batch file LK should be on both of the disks in drive A which should also contain all the object files that have been accumulated by the 17 different compilation steps that have preceded this. On drive B should also be a copy of the LK batch file as well as a copy of LINK, a microsoft disk

---

*Program listings have been removed from the appendices and are now available on diskette.

Table 6.4 Batch File for Linking All Components of FPSE.

```
REM "LK" links all .OBJ files in the FPSE program and stores the .EXE
PAUSE --Put .OBJ disk in A: and LINK disk in B: -- A: is defalt.
B:LINK FPSE+F1+F11+F12+F2+F21+F22+F23+F24+F25+F26+F27+F28+F3+F4+F41+F42,C:FPSE.E
XE,NUL.MAP,B:FORTRAN.LIB+B:HALOF.LIB
PAUSE --Put FPSE.EXE disk in B:
COPY LK.BAT C:
COPY C:FPSE.EXE B:
C:
FPSE
```

Table 6.4 Batch File for Linking All Components of FPSE.

```
REM "LK" links all .OBJ files in the FPSE program and stores the .EXE
PAUSE --Put .OBJ disk in A: and LINK disk in B: -- A: is defalt.
B:LINK FPSE+F1+F11+F12+F2+F21+F22+F23+F24+F25+F26+F27+F28+F3+F4+F41+F42,C:FPSE.E
XE,NUL.MAP,B:FORTRAN.LIB+B:HALOF.LIB
PAUSE --Put FPSE.EXE disk in B:
COPY LK.BAT C:
COPY C:FPSE.EXE B:
C:
FPSE
```

operating system utility and a copy of FORTRAN.LIB which is the FORTRAN library which is the one that uses the particular processor that the IBM personal computer has available to it as well as the library for the graphics component if this is installed. These programs also take up most of the disk and no additional substantial program can be added to it. The default disk should be drive A.

With this setup, type LK and hit the enter button. The batch file comes back!14th the remark line to describe what it is that you called up and the pause line that tells you to do what has just been instructed. This gives you a chance to see if this has actually been done. When you strike your key when ready, the batch file automatically enters the command line to link the program. This is 1-1/2 lines long and would otherwise have to be keyed in every time a linking is required. This is set up so that the source of the object files is drive A, the source of the program is drive B, and destination of the executable program is drive C. Therefore, linking can take place automatically. Note that the linker discovers that MOVEFR is defined more than once in the HALOF.LIB which is the graphics program library. Since this subroutine is not called up, it is not an error in this program. During the linking operation, the program uses all the memory space available and if additional memory space is needed, it creates a file VM.TMP on the default disk drive.

Occasionally, during the development of this program there hasn't been enough space for this temporary file to be fully created and the linking was stopped. We found that the size of the object files could be reduced by 20 to 30 percent by removing the meta command $DEBUG. The DEBUG feature rarely works as it was intended. By making this change in the components of the program we had already debugged, it was possible to keep the procedure outlined in these paragraphs the same. After the linking is complete, the program FPSE.EXE is on disk C. Since this disk is not permanent, the remaining part of the batch file LK transfers a copy of this program to a disk which is inserted in B in place of the linking diskette. After striking any key, the transfer is made from C to B and the computer program is started automatically from the C disk.

These two batch files have been used in the last stages of the development of this program at Martini Engineering and have been found to be quite beneficial. We recommend them for those who would take up this computer program, particularly on an IBM personal computer or a machine compatible with it. Very similar utilities are also available for those using the CP/M operating systems and probably for almost any first class operating system on mainframe computers as well.

7.0 STATUS OF THE CODE AND REQUIREMENTS FOR FURTHER DEVELOPMENT

A computer code to optimize the design and predict the performance of free-piston Stirling engines has been developed on a microcomputer for use on micro- or mainframe computers. It appears that the code has the potential to become a valuable design tool. However, some additional development work is required before it potential can be fully realized.

Sample code calculations are shown in this report for the following cases:

(1) Engine performance predictions
- a. isothermal analysis with specified piston motions
- b. isothermal analysis with free-piston and displacer motions
- c. adiabatic analysis with specified piston motions
- d. adiabatic analysis with free-piston and displacer motions

(2) Optimization of the engine design
- a. isothermal analysis with specified piston motions
- b. isothermal analysis with free-piston motions

The code needs additional development in the following areas:

(1) The effect of leakage on output needs to be reviewed. There may be an error in how the centering port leakage is applied.

(2) In the optimization program the method of adjusting pressure to obtain the target power is satisfactory only for specified piston motion. A secant method for adjusting pressure to quickly obtain the desired engine power should be added.

(3) During the optimization search, sometimes a solution never finishes. Provision should be added for abandoning a solution in this case.

(4) Much faster optimization searches can possibly be obtained by using a large time steps and no leakage. This should be tried.

(5) The moving gas node analysis has potential that was not used in this program for directly calculating the heat requirement. This needs to be added.

(6) The speed of the moving gas node analysis can be improved by using a fixed number of constant mass gas nodes plus one variable mass gas node in the cold space to allow for leakage. This type of analysis has been found to be stable and may be faster than the isothermal analysis in reaching a solution. This improvement should be tried.

(7) The Rios second-order Runge-Kutta analysis was not stable beyond two cycles and thus was not usuable. The free-piston environment prevented reinitialization after each cycle, as had been done to keep the Rios analysis stable when used to simulate crank operated machines. Further thought should be given to the development of this technique to determine if it is suitable for use in the design of free-piston engines.

(8) The performance calculation techniques should be validated against data. There are actually three differenct performance calculation techniques to chose from:

a. The Martini isothermal analysis which uses loss calculations to correct the basic isothermal assumptions, plus a correction to go from isothermal to adiabatic analysis in arriving at predicted performance for a real engine.

b. The Martini adiabatic moving gas node analysis which currently assumes adiabatic expansion and compression spaces but could easily be modified to allow heat transfer in these spaces. It could be fixed to operate in the free-piston mode.

c. The Rios analysis which also uses loss calculations to correct the basic assumption.

These three techniques should be comparatively evaluated as to their suitability for performance predictions and engine design. With fully instrumented engine data, it would be possible to at least partially separate the different loss components and determine what methods of analysis are reasonably accurate.

(9) An effort should be made to compare different available optimization techniques to see of others might be quicker to arrive at the same optimum design.

(10) The option of adjusting bore size to get the desired power during optimization should be comparatively evaluated against the option of adjusting pressure level.

(11) The optimization procedure should be validated by:

a. excercising it against existing engine designs
b. introducing geometrical constrainsts on the optimization variables where appropriate
c using it to derive new engine designs.

8.0 REFERENCES

1. W.R. Martini, "ISO82--A Fast Design Program for Stirling Cycle Heat Engines and Heat Pumps." Final report to ORNL under purchase order 62X-43168V. April 1983.

2. W.R. Martini, "A Revised Isothermal Analysis Program for Stirling Engines." 1983 IECEC Record, pp. 743-748.

3. W.R. Martini, "Stirling Engine Design manual." DOE/NASA/3152-78-1. NASA-CR-135382, April 1978.

4. W.R. Martini, "Stirling Engine Design Manual -- Second Edition." DOE/NASA/3194-1, NASA CR-168088, January 1983.

5. W.R. Martini, "A Simple Method of Calculating Stirling Engines for Engine Design Optimization." 1978 IECEC Record, pp. 1753-1762.

6. P.A. Rios, "An Analytical and Experimental Investigation of the Stirling Cycle." PhD Thesis, Massachusetts Institute of Technology, September, 1969.

7. J. Schreiber, "Testing Results and Description of a 1-kW Free-Piston Stirling Engine with a Dashpot Load." DOE/NASA/1005-1, NASA TM-83407, August 1983.

8. J. Schreiber, "Testing and Performance Characteristics of a 1-kW Free-Piston Stirling Engine." NASA TM 82999, April, 1983.

APPENDIX A

INPUT VALUE TABLE

(N1.NOM)

N1.NOM
14 APRIL 1984

IN=Input Number
ON=Optimization Number

****
** INPUT TABLE FOR **
** THE NASA-LEWIS **
** FREE-PISTON **
** STIRLING ENGINE **
****

IN	ON	SYMBOL	MEANING	VALUE	UNITS
			****************** OPERATING CONDITIONS **************		
01		PAVGB	AVERAGE WORKING GAS PRESSURE	72.	BAR
02		OG	OPTIONS FOR OPERATING GASSES 1 - H2 2 - HE 3 - AIR	2	--
03		TMHTRC	METAL TEMPERATURE OF GAS HEATER	600.	DEG. C
04		TMCLRC	METAL TEMPERATURE OF GAS COOLER	40.	DEG. C
05	01	PHASED	DISPLACER PHASE ANGLE	49.6	DEG.
06	02	PPSTR	POWER PISTON STROKE	2.70	CM
07	03	DSPSTR	DISPLACER STROKE	2.60	CM
08		JPWR	POWER ADJUST OPTION 0 - ADJUST AVERAGE PRESSURE 1 - ADJUST BORE SIZE	0	--
09		NDF	CASE NUMBER DEFINED BY USER	1	--
10		TSTEP	TIME STEP USED DURING FORCE BALANCE SIMULATION	1.0	MILLISEC
11		GRAOPT	GRAPHIC OPTION 0 - NO GRAPHICS 1 - FULL GRAPHICS	0	--
12		DEGFVT	ENGINE ORIENTATION IN DEGREES FROM VERTICAL, HEATER END DOWN	0	DEGREES
13		GVTMAG	GRAVITY MAGNITUDE RELATIVE TO EARTH GRAVITY	1.	--
14		LDOPT	OPTION FOR CHOICE OF ENGINE LOAD 1 - DASHPOT 2 - HYDRAULIC PUMP 3 - INERTIAL COMPRESSOR 4 - LINEAR ALTERNATOR	1	--
15		ICALC	OPTION FOR METHOD OF CALCULATION 1 - ISOTHERMAL & SPECIFIED MOTION 2 - ISOTHERMAL & CALCULATED MOTION 3 - ADIABATIC & SPECIFIED MOTION 4 - ADIABATIC & CALCULATED MOTION	1	--
16		IOPT	OPTION FOR OPTIMIZATION 0 - NO OPTIMIZATION 1 - DO OPTIMIZATION	0	--
17		IVAR	NUMBER OF INDEPENDENT VARIABLES IN OPTIMIZATION ROUTINE	3	--
18		PWRTGT	TARGET POWER FOR OPTIMIZATION	1000.	WATTS
19		PRCNG	PERCENT CHANGE IN OPTIMIZATION SEARCH	10.	%
			******** GEOMETRY ********		
20		NCYL	NUMBER OF CYLINDERS PER ENGINE	1	--

IN	ON	SYMBOL	MEANING	VALUE	UNITS
21	03	DSTRMX	MAXIMUM DISPLACER STROKE	4.04	CM
22	02	PPSTRM	MAXIMUM POWER PISTON STROKE	4.20	CM
23	04	CYLOFS	DESIGN CYLINDER OFFSET	4.70	CM
24		DIAPP	DIAMETER OF POWER PISTON	5.718	CM
25	05	DSPLTH	DISPLACER LENGTH	15.19	CM
26	06	GAP	GAP BETWEEN DISPLACER AND CYLINDER WALL	0.0365	CM
27		DRDOD	DISPLACER ROD DIAMETER	1.663	CM
28		DICYL	ID OF ENGINE CYLINDER AROUND DISPLACER	5.779	CM
29		SPHZ	ENGINE SPEED	29.7	HZ
******* WEIGHT *******					
30	20	PPMAS	POWER PISTON MASS	6.2	KG
31	21	DISPMS	DISPLACER MASS	0.426	KG
32		INTOPT	INTEGRATION OPTION 0 - MARTINI METHOD 1 - RIOS METHOD	0	--
******* SEALS *******					
33		PPCLR	POWER PISTON CLEARANCE (ON DIAMETER)	33.	MICRONS
34		PPSLLT	POWER PISTON SEAL LENGTH	15.25	CM
35		DRDCLR	DISPLACER ROD CLEARANCE ON DIAMETER	25.4	MICRONS
36		DRDLTH	AVE. LENGTH OF DISPLACER ROD SEAL	7.6	CM
37		DSPCLR	DISPLACER BODY -- DISPLACER CYLINDER CLEARANCE (ON DIAM.)	381.	MICRONS
38		DSPCLL	DISPLACER SEAL LENGTH	0.0	CM
39		BNCOEF	END STOP BOUNCE COEFFICIENT	0.8	--
40		FEXPR	EXP. FACTOR FOR CENTERING PORTS	10.	--
***** VOLUMES *****					
41	07	VOLDSP	VOLUME DISPLACER GAS SPRING (AVG.)	31.79	CC
42	08	VOLBS	VOLUME OF BOUNCE SPACE	20.5	LITERS
43		HTDV	HOT DEAD VOLUME (IN ADD. TO TUBES)	2.39	CC
44		CLDDV	COLD DEAD VOLUME (IN ADD. TO SLOTS)	72.53	CC
45		NGN	MAX.NUM. OF GAS NODES (NOT INPUT.)	99	--
46		NTS	NUMBER OF TIME STEPS/CYCLE	24	--
******* CENTERING PORTS *******					
47		HLLNCY	HOLE LENGTHS IN ENGINE CYLINDER	1.02	CM
48		DORPP	DIAMETER OF ORIFICE IN POWER PISTON	0.1575	CM
49		DORCYL	DIAMETER OF ORIFICE IN CYLINDER	0.1067	CM
50		HLLNDP	HOLE LENGTHS OF DISPLACER PORTS	0.76	CM
51		DORDSP	DIAMETER OF ORIFICE IN DISPLACER	0.1321	CM
52		DORDR	DIAMETER OF ORIFICE IN DISPLACER ROD	0.1016	CM
53		VRGS	REST VOLUME OF DISPLACER GAS SPRING	31.79	CC
54		HLLNPP	HOLE LENGTHS IN POWER PISTON	2.92	CM
55		NHLPP	NUMBER OF CENTERING PORTS	2	--
***** HEATER *****					
56	09	NHTRTB	NUMBER OF HEATER TUBES	34	--
57	10	HTLNGH	HEATER TUBE LENGTH (HEATED)	18.34	CM
58	11	HTID	ID OF HEATER TUBES	0.2362	CM
59		HTUHLH	UNHEATED LENGTH OF HEATER TUBES	9.26	CM
60		V1	ENTRANCE & EXIT VELOCITY HEADS	1.5	
61			OPEN		
***** REGENERATOR (ANNULAR) *****					
62	12	REGLTH	REGENERATOR LENGTH	6.446	CM
63	13	SANREG	THICKNESS OF ANNULAR REGENERATOR	0.554	CM
64	14	DWIRE	DIAMETER OF WIRE IN MATRIX	88.9	MICRONS
65	15	PORMTX	POROSITY OF MATRIX	75.9	%

IN	ON	SYMBOL	MEANING	VALUE	UNITS
66			OPEN		
67			OPEN		
68			OPEN		
***** COOLER *****					
69	16	NCLRTB	NUMBER OF COOLER SLOTS (RECTANGULAR)	135	--
70	17	CTWIDT	COOLER SLOT WIDTH	0.0508	CM
71	18	CTDPTH	COOLER SLOT DEPTH	0.376	CM
72	19	CTLNTH	COOLER SLOT LENGTH	7.92	CM
73		V2	ENTRANCE & EXIT VELOCITY HEADS	1.5	
74			OPEN		
***** LOAD PARAMETERS-ELECTRIC GENERATOR *********					
75		CELECT	PROPORTIONALITY CONSTANT FOR LINEAR ALTERNATOR	0.0	N/(CM/SEC)**2
****** LOAD PARAMETERS-INERTIAL COMPRESSOR ********					
76		XP	LENGTH OF DOUBLE ACTING HYDRAULIC PISTON	1.0	CM
77		XBP	LENGTH OF DEAD BAND PORT	3.0	CM
78		PMIN	ABSOLUTE PRESSURE OF INLET FLUID	1.	BAR
79		ALDPS	AREA OF LOAD PISTON	4.0	CM**2
80		PMAX	OUTLET PRESSURE OF PUMPED FLUID	20.	BAR
81		CLEND	END CLEARANCE	.01	CM
***** LOAD PARAMETERS-DASHPOT ******					
82		CDSPT	PROPORTIONALITY CONSTANT FOR DASHPOT	0.1	N/(CM/SEC)**2
***** ADDITIONAL OPERATING CONDITIONS ****					
83		CNVCRT	CONVERGENCE CRITERIA, FRACTION CHANGE	0.0005	--
84			OPEN		
85			OPEN		
***** TEMPERATURE CONDUCTION & PROPERTY VALUES ******					
--		KM	THERMAL CONDUCTIVITY (300 SERIES S.S.) KM=EXP(AA+BB+ALOG(T))	--	M/CMK
86		AA		-4.565	--
87		BB		0.4684	--
88		RHOM	METAL DENSITY	7.93	G/CC
89		CPM	METAL HEAT CAPACITY	0.46	J/G K
90		WLHC	WALL LENGTH FOR HEAT CONDUCTION	4.45	CM
91		SCYLW2	THICKNESS OF OUTER CYLINDER WALL	0.371	CM
92		SCYLW1	THICKNESS OF INNER CYLINDER WALL	0.145	CM
93		SDSPW	THICKNESS OF DISPLACER WALL	0.0813	CM
94		NRADSH	NUMBER OF RADIATION SHIELDS	1	--
95		EMIS	EMISSIVITY OF RADIATION SHIELDS	0.5	--
96		NRIOSL	OPTION ON LOSS EQUATIONS 0 - USE MARTINI LOSS EQUATIONS 1 - USE RIOS LOSS EQUATIONS	0	--
97			OPEN		
98			OPEN		
99			OPEN		
***** ORDER OF INDEPENDENT PARAMETERS SEARCHED IN ****** **** NESTING DO LOOP SEARCH ****					
100			OPEN		
101		OPT(1)	OPT. NUMBER OF FIRST (INNERMOST) ADJUSTABLE PARAMETER	13	--
102		OPT(2)	OPT. NUMBER OF SECOND ADJ. PARAM.	15	--
103		OPT(3)	OPT. NUMBER OF THIRD ADJ. PARAM.	14	--
104		OPT(4)	OPT. NUMBER OF FOURTH ADJ. PARAM.	00	--
105		OPT(5)	OPT. NUMBER OF FIFTH ADJ. PARAM.	00	--

IN	ON	SYMBOL	MEANING	VALUE	UNITS
66			OPEN		
67			OPEN		
68			OPEN		
***** COOLER *****					
69	16	NCLRTB	NUMBER OF COOLER SLOTS (RECTANGULAR)	135	--
70	17	CTWIDT	COOLER SLOT WIDTH	0.0508	CM
71	18	CTDPTH	COOLER SLOT DEPTH	0.376	CM
72	19	CTLNTH	COOLER SLOT LENGTH	7.92	CM
73		V2	ENTRANCE & EXIT VELOCITY HEADS	1.5	
74			OPEN		
***** LOAD PARAMETERS-ELECTRIC GENERATOR *********					
75		CELECT	PROPORTIONALITY CONSTANT FOR LINEAR ALTERNATOR	0.0	N/(CM/SEC)**2
****** LOAD PARAMETERS-INERTIAL COMPRESSOR ********					
76		XP	LENGTH OF DOUBLE ACTING HYDRAULIC PISTON	1.0	CM
77		XBP	LENGTH OF DEAD BAND PORT	3.0	CM
78		PMIN	ABSOLUTE PRESSURE OF INLET FLUID	1.	BAR
79		ALDPS	AREA OF LOAD PISTON	4.0	CM**2
80		PMAX	OUTLET PRESSURE OF PUMPED FLUID	20.	BAR
81		CLEND	END CLEARANCE	.01	CM
***** LOAD PARAMETERS-DASHPOT ******					
82		CDSPT	PROPORTIONALITY CONSTANT FOR DASHPOT	0.1	N/(CM/SEC)**2
***** ADDITIONAL OPERATING CONDITIONS ****					
83		CNVCRT	CONVERGENCE CRITERIA, FRACTION CHANGE	0.0005	--
84			OPEN		
85			OPEN		
***** TEMPERATURE CONDUCTION & PROPERTY VALUES *****					
--		KM	THERMAL CONDUCTIVITY (300 SERIES S.S.) KM=EXP(AA+BB+ALOG(T))	--	M/CMK
86		AA		-4.565	--
87		BB		0.4684	--
88		RHOM	METAL DENSITY	7.93	G/CC
89		CPM	METAL HEAT CAPACITY	0.46	J/G K
90		WLHC	WALL LENGTH FOR HEAT CONDUCTION	4.45	CM
91		SCYLW2	THICKNESS OF OUTER CYLINDER WALL	0.371	CM
92		SCYLW1	THICKNESS OF INNER CYLINDER WALL	0.145	CM
93		SDSPW	THICKNESS OF DISPLACER WALL	0.0813	CM
94		NRADSH	NUMBER OF RADIATION SHIELDS	1	--
95		EMIS	EMISSIVITY OF RADIATION SHIELDS	0.5	--
96		NRIOSL	OPTION ON LOSS EQUATIONS 0 - USE MARTINI LOSS EQUATIONS 1 - USE RIOS LOSS EQUATIONS	0	--
97			OPEN		
98			OPEN		
99			OPEN		
***** ORDER OF INDEPENDENT PARAMETERS SEARCHED IN ***** **** NESTING DO LOOP SEARCH ****					
100			OPEN		
101		OPT(1)	OPT. NUMBER OF FIRST (INNERMOST) ADJUSTABLE PARAMETER	13	--
102		OPT(2)	OPT. NUMBER OF SECOND ADJ. PARAM.	15	--
103		OPT(3)	OPT. NUMBER OF THIRD ADJ. PARAM.	14	--
104		OPT(4)	OPT. NUMBER OF FOURTH ADJ. PARAM.	00	--
105		OPT(5)	OPT. NUMBER OF FIFTH ADJ. PARAM.	00	--

IN	ON	SYMBOL	MEANING	VALUE	UNITS
106		OPT(6)	OPT. NUMBER OF SIXTH ADJ. PARAM.	00	--
107		OPT(7)	OPT. NUMBER OF SEVENTH ADJ. PARAM.	00	--
108		OPT(8)	OPT. NUMBER OF EIGHTH ADJ. PARAM.	00	--
109		OPT(9)	OPT. NUMBER OF NINTH ADJ. PARAM.	00	--
110		OPT(10)	OPT. NUMBER OF TENTH ADJ. PARAM.	00	--
111		OPT(11)	OPT. NUMBER OF ELEVENTH ADJ. PARAM.	00	--
112		OPT(12)	OPT. NUMBER OF TWELFTH ADJ. PARAM.	00	--
113		OPT(13)	OPT. NUMBER OF THIRTEENTH ADJ. PARAM.	00	--
114		OPT(14)	OPT. NUMBER OF FOURTEENTH ADJ. PARAM.	00	--
115		OPT(15)	OPT. NUMBER OF FIFTEENTH ADJ. PARAM.	00	--

APPENDIX B

NOMENCLATURE FOR ALL PROGRAMS

(NASA.NOM)

