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WASTE HEAT RECOVERY UNIT DESIGN FOR GAS TURBINE PROPULSION SYST--ETC(U)  
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- Row 1:** Frame 1: Title page with document number and school name. Frame 2: Abstract. Frame 3: Table of contents. Frame 4: Introduction. Frame 5: Design objectives. Frame 6: System description. Frame 7: Component details. Frame 8: Performance analysis. Frame 9: Design calculations. Frame 10: Summary and conclusions.
- Row 2:** Frame 11: Detailed schematic of the waste heat recovery unit. Frame 12: Thermodynamic cycle diagrams. Frame 13: Material selection charts. Frame 14: Manufacturing process flowcharts. Frame 15: Cost analysis tables. Frame 16: Environmental impact studies. Frame 17: Maintenance procedures. Frame 18: Safety protocols.
- Row 3:** Frame 19: Comparison of alternative designs. Frame 20: Experimental data plots. Frame 21: Simulation results. Frame 22: Prototype construction details. Frame 23: Test results. Frame 24: Design modifications. Frame 25: Final design specifications. Frame 26: Bill of materials. Frame 27: Assembly drawings. Frame 28: Component drawings.
- Row 4:** Frame 29: Performance graphs. Frame 30: Design review notes. Frame 31: Design decisions. Frame 32: Design rationale. Frame 33: Design history. Frame 34: Design changes. Frame 35: Design approvals. Frame 36: Design sign-off. Frame 37: Design release. Frame 38: Design closure. Frame 39: Design archive. Frame 40: Design legacy.
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THESIS

WASTE HEAT RECOVERY UNIT DESIGN  
FOR GAS TURBINE PROPULSION SYSTEMS

by

Robert Meredith Combs

September 1979

Thesis Advisor:

P. F. Pucci

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Waste Heat Recovery Unit Design  
for Gas Turbine Propulsion Systems

by

Robert Meredith Combs  
Lieutenant Commander, United States Navy  
B.A., University of North Carolina, 1967  
M.S., Naval Postgraduate School, 1973

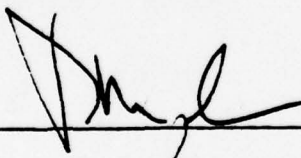
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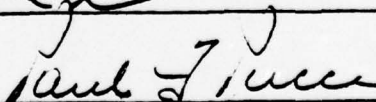
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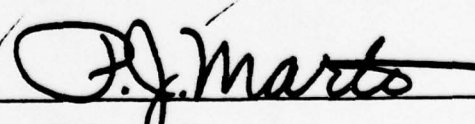
NAVAL POSTGRADUATE SCHOOL  
September 1979

Author:


  
\_\_\_\_\_

Approved by:

  
\_\_\_\_\_ Thesis Advisor

  
\_\_\_\_\_ Second Reader

  
\_\_\_\_\_ Chairman, Department of Mechanical Engineering

  
\_\_\_\_\_ Dean of Science and Engineering

### ABSTRACT

A design model for a once-through waste heat recovery unit with a segmented fin-tube arrangement was developed along with a simple model of a combined gas and steam (COGAS) turbine propulsion system. These models were integrated and applied in a computer program written in FORTRAN IV for the IBM 360-67 computer. Waste heat recovery unit designs were produced and tested at off-design conditions. Using the space constraints and power requirements of a Navy destroyer-type ship, one design was selected and employed to make estimates of possible fuel savings to be realized through the application of a COGAS system.

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## NOMENCLATURE

### English Letter Symbols

A	- Area (ft <sup>2</sup> )
A <sub>1</sub>	- Estimated Area for Boiling in First Superheater Pass (ft <sup>2</sup> )
A <sub>b</sub>	- Frontal Area Blocked by Tubes and Fins (ft <sup>2</sup> )
A <sub>bt</sub>	- Bare Tube Area (ft <sup>2</sup> )
A <sub>f</sub>	- Heat Exchanger Frontal Area (ft <sup>2</sup> )
A <sub>fin</sub>	- Fin Area (ft <sup>2</sup> )
A <sub>ff</sub>	- Cross-Sectional Area for Fluid Flow (ft <sup>2</sup> )
A <sub>i</sub> <sup>b</sup>	- Inside Area Required for Boiling in First Superheater Pass (ft <sup>2</sup> )
A <sub>i</sub> <sup>sh</sup>	- Inside Area Required for Superheating in First Superheater Pass (ft <sup>2</sup> )
A <sub>ip</sub>	- Inside Heat Transfer Area Per Pass (ft <sup>2</sup> )
A <sub>min</sub>	- Minimum Cross-Sectional Area for Gas Flow (ft <sup>2</sup> )
A <sub>op</sub>	- Outside Heat Transfer Area Per Pass (ft <sup>2</sup> )
A <sub>ti</sub>	- Total Heat Exchanger Inside Area (ft <sup>2</sup> )
A <sub>to</sub>	- Total Heat Exchanger Outside Area (ft <sup>2</sup> )
C	- Constant
C <sub>bhp</sub>	- Correction Factor to Gas Turbine BHP for Duct Loss
C <sub>max</sub>	- Maximum Heat Capacity (Btu/hr-F)
C <sub>min</sub>	- Minimum Heat Capacity (Btu/hr-F)
C <sub>pf</sub>	- Specific Heat of Water/Steam (Btu/lbm-F)
C <sub>pg</sub>	- Specific Heat of Gas (Btu/lbm-F)
C <sub>sfc</sub>	- Correction Factor to Gas Turbine BHP for Duct Loss

$d_f$	-	Fin Outside Diameter (ft)
$d_{fb}$	-	Diameter of Fin Base (ft)
$d_i$	-	Inside Tube Diameter (ft)
$d_o$	-	Outside Tube Diameter (ft)
$d_r$	-	Fin Root Diameter (ft)
$f$	-	Friction Factor
$G$	-	Gas Flow Rate Per Square Foot ( $\text{lbm/hr-ft}^2$ )
$G_{\text{max}}$	-	Maximum Gas Flow Rate Per Square Foot ( $\text{lbm/hr-ft}^2$ )
$h_1$	-	Enthalpy of Steam at Turbine Inlet (Btu/lbm)
$h_2$	-	Turbine Exhaust Steam Enthalpy (Btu/lbm)
$h_{2s}$	-	Turbine Exhaust Steam Enthalpy Assuming Isentropic Expansion (Btu/lbm)
$h_f$	-	Enthalpy of Saturated Water (Btu/lbm)
$h_{f1}$	-	Enthalpy of Water at Heat Exchanger Inlet (Btu/lbm)
$h_{f2}$	-	Enthalpy of Water at Heating Section Outlet (Btu/lbm)
$h_{f3}$	-	Enthalpy of Steam at Boiling Section Outlet (Btu/lbm)
$h_{f4}$	-	Enthalpy of Steam at Superheater Outlet (Btu/lbm)
$h_{fg}$	-	Enthalpy Increment for Boiling (Btu/lbm)
$h_{fw}$	-	Enthalpy of Heat Exchanger Feedwater (Btu/lbm)
$h_\lambda$	-	Heat Exchanger Inside Heat Transfer Coefficient in Heating or Superheating Section ( $\text{Btu/hr-ft}^2\text{-F}$ )
$h_{\text{tpf}}$	-	Heat Exchanger Inside Heat Transfer Coefficient in the Two-Phase Region ( $\text{Btu/hr-ft}^2\text{-F}$ )
$j$	-	Heat Transfer Colburn j-factor
$k_g$	-	Thermal Conductivity of Gas (Btu-hr-ft-F)
$k_\lambda$	-	Thermal Conductivity of Steam/Water (Btu/hr-ft-F)

$k_w$	- Thermal Conductivity of Heat Exchanger Tube Wall (Btu/hr-ft-F)
$l$	- Fin Height (ft)
$l_c$	- Length of Cut from Fin Tip (ft)
$L$	- Tube Length (ft)
$\dot{m}_f$	- Steam/Water Flow Rate (lbm/hr)
$\dot{m}_g$	- Gas Flow Rate (lbm/hr)
$\dot{m}_g^b$	- Gas Flow Rate in Boiling Section of First Superheater Pass (lbm/hr)
$\dot{m}_g^{sh}$	- Gas Flow Rate in Superheating Section of First Superheater Pass (lbm/hr)
$n$	- Number of Passes
$N, NTU$	- Number of Transfer Units
$N_f$	- Number of Fins Per Inch
$N_s$	- Number of Segments in One Fin
$N_{t/r}$	- Number of Tubes Per Row
$P$	- Pressure (psia)
$P_1$	- Steam Pressure at Steam Turbine Inlet (psia)
$P_f$	- Steam/Water Pressure in Heat Exchanger (psia)
$P_{gt}$	- Gas Turbine Horsepower
$P_{st}$	- Steam Turbine Horsepower
$P_{tot}$	- Total System Horsepower
$Q$	- Heat Transfer Rate (Btu/hr)
$Q_b$	- Heat Transfer Rate in Boiling Section (Btu/hr)
$Q_h$	- Heat Transfer Rate in Heating Section (Btu/hr)
$Q_p$	- Heat Transfer in a Heat Exchanger Pass (Btu/hr)
$Q_{sh}$	- Heat Transfer Rate in Superheating Section (Btu/hr)

$Q_{rb}$	- Required Heat Transfer Rate in Boiling Section of First Superheater Pass (Btu/hr)
$q''$	- Heat Flux (Btu/hr-ft <sup>2</sup> )
$R_{th}$	- Thermal Resistance (hr-ft <sup>2</sup> -F/Btu)
$R_o$	- Heat Exchanger Outside Resistance (hr-ft <sup>2</sup> -F/Btu)
$s$	- Entropy (Btu/lbm-F)
$s_1$	- Entropy of Steam at Turbine Inlet (Btu/lbm-F)
$s_f$	- Entropy of Saturated Water (Btu/lbm-F)
$s_{fg}$	- Entropy Increment for Evaporation (Btu/lbm-F)
$S_n$	- Tube Spacing Normal to Gas Flow (ft)
$S_p$	- Tube Spacing Parallel to Gas Flow (ft)
$T_1$	- Steam Temperature at Turbine Inlet (F)
$T_{fb}$	- Steam/Water Bulk Temperature (F)
$T_{f1}$	- Water Temperature at Heat Exchanger Inlet (F)
$T_{f2}$	- Water Temperature at Heating Section Outlet (F)
$T_{f3}$	- Steam Temperature at Boiling Section Outlet (F)
$T_{f4}$	- Steam Temperature at Superheating Section Outlet (F)
$t_f$	- Fin Thickness (ft)
$T_{g1}$	- Average Gas Temperature at Heat Exchanger Inlet (F)
$T_{g2}$	- Average Gas Temperature at Boiling Section Inlet (F)
$T_{g3}$	- Average Gas Temperature at Heating Section Inlet (F)
$T_{g4}$	- Average Gas Temperature at Heat Exchanger Outlet (F)
$T_{gb}$	- Gas Bulk Temperature (F)

- $T_{gf}$  - Gas Side Film Temperature (F)
- $T_{sat f}$  - Temperature of Saturated Water (F)
- $T_{wo}$  - Average Outside Tube Wall Temperature (F)
- $U_{oi}$  - Overall Heat Transfer Coefficient (Btu/hr-ft<sup>2</sup>-F)
- $w_s$  - Fin Segment Width (ft)
- $W_t$  - Steam Turbine Work (Btu/lbm)
- $W_{ts}$  - Isentropic Steam Turbine Work (Btu/lbm)
- $x$  - Steam Quality
- $x_a$  - Average Steam Quality
- $x_2$  - Turbine Exhaust Steam Quality
- $x_{2s}$  - Turbine Exhaust Steam Quality Assuming Isentropic Expansion

#### Dimensionless Groups

- $N_u$  - Nusselt Number
- $P_r$  - Prandtl Number
- $R_e$  - Reynolds Number
- $S_t$  - Stanton Number

#### Greek Letter Symbols

- $\Delta P$  - Pressure Change (psia)
- $\Delta T$  - Temperature Change (F)
- $\epsilon$  - Effectiveness
- $\epsilon_b$  - Effectiveness of Boiling Section of First Superheater Pass
- $\epsilon_{oa}$  - Effectiveness Overall for a Heat Exchanger Section
- $\epsilon_p$  - Effectiveness for a Heat Exchanger Pass
- $\mu_b$  - Viscosity at Bulk Temperature (lbm/ft-hr)

- $\mu_w$  - Viscosity at Tube Wall Temperature (lbm/ft-hr)
- $\eta_f$  - Fin Efficiency
- $\eta_{th}$  - System Thermal Efficiency
- $\eta_{st}$  - Steam Turbine Efficiency
- $\rho$  - Density (lbm/ft<sup>3</sup>)
- $\rho_l$  - Density of Saturated Water (lbm/ft<sup>3</sup>)
- $\rho_v$  - Density of Saturated Vapor (lbm/ft<sup>3</sup>)

## I. INTRODUCTION

### A. BACKGROUND

The U. S. Navy has made a commitment to gas turbine propulsion systems, with two classes of gas turbine ships entering the fleet (DD-963 and FFG-7) and one class proposed (DDG-47) at the time of this writing. The DD-963 class has two shafts with two General Electric LM 2500 gas turbines powering each shaft. The FFG-7 class is a single-shaft ship with two LM 2500 gas turbines. The DDG-47 class propulsion plant, as proposed, will be similar to that of the DD-963 class.

Currently, means for conserving fuel are being sought in all sectors of the economy and government. In most of our steam turbine-powered ships fuel conservation must be pursued largely through operating practices such as reduced steaming time or reduced speed when steaming. Several alternatives exist, however, for fuel consumption reduction for the gas turbine propulsion system. These alternatives involve combining another type of propulsion system with the gas turbine in order to reduce the overall fuel consumption by either operating the combined systems in parallel or by operating the less expensive system in the cruise mode. Some examples of these combinations are:

Gas Turbine and Diesel (CODOG, GODAG)

Gas Turbine and Steam (COGAS) (steam system not  
separately fired)

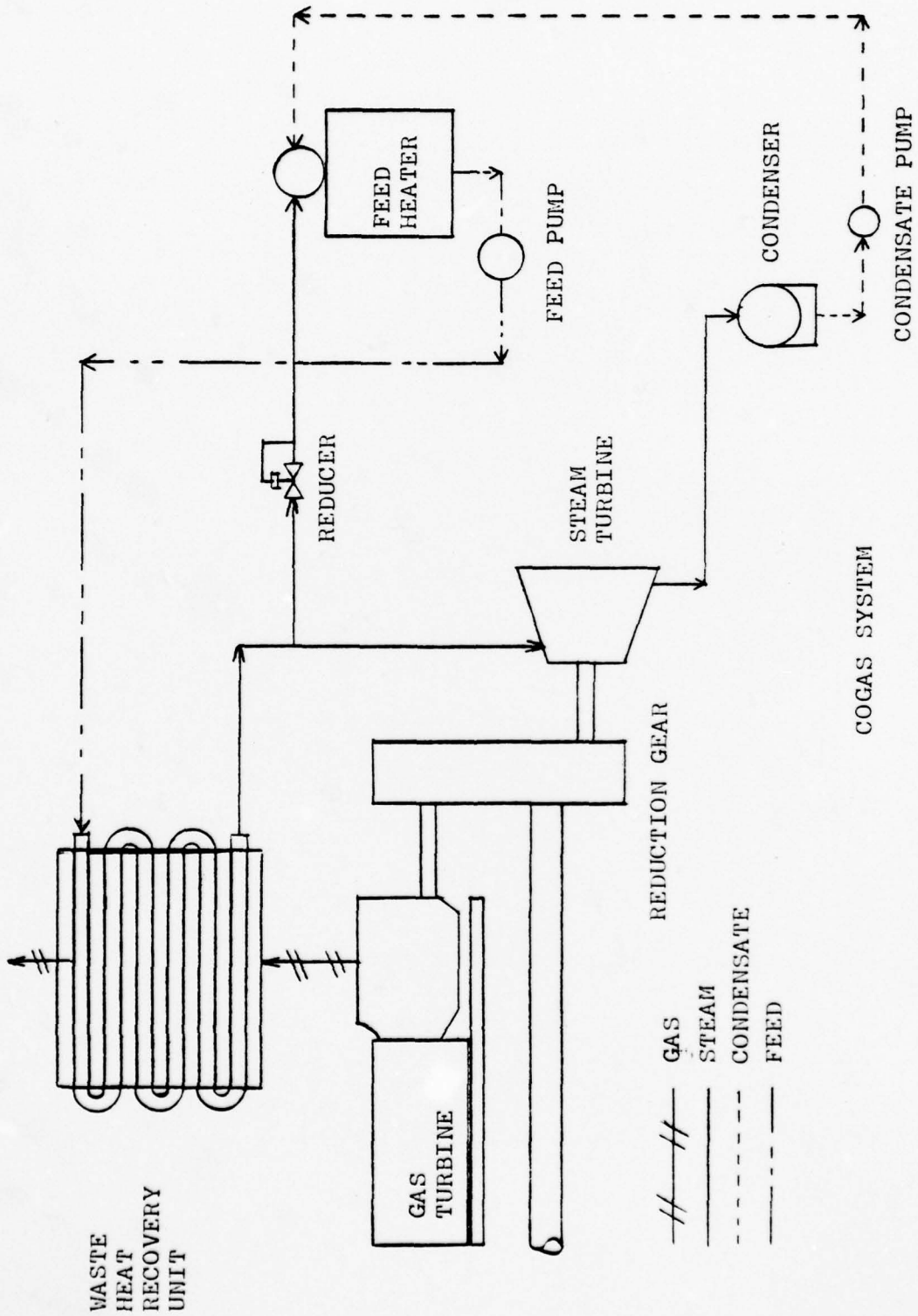
Gas Turbine and Steam (COSAG) (steam system  
separately fired)

The COMbined Gas turbine And Steam turbine (COGAS) system is probably the best of these alternatives with respect to fuel consumption, initial cost, maintenance, and manning requirements.

The COGAS ship propulsion plant uses the exhaust heat from a gas turbine to generate steam in a waste heat recovery unit (WHRU). This steam is used to drive a steam turbine which is operated in parallel with the gas turbine, for ship propulsion. A common reduction gear connects both turbines to the propeller shaft. Figure 1 illustrates the COGAS system.

Several studies have examined the potential of the COGAS system for improving propulsion plant fuel efficiency. Giblon and Rolih [Ref. 1] studied the commercial ship application of COGAS. References 2 and 3 investigated the feasibility of the COGAS system for military ship application. In all three studies the COGAS system was designed around a gas turbine brake horsepower of about 23,000. Additionally, all three employed a drum-type boiler as the waste heat recovery unit.

In this study, COGAS system designs were considered for a destroyer-sized ship with two shafts and two LM-2500 gas turbines for each shaft. One gas turbine was equipped with a WHRU. In the COGAS mode of operation the WHRU-equipped gas turbine was operated in parallel with the steam turbine,



COGAS SYSTEM

FIGURE 1

powering one shaft. The other shaft was allowed to drag. It was assumed that the principal employment of the COGAS system would be for "cruise" conditions. That is, the COGAS system would be operated primarily for steady steaming. The horsepower range over which the COGAS system could be operated is, theoretically, limited only to the range of powers over which the gas turbine can be operated. Thus, the power range would vary from the COGAS system power output with the gas turbine at idle to the system power output attained with the gas turbine operating at its maximum continuous power rating.

When the COGAS system operating range is selected, the desired goal of fuel conservation must be balanced against system reliability and routine maintenance requirements. If only one gas turbine is equipped for COGAS operations, the system downtime will increase as the turbine is operated at higher power settings. In order to increase the time between major gas turbine maintenance requirements, two COGAS systems could be installed in a twin-shaft ship. The increased overall reliability which this redundancy would afford, however, would be at least partially offset by the higher initial cost, the increased manning requirements, and the added weight of two systems.

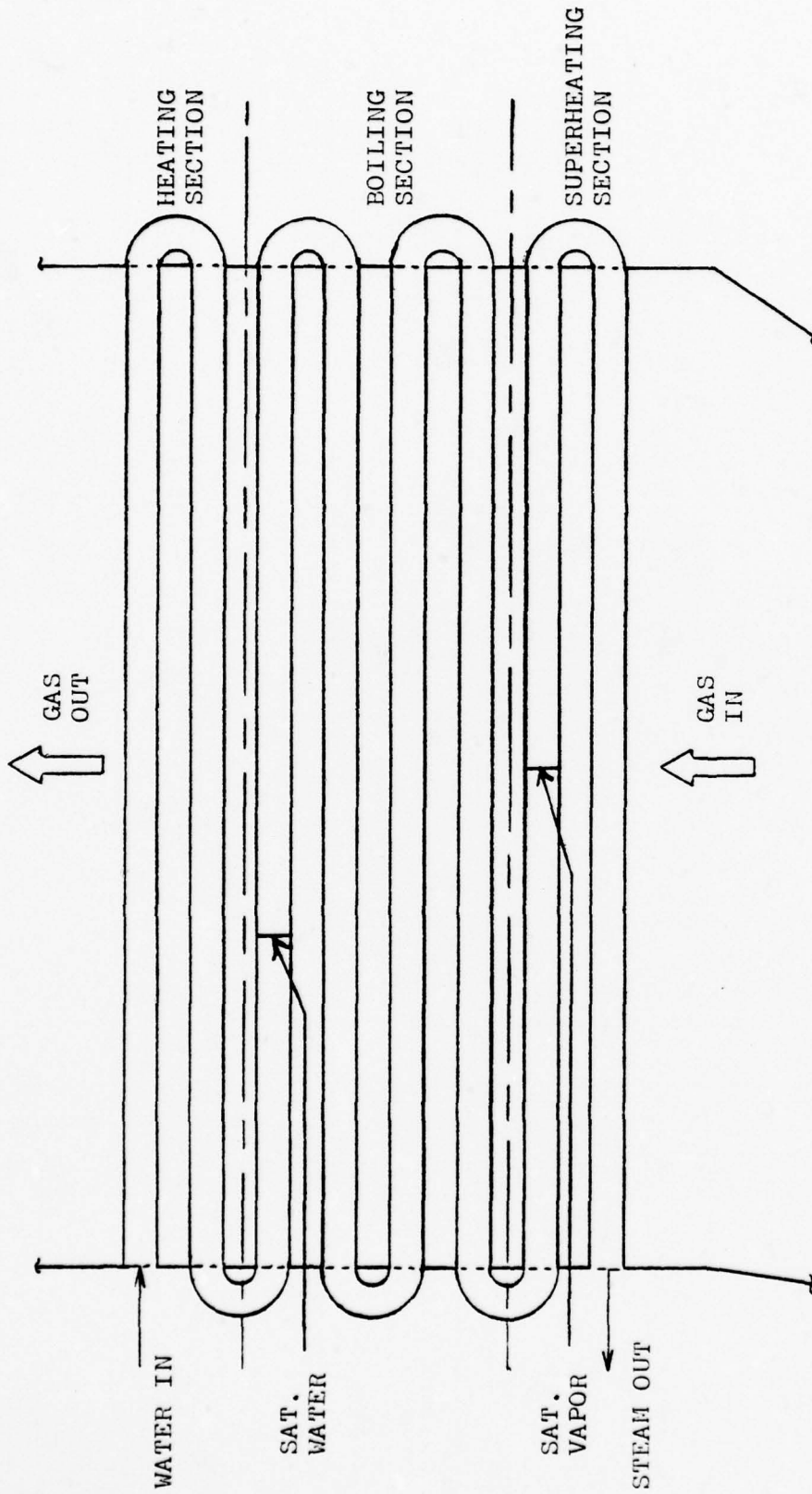
A once-through counter-cross-flow heat exchanger was selected as the WHRU. Reference 6 states some of the principal advantages of the once-through steam generator over the drum-type boiler. These advantages are as follows:

lower initial cost, faster response, more compactness, and lower operating cost. Additionally, the once-through unit provides a somewhat simpler model than the drum-type heat exchanger. A schematic representation of a once-through WHRU installed in the exhaust ducting of a gas turbine is shown in figure 2.

#### B. OBJECTIVES

There were five main objectives for this thesis.

1. Develop a design model for the once-through WHRU. This model was to size a WHRU and predict its performance given initial conditions such as feedwater inlet temperature, steam outlet temperature, WHRU operating pressure, inlet and outlet gas conditions, and gas flow rate.
2. Consider several sets of initial conditions and design constraints (e.g., maximum frontal dimensions) and produce WHRU designs for each set.
3. Evaluate these designs and integrate them with a simple COGAS system model in order to test the design model and to develop a clearer understanding of the WHRU performance in the COGAS system.
4. From the evaluated designs, predict the performance of the COGAS system.
5. Provide a framework for future studies involving a detailed, complete COGAS system cycle analysis and optimization.



ONCE-THROUGH WASTE HEAT RECOVERY UNIT

FIGURE 2

## II. MODEL DESCRIPTION

### A. OVERVIEW AND INITIAL CALCULATIONS

The waste heat recovery unit (WHRU) is modeled as a once-through counter-cross-flow heat exchanger. The model is applied in a computer program for use in heat exchanger design for a combined gas and steam (COGAS) turbine propulsion plant system. The same model could be adapted for use in a complete cycle analysis of the COGAS system.

The WHRU model is divided into three principal sections: heating, boiling and superheating. The specified initial conditions for the model are: (1) gas temperature into the heat exchanger ( $T_{g1}$ ), (2) minimum average gas exit temperature from the heat exchanger ( $T_{g4}$ ), (3) gas flow rate ( $\dot{m}_g$ ), (4) water inlet temperature ( $T_{f1}$ ), (5) water/steam pressure ( $P_f$ ). Useful background material for the model formulation was obtained from references 1-5.

Two simplifications should be noted at this point. First, the water-side pressure drop in the WHRU is neglected. Second, gas temperatures, evaluated at several points in the model, are average temperatures. Specifically, the average inlet and outlet gas temperatures for the heating and superheating sections and the average inlet and outlet gas temperatures for each pass in the boiling section are evaluated. In each of these calculations the gas temperature distribution is neglected. Clearly, even if the gas

turbine exhaust flow is uniform in temperature as it approaches the WHRU, the gas temperature will not be uniform after the first WHRU pass is encountered. Due to the varying gas-to-fluid temperature difference across each pass the gas temperature will be distributed non-uniformly after the first WHRU pass. One can, however, calculate the average gas temperature approaching a particular pass based on the heat release from the gas in the previous pass and the average gas temperature entering the previous pass. Averaged gas temperatures calculated in this manner are used throughout the model.

Prior to the heating section, some initial calculations are performed to determine the water/steam mass flow rate and to set the pinch point. In order to calculate the water/steam mass flow rate an energy balance is performed, using the starting conditions, as follows:

$$Q = \dot{m}_g C_{pg} (T_{g1} - T_{g4})$$

where  $C_{pg}$  is evaluated at the average gas temperature  $T_{gavg} = (T_{g1} + T_{g4})/2$ . The fluid mass flow rate is calculated from

$$\dot{m}_f = \frac{Q}{h_{f4} - h_{f1}}$$

where  $h_{f1}$  and  $h_{f4}$  are inlet and outlet fluid enthalpy

respectively. Intermediate fluid and gas temperatures are calculated as follows:

1. The heating section is assumed to heat the water from inlet conditions to the saturation temperature,  $T_{f2}$ . A heat balance is performed on the water side yielding a heating section heat transfer of

$$Q_h = \dot{m}_f (h_{f2} - h_{f1}).$$

The required average gas temperature entering the heating section is then calculated from

$$T_{g3} = T_{g4} + \frac{Q_h}{\dot{m}_g C_{pg}} .$$

2. In the boiling section it is assumed that sufficient heat is added to produce saturated vapor at the outlet. An energy balance on the steam-side provides the total heat transfer in the boiling section,

$$Q_b = \dot{m}_f (h_{f3} - h_{f2})$$

where  $h_{f3}$  is the enthalpy of saturated vapor at the pressure specified. The required average gas temperature entering the boiling section is

$$T_{g2} = T_{g3} + \frac{Q_b}{\dot{m}_g C_{pg}} .$$

3. In the superheating section, the steam temperature is raised from the saturation temperature to the outlet temperature specified in the initial conditions. The heat transfer in the superheating sections is

$$Q_{sh} = \dot{m}_f (h_{f4} - h_{f3})$$

where  $h_{f4}$  is the enthalpy of steam corresponding to the steam outlet temperature  $T_{f4}$ . The gas inlet temperature  $T_{g1}$  is known from the initial conditions.

The "pinch point", for the purposes of this model, is defined as the difference between the gas temperature entering the heating section and the water temperature leaving the heating section (saturation temperature). This temperature difference will normally correspond to the smallest temperature difference between gas and fluid in the heat exchanger. The only other likely location for the smallest temperature difference between gas and fluid is at the gas inlet, or superheater outlet. Figure 3 depicts the typical gas and fluid temperature distribution in the WHRU.

The model must provide some internal control over the pinch point temperature difference as defined above. This is desirable because the gas-fluid temperature difference at the fluid saturation point is indicative of the amount of heat transfer area which will be necessary to heat the incoming water to the saturation point. As the temperature

TYPICAL WHRU GAS-FLUID TEMPERATURE DISTRIBUTION

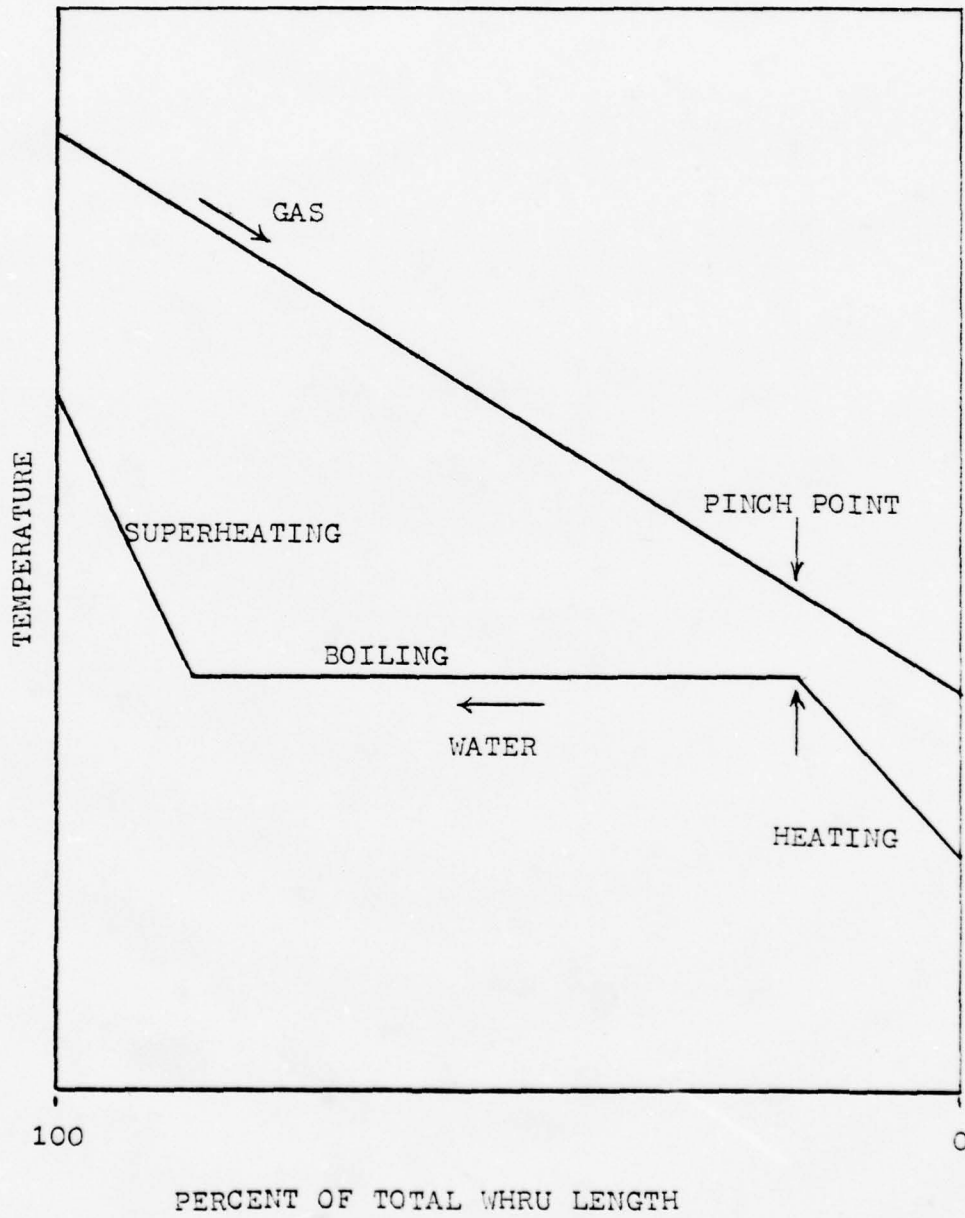


FIGURE 3

difference at the pinch point increases the heating portion of the heat exchanger becomes more efficient from the point of view of heat transfer area required. The minimum pinch point temperature difference is set at 25 F. After the interim temperatures are established the pinch point temperature difference is checked. If the difference is less than 25 F, the gas temperature at the heating section inlet is reset to

$$T_{g3} = T_{f2} + 25.$$

From the overall energy balance

$$C_{pg} \dot{m}_g (T_{g1} - T_{g4}) = \dot{m}_f (h_{f4} - h_{f1})$$

and the energy balance across the heating section

$$C_{pg} \dot{m}_g (T_{g3} - T_{g4}) = \dot{m}_f (h_{f2} - h_{f1}),$$

a revised gas outlet temperature may now be calculated from

$$T_{g4} = \frac{T_{g3} - \alpha T_{g1}}{1 - \alpha}$$

where

$$\alpha = \frac{h_{f2} - h_{f1}}{h_{f4} - h_{f1}}.$$

After this new gas inlet temperature is established, all initial calculations are performed again, to establish a new water/steam mass flow rate and to recheck the pinch point temperature difference. Once these calculations are complete, the geometric parameters for the heat exchanger must be specified.

#### B. GEOMETRY

A fin-tube with helically curved extended surfaces on circular tubes is assumed for this model. The fins are segmented. The tubes are configured in banks of one row each and the rows are staggered. The base tube surface is taken from Ref. 7. The description of the finned tubes is as follows.

$$d_i = \text{tube inside diameter} = 1.86 \text{ in.}$$

$$d_o = \text{tube outside diameter} = 2.00 \text{ in.}$$

$$d_r = \text{fin root diameter} = 2.00 \text{ in.}$$

$$N_f = \text{fins per inch} = 5.94$$

$$l = \text{fin height} = 1.015 \text{ in.}$$

$$l_c = \text{length of cut from fin tip} = 0.82 \text{ in.}$$

$$d_f = \text{fin outside diameter} = 4.03 \text{ in.}$$

$$t_f = \text{fin thickness} = 0.048 \text{ in.}$$

$$w_s = \text{fin segment width} = 0.17 \text{ in.}$$

$$N_s = \text{number of segments in 360 degrees} = 38$$

The finned tube configuration is shown in figure 4. The tube length,  $L$ , and number of tubes per row  $N_{t/r}$  are chosen by the designer according to the frontal area,  $A_f$ ,

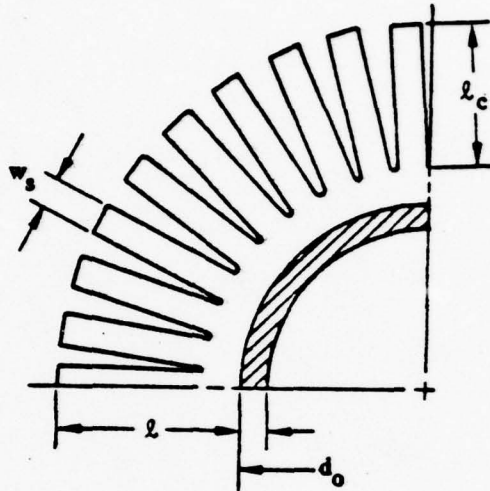


Figure 4: Segmented Fin-Tube Configuration

desired. The tube layout is shown below in figure 5. The center-to-center tube spacing in the transverse direction is 4.50 inches. The equilateral, staggered tube arrangement used in this model leads to a spacing normal to the gas flow,  $S_n$ , of 4.50 inches and a spacing parallel to the gas flow,  $S_p$ , of 3.90 inches as shown in figure 5. The heat exchanger height is established by the number of WHRU passes (rows) and the tube spacing parallel to the gas flow ( $S_p$ ).

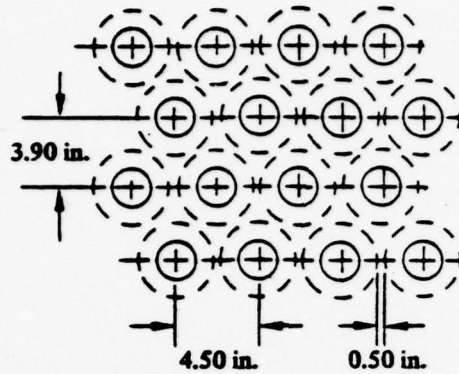


Figure 5: Model Tube Layout

In order to establish the minimum gas flow cross-sectional area the total "blocked" frontal area,  $A_b$ , of the heat exchanger must be calculated from

$$A_b = N_{t/r} L d_o + L N_f L N_{t/r}^2 t_f ,$$

and the minimum gas flow area is

$$A_{min} = A_f - A_b$$

The total inside area available for heat transfer per pass is

$$A_{ip} = \pi d_i L N_{t/r} .$$

The gas side surface area available per pass for heat transfer is the sum of the fin surface area and the bare tube surface area per pass. The fin surface area per tube is calculated from

$$A_{fin} = N_f L [N_s (2 \ell_c w_s + 2 t_f \ell_c + w_s t_f) - \frac{\pi}{2} (d_{fb}^2 - d_o^2)]$$

where  $d_{fb} = d_f - 2\ell_c$ . The bare tube area per tube is

$$A_{bt} = \pi d_o L - \pi d_o t_f N_f L .$$

Therefore, the total outside area per pass available for heat transfer is

$$A_{op} = N_{t/p} (A_{fin} + A_{bt}) .$$

The cross-sectional area for fluid flow is calculated from

$$A_{ff} = \frac{\pi}{4} d_i^2 N_{t/p} .$$

With the mass flow rates, terminal temperatures and heat exchanger geometry established, the remainder of the model may be solved for number of passes, actual interim temperatures, location of the fluid phase changes, and the gas side pressure drop.

### C. HEATING SECTION

The gas-side Reynolds number for the heating section is calculated initially using the gas bulk temperature to find the gas properties. With this Reynolds number, a j-factor and a friction factor,  $f$ , are obtained from polynomials fit to the data for tube layout number 5 in Ref. 7 (fig. 5). The friction factor will be used later to calculate the gas side pressure drop in the heating section. The j-factor is related to the heat transfer coefficient  $h_g$  by the following relationship.

$$j = S_t P_r^{2/3}$$

By introducing

$$S_t = \frac{N_u}{R_e P_r}$$

the previous expression can be written as

$$j = \frac{N_u}{R_{eg} P_{rg}} P_r^{2/3} = \frac{N_u}{R_{eg} P_{rg}^{1/3}},$$

and

$$N_u = j R_{eg} P_{rg}^{1/3},$$

where

$$N_u = \frac{h_g d_o}{K_g}$$

Therefore, a relationship may be written for the heat transfer coefficient as follows:

$$h_g = j \frac{K_g}{d_o} R_{eg} P_{rg}^{1/3}$$

The water-side heat transfer coefficient is calculated by using the Dittus-Boelter correlation

$$h_f = 0.023 \frac{K_f}{d_i} R_{ef}^{0.8} P_{rf}^{0.4}$$

where all properties are obtained at the bulk temperature of the water in the heating section. Using the tube wall resistance together with  $h_g$  and  $h_f$ , the overall heat transfer coefficient for the heating section may be written in terms of the inside area as

$$U_{oi} = \frac{1}{\frac{1}{h_f} + \frac{A_{ip} \ln(d_o/d_i)}{2\pi K_w N_{t/p} L} + \frac{A_{ip}}{A_{op}} \frac{1}{\eta_t h_g}}$$

where

$$\eta_t = 1 - (1 - \eta_f) \frac{A_{fin}}{A_{op}}$$

The fin efficiency,  $\eta_f$ , is calculated from the expression

$$\eta_f = \frac{\tanh ML}{ML},$$

where

$$M = \sqrt{h_g P / KA}$$

and, if the fin is approximated by a set of rectangular strips extending from the tube wall,  $L = \frac{d_f - d_o}{2}$ . Now, the cross-sectional area,  $A$ , of a rectangular strip may be written as

$$A = w_s t_f,$$

and the perimeter is

$$P = 2(w_s + t_f).$$

So, using known geometric parameters and the thermal conductivity of the fin metal, the parameter  $ML$  may be expressed as

$$ML = C \sqrt{h_g}$$

where

$$C = \left( \frac{d_f - d_o}{2} \right) \sqrt{\frac{2(w_s + t_f)}{w_s t_f K}} .$$

Now,

$$\eta_t = \left[ 1 - \left( 1 - \frac{\tanh C \sqrt{h_g}}{C \sqrt{h_g}} \right) \frac{A_{fin}}{A_{op}} \right] .$$

The number of passes required in the heating section is calculated, using the effectiveness-NTU method, in the following way.

1. An average pass effectiveness for the heating section is calculated from the following expression for cross-flow effectiveness with both fluids unmixed obtained from Ref. 8,

$$\epsilon_p = 1 - \exp\left[\frac{\exp(-NCn) - 1}{C \eta}\right]$$

where

$$C = \frac{C_{min}}{C_{max}} = \frac{C_{pf} \dot{m}_f}{C_{pg} \dot{m}_g} ,$$

$$N = NTU = \frac{U_{oi} A_{ip}}{C_{min}} ,$$

$$\eta = N^{-0.22} .$$

Water and gas properties are taken at bulk temperatures.

2. An overall heating section effectiveness is calculated from

$$\epsilon_{oa} = \frac{\left( \frac{1 - \epsilon_p C_{\min}/C_{\max}}{1 - \epsilon_p} \right)^n - 1}{\left( \frac{1 - \epsilon_p C_{\min}/C_{\max}}{1 - \epsilon_p} \right)^n - \frac{C_{\min}}{C_{\max}}}$$

where  $n$  = number of passes. This expression was obtained from Ref. 9. The overall effectiveness formulation was actually derived with the condition that fluids are mixed between passes. It can be shown [Ref. 9], however, that the error is not large when the expression is used for the case where fluids are unmixed between passes.

3. The expression for  $\epsilon_{oa}$  is now used in an iterative fashion starting with  $n$  = number of passes = 1. Each time  $\epsilon_{oa}$  is solved, the gas temperature into the heating section,  $T_{g3}$ , is found from

$$T_{g3} = \frac{\epsilon_{oa} C_{\min} T_{g1} - C_{\max} T_{g4}}{\epsilon_{oa} C_{\min} - C_{\max}}$$

which is derived from

$$\epsilon_{oa} = \frac{C_{\max} (T_{g3} - T_{g4})}{C_{\min} (T_{g3} - T_{f1})}$$

4. Once the inlet gas temperature is established for a particular number of passes, an energy balance may be

performed to solve for the total heat transfer which would take place in the heating section for that number of passes.

$$Q_h = \dot{m}_g C_{pg} (T_{g3} - T_{g4})$$

5. The enthalpy of the water at the outlet of the heating section for a particular iteration may be found from

$$h_{fL} = h_{f2} + \frac{Q_h}{\dot{m}_f},$$

and this yields the temperature of the water at the outlet,  $T_{f2}$ , for the number of passes under consideration.

6. The outlet water temperature,  $T_{f2}$ , may be checked to see if it exceeds the saturation temperature.

7. This set of calculations is performed until  $T_{f2}$  exceeds the saturation temperature. This naturally means that boiling begins in the last pass of the current total number of passes. Initiation of boiling will be treated in the boiling section of the model. Therefore, the heating section ends with the pass prior to that which initiates boiling. The results of the above calculations are: (a) The total number of passes contained in the heating section, (b) the new gas temperature at the inlet to the heating section  $T_{g3}$ , and (c) the new water outlet temperature  $T_{f2}$ .