**********************   NASA.NOM   ************4-13-84************

```
A     =WINDAGE CREDIT, WATTS (ALSO TEMPORARY VARIABLE)
AA    =THERMAL CONDUCTIVITY COEFFECIENT, REAL
AC    =HEAT TRANSFER AREA FOR COOLER, SQ. CM.
ADCORH=CORRECTION TO BASIC HEAT INPUT DUE TO ADIABATIC SPACES, WATTS
ADCORP=CORRECTION TO BASIC POWER DUE TO ADIABATIC SPACES, WATTS
AF    =AREA OF FLOW, SQ. CM.
AFC   =AREA OF FLOW THRU REGENERATOR SLOTS, SQ. CM.
AFH   =AREA OF FLOW THRU HEATER TUBES, SQ. CM.
AFL   =AREA OF FLOW FOR LEAKAGE OF WORKING GAS, SQ. CM.
AFR   =FREE AREA OF FLOW THRU REGENERATOR, SQ. CM.
AH    =HEAT TRANSFER AREA OF HEATER, SQ. CM.
AHT   =HEAT TRANSFER AREA FOR REGENERATOR, SQ. CM.
AHTN  =HEAT TRANSFER AREA FOR A PARTICULAR NODE, SQ. CM.
ALDPS =AREA OF LOAD PISTON, CM**2
ALPH  =PHASE ANGLE, RADIANS
ANSWER=ANSWER TO QUESTION, Y OR N
AP    =AREA OF POWER PISTON, SQ. CM.
APMAR =AREA OF POWER PISTON MINUS AREA OF ROD IN COMP. SP., SQ. CM
ARG   =ANGLE BETWEEN PRESSURE WAVE AND VOLUNE WAVE IN RIOS CALC., RAD.
B     =INDICATED EFFICIENCY FOR HEAT ENGINE, %
BB    =THERMAL CONDUCTIVITY COEFFICIENT, REAL
BBEST =BEST INDICATED EFFICIENCY FOUND SO FAR,%
BH    =BASIC HEAT INPUT, WATTS
BHL   =LAST BASIC HEAT INPUT, WATTS
BNCOEF=BOUNCE COEFFICIENT ON HITTING END STOPS
BNVOL =VOLUMETRIC DISPLACEMENT USED IN CLEARANCE RATIOS, CC
BP    =BASIC POWER OUTPUT FOR HEAT ENGINE, WATTS
BPL   =LAST BASIC POWER OUTPUT, WATTS
C1    =CONVERGENCE CRITERIA
C2    =CONVERGENCE CRITERIA
C3    =CONVERGENCE CRITERIA
C4    =CONVERGENCE CRITERIA
CALCNU=CALCULATED FREQUENCY, HZ
CALCSP=CALCULATED ENGINE SPEED, HZ
CD    =TOTAL COLD DEAD VOLUME, CC
CDSPT =PROPORTIONALITY CONSTANT FOR DASH POT,N/(CM/SEC)**2
CELECT=PROPORTIONALITY CONSTANT FOR LINEAR ALTERNATOR,N/(CM/SEC)**2
CF    =COOLER WINDAGE, WATTS
CFLOW =RETARDING FORCE FLOW COEFF., NEWTONS/(CM/SEC)**2
CHMTX(19)=ARRAY OF MULTIPLIERS USED IN  OPTIMIZING SEARCH, REAL
CLDDV =COLD DEAD VOLUME,CC
CLEND =END CLEARANCE,CM
CLK   =LEAKAGE COEFFICIENT THRU POWER PISTON SEAL, GM MOL/(SEC*MPa)
CLKDP =LEAKAGE COEFFICIENT THRU DISPLACER ROD SEAL, GM MOL/(SEC*MPa)
CLRATO=TEMPERATURE CORRECTED CLEARANCE RATIO, DIMENSIONLESS
CMTXN =HEAT CAP. OF ONE OF THE THREE REGEN. MATRIX METAL NODES, J/K
CMU   =COLD GAS VISCOSITY, G/CM/SEC
CN    =MINIMUM FC1 DURING CYCLE, DIMENSIONLESS
CNDCYL=CONDUCTANCE OF ONE ENGINE CYLINDER WALL, WATTS/K
CNDDSP=DISPLACER WALL CONDUCTANCE, WATTS/K
CNDRW =CONDUCTANCE OF ONE REGENERATOR WALL, WATTS/K
CNTIM =TIME FROM THE START OF THE CYCLE WHEN THE MASS OF GAS IN THE
       COLD SPACE IS AT A MINIMUM, SEC
CNTU  =NUMBER OF HEAT TRANSFER UNITS IN COOLER, DIMENSIONLESS
CNVCRT=CONVERGENCE CRITERIA, FRACTION CHANGE IN POWER-OUT AND
```

```
       HEAT-IN INTEGRALS
CONDMX=CONDUCTANCE OF REGENERATOR MATRIX, J/K
COR   =INTERMEDIATE  VALUE  IN  RIOS  FLOW  LOSS  CALCULATIONS
CP    =HEAT CAPACITY OF WORKING GAS, J/(G*K), (ASSUMED NOT TO VARY
       SIGNIFICANTLY WITH TEMPERATURE)
CPM   =METAL HEAT CAPACITY,J/G K
CTDPTH=COOLER SLOT DEPTH,CM
CTLNTH=COOLER SLOT LENGTH,CM
CTWIDT=COOLER SLOT WIDTH,CM
CV    =HEAT CAPACITY OF WORKING GAS AT CONSTANT VOLUME, J/(G*K)
CW    =FRICTION FACTOR FOR MET NET AND OTHERS
CX    =MAXIMUM FC1 DURING CYCLE, DIMENSIONLESS
CXTIM =TIME FROM THE START OF THE CYCLE WHEN THE MASS OF GAS IN THE
       COLD SPACE IS AT A MAXIMUM, SEC
CYCTIM=TIME FOR ONE CYCLE, SEC
CYLOFS=DISPLACER CYLINDER OFFSET,CM
DALF  =RADIANS PER DOUBLE TIME INCREMENT, RIOS CALCULATION
DEFF  =EFFECTIVE DIAMETER FOR COOLER SLOTS, CM**3
DEGFVT=ENGINE ORIENTATION IN DEGREES FROM VERTICAL, HEATER END DOWN,
       DEGREES
DFCDT =RATE AT WHICH FC CHANGES, FRACTION/SEC.
DFCDTM=MAXIMUM RATE AT WHICH FC CHANGES, FRACTION/SEC.
DFHDT =RATE AT WHICH FH CHANGES, FRACTION/SEC.
DFHDTM=MAXIMUM RATE AT WHICH FH CHANGES, FRACTION/SEC.
DIAPP =DIAMETER OF POWER PISTON,CM
DICYL =ID OF ENGINE CYLINDER AROUND DISPLACER,CM
DID   =DISPLACER OR HOT CAP INSIDE DIAMETER, CM
DISPMS=DISPLACER MASS, KG
DMC   ="MASS" CHANGE IN COLD SPACE, RIOS, J/K
DMR1  =DISPLACER ROD SEAL LEAKAGE DURING ONE TIME STEP, J/K
DMR2  =POWER PISTON SEAL LEAKAGE DURING ONE TIME STEP, J/K
DMR3  =DISPLACER CENTERING PORT LEAKAGE DURING ONE TIME STEP, J/K
DMR4  =POWER PISTON CENTERING PORT LEAKAGE DURING ONE TIME STEP, J/K
DMRE  =SUM OF MASS CHANGES IN RIOS CALCULATIONS, DIMENSIONLESS
DMW   ="MASS" CHANGE IN HOT SPACE, RIOS, J/K
DORCYL=DIAMETER OF ORIFICE IN CYLINDER,CM
DORDR =DIAMETER OF ORIFICE IN  DISPLACER ROD,CM
DORDSP=DIAMETER ORIFICE IN DISPLACER,CM
DORPP =DIAMETER OF ORIFICE IN POWER PISTON,CM
DP    =PRESSURE DROP IN GENERAL, MPA
DP1   =PRESSURE  DROP  THROUGH CENTERING PORT  HOLES  IN  ENGINE
       CYLINDER, MPA
DP2   =PRESSURE  DROP  THROUGH CENTERING PORT  HOLES  IN  P.PIST.
       CYLINDER, MPA
DPC   =PRESSURE DROP IN COOLER, MPA
DPH   =PRESSURE DROP IN HEATER, MPA
DPPP  =PRESSURE DROP THRU P. PIST. CENTERING PORTS, MPA
DPR   =PRESSURE DROP IN REGENERATOR, MPA
DRA   =AREA OF ROD IN COMPRESSION SPACE, SQ. CM.
DRDCLR=DISPLACER ROD CLEARANCE ON DIAMETER,MICRON
DRDLTH=AVERAGE LENGTH OF DISPLACER ROD SEAL,CM
DRDOD =DISPLACER ROD DIAMETER,CM
DSPCLL=DISPLACER SEAL LENGTH,CM
DSPCLR=DISPLACER BODY,DISPLACER CYLINDER CLEAR,(ON DIAMETER),MICRON
DSPLTH=DISPLACER LENGTH,CM
```

```
DSPMAX=LARGEST POSITIVE POSITION OF DISPLACER DURING CYCLE, CM
DSPMIN=SMALLEST NEGATIVE POSITION OF DISPLACER DURING CYCLE, CM
DSPSTR=DISPLACER STROKE,CM
DSTRMX=MAXIMUM DISPLACER STROKE,CM
DTC   =RELATES EFFEC. COMPRESSION SPACE TEMP TO COOLER METAL TEMP,K
DTH   =RELATES EFFEC. EXPANSION SPACE TEMP TO HEATER METAL TEMP,K
DTS   =TIME STEP, SECONDS (IN GENERAL)
DTSCP =TIME THAT CENTERING PORT IS OPEN DURING TIME STEP, SEC
DTSOV =PART OF TIME STEP OVER AT END OF CYCLE, SEC
DW    =DIAMETER OF "WIRE" IN REGENERATOR, CM
DWIRE =DIAMETER OF WIRE IN MATRIX,MICRONS
DX    =1./XNDS
ELTIME=ELAPSED TIME FROM BEGINING OF THE CYCLE, SECONDS
EMIS  =EMISSIVITY OF RADIATION SHIELDS
F1    =FRACTION OF CYCLE TIME THAT FLOW OUT OF EXPANSION SPACE IS
       ASSUMED TO OCCUR AT CONSTANT RATE
F3    =FRACTION OF CYCLE TIME THAT FLOW OUT OF COMPRESSION SPACE IS
       ASSUMED TO OCCUR AT CONSTANT RATE
FA    =AREA FACTOR FOR RADIATION HEAT TRANSFER
FANG1 =PHASE ANGLE BETWEEN MAX. PISTON AND DISPLACER POSITIONS, DEG.
FANG2 =PHASE ANGLE BETWEEN MIN. PISTON AND DISPLACER POSITIONS, DEG.
FAREG =FACE AREA OF ONE ANNULAR REGENERATOR, CM
FBALDS=FORCE BALANCE ON DISPLACER, NEWTONS
FBALPP=FORCE BALANCE ON POWER PISTON, NEWTONS (TOWARD HOT END IS +.)
FC    =FRICTION FACTOR IN COOLER.
FC0   =FRACTION OF WORKING GAS MASS IN COLD SPACE IN THE PAST
FC1   =FRACTION OF WORKING GAS MASS IN COLD SPACE IN THE PRESENT
FC2   =FRACTION OF WORKING GAS MASS IN COLD SPACE IN THE FUTURE
FCR   =FRACTION LESS THAN ONE IN YCR UNITS USED IN INTERPOLATION
FDMC  =FACTOR TO CONVERT DMC IN J/K TO DIMENSIONLESS GR. USED BY RIOS
FDMW  =FACTOR TO CONVERT DMW IN J/K TO DIMENSIONLESS GR. USED BY RIOS
FDPR  =FACTOR TO CONVERT PRESSURE CHANGE IN MPA/SEC. TO A
       DIMENSIONLESS GROUP USED BY RIOS.
FDVC  =FACTOR TO CONVERT COLD VOL. CHANGE IN CC TO DIMENSIONLESS GR.
FDVW  =FACTOR TO CONVERT HOT VOL. CHANGE IN CC TO DIMENSIONLESS GR.
FE    =EMISSIVITY FACTOR FOR RADIATION HEAT TRANSFER
FEXPR =EXPERIENCE FACTOR FOR CENTERING PORT LEAKAGE.
FFF   =FILLER FACTOR, FRACT. OF REGEN. VOLUME FILLED WITH SOLID
FGVDSP=FORCE OF GRAVITY ON DISPLACER, NEWTONS
FGVPP =FORCE OF GRAVITY ON POWER PISTONS, NEWTONS
FH    =FRICTION FACTOR IN HOT SPACE, DIMENSIONLESS
FH0   =FRACTION OF WORING GAS MASS IN HOT SPACE IN PAST
FH1   =FRACTION OF WORING GAS MASS IN HOT SPACE IN PRESENT
FH2   =FRACTION OF WORING GAS MASS IN HOT SPACE IN FUTURE
FLOAD =FORCE ON POWER PISTON DUE TO LOAD, NEWTONS
       (TOWARD HOT END IS +.)
FMDSP(4)=FORCE PER MASS RATIO ON THE DISPLACER FOR PAST 4 TIMES,
       100*NEWTONS/KG
FMPP(4)=FORCE PER MASS RATIO ON THE DISPLACER FOR PAST 4 TIMES,
       100*NEWTONS/KG
FN    =RADITION SHIELD FACTOR
FORG(19)=ORIGINAL VALUES OF OPTIMIZABLE INPUT, VARIOUS
FR    =FRACTION OF CYCLE TIME THAT FLOW IN THE REGENERATOR IS
       ASSUMED TO OCCUR AT CONSTANT RATE IN ONE DIRECTION
FRAD  =RADIATION H. T. FACTOR FOR ONE DISP. OR HOT CAP, W/K**4
```

```
FRDRCP=FLOW RESISTANCE OF DISPLACER CENTERING PORTS,CC/(SEC*BAR)
FRPPCP=FLOW RESISTANCE OF POWER PISTON CENTERING PORTS,CC/SEC*BAR
FRRIOS(3)=FLOW FRICTION IN REGENERATOR USING THE RIOS ANALYSIS.
FTR    =FRACTION LESS THAN ONE IN XTR UNITS USED IN INTERPOLATION
FTRL(19)=TRIAL ARRAY OF OPTIMIZABLE INPUT VALUES, VARIOUS
GA     =(KK-1)/KK
GAP    =GAP BETWEEN DISPLACER AND CYLINDER WALL,CM
GC     =MASS VELOCITY THROUGH COOLER, G/SEC/SQ. CM.
GDMS(11)=CALCULATED MASS FLOW VALUES
GH     =MASS VELOCITY IN HEATER, G/SEC/SQ. CM.
GI2(11)=PARAMETER IN RIOS CALCULATION
GI3(11)=PARAMETER IN RIOS CALCULATION
GINT(11)=FLOW LOSS VARIABLE
GLH    =HEATER PRESSURE DROP INTEGRAL
GLR    =REGENERATOR PRESSURE DROP INTEGRAL
GLS    =COOLER PRESSURE DROP INTEGRAL
GR     =MASS VELOCITY IN REGENERATOR, G/SEC/SQ. CM.
GRAOPT=GRAPHIC OPTION. 0-NO GRAPHICS, 1-FULL GRAPHICS,I
GRL    =REGENERATOR REHEAT FACTOR, RIOS
GVTMAG=GRAVITY MAGNITUDE RELATIVE TO EARTH GRAVITY,REAL
H(1)   =FRACTION OF TOTAL REDUCED DEAD VOLUME FROM COLD END TO MIDWAY
        IN COOLER.
H(2)   =FRACTION OF TOTAL REDUCED DEAD VOLUME FROM COLD END THROUGH
        THE COOLER.
H(3)   =FRACTION OF TOTAL REDUCED DEAD VOLUME FROM COLD END THROUGH
        HALF THE REGENERATOR.
H(4)   =FRACTION OF TOTAL REDUCED DEAD VOLUME FROM COLD END THROUGH
        THE REGENERATOR.
H(5)   =FRACTION OF TOTAL REDUCED DEAD VOLUME FROM COLD END THROUGH
        THE MIDDLE OF THE GAS HEATER.  (1.-H(5)) INCLUDES THE REST
        OF THE HEATER AND THE APPENDIX GAP.)
HAC    =COLD ACTIVE VOLUME AMPLITUDE, CC
HAV    =HOT ACTIVE VOLUME AMPLITUDE, CC
HC     =HEAT TRANSFER COEFFICIENT AT COOLER, WATTS/SQ. CM./DEG. K
HCV    =REDUCED COOLER AND COLD DUCT DEAD VOLUME, DIMENSIONLESS
HD     =TOTAL HOT DEAD VOLUME, CC
HEC    =REDUCED COLD END CLEARANCE DEAD VOLUME, DIMENSIONLESS
HGV    =REDUCED APPENDIX GAP DEAD VOLUME, DIMENSIONLESS
HH     =HEAT TRANSFER COEFFICIENT IN HEATER, WATTS/ SQ. CM./DEG. K
HHC    =REDUCED HOT CLEARANCE DEAD VOLUME, DIMENSIONLESS
HHV    =REDUCED HEATER DEAD VOLUME, DIMENSIONLESS
HLLNCY=HOLE LENGTH OF CENTERING PORTS IN ENGINE CYLINDER, CM
HLLNDP=HOLE LENGTH OF CENTERING PORTS IN DISPLACER, CM
HLLNPP=HOLE LENGTH OF CENTERING PORTS IN POWER PISTON, CM
HMU    =GAS VISCOSITY IN HEATER, G/SEC/CM
HN     =MINIMUM FH DURING CYCLE, DIMENSIONLESS
HNTIM  =TIME FROM THE START OF THE CYCLE WHEN THE MASS OF GAS IN THE
        HOT SPACE IS AT A MINIMUM, SEC
HNTU   =NUMBER OF HEAT TRANSFER UNITS IN THE HEATER, DIMENSIONLESS
HRV    =REDUCED REGENERATOR DEAD VOLUME, DIMENSIONLESS
HTDV   =HOT DEAD VOLUME,CC
HTID   =ID OF HEATER TUBES,CM
HTLNGH=HEAT TUBE LENGTH (HEATED),CM
HTUHLH=UNHEATED LENGTHS OF HEATER TUBES,CM
HW     =HEATER WINDAGE LOSS, WATTS
```

```
HX     =MAXIMUM FH DURING CYCLE, DIMENSIONLESS
HXTIM  =TIME FROM THE START OF THE CYCLE WHEN THE MASS OF GAS IN THE
        HOT SPACE IS AT A MAXIMUM, SEC
HY     =HEAT TRANS. COEFF. IN REGEN., W/(CM**2*K)
I      =INTEGER COUNTER
ICALC  =OPTION FOR METHOD OF CALCULATION:
        1-ISOTHERMAL AND SPECIFIED MOTION,
        2-ISOTHERMAL AND CALCULATED MOTION,
        3-ADIABATIC AND SPECIFIED MOTION,
        4-ADIABATIC PLUS CALCULATED MOTION
ICR    =INTEGER JUST LESS THAN YCR
IDFLT  =Array of default values for integer input variables
IEND1  =END OF POWER OUT CYCLE FLAG, 0=NO, 1=YES
IEND2  =END OF HEAT IN CYCLE FLAG, 0=NO, 1=YES
IFIRST=FLAG  TO  MAKE  THE SOLUTION GO THRU  ISOTHERMAL  ANALYSIS
       FIRST
IND(2,2)=CHOICE MATRIX IN RIOS INTEGRATION METHOD, DIMENSIONLESS
INTOPT=INTEGRATION OPTION:
        0 - MARTINI METHOD
        1 - RIOS METHOD
IOPT   =OPTION FOR OPTIMIZATION:
        0 - NO OPTIMIZATION,
        1 - DO OPTIMIZATION.
IP     =INDICATED POWER OUTPUT FOR HEAT ENGINE, WATTS
IR     =COUNTER TO ACCUMULATE RIOS INTEGRALS
ISIG   =NUMBER OF PRESSURES ADDED TO FIND AVERAGE PRESSURE, INTEGER
ITR    =INTEGER JUST LESS THAN XTR
ITYPE  =Array of flags to indicate integer input variables
IVAR   =NUMBER OF INDEPENDANT VARIABLES IN OPTIMIZATION ROUTINE,I
J      =INTEGER COUNTER
JCMP   =NODE NUMBER OF COMPRESSION SPACE
JCR    =INTEGER JUST GREATER THAN YCR
JEXP   =NODE NUMBER OF EXPANSION SPACE
JPWR   =POWER ADJUST OPTION:
        0 - ADJUST AVERAGE PRESSURE
        1 - ADJUST BORE SIZE
JQ     =INTEGER TRANSFER VARIABLE
JTR    =INTEGER JUST GREATER THAN YCR
K      =FIRST TIME COUNTER FLAG, INTEGER
K1     =FIRST TIME COUNTER FLAG, INTEGER
K2     =FIRST TIME COUNTER FLAG, INTEGER
K3     =CONSTANT IN REHEAT LOSS EQUATION (F28)
K3     =FIRST TIME COUNTER FLAG, INTEGER (F26)
K4     =FIRST TIME COUNTER FLAG, INTEGER
KA     =COEFFICIENT FOR GAS THERMAL CONDUCTIVITY CALCULATION
KB     =COEFFICIENT FOR GAS THERMAL CONDUCTIVITY CALCULATION
KG     =GAS THERMAL CONDUCTIVITY, WATTS/CM K
KK     =CP/CV
KM     =METAL THERMAL CONDUCTIVITY, WATTS/CM K
KMX    =THERMAL CONDUCTIVITY OF REGEN. MATRIX, WATTS/CM K
KR     =1./KK
L      =COUNTER TO DETERMINE NUMBER OF NODES AFTER GAS FLOW, INTEGER
LDOPT  =OPTION FOR CHOICE OF ENGINE LOAD,1-DASHPOT,2-HYDRAULIC PUMP,
        3-INERTIAL COMPRESSOR,4-LINEAR ALTERNATOR,I
M      =NUMBER OF MOLES OF GAS IN WORKING FLUID, GRAM MOLES
M1,M2,M3 =CONSTANTS TO CALCULATE VISCOSITY
MR0    =GAS INVENTORY TIMES GAS CONSTANT IN PAST, JOULE/DEG. K
```

```
MR1    =GAS INVENTORY TIMES GAS CONSTANT IN PRESENT, JOULE/DEG. K
MR2    =GAS INVENTORY TIMES GAS CONSTANT IN FUTURE, JOULE/DEG. K
MRCS0  =GAS INVENTORY TIMES GAS CONSTANT IN COLD SPACE IN PAST,
        JOULE/DEG. K
MRCS1  =GAS INVENTORY TIMES GAS CONSTANT IN COLD SPACE IN PRESENT,
        JOULE/DEG. K
MRCS2  =GAS INVENTORY TIMES GAS CONSTANT IN COLD SPACE IN FUTURE,
        JOULE/DEG. K
MRDBS0=GAS INVENTORY TIMES GAS CONSTANT IN DISPL. BOUNCE SPACE IN
        PAST, JOULE/DEG. K
MRDBS1=GAS INVENTORY TIMES GAS CONSTANT IN DISPL. BOUNCE SPACE IN
        PRESENT, JOULE/DEG. K
MRDBS2=GAS INVENTORY TIMES GAS CONSTANT IN DISPL. BOUNCE SPACE IN
        FUTURE,  JOULE/DEG. K
MRHS0  =GAS INVENTORY TIMES GAS CONSTANT IN HOT SPACE IN PAST,
        JOULE/DEG. K
MRHS1  =GAS INVENTORY TIMES GAS CONSTANT IN HOT SPACE IN PRESENT,
        JOULE/DEG. K
MRHS2  =GAS INVENTORY TIMES GAS CONSTANT IN HOT SPACE IN FUTURE,
        JOULE/DEG. K
MRPBS0=GAS INVENTORY TIMES GAS CONSTANT IN POWER PISTON BOUNCE SPACE
        IN PAST, JOULE/DEG. K
MRPBS1=GAS INVENTORY TIMES GAS CONSTANT IN POWER PISTON BOUNCE SPACE
        IN PRESENT, JOULE/DEG. K
MRPBS2=GAS INVENTORY TIMES GAS CONSTANT IN POWER PISTON BOUNCE SPACE
        IN FUTURE, JOULE/DEG. K
MU     =GAS VISCOSITY, G/CM/SEC
MW     =MOLECULAR WEIGHT, G/G MOLE
MX     =MASS OF REGENERATOR MATRIX, GRAMS
NCASE  =TOTAL NUMBER OF INPUT CASES CONSIDERED DURING OPTIMIZATION
        (MORE THAN THE NUMBER OF OPTIMIZATION VARIABLES SINCE EACH
        VARIABLE REQUIRES, IN GENERAL, PRESSURE ADJUSTMENT TO YIELD
        THE DESIRED POWER.)
NCH    =CHOICE NUMBER IN OPTIMIZATION ROUTINE
NCHBST=CHOICE NUMBER RELATING TO BEST EFFICIENCY
NCHMAX=MAXIMUM CHOICE NUMBER
NCLRTB=NUMBER OF COOLER SLOTS
NCYC   =NUMBER OF CYCLES FOR CURRENT SET OF GEOMETRICAL PARAMETERS AND
        OPERATING CONDITIONS; EQUALS TOTAL NUMBER OF CYCLES IF THERE
        IS NO OPTIMIZATION.
NCYCL  =NCYC WHEN NTRIAL CHANGES.
NCYCT  =TOTAL NUMBER OF CYCLES DURING OPTIMIZATION
NCYL   =NUMBER OF CYLINDERS PER ENGINE
NDF    =CASE NUMBER DEFINED BY USER
NDS    =NUMBER OF INTERVALS IN WHICH THE DEAD SPACE IS DIVIDED IN THE
        RIOS METHOD
NFRST  =FIRST TIME FLAG FOR OPTIMIZATION AND CONTROL
NGN    =CURRENT NUMBER OF GAS NODES
NHLPP  =NUMBER OF CENTERING PORTS IN THE POWER PISTON,
NHTRTB=NUMBER OF HEATER TUBES
NIN    =NDS+1
NO     =CHOICE NUMBER IN RIOS INTEGRATION METHOD
NPAJST=PRESSURE OR DIAMETER ADJUSTMENT FLAG
       0 -- NOT ADJUSTED
       1 -- ADJUSTED
```

```
NRADSH=NUMBER OF RADIATION SHIELDS IN DISPLACER
NRIOSL=OPTION ON LOSS EQUATIONS:
        0 - USE MARTINI LOSS EQUATIONS
        1 - USE RIOS LOSS EQUATIONS
NSHCUT=SHORT CUT FLAG IN OPTIMIZATION ROUTINE
NT    =NUMBER OF TRANSFER UNITS IN REGENERATOR
NTRIAL=COUNTER FOR NUMBER OF TRIALS IN OPTIMIZATION SEARCH
NTRLST=LAST NTRIAL
NTS   =NUMBER OF TIME STEPS PER CYCLE
NU    =ENGINE FREQUENCY, HZ
NXCORD =Adjusted  x  coordinate for input screen displav
OG    =OPTIONS FOR OPERATING GASES. 1-H2,2-HE,3-AIR,I
OPT(15)=ARRAY GIVING THE OPTIMIZATION NUMBERS IN THE ORDER IN WHICH
         THEY ARE TO BE TESTED, INTEGER
OPTFND=FLAG TO SHOW WHETHER OPTIMIZATION IS FOUND
        0 - NOT FOUND
        1 - FOUND
P1    =COMMON PRESSURE AFTER ADIABATIC TOTAL VOLUME CHANGE, MPA
P4    =PI/4
PAVGB =AVERAGE WORKING GAS PRESSURE,BAR
PBIC  =PRESSURE IN BOTTOM OF INERTIA PUMPING CHANBER, BAR
PDPBS0=PRESSURE IN DISPLACER BOUNCE SPACE IN PAST, MPA
PDPBS1=PRESSURE IN DISPLACER BOUNCE SPACE IN PRESENT, MPA
PDPBS2=PRESSURE IN DISPLACER BOUNCE SPACE IN FUTURE, MPA
PG    =AVERAGE GAS PRESSURE, MPA
PHASED=DISPLACER PHASE ANGLE,DEGREES
PHASEO=ORIGINAL INPUT DISPLACER PHASE ANGLE,DEGREES
PI    =3.14159
PMAX  =OUTLET PRESSURE OF PUMPED FLUID,BAR
PMAXR =PX/PG=DIMENSIONLESS MAXIMUM PRESSURE USED BY RIOS.
PMIN  =ABSOLUTE PRESSURE OF INLET FLUID,BAR
PN    =MINIMUM PRESSURE, MPA
PNEW(200)=ARRAY OF NEW PRESSURES AFTER HEAT TRANSFER AT CONSTANT
          PRESSURE, MPA
POPT  =AVERAGE PRESSURE FOR OPTIMUM CASE, MPA
PORMTX=POROSITY OF MATRIX,%
PP    =0.006894 MPA/PSIA
PPCLR =POWER PISTON CLEARANCE (ON DIAMETER),MICROS
PPMAS =POWER PISTON MASS,KG
PPPBS0=PRESSURE IN POWER PISTON BOUNCE SPACE IN PAST, MPA
PPPBS1=PRESSURE IN POWER PISTON BOUNCE SPACE IN PRESENT, MPA
PPPBS2=PRESSURE IN POWER PISTON BOUNCE SPACE IN FUTURE, MPA
PPSLLT=POWER PISTON SEAL LENGTH,CM
PPSTR =POWER PISTON STROKE,CM
PPSTRO=ORIGINAL POWER PISTON STROKE,CM
PPSTRM=MAXIMUM POWER PISTON STROKE,CM
PR    =PRANDTL NUMBER TO THE 2/3 POWER
PRCNG =PERCENT CHANGE IN OPTIMIZATION SEARCH,%
PSTMAX=MAXIMUM POWER PISTON POSITION DURING CYCLE, CM
PSTMIN=MINIMUM POWER PISTON POSITION DURING CYCLE, CM
PTIC  =PRESSURE IN TOP INERTIAL PUMPING CHANBER, BAR
PWG0  =PRESSURE OF WORKING GAS IN THE PAST, MPA
PWG1  =PRESSURE OF WORKING GAS IN THE PRESENT, MPA
PWG2  =PRESSURE OF WORKING GAS IN THE FUTURE, MPA
PWGEND=PRESSURE OF WORKING GAS AT END OF CYCLE, MPA
PWRTGT=TARGET POWER FOR OPTIMIZATION,WATTS
```

```
PX     =MAXIMUM PRESSURE, MPA
QAPDX  =NET HEAT TRANS. FROM GAS IN APDX SPACE TO THE METAL, JOULES
QB     =BETA FOR SHUTTLE HEAT LOSS CALCULATION
QC     =HEAT ABSORBED BY COOLER, WATTS
QCCYL  =HEAT CONDUCTION THRU ALL CYLINDER WALLS OF ENGINE, WATTS
QCDSPW=HEAT CONDUCTION THRU ALL DISPLACER WALLS OF ENGINE, WATTS
QCGAS  =HEAT CONDUCTION THRU ALL GAS INSIDE CYLINDERS OF ENGINE, WATTS
QCLR   =HEAT ABSORBED FROM GAS BY COOLER, JOULES
QCMTX  =HEAT CONDUCTION THRU ALL REGEN. MATRICIES OF ENGINE, WATTS
QCRAD  =HEAT RADIATION INSIDE ALL DISPLACERS OF ENGINE, WATTS
QCRWL  =HEAT CONDUCTION THRU ALL REGENERATOR WALLS OF ENGINE, WATTS
QDK    =REHEAT FACTOR
QFS    =PUMPING LOSS FACTOR
QHTR   =NET HEAT TRANS. FROM HEATER TO GAS DURING ONE CYCLE, JOULES
QL1    =SHUTTLE FACTOR
QLM    =REHEAT FACTOR
QN     =NET HEAT REQUIRED FOR HEAT ENGINE, WATTS
QNCCR  =NET HEAT COND. AT THE COLD NODE OF THE REGENERATOR, JOULES
QNCHR  =NET HEAT COND. AT THE HOT NODE OF THE REGENERATOR, JOULES
QNCMR  =NET HEAT COND. AT THE MIDDLE NODE OF THE REGENERATOR, JOULES
QNPH   =REHEAT PRESSURIZATION EFFECT
QNTU   =NUMBER OF REGENERATOR TRANSFER UNITS, DIMENSIONLESS
QP     =PUMPING OR APPENDIX LOSS FOR ALL CYLINDERS, WATTS
QPRIOS=WINDAGE FACTOR, RIOS ANALYSIS
QQ     =TRANSFER REAL VARIABLE
QR1    =REGENERATOR WINDAGE LOSS COMPONENT, WATTS
QR2    =REGENERATOR WINDAGE LOSS COMPONENT, WATTS
QR3    =REGENERATOR WINDAGE LOSS COMPONENT, WATTS
QRATO1(8,9)=ARRAY OF RATIOS FOR HYDROGEN OR AIR BETWEEN ADIABATIC HEAT
             INPUT AND ISOTHERMAL HEAT INPUT DEPENDING CLRATO, TRATIO.
QRATO2(8,9)=ARRAY OF RATIOS FOR HELIUM BETWEEN ADIABATIC HEAT INPUT
             AND ISOTHERMAL HEAT INPUT DEPENDING CLRATO, TRATIO.
QREG   =NET HEAT TRANSFERRED FROM THE GAS TO THE REGENERATOR DURING ONE
        CYCLE, JOULES
QS     =SHUTTLE LOSS FOR ALL CYLINDERS, WATTS
QTOT   =TOTAL HEAT TRANSFERRED FROM GAS FOR ONE CYCLE, JOULES
QTRAN  =HEAT TRANSFERRED BY ONE NODE FROM GAS TO METAL, JOULES
R      =GAS CONSTANT, 8.314 JOULE/(G MOLE*K)
RA     =0.0174533 RADIANS PER DEGREE
RCRDAN=RADIAL CLEARANCE OF ROD SEAL ANNULUS, CM
RCSLAN=RADIAL CLEARANCE OF SEAL ANNULUS ON POWER PISTON, CM
RD     =TOTAL REGENERATOR DEAD VOLUME, CU. CM.
RDFLT  =Array of default values for real input variables
RDMC(360)=ARRAY OF DIMENSIONLESS MASS CHANGES IN COLD SPACE FOR RIOS
          LOSS EQUATIONS
RDMW   =MASS GAS CONSTANT=R/MW, JOULES/(GM*K)
RDPR(360)=ARRAY OF DIMENSIONLESS PRESSURE CHANGES
RDVC(360)=ARRAY OF DIMENSIONLESS VOLUME CHANGES IN COLD SPACE.
RDVW   =RIOS DIMENSIONLESS VOLUME CHANGE IN THE HOT SPACE.
RE     =REYNOLDS NUMBER, HEATER OR COOLER
REC    =REYNOLDS NUMBER IN COOLER
REGLTH=REGENERATOR LENGTH,CM
REH    =REYNOLDS NUMBER IN HEATER
RER    =REGENERATOR REYNOLDS NUMBER FACTOR
RERIOS(3)=REYNOLDS NUMBER IN THE REGENERATOR BY THE RIOS ANALYSIS
RH     =REHEAT LOSS FOR ALL CYLINDERS IN AN ENGINE, WATTS
```

```
RHOLK =GAS DENSITY THROUGH LEAK, G./CC
RHOM  =METAL DENSITY,G/CC
RM    =GAS DENSITY IN GENERAL, G/CC
RMU   =GAS VISCOSITY IN REGENERATOR, G/SEC/CM
RNTU  =NUMBER OF HEAT TRANSFER UNITS IN REGENERATOR, DIMENSIONLESS
RP    =MAXIMUM PRESSURE/MINIMUM PRESSURE
RPR(360)=ARRAY OF DIMENSIONLESS PRESSURES
RR    =REGENERATOR REYNOLDS NUMBER
RRDMW(360)=ARRAY OF DIMENSIONLESS MASS CHANGES IN HOT SPACE
RT    =REYNOLDS NUMBER, HEATER
RVT   =DISPLACED MASS RATIO
RW    =REGENERATOR WINDAGE, WATTS, FOR ALL CYLINDERS IN ENGINE
RZ    =REYNOLDS NUMBER, COOLER
SANREG=THICKNESS OF ANNULAR REGENERATOR, CM
SCYLW1=THICKNESS OF INNER CYLINDER WALL,CM
SCYLW2=THICKNESS OF OUTER CYLINDER WALL,CM
SDSPST=STORAGE FOR INPUT VALUE DSPSTR
SDSPW =THICKNESS OF DISPLACER WALL,CM
SIG   =STEFAN-BOLTZMAN CONSTANT = 5.67E-12 WATTS/(CM**2*K**4)
SIGPBS=SUM OF ALL BOUNCE SPACE PRESSURES FOR CYCLE, MPA
SIGPWG=SUM OF ALL WORKING GAS PRESSURES FOR CYCLE, MPA
SIGXPP=SUM OF ALL POWER PISTON POSITIONS FOR CYCLE, CM
SL    =TEMPERATURE SWING LOSS FOR FULL ENGINE, WATTS
SPD   =ENGINE SPEED, RADIANS/SEC
SPHASE=STORAGE FOR INPUT VALUE PHASED
SPHTAC=SPECIFIC HEAT TRANSFER AREA IN COOLER, CM**2 OF HEAT TRANS.
       AREA PER CM**3 OF GAS
SPHTAH=SPECIFIC HEAT TRANSFER AREA IN HEATER, CM**2 OF HEAT TRANS.
       AREA PER CM**3 OF GAS
SPHTAR=SPECIFIC HEAT TRANSFER AREA IN REGENERATOR, CM**2 OF HEAT TRANS.
       AREA PER CM**3 OF GAS
SPHZ  =ENGINE SPEED, HZ
SPPSTR=STORAGE FOR INPUT VALUE PPSTR
ST    =STANTON NUMBER TIMES PRANDTL NUMBER TO THE 2/3 POWER
TCMP  =EFFECTIVE COMPRESSION SPACE TEMPERATURE, K
TCMPC =EFFECTIVE COMPRESSION SPACE TEMPERATURE, C
TCMPL =TCMP FOR LAST CYCLE
TCR   =RATIO OF THERMAL CAPACITY OF TIDAL GAS TO THERMAL CAPACITY
       OF MATRIX, DIMENSIONLESS
TDM   =THERMAL DIFFUSIFITY OF METAL, SQ. CM/SEC
TDMAX =TIME FROM START OF CYCLE TO MAXIMUM DISPLACER POSITION, SEC.
TDMIN =TIME FROM START OF CYCLE TO MINIMUM DISPLACER POSITION, SEC.
TEXP  =EFFECTIVE EXPANSION SPACE TEMPERATURE, K
TEXPC =EFFECTIVE EXPANSION SPACE TEMPERATURE, C
TEXPL =TEXP FOR LAST CYCLE
TGN(2,200)=TEMPERATURE OF GAS NODES BEFORE AND AFTER FLOW, K
TMCLRC=METAL TEMPERATURE OF GAS COOLER,DEG.C
TMCMPK=TEMP. METAL IN COMPRESSION SPACE HEAT EXCHANGER, K
TMET  =TEMP. OF METAL OPPOSITE MID-POINT OF GAS NODE, K
TMEXPK=TEMP. METAL IN EXPANSION SPACE HEAT EXCHANGER, K
TMHTRC=METAL TEMPERATURE OF GAS HEATER,DEG.C
TMPNAM =Variable name input by user
TMPVAL =Variable value input by user
TPMAX =TIME FROM START OF CYCLE TO MAXIMUM POWER PISTON POSITION, SEC.
TPMIN =TIME FROM START OF CYCLE TO MINIMUM POWER PISTON POSITION, SEC.
TR    =REGENERATOR TEMPERATURE, K
TR3C  =TEMPERATURE OF COLD THIRD OF REGENERATOR MATRIX, K
```

```
TR3H   =TEMPERATURE OF HOT THIRD OF REGENERATOR MATRIX, K
TR3M   =TEMPERATURE OF MIDDLE THIRD OF REGENERATOR MATRIX, K
TRATIO=EFFECTIVE GAS TEMPERATURE RATIO, DIMENSIONLESS
TSPCYC=TIME STEPS PER CYCLE, REAL
TSTEP =TIME STEP USED DURING FORCE BALANCE SIMULATION,MILLI-SECONDS
TWLM   =TEMPERATURE WAVE LENGTH IN METAL, CM
TXW    =CUMULATIVE TEMPERATURE TIMES MASS, K*GM
UDM(5)=CRITICAL MASS FLOW VALUES FROM SUBPLOT
UI23   =CRITICAL PRESSURE DROP VALUE, RIOS ALALYSIS
UI24   =CRITICAL PRESSURE DROP VALUE, RIOS ALALYSIS
UI33   =CRITICAL PRESSURE DROP VALUE, RIOS ALALYSIS
UI34   =CRITICAL PRESSURE DROP VALUE, RIOS ALALYSIS
UIN(5)=CRITICAL PRESSURE DROP INTEGRALS FROM SUBPLOT
UTR    =(HOT METAL TEMP, K)/(COLD METAL TEMP, K)
V1     =VELOCITY HEAD LOSSES IN HEATER DUE TO BENDS, ENTRANCE AND EXIT
V2     =VELOCITY HEAD LOSSES IN COOLER DUE TO BENDS, ENTRANCE AND EXIT
VA     =VAPDX
VAPDX =VOLUME OF APPENDIX GAS, CM**3
VB     =CUMULATIVE VOLUME FROM HOT END THRU EXPANSION SPACE, CC
VC     =(F28) VELOCITY THROUGH GAS COOLER OR CONNECTING DUCT, CM/SEC
VC     =(F26) CUMULATIVE VOLUME FROM HOT END THRU HEATER, CC
VC0    =COLD VOLUME IN THE PAST,CC
VC1    =COLD VOLUME IN THE PRESENT, CC
VC2    =COLD VOLUME IN THE FUTURE, CC
VCMAX =MAXIMUM COLD VOLUME FOR THE CYCLE, CC
VCMIN =MINIMUM COLD VOLUME FOR THE CYCLE, CC
VD     =CUMULATIVE VOLUME FROM HOT END THRU REGENERATOR, CC
VDPBS0=VOLUME OF DISPLACER BOUNCE SPACE IN PAST, CC
VDPBS1=VOLUME OF DISPLACER BOUNCE SPACE IN PRESENT, CC
VDPBS2=VOLUME OF DISPLACER BOUNCE SPACE IN FUTURE, CC
VDRIOS=DIMENSIONLESS DEAD VOLUME, RIOS
VDSP0 =VELOCITY OF THE DISPLACER IN THE PAST, CM/SEC
VDSP1 =VELOCITY OF DISPLACER IN THE PRESENT, CM/SEC
VDSP2 =VELOCITY OF DISPLACER IN THE FUTURE, CM/SEC
VE     =CUMULATIVE VOLUME FROM HOT END THRU COOLER, CC
VGN(2,200)=CUMULATIVE VOLUME OF GAS NODES FROM HOT END BEFORE AND AFTER
          FLOW, CC
VH     =VELOCITY THROUGH GAS HEATER, CM/SEC
VH0    =HOT VOLUME IN THE PAST, CC
VH1    =HOT VOLUME IN THE PRESENT, CC
VH2    =HOT VOLUME IN THE FUTURE, CC
VHEND =HOT VOLUME AT END OF CYCLE, CC
VHFRST=HOT VOLUME AT START OF CYCLE, CC
VHMAX =MAXIMUM HOT VOLUME FOR CYCLE, CC
VHMIN =MINIMUM HOT VOLUME FOR CYCLE, CC
VHZERO=HOT VOLUME AT MIDPOINT OF DISPLACER STROKE, CC
VMDPT =CUMULATIVE VOLUME TO MID-POINT OF GAS NODE, CC
VN     =MINIMUM TOTAL VOLUME, CU CM
vname  =Array of input variable names
VOLBS =VOLUME OF BOUNCE SPACE,LITERS
VOLDSP=VOLUME DISPLACER GAS SPRING (AVG),CC
VPP0  =VELOCITY OF POWER PISTON IN THE PAST, CM/SEC
VPP1  =VELOCITY OF POWER PISTON IN THE PRESENT, CM/SEC
VPP2  =VELOCITY OF POWER PISTON IN THE FUTURE, CM/SEC
VPPBS0=VOLUME OF POWER PISTON BOUNCE SPACE IN THE PAST, CC
VPPBS1=VOLUME OF POWER PISTON BOUNCE SPACE IN THE PRESENT, CC
```

```
VPPBS2=VOLUME OF POWER PISTON BOUNCE SPACE IN THE FUTURE, CC
VRGS  =REST GAS VOLUME OF GAS SPRING, CC
VT0   =TOTAL WORKING GAS VOLUME IN THE PAST, CC
VT1   =TOTAL WORKING GAS VOLUME IN THE PRESENT, CC
VT2   =TOTAL WORKING GAS VOLUME IN THE FUTURE, CC
VTEND =TOTAL WORING GAS VOLUME AT END OF CYCLE, CC
VTFRST=TOTAL WORKING GAS VOLUME AT FIRST OF NEXT CYCLE, CC
VTMAX =MAXIMUM WORKING GAS VOLUME, CC
VX    =MAXIMUM TOTAL VOLUME, CU CM
W1    =WORK OUTPUT FOR ONE CYCLE, JOULES
W1A   =UNCORRECTED WORK OUTPUT FOR ONE CYCLE, JOULES
W1CYC =COMPLETE UNCORRECTED WORK OUTPUT FOR FULL CYCLE, JOULES
W1END =CORRECTION TO WORK OUTPUT AT END OF CYCLE, JOULES
W1M1  =FIRST IMMEDIATE PAST W1
W1M2  =SECOND IMMEDIATE PAST W1
W2    =HEAT INPUT FOR ONE CYCLE AND ONE CYLINDER, JOULES
W2A   =UNCORRECTED HEAT INPUT FOR ONE CYCLE, JOULES
W2COMP=APPROXIMATE WORK TO COMPLETE HEAT INPUT INTEGRAL TO START OF
       FIRST CYCLE, JOULES
W2CYC =COMPLETE UNCORRECTED HEAT INPUT FOR FULL CYCLE, JOULES
W2END =CORRECTION TO HEAT INPUT AT END OF CYCLE, JOULES
W2M1  =FIRST IMMEDIATE PAST W2
W2M2  =SECOND IMMEDIATE PAST W2
WC    =CONSTANT FLOW RATE INTO OR OUT OF COMPRESSION SPACE, G/SEC
WCRIOS=DIMENSIONLESS COLD WORK, RIOS
WCUM  =CUMULATIVE MASS, GM (USED TO FIND TOTAL MASS WHEN NODES ARE
       COMBINED)
WGM   =WORKING GAS MASS
WGN(2,200)=MASSES OF GAS IN NODES BEFORE AND AFTER FLOW, GRAMS
WH    =CONSTANT FLOW RATE INTO OR OUT OF EXPANSION SPACE, G/SEC
WKINT =WORK OUTPUT INTEGRAL, JOULES
WLHC  =WALL LENGTH FOR HEAT CONDUCTION,CM
WR    =CONSTANT FLOW RATE THRU REGENERATOR, G/SEC
WRATO1(8,9)=ARRAY OF RATIOS FOR HYDROGEN OR AIR BETWEEN ADIABATIC
            WORK AND ISOTHERMAL WORK DEPENDING CLRATO, TRATIO.
WRATO2(8,9)=ARRAY OF RATIOS FOR HELIUM BETWEEN ADIABATIC WORK
            AND ISOTHERMAL WORK DEPENDING CLRATO, TRATIO.
WWRIOS=DIMENSIONLESS HOT WORK
X     =DUMMY REAL VARIABLE
X1    =CONVERGENCE CRITERIA
X2    =CONVERGENCE CRITERIA
X3    =TEMPORARY VARIABLES
X4    =TEMPORARY VARIABLES
XB    =WALL EFFECT PARAMETER
XBP   =LENGTH OF DEAD BAND PORT,CM
XCOORD =Array of  x  coordinates for input screen display
XDSP0 =POSITION OF DISPLACER FROM ZERO POINT IN THE PAST, CM
XDSP1 =POSITION OF DISPLACER FROM ZERO POINT IN THE PRESENT, CM
XDSP2 =POSITION OF DISPLACER FROM ZERO POINT IN THE FUTURE, CM
XDSPMX=MAXIMUM DIPLACER POSITION FROM NULL,CM
XI1   =PRESSURE DROP INTEGRAL - ACCOUNTS FOR THE RELATIONSHIP BETWEEM
       THE SHAPES OF MASS AND PRESSURE FLUCTUATIONS
XI2   =INFLUENCE OF MASS FLOW TIME VARIATION ON THE HEAT TRANSFER
XI3   =XI1/XI2
XINT  =BASIC PRESSURE DROP INTEGRAL, RIOS
XNDS  =NDS
```

```
XNHT   =VALUE OF EXPONENT IN HEAT TRANS. RELATION OF REGENERATOR MATRIX
XP     =LENGTH OF DOUBLE ACTING HYDRAULIC PISTON,CM
XP1    =X COORDINATE AT START OF PLOTTED LINE, 0.<XP1<1.0
XP2    =X COORDINATE AT END OF PLOTTED LINE, 0.<XP2<1.0
XPP0   =POSITION OF POWER PISTON IN THE PAST, CM
XPP1   =POSITION OF POWER PISTON IN THE PRESENT, CM
XPP2   =POSITION OF POWER PISTON IN THE FUTURE, CM
XPPMX  =MAXIMUM POWER PISTON FROM NULL, CM
XTR    =TRATIO IN UNITS OF ARRAYS QRATO AND WRATO, DIMENSIONLESS
XX     =TEMPORARY VARIABLE
XY     =RATIO OF NEW TO OLD GAS TEMPERATURES AFTER VOLUME CHANGE
Y      =TEMPORARY VARIABLE
YCOORD =Array of  y  coordinates for input screen display
YCR    =CLRATO IN UNITS OF ARRAYS QRATO AND WRATO, DIMENSIONLESS
YK     =WALL EFFECT FACTOR IN SHUTTLE HEAT LOSS
YP1    =Y COORDINATE AT START OF PLOTTED LINE, 0.<YP1<1.0
YP2    =Y COORDINATE AT END OF PLOTTED LINE, 0.<YP2<1.0
YY     =TEMPORARY VARIABLE
Z      =TEMPORARY VARIABLE
ZH     =TOTAL STATIC HEAT CONDUCTION LOSS FOR COMPLETE ENGINE, WATTS
```

APPENDIX C

VARIABLE USE TABLE

(VARTAB.NOM)

******************** VARTAB.NOM **********4-13-84************

This table shows all the variables and where they are generated and where they are used. For brevity the file names are used rather than the subroutine names.

Name Variable	Common Block	Gen. in File N.	Used in -------- File numbers ---	Comments ---------------
A		F3	F3	LOCAL VARIABLE
AA	INPUT	FPSE	All	I 86
AC	INTMED	F21	F28	
ADCORH	OUTPUT	F28	F3	
ADCORP	OUTPUT	F28	F3	
AF		F21	F21	LOCAL VARIABLE
AFC		F28	F28	LOCAL VARIABLE
AFH		F28	F28	LOCAL VARIABLE
AFL		F21	F21	LOCAL VARIABLE
AFR		F28	F28	LOCAL VARIABLE
AH	INTMED	F21	F28	
AHT		F28	F28	LOCAL VARIABLE
AHTN		F26	F26	LOCAL VARIABLE
ALDPS	INPUT	FPSE	All	I 79
ALPH	INTMED	F21	F28	
ANSWER		FPSE	FPSE	CHARACTER
AP	INTMED	F21	F22, 23, 21	
APMAR	INTMED	F21	F22, 23, 21	
ARG		F28	F28	LOCAL VARIABLE
B	OUTPUT	F28	F3	
BB	INPUT	FPSE	All	I 87
BBEST	OUTPUT	F28	F3	
BH	OUTPUT	F28	F3	
BHL		F28	F28	LOCAL VARIABLE
BNCOEF	INPUT	FPSE	all	I 39
BNVOL	INTMED	F21	F28	
BP	OUTPUT	F28	F3	
BPL		F28	F28	LOCAL VARIABLE
C1		F2	F2	LOCAL VARIABLE
C2		F2	F2	LOCAL VARIABLE
C3		F2	F2	LOCAL VARIABLE
C4		F2	F2	LOCAL VARIABLE
CALCNU	INTMED	F27	F28	
CALCSP	OUTPUT	F28	F3	
CD	INTMED	F21	F22, F23, F26, F27, F28	
CDSPT	INPUT	FPSE	All	I 82
CELECT	INPUT	FPSE	All	I 75
CF	OUTPUT	F28	F3	
CFLOW	INTMED	F23	F28	
CHMTX(19)	OPTI	F42	F42	
CLDDV	INPUT	FPSE	All	I 44
CLEND	INPUT	FPSE	All	I 81
CLK	INTMED	F21	F24	
CLKDP	INTMED	F21	F24	
CLRATO		F28	F28	LOCAL VARIABLE
CMTXN	INTMED	F21	F26	

*Note: Sverdrup Technology has combined the files W. Martin' used for his programs as follows

F1.FOR contains FPSE.FOR and FPIN.FOR
FPIN.FOR replaces F1.FOR, F11.FOR, & F12.FOR
F2A.FOR contains F2.FOR and F21.FOR
F2B.FOR contains F22.FOR through F28.FOR
F3.FOR contains F3.FOR, F4.FOR, F41.FOR, & F42.FOR

Name	Common	Gen. in	Used in	[illegible]
CMU		F28	F28	[illegible]
CN	INTMED	F2	F28	
CNDCYL	INTMED	F21	F28	
CNDDSP	INTMED	F21	F28	
CNDRW	INTMED	F21	F28	
CNTIM	INTMED	F2	F23	
CNTH		F28	F28	[illegible]
CNVCRT	INPUT	FPSE	All	I 83
CONDMX	INTMED	F21	F26	
COR		F28	F28	LOCAL VARIABLE
CP	INTMED	F21	F28	
CPM	INPUT	FPSE	All	I 89
CTDPTH	INPUT	FPSE	All	I [illegible]
CTLNTH	INPUT	FPSE	All	I [illegible]
CTWIDT	INPUT	FPSE	All	I 70
CV	INTMED	F21	F28, F26	
CW		F21, 28	F21, 28	LOCAL VARIABLE
CX	INTMED	F2	F28	
CXTIM	INTMED	F2	F25	
CYCTIM		F2	F2	[illegible]
CYLOFS	INPUT	FPSE	[illegible]	
[illegible]		F27, 28	F27, 28	LOCAL VARIABLE
DELF		F28	F28	LOCAL VARIABLE
DEGFVT	INPUT	FPSE	All	I 12
DFCDT		F2	F2	LOCAL VARIABLE
DFCDTM	INTMED	F2	F28	
DFHDT		F2	F2	LOCAL VARIABLE
DFHDTM	INTMED	F2	F28	
DIAPP	INPUT	FPSE	All	I 24
DICYL	INPUT	FPSE	All	I 28
[illegible]	INTMED	F21	F28	
DISPMS	INPUT	FPSE	All	I [illegible]
DMC		F27	F27	LOCAL VARIABLE
DMR1		F24	F24	LOCAL VARIABLE
DMR2		F24	F24	LOCAL VARIABLE
DMR3		F24	F24	LOCAL VARIABLE
DMR4		F24	F24	LOCAL VARIABLE
DMRF		F28	F28	LOCAL VARIABLE
DMW		F27	F27	LOCAL VARIABLE
[illegible]	INPUT	FPSE	All	I 45
[illegible]	INPUT	FPSE	All	I 52
[illegible]	INPUT	FPSE	All	I 51
[illegible]	INPUT	FPSE	All	I 48
DP		GU		
DP1		F21	F21	LOCAL VARIABLE
DP2		F21	F21	LOCAL VARIABLE
[illegible]		F28	F28	LOCAL VARIABLE
DPH		F28	F28	LOCAL VARIABLE
DPPP		F21	F21	LOCAL VARIABLE
DPR		F28	F28	LOCAL VARIABLE
[illegible]	INTMED	F21	F23	
[illegible]	INPUT	FPSE	All	I [illegible]
[illegible]	INPUT	FPSE	All	I [illegible]
[illegible]	INPUT	FPSE	All	I [illegible]
[illegible]	INPUT	FPSE	All	I [illegible]

Name	Common	Gen. in	Used in --------	Comments ---------------
DSPCLR	INPUT	FPSE	All	I 37
DSPLTH	INPUT	FPSE	All	I 25
DSPMAX		F2	F2	LOCAL VARIABLE
DSPMIN		F2	F2	LOCAL VARIABLE
DSPSTR	INPUT	FPSE	All	I 07
DSTRMX	INPUT	FPSE	All	I 21
DTC		F28	F28	LOCAL VARIABLE
DTH		F28	F28	LOCAL VARIABLE
DTS	INTMED	F21	F22,F23,F24,F26,F27	
DTSCP		F24	F24	LOCAL VARIABLE
DTSOV		F2	F2	LOCAL VARIABLE
DW	INTMED	F21	F28	
DWIRE	INPUT	FPSE	All	I 64
DX		F28	F28	LOCAL VARIABLE
ELTIME	INTMED	F22	F23,F25,F27	
EMIS	INPUT	FPSE	All	I 95
F1		F28	F28	LOCAL VARIABLE
F3		F28	F28	LOCAL VARIABLE
FA		F21	F21	LOCAL VARIABLE
FANG1		F2	F2	LOCAL VARIABLE
FANG2		F2	F2	LOCAL VARIABLE
FAREG		F21,28	F21,28	LOCAL VARIABLE
FBALDS		F23	F23	LOCAL VARIABLE
FBALPP		F23	F23	LOCAL VARIABLE
FC		F28	F28	LOCAL VARIABLE
FC0	INTMED	F2	F28	
FC1	INTMED	F2	F28	
FC2	INTMED	F2	F28	
FCR		F28	F28	LOCAL VARIABLE
FDMC	RIOS	F27	F28	
FDMW	RIOS	F27	F28	
FDPR	RIOS	F27	F28	
FDVC	RIOS	F27	F28	
FDVW		F27	F27	LOCAL VARIABLE
FE		F21	F21	LOCAL VARIABLE
FEXPR	INPUT	FPSE	All	I 40
FFF	INTMED	F21	F28	
FGVDSP	INTMED	F21	F23	
FGVPP	INTMED	F21	F23	
FH		F28	F28	LOCAL VARIABLE
FH0	INTMED	F2	F28	
FH1	INTMED	F2	F28	
FH2	INTMED	F2	F28	
FLOAD		F23	F23	LOCAL VARIABLE
FMDSP(4)	ADAMS	F22	F23	
FMPP(4)	ADAMS	F22	F23	
FN		F21	F21	LOCAL VARIABLE
FORG(19)	OPTI	F42	F3	
FR		F28	F28	LOCAL VARIABLE
FRAD	INTMED	F21	F28	
FRDRCP	INTMED	F21	F24	
FRPPCP	INTMED	F21	F24	
FRRIOS		F28	F28	LOCAL VARIALBE
FTR		F28	F28	LOCAL VARIABLE
FTRL(19)		F42	F42	LOCAL VARIABLE

Name	Common	Gen. in	Used in --------	Comments -----------
GA	INTMED	F21	F26	
GAP	INPUT	FPSE	All	I 26
GC		F21,28	F28,21	LOCAL VARIABLE
GDMS(11)		F28	F28	LOCAL VARIABLE
GH		F28	F28	LOCAL VARIABLE
GI2(11)		F28	F28	LOCAL VARIABLE
GI3(11)		F28	F28	LOCAL VARIABLE
GINT(11)		F28	F28	LOCAL VARIABLE
GLH		F28	F28	LOCAL VARIABLE
GLR		F28	F28	LOCAL VARIABLE
GLS		F28	F28	LOCAL VARIABLE
GR		F21,28	F21,28	LOCAL VARIABLE
GRAOPT	INPUT	FPSE	All	I 11
GRL		F28	F28	LOCAL VARIABLE
GVTMAG	INPUT	FPSE	All	I 13
H(5)		F28	F28	LOCAL VARIABLE
HAC		F28	F28	LOCAL VARIABLE
HAV		F28	F28	LOCAL VARIABLE
HC	INTMED	F26	F28	
HCV		F28	F28	LOCAL VARIABLE
HD	INTMED	F21	F21,22,23,26,27,28	
HEC		F28	F28	LOCAL VARIABLE
HGV		F28	F28	LOCAL VARIABLE
HH	INTMED	F26	F28	
HHC		F28	F28	LOCAL VARIABLE
HHV		F28	F28	LOCAL VARIABLE
HLLNCY	INPUT	FPSE	All	I 47
HLLNDP	INPUT	FPSE	All	I 50
HLLNPP	INPUT	FPSE	All	I 54
HMU		F28	F28	LOCAL VARIABLE
HN	INTMED	F2	F25	
HNTIM	INTMED	F2	F25	
HNTU		F28	F28	LOCAL VARIABLE
HRV		F28	F28	LOCAL VARIABLE
HTDV	INPUT	FPSE	All	I 43
HTID	INPUT	FPSE	All	I 58
HTLNGH	INPUT	FPSE	All	I 57
HTUHLH	INPUT	FPSE	All	I 59
HW	OUTPUT	F28	F3	
HX	INTMED	F2	F25	
HXTIM	INTMED	F2	F25	
HY	INTMED	F28	F26,28	
I		All	All	LOCAL VARIABLE
ICALC	INPUT	FPSE	All	I 15
ICR		F28	F28	LOCAL VARIABLE
IDFLT		FPIN	FPIN	Local variable
IEND1		F2	F2	LOCAL VARIABLE
IEND2		F2	F2	LOCAL VARIABLE
IFIRST		F2	F2	LOCAL VARIABLE
IND(2,2)	INTMED	F27	F27	
INTOPT	INPUT	FPSE	All	I 32
IOPT	INPUT	FPSE	All	I 16
IP	OUTPUT	F28	F3	
IR	RIOS	F27	F28	
ISIG		F2	F2	LOCAL [illegible]
ITR		F28	F28	LOCAL [illegible]

Name	Common	Gen. in	Used in --------	Comments --------------
ITYPE		FPIN	FPIN	Local variable
IVAR	INPUT	FPSE	All	I 17
J		F2,26	F2,26	LOCAL VARIABLE
JCMP		F26	F26	LOCAL VARIABLE
JCR		F28	F28	LOCAL VARIABLE
JEXP		F26	F26	LOCAL VARIABLE
JPWR	INPUT	FPSE	All	I 08
JQ		F12	F12	LOCAL VARIABLE
JTR		F28	F28	LOCAL VARIABLE
K		F26	F26	LOCAL VARIABLE
K1		F26	F26	LOCAL VARIABLE
K2		F26	F26	LOCAL VARIABLE
K3		F28,26	F28,26	LOCAL VARIABLE
K4		F26	F26	LOCAL VARIABLE
KA		F21	F21	LOCAL VARIABLE
KB		F21	F21	LOCAL VARIABLE
KG	INTMED	F21	F28	
KK	INTMED	F21	F23,26,27	
KM	INTMED	F21	F28	
KMX	INTMED	F21	F28	
KR	INTMED	F21	F26	
L		F26,27	F26,27	LOCAL VARIABLE
LDOPT	INPUT	FPSE	All	I 14
M		F28	F28	LOCAL VARIABLE
M1	INTMED	F21	F28	
M2	INTMED	F21	F28	
M3	INTMED	F21	F28	
MR0	INTMED	F24	F25	
MR1	INTMED	F27	F27	
MR2	INTMED	F24	F27	
MRCS0	INTMED	F27	F27	
MRCS1	INTMED	F27	F27	
MRCS2	INTMED	F27	F27	
MRDBS0	INTMED	F24	F27	
MRDBS1	INTMED	F24	F27	
MRDBS2	INTMED	F24	F27	
MRHS0	INTMED	F27	F27	
MRHS1	INTMED	F27	F27	
MRHS2	INTMED	F27	F27	
MRPBS0	INTMED	F24	F27	
MRPBS1	INTMED	F24	F27	
MRPBS2	INTMED	F24	F27	
MU		F21,28	F28,21	LOCAL VARIABLE
MW	INTMED	F21	F28	
MX		F28	F28	LOCAL VARIABLE
NCASE	OUTPUT			
NCH	OUTPUT	F4	F3	
NCHBST	OUTPUT	F4	F3	
NCHMAX	OUTPUT	F4	F3	
NCLRTB	INPUT	FPSE	All	I 69
NCYC	OUTPUT	FPSE	F28,3	
NCYCL	OUTPUT	F4	F41	
NCYCT	OUTPUT			
NCYL	INPUT	FPSE	All	I 20
NDF	INPUT	FPSE	All	I 09
NDS		F28	F28	LOCAL VARIABLE

Name	Common	Gen. in	Used in --------	Comments --------------
NFRST	OUTPUT	F4	F3	
NGN	INPUT	FPSE	All	I 45
NHLPP	INPUT	FPSE	All	I 55
NHTRTB	INPUT	FPSE	All	I 56
NIN		F28	F28	LOCAL VARIABLE
NO	INTMED	F27	F27	
NPAJST	OUTPUT			
NRADSH	INPUT	FPSE	All	I 94
NRIOSL	INPUT	FPSE	All	I 96
NSHCUT	OUTPUT	F4	F3	
NT		F28	F28	LOCAL VARIABLE
NTRIAL	OUTPUT	F4	F3	
NTRLST	OUTPUT	F4	F41	
NTS	INPUT	FPSE	All	I 46
NU	INTMED	F21	F28	
NXCORD		FPIN	FPIN	Local variable
OG	INPUT	FPSE	All	I 02
OPT(1)	OPTI	FPSE	F42	I101
OPT(2)	OPTI	FPSE	F42	I102
OPT(3)	OPTI	FPSE	F42	I103
OPT(4)	OPTI	FPSE	F42	I104
OPT(5)	OPTI	FPSE	F42	I105
OPT(6)	OPTI	FPSE	F42	I106
OPT(7)	OPTI	FPSE	F42	I107
OPT(8)	OPTI	FPSE	F42	I108
OPT(9)	OPTI	FPSE	F42	I109
OPT(10)	OPTI	FPSE	F42	I110
OPT(11)	OPTI	FPSE	F42	I111
OPT(12)	OPTI	FPSE	F42	I112
OPT(13)	OPTI	FPSE	F42	I113
OPT(14)	OPTI	FPSE	F42	I114
OPT(15)	OPTI	FPSE	F42	I115
OPTFND	OUTPUT	F4	F3	
P1		F26	F26	LOCAL VARIABLE
P4	INTMED	F21	F28	
PAVGB	INPUT	FPSE	All	I 01
PBIC	INTMED	F27	F27	
PDPBS0	INTMED	F24	F27	
PDPBS1	INTMED	F24	F27	
PDPBS2	INTMED	F24	F27	
PG	INTMED	F21	F28,3	
PHASED	INPUT	FPSE	All	I 05
PHASEO		F2	F2	LOCAL VARIABLE
PI	INTMED	F21	F28	
PMAX	INPUT	FPSE	All	I 80
PMAXR		F28	F28	LOCAL VARIABLE
PMIN	INPUT	FPSE	All	I 78
PIN	INTMED	F2	F28	
PNEW(200)		F26	F26	LOCAL VARIABLE
POPT	F42	F42	F42	
PORMTX	INPUT	FPSE	All	I 65
PP	INTMED	F21	F28	
PPCLR	INPUT	FPSE	All	I 33
PPMAS	INPUT	FPSE	All	I 30
PPPBS0	INTMED	F24	F27	
PPPBS1	INTMED	F24	F27	

Name	Common	Gen. in	Used in --------	Comments --------------
PPPBS2	INTMED	F24	F27	
PPSLLT	INPUT	FPSE	All	I 34
PPSTR	INPUT	FPSE	All	I 06
PPSTRM	INPUT	FPSE	All	I 22
PPSTRO		F2	F2	LOCAL VARIABLE
PR	INTMED	F21	F28	
PRCNG	INPUT	FPSE	All	I 19
PSTMAX		F2	F2	LOCAL VARIABLE
PTIC	INTMED	F27	F27	
PWG0	INTMED	F27	F27	
PWG1	INTMED	F23	F24, 25, 26, 27	
PWG2	INTMED	F25	F26, 27	
PWGEND		F2	F2	LOCAL VARIABLE
PWRTGT	INPUT	FPSE	All	I 18
PX	INTMED	F2	F28	
QAPDX		F26, 2	F26, 2	LOCAL VARIABLE
QB		F28	F28	LOCAL VARIABLE
QC		F28	F28	LOCAL VARIABLE
QCCYL	OUTPUT	F28	F3	
QCDSPW	OUTPUT	F28	F3	
QCGAS	OUTPUT	F28	F3	
QCLR		F26, 2	F26, 2	LOCAL VARIABLE
QCMTX	OUTPUT	F28	F3	
QCRAD	OUTPUT	F28	F3	
QCRWL	OUTPUT	F28	F3	
QDK		F28	F28	LOCAL VARIABLE
QFS		F28	F28	LOCAL VARIABLE
QHTR		F26, 2	F26, 2	LOCAL VARIABLE
QL1		F28	F28	LOCAL VARIABLE
QLM		F28	F28	LOCAL VARIABLE
QN	OUTPUT	F28	F3	
QNCCR		F26	F26	LOCAL VARIABLE
QNCHR		F26	F26	LOCAL VARIABLE
QNCMR		F26	F26	LOCAL VARIABLE
QNPH		F28	F28	LOCAL VARIABLE
QNTU		F28	F28	LOCAL VARIABLE
QP	OUTPUT	F28	F3	
QPRIOS		F28	F28	LOCAL VARIABLE
QQ		F12	F12	LOCAL VARIABLE
QR1		F28	F28	LOCAL VARIABLE
QR2		F28	F28	LOCAL VARIABLE
QR3		F28	F28	LOCAL VARIABLE
QRATO1(8, 9)		F28	F28	LOCAL VARIABLE
QRATO2(8, 9)		F28	F28	LOCAL VARIABLE
QREG		F26, 2	F26, 2	LOCAL VARIABLE
QS	OUTPUT	F28	F3	
QTOT		F26	F26	LOCAL VARIABLE
QTRAN		F26	F26	LOCAL VARIABLE
R	INTMED	F21	F24, 28	
RA	INTMED	F21	F22	
RCRDAN		F21	F21	LOCAL VARIABLE
RCSLAN		F21	F21	LOCAL VARIABLE
RD	INTMED	F21	F22, 23, 25, 26, 27, 28	
RDFLT		FPIN	FPIN	Local variable
RDMC(360)	RIOS	F27	F28	
RDMW	INTMED	F21	F26	

Name	Common	Gen. in	Used in	Comments
RDPR(360)	RIOS	F27	F28	
RDVC(360)	RIOS	F27	F28	
RDVW		F27	F27	LOCAL VARIABLE
RE		F21,28	F21,28	LOCAL VARIABLE
REC		F28	F28	LOCAL VARIABLE
REGLTH	INPUT	FPSE	All	I 62
REH		F28	F28	LOCAL VARIABLE
RER		F28	F28	LOCAL VARIABLE
RERIOS(3)		F28	F28	LOCAL VARIABLE
RH	OUTPUT	F28	F3	
RHOLK		F21	F21	LOCAL VARIABLE
RHOM	INPUT	FPSE	All	I 88
RM		F21,28	F21,28	LOCAL VARIABLE
RMU		F28	F28	LOCAL VARIABLE
RNTU		F28	F28	LOCAL VARIABLE
RP		F28	F28	LOCAL VARIABLE
RPR(360)	RIOS	F27	F28	
RR		F28	F28	LOCAL VARIABLE
RRDMW(360)	RIOS	F27	F28	
RT		F28	F28	LOCAL VARIABLE
RVT		F28	F28	LOCAL VARIABLE
RW	OUTPUT	F28	F3	
RZ		F28	F28	LOCAL VARIABLE
SANREG	INPUT	FPSE	All	I 63
SCYLW1	INPUT	FPSE	All	I 92
SCYLW2	INPUT	FPSE	All	I 91
SDSPST	FPIST	FPSE	FPSE	
SDSPW	INPUT	FPSE	All	I 93
SIG		F21	F21	LOCAL VARIABLE
SIGPBS		F2	F2	LOCAL VARIABLE
SIGPWG		F2	F2	LOCAL VARIABLE
SIGXPP		F2	F2	LOCAL VARIABLE
SL	OUTPUT	F28	F3	
SPD		F28	F28	LOCAL VARIABLE
SPHASE	FPIST	FPSE	FPSE	
SPHTAC	INTMED	F21	F26	
SPHTAH	INTMED	F21	F26	
SPHTAR	INTMED	F21	F26	
SPHZ	INPUT	FPSE	All	I 29
SPPSTR	FPIST	FPSE	FPSE	
ST		F28	F28	LOCAL VARIABLE
TCMP	INTMED	F21	F28,27	
TCMPC	OUTPUT	F28	F3	
TCMPL		F28	F28	LOCAL VARIABLE
TCR		F28	F28	LOCAL VARIABLE
TDM		F28	F28	LOCAL VARIABLE
TDMAX		F2	F2	LOCAL VARIABLE
TDMIN		F2	F2	LOCAL VARIABLE
TEXP	INTMED	F21	F28,27	
TEXPC	OUTPUT	F28	F3	
TEXPL		F28	F28	LOCAL VARIABLE
TGN(2,200)	INTMED	F21	F26	
TMCLRC	INPUT	FPSE	All	I 04
TMCMPK	INTMED	F21	F26,28	
TMET		F26	F26	LOCAL VARIABLE

Name	Common	Gen. in	Used in --------	Comments --------------
TMEXPK	INTMED	F21	F26,28	
TMHTRC	INPUT	FPSE	All	I 03
TMPNAM		FPIN	FPIN	Local variable
TMPVAL		FPIN	FPIN	Local variable
TPMAX		F2	F2	LOCAL VARIABLE
TPMIN		F2	F2	LOCAL VARIABLE
TR	INTMED	F21	F25,27,28	
TR3C	INTMED	F21	F26	
TR3H	INTMED	F21	F26	
TR3M	INTMED	F21	F26	
TRATIO		F28	F28	LOCAL VARIABLE
TSPCYC	OUTPUT	F28	F3	
TSTEP	INPUT	FPSE	All	I 10
TWLM		F28	F28	LOCAL VARIABLE
TXW		F26	F26	LOCAL VARIABLE
UDM(5)		F28	F28	LOCAL VARIABLE
UI23		F28	F28	LOCAL VARIABLE
UI24		F28	F28	LOCAL VARIABLE
UI33		F28	F28	LOCAL VARIABLE
UI34		F28	F28	LOCAL VARIABLE
UIN(5)		F28	F28	LOCAL VARIABLE
UTR		F28	F28	LOCAL VARIABLE
V1	INPUT	FPSE	All	I 60
V2	INPUT	FPSE	All	I 73
VA		F21,26	F21,26	LOCAL VARIABLE
VAPDX	INTMED	F21	F26,27	
VB		F21,26	F21,26	LOCAL VARIABLE
VC		F21,28,26	F21,28,26	LOCAL VARIABLE
VC0	INTMED	F27		
VC1	INTMED	F27,21,	F22,21	
VC2	INTMED	F27,22	F22,23,25	
VCMAX	INTMED	F22	F23	
VCMIN	INTMED	F22	F23	
VD		F21,26	F21,26	LOCAL VARIABLE
VDPBS0	INTMED	F21	F23,F24	
VDPBS1	INTMED	F21	F23,F24	
VDPBS2	INTMED	F21	F23,F24	
VDRIOS		F28	F28	LOCAL VARIABLE
VDSP0	INTMED	F2		
VDSP1	INTMED	F22	F23	
VDSP2	INTMED		F23	CHECK
VE		F21,26	F21,26	LOCAL VARIABLE
VGN(2,200)	INTMED	F21	F26	
VH		F28	F28	LOCAL VARIABLE
VH0	INTMED	F27		
VH1	INTMED	F22,21	F25,27,21	
VH2	INTMED	F22	F23,25,26,27	
VHEND		F2	F2	LOCAL VARIABLE
VHFRST		F2	F2	LOCAL VARIABLE
VHMAX	INTMED	F22	F23	
VHMIN	INTMED	F22	F23	
VHZERO		F2	F2	LOCAL VARIABLE
VMDPT		F26	F26	LOCAL VARIABLE
VN		F21	F21	LOCAL VARIABLE
VNAME		FPIN	FPIN	Local variable
VOLBS	INPUT	FPSE	All	I 42
VOLDSP	INPUT	FPSE	All	I 41
VPP0	INTMED	F2	F2	

Name	Common	Gen. in	Used in ---------	Comments ----------
VPP1	INTMED	F22	F23	
VPP2	INTMED	F22	F23	
VPPBS0	INTMED	F21	F23, F24	
VPPBS1	INTMED	F21	F23, F24	
VPPBS2	INTMED	F21	F23, F24	
VRGS	INPUT	FPSE	All	I 53
VT0	INTMED	F2	F2	
VT1	INTMED	F22	F25, 26	
VT2	INTMED	F22	F23, 25, 26	
VTEND		F2	F2	LOCAL VARIABLE
VTFRST		F2	F2	LOCAL VARIABLE
VTMAX	PLOT	F21	F2	
VX	INTMED	F21		
W1	INTMED	F2	F28	
W1A		F2	F2	LOCAL VARIABLE
W1CYC		F2	F2	LOCAL VARIABLE
W1M1		F2	F2	LOCAL VARIABLE
W1M2		F2	F2	LOCAL VARIABLE
W1END		F2	F2	LOCAL VARIABLE
W2	INTMED	F2	F28	
W2A		F2	F2	LOCAL VARIABLE
W2COMP		F2	F2	LOCAL VARIABLE
W2CYC		F2	F2	LOCAL VARIABLE
W2END		F2	F2	LOCAL VARIABLE
W2M1		F2	F2	LOCAL VARIABLE
W2M2		F2	F2	LOCAL VARIABLE
WC		F21, 28	F21, 28	LOCAL VARIABLE
WCRIOS	RIOS	F27	F28	
WCUM		F26	F26	LOCAL VARIABLE
WGM		F21	F21	LOCAL VARIABLE
WGN(2, 200)	INTMED	F21	F21, 26	
WH		F28	F28	LOCAL VARIABLE
WLHC	INPUT	FPSE	All	I 90
WR		F28	F28	LOCAL VARIABLE
WRATO1(8, 9)		F28	F28	LOCAL VARIABLE
WRATO2(8, 9)		F28	F28	LOCAL VARIABLE
WWRIOS	RIOS	F27	F28	
X		All	All	LOCAL VARIABLE
X1	INTMED	F28	F2	
X2	INTMED	F28	F2	
X3		F26, 23	F26, 23	LOCAL VARIABLE
X4		F26, 23	F26, 23	LOCAL VARIABLE
XB		F28	F28	LOCAL VARIABLE
XBP	INPUT	FPSE	All	I 77
XCOORD		FPIN	FPIN	Local variable
XDSP0	INTMED	F2		CHECK
XDSP1	INTMED	F22	F23	
XDSP2	INTMED	F22	F23	
XDSPMX	INTMED	F21	F22, 23	
XI1		F28	F28	LOCAL VARIABLE
XI2		F28	F28	LOCAL VARIABLE
XI3		F28	F28	LOCAL VARIABLE
XINT		F28	F28	LOCAL VARIABLE
XNDS		F28	F28	LOCAL VARIABLE
XNHT		F28	F28	LOCAL VARIABLE
XP	INPUT	FPSE	All	I 76

Name	Common	Gen. in	Used in --------	Comments ---------------
XP1		F2,28	F2,28	LOCAL VARIABLE
XP2		F2,28	F2,28	LOCAL VARIABLE
XPP0	INTMED	F2	F2	
XPP1	INTMED	F22	F23,24	
XPP2	INTMED	F22	F23,24	
XPPMX	INTMED	F21	F23	
XTR		F28	F28	LOCAL VARIABLE
XX		F26,21,24	F26,21,24	LOCAL VARIABLE
XY		F26,24	F26,24	LOCAL VARIABLE
Y		All	All	LOCAL VARIABLE
YCOORD		FPIN	FPIN	Local variable
YCR		F28	F28	LOCAL VARIABLE
YK		F28	F28	LOCAL VARIABLE
YP1		F2,28	F2,28	LOCAL VARIABLE
YP2		F2,28	F2,28	LOCAL VARIABLE
YY		F24,28	F24,28	LOCAL VARIABLE
Z		F24,22	F24,22	LOCAL VARIABLE
ZH		F28	F28	LOCAL VARIABLE

APPENDIX D

DERIVATION OF RIOS ADIABATIC ANALYSIS EQUATIONS

APPENDIX D - DERIVATION OF RIOS ADIABATIC ANALYSIS EQUATIONS

As a price for extending the contract, the method of integration of the equations assuming adiabatic hot and cold spaces used by Rios in his thesis is added to the program. The original MIT thesis bears a date of September 1969 and is entitled, "An Analytical and Experimental Investigation of the Stirling Cycle." It is on file at Martini Engineering as 1969am in the form of a microfilm and a white on black paper copy. It contains 180 pages.

The form of the equations used in the computer program in the second edition of the design manual are specially formulated to use dimensionless groups and to use cranks to move two pistons with fixed angle. Also inherent in the equations is the provision that the mass of gas remains constant. In this derivation we plan to keep the equations in a dimensional form so it will fit with the rest of the analysis and accept the quantities the rest of the analysis has to give it.

It is still assumed that during a cycle the gas in the heater is at a fixed temperature. Initially, this would be the heater metal temperature. At later iterations the effective heater gas temperature would be adjusted so that the heat that must be supplied to the engine can be transferred through the heat exchanger because of its area, heat transfer coefficient and the temperature drop between the heater metal temperature and the effective heater gas temperature.

It is also still assumed that the gas in the cooler is handled in the same way as the heater.

The gas in the regenerator is assumed to remain at the log mean temperature between heat source and heat sink metal temperatures. This temperature is what is used elsewhere in the program and is more correct than the arithmetic mean used by Rios.

The gas in the hot space is assumed to be adiabatic. However, its mass may never go to zero as the Rios computer program demands.

The gas in the cold space is handled in the same manner as the hot space.

Now the Rios's integration method must be adapted. He calculated arrays of reduced volumes and volume derivatives at the beginning of every degree of crank rotation and then half-way through every degree. In a free piston arrangement we do not have this information. The information at the beginning of the time increment was used to determine the pressure at the middle. The pressure at the middle of the time increment was used to calculate a truer derivative to calculate the pressure at the end of the time increment. In our computer program we only know the conditions according to the following table.

	Past, 0	Current, 1	Future, 2
Total volume	VTO	VT1	VT2
Hot volume[a]	VHO	VH1	VH2
Cold volume[b]	VCO	VC1	VC2
Pressure	PWGO	PWG1	?
Total working gas "mass"[c]	MRO	MR1	MR2
Hot space inventory[c]	MRHSO	MRHS1	?
Cold space inventory[c]	MRCSO	MRCS1	?

[a]Includes hot dead volume, HD in heater.
[b]Includes cold dead volume, CD in cooler.
[c]It is convenient to use the mass times the gas constant, units j/k.

Because of the rest of the computer program, we know everything about the future time step except what the pressure should be. Like Rios did, the way we will determine the future pressure is to determine the time derivative of pressure at the current time and use this to determine the future pressure based upon the past pressure. See figure D-1 for further details.

Because of leakage the working gas mass is not constant from time step to time step. Nevertheless, all the changes in gas inventory in the different part of the engine are equal to this gas inventory change.

$$d(MR)_{HS} + d(MR)_H + d(MR)_R + d(MR)_C + d(MR)_{CS} = d(MR)_{TOTAL} \qquad \text{(A-1)}$$

where MR = the mass in gram moles times the gas constant in j/g mol K. Units j/k.

$$PWG2 = PWG0 + \frac{dP}{dt}(2)(DTS) \qquad \text{(A-2)}$$

For either the hot space or cold space Rios starts with the differential form of the first law of thermodynamics

$$dE = dQ - pdV + hdm \qquad \text{(A-3)}$$

Since these spaces are assumed to be adiabatic, $dQ = 0$. The perfect gas relationship allows the above equation to be interpreted differently for gas entering and leaving the gas space. For gas entering (Rios is wrong at this point):

$$\underset{\substack{\text{energy change in}\\\text{contained gas due}\\\text{to temperature}\\\text{change}}}{\underline{mC_v dT}} = \underset{\substack{\text{energy change}\\\text{in contained}\\\text{gas due to}\\\text{volume change}}}{\underline{-pdV}} = \underset{\substack{\text{energy change in}\\\text{contained gas due}\\\text{due to gas flow}}}{\underline{C_p T * dm}} \qquad \text{(A-4)}$$

where:

m mass inventory of gas in hot or cold space, g mol

C_v heat capacity at constant volume, j/g mol °K

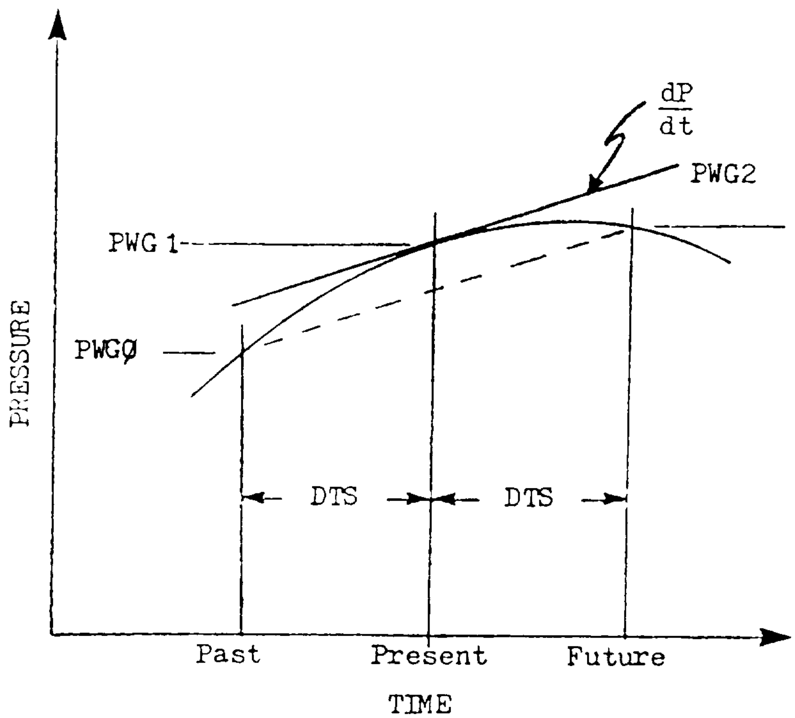

FIGURE D-1. SECOND-ORDER INTEGRATION METHOD.

dT differential temperature change, K

p pressure, MPa

dV differential volume change, cm^3

C_p heat capacity at constant pressure, j/g mol °K

T* temperature of the gas entering either from the heater or cooler, assumed to be constant, °K

dm differential change in gas inventory, g mol

Now use the perfect gas relationship.

$$PV = mRT \tag{A-5}$$

Differentiate assuming the mass is constant

$$PdV + VdP = mRdT \tag{A-6}$$

Now if equation (A-6) is solved for dT and substituted into equation (A-4) and the equation simplified, remembering that $R = C_p - C_v$, the results is as Rios states:

$$dm = \frac{PdV}{RT*} + \frac{1}{K}\ \frac{VdP}{RT*} \qquad \left[dm > 0\right] \tag{A-7}$$

where $K = C_p/C_v$

Now for the case where gas is leaving the hot or cold space, equation (A-3) translates to:

$$mC_v dT = -PdV + C_p Tdm \qquad \left[dm > 0\right] \tag{A-8}$$

(This is also different than what Rios has.)

The only new nomenclature is: T = temperature of the gas in the hot or cold space which is now leaving. Now if equation (A-5) is solved for T and substituted into equation (A-8), and if equation (A-6) is solved for dT and also substituted into equation (A-8), then as before equation (A 8) can be simplified and solved for dm to give

$$dm = m\left(\frac{dV}{V} + \frac{1}{K}\ \frac{dP}{P}\right) \qquad \left[dm > 0\right] \tag{A-9}$$

(This equation is the same as Rios shows.)

Now for each of the dead volumes, we can differentiate equation (A-5) knowing that V, R, and T are constant. Thus:

$$dm = \frac{VdP}{RT} \tag{A-10}$$

For each dead volume the volume and temperature would be different.

Now we need to translate these differential equations into difference equations using the values calculated in the rest of the program. Also, the rest of the computer program keeps track of mass in terms of MR. (see eq. (A-1)).

Thus, for the hot space, mass increasing:

$$d(MR)_{HS} = \frac{PWG1 * (VH2 - VH0)}{TEXP} + \frac{(VH1 - HD) * (PWG2 - PWG0)}{KK * TEXP} \tag{A-11}$$

(The nomenclature now is the same as the rest of the computer program). For the hot space mass decreasing:

$$d(MR)_{HS} = MRHS1 * \left(\frac{VH2 - VH0}{VH1 - HD} + \frac{PWG2 - PWG0}{KK * PWG1}\right) \tag{A-12}$$

Note here that MRHS1, the mass in MR units of the gas in the hot space at present time must be input at the start of the solution and kept track of during the solution. Rios was able to get a solution quickly because he did not have any adiabatic dead volume and the mass in both the hot and cold space could be reset to zero each cycle. In our solution, the initial value for MRHS will come from isothermal analysis. The value during the solution will be determined each time step using either equations (A-11) or (A-12).

Next, the dead volume differentials will be translated to difference equations. For the heater

$$d(MR)_H = \frac{HD * (PWG2 - PWG0)}{TEXP} \tag{A-13}$$

For the regenerator and appendix space:

$$d(MR)_R = \frac{(RD + VAPDX) * (PWG2 - PWG0)}{TR} \tag{A-14}$$

For the cooler:

$$d(MR)_C = \frac{VC * (PWG2 - PWG0)}{TCMP} \tag{A-15}$$

Then the cold space differential for mass increasing in the cold space is:

$$d(MR)_{CS} = \frac{PWG1 * (VC2 - VC0)}{TCMP} + \frac{(VC1 - CD) * (PWG2-PWG0)}{KK * TCMP} \tag{A-16}$$

And for mass decreasing:

$$d(MR)_{cs} = MRCS1 * \left(\frac{VC2 - VC0}{VC1 - CD} + \frac{PWG2 - PWG0}{KK * PWG1}\right) \qquad (A\text{-}17)$$

Here again, MRCS1 must be calculated initially using the isothermal analysis and then must be determined each time step using either equations (A-16) or (A-17).

Finally, the total working gas mass does change. Thus;

$$d(MR)_{total} = MR2 - MR0 \qquad (A\text{-}18)$$

Rios identified four cases that happen during the cycle. The table below defines these cases and shows what equations should be substituted into equation (A-1) and solved for PWG2.

Case	Hot space	Cold space	Equations to substitute in equation (A-1)
1	dm > 0	dm > 0	A-11, A-13, A-14, A-15, A-16, A-18
2	dm < 0	dm < 0	A-12, A-13, A-14, A-15, A-17, A-18
3	dm > 0	dm < 0	A-11, A-13, A-14, A-15, A-17, A-18
4	dm < 0	dm > 0	A-12, A-13, A-14, A-15, A-16, A-18

These substitutions were made and equation solved for PWG2. The results are given below. For all cases:

$$Z = \frac{HD}{TEXP} + \frac{RD + VAPDX}{TR} + \frac{CD}{TCMP} \qquad (A\text{-}19)$$

For Case 1:

$$X = MR2 - MR0 - PWG1 * \left(\frac{VH2 - VH0}{TEXP} + \frac{VC2 - VC0}{TCMP}\right)$$

$$Y = \frac{VH1 - HD}{KK * TEXP} + Z + \frac{VC1 - CD}{KK * TCMP} \qquad (A\text{-}20)$$

$$PWG2 = PWG0 + X/Y$$

For Case 2:

$$X = MR2 - MR0 - \frac{MRHS1 * (VH2 - VH0)}{(VH1 - HD)} - \frac{MRCS1 * (VC2 - VC0)}{(VC1 - CD)}$$

$$Y = \frac{MRHS1}{KK * PWG1} + Z + \frac{MRCS1}{KK * PWG1} \qquad (A\text{-}21)$$

$$PWG2 = PWG0 + X/Y$$

For Case 3:

$$X = MR2 - MRO - \frac{PWG1 * (VH2 - VHO)}{TEXP} - \frac{MRCS1 * (VC2 - VCO)}{VC1 - CD}$$

$$Y = \frac{VH1 - HD}{KK * TEXP} + Z + \frac{MRCS1}{KK * PWG1} \tag{A-22}$$

$$PWG2 = PWGO + X/Y$$

For Case 4:

$$X = MR2 - MRO - \frac{MRHS1(VH2 - VHO)}{VH1 - HD} - \frac{PWG1 * (VC2 - VCO)}{TCMP}$$

$$Y = \frac{MRSH1}{KK * PWG1} + Z + \frac{VC1 - CD}{KK * TCMP} \tag{A-23}$$

$$PWG2 = PWGO + X/Y$$

The program starts by choosing Case 4 since at zero time the displacer is in midstroke toward the hot end and the power piston has just started the expansion stroke.

After PWG2 is first calculated by equation (A-23), the mass increments in the hot space and cold space are calculated. The mass increment difference equations are:

For hot space mass increasing:

$$MRHS2 = MRHSO + \frac{PWG1 * (VH2 - VHO)}{TEXP} + \frac{(VH1 - HD) * (PWG2 - PWGO)}{KK * TEXP} \tag{A-24}$$

For hot space mass decreasing:

$$MRHS2 = MRHSO + MRHS1 * \left(\frac{VH2 - VHO}{VH1 - HD} + \frac{PWG2 - PWGO}{KK * PWG1}\right) \tag{A-25}$$

For cold space mass increasing:

$$MRCS2 = MRCSO + \frac{PWG1 * (VC2 - VCO)}{TCMP} + \frac{(VC1 - CD) * (PWG2 - PWGO)}{KK * TCMP} \tag{A-26}$$

For cold space mass decreasing:

$$MRCS2 = MRCSO + MRCS1 * \left(\frac{VC2 - VCO}{VC1 - CD} + \frac{PWG2 - PWGO}{KK * PWG1}\right) \tag{A-27}$$

The table below shows what equations will be used to calculate the masses of gas in the hot and cold gas spaces.

Case	MRHS2 calculation by equation	MRSC2 calculation by equation
1	A-24	A-26
2	A-25	A-27
3	A-24	A-27
4	A-25	A-26

Once the new masses are calculated we determine what case should be used for the next time increment by the sign of the mass derivatives.

This Rios integration method merely calculates the next pressure and determines the case for the next time increment. Other parts of the program determine convergence by noting very little change in either the hot space or the cold space effective temperature.