With these new heating section terminal temperatures an average outside wall temperature for the section may be calculated from

$$T_{wo} = T_{gb} - \left( \frac{U_{oi} A_{ti}}{h_g A_{to}} \right) (T_{gb} - T_{fb})$$

where  $A_{ti}/A_{to}$  are total inside/outside areas for the section and  $T_{gb}/T_{fb}$  are the new gas/fluid bulk temperatures for the section. The expression for  $T_{wo}$  is derived from the following formulation for heat transfer in the heating section,

$$Q = \frac{T_{gb} - T_{fb}}{\sum R_{th}} = \frac{T_{gb} - T_{wo}}{R_o}$$

which reduces to

$$T_{wo} = T_{gb} - \frac{R_o}{\sum R_{th}} (T_{gb} - T_{fb})$$

where

$$R_o = \frac{1}{\eta_t h_g A_{to}}$$

and

$$\sum R_{th} = \frac{1}{U_{oi} A_{ti}} .$$

The gas-side film temperature is

$$T_{gf} = \frac{T_{gb} - T_{wo}}{2} .$$

This gas-side film temperature is now introduced at the beginning of the calculations for the heating section, to replace the gas bulk temperature. All calculations are performed again with  $T_{gf}$ .

The gas-side pressure drop in the heating section may now be calculated using the previously obtained friction factor,  $f$ , from the correlation contained in Ref. 7. The gas-side pressure drop is

$$\Delta P_g = \frac{2f G_{\max}^2 N_{t/r}}{\rho} \left( \frac{\mu_w}{\mu_b} \right)^{0.14}$$

where

$$G_{\max} = \frac{\dot{m}_g}{A_{\min}}$$

$$N_{t/r} = \text{number of tubes per row}$$

$$\rho = \text{gas density}$$

$$\mu_w = \text{gas viscosity at wall temperature}$$

$$\mu_b = \text{gas viscosity at bulk temperature.}$$

#### D. BOILING SECTION

The boiling section is solved pass-by-pass since most of the section will involve two-phase flow on the cold side and the inside heat transfer coefficient will change with quality,  $x$ , and heat flux,  $q''$ . The correlation for the two-phase region inside heat transfer coefficient selected

for this model is that recommended by Tong [Ref. 10] for both nucleate boiling and forced convection. The equation for the two-phase flow heat transfer coefficient was given by Schrock and Grossman in Tong [Ref. 10] as

$$\frac{h_{\text{TPf}}}{h_{\ell}} = B \left[ \frac{q''}{G h_{\text{fg}}} + A \left( \frac{1}{X_{\text{tt}}} \right)^n \right]$$

The constants are given by Wright [Ref. 10]:  $B = 6.70 \times 10^3$ ,  $A = 3.5 \times 10^{-4}$ ,  $n = 0.66$ . The heat transfer coefficient assuming a total liquid flow is

$$h_{\ell} = 0.023 \frac{K_{\ell} d_i G (1-x)}{d_i \mu_{\ell}}^{0.8} \left[ \frac{C_{p\ell} \mu_{\ell}}{K_{\ell}} \right]^{0.1},$$

and the Martinelli parameter is

$$\frac{1}{X_{\text{tt}}} = \left[ \frac{x}{1-x} \right]^{0.9} \left[ \frac{\rho_{\ell}}{\rho_v} \right]^{0.5} \left[ \frac{\mu_v}{\mu_{\ell}} \right]^{0.1}$$

The limits of the data for this correlation are

quality: 0.05 - 0.57

heat flux:  $6.0 \times 10^4 - 1.45 \times 10^6$  BTU/hr-ft<sup>2</sup>.

In this model, heat flux in the boiling section will be at levels considerably below  $6 \times 10^4$  BTU/hr-ft<sup>2</sup> and the full range of quality must be considered. Therefore, in order to observe the performance of the Schrock and Grossman correlation at lower heat flux and quality above 0.57 a plot was made (fig. 6) of the ratio  $h_{\text{tpf}}/h_{\ell}$  vs. quality

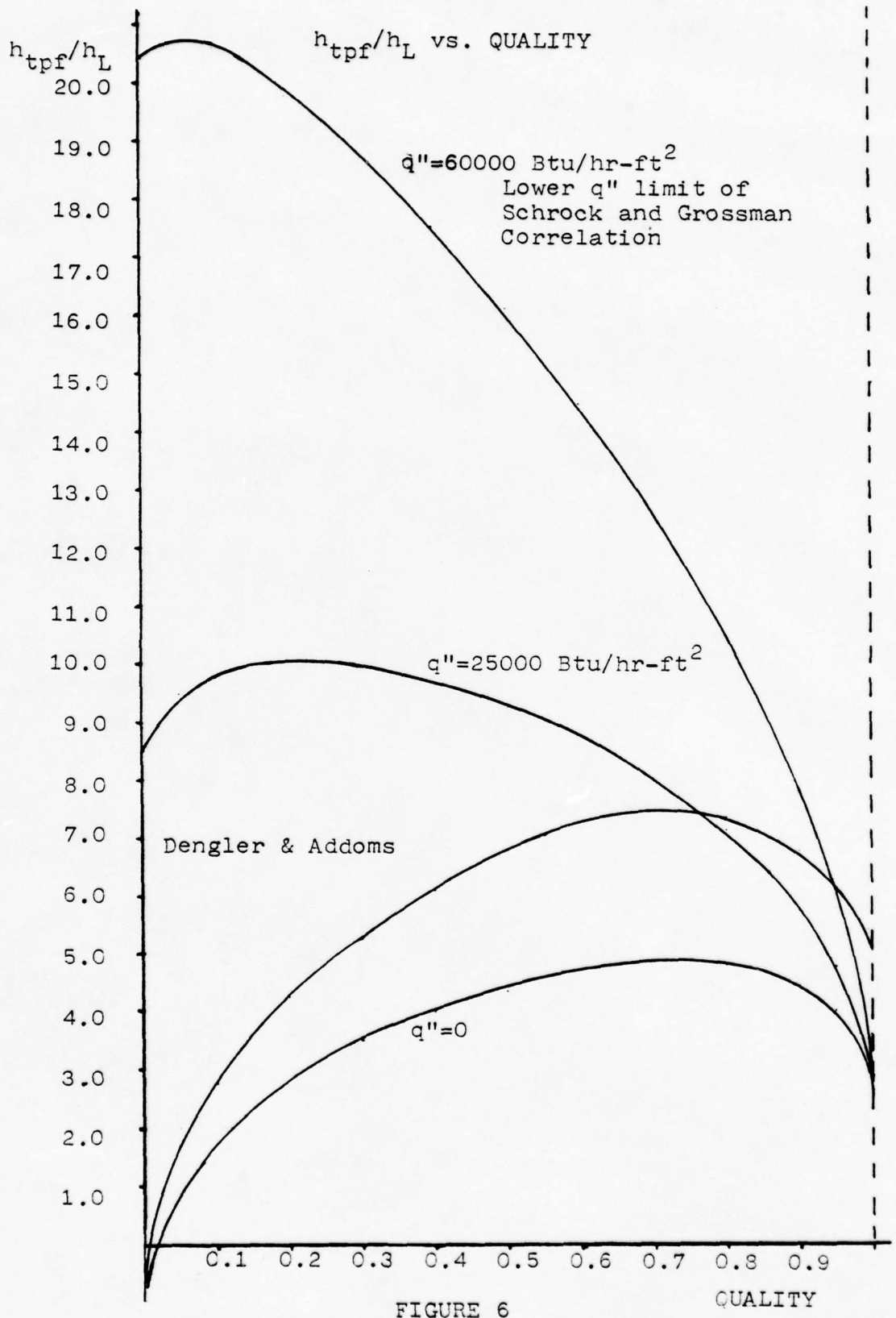


FIGURE 6

where  $h_2$  is the heat transfer coefficient from the Dittus-Boelter correlation for water at saturated liquid conditions. The correlation of Dengler and Addoms as given in Tong [Ref. 10] for entirely forced convection vaporization is included for comparison. Tong [Ref. 10] indicates that low heat flux and high water-vapor mixture velocity favor the forced convection mechanism. After a review of the information available in Tong, it is not entirely clear whether the forced convection mechanism or the nucleate boiling mechanism is dominant for the relatively low flow velocities and low heat flux of this model. In any case, the Schrock and Grossman correlation applied at low heat flux represents a type of compromise between the entirely forced convection assumptions of Dengler and Addoms and the "mixed" assumption of Schrock and Grossman. When the Schrock and Grossman correlation is applied under the conditions of very low heat flux and quality ( $x < 0.05$ ), as in the first pass of the boiling section of this model, it can be seen that the ratio  $h_{tpf}/h_2$  becomes less than one. This is both unrealistic and computationally difficult to handle. Therefore, in the boiling section, the model assumes that  $h_{tpf} = h_2$  for the first pass or for any pass where  $x < 0.05$ . This assumption will produce a more realistic but still conservative design.

One other simplification should be explained prior to discussion of the actual model calculations for the boiling section. Since the boiling section calculations are performed

for one complete pass at a time, the average quality,  $x_a$ , in a particular pass is used as the "local" quality to compute the inside heat transfer coefficient from the Schrock and Grossman correlation.

The first pass in the boiling section, as indicated in the calculations for the heating section, will, in general, involve both heating water to the saturation temperature and the initiation of boiling. From the calculations for the last pass of the heating section we have the following quantities for the first pass of the boiling section: water inlet temperature ( $T_{fin}^1$ ), average gas outlet temperature ( $T_{gout}^1$ ). The gas side heat transfer coefficient,  $h_g$ , is obtained, using the average gas temperature in the boiling section, in the same way as for the heating section.

A rough estimate for the gas temperature into the first pass must be obtained in order to begin calculations for that pass. This is accomplished by calculating a rough overall heat transfer coefficient,  $U_{oi}^1$ , for the pass using the tube wall resistance,  $h_g$ , and neglecting inside resistance. A pass effectiveness,  $\epsilon_p^1$ , is then calculated assuming that only boiling takes place in the pass. The expression for effectiveness for fluids unmixed between passes for  $C = 0$  becomes

$$\epsilon_p = (1 - \exp(-N))$$

where  $N = NTU$ . Using  $\epsilon_p$  calculated from this expression, the rough gas temperature for the first pass is

$$T_{g_{in}}^1 = \frac{\epsilon_p^1 T_{f_{in}}^1 - T_{g_{out}}^1}{\epsilon_p^1 - 1}$$

Since this pass has been simplified by allowing the inside heat transfer coefficient to be computed by the Dittus-Boelter correlation this initial guess for  $T_{g_{in}}^1$  is not essential. It would, however, become important if we were attempting to "split" the pass with two inside heat transfer coefficients, one for heating and one for boiling. Instead, the inside heat transfer coefficient,  $h_f^1$ , is calculated for the entire pass using the Dittus-Boelter correlation with water conditions corresponding to the average water conditions in the heating section of the pass, that is,

$$T_{f_{avg}}^1 = \frac{T_{f_{in}}^1 + T_{satf}}{2}$$

With this inside heat transfer coefficient, an expression for the overall heat transfer coefficient for the first pass may be written,

$$U_{oi}^1 = \frac{1}{\frac{1}{h_f^1} + \frac{A_{ip}}{2 \pi K_w N_{t/p} L} + \frac{A_{ip}}{A_{op}} \frac{1}{h_g^1 \eta_t}}$$

The pass effectiveness,  $\epsilon_p^1$ , is now calculated in the same manner as previously described. With  $\epsilon_p^1$ , the average gas

temperature in is calculated from

$$T_{g_{in}}^1 = \frac{\epsilon_p^1 C_{\min} T_{f_{in}}^1 - C_{\max} T_{g_{out}}^1}{\epsilon_p^1 C_{\min} - C_{\max}} .$$

The pass heat transfer may be calculated from

$$Q_p^1 = \dot{m}_g C_{pg} (T_{g_{in}}^1 - T_{g_{out}}^1) .$$

The expression for outlet enthalpy from the pass is

$$h_{f_{out}}^1 = h_{f_{in}}^1 + \frac{Q_p^1}{\dot{m}_f} ,$$

and outlet quality is calculated from

$$x_{out}^1 = \frac{h_{f_{out}}^1 - h_{satf}}{h_{fg}} .$$

In order to determine the location of the interface between heating and boiling the total inside area devoted to heating in the first pass is calculated from

$$A_{ih}^1 = \left( \frac{h_{satf} - h_{f_{in}}^1}{h_{f_{out}}^1 - h_{f_{in}}^1} \right) A_{ip} .$$

Subsequent fluid passes in the boiling section are calculated until the quality at the outlet of a pass is found to be greater than 1.0. When this occurs, the boiling section is allowed to end with the last pass for which  $x_{out} \leq 1.0$ . A "mixed" pass where both boiling and superheating

takes places will be calculated in the superheating section of the model.

After the first pass, boiling section fluid passes are calculated in the following manner.

1. The steam quality at the outlet of the previous pass becomes the inlet quality for the current pass,  $x_{in}$ . The average gas temperature at the inlet to the previous pass becomes the outlet average gas temperature,  $T_{g_{out}}$ , for the current pass.
2. Using the last overall heat transfer coefficient calculated for the previous pass,  $U_{oi}$ , approximate values of NTU and  $\epsilon_p$  are calculated.
3. With this approximate  $\epsilon_p$  the average gas temperature into the current pass is calculated from

$$T_{g_{in}} = \frac{\epsilon_p T_{f_{sat}} - T_{g_{out}}}{\epsilon_p - 1}.$$

4. Using this gas temperature in,  $T_{g_{in}}$ , the pass heat transfer,  $Q_p$ , is calculated. This allows the calculation of enthalpy out,  $h_{f_{out}}$ , and quality out,  $x_{out}$ , as well as the average quality in the current pass,  $x_a$ .
5. The inside heat transfer coefficient,  $h_{tpf}$ , may now be calculated,

$$h_{tpf} = B \left[ \frac{Q_p/A_{ip}}{G h_{fg}} + A \left( \frac{1}{x_{tt}} \right)^n \right] h_\ell,$$

where the Martinelli parameter  $\frac{1}{x_{tt}}$  is calculated using average quality,  $x_a$ , and all other terms are as previously described.

6. A new overall heat transfer coefficient is now calculated from which a new pass effectiveness can be calculated.

7. This new pass effectiveness yields a new average gas temperature into the pass from which a new pass heat transfer may be calculated.

8. The new pass heat transfer is compared with the previously calculated pass heat transfer. If the two heat transfer calculations do not agree to within 5% the entire set of calculations is repeated.

9. When the pass heat transfer calculation converges, the final quality at the outlet of the pass is calculated. If the quality is less than 1.0 another pass is calculated for the boiling section.

10. If the quality is 1.0, the boiling section ends with the current pass. If the quality out exceeds 1.0 the boiling section ends with the previous pass.

Calculations for the average gas film temperature and gas-side pressure drop are performed in the same manner as for the heating section.

#### E. SUPERHEATING SECTION

The first pass of the superheating section will, in general, involve both boiling and superheating. The inside heat transfer coefficients will be quite different for the

boiling and superheating portions for the pass, and, for this reason, the pass will be "split" to allow more accurate calculation of the heat transfer in these two regions. An outline of the calculation scheme is as follows:

1. Calculate the gas-side heat transfer coefficient for the section in the same manner as for the previous two sections.
2. Estimate the average gas temperature into the first pass. This is only a rough guess for  $T_{g_{in}}$ , to begin the calculation.
3. Calculate the required heat transfer in the boiling portion

$$Q_{rb} = \dot{m}_f (h_{f_{in}} - h_{satv})$$

where  $h_{f_{in}}$  is the enthalpy out of the last pass of the boiling section and  $h_{satv}$  is the enthalpy of saturated vapor.

4. Using  $Q_{rb}$  and the average quality in the boiling portion of the first pass, calculate the inside heat transfer coefficient,  $h_{tpf}$ , using the Schrock and Grossman correlation, as in the boiling section of the model. This, together with the gas-side heat transfer coefficient and the wall resistance, will yield an overall heat transfer coefficient for the boiling section,  $U_{oi}^b$ .
5. The calculation of the area required for the boiling portion of the pass is performed in an iterative scheme as follows.

a. An initial estimate for the required boiling area,  $A_1$ , is made.

b. The mass flow rate of the gas over the boiling portion is then

$$\dot{m}_g^b = \frac{A_1}{A_{ip}} \dot{m}_g .$$

c. An effectiveness for the boiling portion may be calculated from

$$\epsilon_b = \frac{Q_{rb}}{C_{min}^b (T_{g_{in}} - T_{f_{sat}})}$$

where

$$C_{min}^b = \dot{m}_g C_{pg} .$$

d. Using the previously calculated overall heat transfer coefficient, the estimated boiling area and the consequent gas-side heat capacity, NTU is calculated from

$$NTU = \frac{U_{oi}^b A_1}{C_{min}^b} .$$

e. A "test" effectiveness,  $\epsilon_b^t$ , can be found by applying this NTU in the relationship for effectiveness

$$\epsilon_b^t = 1 - \exp(-NTU) .$$

f. The two effectiveness calculations,  $\epsilon_b$  and  $\epsilon_b^t$ , are compared.

(1) If  $\epsilon_b^t$  is greater than  $\epsilon_b$ , then the original estimate for the boiling area,  $A_1$ , was too large for the heat transfer required and the specified gas temperature into the pass. So, the estimate for the boiling area is decreased and a new  $A_1$  is established.

(2) If  $\epsilon_b^t$  is less than  $\epsilon_b$ ,  $A_1$  is increased.

g. A new gas-side heat capacity is calculated from

$$C_{\min}^b = \frac{A_1}{A_{ip}} \dot{m}_g C_{pg} .$$

h. A new boiling portion effectiveness is calculated using the latest boiling area estimate

$$\epsilon_b = \frac{Q_{rb}}{C_{\min}^b (T_{g_{in}} - T_{f_{sat}})} .$$

i. As before, an NTU is calculated with the new  $A_1$ . This generates a new "test" effectiveness,  $\epsilon_b^t$ , which is compared with  $\epsilon_b$ . If  $\epsilon_b$  and  $\epsilon_b^t$  are not equal, a new  $A_1$  is calculated based on the comparison.

j. These calculations are continued until  $\epsilon_b \doteq \epsilon_b^t$ . The current  $A_1$  is then set equal to  $A_1^b$ .

6. Once the area required for boiling,  $A_1^b$ , for a particular average gas inlet temperature has been established, the following first pass quantities can be calculated:

a.  $A_i^{sh}$  = area available for superheating

$$A_i^{sh} = A_{ip} - A_i^b$$

- b.  $\dot{m}_g^b$  = gas flow rate over the boiling portion
- c.  $\dot{m}_g^{sh}$  = gas flow rate over the superheating portion
- d.  $T_{g,out}^b$  = gas temperature out of the boiling portion

$$T_{g,out}^b = T_{g,in} - \frac{Q_{rb}}{\dot{m}_g^b C_{pg}}$$

- e.  $T_{g,out}^{sh}$  = gas temperature out of the superheating portion

$$T_{g,out}^{sh} = \frac{A_{ip} T_{g,out} - A_i^b T_{g,out}^b}{A_i^{sh}}$$

(The weighted average of  $T_{g,out}^{sh}$  and  $T_{g,out}^b$  must equal the  $T_{g,out}$  previously calculated.)

7. Since the heat transfer to the cold side must satisfy an energy balance involving the average temperatures of the gas, the expected heat transfer in the superheating portion may be calculated from the heat release on the gas side

$$Q_p = \dot{m}_g C_{pg} (T_{g,in} - T_{g,out}),$$

and the required heat transfer in the superheating portion as

$$Q_{sh} = Q_p - Q_{rb}.$$

8. The enthalpy and temperature of the steam out of the first pass may be calculated from the assumed heat transfer in the superheating portion,  $Q_{sh}$ .

9. The steam properties for the superheating portion may now be found. These properties, along with  $h_g$  and wall resistance, will yield an overall heat transfer coefficient,  $U_{oi}^{sh}$ , for the superheating portion. The Dittus-Boelter correlation is applied to calculate the inside heat transfer coefficient.

10. The heat capacities on the gas and fluid sides are calculated, using the current gas mass flow rate over the superheating portion,  $\dot{m}_g^{sh}$ , to calculate the gas heat capacity. The heat capacities along with  $U_{oi}^{sh}$  and  $A_i^{sh}$  yield the effectiveness for the superheating portion of the pass,  $\epsilon_{sh}$ .

11. A new average gas temperature into the pass may now be calculated from the superheating portion effectiveness and the superheating portion heat transfer required to satisfy the original heat balance from the expression

$$T_{gin}^* = T_{fin} + \frac{Q_{sh}}{\epsilon_{sh} C_{min}^{sh}} .$$

This temperature,  $T_{gin}^*$ , is a measure of the temperature which would be required to produce the originally specified  $Q_{sh}$  under the actual conditions of the heat transfer characteristics of the superheating portion.

12. If the  $T_{g_{in}}^*$  is the same as the originally specified average gas temperature into the pass,  $T_{g_{in}}$ , then the heat transfer in the superheating portion,  $Q_{sh}$ , is possible under the current distribution of area between boiling and superheating and the heat balance is satisfied between steam and gas sides for the specified gas temperature in. In this event, the calculations for the first pass of the superheating section are complete.

13. If  $T_{g_{in}}^*$  is less/greater than the current  $T_{g_{in}}$  the average gas temperature into the pass is increased/decreased and the entire set of calculations is performed again until  $T_{g_{in}}^* \doteq T_{g_{in}}$ .

14. The second and subsequent superheating section passes are calculated in much the same way as in the heating section. That is, an overall pass effectiveness is calculated for a specified number of passes, using the multipass effectiveness relationship from Kays and London [Ref. 9].

15. The average steam-side heat transfer coefficient,  $h_f$ , is calculated using the Dittus-Boelter correlation with steam properties at steam bulk temperature for the remainder of the superheating section. The overall heat transfer coefficient and the average pass effectiveness,  $\epsilon_p$ , are then calculated.

16. The formulation for overall effectiveness with the number of passes,  $n$ , variable, is

$$\epsilon_{oa} = \frac{\left( \frac{1 - \epsilon_p C_{min}/C_{max}}{1 - \epsilon_p} \right)^n - 1}{\left( \frac{1 - \epsilon_p C_{min}/C_{max}}{1 - \epsilon_p} \right)^n - \frac{C_{min}}{C_{max}}}$$

As in the heating section this expression is used in an iterative fashion, beginning with  $n = 1$ .

17. Each time  $\epsilon_{oa}$  is solved, the gas temperature into the superheating section is calculated from

$$T_{g_{in}} = \frac{\epsilon_{oa} C_{min} T_{f_{in}} - C_{max} T_{g_{out}}}{\epsilon_{oa} C_{min} - C_{max}}$$

where  $T_{f_{in}}$  is the temperature of the steam into the second pass of the superheater and  $T_{g_{out}}$  is the average gas temperature out of the second pass of the superheater. This gas temperature in is compared with the originally specified gas temperature into the heat exchanger,  $T_{g1}$ .

18. If the calculated gas temperature in,  $T_{g_{in}}$ , is less than  $T_{g1}$  the number of passes is increased by one and the calculation is performed again. If  $T_{g_{in}}$  exceeds  $T_{g1}$ , the superheater is allowed to stop with the previous pass.

Calculations for the average gas film temperature and the gas-side pressure drop are performed in the same manner as for the heating and boiling sections.

#### F. MATCHING SUPERHEATER GAS INLET TEMPERATURE

The model calculations thus far lead to a waste heat recovery unit design for which the gas temperature at the

inlet is, in general, lower than that specified in the initial conditions. This condition occurs because the superheater ends with the last complete pass calculated for which the entering gas temperature is less than or equal to the originally specified WHRU inlet temperature. This outcome is, of course, unsatisfactory since the inlet gas temperature is an independent quantity which is a function of the horsepower setting on the gas turbine. An iterative scheme is employed for matching the  $T_{g_{in}}$  calculated in the superheating section with the  $T_{g1}$  specified in the initial conditions.

Since the model does not allow the calculation of fractional passes and since the scheme for the calculation of superheater passes will not allow inclusion of a pass which would require a gas inlet temperature higher than that specified in the initial conditions, the final gas inlet temperature calculated for the WHRU will generally be lower than that initially specified. In order to match this superheater gas inlet temperature with that specified initially, the heat exchanger gas outlet temperature is allowed to rise. Each time the gas outlet temperature is increased, the entire waste heat recovery unit calculation is performed again, and the calculated superheater gas inlet temperature is compared with the gas turbine exhaust temperature. When a match is achieved the design is fixed.

#### G. OFF-DESIGN CALCULATIONS

Once a particular design has been selected the designer must test that design at several off-design points. A design will define the following WHRU characteristics:

Dimensions (length, width, height)

Operating pressure

Superheater outlet temperature

Fin-tube configuration.

The off-design calculation requires that the selected WHRU design performance be predicted for a gas inlet temperature and flow rate different from that which was used to produce the selected design. The design model can be used in an iterative fashion to make this calculation. All model calculations are made as prescribed in the previous sections, with the exception of the pinch point calculations which are not performed.

The off-design procedure requires that the designer fix the WHRU frontal dimensions, operating pressure, fin-tube configuration and minimum gas outlet temperature. A design is then produced for a gas inlet temperature and flow rate at an off-design point. This design is checked to determine whether it conforms to the height dimension of the WHRU designed at the gas conditions of the off-design point. If the height dimension is not matched then the number of WHRU passes must be adjusted until a match with the design-point WHRU is achieved. The number of WHRU passes

may be altered by either adjusting the WHRU gas outlet temperature or the superheater outlet steam temperature. The effect of either of these adjustments is to change the steam flow rate and the heat transfer rate. It would be possible to adjust the steam flow rate and allow the superheater steam outlet temperature to remain fixed. However, for the method of this model, the computation time required for this means of control would be large. The actual procedure used produces designs relatively quickly which closely approximate the results which would be obtained by a fine control on steam flow. Each time the superheater steam outlet or gas outlet temperature is adjusted, a new design is produced. This procedure is continued until a design is produced for which the height (number of passes) equals that of the design point WHRU. When the WHRU height at the off-design gas conditions is equal to that of the design point WHRU, the gas inlet temperature is matched with the gas inlet temperature specified for the off-design point, using the procedure described in Section E.

#### H. COGAS SYSTEM OUTPUT MODEL

The COGAS system output model calculates performance parameters for the combined steam and gas turbine system for a specified gas turbine input power. The WHRU model provides a steam flow rate, pressure, and temperature for a specified set of gas turbine exhaust gas conditions which correspond to a particular gas turbine horsepower setting.

This WHRU output is applied in a simple Rankine cycle to calculate the steam-side power output. The gas-side pressure drop calculated in the WHRU model is used to arrive at a revised gas turbine horsepower. By combining these two power outputs, a COGAS system power can be calculated. Other performance indicators such as specific fuel consumption, thermal efficiency and steam turbine share of the load are also calculated in the COGAS system output model.

1. Rankine Cycle

The following conditions are assumed for the Rankine cycle calculations:

- a. No line losses
- b. Steam turbine efficiency =  $\eta_{st} = 0.85$
- c. Condenser pressure = 2.0 psia (4 in Hg)
- d. Feedwater heater pressure = 15 psia
- e. Feedwater temperature = 200 F
- f. Pumping power required is neglected
- g. Fuel LHV = 18400 Btu/lbm

The following input conditions are received from the WHRU model: steam turbine inlet pressure ( $P_1$ ), steam turbine inlet temperature ( $T_1$ ), steam flow rate ( $\dot{m}_f$ ), gas turbine exhaust pressure drop ( $\Delta P_{gas}$ ). From  $P_1$  and  $T_1$  the turbine inlet enthalpy ( $h_1$ ) and inlet entropy ( $s_1$ ) can be found. The turbine exhaust steam quality, assuming isentropic expansion,  $x_{2s}$ , is calculated from

$$x_{2s} = \frac{s_1 - s_f}{s_{fg}},$$

where

$s_f$  = entropy of saturated water

$s_{fg}$  = entropy increment for evaporation.

The steam turbine exhaust enthalpy assuming isentropic expansion,  $h_{2s}$ , may now be calculated from

$$h_{2s} = h_f + x_{2s} h_{fg}$$

where

$h_f$  = enthalpy of saturated water

$h_{fg}$  = enthalpy increment for evaporation.

The isentropic turbine work is

$$W_{ts} = h_1 - h_{2s},$$

and the actual steam turbine work is calculated from

$$W_t = \eta_{st} W_{ts}.$$

The actual turbine exhaust enthalpy and quality are

$$h_2 = h_1 - W_t$$

and

$$x_2 = \frac{h_2 - h_{2f}}{h_{fg}} .$$

In this model it is assumed that heating steam for the feed-water heater is provided, via a reducing station, from the main steam line. The fraction of the steam mass flow rate from the WHRU required for the feedwater heater is

$$m = \frac{h_{fw} - h_2}{h_1 - h_2}$$

where

$h_{fw}$  = enthalpy of the feedwater

$h_2$  = enthalpy of the condensate at feedwater heater pressure.

Therefore, the steam turbine power output is

$$P_{st} = (1 - m) \dot{m}_f W_t .$$

## 2. Gas Turbine Performance Calculations

The original gas turbine horsepower, exhaust gas flow rate, and exhaust gas temperature inputs to the WHRU model were hand-calculated using figure 4 of Ref. 11 and figures 1, 6, and 8 of Ref. 10. The assumptions used to calculate the WHRU model inputs were:

Ambient temperature = 100 F

Ambient pressure = 14.696 psia

Humidity = 0.0

Fuel LHV = 18400 Btu/lbm

Inlet loss = 4.0 in. H<sub>2</sub>O

Exhaust loss = 6.0 in. H<sub>2</sub>O

In the COGAS system output model, the gas turbine horsepower correction factor for the gas-side pressure drop in the WHRU (BHP for 6" loss/BHP for WHRU loss) is found by solving

$$C_{bhp} = 1.0125 + 0.002125 \Delta P_{gas} ,$$

where  $C_{bhp}$  = BHP for 6" loss/BHP for WHRU loss. This relationship was found by extending the duct loss relationship of fig. 7, Ref. 11 linearly from the point of 6 in. H<sub>2</sub>O exhaust duct loss already assumed. The final gas turbine horsepower is

$$P_{gt} = \frac{P_{gt}^*}{C_{bhp}}$$

where  $P_{gt}^*$  is the input gas turbine horsepower. The total COGAS system horsepower,  $P_{tot}$ , is found by adding the steam turbine and final gas turbine horsepowers.

In order to calculate the gas turbine specific fuel consumption fig. 4 of Ref. 11 is entered with the final

gas turbine horsepower, and the s.f.c. is read from the propeller law curve superimposed on that figure. The s.f.c. correction factor for exhaust loss in the WHRU,  $C_{sfc}$ , is found in the same manner as  $C_{bhp}$  from fig. 6 of Ref. 11 where

$$C_{sfc} = (\text{s.f.c. for total exhaust } \Delta P) / (\text{s.f.c. for 6" exhaust } \Delta P)$$

and the gas turbine specific fuel consumption is

$$\text{s.f.c.}_{gt} = C_{sfc} \text{ sfc}_{6 \text{ in. loss}}$$

The specific fuel consumption for the combined system is calculated by first finding the fuel consumption rate of the gas turbine

$$\dot{m}_{\text{fuel}} = \text{s.f.c.}_{gt} P_{gt} .$$

The COGAS system s.f.c. is then calculated from

$$\text{s.f.c.}_{\text{COGAS}} = \frac{\dot{m}_{\text{fuel}}}{P_{\text{tot}}}$$

To allow the direct comparison of the COGAS system with the all gas turbine system the specific fuel consumption of the gas turbine at the new, higher COGAS system power,  $\text{s.f.c.}_{gt}^*$ , is calculated in the same manner as  $\text{s.f.c.}_{gt}$ .

The thermal efficiencies for the gas turbine at input power, the COGAS system, and the gas turbine at COGAS system power are calculated from the relationship

$$\eta_{th} = \frac{2545}{\text{s.f.c. LHV}} \cdot$$

Additionally, the steam turbine share of the load is calculated from  $P_{st}/P_{tot}$ .

### III. RESULTS AND CONCLUSIONS

#### A. BACKGROUND

The foregoing model was applied in a computer simulation program written in FORTRAN IV for the IBM 360-67 computer. A listing of this program appears in Appendix A. Additionally a set of supporting programs was written for water, steam, and air properties. A listing of this set of programs appears in Appendix B.

In order to test the model and develop an understanding of the behavior of the WHRU, a set of designs were produced for a variety of initial conditions. These designs were then reviewed, and an analysis of the model behavior was performed. After completion of the model analysis, several of the designs were selected for observation at off-design conditions. The off-design simulations were produced for gas turbine input powers corresponding to ship speeds of 9, 16, and 20 knots, which represents the entire range of gas turbine input powers considered in this thesis. Finally, two designs were selected for detailed testing at off-design conditions. These latter two designs were tested at gas turbine input horsepowers corresponding to speeds of 9 to 20 knots, at one knot increments.

#### B. DESIGN VARIABLES

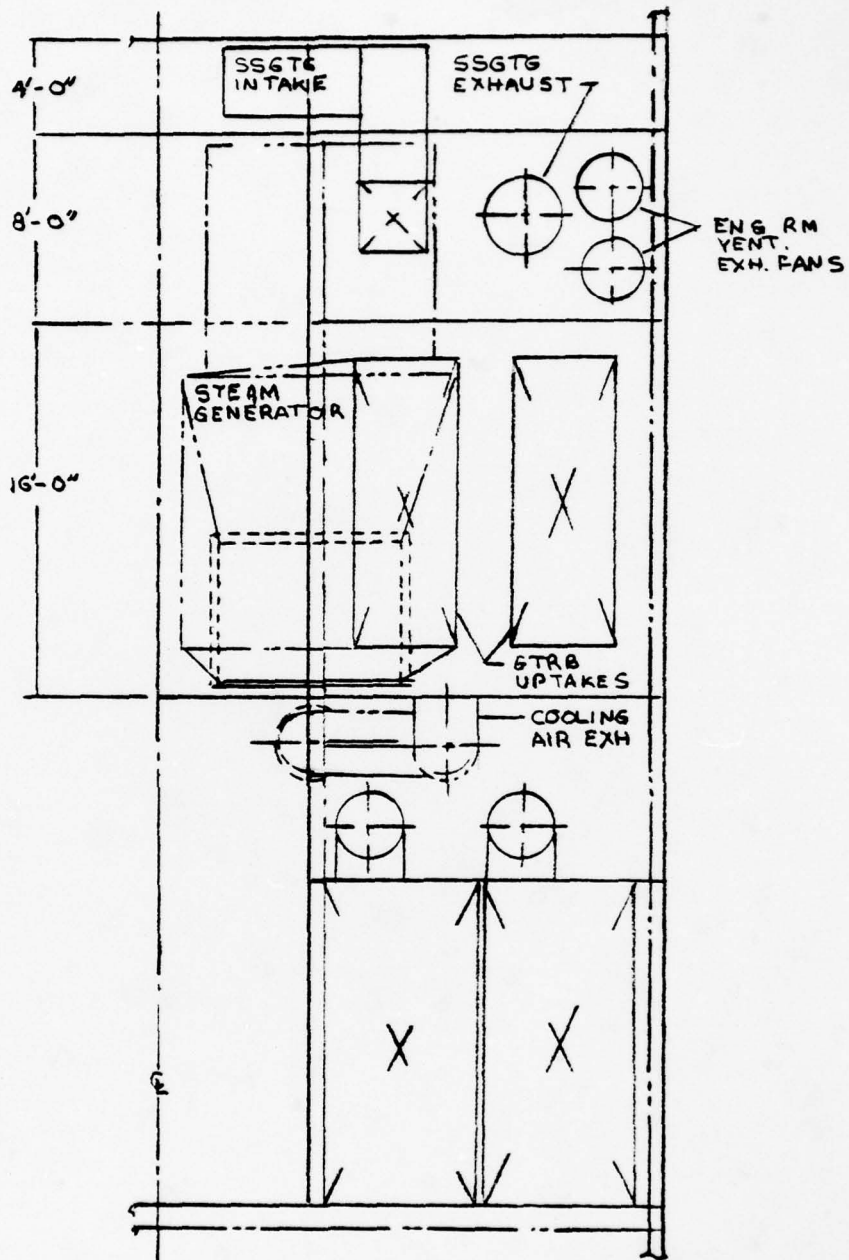
The following set of design variables was selected to produce the basic set of designs.

1. WHRU operating pressure: Three WHRU operating pressures of 400, 600, and 800 psia were selected for design production.
2. WHRU geometric scale: In order to test the model response to a range of fin-tube sizes, designs were produced for the basic fin-tube configuration described in the geometry subsection at 1.0, 0.75, and 0.50 scale.
3. Frontal dimensions: The approximate WHRU space constraints for a DD-963-type engineroom are shown in figures 7, 8 and 9. Consistent with these constraints, frontal dimensions of 12' x 12' and 12' x 15' were selected for the initial design set.
4. Gas turbine input power: The gas turbine input horsepower determines the input gas conditions, temperature and flow rate, for the WHRU. Since the most advantageous use of the COGAS system was assumed to be for "cruise" speed conditions, the range of gas turbine input horsepower considered corresponds to the gas turbine power required for a ship speed range of 9 to 20 knots, with the gas turbine operating alone. The three gas turbine input powers selected for the production of WHRU designs are shown in Table I.

Gas Turbine Input Powers

<u>GTHP</u>	<u>Approx. Speed (kts)</u>	<u>Temperature (F)</u>	<u>Flow Rate (lbm/hr)</u>
16421	20	849	407589
8526	16	742	328641
1684	9	689	159731

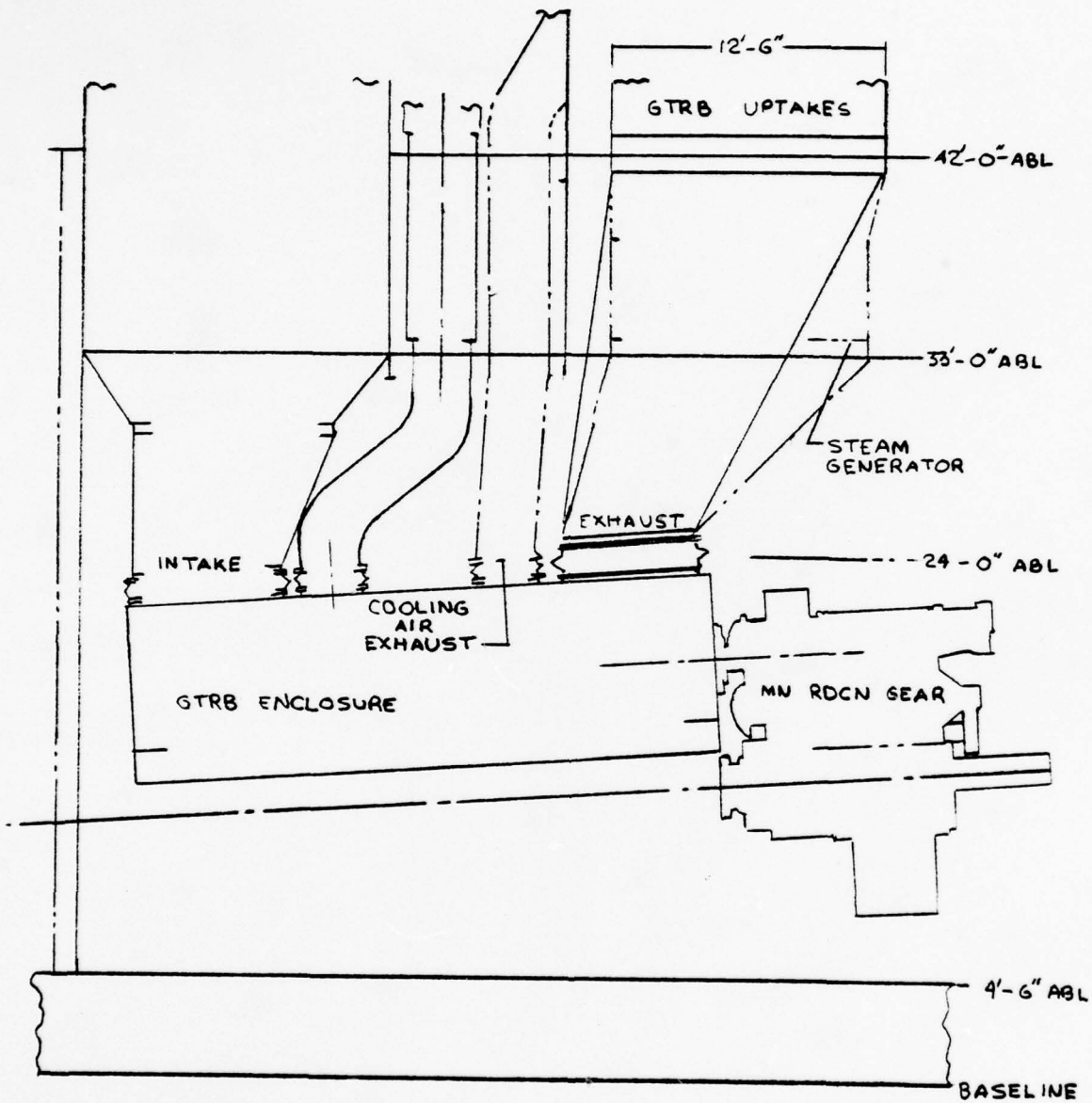
Table I



PLAN VIEW

ENGINE ROOM

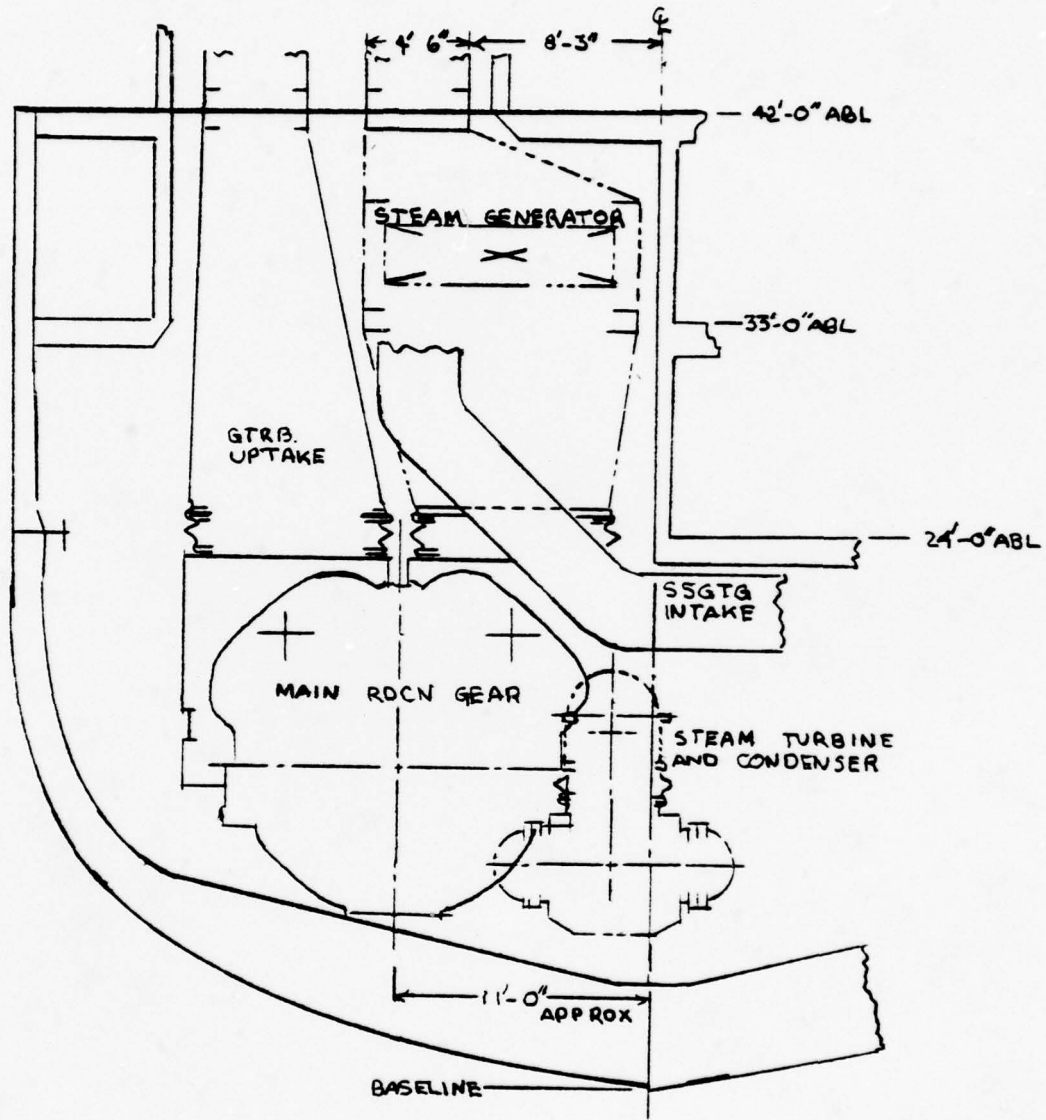
FIGURE 7



ELEVATION

ENGINE ROOM

FIGURE 8



SECTION

ENGINE ROOM

FIGURE 9

5. WHRU gas outlet temperature: The WHRU gas outlet temperature is fixed at 400 F. Reference 3 states that the principal cause of "hot" corrosion in the WHRU would be due to the formation of  $H_2SO_4$  from an expected concentration of  $SO_3$  of up to 50 parts per million. Reference 13 states that dew point condensation of vapor in the exhaust gas becomes a problem for corrosion if the stack temperature is depressed below 250 F. Therefore, a minimum average gas outlet temperature of 400 F is considered to be reasonably safe from the aspect of gas-side corrosion prevention. It should be further noted that the outlet gas temperature calculated by the program is an average temperature, based on the heat release from the gas. Therefore, the actual temperature of the gas in the stack will be cooler than 400 F in some locations due to the non-uniform distribution of the gas temperature as it leaves the WHRU. It should further be noted that, although this temperature is a fixed design variable for design production, it will vary somewhat from 400 F in response to the program calculations for setting the minimum pinch point and for matching the gas inlet temperature with that specified in the initial conditions.