APPENDIX E

EFFECT OF CONVERGENCE CRITERIA ON RESULTS

(COMPUTER OUTPUT)

DOUBLE PRECISION

CONVERGENCE CRITERIA IS: .01000

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	37.8048	58.8702	6.3023	.1000
2	.62195	.70565	46.2809	61.7328	6.4564	.1000
3	.22421	.04863	32.0421	54.6293	6.2992	.1000
4	.30766	.11507	38.2409	63.0954	6.3203	.1000
5	.19346	.15497	38.1151	63.5116	6.2959	.1000
6	.00329	.00660	38.5291	64.1757	6.2831	.1000
7	.01086	.01046	38.8823	64.6377	6.2689	.1000
8	.00917	.00720	39.3185	65.3865	6.2570	.1000
9	.01122	.01158	39.5269	65.7471	6.2463	.1000
10	.00530	.00552	39.7069	66.0397	6.2465	.1000

CURRENT OPERATING CONDITIONS ARE:

01=	66.000	02=	2	03=	600.000	04=	40.000	05=	91.994
06=	2.250	07=	2.815	08=	0	09=	1	10=	.100
11=	0	12=	.000	13=	1.000	14=	4	15=	2
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	22	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0400	76=	1.0000	77=	3.0000	78=	1.0000	79=	4.0000
80=	20.0000	81=	.0100	82=	.1000	83=	.0100	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0	116=	0	117=	0	118=	0	119=	0
120=	0								

```
 ENTERED PRINT ROUTINE AFTER     10 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN       .0100
                    RUN#  1   FOR
                    SUNPOWER RE1000 ENGINE
                    FREE MOTIONS -- LINEAR ALTERNATOR
                         LOAD CONSTANT =     .040 N/(CM/SEC)**2.
                    ISOTHERMAL ANALYSIS WITH CORRECTIONS
                    MARTINI LOSS EQUATIONS
                    SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70       CHRG. PRESS., BAR   =      66.00
HEAT IN, DEG C =     600.00       HEAT OUT, DEG. C    =      40.00
W. GAS 1=H2,2=HE,3=AIR 2          PHASE ANG. DEGREES  =      91.99
POWER P.STR,CM =       2.25       DISPL. STROKE, CM   =       2.82
CALC.FREQ., HZ =      24.08       TIME STEPS/CYCLE    =     415.20

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                      HEAT REQUIREMENT, WATTS
  BASIC                 956.3337   BASIC                  1590.5554
  ADIABATIC CORR.       -42.6077   ADIABATIC CORR.          80.8164
  HEATER FLOW LOSS      -83.1802   REHEAT                  581.1259
  REGEN.FLOW LOSS      -106.2699   SHUTTLE                 123.9003
  COOLER FLOW LOSS       -5.2244   PUMPING                   8.1831
  INDICATED             719.0514   TEMP. SWING                .9977
                                   CYL. WALL COND.         195.0205
                                   DISPLCR WALL COND.       34.0720
--------------------------------   REGEN. WALL COND.        61.5455
INDICATED EFFICIENCY, %  28.14     CYL. GAS COND.            6.1455
                                   REGEN. MTX. COND.         4.6283
--------------------------------   RAD.INSIDE DISPL.         4.7949
EXP.SP.EFFECT.TEMP.,C   576.03     FLOW FRIC. CREDIT      -136.3151
COMP.SP.EFFECT.TEMP.,C   54.11     TOTAL HEAT TO ENG.     2555.4705
```

CONVERGENCE CRITERIA IS: .00500

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	37.8048	58.8702	6.3023	.1000
2	.62195	.70565	46.2809	61.7328	6.4564	.1000
3	.22421	.04863	32.0421	54.6293	6.2992	.1000
4	.30766	.11507	38.2409	63.0954	6.3203	.1000
5	.19346	.15497	38.1151	63.5116	6.2959	.1000
6	.00329	.00660	38.5291	64.1757	6.2831	.1000
7	.01086	.01046	38.8823	64.6377	6.2689	.1000
8	.00917	.00720	39.3185	65.3865	6.2570	.1000
9	.01122	.01158	39.5269	65.7471	6.2463	.1000
10	.00530	.00552	39.7069	66.0397	6.2465	.1000
11	.00455	.00445	39.9167	66.3575	6.2298	.0500
12	.00528	.00481	40.0654	66.5949	6.2245	.0500
13	.00373	.00358	40.2173	66.8346	6.2191	.0500

CURRENT OPERATING CONDITIONS ARE:

01=	66.000	02=	2	03=	600.000	04=	40.000	05=	93.119
06=	2.261	07=	2.827	08=	0	09=	1	10=	.100
11=	0	12=	.000	13=	1.000	14=	4	15=	2
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	22	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0400	76=	1.0000	77=	3.0000	78=	1.0000	79=	4.0000
80=	20.0000	81=	.0100	82=	.1000	83=	.0050	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0	116=	0	117=	0	118=	0	119=	0
120=	0								

```
 ENTERED PRINT ROUTINE AFTER     13 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN       .0050
                    RUN#  1    FOR
                    SUNPOWER RE1000 ENGINE
                    FREE MOTIONS -- LINEAR ALTERNATOR
                        LOAD CONSTANT =     .040 N/(CM/SEC)**2.
                    ISOTHERMAL ANALYSIS WITH CORRECTIONS
                    MARTINI LOSS EQUATIONS
                    SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70        CHRG. PRESS., BAR   =      66.00
HEAT IN, DEG C =     600.00        HEAT OUT, DEG. C    =      40.00
W. GAS 1=H2,2=HE,3=AIR 2           PHASE ANG. DEGREES  =      93.12
POWER P.STR,CM =       2.26        DISPL. STROKE, CM   =       2.83
CALC.FREQ., HZ =      24.07        TIME STEPS/CYCLE    =     830.79

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                      HEAT REQUIREMENT, WATTS
  BASIC                 968.1708    BASIC                  1608.9434
  ADIABATIC CORR.       -43.1398    ADIABATIC CORR.          81.7501
  HEATER FLOW LOSS      -84.2486    REHEAT                  582.2778
  REGEN.FLOW LOSS      -107.4881    SHUTTLE                 124.9339
  COOLER FLOW LOSS       -5.2915    PUMPING                   8.2534
  INDICATED             728.0027    TEMP. SWING               1.0050
                                    CYL. WALL COND.         194.9924
                                    DISPLCR WALL COND.       34.0671
--------------------------------    REGEN. WALL COND.        61.5366
INDICATED EFFICIENCY, %  28.27      CYL. GAS COND.            6.1446
                                    REGEN. MTX. COND.         4.6277
--------------------------------    RAD.INSIDE DISPL.         4.7926
EXP.SP.EFFECT.TEMP.,C   575.93      FLOW FRIC. CREDIT      -137.9927
COMP.SP.EFFECT.TEMP.,C   54.08      TOTAL HEAT TO ENG.     2575.3319
```

CONVERGENCE CRITERIA IS: .00200

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	37.8048	58.8702	6.3023	.1000
2	.62195	.70565	46.2809	61.7328	6.4564	.1000
3	.22421	.04863	32.0421	54.6293	6.2992	.1000
4	.30766	.11507	38.2409	63.0954	6.3203	.1000
5	.19346	.15497	38.1151	63.5116	6.2959	.1000
6	.00329	.00660	38.5291	64.1757	6.2831	.1000
7	.01086	.01046	38.8823	64.6377	6.2689	.1000
8	.00917	.00720	39.3185	65.3865	6.2570	.1000
9	.01122	.01158	39.5269	65.7471	6.2463	.1000
10	.00530	.00552	39.7069	66.0397	6.2465	.1000
11	.00455	.00445	39.9167	66.3575	6.2298	.0500
12	.00528	.00481	40.0654	66.5949	6.2245	.0500
13	.00373	.00358	40.2173	66.8346	6.2191	.0500
14	.00379	.00360	40.3440	67.0336	6.2089	.0500
15	.00315	.00298	40.4576	67.2126	6.2046	.0500
16	.00282	.00267	40.5659	67.3797	6.2003	.0500
17	.00268	.00249	40.6661	67.5358	6.1963	.0500
18	.00247	.00232	40.7583	67.6792	6.1927	.0500
19	.00227	.00212	40.8439	67.8117	6.1893	.0500
20	.00210	.00196	40.9234	67.9347	6.1861	.0500
21	.00195	.00181	41.0205	68.0787	6.1800	.0250
22	.00237	.00212	41.0960	68.1995	6.1767	.0250
23	.00184	.00178	41.1639	68.3054	6.1734	.0250

CURRENT OPERATING CONDITIONS ARE:

01=	66.000	02=	2	03=	600.000	04=	40.000	05=	91.836
06=	2.280	07=	2.849	08=	0	09=	1	10=	.100
11=	0	12=	.000	13=	1.000	14=	4	15=	2
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	22	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0400	76=	1.0000	77=	3.0000	78=	1.0000	79=	4.0000
80=	20.0000	81=	.0100	82=	.1000	83=	.0020	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0	116=	0	117=	0	118=	0	119=	0
120=	0								

```
 ENTERED PRINT ROUTINE AFTER    23 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN       .0020
                     RUN#  1   FOR
                     SUNPOWER RE1000 ENGINE
                     FREE MOTIONS -- LINEAR ALTERNATOR
                          LOAD CONSTANT =    .040 N/(CM/SEC)**2.
                     ISOTHERMAL ANALYSIS WITH CORRECTIONS
                     MARTINI LOSS EQUATIONS
                     SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70       CHRG. PRESS., BAR   =      66.00
HEAT IN, DEG C =     600.00       HEAT OUT, DEG. C    =      40.00
W. GAS 1=H2,2=HE,3=AIR 2          PHASE ANG. DEGREES =      91.84
POWER P.STR,CM =       2.28       DISPL. STROKE, CM   =       2.85
CALC.FREQ., HZ =      24.07       TIME STEPS/CYCLE    =    1662.09

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                     HEAT REQUIREMENT, WATTS
  BASIC                 990.6545   BASIC                   1643.8460
  ADIABATIC CORR.       -44.1679   ADIABATIC CORR.           83.5202
  HEATER FLOW LOSS      -86.4874   REHEAT                   591.0968
  REGEN.FLOW LOSS      -110.0525   SHUTTLE                  126.8023
  COOLER FLOW LOSS       -5.4339   PUMPING                    8.3916
  INDICATED             744.5129   TEMP. SWING                1.0313
                                   CYL. WALL COND.          194.9141
                                   DISPLCR WALL COND.        34.0534
--------------------------------   REGEN. WALL COND.         61.5119
INDICATED EFFICIENCY, %   28.43    CYL. GAS COND.             6.1422
                                   REGEN. MTX. COND.          4.6258
--------------------------------   RAD.INSIDE DISPL.          4.7870
EXP.SP.EFFECT.TEMP.,C   575.70     FLOW FRIC. CREDIT       -141.5136
COMP.SP.EFFECT.TEMP.,C   54.07     TOTAL HEAT TO ENG.      2619.2090
```

CONVERGENCE CRITERIA IS: .00100

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	37.8048	58.8702	6.3023	.1000
2	.62195	.70565	46.2809	61.7328	6.4564	.1000
3	.22421	.04863	32.0421	54.6293	6.2992	.1000
4	.30766	.11507	38.2409	63.0954	6.3203	.1000
5	.19346	.15497	38.1151	63.5116	6.2959	.1000
6	.00329	.00660	38.5291	64.1757	6.2831	.1000
7	.01086	.01046	38.8823	64.6377	6.2689	.1000
8	.00917	.00720	39.3185	65.3865	6.2570	.1000
9	.01122	.01158	39.5269	65.7471	6.2463	.1000
10	.00530	.00552	39.7069	66.0397	6.2465	.1000
11	.00455	.00445	39.9167	66.3575	6.2298	.0500
12	.00528	.00481	40.0654	66.5949	6.2245	.0500
13	.00373	.00358	40.2173	66.8346	6.2191	.0500
14	.00379	.00360	40.3440	67.0336	6.2089	.0500
15	.00315	.00298	40.4576	67.2126	6.2046	.0500
16	.00282	.00267	40.5659	67.3797	6.2003	.0500
17	.00268	.00249	40.6661	67.5358	6.1963	.0500
18	.00247	.00232	40.7583	67.6792	6.1927	.0500
19	.00227	.00212	40.8439	67.8117	6.1893	.0500
20	.00210	.00196	40.9234	67.9347	6.1861	.0500
21	.00195	.00181	41.0205	68.0787	6.1800	.0250
22	.00237	.00212	41.0960	68.1995	6.1767	.0250
23	.00184	.00178	41.1639	68.3054	6.1734	.0250
24	.00165	.00155	41.2236	68.3989	6.1703	.0250
25	.00145	.00137	41.2788	68.4830	6.1674	.0250
26	.00134	.00123	41.3313	68.5642	6.1646	.0250
27	.00127	.00119	41.3795	68.6376	6.1619	.0250
28	.00117	.00107	41.4247	68.7077	6.1594	.0250
29	.00109	.00102	41.4659	68.7713	6.1569	.0250
30	.00099	.00093	41.5042	68.8297	6.1572	.0250

CURRENT OPERATING CONDITIONS ARE:

01=	66.000	02=	2	03=	600.000	04=	40.000	05=	91.614
06=	2.287	07=	2.857	08=	0	09=	1	10=	.100
11=	0	12=	.000	13=	1.000	14=	4	15=	2
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	22	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0400	76=	1.0000	77=	3.0000	78=	1.0000	79=	4.0000
80=	20.0000	81=	.0100	82=	.1000	83=	.0010	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0

```
 ENTERED PRINT ROUTINE AFTER    30 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN       .0010
                   RUN#  1   FOR
                   SUNPOWER RE1000 ENGINE
                   FREE MOTIONS -- LINEAR ALTERNATOR
                        LOAD CONSTANT =     .040 N/(CM/SEC)**2.
                   ISOTHERMAL ANALYSIS WITH CORRECTIONS
                   MARTINI LOSS EQUATIONS
                   SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70       CHRG. PRESS., BAR   =     66.00
HEAT IN, DEG C =     600.00       HEAT OUT, DEG. C    =     40.00
W. GAS 1=H2,2=HE,3=AIR 2          PHASE ANG. DEGREES =     91.61
POWER P.STR,CM =       2.29       DISPL. STROKE, CM   =      2.86
CALC.FREQ., HZ =      24.06       TIME STEPS/CYCLE    =   1662.19

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                     HEAT REQUIREMENT, WATTS
  BASIC                  998.7834  BASIC                   1656.3628
  ADIABATIC CORR.        -44.5415  ADIABATIC CORR.           84.1547
  HEATER FLOW LOSS       -87.3130  REHEAT                   593.8710
  REGEN.FLOW LOSS       -110.9985  SHUTTLE                  127.4825
  COOLER FLOW LOSS        -5.4867  PUMPING                    8.4418
  INDICATED              750.4436  TEMP. SWING                1.0402
                                   CYL. WALL COND.          194.8838
                                   DISPLCR WALL COND.        34.0481
--------------------------------   REGEN. WALL COND.         61.5023
INDICATED EFFICIENCY, %  28.48     CYL. GAS COND.             6.1412
                                   REGEN. MTX. COND.          4.6251
--------------------------------   RAD.INSIDE DISPL.          4.7850
EXP.SP.EFFECT.TEMP.,C  575.62      FLOW FRIC. CREDIT       -142.8122
COMP.SP.EFFECT.TEMP.,C  54.05      TOTAL HEAT TO ENG.      2634.5262
```

CONVERGENCE CRITERIA IS: .00050

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	37.8048	58.8702	6.3023	.1000
2	.62195	.70565	46.2809	61.7328	6.4564	.1000
3	.22421	.04863	32.0421	54.6293	6.2992	.1000
4	.30766	.11507	38.2409	63.0954	6.3203	.1000
5	.19346	.15497	38.1151	63.5116	6.2959	.1000
6	.00329	.00660	38.5291	64.1757	6.2831	.1000
7	.01086	.01046	38.8823	64.6377	6.2689	.1000
8	.00917	.00720	39.3185	65.3865	6.2570	.1000
9	.01122	.01158	39.5269	65.7471	6.2463	.1000
10	.00530	.00552	39.7069	66.0397	6.2465	.1000
11	.00455	.00445	39.9167	66.3575	6.2298	.0500
12	.00528	.00481	40.0654	66.5949	6.2245	.0500
13	.00373	.00358	40.2173	66.8346	6.2191	.0500
14	.00379	.00360	40.3440	67.0336	6.2089	.0500
15	.00315	.00298	40.4576	67.2126	6.2046	.0500
16	.00282	.00267	40.5659	67.3797	6.2003	.0500
17	.00268	.00249	40.6661	67.5358	6.1963	.0500
18	.00247	.00232	40.7583	67.6792	6.1927	.0500
19	.00227	.00212	40.8439	67.8117	6.1893	.0500
20	.00210	.00196	40.9234	67.9347	6.1861	.0500
21	.00195	.00181	41.0205	68.0787	6.1800	.0250
22	.00237	.00212	41.0960	68.1995	6.1767	.0250
23	.00184	.00178	41.1639	68.3054	6.1734	.0250
24	.00165	.00155	41.2236	68.3989	6.1703	.0250
25	.00145	.00137	41.2788	68.4830	6.1674	.0250
26	.00134	.00123	41.3313	68.5642	6.1646	.0250
27	.00127	.00119	41.3795	68.6376	6.1619	.0250
28	.00117	.00107	41.4247	68.7077	6.1594	.0250
29	.00109	.00102	41.4659	68.7713	6.1569	.0250
30	.00099	.00093	41.5042	68.8297	6.1572	.0250
31	.00092	.00085	41.5512	68.9007	6.1544	.0125
32	.00113	.00103	41.5852	68.9540	6.1519	.0125
33	.00082	.00077	41.6171	69.0032	6.1507	.0125
34	.00077	.00071	41.6463	69.0483	6.1495	.0125
35	.00070	.00065	41.6722	69.0883	6.1484	.0125
36	.00062	.00058	41.6961	69.1249	6.1472	.0125
37	.00057	.00053	41.7183	69.1589	6.1462	.0125
38	.00053	.00049	41.7386	69.1903	6.1451	.0125
39	.00049	.00045	41.7574	69.2189	6.1441	.0125

CURRENT OPERATING CONDITIONS ARE:

01=	66.000	02=	2	03=	600.000	04=	40.000	05=	91.597
06=	2.292	07=	2.863	08=	0	09=	1	10=	.100
11=	0	12=	.000	13=	1.000	14=	4	15=	2
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	22	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135

70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0400	76=	1.0000	77=	3.0000	78=	1.0000	79=	4.0000
80=	20.0000	81=	.0100	82=	.1000	83=	.0005	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0	116=	0	117=	0	118=	0	119=	0
120=	0								

```
 ENTERED PRINT ROUTINE AFTER    39 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN      .0005
                   RUN#  1   FOR
                   SUNPOWER RE1000 ENGINE
                   FREE MOTIONS -- LINEAR ALTERNATOR
                        LOAD CONSTANT =     .040 N/(CM/SEC)**2.
                   ISOTHERMAL ANALYSIS WITH CORRECTIONS
                   MARTINI LOSS EQUATIONS
                   SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70       CHRG. PRESS., BAR    =      66.00
HEAT IN, DEG C =     600.00       HEAT OUT, DEG. C     =      40.00
W. GAS 1=H2,2=HE,3=AIR 2          PHASE ANG. DEGREES =      91.60
POWER P.STR,CM =       2.29       DISPL. STROKE, CM    =       2.86
CALC.FREQ., HZ =      24.06       TIME STEPS/CYCLE     =    3324.99

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                      HEAT REQUIREMENT, WATTS
  BASIC                 1004.6925   BASIC                     1665.4221
  ADIABATIC CORR.        -44.8123   ADIABATIC CORR.             84.6140
  HEATER FLOW LOSS       -87.8469   REHEAT                     595.4148
  REGEN.FLOW LOSS       -111.6095   SHUTTLE                    128.0116
  COOLER FLOW LOSS        -5.5209   PUMPING                      8.4771
  INDICATED              754.9029   TEMP. SWING                  1.0454
                                    CYL. WALL COND.            194.8632
                                    DISPLCR WALL COND.          34.0445
 --------------------------------   REGEN. WALL COND.           61.4958
INDICATED EFFICIENCY, %  28.54      CYL. GAS COND.               6.1406
                                    REGEN. MTX. COND.            4.6246
 --------------------------------   RAD.INSIDE DISPL.            4.7836
EXP.SP.EFFECT.TEMP.,C   575.56      FLOW FRIC. CREDIT         -143.6517
COMP.SP.EFFECT.TEMP.,C   54.05      TOTAL HEAT TO ENG.        2645.2857
```

APPENDIX F

EFFECT OF CONVERGENCE CRITERIA ON RESULTS

(COMPUTER OUTPUT)

SINGLE PRECISION

Convergence criteria is: .01000

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa
1	.00000	.00000	37.8047	60.0275	6.3023
2	.62195	.69986	46.2530	36.5713	6.4682
3	.22347	.39076	30.9251	23.0194	6.2259
4	.33139	.37056	40.7464	59.2616	6.2110
5	.31758	1.57442	41.3248	70.1108	6.2858
6	.01420	.18307	39.4081	67.4282	6.3029
7	.04638	.03826	38.7702	64.0875	6.2768
8	.01619	.04954	39.1211	64.3247	6.2653
9	.00905	.00370	39.4816	65.0930	6.2538
10	.00922	.01194	39.6682	65.6441	6.2436
11	.00473	.00847	39.8061	65.9583	6.2444

ENTERED PRINT ROUTINE AFTER 11 CYCLES.
Fractional change in two successive integrals of heat in and power out has been less than .0100

RUN# 17 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .040 N/(cm/sec)**2.
ISOTHERMAL ANALYSIS WITH CORRECTIONS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	66.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2,2=HE,3=AIR	2	PHASE ANG. DEGREES =	92.00
POWER P.STR,CM =	2.25	DISPL. STROKE, CM =	2.82
CALC.FREQ., HZ =	24.08	TIME STEPS/CYCLE =	415.22

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	958.6682	BASIC	1588.5030
ADIABATIC CORR.	-42.6793	ADIABATIC CORR.	80.7161
HEATER FLOW LOSS	-83.4276	REHEAT	581.9340
REGEN.FLOW LOSS	-106.5504	SHUTTLE	124.1131
COOLER FLOW LOSS	-5.2400	PUMPING	8.1986
INDICATED	720.7709	TEMP. SWING	1.0001
		CYL. WALL COND.	195.0585
		DISPLCR WALL COND.	34.0786
		REGEN. WALL COND.	61.5575
INDICATED EFFICIENCY, %	28.22	CYL. GAS COND.	6.1467
		REGEN. MTX. COND.	4.6292
		RAD.INSIDE DISPL.	4.7959
EXP.SP.EFFECT.TEMP.,C	575.06	FLOW FRIC. CREDIT	-136.7028
COMP.SP.EFFECT.TEMP.,C	54.06	TOTAL HEAT TO ENG.	2554.0290

```
Convergence criteria is:     .00500
```

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa
1	.00000	.00000	37.8047	60.0275	6.3023
2	.62195	.69986	46.2530	36.5713	6.4682
3	.22347	.39076	30.9251	23.0194	6.2259
4	.33139	.37056	40.7464	59.2616	6.2110
5	.31758	1.57442	41.3248	70.1108	6.2858
6	.01420	.18307	39.4081	67.4282	6.3029
7	.04638	.03826	38.7702	64.0875	6.2788
8	.01619	.04954	39.1211	64.3247	6.2653
9	.00905	.00370	39.4816	65.0930	6.2538
10	.00922	.01194	39.6682	65.6441	6.2436
11	.00473	.00847	39.8061	65.9583	6.2444
12	.00348	.00479	39.9427	66.2037	6.2347

ENTERED PRINT ROUTINE AFTER 12 CYCLES.
Fractional change in two successive integrals of heat in and power out has been less than .0050

RUN# 16 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .040 N/(cm/sec)**2.
ISOTHERMAL ANALYSIS WITH CORRECTIONS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	66.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2, 2=HE, 3=AIR	2	PHASE ANG. DEGREES =	92.43
POWER P.STR, CM =	2.25	DISPL. STROKE, CM =	2.82
CALC.FREQ., HZ =	24.08	TIME STEPS/CYCLE =	415.23

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	961.9366	BASIC	1594.3800
ADIABATIC CORR.	-42.8316	ADIABATIC CORR.	81.0140
HEATER FLOW LOSS	-83.7306	REHEAT	582.0237
REGEN.FLOW LOSS	-106.9005	SHUTTLE	124.3927
COOLER FLOW LOSS	-5.2596	PUMPING	8.2193
INDICATED	723.2144	TEMP. SWING	1.0017
		CYL. WALL COND.	195.0430
		DISPLCR WALL COND.	34.0759
		REGEN. WALL COND.	61.5525
INDICATED EFFICIENCY, %	28.25	CYL. GAS COND.	6.1462
		REGEN. MTX. COND.	4.6289
		RAD. INSIDE DISPL.	4.7949
EXP.SP.EFFECT.TEMP.,C	576.02	FLOW FRIC. CREDIT	-137.1808
COMP.SP.EFFECT.TEMP.,C	54.06	TOTAL HEAT TO ENG.	2560.0920

Convergence criteria is: .00200

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa
1	.00000	.00000	37.8047	60.0275	6.3023
2	.62195	.69986	46.2530	36.5713	6.4682
3	.22347	.39076	30.9251	23.0194	6.2259
4	.33139	.37056	40.7464	59.2616	6.2110
5	.31756	1.57442	41.3248	70.1108	6.2858
6	.01420	.18307	39.4081	67.4282	6.3029
7	.04638	.03826	38.7702	64.0875	6.2788
8	.01619	.04954	39.1211	64.3247	6.2653
9	.00905	.00370	39.4816	65.0930	6.2538
10	.00922	.01194	39.6682	65.6441	6.2436
11	.00473	.00847	39.8061	65.9583	6.2444
12	.00348	.00479	39.9427	66.2037	6.2347
13	.00343	.00372	40.0639	66.4439	6.2259
14	.00304	.00363	40.1962	66.6812	6.2176
15	.00330	.00357	40.3235	66.9181	6.2096
16	.00316	.00355	40.4371	67.1508	6.2126
17	.00282	.00348	40.5389	67.3278	6.2048
18	.00252	.00264	40.6207	67.5063	6.1981
19	.00202	.00265	40.7115	67.6369	6.1916
20	.00223	.00193	40.7972	67.7382	6.1854
21	.00210	.00150	40.8833	67.9155	6.1897
22	.00211	.00262	40.9621	68.0445	6.1834
23	.00193	.00190	41.0171	68.1564	6.1779

ENTERED PRINT ROUTINE AFTER 23 CYCLES.
Fractional change in two successive integrals of heat
in and power out has been less than .0020

RUN# 16 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .040 N/(cm/sec)**2.
ISOTHERMAL ANALYSIS WITH CORRECTIONS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	66.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2, 2=HE, 3=AIR	2	PHASE ANG. DEGREES =	91.90
POWER P.STR, CM =	2.28	DISPL. STROKE, CM =	2.84
CALC.FREQ., HZ =	24.08	TIME STEPS/CYCLE =	415.21

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	987.8560	BASIC	1641.4800
ADIABATIC CORR.	-44.0377	ADIABATIC CORR.	83.4007
HEATER FLOW LOSS	-86.3844	REHEAT	590.6995
REGEN.FLOW LOSS	-109.9459	SHUTTLE	126.3998
COOLER FLOW LOSS	-5.4287	PUMPING	8.3812
INDICATED	742.0593	TEMP. SWING	1.0301
		CYL. WALL COND.	194.9240
		DISPLCR WALL COND.	34.0551
----------------------------------		REGEN. WALL COND.	61.5150
INDICATED EFFICIENCY, %	28.37	CYL. GAS COND.	6.1425
		REGEN. MTX. COND.	4.6260
----------------------------------		RAD. INSIDE DISPL.	4.7876
EXP.SP.EFFECT.TEMP.,C	575.71	FLOW FRIC. CREDIT	-141.3573
COMP.SP.EFFECT.TEMP.,C	54.07	TOTAL HEAT TO ENG.	2616.0840

Convergence criteria is: .00100

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa
1	.00000	.00000	37.8047	60.0275	6.3023
2	.62195	.69986	46.2530	36.5713	6.4682
3	.22347	.39076	30.9251	23.0194	6.2259
4	.33139	.37056	40.7464	59.2616	6.2110
5	.31758	1.57442	41.3248	70.1108	6.2858
6	.01420	.18307	39.4081	67.4282	6.3029
7	.04638	.03826	38.7702	64.0875	6.2788
8	.01619	.04954	39.1211	64.3247	6.2653
9	.00905	.00370	39.4816	65.0930	6.2538
10	.00922	.01194	39.6682	65.6441	6.2436
11	.00473	.00847	39.8061	65.9583	6.2444
12	.00348	.00479	39.9427	66.2037	6.2347
13	.00343	.00372	40.0639	66.4439	6.2259
14	.00304	.00363	40.1962	66.6812	6.2176
15	.00330	.00357	40.3235	66.9181	6.2096
16	.00316	.00355	40.4371	67.1508	6.2126
17	.00282	.00348	40.5389	67.3278	6.2048
18	.00252	.00264	40.6207	67.5063	6.1981
19	.00202	.00265	40.7115	67.6369	6.1916
20	.00223	.00193	40.7972	67.7382	6.1854
21	.00210	.00150	40.8833	67.9155	6.1897
22	.00211	.00262	40.9621	68.0445	6.1834
23	.00193	.00190	41.0171	68.1564	6.1779
24	.00134	.00164	41.0830	68.2369	6.1728
25	.00161	.00118	41.1463	68.3712	6.1779
26	.00154	.00197	41.2074	68.3821	6.1724
27	.00149	.00016	41.2508	68.5487	6.1677
28	.00105	.00244	41.3027	68.5930	6.1631
29	.00126	.00065	41.3451	68.6668	6.1690
30	.00103	.00108	41.3936	68.6863	6.1639
31	.00117	.00028	41.4232	68.7977	6.1598
32	.00072	.00162	41.4636	68.8423	6.1558
33	.00097	.00065	41.4964	68.8949	6.1621

ENTERED PRINT ROUTINE AFTER 33 CYCLES.
Fractional change in two successive integrals of heat in and power out has been less than .0010

RUN# 17 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .040 N/(cm/sec)**2.
ISOTHERMAL ANALYSIS WITH CORRECTIONS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	66.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2,2=HE,3=AIR	2	PHASE ANG. DEGREES =	91.90
POWER P.STR,CM =	2.29	DISPL. STROKE, CM =	2.86
CALC.FREQ., HZ =	24.08	TIME STEPS/CYCLE =	415.24

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	999.3320	BASIC	1659.1540
ADIABATIC CORR.	-44.5684	ADIABATIC CORR.	84.2962
HEATER FLOW LOSS	-87.6661	REHEAT	594.4083
REGEN.FLOW LOSS	-111.4200	SHUTTLE	127.3271
COOLER FLOW LOSS	-5.5112	PUMPING	8.4523
INDICATED	750.1664	TEMP. SWING	1.0429
		CYL. WALL COND.	134.8779
		DISPLCR WALL COND.	34.0471
		REGEN. WALL COND.	61.5005
INDICATED EFFICIENCY, %	28.44	CYL. GAS COND.	6.1410
		REGEN. MTX. COND.	4.6250
		RAD. INSIDE DISPL.	4.7846
EXP.SP.EFFECT.TEMP.,C	575.62	FLOW FRIC. CREDIT	-143.3761
COMP.SP.EFFECT.TEMP.,C	54.04	TOTAL HEAT TO ENG.	2637.2810

Convergence criteria is! .00050

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa
1	.00000	.00000	37.8047	60.0275	6.3023
2	.62195	.69985	46.2530	36.5713	6.4682
3	.22347	.39076	30.9251	23.0194	6.2259
4	.33139	.37056	40.7464	59.2616	6.2110
5	.31758	1.57442	41.3248	70.1108	6.2858
6	.01420	.18307	39.4081	67.4282	6.3029
7	.04638	.03826	38.7702	64.0875	6.2788
8	.01619	.04954	39.1211	64.3247	6.2653
9	.00905	.00370	39.4816	65.0930	6.2538
10	.00922	.01194	39.6682	65.6441	6.2436
11	.00473	.00847	39.8061	65.9583	6.2444
12	.00348	.00479	39.9427	66.2037	6.2347
13	.00343	.00372	40.0639	66.4439	6.2259
14	.00304	.00363	40.1962	66.6812	6.2176
15	.00330	.00357	40.3235	65.9181	6.2096
16	.00316	.00355	40.4371	67.1508	6.2126
17	.00282	.00348	40.5389	67.3278	6.2048
18	.00252	.00264	40.6207	67.5063	6.1981
19	.00202	.00265	40.7115	67.6369	6.1916
20	.00223	.00193	40.7972	67.7392	6.1854
21	.00210	.00150	40.8833	67.9155	6.1897
22	.00211	.00262	40.9621	68.0445	6.1834
23	.00193	.00190	41.0171	68.1564	6.1779
24	.00134	.00164	41.0830	68.2369	6.1728
25	.00161	.00118	41.1463	68.3712	6.1779
26	.00154	.00197	41.2074	68.3821	6.1724
27	.00149	.00016	41.2508	68.5487	6.1677
28	.00105	.00244	41.3027	68.5930	6.1631
29	.00126	.00065	41.3451	68.6668	6.1690
30	.00103	.00103	41.3936	68.6863	6.1639
31	.00117	.00028	41.4232	68.7977	6.1598
32	.00072	.00162	41.4636	68.8423	6.1558
33	.00097	.00065	41.4964	68.8949	6.1621
34	.00079	.00076	41.5340	68.8768	6.1574
35	.00091	.00026	41.5590	69.0120	6.1536
36	.00060	.00196	41.5872	69.0062	6.1499
37	.00068	.00008	41.6162	69.0700	6.1565
38	.00070	.00092	41.6401	69.0450	6.1522
39	.00057	.00036	41.6579	69.1453	6.1486
40	.00043	.00145	41.6777	69.1532	6.1452
41	.00048	.00011	41.6965	69.1772	6.1519

ENTERED PRINT ROUTINE AFTER 41 CYCLES.
Fractional change in two successive integrals of heat in and power out has been less than .0005

RUN# 17 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .040 N/(cm/sec)**2.
ISOTHERMAL ANALYSIS WITH CORRECTIONS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	66.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2,2=HE,3=AIR	2	PHASE ANG. DEGREES =	91.46
POWER P.STR,CM =	2.29	DISPL. STROKE, CM =	2.86
CALC.FREQ., HZ =	24.08	TIME STEPS/CYCLE =	415.25

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	1004.1410	BASIC	1665.9360
ADIABATIC CORR.	-44.7811	ADIABATIC CORR.	84.6410
HEATER FLOW LOSS	-88.1398	REHEAT	596.6191
REGEN.FLOW LOSS	-111.9641	SHUTTLE	127.7400
COOLER FLOW LOSS	-5.5416	PUMPING	8.4825
INDICATED	753.7146	TEMP. SWING	1.0492
		CYL. WALL COND.	194.8708
		DISPLCR WALL COND.	34.0458
		REGEN. WALL COND.	61.4982
INDICATED EFFICIENCY, %	28.48	CYL. GAS COND.	6.1408
		REGEN. MTX. COND.	4.6248
		RAD. INSIDE DISPL.	4.7838
EXP.SP.EFFECT.TEMP.,C	575.57	FLOW FRIC. CREDIT	-144.1219
COMP.SP.EFFECT.TEMP.,C	54.03	TOTAL HEAT TO ENG.	2646.3100

APPENDIX G

EFFECT OF PRESSURE ON ISOTHERMAL

FREE-PISTON ANALYSIS

0.2 MSEC TIME STEP

0.005 CONVERGENCE CRITERIA

Convergence criteria is: .00500

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa
1	.00000	.00000	5.7592	9.0084	.9571
2	.94241	.95496	15.8064	1.3638	.9274
3	1.74455	.84851	9.5836	14.6588	.9099
4	.39369	9.74883	10.8575	17.9246	.9154
5	.13292	.22279	10.2852	17.1418	.9177
6	.05271	.04359	10.1734	16.9289	.9143
7	.01087	.01242	9.9621	16.8045	.9222
8	.02077	.00735	9.6680	16.3272	.9201
9	.02952	.02840	9.7157	16.3759	.9173
10	.00493	.00293	9.7765	16.4754	.9160
11	.00625	.00509	9.8140	16.5405	.9149
12	.00383	.00395	9.8536	16.6065	.9127

ENTERED PRINT ROUTINE AFTER 12 CYCLES.
Fractional change in two successive integrals of heat in and power out has been less than .0050

RUN# 32 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .040 N/(cm/sec)**2.
ISOTHERMAL ANALYSIS WITH CORRECTIONS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	10.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2, 2=HE, 3=AIR	2	PHASE ANG. DEGREES =	94.67
POWER P.STR, CM =	2.64	DISPL. STROKE, CM =	3.97
CALC.FREQ., HZ =	9.46	TIME STEPS/CYCLE =	528.56

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	93.2126	BASIC	157.0929
ADIABATIC CORR.	-4.7453	ADIABATIC CORR.	7.9075
HEATER FLOW LOSS	-5.5757	REHEAT	18.4233
REGEN.FLOW LOSS	-13.0138	SHUTTLE	233.6638
COOLER FLOW LOSS	-.4459	PUMPING	.5608
INDICATED	69.4319	TEMP. SWING	.0006
		CYL. WALL COND.	185.3751
		DISPLCR WALL COND.	32.3869
		REGEN. WALL COND.	59.5015
INDICATED EFFICIENCY, %	9.97	CYL. GAS COND.	5.8416
		REGEN. MTX. COND.	4.3994
		RAD. INSIDE DISPL.	4.3467
EXP.SP.EFFECT.TEMP.,C	556.29	FLOW FRIC. CREDIT	-12.0826
COMP.SP.EFFECT.TEMP.,C	60.23	TOTAL HEAT TO ENG.	695.4179

Convergence criteria is: .00500

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa
1	.00000	.00000	11.5075	18.0502	1.9139
2	.88492	.90975	25.8880	-2.1325	1.8887
3	1.24966	1.11814	17.5491	22.4622	1.8030
4	.32211	11.53346	22.5048	37.3540	1.8474
5	.28239	.66297	20.5535	35.2236	1.8649
6	.09670	.05703	19.9030	33.6598	1.8572
7	.03165	.04440	19.9842	34.3983	1.8642
8	.00408	.02194	19.5367	33.4608	1.8594
9	.02239	.02725	19.6302	33.5835	1.8533
10	.00478	.00367	19.8014	33.9317	1.8510
11	.00872	.01037	19.8696	34.0590	1.8490
12	.00345	.00375	19.9235	34.1521	1.8440

ENTERED PRINT ROUTINE AFTER 12 CYCLES.
Fractional change in two successive integrals of heat in and power out has been less than .0050

RUN# 31 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .040 N/(cm/sec)**2.
ISOTHERMAL ANALYSIS WITH CORRECTIONS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	20.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2,2=HE,3=AIR	2	PHASE ANG. DEGREES =	95.23
POWER P.STR,CM =	2.63	DISPL. STROKE, CM =	4.04
CALC.FREQ., HZ =	13.50	TIME STEPS/CYCLE =	370.48

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	268.8846	BASIC	460.9116
ADIABATIC CORR.	-14.7798	ADIABATIC CORR.	23.0837
HEATER FLOW LOSS	-19.1771	REHEAT	82.2359
REGEN.FLOW LOSS	-34.2565	SHUTTLE	236.4990
COOLER FLOW LOSS	-1.2686	PUMPING	1.7358
INDICATED	199.4026	TEMP. SWING	.0165
		CYL. WALL COND.	180.7845
		DISPLCR WALL COND.	31.5848
----------------------------------		REGEN. WALL COND.	57.0528
INDICATED EFFICIENCY, %	18.96	CYL. GAS COND.	5.6969
		REGEN. MTX. COND.	4.2905
----------------------------------		RAD.INSIDE DISPL.	4.1263
EXP.SP.EFFECT.TEMP.,C	546.02	FLOW FRIC. CREDIT	-36.3054
COMP.SP.EFFECT.TEMP.,C	62.20	TOTAL HEAT TO ENG.	1051.7110

```
Convergence criteria is:      .00500
Cycle  Change     Change     Work       Heat       End
Numb.  Power      Heat       Out        In         Pressure
       Out        In         Joules     Joules     MPa
  1    .00000     .00000     17.2448    27.1248    2.8703
  2    .82755     .86438     33.6654     1.8532    2.8881
  3    .95221     .93168     20.8613    17.1923    2.7176
  4    .38034    8.27729     30.8814    45.0713    2.7677
  5    .48032    1.62161     29.0772    54.5201    2.8381
  6    .05842     .20964     26.2974    52.4712    2.8685
  7    .09560     .03758     24.3778    45.4871    2.8751
  8    .07299     .13310     23.4632    35.6411    2.8387
  9    .03752     .21646     24.7354    37.0250    2.8011
 10    .05422     .03883     26.5887    43.7341    2.7922
 11    .07492     .18121     26.7389    46.7834    2.8048
 12    .00565     .06972     26.0346    45.8288    2.8095
 13    .02634     .02040     25.6579    43.8115    2.8037
 14    .01447     .04402     25.9108    43.6084    2.7898
 15    .00986     .00463     26.3590    44.6064    2.7837
 16    .01729     .02268     26.5990    45.3952    2.7794
 17    .00911     .01768     26.6370    45.6921    2.7757
 18    .00143     .00654     26.6720    45.7809    2.7718
 19    .00131     .00194     26.7637    45.8714    2.7676
ENTERED PRINT ROUTINE AFTER     19 CYCLES.
Fractional change in two successive integrals of heat
in and power out has been less than       .0050
                       RUN# 30    FOR
                       SUNPOWER RE1000 ENGINE
                       FREE MOTIONS -- LINEAR ALTERNATOR
                             Load constant =     .040 N/(cm/sec)**2.
                       ISOTHERMAL ANALYSIS WITH CORRECTIONS
                       MARTINI LOSS EQUATIONS
                       SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =       29.70        CHRG. PRESS., BAR    =       30.00
HEAT IN, DEG C =      600.00        HEAT OUT, DEG. C     =       40.00
W. GAS 1=H2,2=HE,3=AIR 2            PHASE ANG. DEGREES   =       96.77
POWER P.STR,CM =        2.55        DISPL. STROKE, CM    =        3.66
CALC.FREQ., HZ =       16.40        TIME STEPS/CYCLE     =      304.93

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                        HEAT REQUIREMENT, WATTS
  BASIC                  438.8512     BASIC                     752.1644
  ADIABATIC CORR.        -24.3141     ADIABATIC CORR.            37.6499
  HEATER FLOW LOSS       -36.7418     REHEAT                    165.7423
  REGEN.FLOW LOSS        -57.2385     SHUTTLE                   217.9078
  COOLER FLOW LOSS        -2.1545     PUMPING                     2.9490
  INDICATED              318.4024     TEMP. SWING                  .0740
                                      CYL. WALL COND.           182.1925
                                      DISPLCR WALL COND.         31.8308
---------------------------------     REGEN. WALL COND.          57.4972
INDICATED EFFICIENCY, %   22.79       CYL. GAS COND.              5.7413
                                      REGEN. MTX. COND.           4.3239
---------------------------------     RAD.INSIDE DISPL.           4.2786
EXP.SP.EFFECT.TEMP.,C    553.61       FLOW FRIC. CREDIT         -65.3610
COMP.SP.EFFECT.TEMP.,C    65.93       TOTAL HEAT TO ENG.       1396.9910
```

```
Convergence criteria is:     .00500
Cycle  Change    Change    Work      Heat      End
Numb.  Power     Heat      Out       In        Pressure
       Out       In        Joules    Joules    MPa
  1    .00000    .00000    22.9710   36.2318   3.8264
  2    .77029    .81884    38.6549   32.3636   3.9479
  3    .68277    .10676    21.3092   -1.3285   3.7635
  4    .44873   1.04105    31.7073   41.7207   3.6719
  5    .48796  32.40430    34.6162   62.2682   3.8010
  6    .09174    .49250    30.8643   65.1540   3.8719
  7    .10839    .04634    28.0182   55.2677   3.8926
  8    .09221    .15174    26.1777   37.2821   3.8396
  9    .06569    .32543    27.3460   36.3799   3.7609
 10    .04463    .02420    30.5582   48.1363   3.7443
 11    .11747    .32316    31.2091   54.0882   3.7740
 12    .02130    .12365    30.1912   53.2469   3.7922
 13    .03262    .01555    29.4645   50.1989   3.7749
 14    .02407    .05724    29.5357   49.0306   3.7646
 15    .00242    .02327    30.0942   50.1135   3.7547
 16    .01891    .02209    30.4609   51.3299   3.7473
 17    .01219    .02427    30.5369   51.6927   3.7415
 18    .00249    .00707    30.5708   51.7489   3.7356
 19    .00111    .00109    30.6828   51.9451   3.7293
ENTERED PRINT ROUTINE AFTER     19 CYCLES.
Fractional change in two successive integrals of heat
in and power out has been less than      .0050
                 RUN# 29    FOR
                 SUNPOWER RE1000 ENGINE
                 FREE MOTIONS -- LINEAR ALTERNATOR
                     Load constant =     .040 N/(cm/sec)**2.
                 ISOTHERMAL ANALYSIS WITH CORRECTIONS
                 MARTINI LOSS EQUATIONS
                 SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70        CHRG. PRESS., BAR     =    40.00
HEAT IN, DEG C =     600.00        HEAT OUT, DEG. C      =    40.00
W. GAS 1=H2,2=HE,3=AIR 2           PHASE ANG. DEGREES    =    95.12
POWER P.STR,CM =       3.43        DISPL. STROKE, CM     =     3.43
CALC.FREQ., HZ =      18.86        TIME STEPS/CYCLE      =   265.07

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                          HEAT REQUIREMENT, WATTS
  BASIC                    578.7675    BASIC                    979.8344
  ADIABATIC CORR.          -29.3771    ADIABATIC CORR.           49.3310
  HEATER FLOW LOSS         -47.9782    REHEAT                   260.0647
  REGEN.FLOW LOSS          -69.8206    SHUTTLE                  177.5176
  COOLER FLOW LOSS          -2.8894    PUMPING                    4.2273
  INDICATED                428.7021    TEMP. SWING                 .1870
                                       CYL. WALL COND.          187.9541
                                       DISPLCR WALL COND.        32.8374
-----------------------------------    REGEN. WALL COND.         59.3154
INDICATED EFFICIENCY, %   25.47        CYL. GAS COND.             5.9228
                                       REGEN. MTX. COND.          4.4606
-----------------------------------    RAD.INSIDE DISPL.          4.5856
EXP.SP.EFFECT.TEMP.,C    567.48        FLOW FRIC. CREDIT        -82.8885
COMP.SP.EFFECT.TEMP.,C    64.48        TOTAL HEAT TO ENG.      1683.3490
```

```
Convergence criteria is:      .00500
Cycle  Change    Change    Work      Heat      End
Numb.  Power     Heat      Out       In        Pressure
       Out       In        Joules    Joules    MPa
  1    .00000    .00000    28.6860   45.3706   4.7823
  2    .71314    .77315    42.4838   45.1070   4.9638
  3    .48100    .00581    23.6944    -.9860   4.7577
  4    .44227   1.02186    33.8846   44.5196   4.6231
  5    .43007  46.15195    37.9247   64.4261   4.7578
  6    .11923    .44714    34.4327   62.8112   4.7929
  7    .09208    .02507    32.9035   56.3745   4.7897
  8    .04441    .10248    32.6248   52.5117   4.7657
  9    .00847    .06852    33.3018   53.7369   4.7414
 10    .02075    .02333    33.9637   56.1097   4.7355
 11    .01988    .04416    34.1292   56.8596   4.7314
 12    .00487    .01336    34.1596   57.0024   4.7271
 13    .00089    .00251    34.2887   57.1250   4.7086
ENTERED PRINT ROUTINE AFTER    13 CYCLES.
Fractional change in two successive integrals of heat
in and power out has been less than      .0050
                  RUN# 28    FOR
                  SUNPOWER RE1000 ENGINE
                  FREE MOTIONS -- LINEAR ALTERNATOR
                       Load constant =     .040 N/(cm/sec)**2.
                  ISOTHERMAL ANALYSIS WITH CORRECTIONS
                  MARTINI LOSS EQUATIONS
                  SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70        CHRG. PRESS., BAR    =      50.00
HEAT IN, DEG C =     600.00        HEAT OUT, DEG. C     =      40.00
W. GAS 1=H2,2=HE,3=AIR 2           PHASE ANG. DEGREES   =      93.69
POWER P.STR,CM =       2.34        DISPL. STROKE, CM    =       3.14
CALC.FREQ., HZ =      21.03        TIME STEPS/CYCLE     =     237.74

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                       HEAT REQUIREMENT, WATTS
  BASIC                  721.1404    BASIC                     1201.4210
  ADIABATIC CORR.        -34.0748    ADIABATIC CORR.             60.7957
  HEATER FLOW LOSS       -60.1742    REHEAT                     371.8056
  REGEN.FLOW LOSS        -82.8674    SHUTTLE                    151.7054
  COOLER FLOW LOSS        -3.6983    PUMPING                      5.6663
  INDICATED              540.3259    TEMP. SWING                   .3909
                                     CYL. WALL COND.            192.3626
                                     DISPLCR WALL COND.          33.6076
---------------------------------    REGEN. WALL COND.           60.7067
INDICATED EFFICIENCY, %   27.12      CYL. GAS COND.               6.0618
                                     REGEN. MTX. COND.            4.5653
---------------------------------    RAD.INSIDE DISPL.            4.7554
EXP.SP.EFFECT.TEMP.,C    574.66      FLOW FRIC. CREDIT         -101.6079
COMP.SP.EFFECT.TEMP.,C    59.84      TOTAL HEAT TO ENG.        1992.2360
```

Convergence criteria is: .00500

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa
1	.00000	.00000	34.3896	54.5407	5.7378
2	.65610	.72730	45.2552	38.5443	5.8913
3	.31596	.29329	28.4381	14.6005	5.6706
4	.37161	.62120	38.7143	54.7625	5.6261
5	.36135	2.75072	40.2479	68.7902	5.7105
6	.03961	.25615	37.5960	65.7414	5.7404
7	.06589	.04432	36.6413	60.8321	5.7220
8	.02539	.07468	36.8656	60.2957	5.7018
9	.00612	.00882	37.3834	61.5911	5.6840
10	.01405	.02148	37.6337	62.3171	5.6867
11	.00670	.01179	37.7775	62.6343	5.6706
12	.00382	.00509	37.8960	62.9007	5.6742
13	.00314	.00425	38.0528	63.1774	5.6589

ENTERED PRINT ROUTINE AFTER 13 CYCLES.
Fractional change in two successive integrals of heat in and power out has been less than .0050

RUN# 27 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .040 N/(cm/sec)**2.
ISOTHERMAL ANALYSIS WITH CORRECTIONS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	60.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2,2=HE,3=AIR	2	PHASE ANG, DEGREES =	92.25
POWER P.STR,CM =	2.29	DISPL. STROKE, CM =	2.93
CALC.FREQ., HZ =	23.00	TIME STEPS/CYCLE =	217.43

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	875.0565	BASIC	1452.8160
ADIABATIC CORR.	-39.6571	ADIABATIC CORR.	73.7325
HEATER FLOW LOSS	-75.1686	REHEAT	501.5879
REGEN.FLOW LOSS	-98.4482	SHUTTLE	133.4746
COOLER FLOW LOSS	-4.6874	PUMPING	7.2672
INDICATED	657.0952	TEMP. SWING	.7304
		CYL. WALL COND.	194.2586
		DISPLCR WALL COND.	33.9389
		REGEN. WALL COND.	61.3050
INDICATED EFFICIENCY, %	27.96	CYL. GAS COND.	6.1215
		REGEN. MTX. COND.	4.6103
		RAD. INSIDE DISPL.	4.7831
EXP.SP.EFFECT.TEMP.,C	575.58	FLOW FRIC. CREDIT	-124.3927
COMP.SP.EFFECT.TEMP.,C	55.76	TOTAL HEAT TO ENG.	2350.2330

Convergence criteria is: .00500

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa
1	.00000	.00000	37.8062	60.0577	6.3110
2	.62194	.69971	46.7120	37.8263	6.4642
3	.23556	.37017	30.8172	22.6737	6.2269
4	.34027	.40058	40.5821	59.0001	6.2147
5	.31687	1.60214	41.3215	69.9782	6.2822
6	.01822	.18607	39.2947	67.3051	6.2930
7	.04905	.03820	38.6661	64.0173	6.2936
8	.01600	.04885	38.9983	64.2123	6.2720
9	.00859	.00305	39.3320	64.9205	6.2541
10	.00855	.01103	39.5182	65.3530	6.2581
11	.00473	.00666	39.6882	65.7023	6.2407
12	.00430	.00534	39.8104	65.9977	6.2459
13	.00308	.00450	39.9527	66.2510	6.2294

ENTERED PRINT ROUTINE AFTER 13 CYCLES.
Fractional change in two successive integrals of heat
in and power out has been less than .0050

RUN# 19 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .040 N/(cm/sec)**2.
ISOTHERMAL ANALYSIS WITH CORRECTIONS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	66.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2,2=HE,3=AIR	2	PHASE ANG. DEGREES =	92.37
POWER P.STR,CM =	2.25	DISPL. STROKE, CM =	2.82
CALC.FREQ., HZ =	24.10	TIME STEPS/CYCLE =	207.46

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	962.6906	BASIC	1596.7030
ADIABATIC CORR.	-42.8700	ADIABATIC CORR.	81.1326
HEATER FLOW LOSS	-84.0065	REHEAT	582.8763
REGEN.FLOW LOSS	-107.2241	SHUTTLE	124.2414
COOLER FLOW LOSS	-5.2784	PUMPING	8.2343
INDICATED	723.5115	TEMP. SWING	1.0039
		CYL. WALL COND.	195.0442
		DISPLCR WALL COND.	34.0761
		REGEN. WALL COND.	61.5529
INDICATED EFFICIENCY, %	28.23	CYL. GAS COND.	6.1463
		REGEN. MTX. COND.	4.6289
		RAD. INSIDE DISPL.	4.7947
EXP. SP. EFFECT. TEMP., C	576.01	FLOW FRIC. CREDIT	-137.6185
COMP. SP. EFFECT. TEMP., C	54.05	TOTAL HEAT TO ENG.	2562.8160

Convergence criteria is: .00500

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa
1	.00000	.00000	38.3755	60.9783	6.4065
2	.61625	.69511	46.9406	37.8336	6.5562
3	.22319	.37956	31.2949	23.8437	6.3236
4	.33331	.36977	40.8908	59.8533	6.3243
5	.30663	1.51023	41.6245	70.5159	6.3818
6	.01794	.17814	39.5250	67.6663	6.4044
7	.05044	.04041	38.9222	64.3592	6.3736
8	.01525	.04887	39.2523	64.4321	6.3648
9	.00848	.00113	39.6488	65.4771	6.3570
10	.01010	.01622	39.8221	65.7801	6.3512
11	.00437	.00463	39.9568	66.2143	6.3452
12	.00338	.00660	40.0923	66.4811	6.3402
13	.00339	.00403	40.1974	66.5810	6.3355

ENTERED PRINT ROUTINE AFTER 13 CYCLES.
Fractional change in two successive integrals of heat in and power out has been less than .0050

RUN# 25 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .040 N/(cm/sec)**2.
ISOTHERMAL ANALYSIS WITH CORRECTIONS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	67.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2,2=HE,3=AIR	2	PHASE ANG. DEGREES =	92.57
POWER P.STR,CM =	2.25	DISPL. STROKE, CM =	2.80
CALC.FREQ., HZ =	24.29	TIME STEPS/CYCLE =	205.89

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	976.1994	BASIC	1616.9270
ADIABATIC CORR.	-43.3461	ADIABATIC CORR.	82.1749
HEATER FLOW LOSS	-85.4799	REHEAT	596.6406
REGEN.FLOW LOSS	-108.6841	SHUTTLE	122.7418
COOLER FLOW LOSS	-5.3791	PUMPING	8.3911
INDICATED	733.3102	TEMP. SWING	1.0559
		CYL. WALL COND.	195.1643
		DISPLCR WALL COND.	34.0971
		REGEN. WALL COND.	61.5908
INDICATED EFFICIENCY, %	28.26	CYL. GAS COND.	6.1501
		REGEN. MTX. COND.	4.6317
		RAD.INSIDE DISPL.	4.7967
EXP.SP.EFFECT.TEMP.,C	576.12	FLOW FRIC. CREDIT	-139.8220
COMP.SP.EFFECT.TEMP.,C	53.77	TOTAL HEAT TO ENG.	2594.5410

```
Convergence criteria is:     .00500
Cycle  Change    Change    Work      Heat       End
Numb.  Power     Heat      Out       In         Pressure
       Out       In        Joules    Joules     MPa
  1    .00000    .00000    38.9444   61.8990    6.5020
  2    .61056    .69051    47.1721   37.8628    6.6682
  3    .21127    .38831    31.2293   25.1906    6.4220
  4    .33797    .33469    41.0906   60.0963    6.4151
  5    .31577   1.38567    41.6701   70.1199    6.4839
  6    .01410    .16679    39.8680   67.9951    6.4945
  7    .04325    .03030    39.2960   65.0277    6.4747
  8    .01435    .04364    39.6245   65.1852    6.4547
  9    .00836    .00242    39.9592   65.9177    6.4587
 10    .00845    .01124    40.1480   66.4581    6.4411
 11    .00473    .00820    40.2609   66.7522    6.4254
 12    .00281    .00443    40.3841   66.9571    6.4320
ENTERED PRINT ROUTINE AFTER     12 CYCLES.
Fractional change in two successive integrals of heat
in and power out has been less than       .0050
                    RUN# 20    FOR
                    SUNPOWER RE1000 ENGINE
                    FREE MOTIONS -- LINEAR ALTERNATOR
                         Load constant =    .040 N/(cm/sec)**2.
                    ISOTHERMAL ANALYSIS WITH CORRECTIONS
                    MARTINI LOSS EQUATIONS
                    SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70        CHRG. PRESS., BAR  =      68.00
HEAT IN, DEG C =     600.00        HEAT OUT, DEG. C   =      40.00
W. GAS 1=H2,2=HE,3=AIR 2           PHASE ANG. DEGREES =      91.93
POWER P.STR,CM =       2.24        DISPL. STROKE, CM  =       2.78
CALC.FREQ., HZ =      24.46        TIME STEPS/CYCLE   =     204.38

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                       HEAT REQUIREMENT, WATTS
  BASIC                  987.9561    BASIC                  1638.0370
  ADIABATIC CORR.        -43.7589    ADIABATIC CORR.          83.2618
  HEATER FLOW LOSS       -86.6511    REHEAT                  610.9302
  REGEN.FLOW LOSS       -109.7754    SHUTTLE                 121.0951
  COOLER FLOW LOSS        -5.4594    PUMPING                   8.5370
  INDICATED              742.3113    TEMP. SWING               1.1078
                                     CYL. WALL COND.         195.2787
                                     DISPLCR WALL COND.       34.1171
---------------------------------    REGEN. WALL COND.        61.6269
INDICATED EFFICIENCY, %  28.25       CYL. GAS COND.            6.1537
                                     REGEN. MTX. COND.         4.6345
---------------------------------    RAD.INSIDE DISPL.         4.7988
EXP.SP.EFFECT.TEMP.,C    576.17      FLOW FRIC. CREDIT      -141.5388
COMP.SP.EFFECT.TEMP.,C    53.56      TOTAL HEAT TO ENG.     2628.0400
```

Convergence criteria is: .00500

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa
1	.00000	.00000	39.5132	62.8203	6.5975
2	.60487	.68590	47.4078	38.1162	6.7583
3	.19960	.39325	31.7529	26.2688	6.5159
4	.33022	.31082	41.3702	60.8163	6.5205
5	.30288	1.31515	41.9458	70.7040	6.5776
6	.01391	.16258	40.0711	68.1483	6.5775
7	.04469	.03615	39.5550	65.4117	6.5680
8	.01288	.04016	39.9288	65.6846	6.5579
9	.00945	.00417	40.2279	66.4517	6.5503
10	.00749	.01168	40.3930	66.7450	6.5438
11	.00410	.00441	40.5250	67.1182	6.5374
12	.00327	.00559	40.6538	67.3341	6.5320
13	.00318	.00322	40.7827	67.6046	6.5266

ENTERED PRINT ROUTINE AFTER 13 CYCLES.
Fractional change in two successive integrals of heat in and power out has been less than .0050

RUN# 24 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .040 N/(cm/sec)**2.
ISOTHERMAL ANALYSIS WITH CORRECTIONS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	69.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2, 2=HE, 3=AIR	2	PHASE ANG. DEGREES =	92.19
POWER P.STR, CM =	2.24	DISPL. STROKE, CM =	2.77
CALC.FREQ., HZ =	24.64	TIME STEPS/CYCLE =	202.94

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	1004.7890	BASIC	1665.6150
ADIABATIC CORR.	-44.3994	ADIABATIC CORR.	84.6769
HEATER FLOW LOSS	-88.4129	REHEAT	625.3972
REGEN.FLOW LOSS	-111.5225	SHUTTLE	119.9740
COOLER FLOW LOSS	-5.5763	PUMPING	8.7150
INDICATED	754.8782	TEMP. SWING	1.1650
		CYL. WALL COND.	195.3661
		DISPLCR WALL COND.	34.1324
		REGEN. WALL COND.	61.6545
INDICATED EFFICIENCY, %	28.29	CYL. GAS COND.	6.1564
		REGEN. MTX. COND.	4.6365
		RAD. INSIDE DISPL.	4.7988
EXP.SP.EFFECT.TEMP.,C	576.13	FLOW FRIC. CREDIT	-144.1741
COMP.SP.EFFECT.TEMP.,C	53.33	TOTAL HEAT TO ENG.	2668.1140

Convergence criteria is: .00500

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa
1	.00000	.00000	40.0820	63.7417	6.6931
2	.59918	.68129	47.6317	38.3519	6.8476
3	.18836	.39832	32.2812	27.3206	6.6090
4	.32228	.28764	41.6425	61.5711	6.6023
5	.28999	1.25365	42.0096	70.8245	6.6715
6	.00881	.15029	40.3280	68.3844	6.6799
7	.04003	.03445	39.8397	65.8319	6.6571
8	.01211	.03733	40.2163	66.3603	6.6579
9	.00945	.00803	40.5045	66.9167	6.6373
10	.00716	.00839	40.6341	67.2184	6.6414
11	.00320	.00451	40.7984	67.5172	6.6221

ENTERED PRINT ROUTINE AFTER 11 CYCLES.
Fractional change in two successive integrals of heat
in and power out has been less than .0050

RUN# 21 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .040 N/(cm/sec)**2.
ISOTHERMAL ANALYSIS WITH CORRECTIONS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	70.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2,2=HE,3=AIR	2	PHASE ANG. DEGREES =	91.57
POWER P.STR,CM =	2.23	DISPL. STROKE, CM =	2.75
CALC.FREQ., HZ =	24.81	TIME STEPS/CYCLE =	201.51

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	1012.3270	BASIC	1675.2970
ADIABATIC CORR.	-44.6243	ADIABATIC CORR.	85.1829
HEATER FLOW LOSS	-89.0564	REHEAT	638.1532
REGEN.FLOW LOSS	-111.9914	SHUTTLE	118.1190
COOLER FLOW LOSS	-5.6216	PUMPING	8.8340
INDICATED	761.0331	TEMP. SWING	1.2139
		CYL. WALL COND.	195.4755
		DISPLCR WALL COND.	34.1515
		REGEN. WALL COND.	61.6891
INDICATED EFFICIENCY, %	28.31	CYL. GAS COND.	6.1599
		REGEN. MTX. COND.	4.6391
		RAD. INSIDE DISPL.	4.8007
EXP.SP.EFFECT.TEMP.,C	575.19	FLOW FRIC. CREDIT	-145.0521
COMP.SP.EFFECT.TEMP.,C	53.11	TOTAL HEAT TO ENG.	2688.6640

Convergence criteria is: .00500

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa
1	.00000	.00000	40.6505	64.6635	6.7886
2	.59350	.67668	47.8506	38.5918	6.9359
3	.17712	.40319	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	.00807	.14148	40.5250	68.8061	6.7786
7	.04100	.03356	40.1100	66.2933	6.7647
8	.01024	.03652	40.4618	66.6408	6.7516
9	.00877	.00524	40.7498	67.3000	6.7406
10	.00712	.00989	40.9159	67.6525	6.7309
11	.00408	.00524	41.0528	67.9752	6.7215
12	.00335	.00477	41.1811	68.2111	6.7127

ENTERED PRINT ROUTINE AFTER 12 CYCLES.
Fractional change in two successive integrals of heat in and power out has been less than .0050

RUN# 23 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .040 N/(cm/sec)**2.
ISOTHERMAL ANALYSIS WITH CORRECTIONS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	71.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2,2=HE,3=AIR	2	PHASE ANG. DEGREES =	92.74
POWER P.STR,CM =	2.22	DISPL. STROKE, CM =	2.73
CALC.FREQ., HZ =	24.99	TIME STEPS/CYCLE =	200.08

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	1029.0930	BASIC	1704.5590
ADIABATIC CORR.	-45.2688	ADIABATIC CORR.	86.6801
HEATER FLOW LOSS	-90.8535	REHEAT	651.1033
REGEN.FLOW LOSS	-113.7718	SHUTTLE	116.9684
COOLER FLOW LOSS	-5.7414	PUMPING	9.0143
INDICATED	773.4375	TEMP. SWING	1.2719
		CYL. WALL COND.	195.5183
		DISPLCR WALL COND.	34.1590
INDICATED EFFICIENCY, %	28.34	REGEN. WALL COND.	61.7025
		CYL. GAS COND.	6.1612
		REGEN. MTX. COND.	4.6402
		RAD.INSIDE DISPL.	4.7990
EXP.SP.EFFECT.TEMP.,C	576.14	FLOW FRIC. CREDIT	-147.7393
COMP.SP.EFFECT.TEMP.,C	52.69	TOTAL HEAT TO ENG.	2728.8380

Convergence criteria is: .00500

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa
1	.00000	.00000	41.2189	65.5856	6.8841
2	.58781	.67207	48.0642	38.8945	7.0457
3	.16607	.40697	32.8134	29.4695	6.8163
4	.31730	.24232	42.1395	62.4682	6.8073
5	.28422	1.11976	42.4165	71.1913	6.8722
6	.00657	.13964	40.8483	69.0817	6.8757
7	.03697	.02963	40.4063	66.8879	6.8477
8	.01082	.03176	40.7592	67.1712	6.8445
9	.00873	.00424	41.0371	67.6491	6.8423
10	.00682	.00711	41.2104	68.2054	6.8171
11	.00422	.00822	41.3291	68.5138	6.8175
12	.00288	.00452	41.4592	68.6910	6.8171

ENTERED PRINT ROUTINE AFTER 12 CYCLES.
Fractional change in two successive integrals of heat in and power out has been less than .0050

RUN# 22 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .040 N/(cm/sec)**2.
ISOTHERMAL ANALYSIS WITH CORRECTIONS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	72.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2,2=HE,3=AIR	2	PHASE ANG. DEGREES =	92.14
POWER P.STR,CM =	2.22	DISPL. STROKE, CM =	2.72
CALC.FREQ., HZ =	25.16	TIME STEPS/CYCLE =	198.73

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	1043.1100	BASIC	1728.2570
ADIABATIC CORR.	-45.8236	ADIABATIC CORR.	87.8958
HEATER FLOW LOSS	-92.4429	REHEAT	666.8961
REGEN.FLOW LOSS	-115.3125	SHUTTLE	115.6702
COOLER FLOW LOSS	-5.8487	PUMPING	9.1747
INDICATED	783.6825	TEMP. SWING	1.3356
		CYL. WALL COND.	195.5769
		DISPLCR WALL COND.	34.1692
----------------------------------		REGEN. WALL COND.	61.7211
INDICATED EFFICIENCY, %	28.33	CYL. GAS COND.	6.1631
		REGEN. MTX. COND.	4.6415
----------------------------------		RAD. INSIDE DISPL.	4.7983
EXP.SP.EFFECT.TEMP.,C	576.10	FLOW FRIC. CREDIT	-150.0991
COMP.SP.EFFECT.TEMP.,C	52.69	TOTAL HEAT TO ENG.	2766.2010

APPENDIX H

EFFECT OF PRESSURE ON ISOTHERMAL

FREE-PISTON ANALYSIS

0.5 MSEC TIME STEP

0.005 CONVERGENCE CRITERIA

Convergence criteria is: .00500

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa
1	.00000	.00000	37.8055	60.2208	6.3286
2	.62194	.69890	47.5820	40.8191	6.4662
3	.25860	.32218	30.1480	21.7777	6.2539
4	.36640	.46648	39.9914	58.1572	6.2403
5	.32650	1.67050	41.2351	69.6771	6.3175
6	.03110	.19808	38.9337	67.1625	6.3292
7	.05581	.03609	38.0869	63.3742	6.2815
8	.02175	.05640	38.3847	63.0299	6.2861
9	.00782	.00543	38.8316	63.9658	6.2893
10	.01164	.01465	39.0336	64.5468	6.2430
11	.00520	.00908	39.0733	64.5978	6.2534
12	.00102	.00079	39.2629	64.5901	6.2603

ENTERED PRINT ROUTINE AFTER 12 CYCLES.
Fractional change in two successive integrals of heat in and power out has been less than .0050

RUN# 8 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .040 N/(cm/sec)**2.
ISOTHERMAL ANALYSIS WITH CORRECTIONS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	66.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2,2=HE,3=AIR 2		PHASE ANG. DEGREES =	95.12
POWER P.STR.CM =	2.23	DISPL. STROKE, CM =	2.79
CALC.FREQ., HZ =	24.18	TIME STEPS/CYCLE =	82.70

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	949.4999	BASIC	1561.9920
ADIABATIC CORR.	-42.2063	ADIABATIC CORR.	79.3773
HEATER FLOW LOSS	-83.5473	REHEAT	576.8146
REGEN.FLOW LOSS	-.36.7647	SHUTTLE	122.1005
COOLER FLOW LOSS	-5.2574	PUMPING	8.1849
INDICATED	711.7242	TEMP. SWING	.9903
		CYL. WALL COND.	195.1540
		DISPLCR WALL COND.	34.0953
-------------------------------		REGEN. WALL COND.	61.5876
INDICATED EFFICIENCY, %	28.25	CYL. GAS COND.	6.1497
		REGEN. MTX. COND.	4.6315
-------------------------------		RAD. INSIDE DISPL.	4.7996
EXP. SP. EFFECT. TEMP., C	576.36	FLOW FRIC. CREDIT	-136.9297
COMP. SP. EFFECT. TEMP., C	53.84	TOTAL HEAT TO ENG.	2518.9480

Convergence criteria is: .00500

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa
1	.00000	.00000	38.3745	61.1443	6.4244
2	.61625	.69428	47.7626	41.9850	6.6009
3	.24464	.31335	29.5391	22.4735	6.3736
4	.38154	.46473	39.9334	57.2282	6.3423
5	.35188	1.54648	41.2891	69.1508	6.3983
6	.03395	.20833	39.2684	67.4040	6.3897
7	.04894	.02526	38.4990	63.2725	6.3742
8	.01959	.06129	38.8551	64.3574	6.3545
9	.00925	.01715	39.1972	64.7084	6.3935
10	.00880	.00545	39.3150	64.4912	6.3767
11	.00301	.00336	39.5063	65.9810	6.3609
12	.00486	.02310	39.6264	66.1253	6.3485
13	.00304	.00219	39.6125	65.1426	6.3362
14	.00035	.01486	39.8360	66.2199	6.3216
15	.00564	.01654	40.0249	67.0068	6.3097
16	.00474	.01188	40.0021	66.0042	6.2994
17	.00057	.01496	40.0930	66.0307	6.3408
18	.00227	.00040	40.4342	67.3862	6.3242
19	.00851	.02053	40.3795	67.7980	6.3142
20	.00135	.00611	40.3101	66.8059	6.3050
21	.00172	.01463	40.3540	66.4931	6.2942
22	.00109	.00468	40.6567	67.7790	6.2819
23	.00750	.01934	40.6963	67.9647	6.2728
24	.00097	.00274	40.6529	67.5638	6.3168
25	.00107	.00590	40.7348	67.0231	6.3031
26	.00202	.00800	40.7941	67.7286	6.2928
27	.00146	.01053	40.9425	68.3454	6.2826
28	.00364	.00911	40.8932	68.4503	6.2736
29	.00121	.00153	40.8526	67.7301	6.2654
30	.00099	.01052	40.8964	67.4143	6.2562
31	.00107	.00466	41.0736	68.0858	6.2994
32	.00433	.00996	41.1905	68.4011	6.2858
33	.00285	.00463	41.0863	68.7729	6.2769
34	.00253	.00544	41.0381	68.2528	6.2692
35	.00117	.00755	41.0357	67.6795	6.2605
36	.00005	.00840	41.1608	68.0439	6.2512
37	.00305	.00539	41.2914	68.7387	6.2412
38	.00317	.01021	41.2466	68.8729	6.2861
39	.00109	.00195	41.2041	68.5715	6.2743

ENTERED PRINT ROUTINE AFTER 39 CYCLES.
Fractional change in two successive integrals of heat in and power out has been less than .0050

RUN# 7 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .040 N/(cm/sec)**2.
ISOTHERMAL ANALYSIS WITH CORRECTIONS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	67.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2,2=HE,3=AIR	2	PHASE ANG. DEGREES =	91.99
POWER P.STR,CM =	2.26	DISPL. STROKE, CM =	2.81
CALC.FREQ., HZ =	24.34	TIME STEPS/CYCLE =	82.19

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	1002.7150	BASIC	1668.7100
ADIABATIC CORR.	-44.5788	ADIABATIC CORR.	84.7996
HEATER FLOW LOSS	-88.9224	REHEAT	606.9114
REGEN.FLOW LOSS	-112.6335	SHUTTLE	123.7993
COOLER FLOW LOSS	-5.6051	PUMPING	8.5860
INDICATED	750.9748	TEMP. SWING	1.0871
		CYL. WALL COND.	195.0285
		DISPLCR WALL COND.	34.0734
		REGEN. WALL COND.	61.5480
INDICATED EFFICIENCY, %	28.29	CYL. GAS COND.	6.1458
		REGEN. MTX. COND.	4.6285
		RAD. INSIDE DISPL.	4.7879
EXP.SP.EFFECT.TEMP.,C	575.77	FLOW FRIC. CREDIT	-145.2392
COMP.SP.EFFECT.TEMP.,C	53.75	TOTAL HEAT TO ENG.	2654.8660

```
Convergence criteria is:     .00500
Cycle  Change     Change     Work       Heat       End
Numb.  Power      Heat       Out        In         Pressure
       Out        In         Joules     Joules     MPa
  1    .00000     .00000     38.9434    62.0682    6.5202
  2    .61057     .68966     48.0201    41.3211    6.6815
  3    .23307     .33426     30.1882    23.8095    6.4247
  4    .37134     .42379     40.2883    59.0509    6.4288
  5    .33457    1.46014     41.4086    69.1007    6.5190
  6    .02781     .17019     39.4093    67.3591    6.4863
  7    .04828     .02520     38.7761    64.8996    6.5046
  8    .01607     .03651     39.0881    64.1540    6.4642
  9    .00805     .01149     39.3559    64.3855    6.4813
 10    .00685     .00361     39.6219    65.2105    6.4439
 11    .00676     .01281     39.7755    66.5965    6.4643
 12    .00368     .02125     39.9227    66.0070    6.4277
 13    .00370     .00885     39.8879    65.6710    6.4489
 14    .00087     .00509     40.1661    67.2880    6.4114
 15    .00698     .02462     40.2191    66.8031    6.4346
 16    .00132     .00721     40.2436    66.1486    6.3991
 17    .00061     .00980     40.4250    67.9718    6.4208
 18    .00451     .02756     40.5875    66.9642    6.3870
 19    .00402     .01482     40.4819    66.9803    6.4100
 20    .00260     .00024     40.7699    67.9233    6.3743
 21    .00711     .01408     40.7757    67.8797    6.3983
 22    .00014     .00064     40.7859    67.5857    6.4190
ENTERED PRINT ROUTINE AFTER     22 CYCLES.
Fractional change in two successive integrals of heat
in and power out has been less than       .0050
                     RUN#  6    FOR
                     SUNPOWER RE1000 ENGINE
                     FREE MOTIONS -- LINEAR ALTERNATOR
                          Load constant =     .040 N/(cm/sec)**2.
                     ISOTHERMAL ANALYSIS WITH CORRECTIONS
                     MARTINI LOSS EQUATIONS
                     SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =        29.70        CHRG. PRESS., BAR    =      68.00
HEAT IN, DEG C =       600.00        HEAT OUT, DEG. C     =      40.00
W. GAS 1=H2,2=HE,3=AIR 2             PHASE ANG. DEGREES   =      92.72
POWER P.STR,CM =         2.24        DISPL. STROKE, CM    =       2.78
CALC.FREQ., HZ =        24.53        TIME STEPS/CYCLE     =      81.54

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                         HEAT REQUIREMENT, WATTS
  BASIC                   1000.4360    BASIC                     1657.8090
  ADIABATIC CORR.          -44.3229    ADIABATIC CORR.             84.2653
  HEATER FLOW LOSS         -89.0040    REHEAT                     615.9672
  REGEN.FLOW LOSS         -112.4494    SHUTTLE                    120.9413
  COOLER FLOW LOSS          -5.6122    PUMPING                      8.6514
  INDICATED                749.0479    TEMP. SWING                  1.1267
                                       CYL. WALL COND.            195.2233
                                       DISPLCR WALL COND.          34.1074
-----------------------------------    REGEN. WALL COND.           61.6095
INDICATED EFFICIENCY, %   28.27        CYL. GAS COND.               6.1519
                                       REGEN. MTX. COND.            4.6332
-----------------------------------    RAD.INSIDE DISPL.            4.7943
EXP.SP.EFFECT.TEMP.,C    576.06        FLOW FRIC. CREDIT         -145.2287
COMP.SP.EFFECT.TEMP.,C    53.45        TOTAL HEAT TO ENG.        2650.0520
```

Convergence criteria is: .00500

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa
1	.00000	.00000	39.5122	62.9924	6.6160
2	.60468	.68504	48.2289	41.9071	6.7619
3	.22061	.33473	30.9872	24.7610	6.5274
4	.35750	.40915	40.6158	59.5811	6.5087
5	.31073	1.40625	41.5138	69.5082	6.5797
6	.02211	.16661	39.7002	67.4130	6.5787
7	.04369	.03014	39.1148	65.0465	6.5713
8	.01475	.03510	39.3517	65.1722	6.5651
9	.00606	.00193	39.5610	65.6539	6.5620
10	.00532	.00739	39.7418	65.6394	6.5593
11	.00457	.00022	39.9588	65.8186	6.5549
12	.00546	.00273	40.1876	66.2991	6.5498
13	.00573	.00730	40.3388	66.8799	6.5455
14	.00376	.00876	40.4178	67.1295	6.5420
15	.00196	.00373	40.4896	67.2567	6.5387

ENTERED PRINT ROUTINE AFTER 15 CYCLES.
Fractional change in two successive integrals of heat in and power out has been less than .0050

RUN# 5 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .040 N/(cm/sec)**2.
ISOTHERMAL ANALYSIS WITH CORRECTIONS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	69.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2,2=HE,3=AIR	2	PHASE ANG. DEGREES =	91.07
POWER P.STR,CM =	2.23	DISPL. STROKE, CM =	2.75
CALC.FREQ., HZ =	24.70	TIME STEPS/CYCLE =	80.96

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	1000.2140	BASIC	1661.4400
ADIABATIC CORR.	-44.1951	ADIABATIC CORR.	84.4649
HEATER FLOW LOSS	-88.7710	REHEAT	628.1825
REGEN.FLOW LOSS	-111.9441	SHUTTLE	116.6626
COOLER FLOW LOSS	-5.6034	PUMPING	8.7164
INDICATED	749.7000	TEMP. SWING	1.1696
		CYL. WALL COND.	195.3623
		DISPLCR WALL COND.	34.1317
		REGEN. WALL COND.	61.6533
INDICATED EFFICIENCY, %	28.14	CYL. GAS COND.	6.1563
		REGEN. MTX. COND.	4.6365
		RAD.INSIDE DISPL.	4.7982
EXP.SP.EFFECT.TEMP.,C	576.14	FLOW FRIC. CREDIT	-144.7430
COMP.SP.EFFECT.TEMP.,C	53.30	TOTAL HEAT TO ENG.	2664.6320

Convergence criteria is: .00500

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa
1	.00000	.00000	40.0808	63.9168	6.7117
2	.59919	.68042	48.4474	42.0225	6.8403
3	.20874	.34254	31.7566	25.8545	6.6295
4	.34452	.38475	40.9136	59.9944	6.6455
5	.28835	1.32046	42.0683	70.4845	6.6891
6	.02822	.17485	39.8718	67.8756	6.7249
7	.05221	.03701	39.3202	65.3913	6.6916
8	.01383	.03660	39.6424	66.1666	6.6608
9	.00819	.01185	39.8318	65.1861	6.6342
10	.00478	.01482	40.0817	66.2976	6.6615
11	.00628	.01705	40.2908	66.3703	6.6329
12	.00522	.00110	40.4260	67.0307	6.6054
13	.00336	.00995	40.5233	67.4787	6.6372
14	.00241	.00668	40.6744	67.3859	6.6080
15	.00373	.00138	40.6784	67.5582	6.6399

ENTERED PRINT ROUTINE AFTER 15 CYCLES.
Fractional change in two successive integrals of heat in and power out has been less than .0050

RUN# 4 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .040 N/(cm/sec)**2.
ISOTHERMAL ANALYSIS WITH CORRECTIONS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	70.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2,2=HE,3=AIR	2	PHASE ANG. DEGREES =	92.61
POWER P.STR,CM =	2.22	DISPL. STROKE, CM =	2.73
CALC.FREQ., HZ =	24.90	TIME STEPS/CYCLE =	80.33

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	1012.7850	BASIC	1682.0190
ADIABATIC CORR.	-44.6190	ADIABATIC CORR.	85.5279
HEATER FLOW LOSS	-90.2289	REHEAT	640.1371
REGEN.FLOW LOSS	-113.4624	SHUTTLE	117.1529
COOLER FLOW LOSS	-5.7125	PUMPING	8.8773
INDICATED	758.7621	TEMP. SWING	1.2245
		CYL. WALL COND.	195.4898
		DISPLCR WALL COND.	34.1540
------------------------------		REGEN. WALL COND.	61.6936
INDICATED EFFICIENCY, %	28.16	CYL. GAS COND.	6.1603
		REGEN. MTX. COND.	4.6395
------------------------------		RAD.INSIDE DISPL.	4.8001
EXP.SP.EFFECT.TEMP.,C	576.18	FLOW FRIC. CREDIT	-146.9602
COMP.SP.EFFECT.TEMP.,C	53.04	TOTAL HEAT TO ENG.	2694.9160

Convergence criteria is: .00500

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa
1	.00000	.00000	40.6494	64.8417	6.8075
2	.59351	.67579	48.6803	41.8594	6.9731
3	.19756	.35444	31.2183	27.2461	6.7395
4	.35871	.34911	41.1303	61.2638	6.7327
5	.31751	1.24854	41.8466	69.9938	6.8137
6	.01742	.14250	40.0650	68.1457	6.8213
7	.04257	.02640	39.5008	65.4819	6.7655
8	.01408	.03909	39.8565	65.3840	6.7695
9	.00901	.00149	40.2357	66.2301	6.7716
10	.00951	.01294	40.4250	66.9694	6.7174
11	.00471	.01116	40.4824	67.3505	6.7259
12	.00142	.00569	40.6304	67.5205	6.7314
13	.00365	.00252	40.7270	67.2803	6.7372