6. Superheater outlet steam temperature: The target WHRU superheater outlet steam temperature is 650 F. This temperature will also vary somewhat in response to steam flow rate changes brought about by the program calculations to match

the gas inlet temperature with that specified in the initial conditions.

7. WHRU water inlet temperature: The WHRU water inlet temperature is fixed at 200 F.

8. The other major COGAS system parameters are fixed as follows:

Condenser pressure: 4 in. Hg

Steam turbine efficiency: 0.85

Feedwater heater pressure: 15.0 psia

Fuel LHV: 18400 Btu/lbm.

#### C. THE DESIGN SET

A set of 54 designs was produced for the combination of design variables just discussed. The array of design variable combinations is described in Table II. The summary computer output pages for the results of each design run are presented in Appendix C.

As discussed in Section A, the purposes for producing this design set were to test the model and to promote an understanding of the likely behavior of a WHRU for a range of conditions. To this end, the following set of output variables was considered.

1. WHRU output
  - a. height (number of passes)
  - b. gas inlet temperature
  - c. gas outlet temperature
  - d. steam flow rate

WHRU DESIGN COMBINATIONS AND DESIGN RUN INDEX

GTHP	Pressure	Front: 12' X 12'						Front: 12' X 15'															
		Scale=1.0	Scale=0.75	Scale=0.50	Scale=1.0	Scale=0.75	Scale=0.50	Scale=1.0	Scale=0.75	Scale=0.50	Scale=1.0	Scale=0.75	Scale=0.50										
16421	400	run #19	run #22	run #25	run #46	run #49	run #52	8526	400	run #20	run #23	run #26	run #47	run #50	run #53	1684	400	run #21	run #24	run #27	run #48	run #51	run #54
	600	run #10	run #13	run #16	run #37	run #40	run #43		600	run #11	run #14	run #17	run #38	run #41	run #44		600	run #12	run #15	run #18	run #39	run #42	run #45
	800	run #1	run #4	run #7	run #28	run #31	run #34		800	run #2	run #5	run #8	run #29	run #32	run #35		800	run #3	run #6	run #9	run #30	run #33	run #36

TABLE II

- e. gas side pressure drop
  - f. pinch point temperature difference
  - g. heat transfer rate
2. COGAS system output
- a. gas turbine horsepower (including loss from the WHRU gas-side pressure drop)
  - b. steam turbine horsepower
  - c. COGAS system horsepower
  - d. steam turbine share of the load
  - e. specific fuel consumption
    - (1) s.f.c. of COGAS system
    - (2) s.f.c. of gas turbine at COGAS system horsepower
  - f. thermal efficiency
    - (1)  $\eta_{th}$  of COGAS system
    - (2)  $\eta_{th}$  of gas turbine at COGAS system horsepower

Clearly, several of these variables are related, such as s.f.c. and  $\eta_{th}$ , and no additional information is provided by studying all variables in a closely related group. Therefore, the following subset of output variables was selected for analysis.

1. WHRU height
2. Steam flow rate
3. Gas-side pressure drop
4. Pinch point temperature difference
5. WHRU heat transfer rate
6. WHRU gas outlet temperature

7. Steam turbine horsepower
8. COGAS system horsepower
9. COGAS specific fuel consumption

The above output variables are presented in tabular form using the format of Table II. Table II also serves as an index for the set of basic designs. Additionally, the significant trends in the variables are presented graphically. Where the trend of the results was ascertained to be the same for the two frontal dimension sets, only the values for the 12' x 12' front were presented graphically. Where clarity was better served, only one scale was plotted as representative of the trend described.

#### Effect of Scaling.

The only significant trends noted with respect to scaling were a decrease in WHRU height with a decrease in scale and the same trend for gas side pressure drop (see Tables III and IV). The trends are shown in figures 10 and 11.

The basic fin-tube dimensions of the model were scaled by factors of 0.75 and 0.50. For any scale with constant frontal dimensions, the total inside and outside areas remain the same. That is, for a constant length tube, the scaled inside/outside area ( $A_i^S/A_o^S$ ) is proportional to the full scale areas ( $A_i/A_o$ ) with the scale factor,  $s$ , as the constant of proportionality. Hence

$$A_i^S = S A_i \quad \text{and} \quad A_o^S = S A_o.$$

WHRU HEIGHT [ft]

<u>GTHP</u>	<u>Pressure</u>	<u>Front: 12' X 12'</u>			<u>Front: 12' X 15'</u>		
		<u>Scale=1.0</u>	<u>Scale=0.75</u>	<u>Scale=0.50</u>	<u>Scale=1.0</u>	<u>Scale=0.75</u>	<u>Scale=0.50</u>
16421	400	4.9	2.9	1.5	4.6	2.7	1.5
	600	6.2	3.7	2.0	5.5	3.4	1.8
	800	6.8	3.9	2.1	5.9	3.7	2.0
8526	400	5.2	3.2	1.6	4.9	2.9	1.5
	600	5.5	3.2	1.6	4.9	2.9	1.5
	800	4.9	2.9	1.5	4.6	2.7	1.5
1684	400	4.2	2.4	1.3	3.9	2.4	1.1
	600	3.9	2.2	1.1	3.6	2.2	1.1
	800	3.6	2.2	1.1	3.3	2.0	1.0

TABLE III

GAS SIDE PRESSURE DROP [in H<sub>2</sub>O]

<u>GTHP</u>	<u>Pressure</u>	<u>Front: 12' X 12'</u>			<u>Front: 12' X 15'</u>		
		<u>Scale=1.0</u>	<u>Scale=0.75</u>	<u>Scale=0.50</u>	<u>Scale=1.0</u>	<u>Scale=0.75</u>	<u>Scale=0.50</u>
16421	400	5.3	4.4	3.5	3.3	2.7	2.5
	600	6.7	5.6	4.9	4.0	3.5	3.0
	800	7.8	6.0	5.3	4.3	3.7	3.3
8526	400	3.8	3.2	2.7	2.4	1.9	1.6
	600	4.1	3.3	2.8	2.4	2.0	1.6
	800	3.7	3.1	2.5	2.4	1.9	1.7
1684	400	0.8	0.7	0.6	0.5	0.4	0.3
	600	0.8	0.6	0.5	0.5	0.4	0.3
	800	0.8	0.6	0.5	0.5	0.4	0.3

TABLE IV

# HEIGHT VS. SCALE

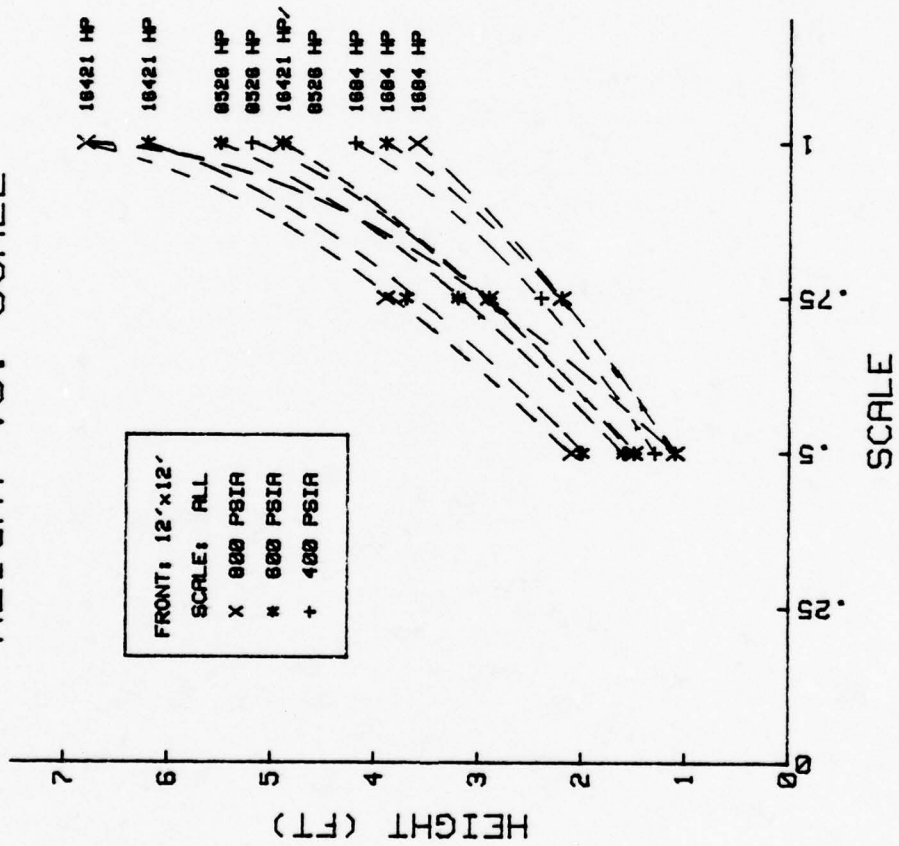


FIGURE 10

# GAS PRESSURE DROP VS. SCALE

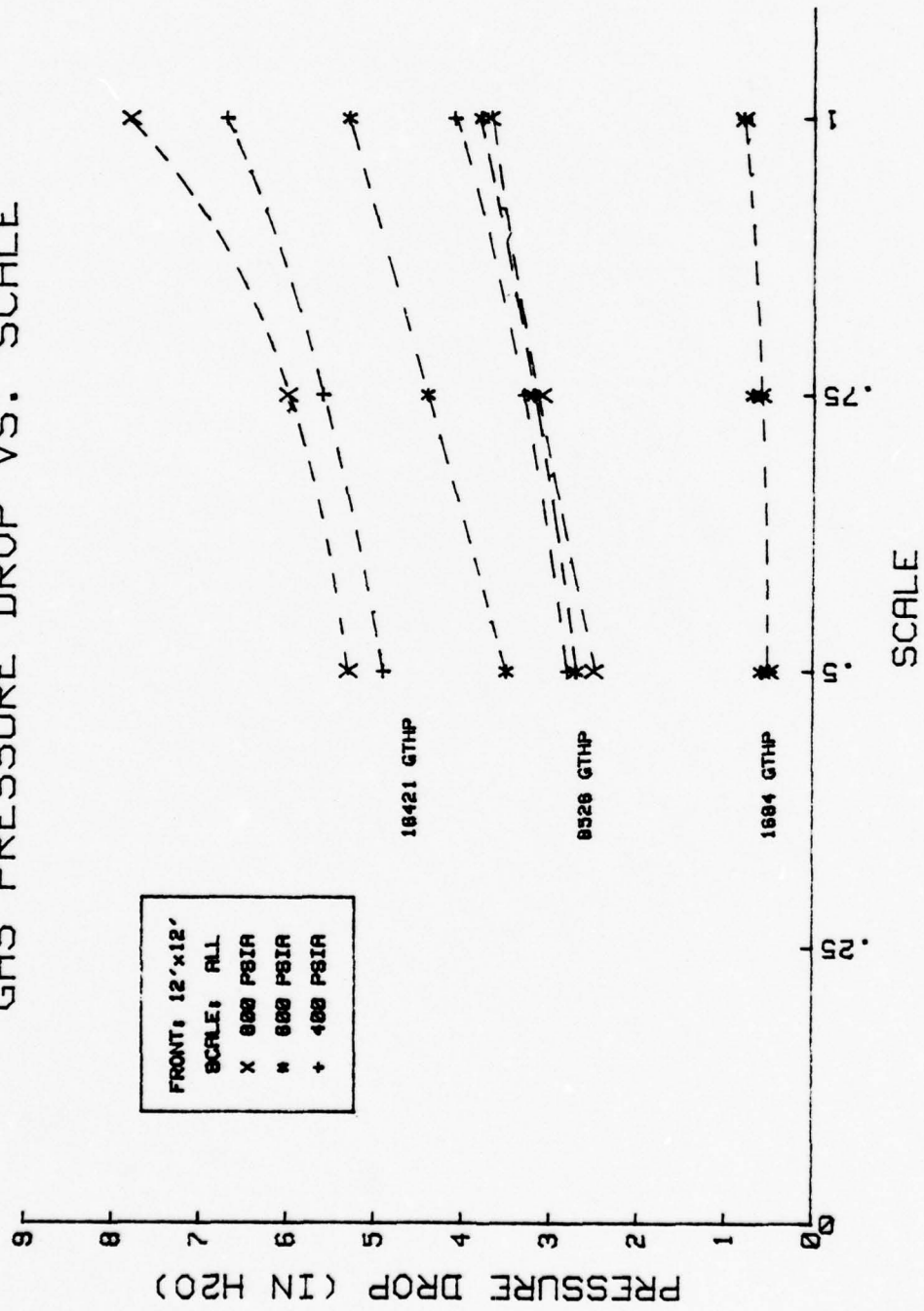


FIGURE 11

Since constant frontal dimensions are to be maintained, the number of tubes per row is scaled up by the scale factor, so

$$A_{ip}^s = \frac{N_{t/p}}{s} s A_i \quad \text{and} \quad A_{op}^s = \frac{N_{t/p}}{s} s A_o ,$$

where  $N_{t/p}$  is the number of tubes per pass. Therefore, the scaled outside and inside areas for a pass for constant frontal dimensions are the same as the full scale areas. Now, the scaled cross-sectional area for fluid flow on the inside will be,

$$A_{ff}^s = \frac{\pi}{4} s^2 d_i^2 \frac{N_{t/p}}{s} = s A_{ff} .$$

So the scaled Reynolds number will be

$$Re^s = \frac{\dot{m}_f s d_i}{s A_{ff} \mu} = \frac{\dot{m}_f d_i}{A_{ff} \mu}$$

which is equal to the Reynolds number for the unscaled geometry. It can also be shown that the outside Reynolds number remains constant with scaling. Recalling that the Dittus-Boelter correlation was used to calculate the inside heat transfer coefficient for the single phase regions and used with a multiplier for the two phase heat transfer coefficient and assuming constant fluid properties, the Nusselt number remains constant

$$N_u = 0.023 R_e^{0.8} P_r^{0.4} = \text{Const.} = C .$$

So, the scaled inside heat transfer coefficient

$$h_f^s = \frac{K}{s d_i} C = \frac{C}{s}$$

increases with a decreasing scale factor. Similarly, for the scaled gas-side heat transfer coefficient,

$$h_g^s = j \frac{k}{s d_o} R_e P_r^{1/3} = \frac{C}{s} ,$$

an increase is seen with a decreasing scale factor.

Therefore, in addition to a decrease in height attributable to a scaling down of the fin-tube dimensions, there is also an improvement in heat transfer which results in a further reduction in height by elimination of passes. This trend is supported by the results.

Recalling the relationship used to calculate the gas-side pressure drop,

$$\Delta P_g = \frac{2f G_{\max}^2 N_{t/r}}{\rho} \left( \frac{\mu_w}{\mu_b} \right)^{0.14} ,$$

it can be shown that the scaled gas-side pressure drop is inversely proportional to the scale factor,

$$\Delta P_g^s = \frac{C}{s} ,$$

where C is a constant based on the assumption of constant gas properties between scales. For the same number of passes, then, an increase in gas-side pressure drop could be expected. However, since the number of passes is decreased with decreasing scale, a net decrease in gas-side pressure drop was experienced (Fig. 11).

Some differences in pinch point with scale were observed in Table V, but no consistent trend could be established. It was expected that pinch point  $\Delta T$  would remain fairly constant with scale for fixed pressure and input gas conditions. That result was apparent to some extent, particularly in the range of high gas temperature and low steam pressure. This finding is consistent with the manner in which the pinch point  $\Delta T$  is established. That is, the program fixes an initial pinch point  $\Delta T$  only when the rough pinch point  $\Delta T$  is less than 25 F in the initial calculations. At the lower pressures and higher gas temperatures this mechanism would not be operative. Also, the final and initial pinch point  $\Delta T$  calculations are based on the average gas temperatures at the inlet to the pass where the  $\Delta T$  is calculated. Therefore, the actual pinch point may be either lower or higher than the one calculated, depending on the actual gas temperature distribution at the inlet to the pass. The pinch point  $\Delta T$  will be discussed at greater length in the analysis of the effects of pressure.

PINCH POINT  $\Delta T$  [F]

<u>GTHP</u>	<u>Pressure</u>	<u>Front: 12' X 12'</u>			<u>Front: 12' X 15'</u>		
		<u>Scale=1.0</u>	<u>Scale=0.75</u>	<u>Scale=0.50</u>	<u>Scale=1.0</u>	<u>Scale=0.75</u>	<u>Scale=0.50</u>
16421	400	71.9	71.5	71.9	64.4	64.8	62.4
	600	37.2	40.7	48.4	38.7	45.8	42.0
	800	32.0	32.9	36.0	32.5	36.4	30.7
8526	400	42.4	41.5	41.1	36.9	36.4	36.9
	600	27.1	37.1	36.7	32.7	31.6	31.5
	800	36.8	36.1	34.8	31.2	30.5	30.4
1684	400	30.1	33.6	39.9	42.6	29.9	36.2
	600	41.8	54.9	33.0	37.3	50.6	29.8
	800	39.6	53.0	30.9	35.0	47.7	84.2

TABLE V

### Effect of Pressure.

The most important effect of pressure on the model performance arises from the calculations which establish the minimum pinch point temperature difference. As related in the model description, the minimum pinch point  $\Delta T$  is set at 25 F. The WHRU outlet gas temperature is adjusted in the initial model calculations in order to ensure this minimum  $\Delta T$ . The initial model calculations establish the steam flow rate from a simple energy balance involving the gas inlet and outlet temperatures ( $T_{g1}, T_{g2}$ ), the gas flow rate, the water inlet temperature ( $T_{f1}$ ), the required steam outlet temperature ( $T_{f4}$ ), and the steam pressure. Tentative interim gas temperatures for the heater inlet,  $T_{g3}$ , and boiling section inlet,  $T_{g2}$ , are also established in this calculation set. In order to establish the minimum pinch point  $\Delta T$ , the model tests the interim heater gas inlet temperature against the criterion

$$T_{g3} \geq T_{f2} + 25$$

where  $T_{f2}$  is the temperature of saturated water at the pressure specified. If  $T_{g3}$  is less than  $T_{f2} + 25$  then  $T_{g3}$  is set equal to  $T_{f2} + 25$  and a new gas outlet temperature is calculated as follows,

$$T_{g4} = \frac{T_{g3} - \alpha T_{g1}}{1 - \alpha}$$

where

$$\alpha = \frac{h_{f2} - h_{f1}}{h_{f4} - h_{f1}} .$$

As an aid to understanding the behavior of the model, it is useful to predict the WHRU gas inlet temperature at which this pinch point calculation becomes operative for a particular pressure. This is accomplished by establishing a "critical" heater gas inlet temperature,  $T_{g3}^*$ , for each pressure considered,

$$T_{g3}^* = T_{f \text{ sat}} + 25 ,$$

where  $T_{f \text{ sat}}$  is the temperature of saturated water at the pressure specified. The ratio  $\alpha$  can also be solved for each pressure considered, based on a constant water inlet temperature of 200 F and a constant superheater outlet temperature of 650 F,

$$\alpha = \frac{h_f - h_1}{h_4 - h_1}$$

where  $h_f$  = enthalpy of saturated water at the pressure under consideration. Finally, assuming a minimum WHRU gas outlet temperature of 4-0 F the minimum WHRU gas inlet temperature at which the pinch point calculation comes into effect may be calculated as follows,

$$T_{gl}^* = \frac{T_{g3}^* - (1 - \alpha)400}{\alpha}$$

Table VI summarizes these calculations for each of the pressures considered in the design set.

Minimum Gas Inlet Temperature for Pinch Point Calculation

<u>Pressure</u> (psia)	<u>T<sub>g3</sub><sup>*</sup></u> (F)	<u>α</u>	<u>T<sub>gl</sub><sup>*</sup></u> (F)
400	470	.219	720
600	497	.262	770
800	543	.299	878

Table VI

Now the pressure at which the pinch point calculation becomes operative for each gas turbine input power considered is predicted. The pressure for which the pinch point calculation begins to adjust gas outlet temperature is listed below for each gas turbine input power considered, in Table VII.

Pressure At Which Pinch Point Calculation Takes Effect

<u>Gas Turbine</u> <u>Input Power</u>	<u>T<sub>gl</sub></u> (F)	<u>Pressure</u> (psia)	<u>T<sub>gl</sub><sup>*</sup></u> (F)
16421	849	800	878
8526	742	600	770
1684	689	400	720

Table VII

It should be recalled that the outlet gas temperature is also adjusted by the iterative technique employed to match the model-calculated gas inlet temperature with the gas inlet temperature of the initial conditions, once the design is established. This is a relatively minor adjustment, however, and is never greater than 10 F. These adjustments to WHRU gas outlet temperature are apparent in the values of Table VIII and are displayed graphically for the 12' x 12' frontal dimensions and 0.75 scale in Fig. 12.

The final calculated pinch point for each of the design sets reflected the influence of the initial pinch point calculation. These results were shown in Table V and Figure 13. It is re-emphasized here that the calculated pinch point  $\Delta T$  is useful only as an indicator of what the actual pinch point might be for a particular heat exchanger design. This is true because the model neglects the possibility of a gas temperature distribution across the inlet of a WHRU pass and, instead, uses the average gas temperature for calculations.

There are two other trends in the design results which emanated directly from the control exercised by the model over the pinch point  $\Delta T$  and the resulting gas-fluid temperature distributions in the designs produced. These trends were apparent when the effects of pressure on WHRU height and WHRU heat transfer/steam flow rate were examined.

WHRU GAS OUTLET TEMPERATURE [F]

<u>GTHP</u>	<u>Pressure</u>	<u>Front: 12' X 12'</u>			<u>Front: 12' X 15'</u>		
		<u>Scale=1.0</u>	<u>Scale=0.75</u>	<u>Scale=0.50</u>	<u>Scale=1.0</u>	<u>Scale=0.75</u>	<u>Scale=0.50</u>
16421	400	405.5	405.5	409.0	400.5	405.5	405.0
	600	404.5	407.5	401.5	405.0	402.3	400.8
	800	415.0	421.0	414.2	419.0	415.0	414.2
8526	400	403.5	401.5	401.5	401.5	401.5	405.1
	600	430.5	433.5	434.4	431.0	435.0	436.5
	800	464.4	465.9	467.4	462.9	465.1	459.9
1684	400	410.5	412.6	409.6	409.6	409.6	420.0
	600	449.4	456.5	458.0	450.9	449.4	452.4
	800	483.0	482.5	482.5	485.5	484.0	485.5

TABLE VIII

# GAS OUTLET TEMP. VS. PRESSURE

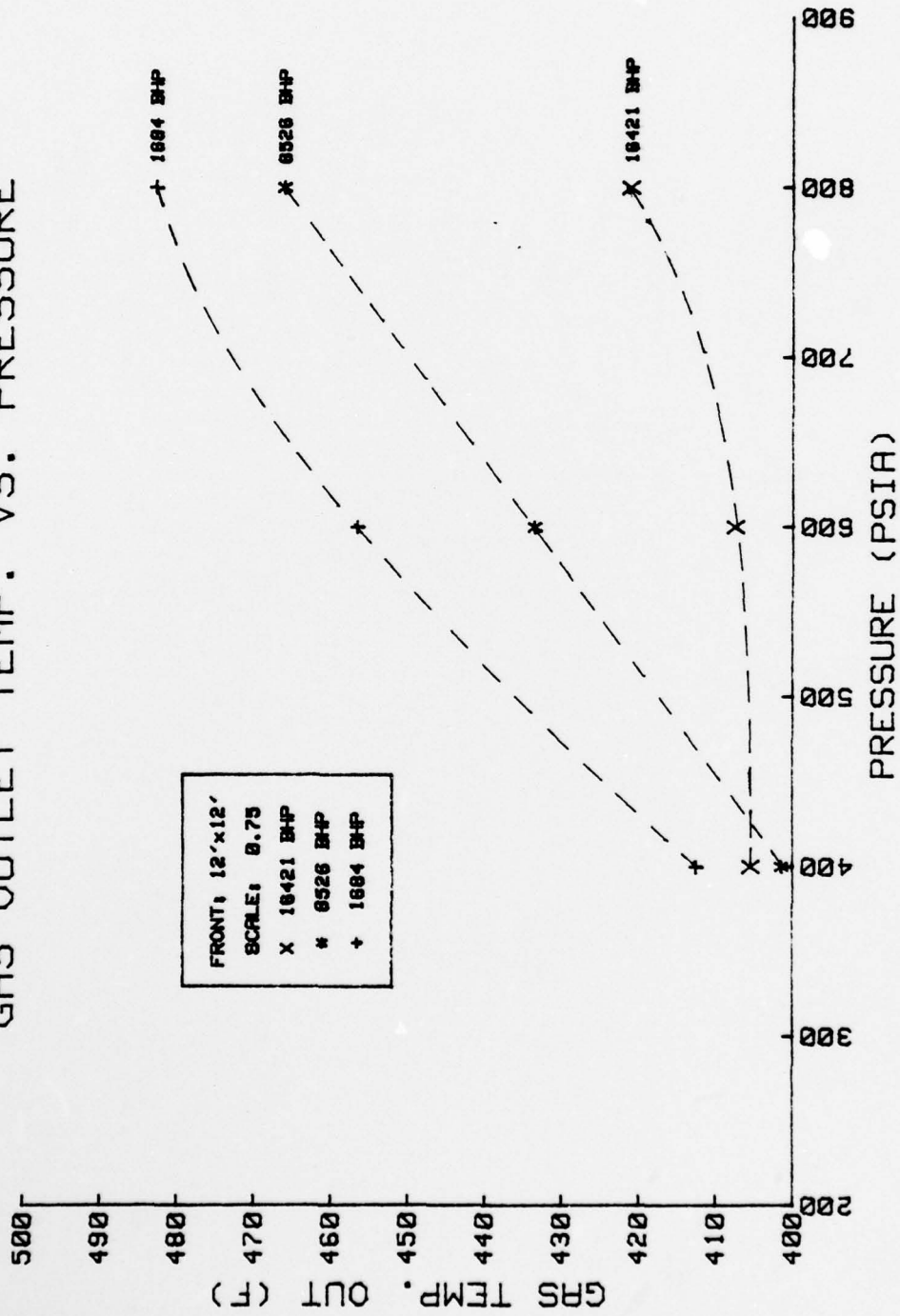


FIGURE 12

# PINCH POINT VS. PRESSURE

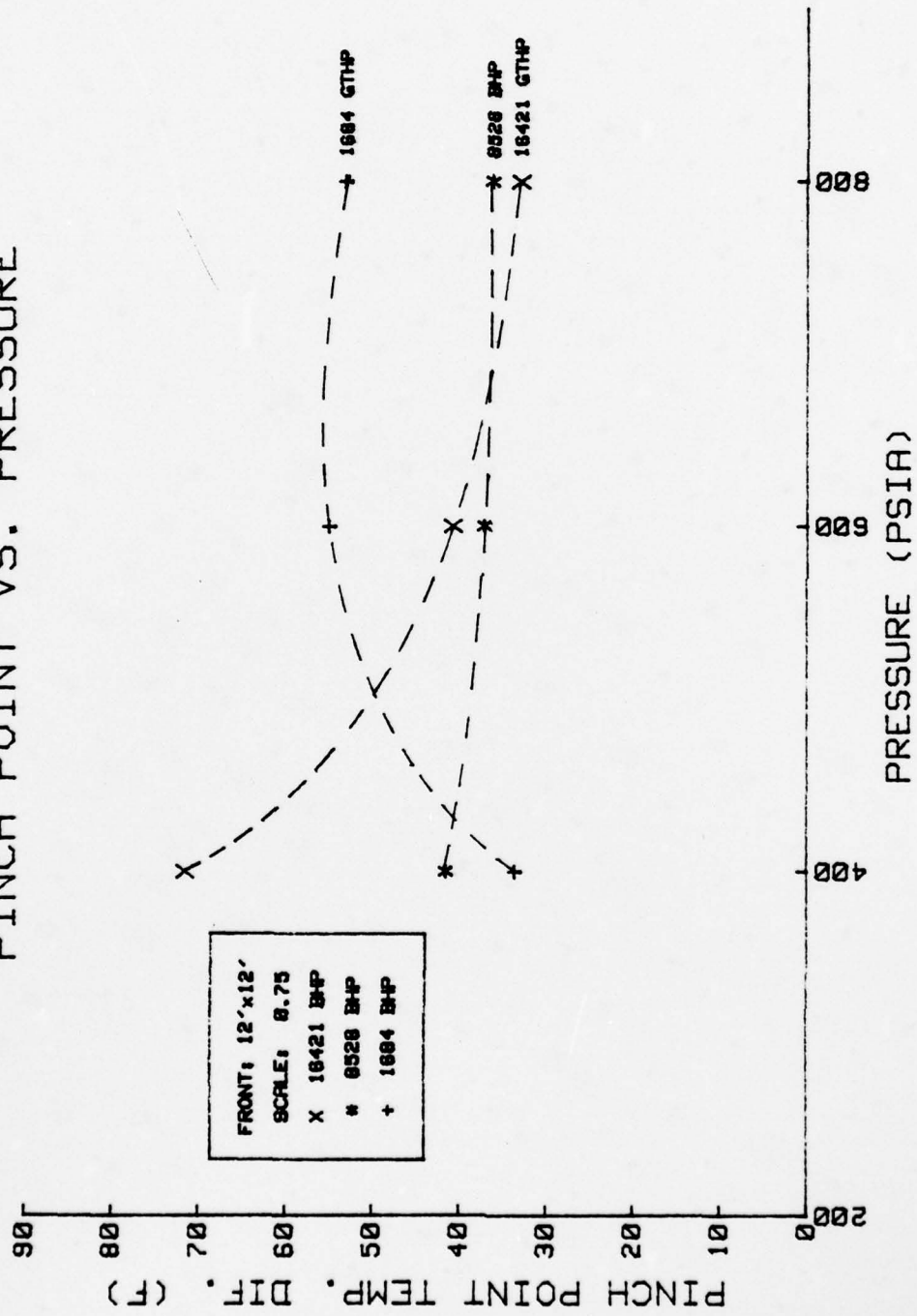


FIGURE 13

The effects of pressure on WHRU heat transfer and steam flow rate are shown in Figures 14 and 15 respectively. Tables IX and X list the actual values obtained for WHRU heat transfer and steam flow rate for the designs produced. WHRU heat transfer and steam flow rate directly reflected the adjustment of the WHRU gas outlet temperature to maintain the minimum pinch point  $\Delta T$ . That is, as the WHRU outlet gas temperature was raised, the heat transfer rate and steam flow decreased. The small increase shown in Figures 14 and 15 in heat transfer and steam flow rate for 16421 gas turbine input power at the 0.50 scale reflects only a minor adjustment difference in  $T_{g_{out}}$  for matching  $T_{g_{in}}$  between 400 psia and 600 psia.

The relationship of WHRU height to WHRU pressure is slightly more complex. Figures 16, 17, and 18 demonstrate the approximate gas-fluid temperature distribution along the total length of the WHRU for the 0.75 scale at the three pressures and input horsepower considered. The general trend observed in these diagrams of decreasing gas-fluid temperature difference with increasing pressure is representative of all the designs produced. This decrease in gas-fluid temperature difference, taken by itself, would produce larger heat exchangers with increasing pressure. This trend may be observed for the 12' x 12' front at the high gas turbine input horsepower in Figure 19. At the medium and low gas turbine horsepower, however, the WHRU

# HEAT TRANSFER VS. PRESSURE

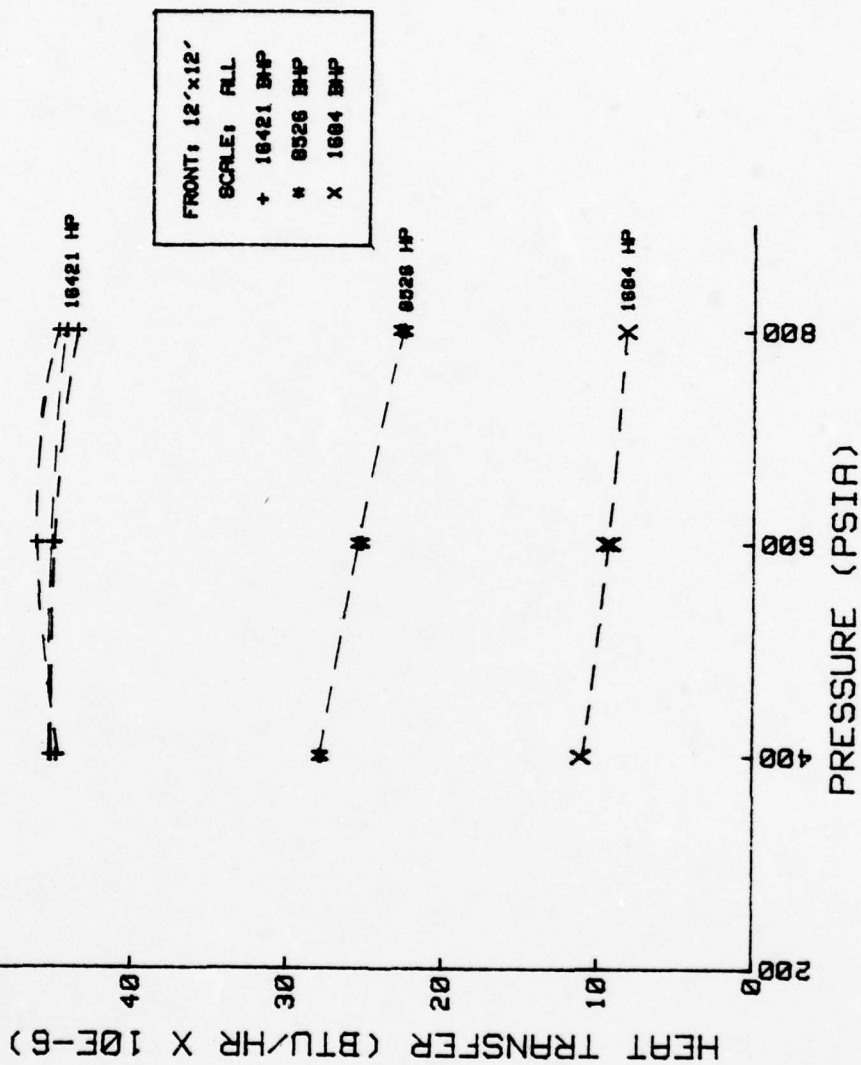


FIGURE 14

# STEAM FLOW RATE VS. PRESSURE

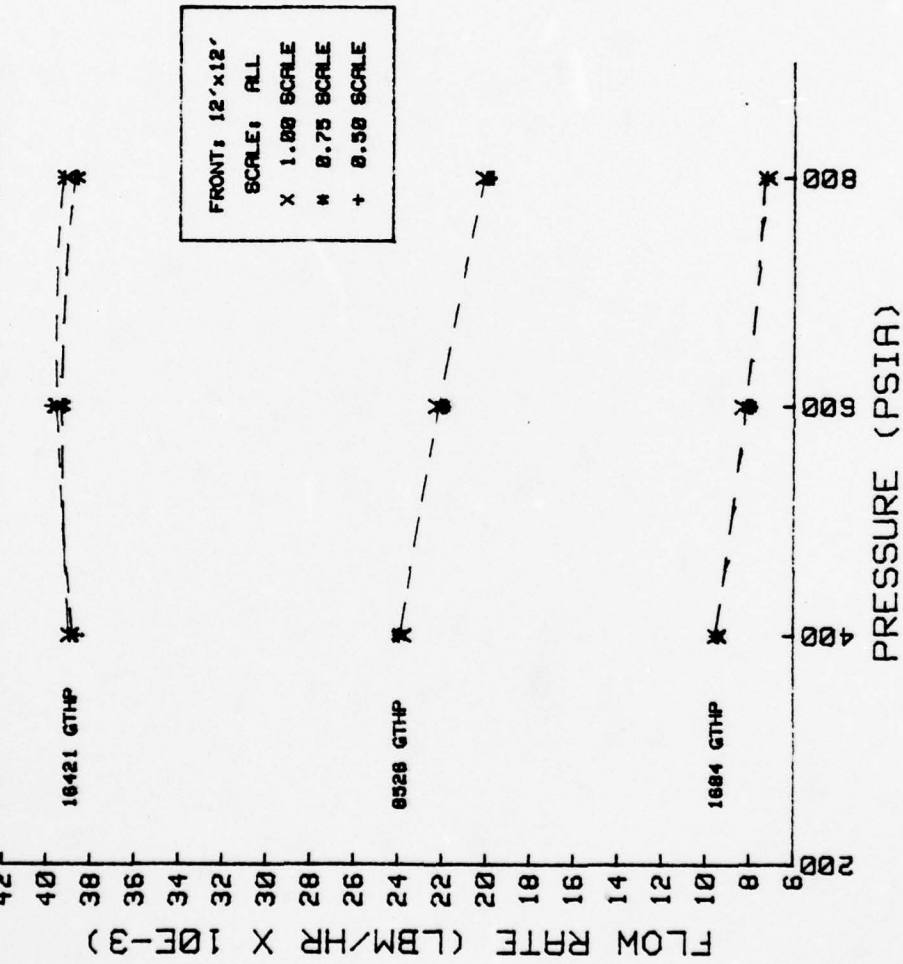


FIGURE 15

WHRU HEAT TRANSFER RATE [Btu/hr]

GTHP	Pressure	Front: 12' X 12'			Front: 12' X 15'		
		Scale=1.0	Scale=0.75	Scale=0.50	Scale=1.0	Scale=0.75	Scale=0.50
16421	400	45283138	45130292	44773652	45588830	45211810	45221999
	600	45079343	44987636	46118695	45221999	45680537	45741675
	800	44223406	43540695	44763462	43836197	44304924	44518908
8526	400	27753732	27745516	27876973	27885189	27959133	27482604
	600	25486109	25280709	25173901	25527190	25198549	25009580
	800	22815901	22569421	22462461	22807685	22635149	23160974
1684	400	11073352	11017446	11125264	11137244	11133251	10697984
	600	9527954	9240438	9160573	9464062	9523961	9396176
	800	8170241	8226146	8194200	8110341	8174234	8126315

TABLE IX

STEAM FLOW RATE [lbm/hr]

<u>GTHP</u>	<u>Pressure</u>	<u>Front: 12' X 12'</u>			<u>Front: 12' X 15'</u>		
		<u>Scale=1.0</u>	<u>Scale=0.75</u>	<u>Scale=0.50</u>	<u>Scale=1.0</u>	<u>Scale=0.75</u>	<u>Scale=0.50</u>
	400	38942	38942	38643	39369	38942	38086
16421	600	39499	39239	39758	39455	39693	39818
	800	39124	38597	39189	38770	39124	39189
	400	23807	23945	23945	23945	23945	23698
8526	600	22207	21997	21964	22174	21894	21789
	800	20106	19999	19892	20212	20052	20426
	400	9494	9425	9526	9524	9524	9176
1684	600	8286	8044	7992	8235	8286	8184
	800	7236	7253	7253	7149	7201	7149

TABLE X

TEMPERATURE DISTRIBUTION DIAGRAMS

SCALE: 0.75  
 FRONT: 12'X12'  
 GTHP: 16421

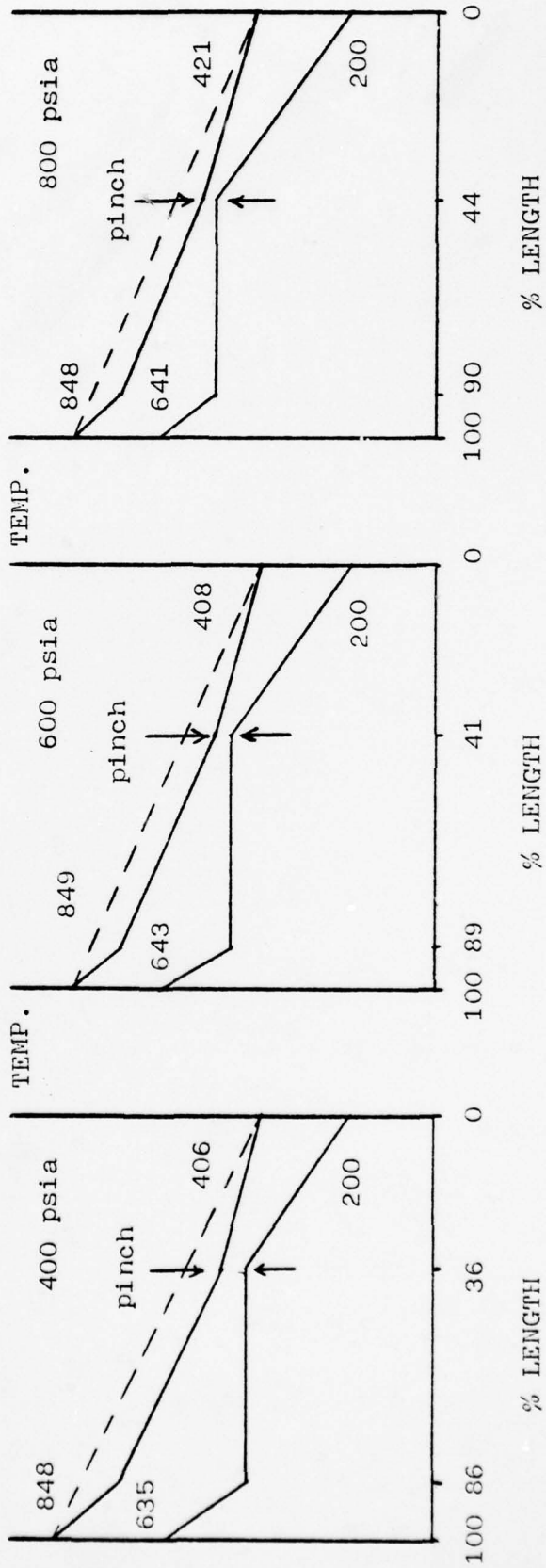


FIGURE 16

AD-A078 154

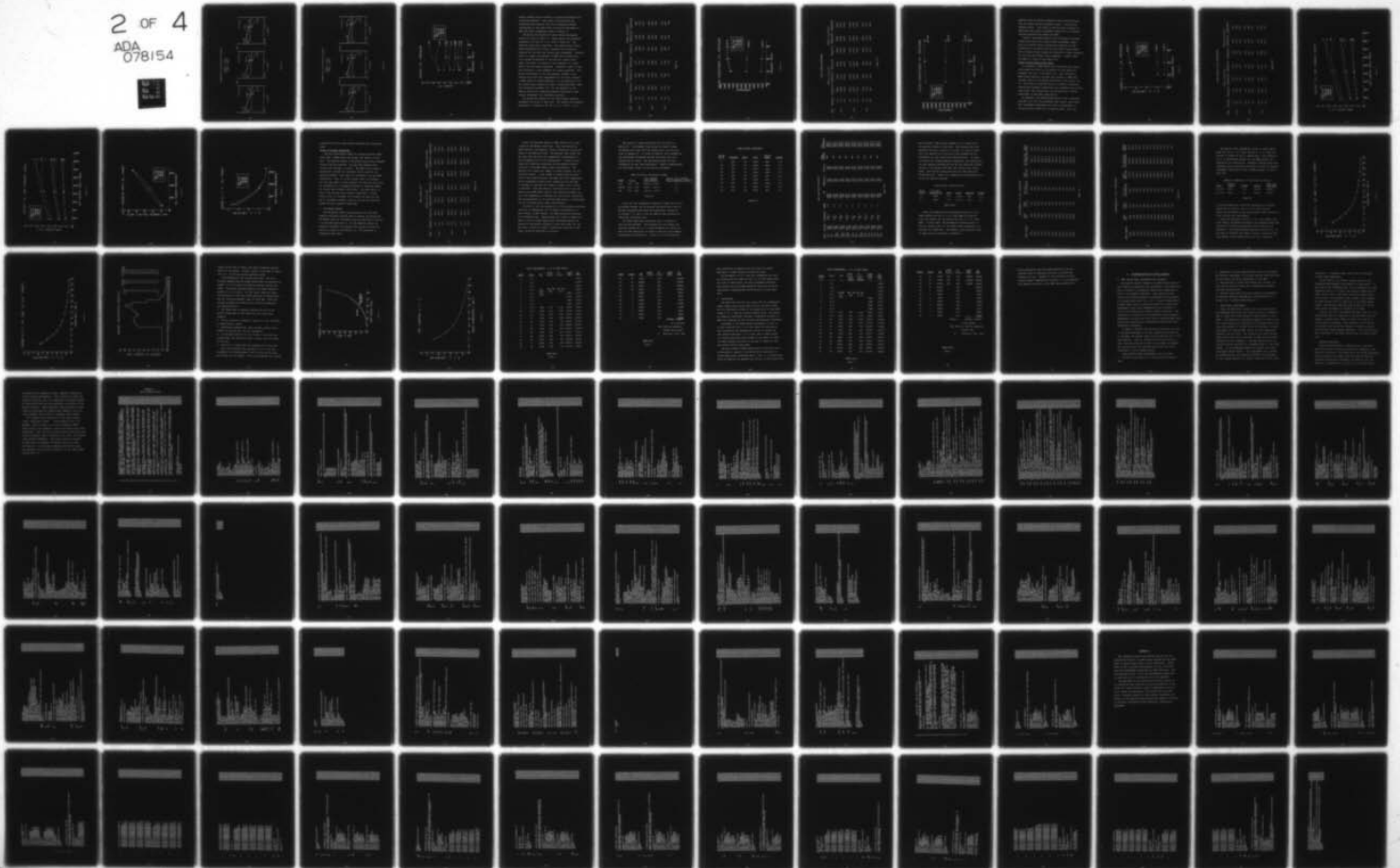
NAVAL POSTGRADUATE SCHOOL MONTEREY CA  
WASTE HEAT RECOVERY UNIT DESIGN FOR GAS TURBINE PROPULSION SYST--ETC(U)  
SEP 79 R M COMBS