ENTERED PRINT ROUTINE AFTER 13 CYCLES.
Fractional change in two successive integrals of heat in and power out has been less than .0050

RUN# 3 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .040 N/(cm/sec)**2.
ISOTHERMAL ANALYSIS WITH CORRECTIONS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	71.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2,2=HE,3=AIR	2	PHASE ANG. DEGREES =	92.00
POWER P.STR,CM =	2.21	DISPL. STROKE, CM =	2.71
CALC.FREQ., HZ =	25.07	TIME STEPS/CYCLE =	79.78

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	1021.0420	BASIC	1686.7410
ADIABATIC CORR.	-44.8980	ADIABATIC CORR.	85.7787
HEATER FLOW LOSS	-91.0885	REHEAT	653.4457
REGEN.FLOW LOSS	-114.1620	SHUTTLE	115.4587
COOLER FLOW LOSS	-5.7710	PUMPING	8.9964
INDICATED	765.1220	TEMP. SWING	1.2768
		CYL. WALL COND.	195.5663
		DISPLCR WALL COND.	34.1674
		REGEN. WALL COND.	61.7177
INDICATED EFFICIENCY, %	28.23	CYL. GAS COND.	6.1627
		REGEN. MTX. COND.	4.6413
		RAD. INSIDE DISPL.	4.8007
EXP.SP.EFFECT.TEMP.,C	576.29	FLOW FRIC. CREDIT	-148.1695
COMP.SP.EFFECT.TEMP.,C	52.79	TOTAL HEAT TO ENG.	2710.5840

Convergence criteria is: .00500

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa
1	.00000	.00000	40.9336	65.3043	6.8554
2	.59066	.67348	48.7631	41.8690	6.9838
3	.19127	.35886	32.2795	28.3167	6.7567
4	.33803	.32368	41.2167	60.8297	6.7698
5	.27687	1.14820	41.9362	70.3260	6.8080
6	.01746	.15611	40.2224	68.6236	6.8345
7	.04087	.02421	39.7070	65.2487	6.8514
8	.01282	.04918	39.9883	65.7087	6.8069
9	.00709	.00705	40.3558	67.5293	6.8297
10	.00919	.02771	40.4877	67.0062	6.7915
11	.00327	.00775	40.4389	66.1029	6.7563
12	.00121	.01348	40.7586	68.2154	6.7781
13	.00791	.03196	40.9802	67.8870	6.7995
14	.00544	.00481	40.8560	67.1294	6.7626
15	.00303	.01116	41.0665	68.9538	6.7856
16	.00515	.02718	41.2251	68.2623	6.7497
17	.00386	.01003	41.1035	67.6497	6.7753
18	.00295	.00897	41.4211	69.4124	6.7369
19	.00773	.02605	41.3882	68.4191	6.7648
20	.00079	.01431	41.4489	68.9261	6.7276
21	.00147	.00741	41.5653	69.1952	6.7540
22	.00281	.00390	41.5272	68.1605	6.7200
23	.00092	.01495	41.6939	70.2058	6.7447
24	.00401	.03001	41.7574	68.5770	6.7122
25	.00152	.02320	41.7187	69.6310	6.7381
26	.00093	.01537	41.9217	69.3221	6.7030
27	.00487	.00444	41.7818	69.0439	6.7314

ENTERED PRINT ROUTINE AFTER 27 CYCLES.
Fractional change in two successive integrals of heat in and power out has been less than .0050

RUN# 9 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .040 N/(cm/sec)**2.
ISOTHERMAL ANALYSIS WITH CORRECTIONS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	71.50
HEAT IN. DEG C =	600.00	HEAT OUT. DEG. C =	40.00
W. GAS 1=H2, 2=HE, 3=AIR	2	PHASE ANG. DEGREES =	92.88
POWER P.STR, CM =	2.22	DISPL. STROKE, CM =	2.72
CALC.FREQ., HZ =	25.17	TIME STEPS/CYCLE =	79.46

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	1051.6750	BASIC	1737.8780
ADIABATIC CORR.	-46.2574	ADIABATIC CORR.	98.3778
HEATER FLOW LOSS	-94.4539	REHEAT	666.9669
REGEN.FLOW LOSS	-117.8176	SHUTTLE	116.1058
COOLER FLOW LOSS	-5.9889	PUMPING	9.2434
INDICATED	787.1572	TEMP. SWING	1.3368
		CYL. WALL COND.	195.4731
		DISPLCR WALL COND.	34.1511
------------------------------		REGEN. WALL COND.	61.6883
INDICATED EFFICIENCY, %	28.38	CYL. GAS COND.	6.1598
		REGEN. MTX. COND.	4.6391
------------------------------		RAD. INSIDE DISPL.	4.7926
EXP.SP.EFFECT.TEMP.,C	576.02	FLOW FRIC. CREDIT	-153.3627
COMP.SP.EFFECT.TEMP.,C	52.64	TOTAL HEAT TO ENG.	2773.4500

Convergence criteria is: .00500

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa
1	.00000	.00000	41.2179	65.7667	6.9033
2	.58782	.67117	48.8205	42.9744	7.0516
3	.18445	.34656	31.9210	27.3725	6.8448
4	.34616	.36305	41.3684	61.1830	6.8093
5	.29596	1.23520	41.9966	70.7865	6.8680
6	.01519	.15696	40.2653	67.6868	6.9122
7	.04123	.04376	39.8236	66.5025	6.8839
8	.01097	.01753	40.1621	65.7220	6.8620
9	.00850	.01174	40.4407	67.1472	6.8377
10	.00694	.02168	40.5700	66.8365	6.8193
11	.00320	.00463	40.7720	67.5785	6.8564
12	.00498	.01110	40.9441	68.4571	6.8335
13	.00422	.01300	40.8827	67.1652	6.8160
14	.00150	.01887	41.0837	68.3268	6.7943
15	.00492	.01729	41.2020	68.3053	6.8364
16	.00288	.00031	41.3449	68.3814	6.8141

ENTERED PRINT ROUTINE AFTER 16 CYCLES.
Fractional change in two successive integrals of heat
in and power out has been less than .0050

RUN# 2 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .040 N/(cm/sec)**2.
ISOTHERMAL ANALYSIS WITH CORRECTIONS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	72.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2,2=HE,3=AIR	2	PHASE ANG. DEGREES =	91.45
POWER P.STR,CM =	2.21	DISPL. STROKE, CM =	2.71
CALC.FREQ., HZ =	25.23	TIME STEPS/CYCLE =	79.27

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	1043.0740	BASIC	1725.1690
ADIABATIC CORR.	-45.7888	ADIABATIC CORR.	87.7428
HEATER FLOW LOSS	-93.1809	REHEAT	670.6785
REGEN.FLOW LOSS	-116.2890	SHUTTLE	114.8566
COOLER FLOW LOSS	-5.9137	PUMPING	9.2121
INDICATED	781.9020	TEMP. SWING	1.3459
		CYL. WALL COND.	195.6023
		DISPLCR WALL COND.	34.1737
		REGEN. WALL COND.	61.7291
INDICATED EFFICIENCY, %	28.28	CYL. GAS COND.	6.1639
		REGEN. MTX. COND.	4.6421
		RAD. INSIDE DISPL.	4.7981
EXP.SP.EFFECT.TEMP.,C	576.11	FLOW FRIC. CREDIT	-151.3254
COMP.SP.EFFECT.TEMP.,C	52.61	TOTAL HEAT TO ENG.	2764.7890

APPENDIX I

EFFECT OF PRESSURE ON ISOTHERMAL FREE-PISTON ANALYSIS

0.1 MSEC TIME STEP

0.005 CONVERGENCE CRITERIA

Convergence criteria is: .00500

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa
1	.00000	.00000	38.3738	60.9473	6.3977
2	.61626	.69526	46.4873	36.6278	6.5602
3	.21143	.39902	31.4060	24.2166	6.3227
4	.32442	.33895	41.0435	59.9677	6.3099
5	.30687	1.47631	41.5356	70.4090	6.3861
6	.01199	.17412	39.6794	67.8131	6.3932
7	.04469	.03687	39.0651	64.5602	6.3804
8	.01548	.04797	39.4270	64.8432	6.3565
9	.00926	.00439	39.7618	65.5961	6.3463
10	.00849	.01161	39.9495	66.0311	6.3473
11	.00472	.00663	40.1039	66.4014	6.3377
12	.00386	.00561	40.2269	66.6840	6.3291
13	.00306	.00426	40.3552	66.9305	6.3210

ENTERED PRINT ROUTINE AFTER 13 CYCLES.

Fractional change in two successive integrals of heat in and power out has been less than .0050

RUN# 15 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .040 N/(cm/sec)**2.
ISOTHERMAL ANALYSIS WITH CORRECTIONS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	67.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2, 2=HE, 3=AIR	2	PHASE ANG. DEGREES =	92.65
POWER P.STR, CM =	2.25	DISPL. STROKE, CM =	2.81
CALC.FREQ., HZ =	24.26	TIME STEPS/CYCLE =	412.15

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	979.1478	BASIC	1623.9490
ADIABATIC CORR.	-43.4919	ADIABATIC CORR.	82.5300
HEATER FLOW LOSS	-85.4560	REHEAT	596.3245
REGEN.FLOW LOSS	-108.6297	SHUTTLE	123.1582
COOLER FLOW LOSS	-5.3746	PUMPING	8.3989
INDICATED	736.1956	TEMP. SWING	1.0552
		CYL. WALL COND.	195.1425
		DISPLCR WALL COND.	34.0933
----------------------------------		REGEN. WALL COND.	61.5840
INDICATED EFFICIENCY, %	28.29	CYL. GAS COND.	6.1494
		REGEN. MTX. COND.	4.6312
----------------------------------		RAD.INSIDE DISPL.	4.7958
EXP.SP.EFFECT.TEMP.,C	576.05	FLOW FRIC. CREDIT	-139.7709
COMP.SP.EFFECT.TEMP.,C	53.82	TOTAL HEAT TO ENG.	2602.0410

Convergence criteria is: .00500

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa
1	.00000	.00000	38.9427	61.8675	6.4931
2	.61057	.69066	46.7219	36.7685	6.6512
3	.19976	.40569	31.9042	25.3469	6.4183
4	.31715	.31064	41.3311	60.6913	6.4069
5	.29547	1.39443	41.7318	70.7182	6.4733
6	.00970	.16521	39.9082	68.1018	6.4916
7	.04370	.03700	39.3656	65.0057	6.4673
8	.01359	.04546	39.7282	65.3378	6.4545
9	.00921	.00511	40.0693	66.1015	6.4438
10	.00859	.01169	40.2421	66.5585	6.4343
11	.00431	.00691	40.3829	66.8668	6.4361
12	.00350	.00463	40.5216	67.1430	6.4269

ENTERED PRINT ROUTINE AFTER 12 CYCLES.
Fractional change in two successive integrals of heat in and power out has been less than .0050

RUN# 14 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .040 N/(cm/sec)**2.
ISOTHERMAL ANALYSIS WITH CORRECTIONS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	68.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2,2=HE,3=AIR	2	PHASE ANG. DEGREES =	92.02
POWER P.STR,CM =	2.24	DISPL. STROKE, CM =	2.79
CALC.FREQ., HZ =	24.44	TIME STEPS/CYCLE =	409.19

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	990.2960	BASIC	1640.6890
ADIABATIC CORR.	-43.8679	ADIABATIC CORR.	83.4060
HEATER FLOW LOSS	-86.6214	REHEAT	610.5700
REGEN.FLOW LOSS	-109.7038	SHUTTLE	121.5468
COOLER FLOW LOSS	-5.4534	PUMPING	8.5403
INDICATED	744.6495	TEMP. SWING	1.1070
		CYL. WALL COND.	195.2704
		DISPLCR WALL COND.	34.1157
		REGEN. WALL COND.	61.6243
INDICATED EFFICIENCY, %	28.30	CYL. GAS COND.	6.1534
		REGEN. MTX. COND.	4.6343
		RAD. INSIDE DISPL.	4.7984
EXP. SP. EFFECT. TEMP., C	576.14	FLOW FRIC. CREDIT	-141.4733
COMP. SP. EFFECT. TEMP., C	53.58	TOTAL HEAT TO ENG.	2631.1820

Convergence criteria is: .00500

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa
1	.00000	.00000	39.5115	62.7881	6.5884
2	.60488	.68606	46.9486	36.8991	6.7519
3	.18823	.41232	32.1409	26.5131	6.5139
4	.31540	.28147	41.5720	61.2070	6.5146
5	.29343	1.30856	41.9930	70.9216	6.5687
6	.01013	.15872	40.1604	68.3496	6.5869
7	.04364	.03627	39.6808	65.5505	6.5614
8	.01194	.04095	40.0373	65.9112	6.5481
9	.00898	.00550	40.3578	66.5767	6.5368
10	.00800	.01010	40.5239	66.9782	6.5375
11	.00412	.00603	40.6752	67.3122	6.5272
12	.00373	.00499	40.7956	67.6238	6.5180

ENTERED PRINT ROUTINE AFTER 12 CYCLES.
Fractional change in two successive integrals of heat in and power out has been less than .0050

RUN# 13 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .040 N/(cm/sec)**2.
ISOTHERMAL ANALYSIS WITH CORRECTIONS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	69.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2,2=HE,3=AIR 2		PHASE ANG. DEGREES =	92.26
POWER P.STR,CM =	2.24	DISPL. STROKE, CM =	2.77
CALC.FREQ., HZ =	24.62	TIME STEPS/CYCLE =	406.22

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	1004.2810	BASIC	1664.7210
ADIABATIC CORR.	-44.3865	ADIABATIC CORR.	84.6303
HEATER FLOW LOSS	-88.0160	REHEAT	624.0253
REGEN.FLOW LOSS	-111.0527	SHUTTLE	120.1373
COOLER FLOW LOSS	-5.5485	PUMPING	8.7011
INDICATED	755.2776	TEMP. SWING	1.1605
		CYL. WALL COND.	195.3584
		DISPLCR WALL COND.	34.1310
		REGEN. WALL COND.	61.6521
INDICATED EFFICIENCY, %	28.32	CYL. GAS COND.	6.1562
		REGEN. MTX. COND.	4.6364
		RAD. INSIDE DISPL.	4.7988
EXP.SP.EFFECT.TEMP.,C	576.13	FLOW FRIC. CREDIT	-143.5423
COMP.SP.EFFECT.TEMP.,C	53.35	TOTAL HEAT TO ENG.	2666.5660

```
Convergence criteria is:     .00500
Cycle  Change   Change   Work     Heat     End
Numb.  Power    Heat     Out      In       Pressure
       Out      In       Joules   Joules   MPa
  1   .00000   .00000   40.0802  63.7090  6.6838
  2   .59920   .68145   47.1792  37.1600  6.8409
  3   .17712   .41672   32.6792  27.5557  6.6066
  4   .30734   .25846   41.8397  61.9085  6.6073
  5   .28031  1.24667   42.1572  71.2595  6.6721
  6   .00759   .15105   40.4200  68.7089  6.6771
  7   .04121   .03579   39.9398  65.9433  6.6618
  8   .01188   .04025   40.3217  66.3570  6.6466
  9   .00956   .00627   40.6237  67.0184  6.6339
 10   .00749   .00997   40.7935  67.4264  6.6336
 11   .00418   .00509   40.9435  67.7826  6.6218
 12   .00368   .00528   41.0599  68.0506  6.6113
 13   .00284   .00395   41.1804  68.2719  6.6124
ENTERED PRINT ROUTINE AFTER     13 CYCLES.
Fractional change in two successive integrals of heat
in and power out has been less than      .0050
                     RUN# 12    FOR
                     SUNPOWER RE1000 ENGINE
                     FREE MOTIONS -- LINEAR ALTERNATOR
                          Load constant =    .040 N/(cm/sec)**2.
                     ISOTHERMAL ANALYSIS WITH CORRECTIONS
                     MARTINI LOSS EQUATIONS
                     SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70      CHRG. PRESS., BAR   =    70.00
HEAT IN, DEG C =     600.00      HEAT OUT, DEG. C    =    40.00
W. GAS 1=H2,2=HE,3=AIR 2         PHASE ANG. DEGREES  =    92.53
POWER P.STR,CM =       2.23      DISPL. STROKE, CM   =     2.76
CALC.FREQ., HZ =      24.79      TIME STEPS/CYCLE    =   403.33

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                        HEAT REQUIREMENT, WATTS
  BASIC                 1021.0060    BASIC                   1692.6990
  ADIABATIC CORR.        -45.0466    ADIABATIC CORR.           86.0627
  HEATER FLOW LOSS       -89.8467    REHEAT                   638.7196
  REGEN.FLOW LOSS       -112.8758    SHUTTLE                  118.9305
  COOLER FLOW LOSS        -5.6704    PUMPING                    8.6790
  INDICATED              767.5666    TEMP. SWING                1.2204
                                     CYL. WALL COND.          195.4079
                                     DISPLCR WALL COND.        34.1397
---------------------------------    REGEN. WALL COND.         61.6677
INDICATED EFFICIENCY, %   28.35      CYL. GAS COND.             6.1577
                                     REGEN. MTX. COND.          4.6375
---------------------------------    RAD.INSIDE DISPL.          4.7973
EXP.SP.EFFECT.TEMP.,C    576.08      FLOW FRIC. CREDIT       -146.2646
COMP.SP.EFFECT.TEMP.,C    53.12      TOTAL HEAT TO ENG.      2707.0350
```

```
Convergence criteria is:      .00500
Cycle  Change   Change   Work     Heat     End
Numb.  Power    Heat     Out      In       Pressure
       Out      In       Joules   Joules   MPa
  1    .00000   .00000   40.6486  64.6300  6.7792
  2    .59351   .67685   47.3997  37.4425  6.9402
  3    .16608   .42066   32.9431  26.6059  6.6998
  4    .30499   .23600   42.0600  62.3767  6.7003
  5    .27675  1.18055   42.3001  71.3692  6.7639
  6    .00571   .14416   40.6818  68.9645  6.7782
  7    .03826   .03369   40.2473  66.4580  6.7603
  8    .01068   .03635   40.6232  66.9031  6.7436
  9    .00934   .00670   40.9096  67.5305  6.7292
 10    .00705   .00938   41.0700  67.8990  6.7273
 11    .00392   .00546   41.2189  68.2383  6.7140
 12    .00363   .00500   41.3429  68.4783  6.7131
ENTERED PRINT ROUTINE AFTER    12 CYCLES.
Fractional change in two successive integrals of heat
in and power out has been less than      .0050
                   RUN# 11    FOR
                   SUNPOWER RE1000 ENGINE
                   FREE MOTIONS -- LINEAR ALTERNATOR
                        Load constant =     .040 N/(cm/sec)**2.
                   ISOTHERMAL ANALYSIS WITH CORRECTIONS
                   MARTINI LOSS EQUATIONS
                   SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =        29.70      CHRG. PRESS., BAR   =     71.00
HEAT IN, DEG C =       600.00      HEAT OUT, DEG. C    =     40.00
W. GAS 1=H2,2=HE,3=AIR 2           PHASE ANG. DEGREES  =     92.35
POWER P.STR,CM =         2.23      DISPL. STROKE, CM   =      2.74
CALC.FREQ., HZ =        24.97      TIME STEPS/CYCLE    =    400.47

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                       HEAT REQUIREMENT, WATTS
  BASIC                1032.3500    BASIC                  1709.9320
  ADIABATIC CORR.       -45.4376    ADIABATIC CORR.          86.9528
  HEATER FLOW LOSS      -51.0385    REHEAT                  652.5814
  REGEN.FLOW LOSS      -113.9777    SHUTTLE                 117.4462
  COOLER FLOW LOSS       -5.7521    PUMPING                   9.0242
  INDICATED             776.1441    TEMP. SWING               1.2770
                                    CYL. WALL COND.         195.5083
                                    DISPLCR WALL COND.       34.1572
--------------------------------    REGEN. WALL COND.        61.6994
INDICATED EFFICIENCY, %   28.37     CYL. GAS COND.            6.1609
                                    REGEN. MTX. COND.         4.6399
--------------------------------    RAD. INSIDE DISPL.        4.7984
EXP.SP.EFFECT.TEMP.,C   576.10      FLOW FRIC. CREDIT      -148.0274
COMP.SP.EFFECT.TEMP.,C   52.90      TOTAL HEAT TO ENG.     2736.1500
```

Convergence criteria is: .00500

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa
1	.00000	.00000	41.2170	65.5511	6.8746
2	.58783	.67224	47.6249	37.7585	7.0386
3	.15547	.42398	33.2318	29.6379	6.8023
4	.30222	.21507	42.3122	62.9074	6.8011
5	.27324	1.12254	42.4981	71.5493	6.8624
6	.00439	.13737	40.9332	69.2594	6.8739
7	.03682	.03200	40.5295	66.9297	6.8532
8	.00986	.03364	40.9045	67.4000	6.8337
9	.00925	.00703	41.1801	68.0065	6.8283
10	.00674	.00900	41.3435	68.3232	6.8233
11	.00397	.00466	41.4816	68.6685	6.8070
12	.00334	.00505	41.6040	68.9201	6.8037
13	.00295	.00366	41.7402	69.1436	6.8001

ENTERED PRINT ROUTINE AFTER 13 CYCLES.
Fractional change in two successive integrals of heat in and power out has been less than .0050

RUN# 10 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .040 N/(cm/sec)**2.
ISOTHERMAL ANALYSIS WITH CORRECTIONS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	72.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2,2=HE,3=AIR	2	PHASE ANG. DEGREES =	93.11
POWER P.STR,CM =	2.22	DISPL. STROKE, CM =	2.72
CALC.FREQ., HZ =	25.14	TIME STEPS/CYCLE =	397.76

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	1049.3710	BASIC	1738.3080
ADIABATIC CORR.	-46.1067	ADIABATIC CORR.	88.4058
HEATER FLOW LOSS	-92.8062	REHEAT	666.1506
REGEN.FLOW LOSS	-115.6985	SHUTTLE	116.2873
COOLER FLOW LOSS	-5.8690	PUMPING	9.2046
INDICATED	788.8903	TEMP. SWING	1.3371
		CYL. WALL COND.	195.5586
		DISPLCR WALL COND.	34.1660
		REGEN. WALL COND.	61.7153
INDICATED EFFICIENCY, %	28.42	CYL. GAS COND.	6.1625
		REGEN. MTX. COND.	4.6411
		RAD. INSIDE DISPL.	4.7971
EXP.SP.EFFECT.TEMP.,C	576.04	FLOW FRIC. CREDIT	-150.6554
COMP.SP.EFFECT.TEMP.,C	52.69	TOTAL HEAT TO ENG.	2776.0780

APPENDIX J

EFFECT OF PRESSURE ON ADIABATIC

FREE-PISTON ANALYSIS

CONVERGENCE CRITERIA = 0.01

INITIAL TIME STEP = 1 MSEC

DOUBLE PRECISION

```
       Computer Name:  IBM/PC-AT
    Operating System:  DOS 3.00
  Built-in BIOS dated:  Thursday, July 3, 1986
      Main Processor:  Intel 80286           Serial Ports:  2
        Co-Processor:  Intel 80287         Parallel Ports:  2
Video Display Adapter:  Enhanced Graphics, 256 K-bytes
   Current Video Mode:  Text, 80 x 25 Color
Available Disk Drives:  3, A: - C:

DOS reports 640 K-bytes of memory:
    40 K-bytes used by DOS and resident programs
   600 K-bytes available for application programs
A search for active memory finds:
   640 K-bytes main memory     (at hex 0000-A000)
    32 K-bytes display memory  (at hex B800-C000)
ROM-BIOS Extensions are found at hex paragraphs: C000

  Computing Index (CI), relative to IBM/XT: Testing...
       Disk Index (DI), relative to IBM/XT: Not computed. No drive specified.

Performance Index (PI), relative to IBM/XT: Not computed.
```

9:14 pm, Wednesday, July 22, 1987

CONVERGENCE CRITERIA IS: .01000

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	28.5988	44.5242	4.7965	1.0000
2	.71401	.77738	73.0936	100.2775	4.5827	1.0000
3	1.55583	1.25220	97.7726	171.8939	4.5404	1.0000
4	.33764	.71418	102.5759	181.7607	4.4795	1.0000
5	.04913	.05740	102.6339	182.4127	4.5521	1.0000
6	.00056	.00359	104.4397	184.5055	4.4928	1.0000
7	.01759	.01147	102.5796	182.3018	4.4521	1.0000
8	.01781	.01194	101.6088	180.2685	4.5129	1.0000
9	.00946	.01115	100.8817	178.6897	4.4708	1.0000
10	.00716	.00876	101.1199	178.3157	4.5236	1.0000

CURRENT OPERATING CONDITIONS ARE:

01=	50.000	02=	2	03=	600.000	04=	40.000	05=	66.163
06=	3.905	07=	4.028	08=	0	09=	0	10=	1.000
11=	0	12=	.000	13=	1.000	14=	4	15=	4
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	54	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0200	76=	1.0000	77=	3.0000	78=	1.0000	79=	4.0000
80=	20.0000	81=	.0100	82=	.1000	83=	.0100	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0	116=	0	117=	0	118=	0	119=	0
120=	0								

```
 ENTERED PRINT ROUTINE AFTER    10 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN      .0100
                   RUN#  0    FOR
                   SUNPOWER RE1000 ENGINE
                   FREE MOTIONS -- LINEAR ALTERNATOR
                        LOAD CONSTANT =     .020 N/(CM/SEC)**2.
                   MARTINI MOVING GAS NODE ANALYSIS
                   MARTINI LOSS EQUATIONS
                   SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70       CHRG. PRESS., BAR  =     50.00
HEAT IN, DEG C =     600.00       HEAT OUT, DEG. C   =     40.00
W. GAS 1=H2,2=HE,3=AIR 2          PHASE ANG. DEGREES =     66.16
POWER P.STR,CM =       3.91       DISPL. STROKE, CM  =      4.03
CALC.FREQ., HZ =      22.97       TIME STEPS/CYCLE   =     43.53

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                     HEAT REQUIREMENT, WATTS
  BASIC                2323.0406   BASIC                  4096.4696
  ADIABATIC CORR.          .0000   ADIABATIC CORR.            .0000
  HEATER FLOW LOSS     -226.6227   REHEAT                  893.5624
  REGEN.FLOW LOSS      -370.4954   SHUTTLE                 250.5208
  COOLER FLOW LOSS      -25.8256   PUMPING                  17.9539
  INDICATED            1700.0969   TEMP. SWING               2.1925
                                   CYL. WALL COND.         192.6602
                                   DISPLCR WALL COND.       33.6596
--------------------------------   REGEN. WALL COND.        60.8006
INDICATED EFFICIENCY, %   33.01    CYL. GAS COND.            6.0711
                                   REGEN. MTX. COND.         4.5723
--------------------------------   RAD.INSIDE DISPL.         4.1295
                                   FLOW FRIC. CREDIT      -411.8704
                                   TOTAL HEAT TO ENG.     5150.7223
```

CONVERGENCE CRITERIA IS: .01000

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	34.2642	53.4851	5.7550	1.0000
2	.65736	.73257	75.8441	105.4377	5.4634	1.0000
3	1.21351	.97135	110.7320	190.9202	5.5094	1.0000
4	.46000	.81074	118.0731	209.9336	5.3372	1.0000
5	.06630	.09959	119.4016	211.9120	5.3882	1.0000
6	.01125	.00942	119.3089	211.9170	5.4571	1.0000
7	.00078	.00002	120.1918	213.5458	5.2900	1.0000

CURRENT OPERATING CONDITIONS ARE:

01=	60.000	02=	2	03=	600.000	04=	40.000	05=	81.662
06=	3.948	07=	4.032	08=	0	09=	0	10=	1.000
11=	0	12=	.000	13=	1.000	14=	4	15=	4
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	45	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0200	76=	1.0000	77=	3.0000	78=	1.0000	79=	4.0000
80=	20.0000	81=	.0100	82=	.1000	83=	.0100	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0	116=	0	117=	0	118=	0	119=	0
120=	0								

```
 ENTERED PRINT ROUTINE AFTER      7 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN       .0100
                  RUN#  0    FOR
                  SUNPOWER RE1000 ENGINE
                  FREE MOTIONS -- LINEAR ALTERNATOR
                       LOAD CONSTANT =     .020 N/(CM/SEC)**2.
                  MARTINI MOVING GAS NODE ANALYSIS
                  MARTINI LOSS EQUATIONS
                  SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70       CHRG. PRESS., BAR   =      60.00
HEAT IN, DEG C =     600.00       HEAT OUT, DEG. C    =      40.00
W. GAS 1=H2,2=HE,3=AIR 2          PHASE ANG. DEGREES =      81.66
POWER P.STR,CM =       3.95       DISPL. STROKE, CM   =       4.03
CALC.FREQ., HZ =      25.20       TIME STEPS/CYCLE    =      39.68

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                      HEAT REQUIREMENT, WATTS
  BASIC                  3029.3419  BASIC                    5382.2590
  ADIABATIC CORR.            .0000  ADIABATIC CORR.              .0000
  HEATER FLOW LOSS       -325.8154  REHEAT                   1214.6156
  REGEN.FLOW LOSS        -517.1593  SHUTTLE                   250.0777
  COOLER FLOW LOSS        -40.1269  PUMPING                    24.5821
  INDICATED              2146.2403  TEMP. SWING                 4.4607
                                    CYL. WALL COND.           191.9098
                                    DISPLCR WALL COND.         33.5285
--------------------------------    REGEN. WALL COND.          60.5638
INDICATED EFFICIENCY, %   32.56     CYL. GAS COND.              6.0475
                                    REGEN. MTX. COND.           4.5545
--------------------------------    RAD.INSIDE DISPL.           4.0241
                                    FLOW FRIC. CREDIT        -584.3951
                                    TOTAL HEAT TO ENG.       6592.2282
```

CONVERGENCE CRITERIA IS: .01000

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	39.9112	62.4641	6.7134	1.0000
2	.60089	.68768	77.6958	108.5194	6.4170	1.0000
3	.94672	.73731	114.2329	195.2987	6.4314	1.0000
4	.47026	.79967	130.6966	232.7135	6.4401	1.0000
5	.14412	.19158	133.0914	238.6489	6.2287	1.0000
6	.01832	.02551	133.3821	239.8750	6.2899	1.0000
7	.00218	.00514	134.8375	240.0621	6.3415	1.0000
8	.01091	.00078	135.4629	239.8686	6.3938	1.0000
9	.00464	.00081	135.5635	240.5502	6.1886	1.0000

CURRENT OPERATING CONDITIONS ARE:

01=	70.000	02=	2	03=	600.000	04=	40.000	05=	78.243
06=	3.916	07=	4.017	08=	0	09=	0	10=	1.000
11=	0	12=	.000	13=	1.000	14=	4	15=	4
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	42	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0200	76=	1.0000	77=	3.0000	78=	1.0000	79=	4.0000
80=	20.0000	81=	.0100	82=	.1000	83=	.0100	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0	116=	0	117=	0	118=	0	119=	0
120=	0								

```
 ENTERED PRINT ROUTINE AFTER      9 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN       .0100
                   RUN#  0   FOR
                   SUNPOWER RE1000 ENGINE
                   FREE MOTIONS -- LINEAR ALTERNATOR
                        LOAD CONSTANT =     .020 N/(CM/SEC)**2.
                   MARTINI MOVING GAS NODE ANALYSIS
                   MARTINI LOSS EQUATIONS
                   SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70       CHRG. PRESS., BAR    =     70.00
HEAT IN, DEG C =     600.00       HEAT OUT, DEG. C     =     40.00
W. GAS 1=H2,2=HE,3=AIR 2          PHASE ANG. DEGREES   =     78.24
POWER P.STR,CM =       3.92       DISPL. STROKE, CM    =      4.02
CALC.FREQ., HZ =      27.17       TIME STEPS/CYCLE     =     36.81

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                      HEAT REQUIREMENT, WATTS
  BASIC                3682.9462    BASIC                 6535.1933
  ADIABATIC CORR.          .0000    ADIABATIC CORR.           .0000
  HEATER FLOW LOSS     -412.2269    REHEAT                1546.4308
  REGEN.FLOW LOSS      -623.7307    SHUTTLE                239.8775
  COOLER FLOW LOSS      -51.3077    PUMPING                 30.3835
  INDICATED            2595.6809    TEMP. SWING              7.7222
                                    CYL. WALL COND.        185.4997
                                    DISPLCR WALL COND.      32.4086
--------------------------------    REGEN. WALL COND.       58.5408
INDICATED EFFICIENCY, %  32.75      CYL. GAS COND.           5.8455
                                    REGEN. MTX. COND.        4.4024
--------------------------------    RAD.INSIDE DISPL.        3.6874
                                    FLOW FRIC. CREDIT     -724.0923
                                    TOTAL HEAT TO ENG.    7925.8994
```

CONVERGENCE CRITERIA IS: .01000

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	41.0383	64.2620	6.9050	1.0000
2	.58962	.67869	79.4195	109.9915	6.6961	1.0000
3	.93525	.71161	114.6301	195.8483	6.6273	1.0000
4	.44335	.78058	132.9314	236.5392	6.5191	1.0000
5	.15965	.20777	136.1457	243.6895	6.4332	1.0000
6	.02418	.03023	136.9811	244.2863	6.6216	1.0000
7	.00614	.00245	136.6121	245.8846	6.5007	1.0000

CURRENT OPERATING CONDITIONS ARE:

01=	72.000	02=	2	03=	600.000	04=	40.000	05=	74.045
06=	3.907	07=	4.019	08=	0	09=	0	10=	1.000
11=	0	12=	.000	13=	1.000	14=	4	15=	4
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	44	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0200	76=	1.0000	77=	3.0000	78=	1.0000	79=	4.0000
80=	20.0000	81=	.0100	82=	.1000	83=	.0100	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0	116=	0	117=	0	118=	0	119=	0
120=	0								

```
 ENTERED PRINT ROUTINE AFTER      7 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN      .0100
                   RUN#  0   FOR
                   SUNPOWER RE1000 ENGINE
                   FREE MOTIONS -- LINEAR ALTERNATOR
                        LOAD CONSTANT =    .020 N/(CM/SEC)**2.
                   MARTINI MOVING GAS NODE ANALYSIS
                   MARTINI LOSS EQUATIONS
                   SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70       CHRG. PRESS., BAR   =      72.00
HEAT IN, DEG C =     600.00       HEAT OUT, DEG. C    =      40.00
W. GAS 1=H2,2=HE,3=AIR 2          PHASE ANG. DEGREES =      74.05
POWER P.STR,CM =       3.91       DISPL. STROKE, CM   =       4.02
CALC.FREQ., HZ =      27.42       TIME STEPS/CYCLE    =      36.46

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                      HEAT REQUIREMENT, WATTS
  BASIC                 3746.4637   BASIC                    6743.1640
  ADIABATIC CORR.           .0000   ADIABATIC CORR.              .0000
  HEATER FLOW LOSS      -427.5736   REHEAT                   1690.9350
  REGEN.FLOW LOSS       -643.0342   SHUTTLE                   249.6553
  COOLER FLOW LOSS       -53.5178   PUMPING                    31.2401
  INDICATED             2622.3382   TEMP. SWING                 8.7873
                                    CYL. WALL COND.           192.8387
                                    DISPLCR WALL COND.         33.6908
--------------------------------    REGEN. WALL COND.          60.8569
INDICATED EFFICIENCY, %  31.68      CYL. GAS COND.              6.0768
                                    REGEN. MTX. COND.           4.5766
--------------------------------    RAD.INSIDE DISPL.           4.1226
                                    FLOW FRIC. CREDIT        -749.0907
                                    TOTAL HEAT TO ENG.       8276.8534
```

CONVERGENCE CRITERIA IS: .01000

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	42.1648	66.0607	7.0967	1.0000
2	.57835	.66970	80.0999	110.5241	6.7438	1.0000
3	.89969	.67307	117.6396	201.3334	6.7680	1.0000
4	.46866	.82162	136.6534	243.6999	6.7751	1.0000
5	.16163	.21043	139.1340	248.5741	6.8058	1.0000
6	.01815	.02000	137.4939	245.6142	6.5997	1.0000
7	.01179	.01191	136.0149	244.1677	6.6714	1.0000
8	.01076	.00589	138.5902	248.3855	6.6991	1.0000
9	.01893	.01727	140.6466	252.3617	6.7245	1.0000
10	.01484	.01601	141.1062	252.6594	6.7528	1.0000
11	.00327	.00118	138.9851	253.1977	6.5574	.5000
12	.01503	.00213	138.8284	251.4863	6.6469	.5000
13	.00113	.00676	138.4697	252.6428	6.5581	.5000

CURRENT OPERATING CONDITIONS ARE:

01=	74.000	02=	2	03=	600.000	04=	40.000	05=	80.493
06=	3.873	07=	4.036	08=	0	09=	0	10=	1.000
11=	0	12=	.000	13=	1.000	14=	4	15=	4
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	76	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0200	76=	1.0000	77=	3.0000	78=	1.0000	79=	4.0000
80=	20.0000	81=	.0100	82=	.1000	83=	.0100	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0	116=	0	117=	0	118=	0	119=	0
120=	0								

```
 ENTERED PRINT ROUTINE AFTER    13 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN      .0100
                   RUN#  0   FOR
                   SUNPOWER RE1000 ENGINE
                   FREE MOTIONS -- LINEAR ALTERNATOR
                        LOAD CONSTANT =     .020 N/(CM/SEC)**2.
                   MARTINI MOVING GAS NODE ANALYSIS
                   MARTINI LOSS EQUATIONS
                   SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70        CHRG. PRESS., BAR   =      74.00
HEAT IN, DEG C =     600.00        HEAT OUT, DEG. C    =      40.00
W. GAS 1=H2,2=HE,3=AIR 2           PHASE ANG. DEGREES =      80.49
POWER P.STR,CM =       3.87        DISPL. STROKE, CM   =       4.04
CALC.FREQ., HZ =      27.95        TIME STEPS/CYCLE    =      71.56

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                       HEAT REQUIREMENT, WATTS
  BASIC                 3870.0965    BASIC                    7061.1267
  ADIABATIC CORR.           .0000    ADIABATIC CORR.              .0000
  HEATER FLOW LOSS      -476.0173    REHEAT                   1782.6607
  REGEN.FLOW LOSS       -744.2643    SHUTTLE                   246.2056
  COOLER FLOW LOSS       -65.7431    PUMPING                    32.5734
  INDICATED             2584.0718    TEMP. SWING                10.1062
                                     CYL. WALL COND.           188.5885
                                     DISPLCR WALL COND.         32.9483
--------------------------------     REGEN. WALL COND.          59.5156
INDICATED EFFICIENCY, %   30.12      CYL. GAS COND.              5.9428
                                     REGEN. MTX. COND.           4.4757
--------------------------------     RAD.INSIDE DISPL.           3.8727
                                     FLOW FRIC. CREDIT        -848.1494
                                     TOTAL HEAT TO ENG.       8579.8668
```

CONVERGENCE CRITERIA IS: .01000

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	43.2904	67.8600	7.2883	1.0000
2	.56710	.66070	79.9596	112.0559	7.0647	1.0000
3	.84705	.65128	116.1956	197.6267	6.9860	1.0000
4	.45318	.76364	135.4135	242.2931	6.9135	1.0000
5	.16539	.22601	141.8309	253.4322	6.7829	1.0000
6	.04739	.04597	140.4986	252.2951	6.9507	1.0000
7	.00939	.00449	142.9498	253.9971	6.8667	1.0000
8	.01745	.00675	144.4711	258.2191	6.7467	1.0000
9	.01064	.01662	141.6557	253.1917	6.9170	1.0000
10	.01949	.01947	144.7112	258.3119	6.8264	1.0000
11	.02157	.02022	140.0376	255.9007	6.7302	.5000
12	.03230	.00933	140.0385	255.1847	6.7954	.5000
13	.00001	.00280	140.9942	256.9038	6.8352	.5000

CURRENT OPERATING CONDITIONS ARE:

01=	76.000	02=	2	03=	600.000	04=	40.000	05=	76.374
06=	3.863	07=	4.037	08=	0	09=	0	10=	1.000
11=	0	12=	.000	13=	1.000	14=	4	15=	4
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	71	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0200	76=	1.0000	77=	3.0000	78=	1.0000	79=	4.0000
80=	20.0000	81=	.0100	82=	.1000	83=	.0100	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0	116=	0	117=	0	118=	0	119=	0
120=	0								

```
 ENTERED PRINT ROUTINE AFTER    13 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN      .0100
                   RUN#  0    FOR
                   SUNPOWER RE1000 ENGINE
                   FREE MOTIONS -- LINEAR ALTERNATOR
                        LOAD CONSTANT =     .020 N/(CM/SEC)**2.
                   MARTINI MOVING GAS NODE ANALYSIS
                   MARTINI LOSS EQUATIONS
                   SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70        CHRG. PRESS., BAR  =       76.00
HEAT IN, DEG C =     600.00        HEAT OUT, DEG. C   =       40.00
W. GAS 1=H2,2=HE,3=AIR 2           PHASE ANG. DEGREES =       76.37
POWER P.STR,CM =       3.86        DISPL. STROKE, CM  =        4.04
CALC.FREQ., HZ =      28.29        TIME STEPS/CYCLE   =       70.70

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                       HEAT REQUIREMENT, WATTS
  BASIC                  3988.2775   BASIC                     7266.9935
  ADIABATIC CORR.            .0000   ADIABATIC CORR.               .0000
  HEATER FLOW LOSS       -498.5310   REHEAT                    1901.8050
  REGEN.FLOW LOSS        -770.0800   SHUTTLE                    248.4265
  COOLER FLOW LOSS        -68.6176   PUMPING                     33.6362
  INDICATED              2651.0488   TEMP. SWING                 11.3310
                                     CYL. WALL COND.            190.1826
                                     DISPLCR WALL COND.          33.2268
--------------------------------     REGEN. WALL COND.           60.0187
INDICATED EFFICIENCY, %  29.87       CYL. GAS COND.               5.9931
                                     REGEN. MTX. COND.            4.5135
--------------------------------     RAD.INSIDE DISPL.            3.9886
                                     FLOW FRIC. CREDIT         -883.5710
                                     TOTAL HEAT TO ENG.        8876.5444
```

CONVERGENCE CRITERIA IS: .01000

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	44.4154	69.6601	7.4799	1.0000
2	.55585	.65170	79.6018	113.5077	7.3781	1.0000
3	.79221	.62945	114.1137	194.3013	7.1657	1.0000
4	.43356	.71179	140.8346	249.4005	7.2019	1.0000
5	.23416	.28358	145.2642	258.7319	6.9541	1.0000
6	.03145	.03742	144.9034	259.4705	6.9887	1.0000
7	.00248	.00285	145.1204	259.5493	7.0088	1.0000

CURRENT OPERATING CONDITIONS ARE:

01=	78.000	02=	2	03=	600.000	04=	40.000	05=	77.373
06=	3.860	07=	3.991	08=	0	09=	0	10=	1.000
11=	0	12=	.000	13=	1.000	14=	4	15=	4
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	39	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0200	76=	1.0000	77=	3.0000	78=	1.0000	79=	4.0000
80=	20.0000	81=	.0100	82=	.1000	83=	.0100	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0	116=	0	117=	0	118=	0	119=	0
120=	0								

```
 ENTERED PRINT ROUTINE AFTER     7 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN      .0100
                   RUN#  0    FOR
                   SUNPOWER RE1000 ENGINE
                   FREE MOTIONS -- LINEAR ALTERNATOR
                        LOAD CONSTANT =     .020 N/(CM/SEC)**2.
                   MARTINI MOVING GAS NODE ANALYSIS
                   MARTINI LOSS EQUATIONS
                   SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70       CHRG. PRESS., BAR  =      78.00
HEAT IN, DEG C =     600.00       HEAT OUT, DEG. C   =      40.00
W. GAS 1=H2,2=HE,3=AIR 2          PHASE ANG. DEGREES =      77.37
POWER P.STR,CM =       3.86       DISPL. STROKE, CM  =       3.99
CALC.FREQ., HZ =      28.66       TIME STEPS/CYCLE   =      34.90

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                      HEAT REQUIREMENT, WATTS
  BASIC                4158.6933    BASIC                  7437.8641
  ADIABATIC CORR.          .0000    ADIABATIC CORR.            .0000
  HEATER FLOW LOSS     -506.6584    REHEAT                 2001.4901
  REGEN.FLOW LOSS      -786.5313    SHUTTLE                 246.3540
  COOLER FLOW LOSS      -71.0972    PUMPING                  35.2456
  INDICATED            2794.4064    TEMP. SWING              12.5352
                                    CYL. WALL COND.         193.0020
                                    DISPLCR WALL COND.       33.7194
--------------------------------    REGEN. WALL COND.        60.9085
INDICATED EFFICIENCY, %  30.59      CYL. GAS COND.            6.0819
                                    REGEN. MTX. COND.         4.5804
--------------------------------    RAD.INSIDE DISPL.         4.1128
                                    FLOW FRIC. CREDIT      -899.9241
                                    TOTAL HEAT TO ENG.     9135.9698
```

CONVERGENCE CRITERIA IS: .01000

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	45.5396	71.4608	7.6715	1.0000
2	.54460	.64270	82.3631	115.1615	7.4151	1.0000
3	.80860	.61153	119.6997	205.0667	7.2577	1.0000
4	.45332	.78069	139.6270	250.2294	7.3861	1.0000
5	.16648	.22023	145.4992	258.8323	7.2486	1.0000
6	.04206	.03438	146.4379	262.6790	7.3524	1.0000
7	.00645	.01486	147.7241	264.7185	7.2250	1.0000
8	.00878	.00776	148.4912	265.2681	7.3173	1.0000

CURRENT OPERATING CONDITIONS ARE:

01=	80.000	02=	2	03=	600.000	04=	40.000	05=	78.085
06=	3.877	07=	3.998	08=	0	09=	0	10=	1.000
11=	0	12=	.000	13=	1.000	14=	4	15=	4
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	46	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0200	76=	1.0000	77=	3.0000	78=	1.0000	79=	4.0000
80=	20.0000	81=	.0100	82=	.1000	83=	.0100	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0	116=	0	117=	0	118=	0	119=	0
120=	0								

```
 ENTERED PRINT ROUTINE AFTER     8 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN      .0100
                   RUN#  0   FOR
                   SUNPOWER RE1000 ENGINE
                   FREE MOTIONS -- LINEAR ALTERNATOR
                        LOAD CONSTANT =    .020 N/(CM/SEC)**2.
                   MARTINI MOVING GAS NODE ANALYSIS
                   MARTINI LOSS EQUATIONS
                   SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70       CHRG. PRESS., BAR  =      80.00
HEAT IN, DEG C =     600.00       HEAT OUT, DEG. C   =      40.00
W. GAS 1=H2,2=HE,3=AIR 2          PHASE ANG. DEGREES =      78.09
POWER P.STR,CM =       3.88       DISPL. STROKE, CM  =       4.00
CALC.FREQ., HZ =      28.92       TIME STEPS/CYCLE   =      34.58

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                      HEAT REQUIREMENT, WATTS
  BASIC                 4294.4265   BASIC                  7671.6646
  ADIABATIC CORR.           .0000   ADIABATIC CORR.            .0000
  HEATER FLOW LOSS      -530.9920   REHEAT                 2082.5336
  REGEN.FLOW LOSS       -771.1359   SHUTTLE                 252.3889
  COOLER FLOW LOSS       -67.2421   PUMPING                  36.5556
  INDICATED             2925.0565   TEMP. SWING              13.5184
                                    CYL. WALL COND.         197.0338
                                    DISPLCR WALL COND.       34.4237
--------------------------------    REGEN. WALL COND.        62.1808
INDICATED EFFICIENCY, %  30.96      CYL. GAS COND.            6.2090
                                    REGEN. MTX. COND.         4.6761
--------------------------------    RAD.INSIDE DISPL.         4.3782
                                    FLOW FRIC. CREDIT      -916.5599
                                    TOTAL HEAT TO ENG.     9449.0038
```

CONVERGENCE CRITERIA IS: .01000

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	46.6630	73.2623	7.8631	1.0000
2	.53337	.63369	86.4116	118.6108	7.6518	1.0000
3	.85182	.61899	126.0791	218.0622	7.5897	1.0000
4	.45905	.83847	145.4305	260.5669	7.5503	1.0000
5	.15349	.19492	150.5624	268.2795	7.5014	1.0000
6	.03529	.02960	149.8464	267.5969	7.4918	1.0000
7	.00476	.00254	147.9498	264.7975	7.4946	1.0000
8	.01266	.01046	146.5545	263.4741	7.5172	.5000
9	.00943	.00500	148.2991	268.9339	7.5822	.5000
10	.01190	.02072	143.8019	262.7468	7.5371	.5000
11	.03033	.02301	142.3661	263.1699	7.4900	.2500
12	.00998	.00161	140.9376	261.1260	7.4467	.2500
13	.01003	.00777	140.4443	260.1328	7.4143	.2500
14	.00350	.00380	140.0247	260.0642	7.4637	.2500

CURRENT OPERATING CONDITIONS ARE:

01=	82.000	02=	2	03=	600.000	04=	40.000	05=	79.298
06=	3.757	07=	3.941	08=	0	09=	0	10=	1.000
11=	0	12=	.000	13=	1.000	14=	4	15=	4
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	149	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0200	76=	1.0000	77=	3.0000	78=	1.0000	79=	4.0000
80=	20.0000	81=	.0100	82=	.1000	83=	.0100	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0	116=	0	117=	0	118=	0	119=	0
120=	0								

```
 ENTERED PRINT ROUTINE AFTER    14 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN       .0100
                   RUN#  0    FOR
                   SUNPOWER RE1000 ENGINE
                   FREE MOTIONS -- LINEAR ALTERNATOR
                        LOAD CONSTANT =     .020 N/(CM/SEC)**2.
                   MARTINI MOVING GAS NODE ANALYSIS
                   MARTINI LOSS EQUATIONS
                   SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70       CHRG. PRESS., BAR  =      82.00
HEAT IN, DEG C =     600.00       HEAT OUT, DEG. C   =      40.00
W. GAS 1=H2,2=HE,3=AIR 2          PHASE ANG. DEGREES =      79.30
POWER P.STR,CM =       3.76       DISPL. STROKE, CM  =       3.94
CALC.FREQ., HZ =      29.37       TIME STEPS/CYCLE   =     136.20

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                      HEAT REQUIREMENT, WATTS
  BASIC                 4112.4574   BASIC                    7637.9589
  ADIABATIC CORR.           .0000   ADIABATIC CORR.              .0000
  HEATER FLOW LOSS      -520.5505   REHEAT                   2100.5383
  REGEN.FLOW LOSS       -790.3608   SHUTTLE                   238.8639
  COOLER FLOW LOSS       -71.4993   PUMPING                    35.7211
  INDICATED             2730.0468   TEMP. SWING                14.2507
                                    CYL. WALL COND.           191.8959
                                    DISPLCR WALL COND.         33.5261
--------------------------------    REGEN. WALL COND.          60.5594
INDICATED EFFICIENCY, %  29.01      CYL. GAS COND.              6.0471
                                    REGEN. MTX. COND.           4.5542
--------------------------------    RAD.INSIDE DISPL.           4.1143
                                    FLOW FRIC. CREDIT        -915.7309
                                    TOTAL HEAT TO ENG.       9412.2990
```

"

Computer Name: IBM/PC-AT — 9:53 pm, Wednesday, July 22, 1987
Operating System: DOS 3.00
Built-in BIOS dated: Thursday, July 3, 1986
Main Processor: Intel 80286 — Serial Ports: 2
Co-Processor: Intel 80287 — Parallel Ports: 2
Video Display Adapter: Enhanced Graphics, 256 K-bytes
Current Video Mode: Text, 80 x 25 Color
Available Disk Drives: 3, A: - C:

DOS reports 640 K-bytes of memory:
40 K-bytes used by DOS and resident programs
600 K-bytes available for application programs
A search for active memory finds:
640 K-bytes main memory (at hex 0000-A000)
32 K-bytes display memory (at hex B800-C000)
ROM-BIOS Extensions are found at hex paragraphs: C000

Computing Index (CI), relative to IBM/XT: Testing...
Disk Index (DI), relative to IBM/XT: Not computed. No drive specified.

Performance Index (PI), relative to IBM/XT: Not computed.
9:55 pm, Wednesday, July 22, 1987

CONVERGENCE CRITERIA IS: .01000

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	51.1493	80.4751	8.6295	1.0000
2	.48851	.59762	80.7176	114.7667	8.4269	1.0000
3	.57808	.42611	118.8008	202.2814	8.3051	1.0000
4	.47181	.76254	145.7117	263.6789	8.3336	.5000
5	.22652	.30353	152.3259	276.2889	8.3828	.5000
6	.04539	.04782	150.3713	274.1696	8.3415	.5000
7	.01283	.00767	150.0041	275.2033	8.2960	.5000
8	.00244	.00377	149.7298	274.9802	8.2386	.5000

CURRENT OPERATING CONDITIONS ARE:

01=	90.000	02=	2	03=	600.000	04=	40.000	05=	82.822
06=	3.734	07=	3.872	08=	0	09=	0	10=	1.000
11=	0	12=	.000	13=	1.000	14=	4	15=	4
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	75	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0200	76=	1.0000	77=	3.0000	78=	1.0000	79=	4.0000
80=	20.0000	81=	.0100	82=	.1000	83=	.0100	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0	116=	0	117=	0	118=	0	119=	0
120=	0								

```
 ENTERED PRINT ROUTINE AFTER     8 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN      .0100
                   RUN#  0   FOR
                   SUNPOWER RE1000 ENGINE
                   FREE MOTIONS -- LINEAR ALTERNATOR
                        LOAD CONSTANT =    .020 N/(CM/SEC)**2.
                   MARTINI MOVING GAS NODE ANALYSIS
                   MARTINI LOSS EQUATIONS
                   SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =     29.70        CHRG. PRESS., BAR  =      90.00
HEAT IN, DEG C =    600.00        HEAT OUT, DEG. C   =      40.00
W. GAS 1=H2,2=HE,3=AIR 2          PHASE ANG. DEGREES =      82.82
POWER P.STR,CM =      3.73        DISPL. STROKE, CM  =       3.87
CALC.FREQ., HZ =     30.67        TIME STEPS/CYCLE   =      65.20

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                      HEAT REQUIREMENT, WATTS
  BASIC                4592.9319    BASIC                  8434.9611
  ADIABATIC CORR.          .0000    ADIABATIC CORR.            .0000
  HEATER FLOW LOSS     -588.0119    REHEAT                 2388.0837
  REGEN.FLOW LOSS      -865.8817    SHUTTLE                 229.3948
  COOLER FLOW LOSS      -80.7307    PUMPING                  40.5399
  INDICATED            3058.3075    TEMP. SWING              19.0252
                                    CYL. WALL COND.         190.8693
                                    DISPLCR WALL COND.       33.3467
--------------------------------    REGEN. WALL COND.        60.2354
INDICATED EFFICIENCY, %  29.43      CYL. GAS COND.            6.0147
                                    REGEN. MTX. COND.         4.5298
--------------------------------    RAD.INSIDE DISPL.         4.0468
                                    FLOW FRIC. CREDIT     -1020.9527
                                    TOTAL HEAT TO ENG.    10390.0949
```

```
"
        Computer Name:  IBM/PC-AT
     Operating System:  DOS 3.00
   Built-in BIOS dated:  Thursday, July 3, 1986
        Main Processor:  Intel 80286              Serial Ports:  2
          Co-Processor:  Intel 80287            Parallel Ports:  2
Video Display Adapter:  Enhanced Graphics, 256 K-bytes
    Current Video Mode:  Text, 80 x 25 Color
Available Disk Drives:  3, A: - C:

DOS reports 640 K-bytes of memory:
    40 K-bytes used by DOS and resident programs
   600 K-bytes available for application programs
A search for active memory finds:
   640 K-bytes main memory     (at hex 0000-A000)
    32 K-bytes display memory  (at hex B800-C000)
ROM-BIOS Extensions are found at hex paragraphs: C000

  Computing Index (CI), relative to IBM/XT: Testing...
       Disk Index (DI), relative to IBM/XT: Not computed. No drive specified.

Performance Index (PI), relative to IBM/XT: Not computed.
                                              9:59 pm, Wednesday, July 22, 1987
CONVERGENCE CRITERIA IS:     .01000
CYCLE  CHANGE    CHANGE    WORK       HEAT        END       TIME
NUMB.  POWER     HEAT      OUT        IN          PRESSURE  STEP
       OUT       IN        JOULES     JOULES      MPA       MSEC.
  1    .00000    .00000    56.7402    89.5067     9.5873   1.0000
  2    .43260    .55247    83.0855   119.4000     9.5893    .5000
  3    .46431    .33398   118.5261   204.3221     9.2892    .5000
  4    .42656    .71124   145.1683   262.9645     9.3336    .5000
  5    .22478    .28701   152.6234   280.1653     9.1687    .5000
  6    .05136    .06541   154.3851   283.8908     9.2200    .5000
  7    .01154    .01330   155.7138   287.3159     9.2481    .5000
  8    .00861    .01206   156.2025   288.0685     9.2611    .5000
  9    .00314    .00262   156.7662   288.7771     9.0800    .5000
CURRENT OPERATING CONDITIONS ARE:
 01= 100.000  02=        2  03=  600.000  04=    40.000  05=   75.716
 06=   3.656  07=    3.756  08=        0  09=         0  10=    1.000
 11=       0  12=     .000  13=    1.000  14=         4  15=        4
 16=       0  17=        3  18= 1000.000  19=    10.000
CURRENT DIMENSIONS ARE:
 20=       1  21=   4.0400  22=   4.2000  23=    4.7000  24=   5.7180
 25= 15.1900  26=    .0365  27=   1.6630  28=    5.7790  29=  29.7000
 30=  6.2000  31=    .4260  32=        0  33=   33.0000  34=  15.2500
 35= 25.4000  36=   7.6000  37= 381.0000  38=     .0000  39=    .8000
 40= 10.0000  41=  31.7900  42=  20.5000  43=    2.3900  44=  72.5300
 45=      68  46=       24  47=   1.0200  48=     .1575  49=    .1067
 50=   .7600  51=    .1321  52=    .1016  53=   31.7900  54=   2.9200
 55=       2  56=       34  57=  18.3400  58=     .2362  59=   9.2600
 60=  1.5000  61=    .0000  62=   6.4460  63=     .5440  64=  88.9000
 65= 75.9000  66=    .0000  67=    .0000  68=     .0000  69=      135
 70=   .0508  71=    .3760  72=   7.9200  73=    1.5000  74=    .0000
 75=   .0200  76=   1.0000  77=   3.0000  78=    1.0000  79=   4.0000
 80= 20.0000  81=    .0100  82=    .1000  83=     .0100  84=    .0000
 85=   .0000  86=  -4.5650  87=    .4684  88=    7.9300  89=    .4600
 90=  4.4500  91=    .3710  92=    .1450  93=     .0813  94=        1
 95=   .5000  96=        0  97=    .0000  98=     .0000  99=    .0000
100=   .0000 101=       13 102=       15 103=        14 104=        0
105=       0 106=        0 107=        0 108=         0 109=        0
110=       0 111=        0 112=        0 113=         0 114=        0
115=       0  116=       0  117=       0  118=        0  119=       0
120=       0
```

```
 ENTERED PRINT ROUTINE AFTER      9 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN       .0100
                   RUN#  0    FOR
                   SUNPOWER RE1000 ENGINE
                   FREE MOTIONS -- LINEAR ALTERNATOR
                        LOAD CONSTANT =     .020 N/(CM/SEC)**2.
                   MARTINI MOVING GAS NODE ANALYSIS
                   MARTINI LOSS EQUATIONS
                   SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =       29.70     CHRG. PRESS., BAR   =     100.00
HEAT IN, DEG C =      600.00     HEAT OUT, DEG. C    =      40.00
W. GAS 1=H2,2=HE,3=AIR 2         PHASE ANG. DEGREES  =      75.72
POWER P.STR,CM =        3.66     DISPL. STROKE, CM   =       3.76
CALC.FREQ., HZ =       32.36     TIME STEPS/CYCLE    =      61.81

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                     HEAT REQUIREMENT, WATTS
  BASIC               5072.5476    BASIC                    9344.0762
  ADIABATIC CORR.         .0000    ADIABATIC CORR.              .0000
  HEATER FLOW LOSS    -665.8639    REHEAT                   2814.7207
  REGEN.FLOW LOSS     -961.3098    SHUTTLE                   211.7298
  COOLER FLOW LOSS     -93.7738    PUMPING                    46.1187
  INDICATED           3351.6001    TEMP. SWING                26.9417
                                   CYL. WALL COND.           187.2329
                                   DISPLCR WALL COND.         32.7114
--------------------------------   REGEN. WALL COND.          59.0878
INDICATED EFFICIENCY, %  28.92     CYL. GAS COND.              5.9001
                                   REGEN. MTX. COND.           4.4435
--------------------------------   RAD.INSIDE DISPL.           3.8346
                                   FLOW FRIC. CREDIT       -1146.5188
                                   TOTAL HEAT TO ENG.      11590.2786
```

APPENDIX K

EFFECT OF PRESSURE ON ADIABATIC

FREE-PISTON ANALYSIS

CONVERGENCE CRITERIA = 0.01

INITIAL TIME STEP = 1 MSEC

SINGLE PRECISION

Convergence criteria is: .01000

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa	Time Step Msec.
1	.00000	.00000	28.5430	44.4360	4.7969	1.0000
2	.71457	.77782	74.4353	101.7938	4.5655	1.0000
3	1.60783	1.29079	98.7119	173.8149	4.5228	1.0000
4	.32614	.70752	102.5878	182.1236	4.4564	1.0000
5	.03926	.04780	102.9620	183.0234	4.5246	1.0000
6	.00365	.00494	104.4905	184.9041	4.4697	1.0000
7	.01485	.01028	103.3019	182.6106	4.5363	1.0000
8	.01138	.01240	102.3861	181.8464	4.4799	1.0000
9	.00887	.00419	101.2155	179.4664	4.4028	1.0000
10	.01143	.01309	101.2586	179.6266	4.4954	1.0000
11	.00043	.00089	99.8989	179.7921	4.4334	.5000
12	.01343	.00092	99.8082	179.6501	4.4681	.5000
13	.00091	.00079	99.9488	180.2364	4.4032	.5000

ENTERED PRINT ROUTINE AFTER 13 CYCLES.
Fractional change in two successive integrals of heat in and power out has been less than .0100

RUN# 30 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .020 N/(cm/sec)**2.
MARTINI MOVING GAS NODE ANALYSIS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	50.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2, 2=HE, 3=AIR	2	PHASE ANG. DEGREES =	70.57
POWER P.STR, CM =	3.88	DISPL. STROKE, CM =	4.04
CALC.FREQ., HZ =	23.06	TIME STEPS/CYCLE =	86.72

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	2304.9840	BASIC	4156.5450
ADIABATIC CORR.	.0000	ADIABATIC CORR.	.0000
HEATER FLOW LOSS	-238.6136	REHEAT	929.3856
REGEN.FLOW LOSS	-393.7831	SHUTTLE	257.1762
COOLER FLOW LOSS	-29.7468	PUMPING	18.2637
INDICATED	1642.8400	TEMP. SWING	2.2619
		CYL. WALL COND.	197.5456
		DISPLCR WALL COND.	34.4170
INDICATED EFFICIENCY, %	31.37	REGEN. WALL COND.	62.1686
		CYL. GAS COND.	6.2077
		REGEN. MTX. COND.	4.7683
		RAD. INSIDE DISPL.	4.3353
		FLOW FRIC. CREDIT	-435.5051
		TOTAL HEAT TO ENG.	5237.5700

Convergence criteria is: .01000

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa	Time Step Msec.
1	.00000	.00000	34.1975	53.3791	5.7555	1.0000
2	.65802	.73310	76.6313	106.1063	5.4489	1.0000
3	1.24085	.98779	111.6715	193.2346	5.5058	1.0000
4	.45726	.82114	118.9481	211.2709	5.3264	1.0000
5	.06516	.09334	119.8078	213.1546	5.3726	1.0000
6	.00723	.00892	119.6750	212.3812	5.4239	1.0000

ENTERED PRINT ROUTINE AFTER 6 CYCLES.
Fractional change in two successive integrals of heat in and power out has been less than .0100

RUN# 30 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .020 N/(cm/sec)**2.
MARTINI MOVING GAS NODE ANALYSIS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	60.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2,2=HE,3=AIR 2		PHASE ANG. DEGREES =	86.13
POWER P.STR,CM =	3.95	DISPL. STROKE, CM =	4.01
CALC.FREQ., HZ =	25.18	TIME STEPS/CYCLE =	39.71

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	3013.8560	BASIC	5348.5410
ADIABATIC CORR.	.0000	ADIABATIC CORR.	.0000
HEATER FLOW LOSS	-329.4142	REHEAT	1261.2610
REGEN.FLOW LOSS	-519.1392	SHUTTLE	259.5436
COOLER FLOW LOSS	-42.6132	PUMPING	24.6812
INDICATED	2122.6890	TEMP. SWING	4.5243
		CYL. WALL COND.	201.5313
		DISPLCR WALL COND.	35.1114
		REGEN. WALL COND.	63.4229
INDICATED EFFICIENCY, %	32.04	CYL. GAS COND.	6.3330
		REGEN. MTX. COND.	4.8645
		RAD. INSIDE DISPL.	4.5952
		FLOW FRIC. CREDIT	-588.9838
		TOTAL HEAT TO ENG.	6625.4260

```
Convergence criteria is:      .01000
Cycle  Change     Change    Work       Heat        End       Time
Numb.  Power      Heat      Out        In          Pressure  Step
       Out        In        Joules     Joules      MPa       Msec.
  1    .00000     .00000    39.8336    62.3402     6.7139    1.0000
  2    .60166     .68830    78.5484    109.2820    6.4010    1.0000
  3    .97191     .75299   116.6637    199.0422    6.4165    1.0000
  4    .48525     .82136   131.5403    234.2840    6.4368    1.0000
  5    .12752     .17706   134.0405    240.4875    6.2107    1.0000
  6    .01901     .02648   134.2915    241.2317    6.2585    1.0000
  7    .00187     .00309   134.3912    240.6260    6.3091    1.0000
ENTERED PRINT ROUTINE AFTER      7 CYCLES.
Fractional change in two successive integrals of heat
in and power out has been less than        .0100
                    RUN# 30    FOR
                    SUNPOWER RE1000 ENGINE
                    FREE MOTIONS -- LINEAR ALTERNATOR
                         Load constant =     .020 N/(cm/sec)**2.
                    MARTINI MOVING GAS NODE ANALYSIS
                    MARTINI LOSS EQUATIONS
                    SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =        29.70       CHRG. PRESS., BAR  =       70.00
HEAT IN, DEG C =       600.00       HEAT OUT, DEG. C   =       40.00
W. GAS 1=H2,2=HE,3=AIR 2            PHASE ANG. DEGREES =       96.65
POWER P.STR,CM =         3.90       DISPL. STROKE, CM  =        4.01
CALC.FREQ., HZ =        27.24       TIME STEPS/CYCLE   =       36.71

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                        HEAT REQUIREMENT, WATTS
  BASIC                 3660.5230     BASIC                  6554.1290
  ADIABATIC CORR.           .0000     ADIABATIC CORR.            .0000
  HEATER FLOW LOSS      -446.5843     REHEAT                 1593.6930
  REGEN.FLOW LOSS       -660.5296     SHUTTLE                 253.3739
  COOLER FLOW LOSS       -57.3561     PUMPING                  30.7397
  INDICATED             2496.0530     TEMP. SWING               8.0082
                                      CYL. WALL COND.         197.0812
                                      DISPLCR WALL COND.       34.3361
-----------------------------------   REGEN. WALL COND.        62.0224
INDICATED EFFICIENCY, %   31.31       CYL. GAS COND.            6.1932
                                      REGEN. MTX. COND.         4.7571
-----------------------------------   RAD.INSIDE DISPL.         4.3189
                                      FLOW FRIC. CREDIT      -776.8491
                                      TOTAL HEAT TO ENG.     7971.8040
```

Convergence criteria is: .01000

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa	Time Step Msec.
1	.00000	.00000	40.9585	64.1346	6.9056	1.0000
2	.59041	.67933	80.2632	110.7806	6.6857	1.0000
3	.95962	.72731	117.0388	199.7856	6.6125	1.0000
4	.45819	.80343	134.1530	238.7630	6.5031	1.0000
5	.14623	.19510	137.1394	245.2684	6.4227	1.0000
6	.02226	.02725	137.5190	245.3689	6.6101	1.0000
7	.00277	.00041	137.6235	247.1985	6.4940	1.0000

ENTERED PRINT ROUTINE AFTER 7 CYCLES.

Fractional change in two successive integrals of heat in and power out has been less than .0100

RUN# 24 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .020 N/(cm/sec)**2.
MARTINI MOVING GAS NODE ANALYSIS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	72.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2, 2=HE, 3=AIR	2	PHASE ANG. DEGREES =	91.05
POWER P.STR, CM =	3.91	DISPL. STROKE, CM =	4.03
CALC.FREQ., HZ =	27.45	TIME STEPS/CYCLE =	36.42

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	3778.3850	BASIC	6786.7130
ADIABATIC CORR.	.0000	ADIABATIC CORR.	.0000
HEATER FLOW LOSS	-439.3748	REHEAT	1652.5320
REGEN.FLOW LOSS	-637.2364	SHUTTLE	255.8176
COOLER FLOW LOSS	-54.7534	PUMPING	31.5025
INDICATED	2647.0200	TEMP. SWING	8.5707
		CYL. WALL COND.	197.1122
		DISPLCR WALL COND.	34.3415
		REGEN. WALL COND.	62.0322
INDICATED EFFICIENCY, %	31.95	CYL. GAS COND.	6.1941
		REGEN. MTX. COND.	4.7579
		RAD. INSIDE DISPL.	4.3271
		FLOW FRIC. CREDIT	-757,9929
		TOTAL HEAT TO ENG.	8285.9080

Convergence criteria is: .01000

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa	Time Step Msec.
1	.00000	.00000	42.0829	65.9296	7.0973	1.0000
2	.57917	.67035	81.2774	111.7511	6.7324	1.0000
3	.93137	.69501	119.4400	204.7475	6.7608	1.0000
4	.46954	.83218	138.4974	246.8776	6.7588	1.0000
5	.15956	.20577	139.8503	250.0273	6.8032	1.0000
6	.00977	.01276	138.7231	247.7342	6.5957	1.0000
7	.00806	.00917	138.3022	247.9315	6.6446	1.0000

ENTERED PRINT ROUTINE AFTER 7 CYCLES.

Fractional change in two successive integrals of heat in and power out has been less than .0100

RUN# 30 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .020 N/(cm/sec)**2.
MARTINI MOVING GAS NODE ANALYSIS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	74.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2, 2=HE, 3=AIR	2	PHASE ANG. DEGREES =	60.45
POWER P.STR,CM =	3.87	DISPL. STROKE, CM =	3.99
CALC.FREQ., HZ =	27.93	TIME STEPS/CYCLE =	35.80

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	3863.3080	BASIC	6925.6740
ADIABATIC CORR.	.0000	ADIABATIC CORR.	.0000
HEATER FLOW LOSS	-455.1402	REHEAT	1733.5860
REGEN.FLOW LOSS	-670.7785	SHUTTLE	241.5455
COOLER FLOW LOSS	-59.6059	PUMPING	32.6731
INDICATED	2677.7830	TEMP. SWING	9.3677
		CYL. WALL COND.	190.0600
		DISPLCR WALL COND.	33.1128
		REGEN. WALL COND.	59.8128
INDICATED EFFICIENCY, %	31.69	CYL. GAS COND.	5.9725
		REGEN. MTX. COND.	4.5877
		RAD. INSIDE DISPL.	3.9265
		FLOW FRIC. CREDIT	-790.5294
		TOTAL HEAT TO ENG.	8449.7920

Convergence criteria is: .01000

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa	Time Step Msec.
1	.00000	.00000	43.2063	67.7253	7.2889	1.0000
2	.56794	.66137	80.8833	112.8856	7.0498	1.0000
3	.87202	.66681	118.1830	200.9208	6.9672	1.0000
4	.46115	.77986	138.7211	246.9792	6.8610	1.0000
5	.17378	.22924	143.3199	255.9675	6.9832	1.0000
6	.03315	.03639	141.4345	254.3263	6.9003	1.0000
7	.01315	.00641	143.9257	256.6958	6.8008	1.0000
8	.01761	.00932	142.5021	255.3152	6.9495	1.0000
9	.00989	.00538	142.9753	254.3604	6.8738	1.0000

ENTERED PRINT ROUTINE AFTER 9 CYCLES.
Fractional change in two successive integrals of heat
in and power out has been less than .0100

RUN# 30 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .020 N/(cm/sec)**2.
MARTINI MOVING GAS NODE ANALYSIS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	76.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2, 2=HE, 3=AIR	2	PHASE ANG. DEGREES =	88.17
POWER P.STR, CM =	3.88	DISPL. STROKE, CM =	4.00
CALC.FREQ., HZ =	28.34	TIME STEPS/CYCLE =	35.28

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	4052.1560	BASIC	7208.9920
ADIABATIC CORR.	.0000	ADIABATIC CORR.	.0000
HEATER FLOW LOSS	-499.2296	REHEAT	1866.1420
REGEN.FLOW LOSS	-733.7512	SHUTTLE	250.6759
COOLER FLOW LOSS	-66.6499	PUMPING	34.2944
INDICATED	2752.5250	TEMP. SWING	10.8660
		CYL. WALL COND.	195.6264
		DISPLCR WALL COND.	34.0826
		REGEN. WALL COND.	61.5646
INDICATED EFFICIENCY, %	31.24	CYL. GAS COND.	6.1474
		REGEN. MTX. COND.	4.7220
		RAD. INSIDE DISPL.	4.2442
		FLOW FRIC. CREDIT	-866.1051
		TOTAL HEAT TO ENG.	8811.2520

```
Convergence criteria is:      .01000
Cycle  Change   Change   Work      Heat      End       Time
Numb.  Power    Heat     Out       In        Pressure  Step
       Out      In       Joules    Joules    MPa       Msec.
  1   .00000   .00000    44.3290    69.5218  7.4805  1.0000
  2   .55671   .65239    80.3305   114.2001  7.3629  1.0000
  3   .81214   .64265   116.3743   197.6075  7.1623  1.0000
  4   .44869   .73036   142.2400   252.3547  7.1820  1.0000
  5   .22226   .27705   145.3085   259.4654  6.9431  1.0000
  6   .02157   .02818   145.3298   260.1332  6.9752  1.0000
  7   .00015   .00257   146.2410   261.2395  6.9970  1.0000
ENTERED PRINT ROUTINE AFTER      7 CYCLES.
Fractional change in two successive integrals of heat
 in and power out has been less than       .0100
                    RUN# 30    FOR
                    SUNPOWER RE1000 ENGINE
                    FREE MOTIONS -- LINEAR ALTERNATOR
                         Load constant =     .020 N/(cm/sec)**2.
                    MARTINI MOVING GAS NODE ANALYSIS
                    MARTINI LOSS EQUATIONS
                    SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =        29.70       CHRG. PRESS., BAR  =     78.00
HEAT IN, DEG C =      600.00        HEAT OUT, DEG. C   =     40.00
W. GAS 1=H2,2=HE,3=AIR 2            PHASE ANG. DEGREES =     77.40
POWER P.STR,CM =        3.87        DISPL. STROKE, CM  =      4.00
CALC.FREQ., HZ =       28.67        TIME STEPS/CYCLE   =     34.88

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                        HEAT REQUIREMENT, WATTS
  BASIC                 4192.1670    BASIC                    7488.7320
  ADIABATIC CORR.           .0000    ADIABATIC CORR.              .0000
  HEATER FLOW LOSS      -510.6435    REHEAT                   1985.5350
  REGEN.FLOW LOSS       -769.3250    SHUTTLE                   245.0460
  COOLER FLOW LOSS       -72.0780    PUMPING                    35.4629
  INDICATED             2840.1200    TEMP. SWING                12.1916
                                     CYL. WALL COND.           191.3981
                                     DISPLCR WALL COND.         33.3459
-----------------------------------  REGEN. WALL COND.          60.2340
INDICATED EFFICIENCY, %   30.97      CYL. GAS COND.              6.0146
                                     REGEN. MTX. COND.           4.6200
-----------------------------------  RAD.INSIDE DISPL.           3.9914
                                     FLOW FRIC. CREDIT        -895.3059
                                     TOTAL HEAT TO ENG.       9171.2650
```

Convergence criteria is: .01000

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa	Time Step Msec.
1	.00000	.00000	45.4511	71.3190	7.6722	1.0000
2	.54549	.64341	85.8521	119.4242	7.3756	1.0000
3	.88889	.67451	126.2561	217.8613	7.2607	1.0000
4	.47062	.82426	142.7622	255.8967	7.3440	1.0000
5	.13074	.17459	147.6756	263.1393	7.2139	1.0000
6	.03442	.02830	149.7649	267.2455	7.3064	1.0000
7	.01415	.01560	147.2981	264.7834	7.1869	1.0000
8	.01647	.00921	149.3688	266.0840	7.2925	1.0000
9	.01406	.00491	146.2424	262.9778	7.1875	1.0000
10	.02093	.01167	147.2057	262.8257	7.2993	1.0000
11	.00659	.00058	144.6242	265.8296	7.1955	.5000
12	.01754	.01143	146.0477	265.8530	7.2101	.5000
13	.00984	.00009	146.1385	267.5661	7.0614	.5000

ENTERED PRINT ROUTINE AFTER 13 CYCLES.
Fractional change in two successive integrals of heat
in and power out has been less than .0100

RUN# 30 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .020 N/(cm/sec)**2.
MARTINI MOVING GAS NODE ANALYSIS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	80.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2,2=HE,3=AIR	2	PHASE ANG. DEGREES =	78.38
POWER P.STR,CM =	3.84	DISPL. STROKE, CM =	4.02
CALC.FREQ., HZ =	29.03	TIME STEPS/CYCLE =	68.90

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	4242.1250	BASIC	7766.9400
ADIABATIC CORR.	.0000	ADIABATIC CORR.	.0000
HEATER FLOW LOSS	-546.2398	REHEAT	2036.7430
REGEN.FLOW LOSS	-803.1697	SHUTTLE	242.4501
COOLER FLOW LOSS	-75.3588	PUMPING	36.1783
INDICATED	2817.3570	TEMP. SWING	13.1972
		CYL. WALL COND.	187.5181
		DISPLCR WALL COND.	32.6700
		REGEN. WALL COND.	59.0129
INDICATED EFFICIENCY, %	29.84	CYL. GAS COND.	5.8926
		REGEN. MTX. COND.	4.5263
		RAD.INSIDE DISPL.	3.7780
		FLOW FRIC. CREDIT	-947.8246
		TOTAL HEAT TO ENG.	9441.0830

Convergence criteria is: .01000

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa	Time Step Msec.
1	.00000	.00000	46.5724	73.1169	7.8638	1.0000
2	.53428	.63442	81.5279	113.9749	7.7119	1.0000
3	.75056	.55880	118.2813	200.0311	7.4777	1.0000
4	.45081	.75504	142.8638	255.8164	7.4487	1.0000
5	.20783	.27888	144.8968	261.5237	7.3872	1.0000
6	.01423	.02231	147.7994	265.4393	7.3059	1.0000
7	.02003	.01497	152.5079	271.5308	7.5570	1.0000
8	.03186	.02295	153.7300	273.7958	7.5025	1.0000
9	.00801	.00834	150.4201	268.9335	7.4866	1.0000
10	.02153	.01776	148.7587	266.0431	7.5172	.5000
11	.01105	.01075	149.1709	272.8339	7.4902	.2500
12	.00277	.02553	144.2757	265.9754	7.4403	.2500
13	.03282	.02514	142.5868	263.8296	7.4768	.2500
14	.01171	.00807	141.9809	262.9780	7.4339	.2500
15	.00425	.00323	141.4197	262.8314	7.4031	.2500

ENTERED PRINT ROUTINE AFTER 15 CYCLES.
Fractional change in two successive integrals of heat in and power out has been less than .0100

RUN# 30 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .020 N/(cm/sec)**2.
MARTINI MOVING GAS NODE ANALYSIS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	82.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2, 2=HE, 3=AIR	2	PHASE ANG. DEGREES =	77.93
POWER P.STR, CM =	3.77	DISPL. STROKE, CM =	3.97
CALC.FREQ., HZ =	29.35	TIME STEPS/CYCLE =	136.27