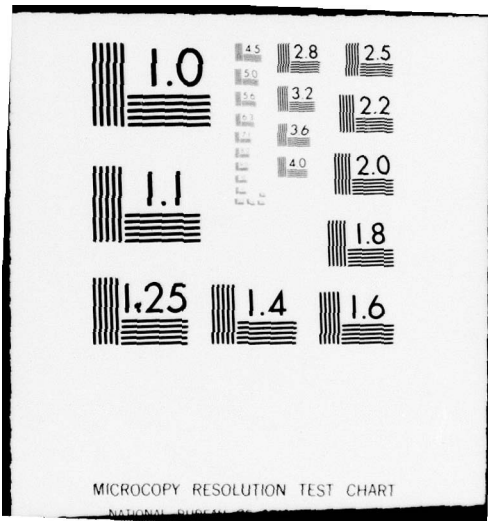
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TEMPERATURE DISTRIBUTION DIAGRAMS

SCALE: 0.75  
 FRCNT: 12'X12'  
 GTHP: 8526

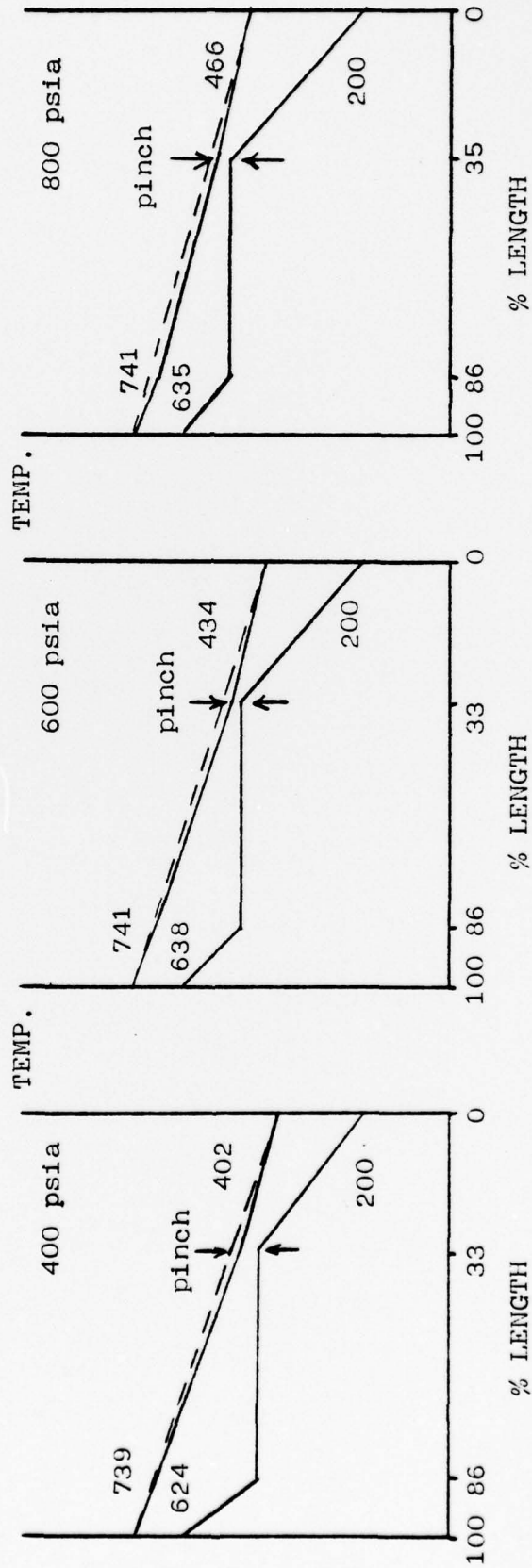


FIGURE 17

TEMPERATURE DISTRIBUTION DIAGRAMS

SCALE: 0.75  
 FRONT: 12'X12'  
 GTHP: 1684

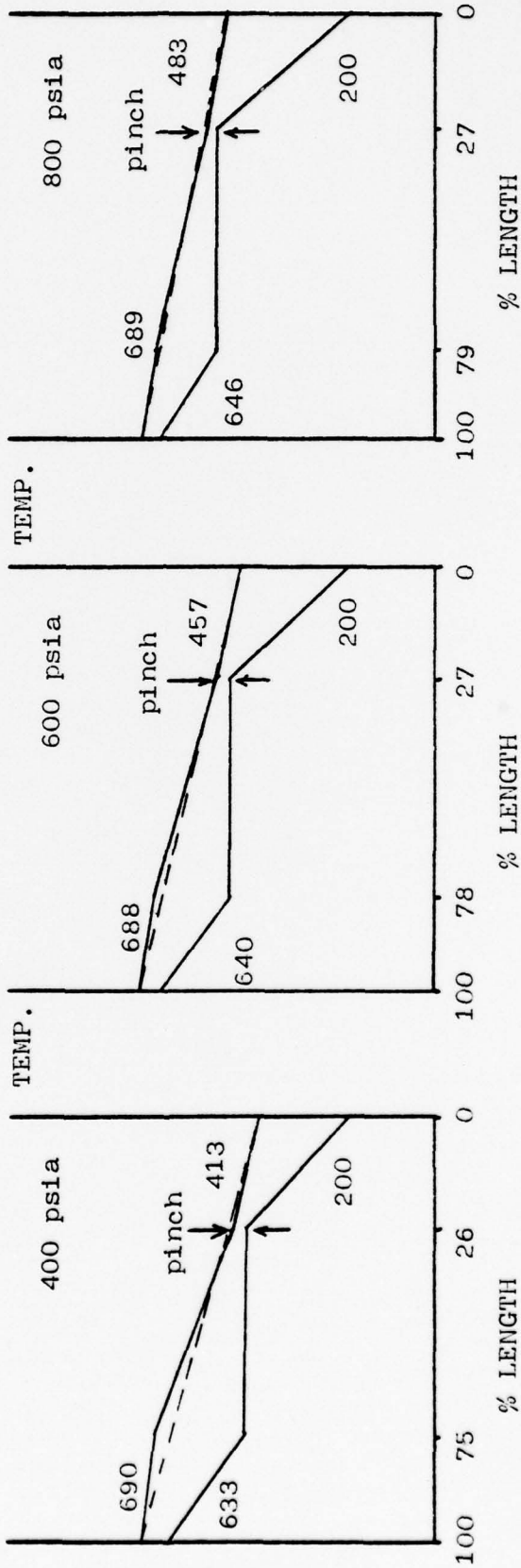


FIGURE 18

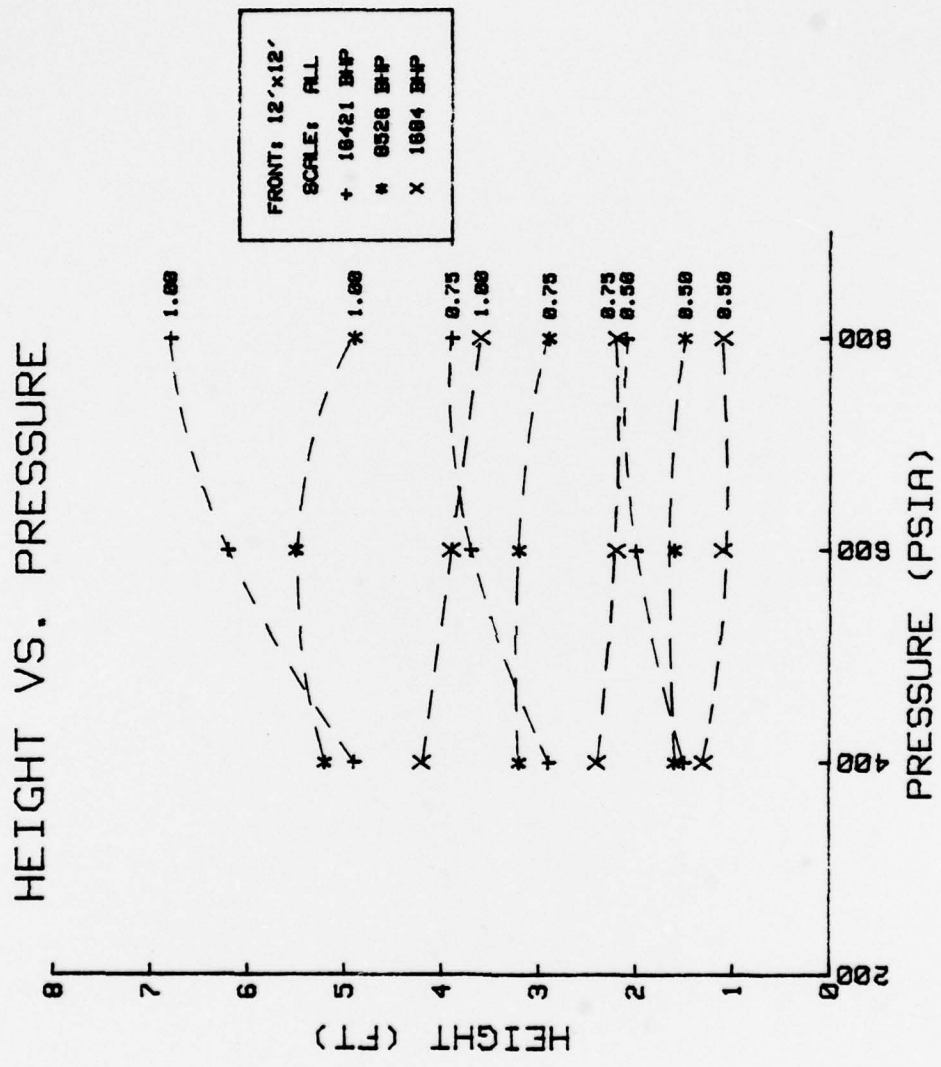


FIGURE 19

height remained fairly constant or actually decreased with increasing pressure. This trend is explained by the decreasing heat transfer rate with increasing pressure attributable to the pinch point calculation adjustment to WHRU gas outlet temperature shown in Figure 12.

The design set results for steam turbine horsepower output are given in Table XI. These results are presented graphically for the 12' x 12' front in Figure 20. Two separate trends were identified. The steam turbine horsepower demonstrated an overall increase with increasing pressure for the high gas turbine input horsepower. Although there is a small net decrease in WHRU heat transfer rate with increasing pressure at the high gas turbine input power, the steam is rejected to the condenser at a lower quality for the higher pressures. Therefore, there is less heat rejection in the condenser for higher pressures. This better performance of the high pressure systems in the Rankine cycle more than compensates for the small decrease in WHRU output at these pressures. For the medium and low gas turbine input powers the trend of decreasing WHRU output with increasing pressure (Fig. 20) was dominant in the Rankine cycle also, producing systems of decreasing steam turbine horsepower with increasing pressure.

The design set results for the COGAS system combined horsepower are given in Table XII. The results are displayed graphically in Figure 21 for the 12' x 12' front. It is

STEAM TURBINE HORSEPOWER

<u>GTHP</u>	<u>Pressure</u>	<u>Front: 12' X 12'</u>			<u>Front: 12' X 15'</u>		
		<u>Scale=1.0</u>	<u>Scale=0.75</u>	<u>Scale=0.50</u>	<u>Scale=1.0</u>	<u>Scale=0.75</u>	<u>Scale=0.50</u>
	400	4822	4805	4733	4849	4822	4881
16421	600	5072	5081	5232	5099	5168	5154
	800	5205	5100	5227	5133	5195	5211
	400	2943	2931	2954	2957	2965	2914
8526	600	2862	2838	2828	2861	2832	2814
	800	2656	2629	2623	2670	2641	2707
	400	1171	1161	1177	1184	1181	1134
1684	600	1071	1040	1028	1062	1072	1055
	800	955	962	954	949	956	948

TABLE XI

# STEAM HORSEPOWER VS. PRESSURE

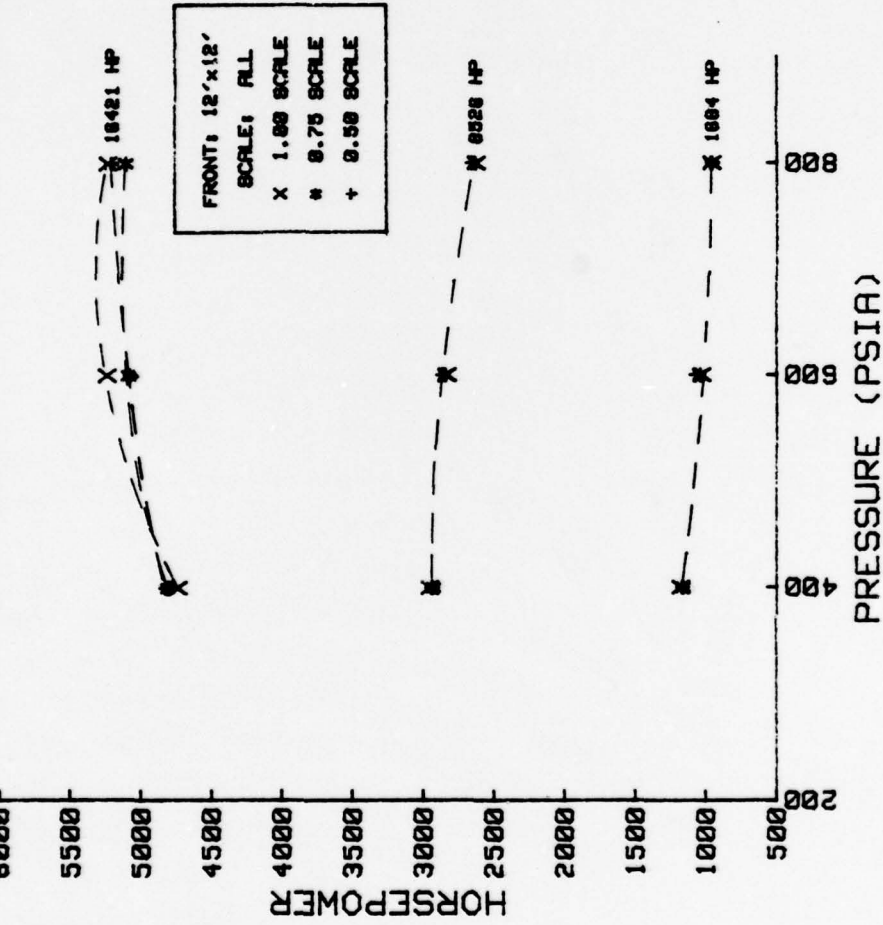


FIGURE 20

COGAS SYSTEM HORSEPOWER

GTHP	Pressure	Front: 12' X 12'			Front: 12' X 15'		
		Scale=1.0	Scale=0.75	Scale=0.50	Scale=1.0	Scale=0.75	Scale=0.50
16421	400	20861	20874	20831	20956	20949	20974
	600	21066	21112	21286	21181	21269	21272
	800	21162	21116	21267	21205	21287	21318
8526	400	11297	11296	11328	11336	11351	11306
	600	11211	11201	11201	11239	11218	11205
	800	11013	10996	10999	11049	11029	11098
1684	400	2832	2822	2839	2846	2843	2796
	600	2733	2701	2690	2724	2734	2717
	800	2616	2623	2616	2611	2618	2610

TABLE XII

# COGAS HORSEPOWER VS. PRESSURE

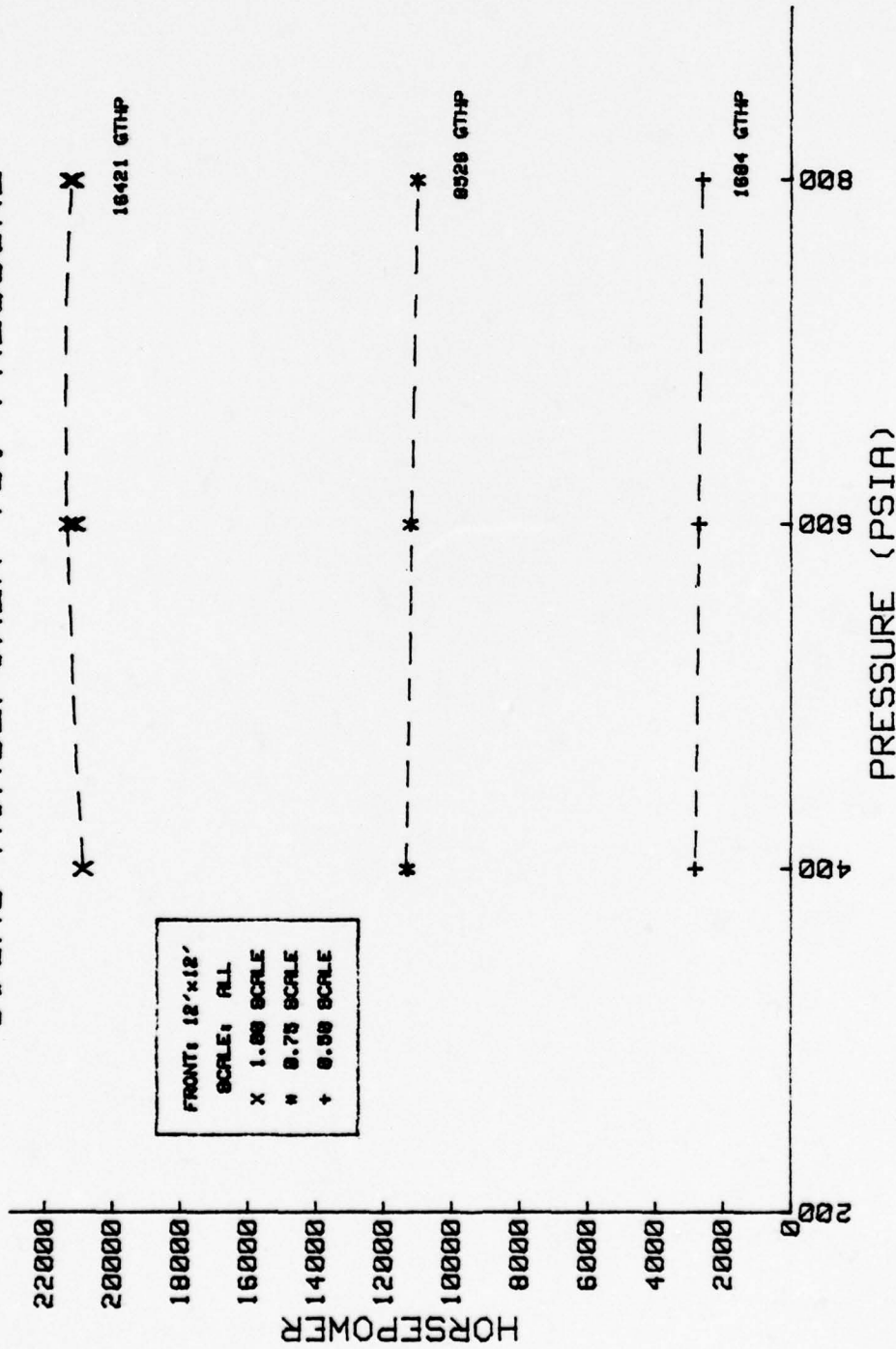


FIGURE 21

apparent that the system horsepower output trend followed that for steam turbine horsepower output. This was the expected result. This trend is modified only slightly by additional gas turbine horsepower losses due to a changing gas-side pressure drop across the WHRU.

Finally, the system specific fuel consumption followed closely the results for steam turbine horsepower output. That is, slightly better systems were observed at lower pressures for the medium and low gas turbine input powers and a slightly better system was produced at higher pressures for the high gas turbine input horsepower. These trends are shown in Figure 22 and Table XIII.

#### Effect of Gas Turbine Input Power.

An increase in WHRU height with increasing gas turbine input power was noted in the results for the design set produced (see Fig. 23 and Table III). This increase in WHRU height generally followed the increase in WHRU heat transfer rate with increasing gas turbine input power, Fig. 24. This trend is modified only by a slightly increasing outside heat transfer coefficient with increasing gas turbine input power (see calculations for gas-side heat transfer coefficient in the model description).

As expected, the COGAS system specific fuel consumption improved (Fig. 25) with increasing gas turbine input power. This improvement represents the trend of improvement in the gas turbine itself with increasing power, since the

COGAS S. F. C. VS. PRESSURE

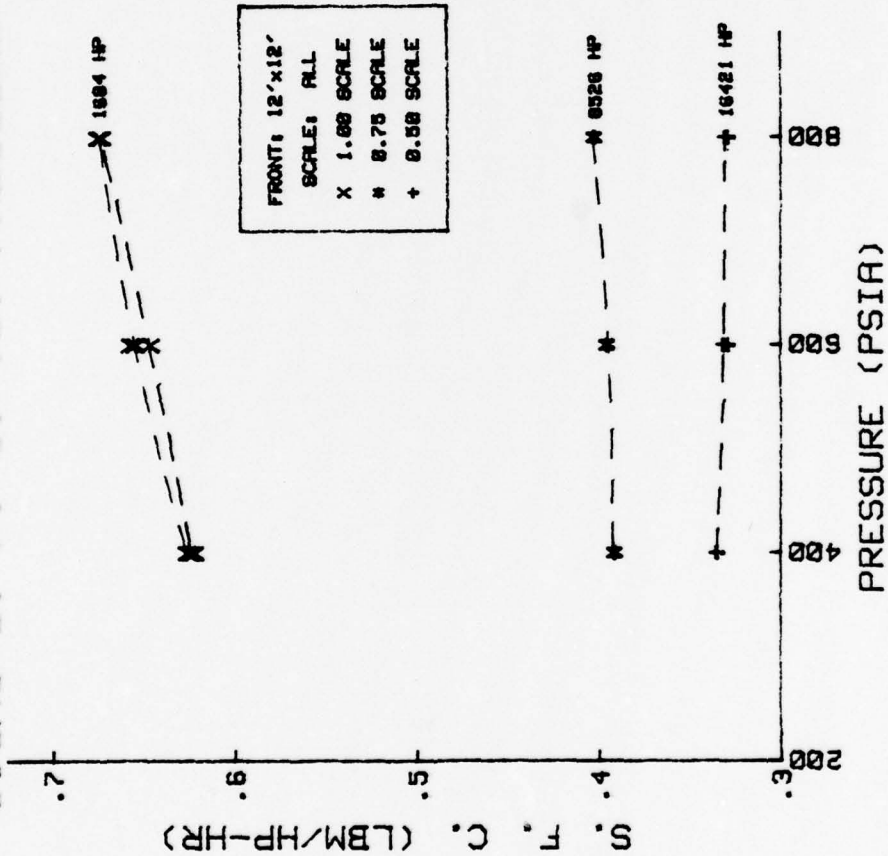


FIGURE 22

COGAS SPECIFIC FUEL CONSUMPTION

<u>GTHP</u>	<u>Pressure</u>	<u>Front: 12' X 12'</u>			<u>Front: 12' X 15'</u>		
		<u>Scale=1.0</u>	<u>Scale=0.75</u>	<u>Scale=0.50</u>	<u>Scale=1.0</u>	<u>Scale=0.75</u>	<u>Scale=0.50</u>
16421	400	.335	.335	.336	.334	.335	.334
	600	.332	.331	.329	.331	.329	.329
	800	.330	.331	.329	.330	.329	.329
8526	400	.392	.392	.391	.391	.391	.392
	600	.395	.396	.396	.395	.395	.396
	800	.402	.403	.403	.401	.402	.400
1684	400	.624	.626	.622	.621	.621	.632
	600	.646	.654	.657	.648	.646	.650
	800	.675	.673	.675	.677	.675	.677

TABLE XIII

# HEIGHT VS. GAS TURBINE INPUT

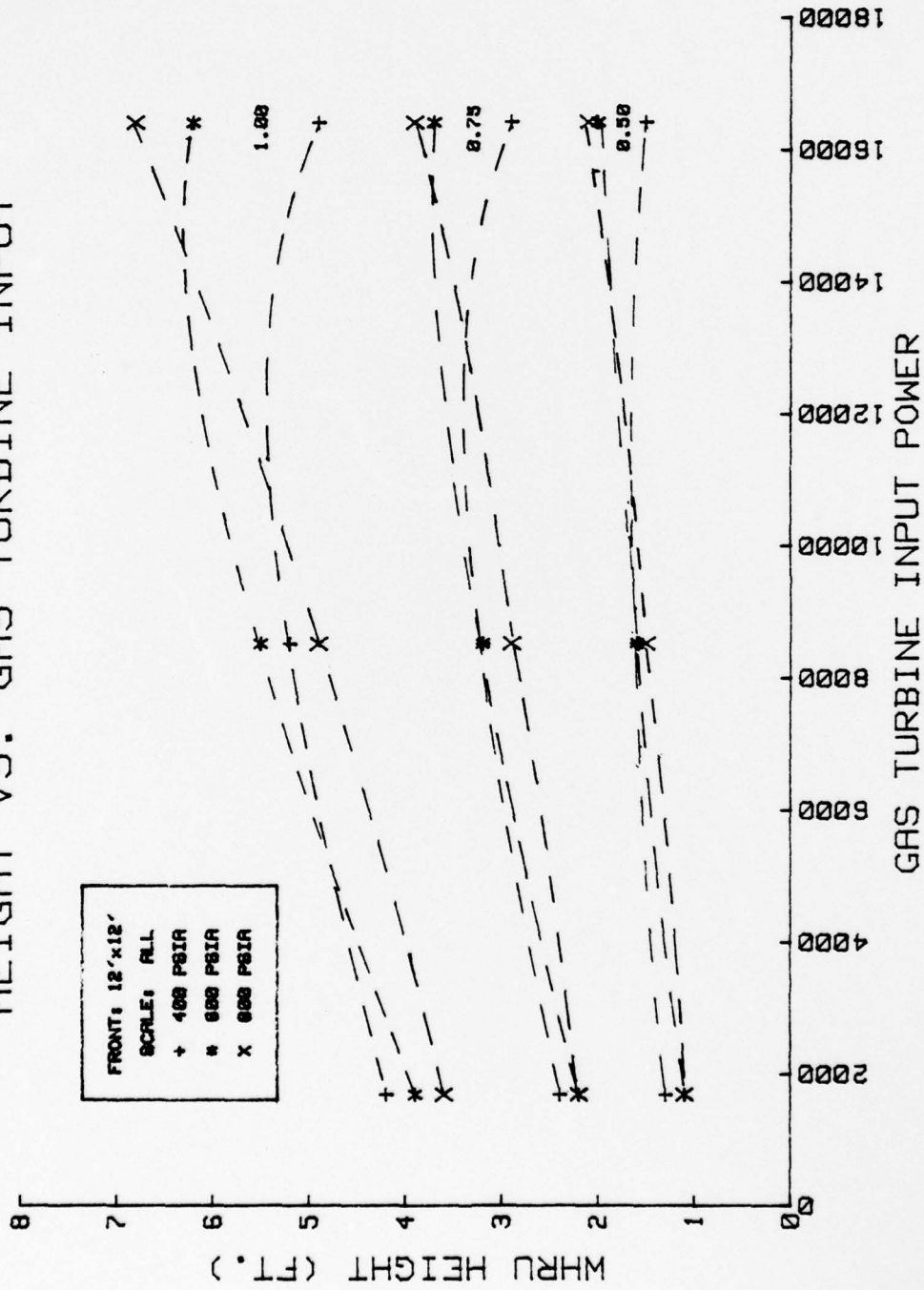


FIGURE 23

# HEIGHT VS. GAS TURBINE INPUT

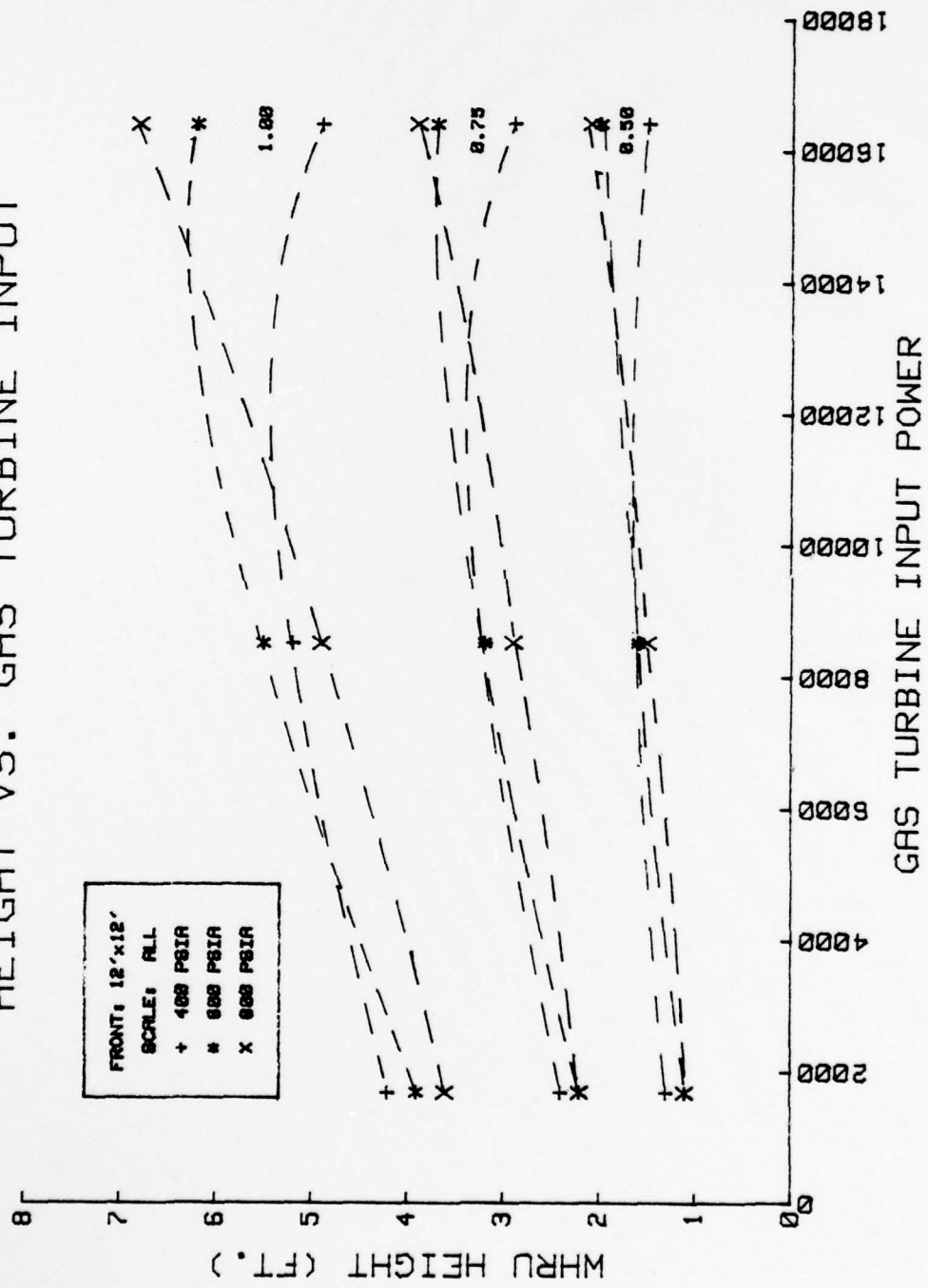


FIGURE 23

HEAT TRANSFER RATE VS. POWER

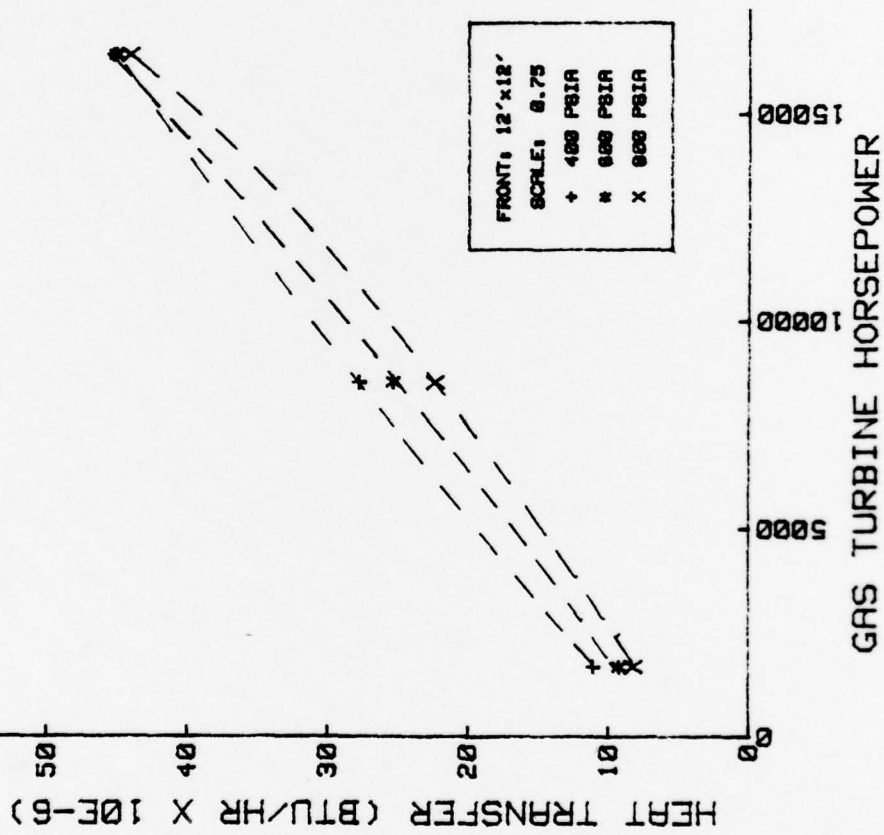


FIGURE 24

COGAS S. F. C. VS. POWER

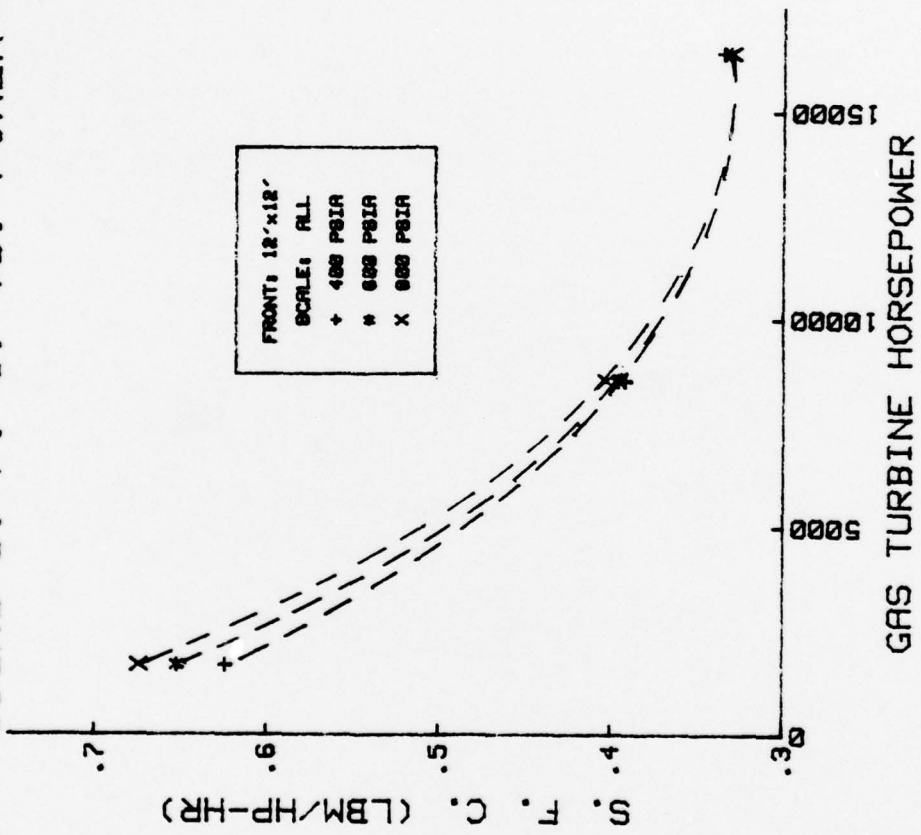


FIGURE 25

contribution of the steam system decreases with increasing power.

#### Effect of Frontal Dimensions.

The only significant trends for changing frontal dimensions were in WHRU height and volume (see Tables III and XIV). The expected result of decreased height with increased frontal area was observed. The gas-side pressure drop follows this decrease in height. The WHRU volume showed a significant increase for increased frontal area for all designs produced. This result is consistent with the model formulation. That is, as the frontal area is increased and the tube length is held constant the area for fluid flow is increased with a consequent decrease in Reynolds number and inside heat transfer coefficient. The same result is seen in the outside heat transfer coefficient. As the frontal area is increased, the minimum flow area for the gas is increased, causing a drop in the gas side Reynolds number and heat transfer coefficient.

#### D. OFF-DESIGN RESULTS

The off-design results were produced using the same computer simulation program used to produce the design set. The method used for off-design runs was described in Section F of the model description. As the computer program is presently designed, the designer must manually adjust the inputs to produce an off-design run. The procedure is reviewed briefly below.

WHRU VOLUME [ft<sup>3</sup>]

GTHP	Front: 12' X 12'				Front: 12' X 15'			
	Pressure	Scale=1.0	Scale=0.75	Scale=0.50	Scale=1.0	Scale=0.75	Scale=0.50	Scale=0.50
16421	400	705.6	417.6	216.0	828.0	486.0	270.0	
	600	892.8	532.8	288.0	990.0	612.0	324.0	
	800	979.2	561.6	302.4	1062.0	666.0	360.0	
8526	400	748.8	460.8	230.4	882.0	522.0	270.0	
	600	792.0	460.8	230.4	882.0	522.0	270.0	
	800	705.6	417.6	216.0	828.0	486.0	270.0	
1684	400	604.8	345.6	187.2	702.0	432.0	198.0	
	600	561.6	316.8	158.4	648.0	396.0	198.0	
	800	518.4	316.8	158.4	594.0	360.0	180.0	

TABLE XIV

First, the designer selects a WHRU design to be investigated at off-design conditions. Once this design has been selected, the pressure, frontal dimensions, height and scale of the WHRU are fixed. The designer then enters the gas flow rate and gas inlet temperature corresponding to the off-design point to be investigated. A design is produced with these gas conditions and the physical characteristics of the WHRU design under consideration. The designer then checks the number of passes (height) for the resulting design. If the number of passes does not match that of the selected design, the WHRU gas outlet temperature and/or superheater steam outlet temperature are adjusted to increase or decrease the number of passes until a match is achieved. Once the physical characteristics of the off-design point WHRU match those of the design-point WHRU, the gas inlet temperature is matched with the initial conditions, and the performance of the selected WHRU design is established for the off-design point under consideration.

In order to test the feasibility of the procedure described above and to demonstrate the off-design performance of a wide variety of WHRU designs, ten WHRU designs were selected for off-design runs. These designs are listed in Table XVI. None of the full-scale designs was considered because the heights of the designs produced at that scale were, for the most part, either too large or borderline according to the space limitation described in Figure 9.

The results of these off-design runs are given in Table XVII. The summary output pages for each of these off-design runs along with the design-point runs are provided in Appendix D. In terms of specific fuel consumption, the performance difference between the design sets considered was not large. The performance range for fuel consumption is even less significant. Table XV demonstrates the performance range for the designs considered.

WHRU Off-Design Performance Ranges

<u>Power</u>	<u>s.f.c.</u>	<u>fuel consumption (lbm/hr)</u>	<u>approx. fuel consumption difference (gal/hr)</u>
high	.329 - .340	6992.8 - 7019.3	3.9
medium	.391 - .403	4429.2 - 4439.7	1.5
low	.615 - .658	1764.6 - 1767.5	0.4

Table XV

Since the fuel consumption comparison showed very little difference between the ten designs considered and since all designs considered satisfied the dimensional constraints of figures 7, 8, and 9, only two designs were selected for additional off-design runs.

For these additional off-design runs, a pressure of 600 psia was selected. This pressure did not produce the smallest designs but it is a steam pressure with which the Navy has some experience in terms of materials requirements, maintenance, and operation. A scale of 0.75 was selected

WHRU DESIGNS CONSIDERED

<u>Design Run #</u>	<u>Pressure</u>	<u>Scale</u>	<u>Front</u>	<u>Design Power</u>	<u>Height</u>
5	800	.75	12x12	med	2.9
14	600	.75	12x12	med	3.2
16	600	.50	12x12	high	2.0
22	400	.75	12x12	high	2.9
24	400	.75	12x12	low	2.4
35	800	.50	12x15	med	1.5
40	600	.75	12x15	high	3.4
41	600	.75	12x15	med	2.9
53	400	.50	12x15	med	1.5

TABLE XVI

WHRU OFF-DESIGN RESULTS

Run #	GT Power	Front/Scale	Height	HP	COGAS s.f.c.	GT s.f.c.	Steam Pressure	Fuel Consumption
4 (0)	16421	12x12.1	2.9	20769	.337	.398	800	6999.1
5	8526	.75		10996	.403	.482		4431.4
6 (0)	1684			2683	.658	.880		1765.4
16	16421	12x12	2.0	21286	.329	.387	600	7003.1
17 (0)	8526	.50		11331	.391	.478		4430.1
18 (0)	1684			2838	.622	.858		1765.2
22	16421	12x12.1	2.9	20874	.335	.396	400	6992.8
23 (0)	8526	.75		11243	.394	.479		4429.7
24 (0)	1684			2848	.620	.857		1765.8
22 (0)	16421	12x12.1	2.4	20615	.340	.401	400	7009.1
23 (0)	8526	.75		11073	.400	.481		4429.2
24	1684			2822	.626	.860		1766.6
34 (0)	16421	12x15	1.5	20971	.334	.394	800	7004.3
35	8526	.50		11098	.400	.481		4439.2
36 (0)	1684			2705	.653	.877		1766.4
40	16421	12x15.2	3.4	21269	.329	.387	600	6997.5
41 (0)	8526	.75		11297	.393	.478		4439.7
42 (0)	1684			2825	.625	.860		1765.6
40 (0)	16421	12x15.2	2.9	21090	.332	.392	600	7001.9
41	8526	.75		11218	.395	.479		4431.1
42 (0)	1684			2801	.630	.863		1764.6
52 (0)	16421	12x15	1.5	21016	.334	.393	400	7019.3
53	8526	.50		11307	.392	.478		4432.3
54 (0)	1684			2874	.615	.853		1767.5
13 (0)	16421	12x12.1	3.2	20956	.334	.395	600	6999.3
14	8526	.75		11201	.396	.479		4435.6
15 (0)	1684			2796	.632	.864		1767.1

TABLE XVII

which yields a tube outside diameter of 1.5 inches and a fin spacing of about 8 fins/inch. The rationale for this selection was that a scale of 0.50 with 1.0 inch OD tubes and a fin spacing of 12 fins/inch would probably be too susceptible to both inside and outside fouling. In order to achieve the closest possible comparison, the design-point for both designs selected was for the gas conditions corresponding to the medium (8526 BHP) gas turbine input horsepower. Both frontal areas were used for these detailed off-design runs. Table XVIII summarizes the characteristics of the two designs selected.

#### Final Design Characteristics

<u>design run #</u>	<u>GT input design point</u>	<u>scale</u>	<u>front</u>	<u>pressure</u>	<u>height</u>
14	8526	0.75	12 x 12	600	3.2
41	8526	0.75	12 x 15	600	2.9

Table XVIII

Table XIX summarizes the performance results for the COGAS system with the 12' x 12' front WHRU and Table XX gives the results for the system with the 12' x 15' front WHRU. In both cases, the performance characteristics of the gas turbine alone, at the COGAS system horsepower, are provided for comparison. The summary output pages for each of these runs are provided in Appendix E.

PERFORMANCE OF 12'x12' FRONT WHRU

<u>GTHP (input)</u>	<u>COGAS HP</u>	<u>COGAS s.f.c.</u>	<u>GT s.f.t. (at COGAS HP)</u>	<u>COGAS fuel use</u>	<u>GT fuel use (at COGAS HP)</u>	<u>Steam Share</u>
1684	2796	.632	.864	1765.9	2415.7	40.6
1895	3062	.624	.829	1910.4	2537.0	39.0
2105	3285	.622	.801	2024.8	2632.4	36.8
3158	4681	.551	.672	2576.9	3143.6	33.6
4316	6142	.491	.591	3018.1	3628.2	30.9
5474	7475	.455	.546	3404.2	4081.8	28.0
6947	9413	.413	.506	3890.8	4760.0	27.6
8526	11201	.396	.479	4432.6	5368.2	25.3
10421	13758	.370	.449	5085.2	6179.8	25.8
12105	15941	.354	.432	5636.4	6884.0	25.7
13790	17773	.347	.423	6161.2	7525.7	24.1
16421	20956	.334	.395	6997.8	8268.2	23.4
20000	25406	.322	.463	8180.7	11762.9	23.2

TABLE XIX

PERFORMANCE OF 12'x15' FRONT WHRU

<u>GTHP (input)</u>	<u>COGAS HP</u>	<u>COGAS s.f.c.</u>	<u>GT s.t.c. (at COGAS HP)</u>	<u>COGAS fuel use</u>	<u>GT fuel use (at COGAS HP)</u>	<u>Steam Share</u>
1684	2802	.630	.863	1776.2	2418.9	40.7
1895	3061	.624	.829	1910.7	2536.6	38.9
2105	3290	.621	.801	2043.1	2634.3	36.9
3158	4681	.551	.672	2571.1	3158.8	33.5
4316	6175	.489	.589	3018.3	3639.4	31.2
5474	7530	.452	.545	3404.5	4100.7	28.4
6947	9440	.412	.505	3892.0	4769.3	27.6
8526	11218	.395	.479	4434.8	5373.6	25.2
10421	13808	.369	.449	5088.5	6195.5	25.8
12105	16038	.352	.431	5640.5	6916.9	25.9
13790	17889	.345	.423	6165.9	7566.7	24.3
16421	21085	.332	.392	7006.4	8259.9	23.6
20000	25582	.320	.463	8186.2	11844.5	23.3

TABLE XX

The specific fuel consumption curves vs. brake horsepower for the 12' x 12' front and the 12' x 15' front are plotted in figures 26 and 27 respectively. The difference in s.f.c. performance between the two WHRU designs considered was not significant. Geometric considerations were therefore used in selecting the better of these two designs. A geometric comparison of the two WHRU designs is given in Table XXI.

Geometric Comparison of the Final Two Designs

<u>Front</u>	<u>Frontal Area</u>	<u>Height</u>	<u>Volume</u>	<u>Total Outside Area</u>
12' x 15'	181.9	2.9	528.96	49586.4
12' x 12'	144.8	3.2	464.64	42776.5

Table XXI

It was concluded that, since both designs met the height constraint of figure 9, the 12' x 12' front was the better choice because of the significantly lower volume and total outside area requirements.

After the selection of the 12' x 12' front WHRU as the final design, estimates were made of the possible COGAS fuel savings for a DD-963-type destroyer over 1000 hours of operation. The NAVSEC Standard Destroyer Profile (Fig. 28) was used to determine the number of hours a destroyer-type ship spends at each speed during 1000 hours operation.

COGAS S.F.C. VS. BHP (12' X 12' FRONT)

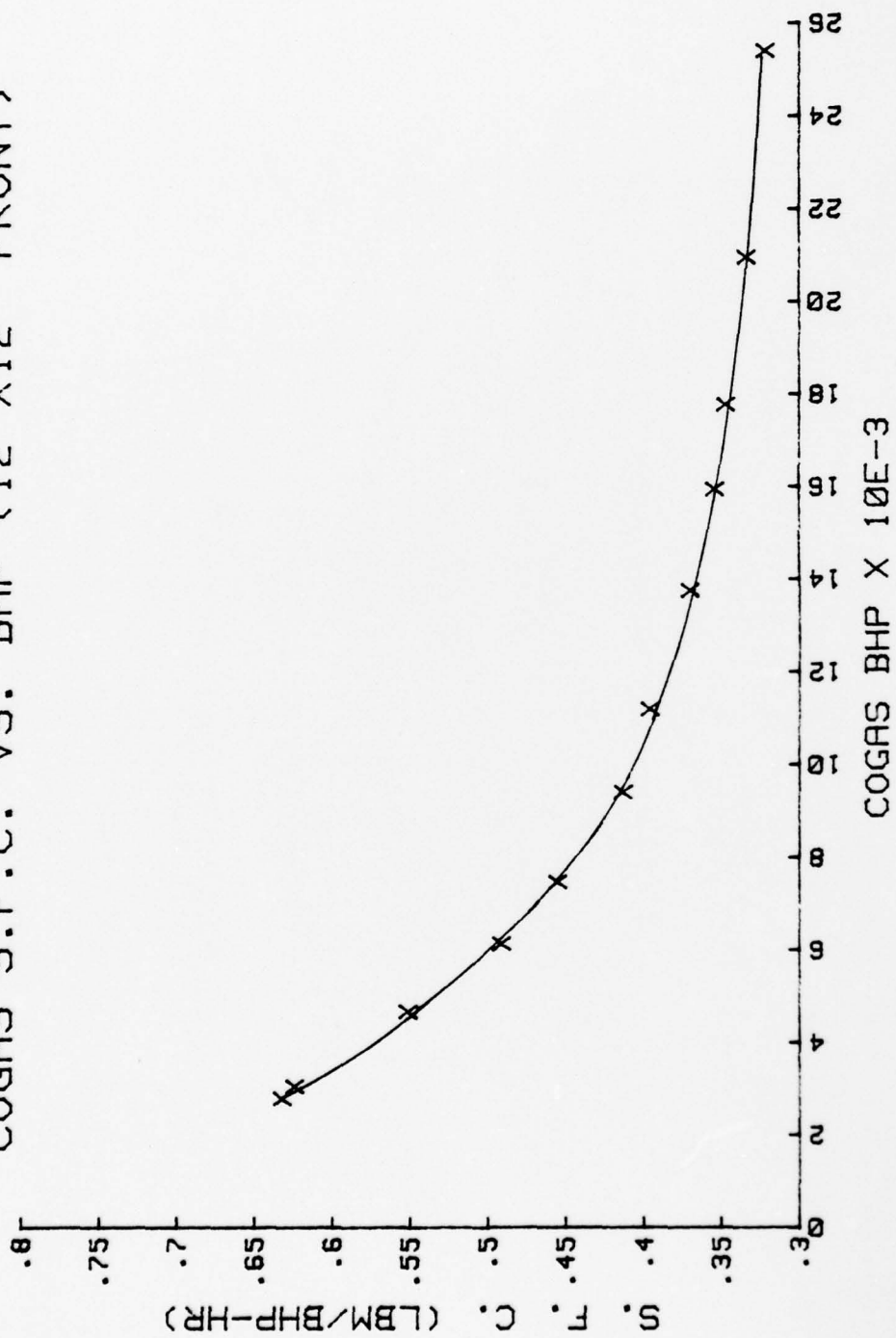


FIGURE 26

COGAS S.F.C. VS. BHP (12'X15' FRONT)

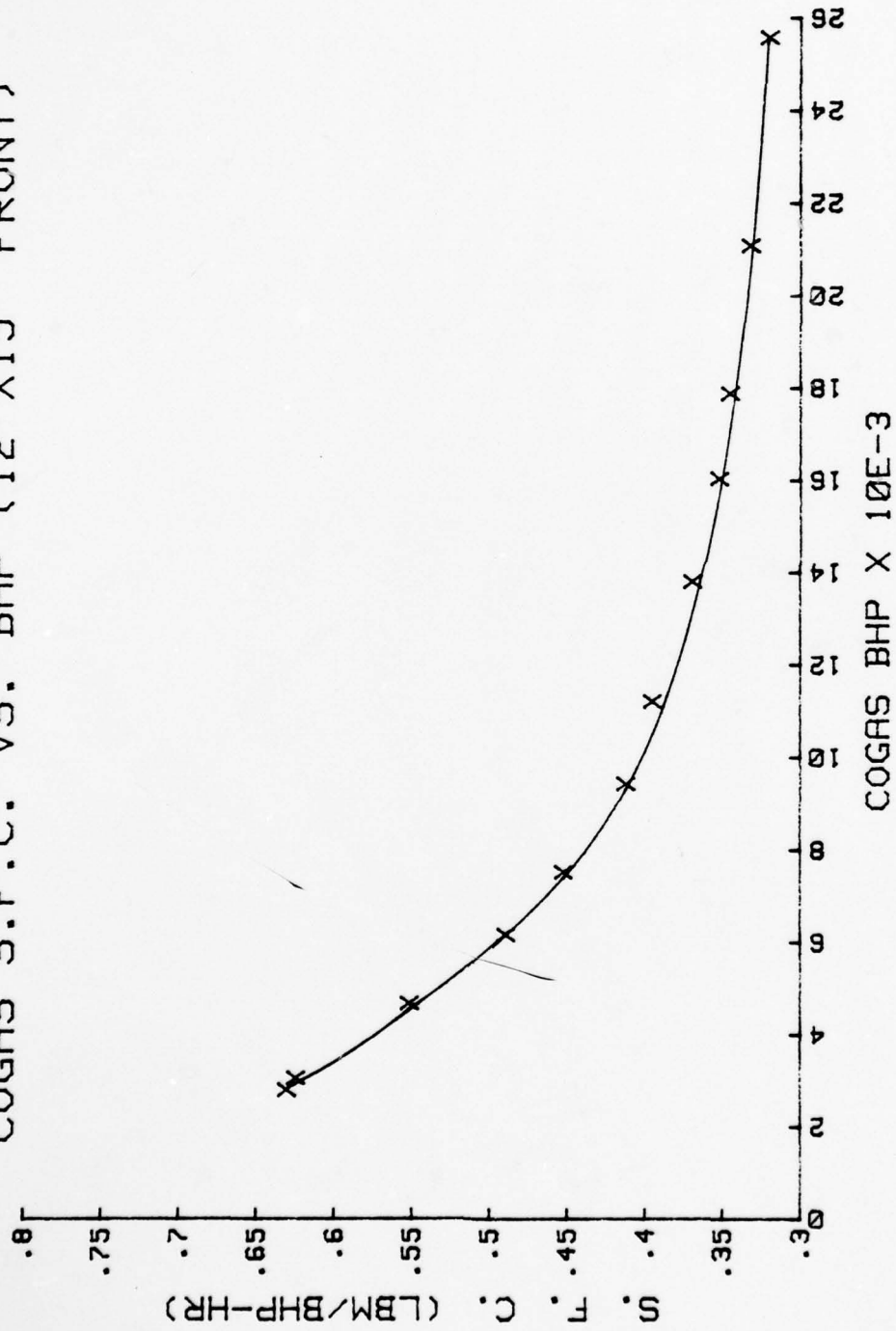


FIGURE 27

# NAVSEC DESTROYER PROFILE

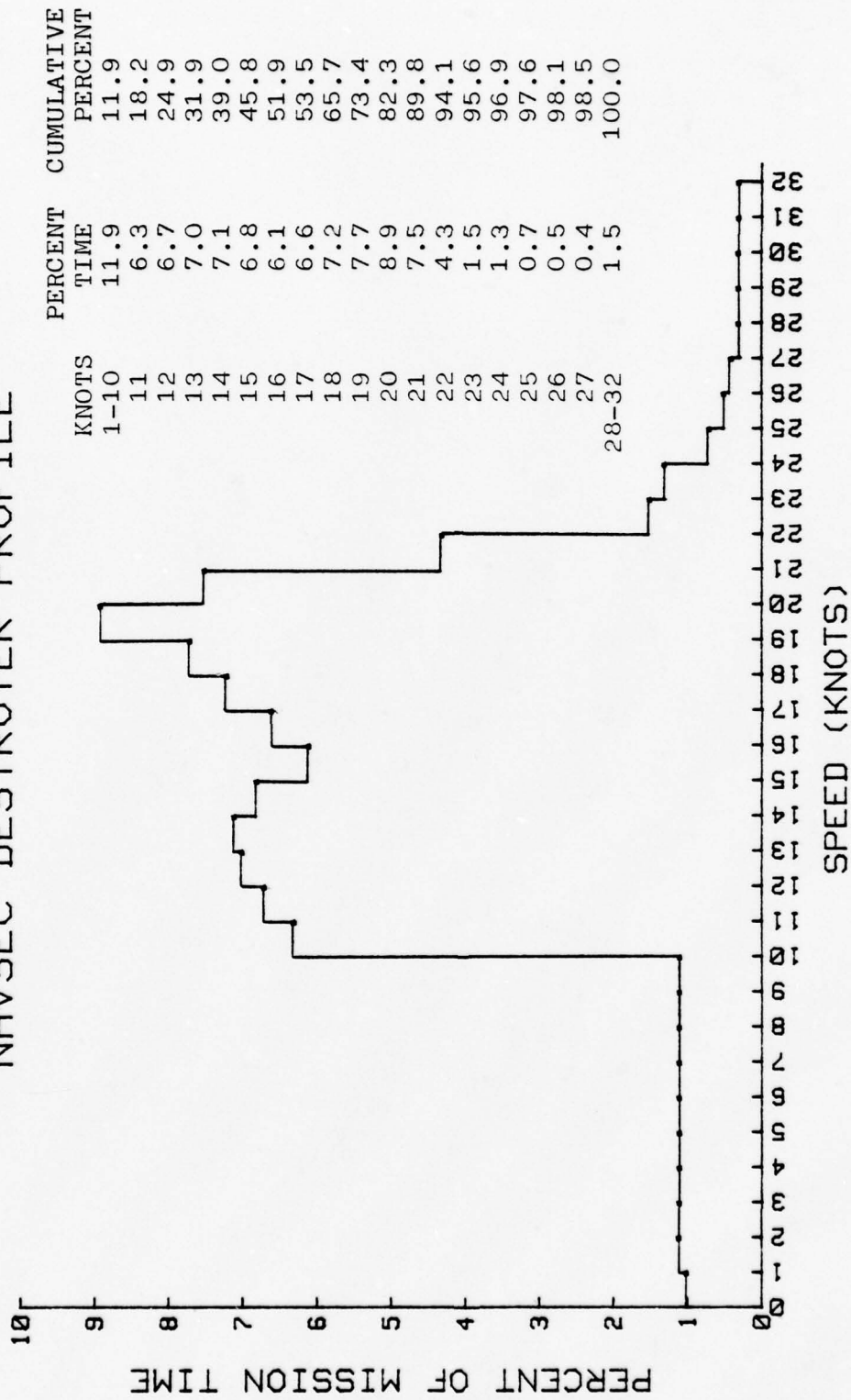


FIGURE 28

Figure 29 was used to obtain the shaft horsepower requirements for each speed. Finally, figure 30 was used to obtain the s.f.c. of the gas turbine operating alone.

Two estimates of fuel savings were made. The first estimate assumed that the COGAS system would be operated for speeds of 5 to 20 knots and would be secured outside that range. The second estimate employed the COGAS system for speeds of 5 to 23 knots. For the latter operating range, the criterion for the high COGAS speed was an imposed maximum gas turbine horsepower input of 20000 BHP. Both fuel savings estimates are based on the following assumptions and simplifications:

1. The COGAS mode of operation implies the use of one engine (COGAS mode) on one shaft with the other shaft dragging.
2. The gas turbine is assumed to operate at idle (1000 BHP) at speeds below 8 knots.
3. Maneuvering combinations, when two main engines would normally be on the line, are not considered.
4. In the speed range of 21 to 27 knots, in the pure gas turbine mode, one engine per shaft is used, with two shafts on the line.
5. From 28 to 32 knots four gas turbines are on the line.

Table XXII provides the estimates of s.f.c. and fuel consumption for COGAS between 5 and 20 knots and for pure gas turbine for all speeds. The total estimated fuel savings

POWER VS. SPEED CHARACTERISTIC

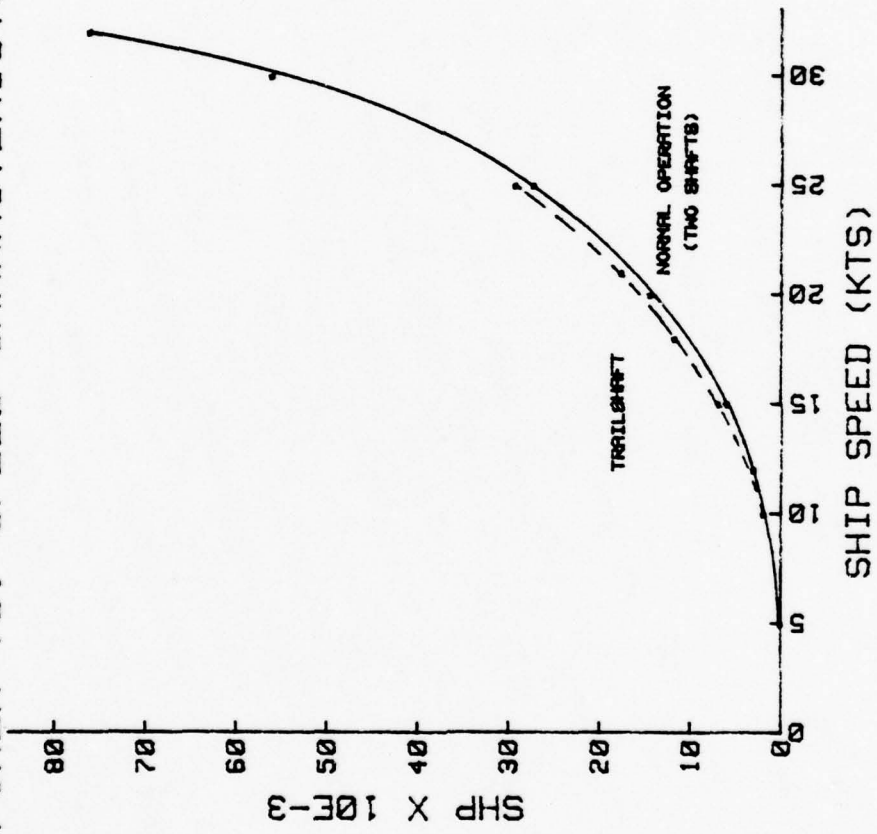


FIGURE 29

GAS TURBINE S. F. C.

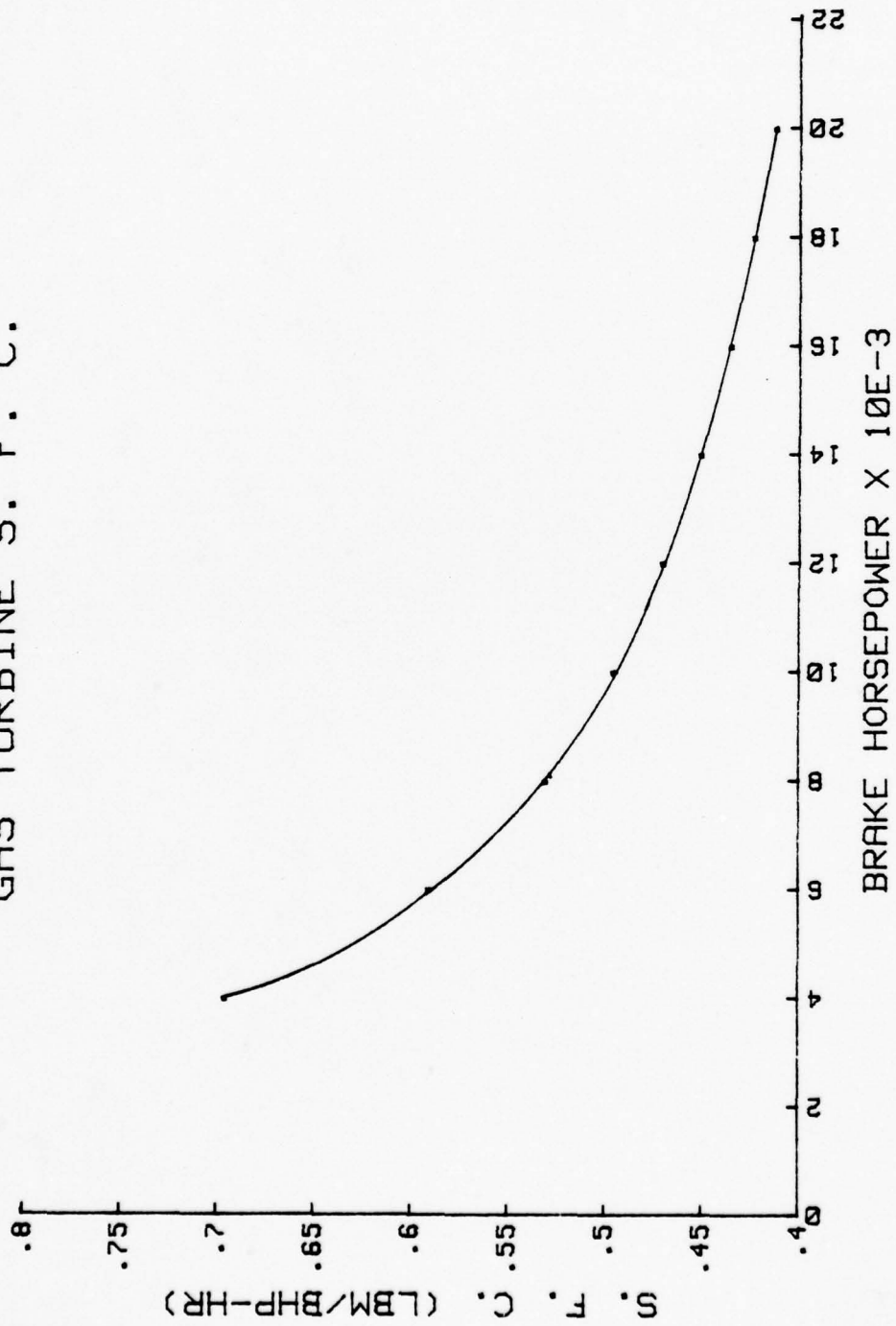


FIGURE 30

COGAS PERFORMANCE: 5 to 20 KNOT RANGE

<u>Speed</u>	<u>Hours</u>	<u>BHP</u>	<u>COGAS</u> <u>s.f.c.</u>	<u>GT</u> <u>s.f.c.</u>	<u>COGAS</u> <u>CONS</u>	<u>GT</u> <u>CONS</u>
1	10					17510
2	12.1					21187
3	12.1					21187
4	12.1	GT IDLE	est. avg. .800	est. avg. 1.751		21187
5	12.1	at 1000			9680	21187
6	12.1				9680	21187
7	12.1				9680	21187
8	12.1				9680	21187
9	12.1	1684	.750	1.100	15282	22414
10	12.1	1895	.705	1.070	16165	24534
11	63	2105	.680	1.000	90178	132615
12	67	3158	.618	.820	130760	173500
13	70	4316	.560	.700	169187	211484
14	71	5579	.512	.610	202808	241626
15	68	7368	.460	.550	230471	275563
16	61	8947	.426	.515	232497	281070
17	66	10421	.400	.489	275114	336327
18	72	12316	.380	.460	339666	407906
19	77	14210	.365	.440	399372	481435
20	89	16526	.350	.433	514785	636862

TABLE XXII

Page 1

<u>Speed</u>	<u>Hours</u>	<u>BHP</u>	<u>COGAS s.f.c.</u>	<u>GT s.f.c.</u>	<u>COGAS CONS</u>	<u>GT CONS</u>
21	75	17368		.519		676049
22	43	20000		.495		425700
23	15	22105		.482		159819
24	13	25263		.463		152058
25	7	28684		.448		89953
26	5	32631		.435		70972
27	4	37895		.418		63360
28	3	44210		.482		62928
29	3	51580		.460		71180
30	3	58947		.444		78517
31	3	69474		.427		88996
32	3	78947		.415		98289
					<u>4774897</u>	<u>5429976</u>

12.1% savings  
over 1000 hrs operation  
655088 lbm savings  
or 96336 gal. dist. fuel

TABLE XXII

over 1000 hours of operation was 12% which is roughly equivalent to 96000 gallons of distillate fuel.

The estimates of s.f.c. and fuel consumption for pure gas turbine and for COGAS for the 5 to 23 knot speed range are given in Table XXIII. The total estimated 1000-hour fuel savings for this COGAS operating range was 19% which translates to approximately 152000 gallons of distillate fuel.

#### E. CONCLUSIONS

The waste heat recovery unit model and the accompanying simple COGAS system output model provide the basic framework for additional studies of the application of the COGAS system to U. S. Navy gas turbine powered ships. The model, as presently formulated, provides a reasonable estimate of WHRU size required for the fin-tube configuration considered.

Estimates of the COGAS system performance in the 5 to 20 knot range and the 5 to 23 knot range are encouraging. Even considering the assumptions involved in making the fuel savings estimates, it is likely that a COGAS version of a DD-963-type ship would consume on the order of 300000 to 450000 gallons less fuel in one year of operation than the current DD-963 class ships.

The most probable COGAS system would be one which would be designed to operate in non-maneuvering situations for either speed range considered above. That is, a system which would be employed for maximum fuel savings in the cruise mode.

COGAS PERFORMANCE: 5 to 23 KNOT RANGE

Speed (kts)	Hours	BHP	COGAS s.f.c. (lbm/ hp-hr)	GT s.f.c. (lbm/ hp-hr)	COGAS CONS (lbm)	GT CONS (lbm)
1	10					17510
2	12.1					21187
3	12.1					21187
4	12.1	GT IDLE at 1000	EST. AVG. .800	EST. AVG. 1.751		21187
5	12.1				9680	21187
6	12.1				9680	21187
7	12.1				9680	21187
8	12.1				9680	21187
9	12.1	1684	.750	1.100	15282	22414
10	12.1	1895	.705	1.070	16165	24534
11	63	2105	.680	1.000	90178	132615
12	67	3158	.618	.820	130760	173500
13	70	4316	.560	.700	169187	211484
14	71	5579	.512	.610	202808	241526
15	68	7368	.460	.550	230471	275563
16	61	8947	.426	.515	232497	281070
17	66	10421	.400	.489	275114	336327
18	72	12316	.380	.460	339666	407906
19	77	14210	.365	.440	399372	481435
20	89	16526	.350	.433	514785	636862

TABLE XXIII

Page 1

<u>Speed</u>	<u>Hours</u>	<u>BHP</u>	<u>COGAS</u> <u>s.f.c.</u>	<u>GT</u> <u>s.f.c.</u>	<u>COGAS</u> <u>CONS</u>	<u>GT</u> <u>CONS</u>
21	75	18421	.340	.519	469735	676049
22	43	20842	.335	.495	300229	425700
23	15	23368	.324	.482	113568	159819
24	13	252263		.463		152058
25	7	28684		.448		89953
26	5	32631		.435		70972
27	4	37895		.418		63360
28	3	44210		.482		63928
29	3	51580		.460		71180
30	3	58947		.444		78517
31	3	69474		.427		88996
32	3	78947		.415		<u>98289</u>

Totals: 4396861 5429976

19.0% savings

fuel saved in 1000 hrs operation

1033115 lbm

or 151928 ga. dist. fuel

TABLE XXIII

During maneuvering and high speed operations the gas turbines would be operated alone with the waste heat recovery unit dry. Because of the relatively low gas turbine exhaust temperatures involved, it is not expected that damage would occur in the WHRU when operated dry.

#### IV. RECOMMENDATIONS FOR FURTHER RESEARCH

##### A. WHRU DESIGN MODEL IMPROVEMENT AND EXPANSION

The type of control imposed on the WHRU design model of this thesis was essentially the adjustment of the steam flow rate to maintain a superheater steam outlet temperature of 650 F at the pressure specified. This steam flow rate control was further extended to accommodate the maintenance of a minimum pinch point  $\Delta T$  of 25 F. Further investigation of WHRU design should include the effects of allowing the superheater outlet steam temperature and/or pressure to "float" with changing gas turbine exhaust conditions. The combination of controls on the superheater outlet pressure, temperature, and flow rate could lead to improved WHRU output while still maintaining an acceptable minimum pinch point temperature difference.

In order to increase the precision of the model and lead to increased knowledge of the gas temperature distribution in the WHRU, the present model could be modified for a "fine mesh" approach. That is, instead of solving one pass at a time, each pass could be divided into a number of segments. The solution could then proceed using either the finite difference or finite element method.

Other possible model improvements are as follows:

1. Include the calculation of fluid/steam-side pressure drop.

2. Additional fin-tube configurations should be considered for possible improvement of the heat transfer characteristics and the weight and space requirements of the WHRU.
3. Consideration of inside and outside heat transfer surface fouling should be given when investigating possible fin-tube configurations.
4. Working fluids other than water should be investigated for possible enhanced thermodynamic characteristics at a minimum cost in system maintainability.

#### B. COGAS MODEL IMPROVEMENTS

After the waste heat recovery unit, the steam turbine and condenser should have the highest priority for modeling. Both of these units were modeled as "black boxes" in this model. The modeling or performance mapping of "state of the art" steam turbines for application in the COGAS model would allow the designer to further refine the estimate of system performance for various WHRU outputs of steam temperature, pressure, and flow rate. The inclusion of a steam turbine model would also allow the designer to make size and weight estimates for that component. The same benefits would be derived from the inclusion of a condenser model in the COGAS system. As the condenser pressure is reduced, the system performance should improve. The improvement must, however, be weighed against the increased condenser size necessary at the reduced pressure for constant steam and cooling water

conditions. A condenser model would allow the designer to make these comparisons.

In the model of this thesis, pumping power for the condensate and feedwater was assumed to be negligible. In the case of the condensate pump, this is probably not a bad assumption since it is likely that electric pumps could be used, and the cost to the ship's electrical output would not be large. The feedwater pump, however, would probably be steam turbine driven at some cost to the COGAS system output. The required feed pump pumping power for various loads should be mapped and included in the model.

Finally, the likely engineroom machinery layout for the COGAS system should be described in enough detail that the lengths of piping runs, number of turns, and location of valves could be estimated. The inclusion of this feature in the model would allow the designer to address pressure drop and heat losses between components. This feature would also contribute to the COGAS system weight and space prediction.

#### C. SYSTEM OPTIMIZATION

Since the COGAS system is operated with a relatively small heat source, optimization should be attempted in the design of the system. The technique of non-linear programming could be applied to a COGAS system optimization where an important system output parameter, say specific fuel consumption, is expressed as a function of the system design

variables such as component weight, component dimensions, and gas turbine backpressure. This function is called the objective function, and it is maximized or minimized subject to constraints which are also expressed as functions of the design variables. These constraint functions may be either linear or non-linear and express some parameter limit not to be exceeded, such as WHRU or condenser total volume.

For a system of the complexity of the COGAS system a "local" optimization approach would probably have to be adopted. That is, each of the major sub-models (WHRU, steam turbine, and condenser) could be optimized using local constraints. Then the entire system could be optimized using linking variables, such as enthalpy, flow rates, and temperatures between components. The process would be repeated as many times as necessary to achieve the final system optimization. One available computer-based system using the technique of non-linear programming is the COPES/CONMIN program [Ref. 14].





```

195 FORMAT(F4.1)
C
C MAKE INITIAL CALCULATIONS
C
CALL HBAL(TG1,TG2,TG3,TG4,TF1,TF2,TF3,TF4,GC,GF,OPA,PFL,OPT,
XDD)
TG1P=TG1
TG2P=TG2
TG3P=TG3
TG4P=TG4
TF1P=TF1
TF2P=TF2
TF3P=TF3
TF4P=TF4
C
C CALCULATIONS FOR SATUFATOR
C
TGBl=(TG3+TG4)/2.
DPGT=0.
TGFl=TGBl
CALL SAT1(GG,GF,TGFl,TGBl,EFFSA,TF2,TFBl,TCM,FG,PF1,TG3,TG4,TF1,
XR,TW,GGM,L,UF,DI,HOSAT,OPA,SCALE,IPSA,DPT,ANTR,L,SUM,REFS)
C
C GAS SIDE PRESSURE DROP
C
VGM=VJSG(TWd)
VGB=VJSG(TGBl)
TGFR=TFGf+RCONV
VCLG=RR*TFGR/PATM
DPG=(2.*EG*GGM**2*RR*VOLG/GC)*(VGM/VGB)**.14
DPGT=DPGT+DPG
IF(OPA) GO TO 24
WRITE(6,150) DPG
FORMAT(10.,,DPG=,F5.1)
WRITE(6,170) TF2
FORMAT(10.,,TF2=,F6.2)
C
C CALCULATIONS FOR BOILER
C
CALL BOIL1(GG,GF,TG2,TG3,TF2,TF3,TFB,TGF,FG,PF1,HF3,X3,TGB,
XTW,GGM,R,OPA,SCALE,IPB,OPT,TGBl,AIH,SUM)
C
C GAS SIDE PRESSURE DPOP
C
VGM=VJSG(TWd)
VGB=VJSG(TGBl)
TGFR=TFGf+RCONV
VCLG=RR*TFGR/PATM

```

```

WHR00970
WHR00980
WHR00990
WHR01000
WHR01010
WHR01020
WHR01030
WHR01040
WHR01050
WHR01060
WHR01070
WHR01080
WHR01090
WHR01100
WHR01110
WHR01120
WHR01130
WHR01140
WHR01150
WHR01160
WHR01170
WHR01180
WHR01190
WHR01200
WHR01210
WHR01220
WHR01230
WHR01240
WHR01250
WHR01260
WHR01270
WHR01280
WHR01290
WHR01300
WHR01310
WHR01320
WHR01330
WHR01340
WHR01350
WHR01360
WHR01370
WHR01380
WHR01390
WHR01400
WHR01410
WHR01420
WHR01430
WHR01440

```

```

190 DPG=(2.*FG*GGM**2*R*VOLG/GC)*(VGM/VGB)**.14
C DFGT=DPGT+DPG
C IF(OPA) GO TO 26
C WRITE(6,190) DPG
C FCRMAT(10,'DPG=',F5.1)
C
C CALCULATIONS FOR SUPERHEATER
C
C CALL SUP1(GG,GF,TG1,TG2,TF3,TF4,FG,PFI,X3,HFCUT,TGINS,
26 XTGB,TWO,TG,GGM,OPA,SCALE,I,FR,IPSH,TG1,TF4,CPT,IPT,IPB,IPSA,
C XAIR,SUM,R,REFSH)
C
C GAS SIDE PRESSURE DROP
C
C VGH=VISG(TWC)
C VGB=VISG(TGB)
C TGR=TFGR+RCNV
C VCLG=RR*TFGR/PATM
C DPG=(2.*FG*GGM**2*R*VOLG/GC)*(VGM/VGB)**.14
C DPGT=DPGT+DPG
C DPGT=27.7*(DPGT/144.)
C WRITE(6,190) DPG
C IF(OPA) GO TO 29
C IF(IPT) GO TO 29
C
C MATCH GAS TEMP. IN
C
C WRITE(6,192)
C FCRMAT(10,'MATCH TG4?')
192 READ(5,52) OPT
C IF(.NOT.OPT) GO TO 28
C CALL OPTM(TG1P,TG1,TG4P,CS,OK,TINC)
29 WRITE(6,1000) TG1P,TG4P
1000 FCRMAT(10,'2F7.1)
C IF(OK.EQ.0.) GO TO 28
C
C REPERFORM INITIAL CALCULATIONS WITH NEW GAS TEMP. OUT
C
C CALL HBAL(TG1P,TG2P,TG3P,TG4P,TF1P,TF2P,TF3P,TF4P,GG,GF,OPA,PFI,
XCPT,OD)
C TG1=TG1P
C TG2=TG2P
C TG3=TG3P
C TG4=TG4P
C TF1=TF1P
C TF2=TF2P
C TF3=TF3P
C TF4=TF4P

```

```

WHR01450
WHR01460
WHR01470
WHR01480
WHR01490
WHR01500
WHR01510
WHR01520
WHR01530
WHR01540
WHR01550
WHR01560
WHR01570
WHR01580
WHR01590
WHR01600
WHR01610
WHR01620
WHR01630
WHR01640
WHR01650
WHR01660
WHR01670
WHR01680
WHR01690
WHR01700
WHR01710
WHR01720
WHR01730
WHR01740
WHR01750
WHR01760
WHR01770
WHR01780
WHR01790
WHR01800
WHR01810
WHR01820
WHR01830
WHR01840
WHR01850
WHR01860
WHR01870
WHR01880
WHR01890
WHR01900
WHR01910
WHR01920

```

```

28      GO TO 20
      C      HPGTO=HPGT
      C
      C      CALCULATE COGAS SYSTEM OUTPUT
      C
      C      CALL POWER(PF1,TF4,GF,DPGT,HPGT,PI,HPTO,STS,GTSFC,
      C      XOASFC,SFCT,GTTH,OATH,THI,ET,PCON,PHTR)
      C      WRITE(6,203)
      C      FORMAT(10,'SUMMARY OUTPUT?')
      C      READ(5,204) SUM
      C      FORMAT(L4)
      C      IF(.NOT.SUM) GO TO 31
      C
      C      SUMMARY OUTPUT FOR THE RUN
      C
      C      CALL OUT(SUM,HPGTO,TGIP,GG,ANTR,L,IPT,IPSA,IPB,AIH,IPSH,
      C      XAIB,TG3,TG4P,TF1P,TF2,TG2,TG1B1,TG1,TF4,TF3,
      C      XPF1,GF,DPGT,HPGT,PI,HPTO,STS,GTSFC,ASFC,SFCT,GTTH,
      C      XOATH,THI,SCALE,OD,ET,PCON,PHTR,REFS,REFSH,SSPD)
      C      WRITE(6,200)
      C      FORMAT(10,'END OF DESIGN RUN. REDESIGN?')
      C      READ(5,201) RED
      C      FORMAT(L4)
      C      IF(RED) GO TO 1
      C      STOP
      C      END
      C
      C      SUBROUTINE HBAL(TG1,TG2,TG3,TG4,TF1,TF2,TF3,TF4,GG,GF,OPA,PF1,OPT,
      C      XND)
      C      LOGICAL OPA,OPT,OC
      C      PP=25.
      C      TF1=200.
      C      IF(OPT) GO TO 2
      C
      C      STARTING CONDITIONS
      C
      C      WRITE(6,300)
      C      FORMAT(10,'ENTER INITIAL CONDITIONS')
      C      WRITE(6,301)
      C      FORMAT(10,'TG1?')
      C      READ(5,302) TG1
      C      FORMAT(F5.1)
      C      WRITE(6,303)
      C      FCRMAT(10,'TG4?')
      C      READ(5,304) TG4
      C      FORMAT(F5.1)

```

```

WHR01930
WHR01940
WHR01950
WHR01960
WHR01970
WHR01980
WHR01990
WHR02000
WHR02010
WHR02020
WHR02030
WHR02040
WHR02050
WHR02060
WHR02070
WHR02080
WHR02090
WHR02100
WHR02110
WHR02120
WHR02130
WHR02140
WHR02150
WHR02160
WHR02170
WHR02180
WHR02190
WHR02200
WHR02210
WHR02220
WHR02230
WHR02240
WHR02250
WHR02260
WHR02270
WHR02280
WHR02290
WHR02300
WHR02310
WHR02320
WHR02330
WHR02340
WHR02350
WHR02360
WHR02370
WHR02380
WHR02390
WHR02400

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305 WRITE(6,305)
FORMAT(10,'GAS FLOW RATE?')
306 READ(5,306) GG
FORMAT(F8.1)
TF1=200.
WRITE(6,307)
FORMAT(10,'TF4?')
307 READ(5,306) TF4
WRITE(6,308)
FORMAT(10,'PF?')
308 READ(5,309) PF1
FORMAT(F5.1)
309
CALCULATE GAS AND WATER PROPERTIES
1
2
TGB=(TG1+TG4)/2.
CPG=SPECG(TGB)
CALL HCH(PF1,TF1,HF1)
CALL SS(PF1,TF4,HF4,SS4,VOLF4)
3
4
OVERALL HEAT TRANSFER/FLUID FLOW RATE
Q=GG*CPG*(TG1-TG4)
GF=Q/(HF4-HF1)
5
INTERMEDIATE TEMPERATURES/HEAT TRANSFER RATES
SATURATOR
TF2=TS1(PF1)
TFB1=(TF1+TF2)/2.
HF2=HSL(TF2)
OSAT=GF*(HF2-HF1)
CALL CPCM(PF1,TFB1,CPFI)
TG3=(OSAT+GG*CPG*TG4)/(GG*CPG)
QMAX=GF*CPFI*(TG3-TF1)
EFFSA=QSAT/QMAX
6
7
BOILER
TF3=TF2
CALL SS(PF1,TF3,HF3,SSS,VOL)
QB=GF*(HF3-HF2)
TG2=(QB+GG*CPG*TG3)/(GG*CPG)
QMAX=GG*CPG*(TG2-TF2)
EFFB=QB/QMAX
8
SUPERHEATER

```

```

WHR02410
WHR02420
WHR02430
WHR02440
WHR02450
WHR02460
WHR02470
WHR02480
WHR02490
WHR02500
WHR02510
WHR02520
WHR02530
WHR02540
WHR02550
WHR02560
WHR02570
WHR02580
WHR02590
WHR02600
WHR02610
WHR02620
WHR02630
WHR02640
WHR02650
WHR02660
WHR02670
WHR02680
WHR02690
WHR02700
WHR02710
WHR02720
WHR02730
WHR02740
WHR02750
WHR02760
WHR02770
WHR02780
WHR02790
WHR02800
WHR02810
WHR02820
WHR02830
WHR02840
WHR02850
WHR02860
WHR02870
WHR02880

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WHR 02890  
 WHR 02900  
 WHR 02910  
 WHR 02920  
 WHR 02930  
 WHR 02940  
 WHR 02950  
 WHR 02960  
 WHR 02970  
 WHR 02980  
 WHR 02990  
 WHR 03000  
 WHR 03010  
 WHR 03020  
 WHR 03030  
 WHR 03040  
 WHR 03050  
 WHR 03060  
 WHR 03070  
 WHR 03080  
 WHR 03090  
 WHR 03100  
 WHR 03110  
 WHR 03120  
 WHR 03130  
 WHR 03140  
 WHR 03150  
 WHR 03160  
 WHR 03170  
 WHR 03180  
 WHR 03190  
 WHR 03200  
 WHR 03210  
 WHR 03220  
 WHR 03230  
 WHR 03240  
 WHR 03250  
 WHR 03260  
 WHR 03270  
 WHR 03280  
 WHR 03290  
 WHR 03300  
 WHR 03310  
 WHR 03320  
 WHR 03330  
 WHR 03340  
 WHR 03350  
 WHR 03360

C CALL SS(PF1,TF4,HF4,SSS,VOL)  
 QSH=GF\*(HF4-HF3)  
 TF3=(TF3+TF4)/2  
 CALL CDS(PF1,TF3,CPF3)  
 QMAX=GF\*CPF3\*(TG1-TF3)  
 EFFSH=QSH/QMAX  
 C SET PINCH PCINT  
 C IF(OD) GO TO 10  
 DIF=IG3-TF2  
 IF(DIF GE PP) GO TO 10  
 TG3=TF2+(PP+1)  
 ENRA=(HF2-HF1)/(HF4-HF1)  
 TG4=(TG3-ENRA\*TG1)/(1-ENRA)  
 GC TO 2  
 IF(OPA) GO TO 20  
 WRITE(6,100) Q, QSAT, QB, QSH  
 FCRMAT(10, Q, QSAT, QB, QSH)  
 X3X1, QSH=, F10.1, 3X, QSAT=, F10.1, 3X, QB=, F10.1,  
 10 WRITE(6,110) GG, GF  
 FCRMAT(10, GG=, F8.1, 3X, GF=, F8.1)  
 110 WRITE(6,120) TF1, TF2, TF3, TF4  
 FFORMAT(10, TF1=, F5.1, 3X, TF2=, F5.1, 3X, TF3=, F5.1, 3X,  
 120 X, TF4=, F5.1)  
 WRITE(6,130) TG1, TG2, TG3, TG4  
 FCRMAT(10, TG1=, F5.1, 3X, TG2=, F5.1, 3X, TG3=, F5.1, 3X,  
 130 X, TG4=, F5.1)  
 WRITE(6,140) EFFSA, EFFB, EFFSH  
 FCRMAT(10, ESAT=, F4.3, 3X, EBO IL=, F4.3, 3X, ESH=, F4.3)  
 140 RETURN  
 20 END  
 C SUBROUTINE OPTM(TG1P, TG1, TG4P, CS, CK, T INC)  
 C LOGICAL CE  
 C OK=1.  
 C C-CHECK CURRENT GAS TEMP. IN WITH ACTUAL  
 C DIF=TG1P-TG1  
 C DIFA=ABS(DIF)  
 C IF(DIFA LE 1.5) GO TO 15  
 C IF(DIFA LE 8.) GO TO 17  
 C IF(DIF LT 0.) GO TO 10  
 5 C