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	4151.0580	BASIC	7714.8240
ADIABATIC CORR.	.0000	ADIABATIC CORR.	.0000
HEATER FLOW LOSS	-532.8634	REHEAT	2115.5360
REGEN.FLOW LOSS	-779.3636	SHUTTLE	241.0808
COOLER FLOW LOSS	-72.8741	PUMPING	35.9856
INDICATED	2765.9570	TEMP. SWING	14.1745
		CYL. WALL COND.	191.6418
		DISPLCR WALL COND.	33.3884
		REGEN. WALL COND.	60.3107
INDICATED EFFICIENCY, %	29.12	CYL. GAS COND.	6.0222
		REGEN. MTX. COND.	4.6258
		RAD. INSIDE DISPL.	4.0526
		FLOW FRIC. CREDIT	-922.5452
		TOTAL HEAT TO ENG.	9499.0970

Convergence criteria is: .01000

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa	Time Step Msec.
1	.00000	.00000	51.0502	80.3153	8.6302	1.0000
2	.48950	.59842	81.7493	115.6993	8.4088	1.0000
3	.60135	.44056	120.7612	205.4203	8.2731	1.0000
4	.47721	.77547	148.9485	270.1057	8.2564	.5000
5	.23341	.31489	153.8181	278.9634	8.3368	.5000
6	.03269	.03279	151.8585	277.3598	8.2867	.5000
7	.01274	.00575	151.8109	278.0777	8.2291	.5000
8	.00031	.00259	151.5250	278.5756	8.1937	.5000

ENTERED PRINT ROUTINE AFTER 8 CYCLES.
Fractional change in two successive integrals of heat in and power out has been less than .0100

RUN# 30 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .020 N/(cm/sec)**2.
MARTINI MOVING GAS NODE ANALYSIS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	90.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2,2=HE,3=AIR	2	PHASE ANG. DEGREES =	66.01
POWER P.STR,CM =	3.74	DISPL. STROKE, CM =	3.90
CALC.FREQ., HZ =	30.71	TIME STEPS/CYCLE =	65.12

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	4654.0680	BASIC	8556.4080
ADIABATIC CORR.	.0000	ADIABATIC CORR.	.0000
HEATER FLOW LOSS	-607.4160	REHEAT	2431.1180
REGEN.FLOW LOSS	-870.6307	SHUTTLE	235.3769
COOLER FLOW LOSS	-84.6615	PUMPING	41.3563
INDICATED	3091.3600	TEMP. SWING	19.2872
		CYL. WALL COND.	193.6535
		DISPLCR WALL COND.	33.7389
		REGEN. WALL COND.	60.9437
INDICATED EFFICIENCY, %	29.32	CYL. GAS COND.	6.0854
		REGEN. MTX. COND.	4.6744
		RAD. INSIDE DISPL.	4.1572
		FLOW FRIC. CREDIT	-1042.7310
		TOTAL HEAT TO ENG.	10544.0700

```
Convergence criteria is:      .01000
Cycle   Change      Change    Work        Heat          End       Time
Numb.   Power       Heat      Out         In            Pressure  Step
        Out         In        Joules      Joules        MPa       Msec.
  1     .00000      .00000     56.6305     89.3286      9.5881    1.0000
  2     .43370      .55336     84.4963    120.8660      9.5783     .5000
  3     .49206      .35305    121.4291    208.7427      9.2594     .5000
  4     .43709      .72706    148.0986    269.1479      9.3024     .5000
  5     .21963      .28938    155.2503    284.9063      9.3037     .5000
  6     .04829      .05855    157.2908    289.9953      9.1179     .5000
  7     .01314      .01786    158.3152    291.7746      9.1412     .5000
  8     .00651      .00614    159.4120    293.6351      9.1613     .5000
ENTERED PRINT ROUTINE AFTER      8 CYCLES.
Fractional change in two successive integrals of heat
in and power out has been less than       .0100
                        RUN# 30    FOR
                        SUNPOWER RE1000 ENGINE
                        FREE MOTIONS -- LINEAR ALTERNATOR
                             Load constant =     .020 N/(cm/sec)**2.
                        MARTINI MOVING GAS NODE ANALYSIS
                        MARTINI LOSS EQUATIONS
                        SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =        29.70        CHRG. PRESS., BAR  =      100.00
HEAT IN, DEG C =       600.00        HEAT OUT, DEG. C   =       40.00
W. GAS 1=H2,2=HE,3=AIR 2             PHASE ANG. DEGREES =       81.53
POWER P.STR,CM =         3.68        DISPL. STROKE, CM  =        3.80
CALC.FREQ., HZ =        32.35        TIME STEPS/CYCLE   =       61.82

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                         HEAT REQUIREMENT, WATTS
  BASIC                  5157.6390    BASIC                    9500.3120
  ADIABATIC CORR.            .0000    ADIABATIC CORR.              .0000
  HEATER FLOW LOSS       -701.9781    REHEAT                   2835.4930
  REGEN.FLOW LOSS        -976.2700    SHUTTLE                   217.3928
  COOLER FLOW LOSS        -98.7872    PUMPING                    46.7226
  INDICATED              3380.6040    TEMP. SWING                27.2619
                                      CYL. WALL COND.           188.0180
                                      DISPLCR WALL COND.         32.7571
---------------------------------     REGEN. WALL COND.          59.1702
INDICATED EFFICIENCY, %   28.82       CYL. GAS COND.              5.9083
                                      REGEN. MTX. COND.           4.5384
---------------------------------     RAD.INSIDE DISPL.           3.8660
                                      FLOW FRIC. CREDIT       -1190.1130
                                      TOTAL HEAT TO ENG.      11731.3300
```

APPENDIX L

EFFECT OF PRESSURE ON ADIABATIC

FREE-PISTON ANALYSIS

CONVERGENCE CRITERIA = 0.005

INITIAL TIME STEP = 0.25 MSEC

DOUBLE PRECISION

"

Computer Name: IBM/PC-AT
Operating System: DOS 3.00
Built-in BIOS dated: Thursday, July 3, 1986
Main Processor: Intel 80286 Serial Ports: 2
Co-Processor: Intel 80287 Parallel Ports: 2
Video Display Adapter: Enhanced Graphics, 256 K-bytes
Current Video Mode: Text, 80 x 25 Color
Available Disk Drives: 3, A: - C:

DOS reports 640 K-bytes of memory:
40 K-bytes used by DOS and resident programs
600 K-bytes available for application programs
A search for active memory finds:
640 K-bytes main memory (at hex 0000-A000)
32 K-bytes display memory (at hex B800-C000)
ROM-BIOS Extensions are found at hex paragraphs: C000

Computing Index (CI), relative to IBM/XT: Testing...
Disk Index (DI), relative to IBM/XT: Not computed. No drive specified.

Performance Index (PI), relative to IBM/XT: Not computed.
10:05 pm, Wednesday, July 22, 1987

CONVERGENCE CRITERIA IS: .00500

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	42.3211	66.0547	7.0704	.2500
2	.57679	.66973	76.9909	110.9607	6.7774	.2500
3	.81921	.67983	112.6644	198.6434	6.6186	.2500
4	.46335	.79021	131.6836	240.8939	6.6186	.2500
5	.16881	.21270	132.3613	245.9497	6.6109	.2500
6	.00515	.02099	132.4149	246.3626	6.6165	.2500
7	.00040	.00168	133.5549	247.7698	6.6240	.2500
8	.00861	.00571	133.0705	247.7724	6.6287	.2500
9	.00363	.00001	133.2528	247.6401	6.5617	.2500

CURRENT OPERATING CONDITIONS ARE:

01=	74.000	02=	2	03=	600.000	04=	40.000	05=	76.890
06=	3.813	07=	4.028	08=	0	09=	0	10=	.250
11=	0	12=	.000	13=	1.000	14=	4	15=	4
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	125	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0200	76=	1.0000	77=	3.0000	78=	1.0000	79=	4.0000
80=	20.0000	81=	.0100	82=	.1000	83=	.0050	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0	116=	0	117=	0	118=	0	119=	0
120=	0								

```
 ENTERED PRINT ROUTINE AFTER      9 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN      .0050
                   RUN#  0   FOR
                   SUNPOWER RE1000 ENGINE
                   FREE MOTIONS -- LINEAR ALTERNATOR
                        LOAD CONSTANT =    .020 N/(CM/SEC)**2.
                   MARTINI MOVING GAS NODE ANALYSIS
                   MARTINI LOSS EQUATIONS
                   SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =     29.70         CHRG. PRESS., BAR  =      74.00
HEAT IN, DEG C =    600.00         HEAT OUT, DEG. C   =      40.00
W. GAS 1=H2,2=HE,3=AIR 2           PHASE ANG. DEGREES =      76.89
POWER P.STR,CM =      3.81         DISPL. STROKE, CM  =       4.03
CALC.FREQ., HZ =     28.01         TIME STEPS/CYCLE   =     142.80

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                       HEAT REQUIREMENT, WATTS
  BASIC                3732.5443     BASIC                  6936.6438
  ADIABATIC CORR.          .0000     ADIABATIC CORR.            .0000
  HEATER FLOW LOSS     -451.2578     REHEAT                 1779.9279
  REGEN.FLOW LOSS      -710.8188     SHUTTLE                 247.0111
  COOLER FLOW LOSS      -62.3938     PUMPING                  31.8143
  INDICATED            2508.0738     TEMP. SWING               9.9799
                                     CYL. WALL COND.         189.9550
                                     DISPLCR WALL COND.       33.1870
--------------------------------     REGEN. WALL COND.        59.9469
INDICATED EFFICIENCY, %   29.52      CYL. GAS COND.            5.9859
                                     REGEN. MTX. COND.         4.5081
--------------------------------     RAD.INSIDE DISPL.         3.9664
                                     FLOW FRIC. CREDIT      -806.6673
                                     TOTAL HEAT TO ENG.     8496.2589
```

Computer Name: IBM/PC-AT
Operating System: DOS 3.00
Built-in BIOS dated: Thursday, July 3, 1986
Main Processor: Intel 80286 Serial Ports: 2
Co-Processor: Intel 80287 Parallel Ports: 2
Video Display Adapter: Enhanced Graphics, 256 K-bytes
Current Video Mode: Text, 80 x 25 Color
Available Disk Drives: 3, A: - C:

DOS reports 640 K-bytes of memory:
40 K-bytes used by DOS and resident programs
600 K-bytes available for application programs
A search for active memory finds:
640 K-bytes main memory (at hex 0000-A000)
32 K-bytes display memory (at hex B800-C000)
ROM-BIOS Extensions are found at hex paragraphs: C000

Computing Index (CI), relative to IBM/XT: Testing...
Disk Index (DI), relative to IBM/XT: Not computed. No drive specified.

Performance Index (PI), relative to IBM/XT: Not computed.
10:27 pm, Wednesday, July 22, 1987

CONVERGENCE CRITERIA IS: .00500

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	43.4553	67.8546	7.2613	.2500
2	.56545	.66073	77.1778	111.5839	6.9604	.2500
3	.77603	.64446	114.9291	201.5237	6.8575	.2500
4	.48915	.80603	135.1515	247.5242	6.8474	.2500
5	.17596	.22826	136.1571	252.9939	6.8331	.2500
6	.00744	.02210	135.3473	252.1798	6.8220	.2500
7	.00595	.00322	135.2010	251.5647	6.8152	.2500
8	.00108	.00244	135.2639	251.5814	6.8085	.2500

CURRENT OPERATING CONDITIONS ARE:

01=	76.000	02=	2	03=	600.000	04=	40.000	05=	77.898
06=	3.798	07=	4.009	08=	0	09=	0	10=	.250
11=	0	12=	.000	13=	1.000	14=	4	15=	4
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	131	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0200	76=	1.0000	77=	3.0000	78=	1.0000	79=	4.0000
80=	20.0000	81=	.0100	82=	.1000	83=	.0050	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0	116=	0	117=	0	118=	0	119=	0
120=	0								

ENTERED PRINT ROUTINE AFTER 8 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN .0050

RUN# 0 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
LOAD CONSTANT = .020 N/(CM/SEC)**2.
MARTINI MOVING GAS NODE ANALYSIS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	76.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2,2=HE,3=AIR	2	PHASE ANG. DEGREES =	77.90
POWER P.STR,CM =	3.80	DISPL. STROKE, CM =	4.01
CALC.FREQ., HZ =	28.38	TIME STEPS/CYCLE =	140.95

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	3838.5617	BASIC	7139.4528
ADIABATIC CORR.	.0000	ADIABATIC CORR.	.0000
HEATER FLOW LOSS	-471.8859	REHEAT	1877.9208
REGEN.FLOW LOSS	-741.4427	SHUTTLE	246.6475
COOLER FLOW LOSS	-66.0587	PUMPING	32.8934
INDICATED	2559.1745	TEMP. SWING	11.1355
		CYL. WALL COND.	191.4722
		DISPLCR WALL COND.	33.4521
--------------------------------		REGEN. WALL COND.	60.4257
INDICATED EFFICIENCY, %	29.20	CYL. GAS COND.	6.0337
		REGEN. MTX. COND.	4.5441
--------------------------------		RAD.INSIDE DISPL.	4.0697
		FLOW FRIC. CREDIT	-842.6073
		TOTAL HEAT TO ENG.	8765.4401

"

```
       Computer Name:  IBM/PC-AT
    Operating System:  DOS 3.00
  Built-in BIOS dated:  Thursday, July 3, 1986
      Main Processor:  Intel 80286              Serial Ports:  2
        Co-Processor:  Intel 80287            Parallel Ports:  2
Video Display Adapter:  Enhanced Graphics, 256 K-bytes
   Current Video Mode:  Text, 80 x 25 Color
Available Disk Drives:  3, A: - C:

DOS reports 640 K-bytes of memory:
   40 K-bytes used by DOS and resident programs
  600 K-bytes available for application programs
A search for active memory finds:
  640 K-bytes main memory     (at hex 0000-A000)
   32 K-bytes display memory  (at hex B800-C000)
ROM-BIOS Extensions are found at hex paragraphs: C000

  Computing Index (CI), relative to IBM/XT: Testing...
       Disk Index (DI), relative to IBM/XT: Not computed. No drive specified.

Performance Index (PI), relative to IBM/XT: Not computed.
                                          10:54 pm, Wednesday, July 22, 1987
```

CONVERGENCE CRITERIA IS: .00500

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	44.5891	69.6552	7.4522	.2500
2	.55411	.65172	77.7231	112.2121	7.1960	.2500
3	.74310	.61096	114.6122	201.8918	7.0021	.2500
4	.47462	.79920	136.0783	249.0893	6.9805	.2500
5	.18729	.23378	138.1878	256.3194	7.0317	.2500
6	.01550	.02903	138.1995	256.7590	7.0005	.2500
7	.00008	.00172	136.9810	255.7389	6.9768	.2500
8	.00882	.00397	136.7460	254.5478	6.9536	.2500
9	.00172	.00466	136.7136	254.7651	6.9331	.2500

CURRENT OPERATING CONDITIONS ARE:

01=	78.000	02=	2	03=	600.000	04=	40.000	05=	77.614
06=	3.780	07=	3.982	08=	0	09=	0	10=	.250
11=	0	12=	.000	13=	1.000	14=	4	15=	4
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	131	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0200	76=	1.0000	77=	3.0000	78=	1.0000	79=	4.0000
80=	20.0000	81=	.0100	82=	.1000	83=	.0050	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0	116=	0	117=	0	118=	0	119=	0
120=	0								

```
 ENTERED PRINT ROUTINE AFTER     9 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN       .0050
                   RUN#  0    FOR
                   SUNPOWER RE1000 ENGINE
                   FREE MOTIONS -- LINEAR ALTERNATOR
                        LOAD CONSTANT =    .020 N/(CM/SEC)**2.
                   MARTINI MOVING GAS NODE ANALYSIS
                   MARTINI LOSS EQUATIONS
                   SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70        CHRG. PRESS., BAR   =     78.00
HEAT IN, DEG C =     600.00        HEAT OUT, DEG. C    =     40.00
W. GAS 1=H2,2=HE,3=AIR 2           PHASE ANG. DEGREES  =     77.61
POWER P.STR,CM =       3.78        DISPL. STROKE, CM   =      3.98
CALC.FREQ., HZ =      28.75        TIME STEPS/CYCLE    =    139.15

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                       HEAT REQUIREMENT, WATTS
  BASIC                 3929.9592    BASIC                  7323.4568
  ADIABATIC CORR.          .0000    ADIABATIC CORR.            .0000
  HEATER FLOW LOSS      -487.8686    REHEAT                 1924.4151
  REGEN.FLOW LOSS       -755.2201    SHUTTLE                 239.7918
  COOLER FLOW LOSS       -67.5045    PUMPING                  33.8977
  INDICATED             2619.3660    TEMP. SWING              11.9319
                                     CYL. WALL COND.         188.6476
                                     DISPLCR WALL COND.       32.9586
--------------------------------     REGEN. WALL COND.        59.5343
INDICATED EFFICIENCY, %  29.22       CYL. GAS COND.            5.9447
                                     REGEN. MTX. COND.         4.4771
--------------------------------     RAD.INSIDE DISPL.         3.8979
                                     FLOW FRIC. CREDIT      -865.4786
                                     TOTAL HEAT TO ENG.     8963.4748
```

"

```
      Computer Name:  IBM/PC-AT
   Operating System:  DOS 3.00
 Built-in BIOS dated: Thursday, July 3, 1986
      Main Processor: Intel 80286              Serial Ports:  2
        Co-Processor: Intel 80287            Parallel Ports:  2
Video Display Adapter: Enhanced Graphics, 256 K-bytes
  Current Video Mode: Text, 80 x 25 Color
Available Disk Drives: 3, A: - C:

DOS reports 640 K-bytes of memory:
    40 K-bytes used by DOS and resident programs
   600 K-bytes available for application programs
A search for active memory finds:
   640 K-bytes main memory      (at hex 0000-A000)
    32 K-bytes display memory   (at hex B800-C000)
ROM-BIOS Extensions are found at hex paragraphs: C000

  Computing Index (CI), relative to IBM/XT: Testing...
       Disk Index (DI), relative to IBM/XT: Not computed. No drive specified.

Performance Index (PI), relative to IBM/XT: Not computed.
                                              11:15 pm, Wednesday, July 22, 1987
```

CONVERGENCE CRITERIA IS: .00500

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	45.7223	71.4566	7.6430	.2500
2	.54278	.64272	77.9461	112.8138	7.3617	.2500
3	.70477	.57877	114.0896	201.4527	7.2281	.2500
4	.46370	.78571	137.3974	251.5339	7.1743	.2500
5	.20429	.24860	138.3819	257.4623	7.2048	.2500
6	.00717	.02357	138.4165	257.6174	7.1483	.2500
7	.00025	.00060	139.3705	258.8617	7.1892	.2500
8	.00689	.00483	138.7004	258.7929	7.1340	.2500
9	.00481	.00027	138.6880	258.0990	7.1719	.2500

CURRENT OPERATING CONDITIONS ARE:

01=	80.000	02=	2	03=	600.000	04=	40.000	05=	77.245
06=	3.768	07=	3.960	08=	0	09=	0	10=	.250
11=	0	12=	.000	13=	1.000	14=	4	15=	4
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	127	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0200	76=	1.0000	77=	3.0000	78=	1.0000	79=	4.0000
80=	20.0000	81=	.0100	82=	.1000	83=	.0050	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0	116=	0	117=	0	118=	0	119=	0
120=	0								

```
 ENTERED PRINT ROUTINE AFTER     9 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN       .0050
                   RUN#  0   FOR
                   SUNPOWER RE1000 ENGINE
                   FREE MOTIONS -- LINEAR ALTERNATOR
                        LOAD CONSTANT =    .020 N/(CM/SEC)**2.
                   MARTINI MOVING GAS NODE ANALYSIS
                   MARTINI LOSS EQUATIONS
                   SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70       CHRG. PRESS., BAR   =     80.00
HEAT IN, DEG C =     600.00       HEAT OUT, DEG. C    =     40.00
W. GAS 1=H2,2=HE,3=AIR 2          PHASE ANG. DEGREES  =     77.25
POWER P.STR,CM =       3.77       DISPL. STROKE, CM   =      3.96
CALC.FREQ., HZ =      29.09       TIME STEPS/CYCLE    =    137.48

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                      HEAT REQUIREMENT, WATTS
  BASIC                 4035.0318   BASIC                  7509.2117
  ADIABATIC CORR.           .0000   ADIABATIC CORR.            .0000
  HEATER FLOW LOSS      -504.8613   REHEAT                 2018.3723
  REGEN.FLOW LOSS       -775.4495   SHUTTLE                 238.6212
  COOLER FLOW LOSS       -69.9141   PUMPING                  34.9839
  INDICATED             2684.8070   TEMP. SWING              13.1214
                                    CYL. WALL COND.         189.8875
                                    DISPLCR WALL COND.       33.1752
--------------------------------    REGEN. WALL COND.        59.9256
INDICATED EFFICIENCY, %  29.12      CYL. GAS COND.            5.9838
                                    REGEN. MTX. COND.         4.5065
--------------------------------    RAD.INSIDE DISPL.         3.9803
                                    FLOW FRIC. CREDIT      -892.5861
                                    TOTAL HEAT TO ENG.     9219.1833
```

"

Computer Name: IBM/PC-AT
Operating System: DOS 3.00
Built-in BIOS dated: Thursday, July 3, 1986
Main Processor: Intel 80286 Serial Ports: 2
Co-Processor: Intel 80287 Parallel Ports: 2
Video Display Adapter: Enhanced Graphics, 256 K-bytes
Current Video Mode: Text, 80 x 25 Color
Available Disk Drives: 3, A: - C:

DOS reports 640 K-bytes of memory:
40 K-bytes used by DOS and resident programs
600 K-bytes available for application programs
A search for active memory finds:
640 K-bytes main memory (at hex 0000-A000)
32 K-bytes display memory (at hex B800-C000)
ROM-BIOS Extensions are found at hex paragraphs: C000

Computing Index (CI), relative to IBM/XT: Testing...
Disk Index (DI), relative to IBM/XT: Not computed. No drive specified.

Performance Index (PI), relative to IBM/XT: Not computed.
11:35 pm, Wednesday, July 22, 1987

CONVERGENCE CRITERIA IS: .00500

CYCLE NUMB.	CHANGE POWER OUT	CHANGE HEAT IN	WORK OUT JOULES	HEAT IN JOULES	END PRESSURE MPA	TIME STEP MSEC.
1	.00000	.00000	46.8550	73.2587	7.8339	.2500
2	.53145	.63371	78.0792	113.2805	7.5954	.2500
3	.66640	.54631	114.1493	201.6138	7.3697	.2500
4	.46197	.77978	139.3602	254.2570	7.3465	.2500
5	.22086	.26111	140.2112	261.4208	7.3470	.2500
6	.00611	.02818	140.3642	261.1081	7.3513	.2500
7	.00109	.00120	141.5032	262.9644	7.3638	.2500
8	.00811	.00711	140.7424	262.8528	7.3656	.2500
9	.00538	.00042	140.5482	262.0261	7.2904	.2500
10	.00138	.00315	140.5629	261.9927	7.2959	.2500

CURRENT OPERATING CONDITIONS ARE:

01=	82.000	02=	2	03=	600.000	04=	40.000	05=	80.866
06=	3.753	07=	3.941	08=	0	09=	0	10=	.250
11=	0	12=	.000	13=	1.000	14=	4	15=	4
16=	0	17=	3	18=	1000.000	19=	10.000		

CURRENT DIMENSIONS ARE:

20=	1	21=	4.0400	22=	4.2000	23=	4.7000	24=	5.7180
25=	15.1900	26=	.0365	27=	1.6630	28=	5.7790	29=	29.7000
30=	6.2000	31=	.4260	32=	0	33=	33.0000	34=	15.2500
35=	25.4000	36=	7.6000	37=	381.0000	38=	.0000	39=	.8000
40=	10.0000	41=	31.7900	42=	20.5000	43=	2.3900	44=	72.5300
45=	128	46=	24	47=	1.0200	48=	.1575	49=	.1067
50=	.7600	51=	.1321	52=	.1016	53=	31.7900	54=	2.9200
55=	2	56=	34	57=	18.3400	58=	.2362	59=	9.2600
60=	1.5000	61=	.0000	62=	6.4460	63=	.5440	64=	88.9000
65=	75.9000	66=	.0000	67=	.0000	68=	.0000	69=	135
70=	.0508	71=	.3760	72=	7.9200	73=	1.5000	74=	.0000
75=	.0200	76=	1.0000	77=	3.0000	78=	1.0000	79=	4.0000
80=	20.0000	81=	.0100	82=	.1000	83=	.0050	84=	.0000
85=	.0000	86=	-4.5650	87=	.4684	88=	7.9300	89=	.4600
90=	4.4500	91=	.3710	92=	.1450	93=	.0813	94=	1
95=	.5000	96=	0	97=	.0000	98=	.0000	99=	.0000
100=	.0000	101=	13	102=	15	103=	14	104=	0
105=	0	106=	0	107=	0	108=	0	109=	0
110=	0	111=	0	112=	0	113=	0	114=	0
115=	0	116=	0	117=	0	118=	0	119=	0
120=	0								

```
 ENTERED PRINT ROUTINE AFTER    10 CYCLES.
FRACTIONAL CHANGE IN TWO SUCCESSIVE INTEGRALS OF HEAT
IN AND POWER OUT HAS BEEN LESS THAN      .0050
                   RUN#  0   FOR
                   SUNPOWER RE1000 ENGINE
                   FREE MOTIONS -- LINEAR ALTERNATOR
                        LOAD CONSTANT =     .020 N/(CM/SEC)**2.
                   MARTINI MOVING GAS NODE ANALYSIS
                   MARTINI LOSS EQUATIONS
                   SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =      29.70      CHRG. PRESS., BAR  =     82.00
HEAT IN, DEG C =     600.00      HEAT OUT, DEG. C   =     40.00
W. GAS 1=H2,2=HE,3=AIR 2         PHASE ANG. DEGREES =     80.87
POWER P.STR,CM =       3.75      DISPL. STROKE, CM  =      3.94
CALC.FREQ., HZ =      29.46      TIME STEPS/CYCLE   =    135.78

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                     HEAT REQUIREMENT, WATTS
  BASIC                  4140.9098  BASIC                  7718.1671
  ADIABATIC CORR.            .0000  ADIABATIC CORR.            .0000
  HEATER FLOW LOSS       -522.0358  REHEAT                 2055.1560
  REGEN.FLOW LOSS        -795.4852  SHUTTLE                 233.6653
  COOLER FLOW LOSS        -72.3040  PUMPING                  36.1071
  INDICATED              2751.0849  TEMP. SWING              13.9835
                                    CYL. WALL COND.         187.7257
                                    DISPLCR WALL COND.       32.7975
--------------------------------    REGEN. WALL COND.        59.2433
INDICATED EFFICIENCY, %  29.17      CYL. GAS COND.            5.9156
                                    REGEN. MTX. COND.         4.4552
--------------------------------    RAD.INSIDE DISPL.         3.8478
                                    FLOW FRIC. CREDIT      -919.7784
                                    TOTAL HEAT TO ENG.     9431.2859
```

APPENDIX M

EFFECT OF PRESSURE ON ADIABATIC

FREE-PISTON ANALYSIS

CONVERGENCE CRITERIA = 0.005

INITIAL TIME STEP = 0.25 MSEC

SINGLE PRECISION

Convergence criteria is: .00500

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa	Time Step Msec.
1	.00000	.00000	42.2383	65.9236	7.0711	.2500
2	.57762	.67038	78.7738	112.9292	6.7964	.2500
3	.86499	.71303	117.8490	207.4365	6.6360	.2500
4	.49604	.83687	132.8834	244.7849	6.6309	.2500
5	.12757	.18005	134.3069	249.0340	6.6299	.2500
6	.01071	.01736	134.0694	249.2262	6.6259	.2500
7	.00177	.00077	133.7013	248.9602	6.6276	.2500

ENTERED PRINT ROUTINE AFTER 7 CYCLES.
Fractional change in two successive integrals of heat
and power out has been less than .0050

RUN# 30 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .020 N/(cm/sec)**2.
MARTINI MOVING GAS NODE ANALYSIS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	74.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2,2=HE,3=AIR	2	PHASE ANG. DEGREES =	76.87
POWER P.STR,CM =	3.82	DISPL. STROKE, CM =	4.04
CALC.FREQ., HZ =	28.00	TIME STEPS/CYCLE =	142.85

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	3743.8990	BASIC	6971.3750
ADIABATIC CORR.	.0000	ADIABATIC CORR.	.0000
HEATER FLOW LOSS	-459.0747	REHEAT	1843.4110
REGEN.FLOW LOSS	-700.0262	SHUTTLE	255.9045
COOLER FLOW LOSS	-63.6428	PUMPING	31.9922
INDICATED	2521.1560	TEMP. SWING	10.2175
		CYL. WALL COND.	196.3468
		DISPLCR WALL COND.	34.2081
		REGEN. WALL COND.	61.7914
INDICATED EFFICIENCY, %	29.28	CYL. GAS COND.	6.1701
		REGEN. MTX. COND.	4.7394
		RAD. INSIDE DISPL.	4.3104
		FLOW FRIC. CREDIT	-809.0879
		TOTAL HEAT TO ENG.	8611.3790

```
Convergence criteria is:      .00500
Cycle  Change     Change    Work       Heat        End       Time
Numb.  Power      Heat      Out        In          Pressure  Step
       Out        In        Joules     Joules      MPa       Msec.
  1    .00000     .00000    43.3706     67.7199    7.2620    .2500
  2    .56629     .66140    79.3667    113.6582    6.9716    .2500
  3    .82996     .67836   117.6094    207.9856    6.7944    .2500
  4    .48185     .82992   135.8742    248.9141    6.8574    .2500
  5    .15530     .19679   136.5900    254.1944    6.8375    .2500
  6    .00527     .02121   136.0478    253.2675    6.8220    .2500
  7    .00397     .00365   136.3173    253.3362    6.8121    .2500
ENTERED PRINT ROUTINE AFTER      7 CYCLES.
Fractional change in two successive integrals of heat
in and power out has been less than        .0050
                        RUN# 30    FOR
                        SUNPOWER RE1000 ENGINE
                        FREE MOTIONS -- LINEAR ALTERNATOR
                             Load constant =     .020 N/(cm/sec)**2.
                        MARTINI MOVING GAS NODE ANALYSIS
                        MARTINI LOSS EQUATIONS
                        SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:
SPEC.FREQ., HZ =        29.70       CHRG. PRESS., BAR  =      76.00
HEAT IN, DEG C =       600.00       HEAT OUT, DEG. C   =      40.00
W. GAS 1=H2,2=HE,3=AIR 2            PHASE ANG. DEGREES =      80.43
POWER P.STR,CM =         3.81       DISPL. STROKE, CM  =       4.03
CALC.FREQ., HZ =        28.37       TIME STEPS/CYCLE   =     141.00

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:
POWER, WATTS                        HEAT REQUIREMENT, WATTS
  BASIC                 3867.1570    BASIC                    7186.8420
  ADIABATIC CORR.          .0000    ADIABATIC CORR.              .0000
  HEATER FLOW LOSS      -478.3193    REHEAT                   1907.6540
  REGEN.FLOW LOSS       -725.7664    SHUTTLE                   254.2589
  COOLER FLOW LOSS       -66.8043    PUMPING                    33.1752
  INDICATED             2596.2670    TEMP. SWING                11.1497
                                     CYL. WALL COND.           195.9528
                                     DISPLCR WALL COND.         34.1395
------------------------------------ REGEN. WALL COND.          61.6674
INDICATED EFFICIENCY, %   29.31      CYL. GAS COND.              6.1577
                                     REGEN. MTX. COND.           4.7299
------------------------------------ RAD.INSIDE DISPL.           4.2888
                                     FLOW FRIC. CREDIT        -841.2025
                                     TOTAL HEAT TO ENG.       8858.8130
```

Convergence criteria is: .00500

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa	Time Step Msec.
1	.00000	.00000	44.5021	69.5170	7.4529	.2500
2	.55498	.65242	79.8778	114.6482	7.1414	.2500
3	.79492	.64921	117.9989	209.0195	7.0152	.2500
4	.47724	.82314	137.2358	251.2925	6.9835	.2500
5	.16303	.20224	138.7358	257.8351	7.0342	.2500
6	.01093	.02604	138.7304	257.8145	6.9987	.2500
7	.00004	.00008	138.0148	257.4344	6.9661	.2500
8	.00516	.00147	138.2345	257.3291	6.9454	.2500
9	.00159	.00041	138.4096	257.5728	6.9248	.2500

ENTERED PRINT ROUTINE AFTER 9 CYCLES.
Fractional change in two successive integrals of heat
in and power out has been less than .0050

RUN# 30 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .020 N/(cm/sec)**2.
MARTINI MOVING GAS NODE ANALYSIS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	78.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2, 2=HE, 3=AIR	2	PHASE ANG. DEGREES =	77.59
POWER P.STR, CM =	3.80	DISPL. STROKE, CM =	4.01
CALC.FREQ., HZ =	28.74	TIME STEPS/CYCLE =	139.20

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	3977.2660	BASIC	7401.4770
ADIABATIC CORR.	.0000	ADIABATIC CORR.	.0000
HEATER FLOW LOSS	-497.2415	REHEAT	1963.8580
REGEN.FLOW LOSS	-747.4787	SHUTTLE	246.0410
COOLER FLOW LOSS	-69.4024	PUMPING	34.2350
INDICATED	2663.1440	TEMP. SWING	12.0208
		CYL. WALL COND.	191.6263
		DISPLCR WALL COND.	33.3857
		REGEN. WALL COND.	60.3058
INDICATED EFFICIENCY, %	29.31	CYL. GAS COND.	6.0217
		REGEN. MTX. COND.	4.6255
		RAD.INSIDE DISPL.	4.0263
		FLOW FRIC. CREDIT	-870.9808
		TOTAL HEAT TO ENG.	9086.6430

Convergence criteria is: .00500

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa	Time Step Msec.
1	.00000	.00000	45.6332	71.3149	7.6438	.2500
2	.54367	.64343	78.5378	113.6355	7.3513	.2500
3	.72107	.59343	115.7731	204.1404	7.2007	.2500
4	.47411	.79645	138.9744	254.0302	7.1565	.2500
5	.20040	.24439	139.5723	260.3812	7.1794	.2500
6	.00430	.02500	139.7359	260.0427	7.1325	.2500
7	.00117	.00130	139.9386	260.3003	7.1574	.2500

ENTERED PRINT ROUTINE AFTER 7 CYCLES.
Fractional change in two successive integrals of heat in and power out has been less than .0050

RUN# 30 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .020 N/(cm/sec)**2.
MARTINI MOVING GAS NODE ANALYSIS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	80.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2,2=HE,3=AIR 2		PHASE ANG. DEGREES =	77.23
POWER P.STR,CM =	3.78	DISPL. STROKE, CM =	3.98
CALC.FREQ., HZ =	29.09	TIME STEPS/CYCLE =	137.51

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	4070.6390	BASIC	7571.8100
ADIABATIC CORR.	.0000	ADIABATIC CORR.	.0000
HEATER FLOW LOSS	-509.9724	REHEAT	2049.1280
REGEN.FLOW LOSS	-759.3469	SHUTTLE	243.8703
COOLER FLOW LOSS	-70.8367	PUMPING	35.2715
INDICATED	2730.4830	TEMP. SWING	13.1527
		CYL. WALL COND.	192.5370
		DISPLCR WALL COND.	33.5444
		REGEN. WALL COND.	60.5924
INDICATED EFFICIENCY, %	29.28	CYL. GAS COND.	6.0504
		REGEN. MTX. COND.	4.6474
		RAD.INSIDE DISPL.	4.0890
		FLOW FRIC. CREDIT	-889.6459
		TOTAL HEAT TO ENG.	9325.0470

Convergence criteria is: .00500

Cycle Numb.	Change Power Out	Change Heat In	Work Out Joules	Heat In Joules	End Pressure MPa	Time Step Msec.
1	.00000	.00000	46.7637	73.1132	7.8346	.2500
2	.53236	.63443	79.1479	114.2906	7.5820	.2500
3	.69251	.56320	115.6417	204.5695	7.4203	.2500
4	.46108	.78991	140.3167	256.1898	7.3325	.2500
5	.21337	.25234	141.9066	264.1675	7.3302	.2500
6	.01133	.03114	141.6468	263.9586	7.3274	.2500
7	.00183	.00079	141.7094	263.8538	7.3281	.2500

ENTERED PRINT ROUTINE AFTER 7 CYCLES.

Fractional change in two successive integrals of heat in and power out has been less than .0050

RUN# 30 FOR
SUNPOWER RE1000 ENGINE
FREE MOTIONS -- LINEAR ALTERNATOR
Load constant = .020 N/(cm/sec)**2.
MARTINI MOVING GAS NODE ANALYSIS
MARTINI LOSS EQUATIONS
SOLUTION IS NOT OPTIMIZED.

OPERATING CONDITIONS ARE:

SPEC.FREQ., HZ =	29.70	CHRG. PRESS., BAR =	82.00
HEAT IN, DEG C =	600.00	HEAT OUT, DEG. C =	40.00
W. GAS 1=H2, 2=HE, 3=AIR	2	PHASE ANG. DEGREES =	78.16
POWER P.STR, CM =	3.76	DISPL. STROKE, CM =	3.96
CALC.FREQ., HZ =	29.44	TIME STEPS/CYCLE =	135.87

COMPUTED PERFORMANCE USING FPSE BY MARTINI ENG.:

POWER, WATTS		HEAT REQUIREMENT, WATTS	
BASIC	4171.8110	BASIC	7767.6450
ADIABATIC CORR.	.0000	ADIABATIC CORR.	.0000
HEATER FLOW LOSS	-527.4219	REHEAT	2069.3280
REGEN.FLOW LOSS	-774.4562	SHUTTLE	235.1304
COOLER FLOW LOSS	-72.5438	PUMPING	36.1181
INDICATED	2797.3890	TEMP. SWING	13.8473
		CYL. WALL COND.	187.7191
		DISPLCR WALL COND.	32.7050
		REGEN. WALL COND.	59.0762
INDICATED EFFICIENCY, %	29.44	CYL. GAS COND.	5.8990
		REGEN. MTX. COND.	4.5311
		RAD.INSIDE DISPL.	3.8283
		FLOW FRIC. CREDIT	-914.6500
		TOTAL HEAT TO ENG.	9501.1780

Report Documentation Page

National Aeronautics and Space Administration

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-182210		

4. Title and Subtitle	5. Report Date
Development of Free-Piston Stirling Engine Performance and Optimization Codes Based on Martini Simulation Technique	September 1989
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
William R. Martini	None (E-4416)
	10. Work Unit No.
	586-01-11
9. Performing Organization Name and Address	11. Contract or Grant No.
Martini Engineering 2303 Harris Richland, Washington 99352	NAS3-22256
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Contractor Report Final
National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135-3191	14. Sponsoring Agency Code

15. Supplementary Notes

Project Manager, Roy C. Tew, Jr., Power Technology Division, NASA Lewis Research Center.

16. Abstract

A FORTRAN computer code is described that could be used to design and optimize a free-displacer, free-piston Stirling engine similar to the RE-1000 engine made by Sunpower. The code contains options for specifying displacer and power piston motion or for allowing these motions to be calculated by a force balance. The engine load may be a dashpot, inertial compressor, hydraulic pump or linear alternator. Cycle analysis may be done by isothermal analysis or adiabatic analysis. Adiabatic analysis may be done using the Martini moving gas node analysis or the Rios second-order Runge-Kutta analysis. Flow loss and heat loss equations are included. Graphical display of engine motions and pressures and temperatures are included. Programming for optimizing up to 15 independent dimensions is included. Sample performance results are shown for both specified and unconstrained piston motions; these results are shown as generated by each of the two Martini analyses. Two sample optimization searches are shown using specified piston motion isothermal analysis. One is for three adjustable input and one is for four. Also, two optimization searches for calculated piston motion are presented for three and for four adjustable inputs. The effect of leakage is evaluated. Suggestions for further work are given.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Stirling engine Stirling computer model	Unclassified – Unlimited Subject Category 85

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No of pages	22. Price*
Unclassified	Unclassified	281	A13

NASA FORM 1626 OCT 86

*For sale by the National Technical Information Service, Springfield, Virginia 22161