```

C      C      INCREASE GAS TEMP OUT
C      IF(CS.LT.0.) TINC=.5*TINC
C      TG4P=TG4P+TINC
C      CS=DIF
C      GO TO 20

C      DECREASE GAS TEMP. OUT
C      IF(CS.GT.0.) TINC=.5*TINC
C      TG4P=TG4P-TINC
C      CS=DIF
C      GO TO 20

C      OK=0.
C      GC TO 20
C      WRITE(6,100)
C      FORMAT(0,'CLOSE ENOUGH?')
C      READ(5,110) CE
C      FORMAT(L4)
C      IF(CE) OK=0.
C      IF(.NOT.CE) GO TO 5
C      RETURN
C      ENC

C      SUBROUTINE CUT(SUM,HPGTO,TGIP,GG,ANTR,L,IPT,IPSA,IPB,
XAIH,IPS1,AIB,TG3,TG4P,TFIP,TF2,TG2,TG1A,TG1,
XTF4,TF3,PF1,GF,DPGT,HFGT,PT,HPT,CS,STS,GT,SCFC,
XOASFC,SFCT,GTTH,DATAH,THT,SCALE,CD,ET,PCON,PHTR,REFS,REFSH,
XSSPD)
C      IMPLICIT REAL*4(L)
C      LOGICAL SUM,OD
C      PJ=3.1416
C      CALL GEOL(ANTR,L,AMIN,DO,AFF,DI,AIP,ANTP,AOP,SN,SF,AFR,CPA
X,SCALE,OPT,SUM,DTF,FPF,DFB,LTAB,FINC,AFINT,LF,TF,ANRP)
C      HEI=(IPT*ANRP-1)*SP+DTF
C      DOI=DO*12.
C      LII=DI*12.
C      FPI=FPF/12.
C      FINH=((DFB-DO)/2.+LTAB)*12.
C      SNI=SN*12.
C      SPI=SP*12.
C      HL=AIH/(PI*DI*ANTR*2.)
C      BL=AIB/(PI*DI*ANTP*2.)
C      PJ=TG3-TF2
C      P2=TG1B1-TF2
C      PF=AMINI(PI,P2)

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WHR03370
WHR03380
WHR03390
WHR03400
WHR03410
WHR03420
WHR0343C
WHR03440
WHR03450
WHR03460
WHR03470
WHR03480
WHR03490
WHR03500
WHR03510
WHR03520
WHR03530
WHR0354C
WHR03550
WHR03560
WHR03570
WHR03580
WHR0359C
WHR03600
WHR03610
WHR03620
WHR03630
WHR03640
WHR0365C
WHR03660
WHR03670
WHR03680
WHR03690
WHR0370C
WHR03710
WHR03720
WHR03730
WHR03740
WHR03750
WHR03760
WHR03770
WHR03780
WHR03790
WHR03800
WHR0381C
WHR03820
WHR03830
WHR03840

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WHR03850  
 WHR03860  
 WHR03870  
 WHR03880  
 WHR03890  
 WHR03900  
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 WHR03980  
 WHR03990  
 WHR04000  
 WHR04010  
 WHR04020  
 WHR04030  
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 WHR04110  
 WHR04120  
 WHR04130  
 WHR04140  
 WHR04150  
 WHR04160  
 WHR04170  
 WHR04180  
 WHR04190  
 WHR04200  
 WHR04210  
 WHR04220  
 WHR04230  
 WHR04240  
 WHR04250  
 WHR04260  
 WHR04270  
 WHR04280  
 WHR04290  
 WHR04300  
 WHR04310  
 WHR04320

PCONH=2.04\*PC3N  
 TSAT=TS L(PFI)  
 W=AFR/L  
 GGS=GG/3600.  
 TFI=TF\*12.  
 LFI=LF\*12.  
 FCGT=GTSEFC\*HPGT  
 FCSYS=OASFC\*HPTO  
 FCGTS=SFACT\*HPTO  
 IF(OD) GO TC 10  
 WRITE(8,100)  
 FORMAT(11,47X,'WASTE HEAT RECOVERY UNIT DESIGN RUN')  
 GC TO 15  
 WRITE(8,110)  
 FCRMAT(1,45X,'WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN')  
 WRITE(8,120)  
 FORMAT(//72X,'GAS TURBINE')  
 WRITE(8,130) HPGTD,SSPD  
 FCRMAT(1,6X,'BRAKE HORSEPOWER:',2X,F7.1,  
 X',',2X,'APPROXIMATE CORRESPONDING SHIP SPEED:',2X,F4.1,2X,'KTS')  
 WRITE(8,140) TGLP  
 FCRMAT(1,6X,'EXHAUST GAS TEMPERATURE:',2X,F6.1,2X,'F')  
 WRITE(8,150) GGS  
 FCRMAT(1,6X,'EXHAUST GAS FLOW RATE:',2X,F8.1,2X,'LBM/HR',  
 X2X,('F5.1,2X,'LBM/SEC'))  
 WRITE(8,160)  
 FCRMAT(//72X,'HEAT EXCHANGER GEOMETRY')  
 WRITE(8,170) ANRP  
 FCRMAT(1,6X,'OVERALL DIMENSIONS:',42X,'NUMBER OF ROWS PER PASS:  
 X',2X,F2.0)  
 WRITE(8,180) L  
 FCRMAT(1,11X,'LENGTH:',2X,F4.1,2X,'FT.')  
 WRITE(8,190) W,ANTR  
 FCRMAT(1,11X,'WIDTH:',3X,F4.1,2X,'FT.',38X,'NUMBER OF TUBES PER  
 X ROW:',2X,F4.0)  
 WRITE(8,195) HEI  
 FCRMAT(1,11X,'HEIGHT:',2X,F4.1,2X,'FT.')  
 FCRMAT(1,67X,'TUBE LENGTH',2X,F3.0,2X,'FT.')  
 WRITE(8,200)  
 FCRMAT(1,6X,'HEAT TRANSFER SURFACE')  
 WRITE(8,210) DII,AOP  
 FCRMAT(1,11X,'OUTSIDE TUBE DIAMETER:',2X,F4.1,2X,'IN.',  
 X23X,'OUTSIDE AREA/PASS:',2X,F7.1,2X,'SQ.FT.')  
 WRITE(8,220) DII  
 FCRMAT(1,11X,'INSIDE TUBE DIAMETER:',2X,F4.1,2X,'IN.')  
 WRITE(8,230) AIP  
 FCRMAT(1,11X,'TUBE/FIN ARRANGEMENT:',35X,'INSIDE AREA/PASS:',

100  
 10  
 110  
 115  
 120  
 130  
 140  
 150  
 160  
 170  
 180  
 190  
 195  
 197  
 200  
 210  
 220  
 230

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240 X2X,F6.1,2X,'SQ. FT. ')
WRITE(8,240)
FORMAT(15X,'FIN TYPE: SEGMENTED')
250 WRITE(8,250)
FORMAT(15X,'FIN SPACING: ',2X,F5.2,2X,'FINS/IN.',23X,
X*FRONTAL AREA: ',2X,F5.1,2X,'SQ. FT. ')
WRITE(8,260)
FORMAT(15X,'FIN HEIGHT: ',2X,F3.1,2X,'IN. ')
270 WRITE(8,270)
FORMAT(15X,'FIN THICKNESS: ',2X,F5.3,2X,'IN.',26X,
X*NUMBER OF PASSES: ',2X,I2,2X,'(TOTAL)')
WRITE(8,280)
FORMAT(172X,'HEATING SECTION: ',7X,I2)
280 WRITE(8,290)
FORMAT(16X,'TRANSVERSE TUBE SPACING: ',2X,F5.2,2X,'IN.',30X,
X*BOILING SECTION: ',7X,I2,3X,'(HEATING LENGTH= ',1X,F4.1,1X,'FT. )')
WRITE(8,300)
FORMAT(172X,'SUPERHEATING SECTION: ',2X,I2,3X,'(BOILING LENGTH= ',
X,1X,F4.1,1X,'FT. )')
WRITE(8,310)
FORMAT(16X,'LONGITUDINAL TUBE SPACING: ',2X,F5.2,2X,'IN. ')
WRITE(8,320)
FORMAT(172X,'HEAT EXCHANGER PERFORMANCE')
290 WRITE(8,330)
FORMAT(10,13X,'SECTION: ',8X,'GAS TEMP. IN: ',2X,'GAS TEMP. OUT: ',3X,
X*FLUID TEMP. IN: ',3X,'FLUID TEMP. OUT: ',3X,'REYNOLDS NUMBER (AVG. )')
WRITE(8,340)
FORMAT(10,13X,'TG3, TG4P, TF1P, TF2, REFS
X14X,F9.1)
WRITE(8,350)
FORMAT(10,13X,'TG2, TG3, TF2, TF3
X*BOILING: ',11X,F5.1,11X,F5.1,13X,F5.1,13X,F5.1)
WRITE(8,360)
FORMAT(10,13X,'TG1, TG2, TF3, TF4, REFSH
X14X,F9.1)
WRITE(8,370)
FORMAT(10,6X,'STEAM PRESSURE: ',2X,F5.1,2X,'PSIA',
X2X,'SATURATION TEMPERATURE= ',2X,F5.1,2X,'F')
WRITE(8,380)
FORMAT(10,6X,'STEAM FLOW RATE: ',2X,F7.1,2X,'LBM/HR. ')
290 WRITE(8,390)
FORMAT(10,6X,'GAS-SIDE PRESSURE DROP: ',2X,F4.1,2X,'IN H2O')
WRITE(8,400)
FORMAT(10,6X,'PINCH POINT: ',2X,F5.1,2X,'F')
WRITE(8,410)
FORMAT(172X,'SYSTEM PERFORMANCE')
290 WRITE(8,420)
FORMAT(10,6X,'GT HORSEPOWER(REVISED): ',2X,F7.1,
X29X,'ASSUMED SYSTEM CHARACTERISTICS:')

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WHR04330
WHR04340
WHR04350
WHR04360
WHR04370
WHR04380
WHR04390
WHR04400
WHR04410
WHR04420
WHR04430
WHR04440
WHR04450
WHR04460
WHR04470
WHR04480
WHR04490
WHR04500
WHR04510
WHR04520
WHR04530
WHR04540
WHR04550
WHR04560
WHR04570
WHR04580
WHR04590
WHR04600
WHR04610
WHR04620
WHR04630
WHR04640
WHR04650
WHR04660
WHR04670
WHR04680
WHR04690
WHR04700
WHR04710
WHR04720
WHR04730
WHR04740
WHR04750
WHR04760
WHR04770
WHR04780
WHR04790
WHR04800

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430 WRITE(8,430) PT,PCONH
    FORMAT(0,6X,STEAM TURBINE HORSEPOWER:',2X,F7.1,
X32X,CONDENSER PRESSURE:',2X,F4.2,2X,'IN. HG')
    WRITE(8,435) ET
    FORMAT(0,6X,STEAM TURBINE EFFICIENCY:',2X,F4.2)
435 WRITE(8,440) HPTO,PHTR
    FORMAT(0,6X,TOTAL SYSTEM HORSEPOWER:',2X,F7.1,
X33X,FW HEATER PRESSURE:',2X,F5.1,2X,'PSIA')
    WRITE(8,445)
    FORMAT(0,6X,LHV OF FUEL: 18400 BTU/LBM')
445 WRITE(8,450) STS
    FORMAT(0,6X,STEAM TURBINE SHARE OF THE LCAD:',2X,F4.1,2X,'PERCE
XNT')
450 WRITE(8,460)
    FORMAT(0,6X,SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):')
460 WRITE(8,470) GTSFC,OA SFC,SFCT
    FC RMAT(0,10X,GT ONLY:',2X,F5.3,4X,'COGAS:',2X,F5.3,4X,
X'GT AT SYSTEM HP:',2X,F5.3)
    WRITE(8,475)
    FC RMAT(0,6X,FUEL CONSUMPTION (LBM-FUEL/HR.):')
475 WRITE(8,476) FCGT,FC SYS,FCGTS
    FC RMAT(0,10X,GT ONLY:',2X,F6.1,3X,'COGAS:',2X,F6.1,3X,
X'GT AT SYSTEM HP:',2X,F6.1)
    WRITE(8,480)
    FC RMAT(0,6X,THERMAL EFFICIENCY:')
480 WRITE(8,490) GTTH,DATA,THT
    FC RMAT(0,10X,GT ONLY:',2X,F5.3,4X,'COGAS:',
X2X,F5.3,4X,'GT AT SYSTEM HP:',2X,F5.3)
    RETURN
    END

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WHR04810
WHR04820
WHR04830
WHR04840
WHR04850
WHR04860
WHR04870
WHR04880
WHR04890
WHR04900
WHR04910
WHR04920
WHR04930
WHR04940
WHR04950
WHR04960
WHR04970
WHR04980
WHR04990
WHR05000
WHR05010
WHR05020
WHR05030
WHR05040
WHR05050
WHR05060
WHR05070
WHR05080
WHR05090
WHR05100

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TCCCLC  
 SAT00020  
 SAT00030  
 SAT00040  
 SAT00050  
 SAT00060  
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 SAT00090  
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 SAT00110  
 SAT00120  
 SAT00130  
 SAT00140  
 SAT00150  
 SAT00160  
 SAT00170  
 SAT00180  
 SAT00190  
 SAT00200  
 SAT00210  
 SAT00220  
 SAT00230  
 SAT00240  
 SAT00250  
 SAT00260  
 SAT00270  
 SAT00280  
 SAT00290  
 SAT00300  
 SAT00310  
 SAT00320  
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 SAT00370  
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 SAT00390  
 SAT00400  
 SAT00410  
 SAT00420  
 SAT00430  
 SAT00440  
 SAT00450  
 SAT00460  
 SAT00470  
 SAT00480

```

PROGRAM FOR HEATING SECTION
SUBROUTINE SAT1(GG,GF,TGF,TGB,EFF,TF2,TFB,TCM,FG,PF,TG3,
XTG4,TF1,R,TWO,GGM,LT,UF,DI,H0,OPA,SCALE,IP,CPT,ANTR,L,SUM,
XREF)
IMPLICIT REAL*4 (A)
LOGICAL OP,OPA,OPT,SUM
OF=TRUE
WRITE(6,94)
FORMAT(10,'XXXXXXXXX BEGIN ECONOMIZER SECTION XXXXXXXXXX')
IF(OP) GO TO 2
WRITE(6,85)
FORMAT(10,'SUPPRESS OUTPUT ?')
READ(5,86) CP
FORMAT(L4)
GC=4.1538E8
PI=3.1416
WRITE(6,700) TG3,TG4
FORMAT(10,'F7.1,3X,F7.1)
TGB=(TG3+TG4)/2.
TGF=TGB
WRITE(6,90) TGF
TFB=(TF1+TF2)/2.

SATURATOR GEOMETRY
CALL GEOL(ANTR,L,AMIN,DO,AF,DI,AIP,ANTP,AOP,SN,SP,AFR,OPA,
XSCALE,OPT,SUM,DTF,FPF,DFB,LTAB,FINC,AFINT,LF,TF,ANRP)
IF(OP) GO TO 6
WRITE(6,90) TGF
FORMAT(10,'TGF=',F7.1)
CALL HCW(PF,TF1,TFIN)

GAS SIDE REYNOLDS NUMBER (DO)
GGM=GG/AMIN
VG=VISC(TGF)
VG=VG*.00036
REG=(GGM*DO)/VG
IF(OP) GO TO 7
WRITE(6,100) REG
FORMAT(10,'REG=',F8.1)

GAS SIDE HEAT TRANSFER COEFFICIENT
CALL SEGS1(REG,CJ,FG)
IF(OP) GO TO 92

```

C C C  
 94  
 85  
 86  
 2  
 700  
 C C C  
 5  
 90  
 6  
 C C C  
 100  
 C C C  
 7

SAT00490  
 SAT00500  
 SAT00510  
 SAT00520  
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 SAT00580  
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 SAT00600  
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 SAT00690  
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 SAT00880  
 SAT00890  
 SAT00900  
 SAT00910  
 SAT00920  
 SAT00930  
 SAT00940  
 SAT00950  
 SAT00960

```

102 WRITE(6,102) CJ,FG
92  FORMAT(10,'J=',F5.4,3X,'F=',F3.2)
   PRG=PRANDG(TGF)
   VG=VJSG(TGF)*3.6E-4
   CPG=SPECG(TGF)
   TCG=VG*CPG/PRG
   HG=((TCG/DO)*REG*PRG**.333)*CJ
   CALL FINE(FINC,HG,AOP,AFINT,EF)
   IF(OP) GO TO 8
105 WRITE(6,105) HG
   C  FORMAT(10,'HG=',F6.2)
   C  FLUID SIDE REYNOLDS NUMBER
   C  8
   CALL VISCW(TFB,VF)
   VF=VF*.778E-11
   CALL VOLCM(PF,TFB,VOLF)
   UF=GF*VOLF/AFF
   REF=(UF*DI)/(VOLF*VF*GC)
   IF(OP) GO TO 9
110 WRITE(6,110) REF
   C  FORMAT(10,'REF=',F8.1)
   C  FLUID SIDE HEAT TRANSFER COEFFICIENT
   C  9
   CALL TCCW(PF,TFB,TCF)
   TCF=TCF*1E-3
   CALL CPCW(PF,TFB,CPF)
   PRF=(VF*CPF/TCF)*GC
   HF=(.023)*((TCF/DI)*(REF**.8)*(PRF**.4)
   IF(OP) GO TO 11
120 WRITE(6,120) HF
   C  FORMAT(10,'HF=',F6.2)
   C  OVERALL HEAT TRANSFER COEFFICIENT
   C  11
   DR=DO/DI
   HO=1./((1/HF)+(AIP*ALOG(DR)/(2.*PI*TCM*ANTP*L))
   X+(AIP/AOP)*(1./HG))
   IF(OP) GO TO 12
130 WRITE(6,130) HO
   C  FORMAT(10,'HO=',F6.2)
   C  PASS EFFECTIVENESS
   C  12
   CMIN=CPF*GF
   CMAX=CPG*GG
   C=CMIN/CMAX

```

SAT00970  
 SAT00980  
 SAT00990  
 SAT01000  
 SAT01010  
 SAT01020  
 SAT01030  
 SAT01040  
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 SAT01080  
 SAT01090  
 SAT01100  
 SAT01110  
 SAT01120  
 SAT01130  
 SAT01140  
 SAT01150  
 SAT01160  
 SAT01170  
 SAT01180  
 SAT01190  
 SAT01200  
 SAT01210  
 SAT01220  
 SAT01230  
 SAT01240  
 SAT01250  
 SAT01260  
 SAT01270  
 SAT01280  
 SAT01290  
 SAT01300  
 SAT01310  
 SAT01320  
 SAT01330  
 SAT01340  
 SAT01350  
 SAT01360  
 SAT01370  
 SAT01380  
 SAT01390  
 SAT01400  
 SAT01410  
 SAT01420  
 SAT01430  
 SAT01440

```

ANTU=HO*AIP /CMIN
SN=ANTU**(-.22)
A=-ANTU*C*SN
B=(EXP(A)-1.)/(C*SN)
EFFP=1.-EXP(B)
IF(OP) GO TO 13
WRITE(6,140) EFFP
FORMAT(0,'PASS EFF.=',F4.3)

SATURATOR EFFECTIVENESS/NUMBER OF PASSES REQUIRED

ARG=(1.-EFFP*C)/(1.-EFFP)
DC 10 N=1,15
TF 2S=TF 2T
TGIS=TGI
EFFS=EFF
IP=N
EFF=(ARG*N-1.)/(ARG*N-C)
TGI=(EFF*CMIN*TF1-CMAX*TG4)/(EFF*CMIN-CMAX)
QL=GG*CPG*(TGI-TG4)
HFO=HFIN+QL/GF
TF 2T=TF 2-5.
CALL TEMP1(PF,TF 2T,HFO)
IF(TF 2T.GT.TF 2) GO TO 15
CONTINUE
IP=IP-1
EFF=EFFS
TF 2=TF 2S
TG 3=TGIS
R=ANRP*IP
TAI=IP*AIP
TAO=IP*AOP
TGB=(TG 4+TG 3)/2.
TFB=(TF 1+TF 2)/2.
TWO=TGB-((HG*TAI)/(HG*TAO))*(TGB-TFB)
IF(OP) GO TO 14
WRITE(6,150) TWO
FORMAT(0,'AVG. WALL TEMP.=',F7.2)
TGF=(TGB+TWO)/2.
DIFT=TGF-TGFT
DIFA=ABS(DIFT)
IF(DIFA.LT.10.) GO TO 20
TGF=TGF
GO TO 5
IF(OPA) GO TO 98
WRITE(6,160) IP
FORMAT(0,'NO. PASSES=',I2)
IF(OPA) GO TO 98

```

140  
 C  
 C  
 C  
 13

15  
 15

150  
 14

600  
 20  
 160

SAT01450  
 SAT01460  
 SAT01470  
 SAT01480  
 SAT01490  
 SAT01500  
 SAT01510  
 SAT01520  
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 SAT01570  
 SAT01580  
 SAT01590  
 SAT01600  
 SAT01610  
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 SAT01680  
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 SAT01800  
 SAT01810  
 SAT01820  
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 SAT01840  
 SAT01850  
 SAT01860  
 SAT01870  
 SAT01880  
 SAT01890  
 SAT01900  
 SAT01910  
 SAT01920

WRITE(6,165) TG3  
 FORMAT(10,' REVISSED GAS TEMP. IN=',F5.1)

165  
 98

LT=L\*R  
 HEI=SP\*(R-1.)+DO  
 VOLSA=HEI\*AFR  
 IF(OPA) GO TO 95  
 WRITE(6,170) HEI, VOLSA  
 FORMAT(10,' SAT. HEIGHT=',F4.1, 4X, 'SAT. VOLUME=',F8.2)  
 RETURN  
 END

170  
 95

C  
 C  
 C)

SUBROUTINE SEGS1(REG,CJ,FG)  
 CJ=.0396176C83718-.00334741588638\*ALOG(REG)  
 FG=1.08824815212-.0771218846786\*ALOG(REG)  
 RETURN  
 END

C  
 C  
 C

SUBROUTINE TEMPI(PF,TFO,HFO)  
 TINC=10.  
 DIF1=0.  
 CALL HCW(PF,TFO,HTEST)  
 DIF=HFO-HTEST  
 DIFA=ABS(DIF)  
 IF(DIFA.LT.5) GO TO 46  
 IF(DIF.LT.0.) GO TO 45  
 IF(DIF1.LT.0.) TINC=.5\*TINC  
 TFC=TFO+TINC  
 DIF1=DIF  
 GO TO 40

40

IF(DIF1.GT.0.) TINC=.5\*TINC  
 TFO=TFC-TINC  
 DIF1=DIF  
 GO TO 40  
 RETURN  
 END

45

SUBROUTINE FINE(FINC,HG,AOP,AFIN,EF)  
 CI=FINC\*SQRT(HG)  
 CIN=CI  
 TML=(EXP(CI)-EXP(CIN))/(EXP(CI)+EXP(CIN))  
 EF=TML/CI  
 WRITE(6,100) EF

46

C  
 C  
 C

100 FCRMAT ('0', 'FIN EFFICIENCY=', 'F5.3')  
ET=1.-('1.-EF)\*(AFIN/AOP)  
HG=ET\*HG  
RETURN  
END

SAT01930  
SAT01940  
SAT01950  
SAT01960  
SAT01970

```

C C
PROGRAM FOR BOILING SECTION
SUBROUTINE BOIL1(GG,GF,TGIN,TGOU,TFI,TFO,TFE,TGF,FG,PF,HF3,XOUT,
XTGB,TWO,GGM,R,OPA,SCALE,IP,OPT,TGI1,AIH,SUM)
IMPLICIT REAL*(L)
LOGICAL OP,CPA,OPG,OPT,SUM
DIMENSION QP(10),TGI(10),TGO(10),HFO(10),X(10),XA(10)
OP=.TRUE.
PI=3.1416
GC=4.153E8
RA=.5
IP=1
WRITE(6,90),XXXXXXXXXX BEGIN BOILING SECTION XXXXXXXXXXXXX
FORMAT(10,'XXXXXXXXXX GO TO 2
IF(OPT) GO TO 2
WRITE(6,91)
FORMAT(10,'SUPRESS OUTPUT ?')
READ(5,92) OP
FCRMT(L4)
IF(OP) OPG=.TRUE.
90
91
92
C C C
BOILER GEOMETRY
CALL GEOL(ANTR,L,AMIN,DO,AFF,DI,AIP,ANIP,AOP,SN,SP,AFR,OPG
X,SCALE,OPT,SUM,DTF,FPF,DFB,LTAB,FINC,AFINT,LF,TF,ANRP)
IF(OP) GO TO 81
WRITE(6,80) PF,TFO
FORMAT(10,'PF=',F5.1,'3X','TFO=',F6.2)
TCM=26.
C1=.66
A=3.4E-4
B=6.7E3
A1=AIP
GFA=GF/AF
TBH=(TFI+TFO)/2.
CALL CPCW(PF,TBH,CPFH)
QF=GF*CPFH*(TFO-TFI)
CALL TCCW(PF,TFO,TCL)
CALL TCS(PF,TFO,TCV)
TCL=TCV*1E-3
TCV=TCV*1E-3
CALL VISSW(TF,VISL)
CALL VISS(PF,TFO,VISV)
VISL=VISL*2.778E-11
VISV=VISV*2.778E-11
CALL CPCW(PF,TFO,CPL)
CALL CPS(PF,TFO,CPV)
80
81
BOI00001C
BOI00002C
BOI00003C
BOI00004C
BOI00005C
BOI00006C
BOI00007C
BOI00008C
BOI00009C
BOI00010C
BOI00011C
BOI00012C
BOI00013C
BOI00014C
BOI00015C
BOI00016C
BOI00017C
BOI00018C
BOI00019C
BOI00020C
BOI00021C
BOI00022C
BOI00023C
BOI00024C
BOI00025C
BOI00026C
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BOI00028C
BOI00029C
BOI00030C
BOI00031C
BOI00032C
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BOI00036C
BOI00037C
BOI00038C
BOI00039C
BOI00040C
BOI00041C
BOI00042C
BOI00043C
BOI00044C
BOI00045C
BOI00046C
BOI00047C
BOI00048C

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80100490  
 80100500  
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 80100690  
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 80100960

CALL SS(PF, TFO, HSV, SSS, ROV)  
 CALL VOLCM(PF, TFO, VOLF)  
 RCL=1./VOLF  
 TGF=(TGIN+TGOU)/2.  
 TGO(1)=TGOU

HTEST=HSL(TFO)  
 HFG=HSV-HTEST  
 IF(OP) GO TO 6  
 WRITE(6,100), TGF  
 FORMAT(10, 'TGF=', F7.1)

5  
 C  
 C  
 C  
 6

GAS SIDE REYNOLDS NUMBER

GGM=GG/AMIN  
 VG=VISC(TGF)  
 VG=VG\*.00036  
 REG=(GGM\*DO)/VG  
 IF(OP) GO TO 7  
 WRITE(6,110), REG  
 FORMAT(10, 'REG=', F8.1)

110  
 C  
 C  
 C  
 7

GAS SIDE HEAT TRANSFER COEFFICIENT

CALL SEGS1(REG, CJ, FG)  
 IF(OP) GO TO 9  
 WRITE(6,120), CJ, FG  
 FORMAT(10, 'J=', F5.4, '3X', 'F=', F3.2)  
 PRG=PRANDG(TGF)  
 VG=VISC(TGF)\*3.6E-4  
 CFG=SPECG(TGF)  
 TCG=VG\*CPG/PRG  
 HG=((TCG/DO)\*REG\*PRG\*\*.333)\*CJ  
 CALL FINE(FINC, HG, ADP, AFINT, EF)  
 IF(OPA) GO TO 10  
 WRITE(6,130), HG  
 FORMAT(10, 'HG=', F6.2)

120  
 9

OVERALL HEAT TRANSFER COEFFICIENT (ROUGH, NEGLECTING INSIDE)

CR=CO/DI  
 HOA=1./((AI\*ALOG(DR)/(2.\*PI\*TCM\*ANTP\*L))+ (AIP/AOP)\* (1./HG))  
 IF(OP) GO TO 8  
 WRITE(6,150), HOA  
 FORMAT(10, 'HO(ROUGH) =', F6.2)

150  
 C  
 C  
 C  
 8

PASS EFFECTIVENESS

CMIN=CPG\*GG

```

160 ANTU=HOA*AIP/CMIN
C EFFP=PASS8(ANTU)
C IF(OP) GO TO 11
C WRITE(6,160) EFFP
C FCRMAT(10, 'PASS EFF.=', F4.3)
C
C ROUGH GAS TEMP. INTO FIRST PASS
C
C TGI(1)=(EFFP*TFI-TGO(1))/(EFFP-1.)
C
C ROUGH FIRST PASS HEAT TRANSFER
C
C QF(1)=GG*CPG*(TGI(1)-TGO(1))
C
C CONDITIONS IN HEATING SECTION OF FIRST PASS
C
C TFBH=(TFI+TFO)/2.
C CALL CPCW(PF,TFBH,CPFH)
C CALL HCVW(PF,TFI,HFIN)
C QRF=GF*(HTEST-HFIN)
C CMIN=CPFH*GG
C CMAX=CPG*GG
C C=CMIN/CMAX
C
C FLUID SIDE REYNOLDS NUMBER
C
C CALL VLSW(TFBH,VF)
C VF=VF*2.778E-11
C CALL VOLCW(PF,TFBH,VOLF)
C UF=GF*VOLF/AFF
C REF=(UF*DI)/(VOLF*VF*GC)
C IF(OP) GO TO 12
C WRITE(6,183) REF
C FCRMAT(10, 'REF=', F8.1)
C
C FLUID SIDE HEAT TRANSFER COEFFICIENT
C
C CALL TCCW(PF,TFBH,TCF)
C TCF=TCF*1E-3
C CALL CPCW(PF,TFBH,CPF)
C PRF=(VF*CPF/TCF)*GC
C HF=(.023)*(TCF/DI)*(REF**.8)*(PRF**.4)
C IF(OP) GO TO 13
C WRITE(6,184) HF
C FCRMAT(10, 'HF=', F6.2)
C
C OVERALL HEAT TRANSFER COEFFICIENT (HEATER)

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80100970
80100980
80100990
80101000
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80101100
80101110
80101120
80101130
80101140
80101150
80101160
80101170
80101180
80101190
80101200
80101210
80101220
80101230
80101240
80101250
80101260
80101270
80101280
80101290
80101300
80101310
80101320
80101330
80101340
80101350
80101360
80101370
80101380
80101390
80101400
80101410
80101420
80101430
80101440

```

```

13 HOSAT=1./((1./HF)+(A1*ALOG(DR)/(2.*PI*TCM*ANTP*L))
X+(AIP/AOP)*(1./HG))
19 EFFH=QRH/(CMIN*(TGI(1)-TFI))
C RA=.5
C
C MIN=CPF*GF
C MAX=CPG*GG
C=CMIN/CMAX
AN=HOSAT*AIP/CMIN
SN=AN**(-.22)
AA=-AN*C*SN
B1=(EXP(AA)-1.)/(C*SN)
EFFP=1.-EXP(B1)
TGI(1)=(EFFP*CMIN*TFI-CMAX*TGO(1))/(EFFP*CMIN-CMAX)
QP(1)=GG*CPG*(TGI(1)-TGO(1))
HFO(1)=HFIN*QP(1)/GF
X(1)=(HFO(1)-HTEST)/HFG
A1H=(HTEST-HFIN)/(HFO(1)-HFIN)*AIP
A1H=QH/QP(1)*AIP
WRITE(6,190) A1H
FORMAT(10,'AREA FOR HEATING=',F5.1)
HC=HOSAT
TGI(1)=TGI(1)
TGO(2)=TGI(1)
HFI(2)=HFO(1)
WRITE(6,188)
FORMAT(10,'1X','PASS',4X,'HEAT TRANSFER',4X,'GAS TEMP IN',4X,
X'ENTHALPY OUT',3X,'QUALITY',4X,'HC')
WRITE(6,189) IP,QP(1),TGI(1),HFO(1),X(1),HO
FORMAT(10,'2X,12,7X,F9.0,9X,F5.1,10X,F6.1,8X,F4.2,4X,F5.1)
C
C SUBSEQUENT FLUID PASSES
C
C IP=IP+1
C ANTU=HO*AIP/(CPG*GG)
C EFFP=PA*SSB(ANTU)
C TGI(IP)=(EFFP*TFO-TGO(IP))/(EFFP-1.)
C QF(IP)=(CPG*GG)*(TGI(IP)-TGO(IP))
C HFO(IP)=HFI(IP)+QP(IP)/GF
C X(IP)=(HFO(IP)-HTEST)/HFG
C IF(X(IP).GT.1.) GO TO 50
C XA(IP)=(X(IP)+X(IP-1))/2.
C
C INSIDE HEAT TRANSFER COEFFICIENT
C IF(XA(IP).GT..05) GO TO 2500
C HTPF=HF

```

```

13
19
C
C
190
198
189
C
C
39
40
C
C
C

```

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80101450
80101460
80101470
80101480
80101490
80101500
80101510
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80101530
80101540
80101550
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80101580
80101590
80101600
80101610
80101620
80101630
80101640
80101650
80101660
80101670
80101680
80101690
80101700
80101710
80101720
80101730
80101740
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80101760
80101770
80101780
80101790
80101800
80101810
80101820
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80101840
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80101860
80101870
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80101890
80101900
80101910
80101920

```

```

GC TO 3000
HL=.023*(TCL/DI)*((DI*GFA/(VISL*GC))**.8)
X*((CPL*VISL*GC)/TCL)**.4
HTPF=(B*(1.-XA(IP))**.8)*((QP(IP)/(AIP*GFA*TFG))
X+.001*((XA(IP)/(1.-XA(IP))**.594))*HL
FC=1./((1./HTPF)+(AIP*ALOG(DR))/(2.*PI*TCM*ANTP*L))+(AIP/AOP)**(1./HBCI)
XG))
ANTU=HO*AIP/(CPG*GG)
EFP=PASSB(ANTU)
TGI(IP)=(EFP*TFQ-TGO(IP))/(EFP-1.)
OPT=(CPG*GG)*(TGI(IP)-TGI(IP))
DIF=QP(IP)-SPT
DIFA=ARS(DIF)
TR=DIFA/QP(IP)
QP(IP)=OPT
IF(TR.GT.05) GO TO 40
HFO(IP)=HFI(IP)+QP(IP)/GF
X(IP)=(HFO(IP)-HTEST)/HFG
IF(X(IP).GT.1.0007) GO TO 50
IF(X(IP).GT.1.) X(IP)=1.
WRITE(6,189) IP, QP(IP), TGI(IP), HFO(IP), X(IP), HC
HFI(IP+1)=HFO(IP)
TGO(IP+1)=TGI(IP) GO TO 39
IF(HFO(IP).LT.HSV) GO TO 55
IF(X(IP).EQ.1.) GO TO 55
IP=IP-1
IF3=HFO(IP)
TGIN=TGI(IP)
XOUT=X(IP) GO TO 55
WRITE(6,240) IP, FINAL CONDITIONS OUT
FORMAT(10,250) IP, PASSES=',I2)
WRITE(6,260) IP, ENTHALPY OUT=',F6.1)
WRITE(6,270) IP, GAS TEMP. IN=',F6.1)
FORMAT(10,280) XOUT, QUALITY OUT=',F4.2)
HF3=HFO(IP)
TGIN=TGI(IP)
XOUT=X(IP)
P=ANRP*IP
TAI=AIP*IP
TAO=AOP*IP
TFB=TFQ
TGB=(TGI(IP)+TGO(1))/2.

```

```

80101930
80101940
80101950
80101960
80101970
80101980
80101990
80102000
80102010
80102020
80102030
80102040
80102050
80102060
80102070
80102080
80102090
80102100
80102110
80102120
80102130
80102140
80102150
80102160
8010217C
80102180
80102190
80102200
80102210
80102220
80102230
80102240
80102250
80102260
80102270
80102280
80102290
80102300
80102310
80102320
80102330
80102340
80102350
80102360
80102370
8010238C
80102390
80102400

```

```

TWO=TGB-((HC*TAI)/(HG*TAO))*(TGB-TFB)
IF(OP) GO TO 57
WRITE(6,290) TWO
FORMAT(10,' ',AVG, WALL TEMP.=',F7.2)
TGFT=(TGB+TW)/2.
DIFT=TGF-TGFT
DIFA=ABS(DIFT)
IF(DIFA.LT.50.) GO TO 60
IP=1
TGF=TGFT
GC TO 5
RETURN
END

```

290  
57

60  
C  
C

```

FUNCTION PASSB(ANTU)
PASSR=-.002641524+1.0343176*ANTU-.53877674*ANTU**2+.16522684*ANTU**5
X*3-.027124182*ANTU**4+.0017919172*ANTU**5
RETURN
END

```

C  
C

```

SUBROUTINE AREA(PF,TFI,TFO,X,AIP,AIH)
CALL VOLCW(PF,TFI,VIN)
CALL VOLCW(PF,TFO,VSAT)
CALL SS(PF,TFO,HSS,SSS,RSS)
VSV=1./RSS
VCUT=VSAT+X*(VSV-VSAT)
AIH=((VSAT-VIN)/(VOUT-VIN))*AIP
RETURN
END

```

80102410  
80102420  
80102430  
80102440  
80102450  
80102460  
80102470  
8010248C  
80102490  
80102500  
80102510  
80102520  
80102530  
80102540  
80102550  
8010256C  
80102570  
80102580  
80102590  
80102600  
80102610  
80102620  
80102630  
80102640  
80102650  
80102660  
8010267C  
80102680  
80102690  
80102700  
80102710  
8010272C  
80102730

SUP000010  
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 SUP000190  
 SUP000200  
 SUP000210  
 SUP000220  
 SUP000230  
 SUP000240  
 SUP000250  
 SUP000260  
 SUP000270  
 SUP000280  
 SUP000290  
 SUP000300  
 SUP000310  
 SUP000320  
 SUP000330  
 SUP000340  
 SUP000350  
 SUP000360  
 SUP000370  
 SUP000380  
 SUP000390  
 SUP000400  
 SUP000410  
 SUP000420  
 SUP000430  
 SUP000440  
 SUP000450  
 SUP000460  
 SUP000470  
 SUP000480

```

C C C
PROGRAM FOR SUPERHEATING SECTION
SUBROUTINE SUP1(GG,GE,TGIN,TGOU,TFI,TFD,FG,PF,X3,HFOU1,TGINS,
XTGB,TMO,TGF,GGM,OPA,SCALE,IPR,IP,TGL,TF4,OPT,IPT,IPB,IPSA,
XATB,SUM,R,REF1)
IMPLICIT REAL*4(L)
LOGICAL OP,CPA,OPG,OD,OPT,SUM
OC=.FALSE.
IPSH=IPT-IPB-IPSA
DIFPP=0
OP=.TRUE.
IF(.NOT.OD) IPR=10
IF(OD) LIM=IPR-1
IF(IPR.EQ.0) GO TO 85
PI=3.1416
GC=4.153E8
RA=5
TEST=TFD+25.
TCM=26.
CI=.66
A=3.4E-4
R=6.7E3
TINC=10.
IP=0
I=0
WRITE(6,100)
FORMAT(0,'XXXXXXXXXX BEGIN SUPERHEATING SECTION XXXXXXXXXXXXX')
IF(OPT) GO TO 2
WRITE(6,90)
FORMAT(0,'SUPPRESS OUTPUT?')
READ(5,91) CP
FORMAT(L4)
IF(OP) OPG=.TRUE.
SUPER HEATER GEOMETRY
WRITE(6,105) TFI,PF
FORMAT(0,'TFI=',F7.1,3X,'PF=',F6.1)
CALL GEOL(ANTR,L,AMIN,DO,AFF,DI,AIP,ANTP,AOP,SN,SP,AFR,OPG,SCALE,
XOPT,SUM,DTF,FPF,DFB,LTAB,FINC,AFIN,LF,TF,ANRP)
DR=DO/DI
GFA=GF/AFF
CALL TCCW(PF,TFI,TCL)
CALL TCS(PF,TFI,CV)

```

SUP00490  
 SUP00500  
 SUP00510  
 SUP00520  
 SUP00530  
 SUP00540  
 SUP00550  
 SUP00560  
 SUP00570  
 SUP00580  
 SUP00590  
 SUP00600  
 SUP00610  
 SUP00620  
 SUP00630  
 SUP00640  
 SUP00650  
 SUP00660  
 SUP00670  
 SUP00680  
 SUP00690  
 SUP00700  
 SUP00710  
 SUP00720  
 SUP00730  
 SUP00740  
 SUP00750  
 SUP00760  
 SUP00770  
 SUP00780  
 SUP00790  
 SUP00800  
 SUP00810  
 SUP00820  
 SUP00830  
 SUP00840  
 SUP00850  
 SUP00860  
 SUP00870  
 SUP00880  
 SUP00890  
 SUP00900  
 SUP00910  
 SUP00920  
 SUP00930  
 SUP00940  
 SUP00950  
 SUP00960

```

TCL=TCL*1E-3
TCV=TCV*1E-3
CALL VI SCW(TFI, VISL)
CALL VI SS(PF, TFI, VISV)
VISL=VISL*2.778E-11
VISV=VISV*2.778E-11
CALL CPCW(PF, TFI, CPL)
CALL SS(PF, TFI, CPV)
CALL VOLCW(PF, TFI, VOL F, ROV)
RCL=1./VOLF
TCF=(TGIN+TGOU)/2.
HSAT=HSL(TFI)
HFG=HSV-HSAT
IF(X3.GE.1.) X3=1.
QRB=GF*((1.-X3)*HFG)
XA=(1.+X3)/2.
IF(OP) GO TO 6
WRITE(6,110) TGF
FORMAT(10,'GAS FILM TEMP.',F7.1)
5
110
C
C
C
6
GAS SIDE REYNOLDS NUMBER
I=I+1
GGM=GG/AMIN
VG=VIG(TGF)
VG=VG*.00036
REG=(GG*DD)/VG
IF(OP) GO TO 7
WRITE(6,120) REG
FORMAT(10,'REG',F8.1)
120
C
C
C
7
GAS SIDE HEAT TRANSFER COEFFICIENT
CALL SEGS1(REG, CJ, FG)
IF(OP) GO TO 8
WRITE(6,130) CJ, FG
FCRMT(10,'J=',F5.4, 'F=',F3.2)
PRG=PRANDG(TGF)
CPG=SPCG(TGF)
TCG=VG*CPG/FRG
HG=((TCG/DD)*REG*PRG**.333)*CJ
CALL FINE(FINC, HG, ANP, AFINT, EF)
IF(X3.LT.1.) GO TO 400
AIB=0.
TGI=1.
TFI=TFI
GO TO 300
130
8

```

```

400 IP=1 GO TO 9
WRITE(6,140) HG
140 FORMAT('0',HG=' ',F6.2)
C
C
C 9 GUESS GAS TEMP. IN (FIRST PASS)
IF(1.GE.2) GO TO 11
TGI1=TGOU+1.2*(QRB/(GG*CPG))
IF(X3.LT..08) TGI1=TGOU+1.01*(QRB/(GG*CPG))
IF(X3.GT..5) TGI1=TGOU+1.5*(QRB/(GG*CPG))
C
C
C 11 ROUGH FIRST PASS HEAT TRANSFER
CMINB=CPG*GG
QPI=CMINB*(TGI1-TGOU)
AI=AIP
RAT=.1
IF(X3.GT..8) RAT=.15
IF(X3.LT..1) RAT=.05
C
C
C 10 INSIDE HEAT TRANSFER COEFFICIENT (BOILING SECTION)
HL=.023*(TCL/DI)*((DI*GFA/(VISL*GC))**.8)
X*((CPL*VISL*GC)/TCL)**.4
HTPF=(B*(1.-XA)**.8)*((QRB/(AI*GFA*HFG))
X+.001*((XA/(1.-XA))**.594))*HL
HC=1./((1./HTPF)+(AI*ALOG(DR)/(2.*PI*TCM*ANTP*L)))+(AIP/AOP)**(1./H
XG))
EFFB=QRB/(CMINB*(TGI1-TFI))
C
C
C CALCULATE AREA REQUIRED FOR BOILING
AN=HO*AI/CMINB
EFFT=PASSB(AN)
DIFPP=DIF
DIF=EFFT-EFFB
DIFA=ABS(DIF)
IF(DIFA.LE..01) GO TO 30
IF(DIF.LT.0.) GO TO 20
IF(DIFPP.LT.0.) RA=.5*RA
AI=AI-RA*AI
CMINB=AI/AIP*GG*CPG
GC TO 10
IF(DIFPP.LT.0.) RA=.5*RA
AI=AI+RA*AI
CMINB=AI/AIP*GG*CPG
GO TO 10
20

```

```

SUP00970
SUP00980
SUPCC59C
SUP01000
SUP01010
SUP01020
SUP01030
SUP01040
SUP01050
SUP01060
SUP01070
SUP01080
SUP01090
SUP0110C
SUP01110
SUP01120
SUP01130
SUP01140
SUP01150
SUP01160
SUP01170
SUP01180
SUP01190
SUP01200
SUP01210
SUP01220
SUP01230
SUP01240
SUP01250
SUP01260
SUP01270
SUP01280
SUP01290
SUP01300
SUP01310
SUP0132C
SUP01330
SUP01340
SUP01350
SUP01360
SUP01370
SUP01380
SUP01390
SUP01400
SUP01410
SUP01420
SUP01430
SUP01440

```

```

30 AIB=A1 GO TO 31
    IF(OP) GO TO 31
    WRITE(6,185) AIB
185 FCRMAT(10,'AREA REQ. FCR BOILING=',F6.2)
31 QP1=GG*CPG*(TGI1-TGOU)
    QSH=QPI-QRB
    AIS=AIP-AIB
    GGB=AIB/AIP*GG
    TGOB=TGI1-QRB/(GGB*CPG)
    GGS=GG-GGB
    IF(AIS.GT.0.) GO TO 33
    TGS=TGI1
    GO TO 34
33 TGS=(AIP*TGOU-AIB*TGOB)/AIS
34 QSH=QPI-QRB
    IF(QSH.GT.0.) GO TO 35
    TGI1=TGI1+20.
    GO TO 10
    SUPERHEATING SECTION OF FIRST PASS

C
C
C
C
C
C
35 STEAM CONDITIONS (FIRST PASS)
    CALL SS(PF,TF0,HTF4,SS,RSS)
    HFO1=HSV+QSH/GF
    IF(OP) GO TO 36
    WRITE(6,188) HFO1
188 FCRMAT(10,'ENTHALPY OUT OF FIRST PASS=',F6.1)
    ESTIMATE FLUID TEMP. OUT (FIRST PASS)
    TF01=TF0-((HTF4-HFO1)/(HTF4-HSV))*(TF0-TFI)
    FIND ACTUAL FLUID TEMP. OUT
    CALL TEMP(PF,TF01,HTEST,HFO1)
    FLUID PROPERTIES FOR SUPERHEATING SECTION
    IF(OP) GO TO 73
    WRITE(6,187) TF01
187 FCRMAT(10,'TEMP. OUT (FIRST PASS)=',F5.1)
    TFB=(TF01+TFI)/2.
    CALL TCS(PF,TFB,TCSI)
    TCSI=TCSI*1E-3
    CALL SS(PF,TFB,GSS,SSS,ROS)
    VOLSI=1./ROS
    SUP0145C
    SUP01460
    SUP01470
    SUP01480
    SUP01490
    SUP0150C
    SUP01510
    SUP01520
    SUP01530
    SUP01540
    SUP01550
    SUP01560
    SUP01570
    SUP01580
    SUP01590
    SUP01600
    SUP01610
    SUP0162C
    SUP01630
    SUP01640
    SUP01650
    SUP01660
    SUP0167C
    SUP01680
    SUP01690
    SUP01700
    SUP01710
    SUP01720
    SUP0173C
    SUP01740
    SUP01750
    SUP01760
    SUP01770
    SUP01780
    SUP01790
    SUP01800
    SUP01810
    SUP01820
    SUP0183C
    SUP01840
    SUP01850
    SUP01860
    SUP01870
    SUP0188C
    SUP01890
    SUP01900
    SUP01910
    SUP01920

```

```

SUP01930
SUP01940
SUP01950
SUP01960
SUP01970
SUP01980
SUP01990
SUP02000
SUP02010
SUP02020
SUP02030
SUP02040
SUP02050
SUP02060
SUP02070
SUP02080
SUP02090
SUP02100
SUP02110
SUP02120
SUP02130
SUP02140
SUP02150
SUP02160
SUP02170
SUP02180
SUP02190
SUP02200
SUP02210
SUP02220
SUP02230
SUP02240
SUP02250
SUP02260
SUP02270
SUP02280
SUP02290
SUP02300
SUP02310
SUP02320
SUP02330
SUP02340
SUP02350
SUP02360
SUP02370
SUP02380
SUP02390
SUP02400

CALL VISS(PF,TFB,VISI)
VISI=VISI#2.778E-11
CALL CPS(PF,TFB,CPS1)
REYNOLDS NUMBE
UFL=GF*VOLS1/AFF
REFI=(UFL*DI)/(VOLS1*VISI*GC)
IF(OP) GO TC 48
WRITE(6,190) REFI
FORMAT(10,'FIRST PASS RE=',F9.1)
FLUID SIDE HEAT TRANSFER COEFFICIENT
PRFI=(VISI*CPS1/TCSI)*GC
HF1=.023*(TCSI/DI)*(REFI**.8)*(PRFI**.4)
IF(OP) GO TO 70
WRITE(6,200) HF1
FORMAT(10,'HF1=',F6.2)
OVERALL HEAT TRANSFER COEFFICIENT
DR=DO/DI
HO1=1./((1./HF1)+(AI*S*ALOG(DR)/(2.*PI*TCM*ANTP*L))
X+(AIP/AOP)*(1./HG))
IF(OP) GO TC 49
WRITE(6,210) HO1
FORMAT(10,'HO(FIRST PASS/SH)=',F6.2)
PASS EFFECTIVENESS
CMINT=CPS1*GF
CMAXT=CPG*GGS
CMIN=AMINI(CMINT,CMAXT)
CMAX=AMAXI(CMINT,CMAXT)
C=CMIN/CMAX
ANTU=HO1*AI S/CMIN
SN=ANTU*(-.22)
AA=-ANTU*CSN
BB=(EXP(AA)-1.)/(C*SN)
EFFS=1.-EXP(BB)
IF(OP) GO TC 47
WRITE(6,220) EFFS
FORMAT(10,'PASS EFF. S/H SECTION=',F4.3)
CALCULATE NEW GAS TEMP. IN
TGII=TFI+QSH/(EFFS*CMIN)

```

SUP02410  
 SUP02420  
 SUP02430  
 SUP02440  
 SUP02450  
 SUP02460  
 SUP02470  
 SUP02480  
 SUP02490  
 SUP02500  
 SUP02510  
 SUP02520  
 SUP02530  
 SUP02540  
 SUP02550  
 SUP02560  
 SUP02570  
 SUP02580  
 SUP02590  
 SUP02600  
 SUP02610  
 SUP02620  
 SUP02630  
 SUP02640  
 SUP02650  
 SUP02660  
 SUP02670  
 SUP02680  
 SUP02690  
 SUP02700  
 SUP02710  
 SUP02720  
 SUP02730  
 SUP02740  
 SUP02750  
 SUP02760  
 SUP02770  
 SUP02780  
 SUP02790  
 SUP02800  
 SUP02810  
 SUP02820  
 SUP02830  
 SUP02840  
 SUP02850  
 SUP02860  
 SUP02870  
 SUP02880

```

CIFP=DIFT
DIFPA=ABS(DIFP)
DIFT=TGII-TGI1
DIFA=ABS(DIFT)
TR=DIFA/TGII
IF(TR.LT.0.1) GO TO 300
IF(DIFA.EQ.DIFPA) RAT=.75*RAT
IF(DIFT.LT.0.) AND(DIFP.LT.0.) RAT=.75*RAT
IF(DIFT.LT.0.) TGI1=TGII+RAT*DIFA
IF(DIFT.GT.0.) AND(DIFP.GT.0.) RAT=.75*RAT
IF(DIFT.GT.0.) TGI1=TGII-RAT*DIFA
QT=GG*CPG*(TGI1-TGOU)
IF(OP) GO TC 301
WRITE(6,215) TGI1
FORMAT(10,'GAS TEMP. INTO FIRST S/H PASS=',F6.1)
RA=.5
GO TO 19
215
301
C
C
C
300
TG02=TGII
TGI1S=TGI1
TFB=(TF01+TF0)/2.
C
C
C
FLUID SIDE HEAT TRANSFER COEFFICIENT
CALL TCS(PF,TFB,TCS2)
TCS2=TCS2*1E-3
CALL CPS(PF,TFB,CPS2)
CALL VISS(PF,TFB,VIS2)
VIS2=VIS2*2.778E-11
CALL SS(PF,TFB,HSS,SSS,ROS)
VOLS2=1./ROS
UF2=GF*VOLS2/AFF
REF2=(UF2*DI)/(VOLS2*VIS2*GC)
IF(OP) GO TO 61
WRITE(6,230) REF2
FORMAT(10,'RE AFTER FIRST PASS=',F8.1)
PRF2=(VIS2*CPS2/TCS2)*GC
HF2=.023*(TCS2/DI)*(REF2*.8)*(PRF2*.4)
WRITE(6,240) HF2
FCR2MAT(10,'HF2=',F6.2)
230
61
240
C
C
C
OVERALL HEAT TRANSFER COEFFICIENT
HO=1./((1./HF2)+(AIP*ALOG(DR)/(2.*PI*TCM*ANTP*L))
X+(AIP/AOP)*(1./HG))
IF(OP) GO TC 63
62

```

```

250 WRITE(6,250) HO
C FCRMAT(0,HO=,F6.2)
C
C 63 PASS EFFECTIVENESS
C MIN=CPS2*GF
C MAX=CPG*GG
C=CMIN/CMAX
ANTU=HO*AIIP/CMIN
SN=ANTU**(-.22)
AA=-ANTU*C*SN
BR=(EXP(AA)-1.)/(C*SN)
EFFP=1.-EXP(BB)
IF(OP) GO TO 64
WRITE(6,260) EFFP
FORMAT(0, PASS EFF.=,F4.3)
260
C SUPERHEATER EFFECTIVENESS/NUMBER OF PASSES
C
C 64 ARG=(1.-EFFP*C)/(1.-EFFP)
IF(OD) GO TO 80
IF(OPT) GO TO 500
DO 50 N=1,8
EFS=EFF
TGITS=TGI
IP=IP+1
EFF=(ARG**N-1.)/(ARG**N-C)
TCI=(EFF*CMIN*F01-CMAX*F02)/(EFF*CMIN-CMAX)
WRITE(6,295) TGI
FORMAT(0, TGI=,F6.1)
IF(TGI.GT.1GIN) GC TO 55
CONTINUE
IF(IP.EQ.1) GO TO 57
IF(IP.EQ.2) .AND.X3.EQ.1.) GO TO 58
IF(IP.EQ.2) TGITS=TGI
IP=IP-1
EFF=EFF S
QL=GG*CPG*(TGITS-TG02)
HFC=HF01+QL/GF
TF4S=TF4
CALL TEMP(PF,TF4S,HTEST,HFO)
GC TO 57
QL=GG*CPG*(TGITS-TG02)
TF4S=TF4
CALL TEMP(PF,TF4S,HTEST,HFO)
GC TO 57
IF(LIM.EQ.0) GO TO 88

```

```

SUP02890
SUP02900
SUP02910
SUP02920
SUP02930
SUP02940
SUP02950
SUP02960
SUP02970
SUP02980
SUP02990
SUP03000
SUP03010
SUP03020
SUP03030
SUP03040
SUP03050
SUP03060
SUP03070
SUP03080
SUP03090
SUP03100
SUP03110
SUP03120
SUP03130
SUP03140
SUP03150
SUP03160
SUP03170
SUP03180
SUP03190
SUP03200
SUP03210
SUP03220
SUP03230
SUP03240
SUP03250
SUP03260
SUP03270
SUP03280
SUP03290
SUP03300
SUP03310
SUP03320
SUP03330
SUP03340
SUP03350
SUP03360

```

SUP03370  
 SUP03380  
 SUP03390  
 SUP03400  
 SUP0341C  
 SUP03420  
 SUP03430  
 SUP03440  
 SUP03450  
 SUP03460  
 SUP03470  
 SUP03480  
 SUP03490  
 SUP03500  
 SUP03510  
 SUP03520  
 SUP03530  
 SUP03540  
 SUP03550  
 SUP03560  
 SUP0357C  
 SUP03580  
 SUP03590  
 SUP03600  
 SUP03610  
 SUP03620  
 SUP03630  
 SUP03640  
 SUP03650  
 SUP03660  
 SUP03670  
 SUP0368C  
 SUP03690  
 SUP03700  
 SUP03710  
 SUP03720  
 SUP0373C  
 SUP03740  
 SUP03750  
 SUP03760  
 SUP03770  
 SUP03780  
 SUP03790  
 SUP03800  
 SUP03810  
 SUP03820  
 SUP03830  
 SUP0384C

```

ARG=(1.-EFFP*.)/(1.-EFFP)
EFF=(ARG**LIM-1.)/(ARG**LIM-C)
TF4=EFF*(TGIN-TF01)+TF01
TF4S=TF4
IP=LIM-1
GO TO 57
IP=IPSH
N=IPSH-1
N=IPSH-1/(ARG**N-C)
EFF=(ARG**CM IN*TF01-CMAX*TGO2)/(EFF*CM IN-CMAX)
TGI=(EFF*CM IN*TF01-CMAX*TGO2)/(EFF*CM IN-CMAX)
TGITS=TGI
QL=GG*CPG*(TGITS-TGO2)
HFC=HF01+QL/GF
TF4S=TF4
CALL TEMP(IP,TF4S,HTEST,HFO)
IF(IP.EQ.1) TF4S=TF01
IF(IP.EQ.1) TGITS=TGI1
R=2.*IP
TAI=IP*AIP
TAO=IP*AOP
TFB=(TFI+TF4S)/2.
TGB=(TGIN+TGO2)/2.
TWO=TGB-((HO*TAI)/(HG*TAO))*(TGB-TFB)
IF(OP) GO TO 65
WRITE(6,270) TWO
FORMAT(10,'AVG. WALL TEMP.=',F7.2)
TGFT=(TGB+TWO)/2.
DIF=TGF-TGFT
DIFA=ABS(DIF)
IF(DIFA.LT.30.) GO TO 60
TCF=TGFT
IP=0
GO TO 5
GC TO 60
TF4S=TF01
WRITE(6,280) IP
FORMAT(10,'NO. PASSES=',I2)
WRITE(6,290) TF4S
FORMAT(10,'FLUID TEMP. OUT OF S/H=',F6.1)
WRITE(6,185) AIB
WRITE(6,292) TGITS
FORMAT(10,'GAS TEMP IN=',F6.1)
TF4=TF4S
TGI=TGITS
R=ANRP*IP
GO TO 87
WRITE(6,600)
FORMAT(10,'LAST PASS PRIOR TO SUPERHEATER')

```

500

57

270  
 25

67  
 88  
 60  
 280

290

292

85  
 600

SUP03850  
 SUP03860  
 SUP03870  
 SUP03880  
 SUP03890  
 SUP03900  
 SUP03910  
 SUP03920  
 SUP03930  
 SUP03940  
 SUP03950  
 SUP03960  
 SUP03970  
 SUP03980  
 SUP03990  
 SUP04000  
 SUP04010  
 SUP04020  
 SUP04030  
 SUP04040  
 SUP04050  
 SUP04060  
 SUP04070

```

87 RETURN
   END
   C
   C
   C
40 SUBROUTINE TEMP(PF, TFO, HTEST, HFO)
   TINC=10.
   DIF1=0.
   CALL SS (PF, TFO, HTEST, SSS, RSS)
   DIF=HFO-HTEST
   DIFA=ABS(DIF)
   IF(DIFA.LT.5) GO TO 46
   IF(DIF.LT.0.) GO TO 45
   IF(DIF1.LT.0.) TINC=.5*TINC
   TFC=TFO+TINC
   DIF1=DIF
   GO TO 40
45 IF(DIF1.GT.0.) TINC=.5*TINC
   TFO=TFO-TINC
   DIF1=DIF
   GO TO 40
46 RETURN
   END

```

```

C
C
      GEOMETRY PROGRAM FOR RECTANGULAR SEGMENTED FINS
      SLROUT INE GEOL(ANTR,L,AMIN,DO,AF,DI,AIP,ANTR,ADP,SN,SP,AFR,CPA
X      SC,OPT,SUM,DTF,FPF,DFB,LTAB,FINC,AFINT,LF,TF,ANRP)
      IMPLICIT REAL*4(L)
      LOGICAL CPA,OPT,SUM
      PI=3.1416
      IF(OPT.OR.SUM) GO TO 90
      WRITE(6,10) SC
      FORMAT(10,' SCALE=',F4.2)
      PI=3.1416
      WRITE(6,80)
100
      FFORMAT('0','ENTER NO. TUBES PER ROW DESIRED')
      READ(5,81) ANTR
      FFORMAT(F3.0)
      WRITE(6,82)
      FFORMAT('0','ENTER TUBE LENGTH DESIRED')
      READ(5,83) L
      FFORMAT(F3.0)
      IF(OPA) GO TO 90
      WRITE(6,84) ANTR,L
      FFORMAT('0','NO. TUBES/ROW=',F3.0,4X,'TUBE LENGTH=',F3.0)
84
C
C
      SET DIMENSIONS
      ANRP=1.
      DC=.1667*SC
      DI=.15542*SC
      TH=.01125*SC
      LF=.084583*SC
      TF=.004*SC
      TABS=38.*1
      LTAB=.0675*SC
      WTAB=.01417*SC
      DFB=.199176*SC
      FPF=71.28*(1./SC)
      SN=.375*SC
      SP=.325*SC
      TCM=26.
C
C
      NUMBER OF TUBES PER PASS
      ANTP=ANRP*ANTR
      DTF=LF*2.+DO
C
C
      FRONTAL AREA

```

```

GE000010
GE000020
GE000030
GE000040
GE000050
GE000060
GE000070
GE000080
GE000090
GE000100
GE000110
GE000120
GE000130
GE000140
GE000150
GE000160
GE000170
GE000180
GE000190
GE000200
GE000210
GE000220
GE000230
GE000240
GE000250
GE000260
GE000270
GE000280
GE000290
GE000300
GE000310
GE000320
GE000330
GE000340
GE000350
GE000360
GE000370
GE000380
GE000390
GE000400
GE000410
GE000420
GE000430
GE000440
GE000450
GE000460
GE000470
GE000480

```

```

C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C
85     AFR=(SN*(ANTR-1.)+DTF)*L
C      IF(OPA.OR.SUM) GO TO 92
C      WRITE(6,85) AFR
C      FCRMAT(0,0,0,FRONTAL AREA=',F6.1)
C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C
92     BLOCKED FRONTAL AREA
C      AB=ANTR*L*DO+FPF*L*ANTR*LF*2.*TF
C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C
C      MIN. FLOW AREA FOR GAS
C      AMIN=AFR-AB
C      IF(OPA.OR.SUM) GO TO 93
C      WRITE(6,86) AMIN
C      FCRMAT(0,0,0,MIN. FLOW AREA(GAS SIDE)=',F7.3)
C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C
86     PASS INSIDE AREA
C      AIP=PI*DI*L*ANTP
C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C
93     FIN AREA
C      AFJN=(TABS*(2.*LT AB*WTAB+2.*TF*L*TAB+WTAB*TF)
C      X*(PI/2.)*(DFB**2-DO**2))*FPF*L
C      AFINT=ANTP*AFIN
C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C
C      BARE TUBE AREA
C      ABT=PI*DO*L-PI*DO*TF*FPF*L
C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C
C      PASS OUTSIDE AREA
C      AOP=ANTP*(AFIN+ABT)
C      IF(OPA.OR.SUM) GO TO 94
C      WRITE(6,87) AOP,AIP
C      FCRMAT(0,0,0,OUT. AREA/PASS=',F7.2,3X,'IN. AREA/PASS=',F7.3)
C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C
87     AREA FOR FLUID FLOW
C      AFF=(PI/4.)*DI**2*ANTP
C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C
94     GEOMETRY FOR FIN EFFICIENCY
C      FINC=LF*(2.*(WTAB+TF)/(WTAB*TF*TCM))**.5)
C      IF(OPA.OR.SUM) GO TO 120
C      WRITE(6,110) FINC
C      FCRMAT(0,0,0,CONST. FOR FIN EFF.=',F6.2)
C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C      C
110

```

GE000970  
GE000980

120 RETURN  
END

```

C C C
PROGRAM FOR COGAS SYSTEM OUTPUT
SUBROUTINE POWER(PF, TSH, GF, DPGT, HPGT, PT, HPTC, STS, GTSFC, OASFC, SFC
X1, GT, H, OATH, TH1, ET, PCON, PHTR)
IMPLICIT REAL*4(L)
DIMENSION T(10), P(10), H(10), S(10), V(10), X(10)
SPA=0.0
PSF=144.
T(1)=TSH
P(1)=PF
P(2)=2.
ET=.85
EP=.8
X(1)=1.
HPCNV=2544.48
LBTU=.001285
TFEED=200.
HV=18400.
PHTR=15.
PCON=P(2)
STATE 1
CALL SS(P(1), T(1), H(1), S(1), V(1))
TURBINE/CONDENSER
CALL HCW(PF, TFEED, HFEED)
S2S=S(1)
T(2)=TSL(P(2))
CALL HCW(PHTR, T(2), HC)
CALL SS(P(2), T(2), H2G, S2G, V2G)
S2F=SSL(T(2))
X2S=(S2S-S2F)/(S2G-S2F)
H2F=HSL(T(2))
H2S=X2S*(H2G-H2F)+H2F
WT=ET*WTS
H(2)=H(1)-WT
FRA=(HFEED-HC)/(H(1)-HC)
PT=(1.-FRA)*GF*WT/HPCNV
WRITE(6,100) PT
FORMAT(10,' POWER OUT OF STEAM TURBINE=',F7.1)
GAS TURBINE
100
C C C

```

```

BAL00010
BAL00020
BALCC03C
BAL00040
BAL00050
BAL00060
BAL00070
BALCC08C
BAL00090
BAL00100
BAL00110
BAL00120
BAL00130
BAL00140
BAL00150
BAL00160
BAL00170
BAL00180
BAL00190
BAL00200
BAL00210
BAL00220
BAL00230
BAL00240
BAL00250
BAL00260
BAL00270
BAL00280
BAL00290
BAL00300
BAL00310
BAL00320
BAL00330
BAL00340
BAL00350
BAL00360
BAL00370
BAL00380
BAL00390
BAL00400
BAL00410
BAL00420
BAL00430
BAL00440
BAL00450
BAL00460
BAL00470
BAL00480

```

```

150 HPR=1.0125+.002125*DPGT
    HPGT=HPGT/HFR
    WRITE(6,150) HPGT
    FORMAT(10,'POWER OUT OF GAS TURBINE=',F8.1)
    HFTO=HPGT*PT
    WRITE(6,200) HPTO
    FORMAT(10,'TOTAL SYSTEM POWER=',F8.1)
    GTSFC=SFC(HPGT)
    SFC=SFC(HPTO)
    SFCF=1.006+.001*DPGT
    GTSFC=SFCF*GTSFC
    GTHE=HPCNV/(GTSFC*HV)
    GFUEL=GT*THE
    OASFC=GFUEL/HPTO
    OFTHE=HPCNV/(OASFC*HV)
    THT=HPCNV/(SFC*HV)
    WRITE(6,250) GTSFC,OASFC,HPTO,SFCT
    FORMAT(10,'SFC(GT ONLY)=',F5.3,3X,'SFC(COGAS)=',F5.3,3X
    X,'SFC(GT AT ',F7.1,2X,'HP)=',F5.3)
    WRITE(6,300) GTTH,DATA
    FORMAT(10,'THERM. EFF. (GT ONLY)=',F6.4,3X,'THERM. EFF. (COGAS)=',F6.4)
    X6.4)
    STS=100.*(PT/HPTO)
    WRITE(6,350) STS
    FORMAT(10,'STEAM TURB. SHARE=',F5.1,2X,'PER CENT')
    RETURN
    END
    C
    C
    C
    FUNCTION SFC(HP)
    SFC=1.4954-.000335*HP+.81953E-8*HP**2-3.6366E-12
    X*HP**3+1.3717E-16*HP**4-2.037E-21*HP**5
    RETURN
    END
BAL00490
BAL00500
BAL00510
BAL00520
BAL00530
BAL00540
BAL00550
BAL00560
BAL00570
BAL00580
BAL00590
BAL00600
BAL00610
BAL00620
BAL00630
BAL00640
BAL00650
BAL00660
BAL00670
BAL00680
BAL00690
BAL00700
BAL00710
BAL00720
BAL00730
BALCC74C
BAL00750
BAL00760
BAL00770
BAL00780
BAL00790
BAL00800
BAL00810
BAL00820
BAL00830
BAL00840

```

AUX00010  
 AUX00020  
 AUX00030  
 AUX00040  
 AUX00050  
 AUX00060  
 AUX00070  
 AUX00080  
 AUX00090  
 AUX00100  
 AUX00110  
 AUX00120  
 AUX00130  
 AUX00140  
 AUX00150  
 AUX00160  
 AUX00170  
 AUX00180  
 AUX00190  
 AUX00200  
 AUX00210  
 AUX00220  
 AUX00230  
 AUX00240  
 AUX00250  
 AUX00260  
 AUX00270  
 AUX00280  
 AUX00290  
 AUX00300  
 AUX00310  
 AUX00320  
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 AUX00340  
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 AUX00360  
 AUX00370  
 AUX00380  
 AUX00390  
 AUX00400  
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 AUX00420  
 AUX00430  
 AUX00440  
 AUX00450  
 AUX00460  
 AUX00470  
 AUX00480

STEAM, WATER, AND AIR PROPERTIES

THIS SET OF SUBPROGRAMS CALCULATES THE THERMODYNAMIC AND TRANSPORT PROPERTIES OF STEAM, WATER, AND AIR.

INSTRUCTIONS:

1. THE CALLING INSTRUCTIONS FOR EACH SUBPROGRAM ARE GIVEN IN THE COMMENTS SECTION OF EACH SUBPROGRAM.
2. ALL CALLING TEMPERATURES ARE FAHRENHEIT.
3. WHERE SEPARATE SUBPROGRAMS FOR SATURATED WATER PROPERTIES ARE NOT PROVIDED, THE SUBPROGRAMS FOR COMPRESSED WATER SHOULD BE USED.
4. WHERE SEPARATE SUBPROGRAMS FOR SATURATED VAPOR PROPERTIES ARE NOT PROVIDED, THE SUBPROGRAM FOR SUPERHEATED STEAM SHOULD BE USED.

RESTRICTIONS:

1. WATER AND STEAM PROPERTIES: THE SUBROUTINES FOR WATER AND STEAM PROPERTIES HAVE BEEN TESTED FOR TEMPERATURES UP TO 1000F AND FOR A PRESSURE RANGE OF 1 PSIA TO 800 PSIA. THE VALUES YIELDED BY THE SUBROUTINES AGREED WITH THE VALUES IN THE ASME STEAM TABLES WITHIN 1.0 PERCENT IN ALL CASES EXCEPT THE STEAM TRANSPORT PROPERTIES WHERE THE ERROR WAS LESS THAN 3.0 PERCENT.
2. AIR PROPERTIES: THE SUBROUTINES FOR AIR PROPERTIES WERE TESTED AT ATMOSPHERIC PRESSURE FOR A TEMPERATURE RANGE OF 200 F TO 1500 F. AGREEMENT TO WITHIN 5.0 PERCENT OF THE VALUES IN THE KEENAN AND KAYE GAS TABLES WAS OBTAINED.

FUNCTION TCG(I)

TCG COMPUTES THERMAL CONDUCTIVITY (BTU/HR-FT-F) OF AIR GIVEN TEMPERATURE

DIMENSION A(7)  
 A(1) = .012999832  
 A(2) = .0000271167  
 A(3) = -.00000012811  
 A(4) = 2.1052E-11  
 A(5) = -3.7245E-14  
 A(6) = 3.5377E-17  
 A(7) = -1.27737E-20  
 DO 5 I=1, 7

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

AUX00490  
 AUX00500  
 AUX00510  
 AUX00520  
 AUX00530  
 AUX00540  
 AUX00550  
 AUX00560  
 AUX00570  
 AUX00580  
 AUX00590  
 AUX00600  
 AUX00610  
 AUX00620  
 AUX00630  
 AUX00640  
 AUX00650  
 AUX00660  
 AUX00670  
 AUX00680  
 AUX00690  
 AUX00700  
 AUX00710  
 AUX00720  
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 AUX00740  
 AUX00750  
 AUX00760  
 AUX00770  
 AUX00780  
 AUX00790  
 AUX00800  
 AUX00810  
 AUX00820  
 AUX00830  
 AUX00840  
 AUX00850  
 AUX00860  
 AUX00870  
 AUX00880  
 AUX00890  
 AUX00900  
 AUX00910  
 AUX00920  
 AUX00930  
 AUX00940  
 AUX00950  
 AUX00960

```

K=I-1
TCG=TCG+A(I)*T**K
RETURN
END

FUNCTION PRANDG(T)
PRAND COMPUTES PRANDTL NUMBER OF AIR GIVEN TEMPERATURE
DIMENSION A(7)
PRANDG=0
A(1)=.71905671
A(2)=-.00135162
A(3)=-.00000091192
A(4)=9.5113E-10
A(5)=-1.56672E-12
A(6)=1.11772E-15
A(7)=-3.0463E-19
DO 5 I=1,7
K=I-1
PRANDG=PRANDG+A(I)*T**K
RETURN
END

FUNCTION VISG(T)
VISG COMPUTES VISCOSITY ((LBM/SEC-FT) X10E7) OF
AIR GIVEN TEMPERATURE
DIMENSION A(6)
TR=T+459.69
VISG=0.
A(1)=-32.2829
A(2)=-.478845
A(3)=-.000521402
A(4)=-.00000396954
A(5)=-1.52477E-10
A(6)=2.27201E-14
DO 5 I=1,6
K=I-1
VISG=VISG+A(I)*TR**K
RETURN
END

```

5  
 C C C  
 C C C  
 5  
 C C C  
 C C C  
 5  
 C

## APPENDIX B

This appendix contains the program listings for the subroutines called by the WHRU design program and the COGAS model to obtain steam, water, and air properties. References 15 and 16 provide relationships for use in calculating the thermodynamic properties of steam and water. The relationships of Ref. 15 for the thermodynamic properties of steam were used in Subroutine SS of this appendix.

The remainder of the subroutines for steam, water and air properties were obtained by fitting polynomials to the values for those properties found in References 17 and 18. In all cases, the polynomial coefficients were obtained using a "canned" program for least squares regression provided with the Hewlett-Packard System 9845 Computer installed in the Naval Postgraduate School Mechanical Engineering Department.

AUX00970  
 AUX0C58C  
 AUX00990  
 AUX01000  
 AUX01010  
 AUX01020  
 AUX01030  
 AUX01040  
 AUX01050  
 AUX01060  
 AUX01070  
 AUX01080  
 AUX01090  
 AUX01100  
 AUX01110  
 AUX01120  
 AUX01130  
 AUX01140  
 AUX01150  
 AUX01160  
 AUX01170  
 AUX01180  
 AUX01190  
 AUX01200  
 AUX01210  
 AUX01220  
 AUX01230  
 AUX01240  
 AUX01250  
 AUX01260  
 AUX01270  
 AUX01280  
 AUX01290  
 AUX01300  
 AUX01310  
 AUX01320  
 AUX01330  
 AUX01340  
 AUX01350  
 AUX01360  
 AUX01370  
 AUX01380  
 AUX01390  
 AUX01400  
 AUX01410  
 AUX01420  
 AUX01430  
 AUX01440

FUNCTION SPECG(T)  
 SFEGG COMPUTES SPECIFIC HEAT (BTU/LBM-F) OF AIR  
 GIVEN TEMPERATURE

DIMENSION A(6)  
 TR=1+459.69  
 SPECG=0  
 A(1)=.2446604  
 A(2)=-.000017494  
 A(3)=-.00000004632  
 A(4)=5.5502E-11  
 A(5)=-3.6663E-14  
 A(6)=7.1728E-18  
 DO 5 I=1,6  
 K=I-1  
 SPECG=SPECG+A(I)\*TR\*\*K  
 RETURN  
 END

C C  
 C C  
 C C  
 C C

5

C C  
 C C  
 C C  
 C C

FUNCTION TSL(P)  
 TSL COMPUTES SATURATION TEMPERATURE (F)  
 GIVEN PRESSURE

DIMENSION A(9), B(6)  
 TSL=0  
 IF (P.LE.450.) GO TO 10  
 B(1)=11545.164  
 B(2)=-8386.0182  
 B(3)=2477.7661  
 B(4)=-363.44271  
 B(5)=26.690978  
 B(6)=-.78073813  
 DO 5 I=1,6  
 J=I-1  
 TSL=TSL+B(I)\*ALOG(P)\*\*J  
 CONTINUE  
 GC TO 20  
 A(1)=35.15789  
 A(2)=24.592588  
 A(3)=2.1182069  
 A(4)=-.3414474

5

10

AUX01450  
 AUX01460  
 AUX01470  
 AUX01480  
 AUX01490  
 AUX01500  
 AUX01510  
 AUX01520  
 AUX01530  
 AUX01540  
 AUX01550  
 AUX01560  
 AUX01570  
 AUX01580  
 AUX01590  
 AUX01600  
 AUX01610  
 AUX01620  
 AUX01630  
 AUX01640  
 AUX01650  
 AUX01660  
 AUX01670  
 AUX01680  
 AUX01690  
 AUX01700  
 AUX01710  
 AUX01720  
 AUX01730  
 AUX01740  
 AUX01750  
 AUX01760  
 AUX01770  
 AUX01780  
 AUX01790  
 AUX01800  
 AUX01810  
 AUX01820  
 AUX01830  
 AUX01840  
 AUX01850  
 AUX01860  
 AUX01870  
 AUX01880  
 AUX01890  
 AUX01900  
 AUX01910  
 AUX01920

A(5) = .15741642  
 A(6) = -.031329585  
 A(7) = .0038658282  
 A(8) = -.00024901784  
 A(9) = .0000068401559  
 PJ = P\*10.  
 DJ 15 I=1,9  
 J=I-1  
 TSSL=SSL+A(I)\*ALOG(PT)\*\*J  
 RETURN  
 END

15  
 20  
 C  
 C  
 C  
 C  
 C  
 C

FUNCTION HSL(T)  
 HSL COMPUTES ENTHALPY (BTU/LBM) OF SATURATED  
 WATER GIVEN TEMPERATURE

DIMENSION A(6)  
 HSL=0.  
 IF (T.LT.360.) GO TO 5  
 A(1) = -9.0411706E2  
 A(2) = 10.673802  
 A(3) = -4.2753836E-2  
 A(4) = 9.41244E-5  
 A(5) = -1.0315357E-7  
 A(6) = 4.560246E-11  
 GO TO 10  
 A(1) = -32.175105  
 A(2) = 1.0088084  
 A(3) = -1.1516996E-4  
 A(4) = 4.8553836E-7  
 A(5) = -7.3618778E-10  
 A(6) = 9.6350315E-13  
 DC 15 I=1,6  
 J=I-1  
 HSL=HSL+A(I)\*T\*\*J  
 RETURN  
 END

5  
 10  
 15

FUNCTION SSL(T)  
 SSL COMPUTES ENTROPY (BTU/LBM-F) OF SATURATED  
 WATER GIVEN TEMPERATURE

C  
 C  
 C  
 C  
 C  
 C

```

IMPLICIT REAL*4 (M,N)
DIMENSION A (8)
SSL=0
IF (P.LT.450.) GO TO 5
N=-560.
N=110.
A(1)=.76209767
A(2)=1.3690825
A(3)=7.5137702E-3
A(4)=5.7828537E-3
A(5)=-1.6168801E-3
A(6)=-2.1403201E-3
A(7)=3.5726534E-3
A(8)=3.4265601E-3
GO TO 10
N=-360.
N=310.
A(1)=.51575516
A(2)=-.39679646
A(3)=-4.5979941E-2
A(4)=3.4251697E-2
A(5)=-6.072333E-3
A(6)=-3.670358E-2
A(7)=1.2035893E-2
A(8)=1.234655E-2
TB=(T+M)/N
DO 15 I=1,8
J=I-1
SSL=SSL+A(I)*TB**J
RETURN
END

```

10  
15  
C  
C  
C  
C  
C  
C  
5

```

SUBROUTINE HCW(P,T,ENTCW)
HCW COMPUTES ENTHALPY (BTU/LBM) OF COMPRESSED WATER
GIVEN PRESSURE AND TEMPERATURE
DIMENSION A(5),B(5,5)
DO 5 I=1,5
A(I)=0.
ENTCW=0.
IF (P.LT.250.) GO TO 6
B(1,1)=-3.18831669083E1
B(1,2)=2.985C4393234E-3
B(1,3)=1.33348288125E-7
B(1,4)=9.70260583567E-10

```

```

AUX01530
AUX01940
AUX01950
AUX01960
AUX01970
AUX01980
AUX01990
AUX02000
AUX02010
AUX02020
AUX02030
AUX02040
AUX02050
AUX02060
AUX02070
AUX02080
AUX02090
AUX02100
AUX02110
AUX02120
AUX02130
AUX02140
AUX02150
AUX02160
AUX02170
AUX02180
AUX02190
AUX02200
AUX02210
AUX02220
AUX02230
AUX02240
AUX02250
AUX02260
AUX02270
AUX02280
AUX02290
AUX02300
AUX02310
AUX02320
AUX02330
AUX02340
AUX02350
AUX02360
AUX02370
AUX02380
AUX02390
AUX02400

```

E(1,5)=-1.103622284847E-12  
 B(2,1)=1.00C48960506  
 B(2,2)=-1.05314335283E-5  
 B(2,3)=1.47462503C9E-8  
 B(2,4)=-3.48793678207E-11  
 B(2,5)=2.62881336815E-14  
 C  
 B(3,1)=2.82721817375E-5  
 B(3,2)=-3.12450383809E-7  
 B(3,3)=5.3331884114E-10  
 B(3,4)=-1.04460627415E-12  
 B(3,5)=3.9935288388E-16  
 C  
 B(4,1)=-1.41016204839E-6  
 B(4,2)=1.11163180527E-8  
 B(4,3)=-3.06157715541E-11  
 B(4,4)=3.50394655357E-14  
 B(4,5)=-1.436555502814E-17  
 C  
 B(5,1)=4.0766436036E-10  
 B(5,2)=-1.87878835824E-13  
 B(5,3)=1.1016365709E-15  
 B(5,4)=-2.068758C6005E-18  
 B(5,5)=1.2174855867E-21  
 GC TO 9  
 IF(P.LT.15.) GO TO 8  
 P(1,1)=-32.298005582  
 B(1,2)=1.27073877487E-2  
 B(1,3)=-1.24633564596E-4  
 B(1,4)=7.14487908312E-7  
 B(1,5)=-1.365035536452E-9  
 C  
 B(2,1)=1.01381573376  
 B(2,2)=-2.9382843C308E-4  
 B(2,3)=2.86589395496E-6  
 B(2,4)=-1.30522857424E-8  
 B(2,5)=2.11847605407E-11  
 C  
 B(3,1)=-1.9110204C795E-4  
 B(3,2)=4.08786757295E-6  
 B(3,3)=-4.09161725681E-8  
 B(3,4)=1.82954852791E-10  
 B(3,5)=-2.91997554328E-13  
 C  
 B(4,1)=9.31823679C19E-7  
 B(4,2)=-2.39081198404E-8  
 B(4,3)=2.47527446556E-10

AUX02410  
 AUX02420  
 AUX02430  
 AUX02440  
 AUX02450  
 AUX02460  
 AUX02470  
 AUX02480  
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 AUX02500  
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 AUX02570  
 AUX02580  
 AUX02590  
 AUX02600  
 AUX02610  
 AUX02620  
 AUX0263C  
 AUX02640  
 AUX02650  
 AUX02660  
 AUX02670  
 AUX0268C  
 AUX02690  
 AUX02700  
 AUX02710  
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 AUX02780  
 AUX0279C  
 AUX02800  
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 AUX02820  
 AUX02830  
 AUX0284C  
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 AUX02870  
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AUX02890  
 AUX02900  
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 AUX02920  
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 AUX02970  
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 AUX02990  
 AUX03000  
 AUX03010  
 AUX03020  
 AUX03030  
 AUX03040  
 AUX03050  
 AUX03060  
 AUX03070  
 AUX03080  
 AUX03090  
 AUX03100  
 AUX03110  
 AUX03120  
 AUX03130  
 AUX03140  
 AUX03150  
 AUX03160  
 AUX03170  
 AUX03180  
 AUX03190  
 AUX03200  
 AUX03210  
 AUX03220  
 AUX03230  
 AUX03240  
 AUX03250  
 AUX03260  
 AUX03270  
 AUX03280  
 AUX03290  
 AUX03300  
 AUX03310  
 AUX03320  
 AUX03330  
 AUX03340  
 AUX03350  
 AUX03360

B(4,4)=-1.11965391764E-12  
 B(4,5)=1.79677751792E-15  
 B(5,1)=-1.37661172896E-9  
 B(5,2)=4.68882864667E-11  
 B(5,3)=-4.84079843213E-13  
 B(5,4)=2.1188231596E-15  
 B(5,5)=-3.28078007136E-18

GG TO 9

B(1,1)=-33.9774136563  
 B(1,2)=1.42585787825  
 B(1,3)=-.329355699335  
 B(1,4)=2.87673452024E-2  
 B(1,5)=-8.42437941683E-4

B(2,1)=1.12118345966  
 B(2,2)=-8.72001344198E-2  
 B(2,3)=1.99827532858E-2  
 B(2,4)=-1.73328585779E-3  
 B(2,5)=5.05202831066E-5

B(3,1)=-2.65590705018E-3  
 B(3,2)=1.96097311421E-3  
 B(3,3)=-4.4506321979E-4  
 B(3,4)=3.83467251626E-5  
 B(3,5)=-1.11243809796E-6

B(4,1)=2.55004247051E-5  
 B(4,2)=-1.92085012998E-5  
 B(4,3)=4.32399525838E-6  
 B(4,4)=-3.70393732743E-7  
 B(4,5)=1.07027718423E-8

B(5,1)=-9.12566489903E-8  
 B(5,2)=6.92372113529E-8  
 B(5,3)=-7.5478901162E-8  
 B(5,4)=1.31989972084E-9  
 B(5,5)=-3.80217009719E-11

DO 10 I=1,5  
 DO 10 J=1,5

K=J-1

A(I)=A(I)+B(I,J)\*F\*\*K

DC 15 I=1,5  
 K=I-1

C

C

C 8

C

C

C

C

C 9

10  
C

AUX0337C  
 AUX03380  
 AUX03390  
 AUX03400  
 AUX03410  
 AUX03420  
 AUX03430  
 AUX03440  
 AUX03450  
 AUX03460  
 AUX03470  
 AUX03480  
 AUX03490  
 AUX03500  
 AUX03510  
 AUX03520  
 AUX03530  
 AUX03540  
 AUX03550  
 AUX03560  
 AUX03570  
 AUX03580  
 AUX03590  
 AUX03600  
 AUX03610  
 AUX03620  
 AUX03630  
 AUX03640  
 AUX03650  
 AUX03660  
 AUX03670  
 AUX03680  
 AUX03690  
 AUX03700  
 AUX03710  
 AUX03720  
 AUX03730  
 AUX03740  
 AUX03750  
 AUX03760  
 AUX03770  
 AUX03780  
 AUX03790  
 AUX03800  
 AUX03810  
 AUX03820  
 AUX03830  
 AUX03840

```

15  ENTWC=ENTCW+A(I)*T**K
    RETURN
    END

C   SLBROUTINE SCW(P,T,ENTRCW)
C   SCW COMPUTES ENTROPY (BTU/LBM-F) OF COMPRESSED WATER
C   GIVEN PRESSURE AND TEMPERATURE
C
5   DIMENSION A(7)
    DC 5 I=1,7
    A(I)=0.
    ENTRCW=0.
    IF(P.GT.350.) GO TO 10
    A(1)=-.06718122
    A(2)=-.002177559
    A(3)=-.00000241971
    A(4)=3.38002E-9
    A(5)=-3.4031E-12
    A(6)=2.018E-15
    DO 6 I=1,6
    K=I-1
    ENTRCW=ENTRCW+A(I)*T**K
    GC TO 25

C   IF(P.GT.560.) GO TO 15
    A(1)=-.0671726
    A(2)=-.002179035
    A(3)=-.0000025082
    A(4)=4.2146E-9
    A(5)=-6.909E-12
    A(6)=8.804E-15
    A(7)=-4.888E-18
    DC 11 I=1,7
    K=I-1
    ENTRCW=ENTRCW+A(I)*T**K
    GO TO 25

C   A(1)=-.0673078
    A(2)=-.002183675
    A(3)=-.00000256749
    A(4)=4.3649E-9
    A(5)=-6.545E-12
    A(6)=6.776E-15
    A(7)=-2.73E-18
    DO 16 I=1,7
  
```

15  
 C C  
 C C  
 C C  
 C C  
 5  
 6  
 C C  
 10  
 11  
 15



AUX04330  
 AUX04340  
 AUX04350  
 AUX04360  
 AUX04370  
 AUX04380  
 AUX04390  
 AUX04400  
 AUX04410  
 AUX04420  
 AUX04430  
 AUX04440  
 AUX04450  
 AUX04460  
 AUX04470  
 AUX04480  
 AUX04490  
 AUX04500  
 AUX04510  
 AUX04520  
 AUX04530  
 AUX04540  
 AUX04550  
 AUX04560  
 AUX04570  
 AUX04580  
 AUX04590  
 AUX04600  
 AUX04610  
 AUX04620  
 AUX04630  
 AUX04640  
 AUX04650  
 AUX04660  
 AUX04670  
 AUX04680  
 AUX04690  
 AUX04700  
 AUX04710  
 AUX04720  
 AUX04730  
 AUX04740  
 AUX04750  
 AUX04760  
 AUX04770  
 AUX04780  
 AUX04790  
 AUX04800

B(5,4)=-7.32465883E-1E

C

DC 15 I=1,5  
 DC 15 J=1,4  
 K=J-1  
 A(I)=A(I)+B(I,J)\*P\*\*K

15  
 C

DC 20 I=1,5  
 K=I-1  
 YC=TC+A(I)\*T\*\*K  
 RETURN  
 END

20  
 25

C  
 C  
 C

SUBROUTINE CPCW(P,T,CP)

CPCW COMPUTES THE SPECIFIC HEAT (BTU/BM-F) OF  
 COMPRESSED WATER GIVEN PRESSURE AND TEMPERATURE

DIMENSION A(7)

CP=0.  
 IF(P.GT.60.) GO TO 10  
 A(1)=1.0287136  
 A(2)=-.001013384  
 A(3)=-.00001238154  
 A(4)=-7.22385E-8  
 A(5)=2.09487E-10  
 A(6)=-2.29792E-13  
 DC 5 I=1,6

5

K=I-1  
 CP=CP+A(I)\*T\*\*K  
 GC TO 20  
 A(1)=1.014979  
 A(2)=-.000548746  
 A(3)=-.0000058493  
 A(4)=-3.07961E-8  
 A(5)=9.5209E-11  
 A(6)=-1.48161E-13  
 A(7)=9.692E-17  
 DC 15 I=1,7

10

K=I-1  
 CP=CP+A(I)\*T\*\*K  
 RETURN  
 END

15  
 20  
 C  
 C  
 C

AUX0481C  
 AUX04820  
 AUX04830  
 AUX04840  
 AUX04850  
 AUX04860  
 AUX04870  
 AUX04880  
 AUX04890  
 AUX04900  
 AUX04910  
 AUX04920  
 AUX04930  
 AUX04940  
 AUX04950  
 AUX04960  
 AUX04970  
 AUX04980  
 AUX04990  
 AUX05000  
 AUX05010  
 AUX05020  
 AUX05030  
 AUX05040  
 AUX05050  
 AUX05060  
 AUX05070  
 AUX05080  
 AUX05090  
 AUX05100  
 AUX05110  
 AUX05120  
 AUX05130  
 AUX05140  
 AUX05150  
 AUX05160  
 AUX05170  
 AUX05180  
 AUX05190  
 AUX05200  
 AUX05210  
 AUX05220  
 AUX05230  
 AUX05240  
 AUX05250  
 AUX05260  
 AUX05270  
 AUX05280

SUBROUTINE VISCW(T,VIS)  
 VISCW COMPUTES VISCOSITY ((LBF-SEC/FT2) X10E7) OF  
 COMPRESSED WATER GIVEN TEMPERATURE

C  
 C  
 C  
 C

DIMENSION A(8)  
 VIS=0.  
 A(1)=614.4041  
 A(2)=-10.547513  
 A(3)=-.09648986  
 A(4)=-.0005260201  
 A(5)=-.000001748041  
 A(6)=-3.460226E-9  
 A(7)=3.74087E-12  
 A(8)=-1.697431E-15  
 DO 5 I=1, 8  
 K=I-1  
 VIS=VIS+A(I)\*T\*\*K  
 RETURN  
 END

5

SUBROUTINE VOLCW(P,T,VOL)

VOLCW COMPUTES SPECIFIC VOLUME (FT3/LBM) OF COMPRESSED  
 WATER GIVEN PRESSURE AND TEMPERATURE

C  
 C  
 C  
 C  
 C  
 C

DIMENSION A(7)  
 VOL=0.  
 IF(P.GT.40.) GO TO 5  
 A(1)=-.016055142  
 A(2)=-.0000025908  
 A(3)=-.000000043087  
 A(4)=-1.231E-10  
 A(5)=2.737E-13  
 A(6)=-2.424E-16  
 DO 4 I=1, 6  
 K=I-1  
 VOL=VOL+A(I)\*T\*\*K  
 GO TO 40  
 IF (P.GT.250.) GO TO 10  
 A(1)=-.01604542  
 A(2)=-.0000024005  
 A(3)=-.000000040334  
 A(4)=-1.0967E-10  
 A(5)=2.843E-13  
 A(6)=-4.747E-16

4  
 5

AUX05290  
 AUX05300  
 AUX05310  
 AUX05320  
 AUX05330  
 AUX05340  
 AUX05350  
 AUX05360  
 AUX05370  
 AUX05380  
 AUX05390  
 AUX05400  
 AUX05410  
 AUX05420  
 AUX05430  
 AUX05440  
 AUX05450  
 AUX05460  
 AUX05470  
 AUX05480  
 AUX05490  
 AUX05500  
 AUX05510  
 AUX05520  
 AUX05530  
 AUX05540  
 AUX05550  
 AUX05560  
 AUX05570  
 AUX05580  
 AUX05590  
 AUX05600  
 AUX05610  
 AUX05620  
 AUX05630  
 AUX05640  
 AUX05650  
 AUX05660  
 AUX05670  
 AUX05680  
 AUX05690  
 AUX05700  
 AUX05710  
 AUX05720  
 AUX05730  
 AUX05740  
 AUX05750  
 AUX05760

```

A(7)=4.132E-19
DO 9 I=1,7
K=I-1
VOL=VOL+A(I)*T**K
GO TO 40
IF(P.GT.500.) GO TO 15
A(1)=0.1599807
A(2)=-.0000010895
A(3)=0.00000023031
A(4)=3.35E-12
A(5)=-1.217E-13
A(6)=2.933E-16
A(7)=-1.748E-19
DO 14 I=1,7
K=I-1
VCL=VOL+A(I)*T**K
GO TO 40
A(1)=.01600488
A(2)=-.0000020146
A(3)=-.00000036511
A(4)=-8.142E-11
A(5)=1.4081E-13
A(6)=-1.148E-16
A(7)=8.034E-20
DO 16 I=1,7
K=I-1
VCL=VOL+A(I)*T**K
RETURN
END
  
```

9

10

14

15

16

40

C

C

C

C

C

5

SUBROUTINE TCS(P,T,TC)

TCS COMPUTES THERMAL CONDUCTIVITY ((BTJ/HR-FT-F)X10E3)  
 OF STEAM GIVEN PRESSURE AND TEMPERATURE

```

DIMENSION A(7),B(5,4)
DO 5 I=1,5
TC=0.
IF(P.GE.50.) GO TO 15
A(1)=9.90499
A(2)=-.01393E8
A(3)=-.00003E914
A(4)=-.0000000589
A(5)=7.615E-11
A(6)=-5.164E-14
  
```





AUX06730  
 AUX06740  
 AUX06750  
 AUX06760  
 AUX06770  
 AUX06780  
 AUX06790  
 AUX06800  
 AUX06810  
 AUX06820  
 AUX06830  
 AUX06840  
 AUX06850  
 AUX06860  
 AUX06870  
 AUX06880  
 AUX06890  
 AUX06900  
 AUX06910  
 AUX06920  
 AUX06930  
 AUX06940  
 AUX06950  
 AUX06960  
 AUX06970  
 AUX06980  
 AUX06990  
 AUX07000  
 AUX07010  
 AUX07020  
 AUX07030  
 AUX07040  
 AUX07050  
 AUX07060  
 AUX07070  
 AUX07080  
 AUX07090  
 AUX07100  
 AUX07110  
 AUX07120  
 AUX07130  
 AUX07140  
 AUX07150  
 AUX07160  
 AUX07170  
 AUX07180  
 AUX07190  
 AUX07200

B(2,3)=-.000013866942  
 B(2,4)=1.37436147E-5  
 B(2,5)=-1.38328347E-6

C

B(3,1)=-1.6226512E-7  
 B(3,2)=-1.3626817E-7  
 B(3,3)=4.8500908E-7  
 B(3,4)=-1.4264727E-7  
 B(3,5)=1.12507264E-8

C

B(4,1)=-5.6530996E-10  
 B(4,2)=2.50520512E-9  
 B(4,3)=2.15632537E-9  
 B(4,4)=5.31864156E-10  
 B(4,5)=-3.83612442E-11

C

B(5,1)=1.9550162513E-12  
 B(5,2)=-5.8231567039E-12  
 B(5,3)=4.10144879154E-12  
 B(5,4)=-9.18383604222E-13  
 B(5,5)=6.33208744846E-14

C

B(6,1)=-2.01614243525E-15  
 B(6,2)=5.38727678341E-15  
 B(6,3)=-3.47742978501E-15  
 B(6,4)=7.47260528587E-16  
 B(6,5)=-5.01661911137E-17

C

B(7,1)=7.02597694356E-19  
 B(7,2)=-1.79132736742E-18  
 B(7,3)=1.10536956813E-18  
 B(7,4)=-2.31734765803E-19  
 B(7,5)=1.52893617959E-20

C

DO 10 I=1,7  
 DC 10 J=1,5

K=J-1  
 A(I)=A(I)+B(I,J)\*P\*\*K

10

DC 15 I=1,7  
 K=I-1

CP=CP+A(I)\*T\*\*K  
 GO TO 40

15

IF(P.GT.150.) GO TO 26

C

C

B(1,1)=.471051822  
 B(1,2)=-.0071901422  
 B(1,3)=.00002902186

AUX07210  
 AUX07220  
 AUX07230  
 AUX07240  
 AUX07250  
 AUX07260  
 AUX07270  
 AUX07280  
 AUX07290  
 AUX07300  
 AUX07310  
 AUX07320  
 AUX07330  
 AUX07340  
 AUX07350  
 AUX07360  
 AUX07370  
 AUX07380  
 AUX07390  
 AUX07400  
 AUX07410  
 AUX07420  
 AUX07430  
 AUX07440  
 AUX07450  
 AUX07460  
 AUX07470  
 AUX07480  
 AUX07490  
 AUX07500  
 AUX07510  
 AUX07520  
 AUX07530  
 AUX07540  
 AUX07550  
 AUX07560  
 AUX07570  
 AUX07580  
 AUX07590  
 AUX07600  
 AUX07610  
 AUX07620  
 AUX07630  
 AUX07640  
 AUX07650  
 AUX07660  
 AUX07670  
 AUX07680

B(1,4)=-1.0947953E-8  
 B(2,1)=-.00C30842028  
 B(2,2)=-3.30841469E-5  
 B(2,3)=-2.56142116E-7  
 B(2,4)=4.0736494E-10  
 B(3,1)=1.40514276E-6  
 B(3,2)=5.510352E-8  
 B(3,3)=9.0367755E-10  
 B(3,4)=-2.13368295E-12  
 B(4,1)=-2.3595704E-9  
 B(4,2)=-3.3266941E-11  
 B(4,3)=-1.54501998E-12  
 B(4,4)=4.3756116E-15  
 B(5,1)=1.95901818E-12  
 B(5,2)=-2.753866E-15  
 B(5,3)=1.26930177E-15  
 B(5,4)=-3.9664668E-18  
 B(6,1)=-6.16157702E-16  
 B(6,2)=7.0953059E-18  
 B(6,3)=-4.0450706E-19  
 B(6,4)=1.34272907E-21  
 DO 20 J=1,6  
 DO 20 J=1,4  
 K=J-1  
 A(I)=A(I)+B(I,J)\*P\*\*K  
 DO 25 I=1,6  
 K=I-1  
 CP=CP+A(I)\*T\*\*K  
 GO TO 40  
 B(1,1)=-3.1654004  
 B(1,2)=-.050468168  
 B(1,3)=-.000157021974  
 B(1,4)=2.3189283E-7  
 B(1,5)=-9.7309759E-11  
 B(2,1)=-.01818816  
 B(2,2)=-.0025378215  
 B(2,3)=8.1211789E-7  
 B(2,4)=-1.15184066E-9  
 B(2,5)=5.0417466E-13

AUX07690  
 AUX07700  
 AUX07710  
 AUX07720  
 AUX07730  
 AUX07740  
 AUX07750  
 AUX07760  
 AUX07770  
 AUX07780  
 AUX07790  
 AUX07800  
 AUX07810  
 AUX07820  
 AUX07830  
 AUX07840  
 AUX07850  
 AUX07860  
 AUX07870  
 AUX07880  
 AUX07890  
 AUX07900  
 AUX07910  
 AUX07920  
 AUX07930  
 AUX07940  
 AUX07950  
 AUX07960  
 AUX07970  
 AUX07980  
 AUX07990  
 AUX08000  
 AUX08010  
 AUX08020  
 AUX08030  
 AUX08040  
 AUX08050  
 AUX08060  
 AUX08070  
 AUX08080  
 AUX08090  
 AUX08100  
 AUX08110  
 AUX08120  
 AUX08130  
 AUX08140  
 AUX08150  
 AUX08160

C B(3,1)=-.000033784538  
 B(3,2)=4.7562105E-7  
 B(3,3)=-1.55257254E-9  
 B(3,4)=2.27C09037E-12  
 B(3,5)=-9.6702875E-16  
 C B(4,1)=2.7766181E-8  
 B(4,2)=-3.9361743E-10  
 B(4,3)=1.30491831E-12  
 B(4,4)=-1.9040844E-15  
 B(4,5)=8.1631412E-19  
 C B(5,1)=-8.4527264E-12  
 B(5,2)=1.21404264E-13  
 B(5,3)=-4.0761977E-16  
 B(5,4)=5.9420773E-19  
 B(5,5)=-2.5627204E-22  
 C DO 30 J=1,5  
 DC 30 J=1,5  
 K=J-1  
 A(I)=A(I)+B(I,J)\*P\*\*K  
 DC 35 I=1,5  
 K=I-1  
 CP=CP+A(I)\*T\*\*K  
 RETURN  
 END  
 C 30  
 C 35  
 C 40  
 C SUBROUTINE SS(PA,TF,HSS,SSS,RSS)  
 C SS COMPUTES ENTHALPY (BTU/LBM), ENTROPY (BTL/LBM-F),  
 C AND DENSITY (FT3/LBM) OF STEAM GIVEN PRESSURE  
 C AND TEMPERATURE  
 C T=TF/1.8+255.38  
 C P=PA/14.6955  
 C R1=(2641.62/T)\*10.\*\*((80870./T)\*\*2)  
 C R2=82.546  
 C R3=162460./T  
 C R4=.21828\*T  
 C R5=126970./T  
 C R0=1.89-R1  
 C FC=1.89-R1\*(372420./T\*\*2+2)  
 C F=775.556+.63296\*T+.000162467\*T\*\*2+47.3635\*ALCG10(T)  
 C R6=R0\*R3-2.\*F0\*(R2-R3)

```

B 7=2.*F 0*(B 4-B 5)-B 0*B 5
B=EO*(1./T)*((B 0*P)/T**2)*((B 2-B 3+((B 0*P)/T**2)*(B 4-B 5)*B C*P))
BET=(1./T)*((B 0-F 0)*P+((B 0/2.)*(P/T)**2)*(B 6+((B 0/2.)*(P/T)**2)*B 0AUX08190
X*(B 0*(B 4-B 5)-2.*B 7))
VCL=.0160185*((4.55504*T)/P+B)
RSS=1./VOL
HSS=F+.043557*(F 0*P+((B 0/2.)*(P/T)**2)*(-B 6+B 0*(B 2-B 3+2.*B 7*(B 0/2.
X)*(P/T)**2))
SSS=.809691*ALOGIC(T)-.253801*ALCGIO(P)+.00C18052*T-11.4276/T-
X.355579-.0241983*BET
RETURN
END

```

```

AUX08170
AUX08180
AUX08190
AUX08200
AUX08210
AUX08220
AUX08230
AUX08240
AUX08250
AUX08260
AUX08270
AUX08280

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AD-A078 154

NAVAL POSTGRADUATE SCHOOL MONTEREY CA  
WASTE HEAT RECOVERY UNIT DESIGN FOR GAS TURBINE PROPULSION SYST--ETC(U)  
SEP 79 R M COMBS

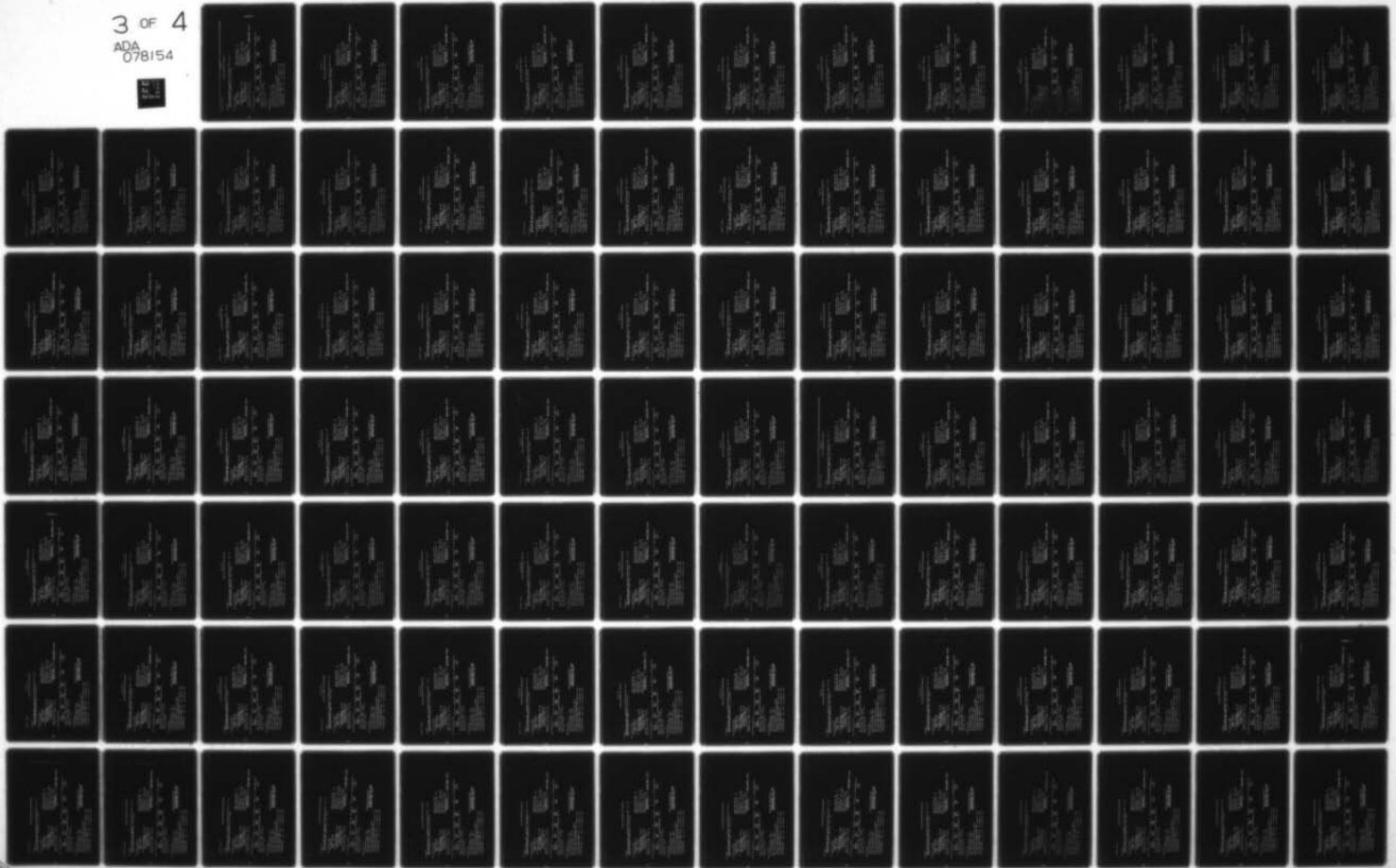
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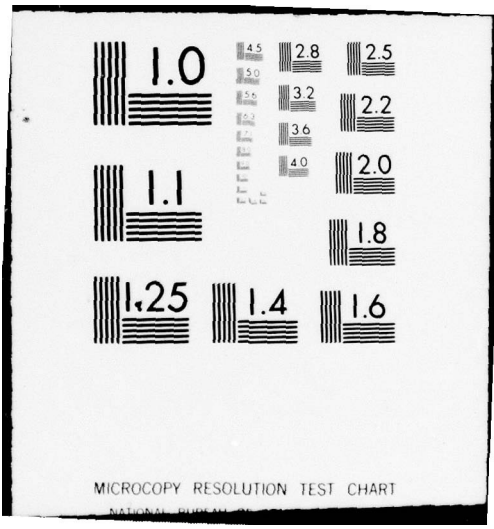
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3 OF 4

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MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A



RUN # 2

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 EXHAUST GAS TEMPERATURE: 742.0 F  
 EXHAUST GAS FLOW RATE: 32864.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.0 FT.  
 HEIGHT: 4.9 FT.

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 2.0 IN.  
 INSIDE TUBE DIAMETER: 1.9 IN.  
 TUBE LENGTH: 12.0 FT.  
 TUBE IN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 5.94 FINS/IN.  
 FIN HEIGHT: 1.0 IN.  
 FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.  
 LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 22.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 3264.9 SQ.FT.  
 INSIDE AREA/PASS: 187.5 SQ. FT.  
 FRONTAL AREA: 143.5 SQ. FT.  
 NUMBER OF PASSES: 15 (TOTAL)  
 HEATING SECTION: 5  
 BOILING SECTION: 8  
 SUPERHEATING SECTION: 2 (HEATING LENGTH= 3.5 FT.,  
 BOILING LENGTH= 0.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	545.7	464.4	200.0	508.9	14149.9
BOILING	715.2	545.7	508.9	518.3	
SUPERHEATING	742.1	715.2	518.3	641.3	108756.9

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 20105.6 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.7 IN H<sub>2</sub>O

PINCH POINT: 36.8 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 8356.1  
 STEAM TURBINE HORSEPOWER: 2656.5  
 TOTAL SYSTEM HORSEPOWER: 11012.6  
 STEAM TURBINE SHARE OF THE LOAD: 24.1 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.533 COGAS: 0.402 GT AT SYSTEM MP: 0.482  
 GT ONLY: 4431.8 COGAS: 4431.8 GT AT SYSTEM MP: 5305.8  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.261 COGAS: 0.344 GT AT SYSTEM MP: 0.287

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #3

WASTE HEAT RECOVERY UNIT DESIGN RUN

60/1775 11.52.26

GAS TURBINE

MAKЕ TURBOPUMP: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
 EXHAUST GAS TEMPERATURE: 689.0 F  
 EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS: 1.0 FT. NUMBER OF ROWS PER PASS: 1.  
 LENGTH: 12.0 FT. NUMBER OF TUBES PER ROW: 32.  
 WEIGHT: 3.0 FT. TUBE LENGTH: 12. FT.  
 HEAT TRANSFER SURFACE OUTSIDE AREA/PASS: 3264.9 SQ.FT.  
 TUBE TYPE: 2.0 IN. INSIDE AREA/PASS: 187.5 SQ. FT.  
 TUBE WALL THICKNESS: 1.6 IN. FRCATAL AREA: 143.5 SQ. FT.  
 FIN TYPE: CEMENTED NUMBER OF PASSES: 11 (TOTAL)  
 FIN SPACING: 5.44 FINS/IN. HEATING SECTION: 3  
 FIN THICKNESS: 1.0 IN. ROLLING SECTION: 5  
 FIN TOLERANCE: 0.048 IN. SUPERHEATING SECTION: 3 (HEATING LENGTH= 4.0 FT.)  
 TRANSVERSE TUBE SPACING: 4.50 IN. (BOILING LENGTH= 4.5 FT.)  
 LONGITUDINAL TUBE SPACING: 3.90 IN.

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	541.6	483.0	200.0	502.0	5039.6
BOILING	530.2	511.6	502.0	518.3	
SUPERHEATING	687.6	630.2	518.3	640.0	40286.1

STEAM PRESSURE: 800.0 PSIA SATURATION TEMPERATURE= 518.3 F)  
 STEAM FLOW RATE: 7236.4 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 0.3 IN H2O  
 PINCH POINT: 39.6 F

SYSTEM PERFORMANCE

GT HEAT RECOVERY EFFICIENCY: 1000.5  
 STEAM TURBINE EFFICIENCY: 955.2  
 TOTAL SYSTEM EFFICIENCY: 2615.7  
 STEAM TURBINE SHARE OF THE LOAD: 36.5 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT TUBE: 1.004 COGAS: 0.615 GT AT SYSTEM HP: 0.890  
 FUEL CONSUMPTION (LBM-FUEL/HR):  
 GT TUBE: 1766.0 COGAS: 1766.0 GT AT SYSTEM HP: 2327.9  
 THERMAL EFFICIENCY:  
 GT TUBE: 0.113 COGAS: 0.205 GT AT SYSTEM HP: 0.155

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.895  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV CF FUEL: 18400 BTU/LB

RUN #4

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

EXHAUST TEMPERATURE: 1642.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
 EXHAUST GAS TEMPERATURE: 849.0 F  
 EXHAUST GAS FLOW RATE: 407509.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.1 FT.  
 HEIGHT: 3.5 FT.

HEAT TRANSFER SURFACE: 1.5 IN.  
 IN-TUBE DIAMETER: 1.4 IN.  
 TUBE IN ARRANGEMENT:  
 TUBE TYPE: SERPENTINE  
 FIN TYPE: UNFINISHED  
 FIN SPACING: 7.92 FMS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.39 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 43.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 3290.5 SQ.FT.  
 INSIDE AREA/PASS: 189.0 SQ. FT.  
 FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 16 (TOTAL)  
 HEATING SECTION: 7  
 BOILING SECTION: 7  
 SUPERHEATING SECTION: 2  
 (HEATING LENGTH= 0.0 FT.)  
 (BOILING LENGTH= 5.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	521.2	421.0	200.0	518.3	27356.4
BOILING	743.9	518.3	518.3	518.3	213355.1
SUPERHEATING	348.3	743.9	518.3	641.3	

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)  
 STEAM FLOW RATE: 38997.2 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 6.0 IN H2O  
 PRESSURE: 32.3 F

SYSTEM PERFORMANCE

GT COPPER (REVISED): 16016.4  
 STEAM TURBINE HORSEPOWER: 5099.7  
 TOTAL SYSTEM HORSEPOWER: 28116.1  
 STEAM FURFRAKE SHARE OF THE LOAD: 24.2 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT #1: 0.437  
 GT #2: 0.331  
 FULL CONSUMPTION (LBM-FUEL/HR):  
 GT #1: 8952.7  
 GT #2: 6992.7  
 THERMAL EFFICIENCY:  
 GT #1: 0.317  
 GT #2: 0.354  
 GT AT SYSTEM HP: 0.391  
 GT AT SYSTEM HP: 8257.0  
 GT AT SYSTEM HP: 0.354

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATED PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LB

RUN #5

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 6626.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 EXHAUST GAS TEMPERATURE: 747.0  
 EXHAUST GAS FLOW RATE: 328691.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.1 FT.  
 HEIGHT: 2.9 FT.

FEAT TRANSFER SURFACE:  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 TUBE LENGTH: 12.0 FT.  
 TUBE FIN TRANSPIRENCY: 1.4 IN.  
 FIN TYPE: RECTANGULAR  
 FIN SPACING: 0.92 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.33 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 43.  
 TUBE LENGTH: 12.0 FT.  
 OUTSIDE AREA/PASS: 3250.5 SQ.FT.  
 INSIDE AREA/PASS: 189.0 SQ. FT.  
 FRONTAL AREA: 144.8 SQ. FT.  
 NUMBER OF PASSES: 12 (TOTAL)  
 HEATING SECTION: 4  
 COOLING SECTION: 4  
 SUPERHEATING SECTION: 2  
 (HEATING LENGTH= 2.1 FT.)  
 (COOLING LENGTH= 3.4 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	567.5	200.0	511.4	511.4	14023.8
COOLING	281.5	318.3	518.3	518.3	109056.4
SUPERHEATING	740.6	518.3	518.3	518.3	

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)  
 STEAM FLOW RATE: 19998.8 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 3.1 IN H2O  
 FINN PITCH: 30.1 F

SYSTEM PERFORMANCE

GT WORK EFFICIENCY (REVISED): 8366.5  
 STEAM TURBINE HORSEPOWER: 2629.1  
 TOTAL SYSTEM HORSEPOWER: 10995.6  
 STEAM TURBINE SHARE OF THE LOAD: 23.9 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.403  
 COGAS: 0.403  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 4432.5  
 COGAS: 4432.5  
 GT AT SYSTEM HP: 5300.1  
 COGAS: 5300.1  
 GT AT SYSTEM HP: 0.287  
 COGAS: 0.287

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 EXHAUST GAS PRESSURE: 0.0 PSIA  
 LHM OF FUEL: 18400 BTU/LBM

RUN #6

WASTE HEAT RECOVERY UNIT DESIGN RLM

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
 EXHAUST GAS TEMPERATURE: 689.0 F  
 EXHAUST GAS FLOW RATE: 159731.0 LB/HR (44.4 LB/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS: FT.  
 LENGTH: 12.0  
 HEIGHT: 12.2  
 WIDTH: 2.2

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE FIN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 7.92 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.36 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 43.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 3290.5 SQ. FT.  
 INSIDE AREA/PASS: 189.0 SQ. FT.  
 FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)  
 HEATING SECTION: 2  
 BOILING SECTION: 2  
 SUPERHEATING SECTION: 5  
 (HEATING LENGTH= 2.4 FT.)  
 (BOILING LENGTH= 1.2 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	537.5	482.5	200.0	484.5	4874.5
BOILING	659.1	537.5	444.5	518.3	38746.0
SUPERHEATING	688.5	658.1	518.3	646.3	

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 7253.1 LB/HR.

GAS-SIDE PRESSURE DROP: 0.6 IN H<sub>2</sub>O

PUMP PWR: 23.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 1660.9

STEAM TURBINE HORSEPOWER: 962.1

TOTAL SYSTEM HORSEPOWER: 2623.1

STEAM TURBINE SHARE OF THE LOAD: 36.7 PERCENT

SPECIFIC FUEL CONSUMPTION (LBP-FUEL/HP-HR):  
 GT ONLY: 1.005  
 CUMAS: 0.673  
 GT AT SYSTEM HP: 0.889

FUEL CONSUMPTION (LBP-FUEL/HR):  
 GT ONLY: 1766.1  
 CUMAS: 1766.1  
 GT AT SYSTEM HP: 2331.6

THERMAL EFFICIENCY:  
 GT ONLY: 0.133  
 CUMAS: 0.205  
 GT AT SYSTEM HP: 0.156

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LB

RUN #7

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
 EXHAUST GAS TEMPERATURE: 849.0 F  
 EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 16.0 FT.  
 HEIGHT: 2.1 FT.

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.0 IN.  
 INSIDE TUBE DIAMETER: 0.9 IN.  
 TUBE WALL ASSIGNMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 11.88 FINS/IN.  
 FIN HEIGHT: 0.5 IN.  
 FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.  
 LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 64.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 3264.9 SQ. FT.  
 INSIDE AREA/PASS: 187.5 SQ. FT.  
 FPCATAL AREA: 143.8 SQ. FT.  
 NUMBER OF PASSES: 13 (TOTAL)  
 HEATING SECTION: 5  
 BOILING SECTION: 7  
 SUPERHEATING SECTION: 1

HEATING LENGTH: 4.5 FT.  
 BOILING LENGTH: 6.2 FT.

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	540.5	514.2	200.0	504.5	27409.0
BOILING	809.1	540.5	504.5	518.3	203528.9
SUPERHEATING	853.5	809.1	518.3	653.1	

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)  
 STEAM FLOW RATE: 39189.5 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 5.3 IN H2O  
 PINCH POINT: 36.0 F

SYSTEM PERFORMANCE

GT WORKFLOW (REVISED): 16040.5  
 STEAM TURBINE HORSEPOWER: 5226.6  
 TOTAL SYSTEM HORSEPOWER: 21267.1  
 STEAM TURBINE SHARE OF THE LOAD: 24.6 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.436  
 COGAS: 0.329  
 GT AT SYSTEM HP: 0.381  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 6975.9  
 COGAS: 6995.9  
 GT AT SYSTEM HP: 8238.4  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.317  
 COGAS: 0.420  
 GT AT SYSTEM HP: 0.357

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FM HEATER PRESSURE: 13.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #8

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRINE HORSEPOWER: 4526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 FUEL CONSUMPTION: 742.0 LBM/HR (91.3 LBM/SEC)  
 EXHAUST GAS FLOW RATE: 328681.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.0 FT.  
 HEIGHT: 1.5 FT.

HEAT EXCHANGER SURFACE:  
 OUTSIDE DIAMETER: 1.0 IN.  
 INSIDE DIAMETER: 0.9 IN.  
 TUBE LENGTH: 12.0 FT.  
 TUBE TYPE: SMOOTH  
 FIN TYPE: SCREWED  
 FIN SPACING: 11.88 FINS/IN.  
 FIN HEIGHT: 0.5 IN.  
 FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.  
 LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 64.  
 TUBE LENGTH: 12. FT.

OUTSIDE AREA/PASS: 3266.9 SQ.FT.  
 INSIDE AREA/PASS: 187.5 SQ. FT.  
 FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)  
 HEATING SECTION: 3  
 BOILING SECTION: 4  
 SUPERHEATING SECTION: 2  
 (FEATING LENGTH= 1.2 FT.)  
 (BOILING LENGTH= 5.6 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
FEATING	549.4	514.4	200.0	514.5	14117.1
BOILING	649.5	514.5	514.5	518.3	111551.0
SUPERHEATING	740.8	649.5	518.3	638.8	

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)  
 STEAM FLOW RATE: 1582.0 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 2.5 IN H2O  
 PINCH POINT: 34.8 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 8376.2  
 STEAM TURBINE HORSEPOWER: 2623.0  
 TOTAL SYSTEM HORSEPOWER: 10999.1  
 STEAM TURBINE SHARE OF THE LOAD: 23.8 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.527 CUMAS: 0.403 GT AT SYSTEM HP: 0.482  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 4433.9 CUMAS: 4433.9 GT AT SYSTEM HP: 5301.3  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.211 CUMAS: 0.343 GT AT SYSTEM HP: 0.287

ASSUMED SYSTEM CHARACTERISTICS:  
 CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #9

WASTE HEAT RECOVERY UNIT DESIGN RUN

DESIGN DATA

DESIGN GAS FLOW: 1049.0, APPROXIMATE CORRESPONDING SHIP SPEED: 5.0 KTS  
 DESIGN GAS TEMPERATURE: 212.0 F  
 DESIGN GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

NUMBER OF TUBES: 64  
 TUBE LENGTH: 12.0 FT.  
 TUBE ID: 1.315 IN.  
 TUBE OD: 1.315 IN.

HEAT EXCHANGER TYPE: SHELL AND TUBE  
 SHELL TYPE: SINGLE PASS  
 TUBE PASS: 1.0 IN.  
 TUBE SPACING: 0.9 IN.  
 SHELL ID: 12.0 FT.  
 SHELL OD: 12.0 FT.  
 SHELL WALL THICKNESS: 0.375 IN.  
 SHELL WEIGHT: 2.25 IN.  
 SHELL INSULATION: 1.95 IN.

DESIGN GAS FLOW: 1049.0 LBM/HR  
 DESIGN GAS TEMPERATURE: 212.0 F

HEAT EXCHANGER PERFORMANCE

DESIGN GAS FLOW: 1049.0 LBM/HR  
 DESIGN GAS TEMPERATURE: 212.0 F  
 DESIGN GAS PRESSURE: 15.0 PSIA  
 DESIGN GAS VISCOSITY: 0.029 CP  
 DESIGN GAS DENSITY: 0.075 LB/FT<sup>3</sup>  
 DESIGN GAS PRANDTL NUMBER: 0.707  
 DESIGN GAS THERMAL CONDUCTIVITY: 0.015 BTU/HR-FT-DEG F  
 DESIGN GAS SPECIFIC HEAT: 0.24 BTU/LB-DEG F  
 DESIGN GAS PRANDTL NUMBER: 0.707  
 DESIGN GAS THERMAL CONDUCTIVITY: 0.015 BTU/HR-FT-DEG F  
 DESIGN GAS SPECIFIC HEAT: 0.24 BTU/LB-DEG F

SYSTEM CHARACTERISTICS

DESIGN GAS FLOW: 1049.0 LBM/HR  
 DESIGN GAS TEMPERATURE: 212.0 F  
 DESIGN GAS PRESSURE: 15.0 PSIA  
 DESIGN GAS VISCOSITY: 0.029 CP  
 DESIGN GAS DENSITY: 0.075 LB/FT<sup>3</sup>  
 DESIGN GAS PRANDTL NUMBER: 0.707  
 DESIGN GAS THERMAL CONDUCTIVITY: 0.015 BTU/HR-FT-DEG F  
 DESIGN GAS SPECIFIC HEAT: 0.24 BTU/LB-DEG F  
 DESIGN GAS PRANDTL NUMBER: 0.707  
 DESIGN GAS THERMAL CONDUCTIVITY: 0.015 BTU/HR-FT-DEG F  
 DESIGN GAS SPECIFIC HEAT: 0.24 BTU/LB-DEG F

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 64.  
 TUBE LENGTH: 12.0 FT.  
 OUTSIDE AREA/PASS: 3264.9 SQ. FT.  
 INSIDE AREA/PASS: 187.5 SQ. FT.  
 FRONTAL AREA: 143.8 SQ. FT.  
 NUMBER OF PASSES: 7 (TOTAL)  
 HEATING SECTION: 2  
 COOLING SECTION: 2  
 SUPERHEATING SECTION: 2  
 (HEATING LENGTH= 1.3 FT.)  
 (COOLING LENGTH= 4.3 FT.)

FLUID TEMP. IN: 200.0  
 FLUID TEMP. OUT: 518.3  
 REYNOLDS NUMBER (AVG.): 5135.4  
 PRANDTL NUMBER (AVG.): 0.707

ASSUMED SYSTEM CHARACTERISTICS

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHM CF FUEL: 18400 BTU/LHM

DESIGN GAS FLOW: 1049.0 LBM/HR  
 DESIGN GAS TEMPERATURE: 212.0 F  
 DESIGN GAS PRESSURE: 15.0 PSIA  
 DESIGN GAS VISCOSITY: 0.029 CP  
 DESIGN GAS DENSITY: 0.075 LB/FT<sup>3</sup>  
 DESIGN GAS PRANDTL NUMBER: 0.707  
 DESIGN GAS THERMAL CONDUCTIVITY: 0.015 BTU/HR-FT-DEG F  
 DESIGN GAS SPECIFIC HEAT: 0.24 BTU/LB-DEG F  
 DESIGN GAS PRANDTL NUMBER: 0.707  
 DESIGN GAS THERMAL CONDUCTIVITY: 0.015 BTU/HR-FT-DEG F  
 DESIGN GAS SPECIFIC HEAT: 0.24 BTU/LB-DEG F

RUN #10

WASTE HEAT RECOVERY UNIT DESIGN RUN

08/22/79 12-18-18

GAS TURBINE

SHAFT SPEED/RPM: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
 INLET GAS TEMPERATURE: 849.0 F  
 EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER CEMENTITY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.0 FT.  
 HEIGHT: 6.2 FT.

HEAT TRANSFER SURFACE:  
 OUTSIDE TUBE DIAMETER: 2.0 IN.  
 TUBE CORE DIAMETER: 1.5 IN.  
 TUBE LENGTH: 12.0 FT.  
 TUBE SPACING: 1.0 IN.  
 FIN SPACING: 0.648 IN.  
 FIN HEIGHT: 1.0 IN.  
 FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.  
 LONGITUDINAL TUBE SPACING: 1.70 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 32.  
 TUBE LENGTH: 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.  
 INSIDE AREA/PASS: 187.5 SQ. FT.  
 FRONTAL AREA: 143.5 SQ. FT.

NUMBER OF PASSES: 19 (TOTAL)  
 HEATING SECTION: 8  
 BOILING SECTION: 9  
 SUPERHEATING SECTION: 2 (HEATING LENGTH= 9.3 FT.)  
 (BOILING LENGTH= 2.5 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	724.5	604.5	200.0	486.3	26712.4
BOILING	724.5	523.5	486.3	486.3	
SUPERHEATING	724.5	773.3	486.3	631.3	224266.2

STEAM PRESSURE: 630.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM FLOW RATE: 19498.7 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 6.7 IN H2O  
 PITCH POINT: 37.2 F

SYSTEM PERFORMANCE

CT ACCEPTANCE (REVISED): 15993.3  
 STEAM TURBINE WORK/SEC: 5072.3  
 TOTAL SYSTEM WORK/SEC: 21065.6  
 STEAM TURBINE SHARE OF THE LOAD: 24.1 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.437 COGAS: 0.332 GT AT SYSTEM HP: 0.392  
 FUEL CONSUMPTION (LBM-FUEL/SEC):  
 GT ONLY: 6265.5 COGAS: 6269.5 GT AT SYSTEM HP: 8261.2  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.310 COGAS: 0.417 GT AT SYSTEM HP: 0.353

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FUEL HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #11

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 6524.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 EXHAUST GAS TEMPERATURE: 742.0 F  
 EXHAUST GAS FLOW RATE: 32064.0 LB/HR ( 91.3 LPM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.0 FT.  
 HEIGHT: 5.5 FT.  
 HEAT TRANSFER SURFACE:  
 OUTSIDE TUBE DIAMETER: 2.0 IN.  
 INSIDE TUBE DIAMETER: 1.9 IN.  
 TUBE FIN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 5.54 FINS/IN.  
 FIN HEIGHT: 1.0 IN.  
 FIN THICKNESS: 0.048 IN.  
 TRANSVERSE TUBE SPACING: 4.50 IN.  
 LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 32.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 3244.5 SQ.FT.  
 INSIDE AREA/PASS: 187.5 SQ. FT.  
 FFONTAL AREA: 143.5 SQ. FT.  
 NUMBER OF PASSES: 17. (TOTAL)  
 HEATING SECTION: 6  
 BOILING SECTION: 8  
 SUPERHEATING SECTION: 3 (HEATING LENGTH= 0.3 FT.)  
 (BOILING LENGTH= 4.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	513.4	430.5	200.0	486.3	15018.2
BOILING	666.9	513.4	486.3	486.3	
SUPERHEATING	740.7	666.9	486.3	636.3	129121.1

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM FLOW RATE: 22200.9 LB/HR.  
 GAS-SEIF PRESSURE DROP: 4.1 IN H2O  
 PINCH POINT: 27.1 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 8155.2  
 STEAM TURBINE HORSEPOWER: 2062.3  
 TOTAL SYSTEM HORSEPOWER: 11211.4  
 STEAM TURBINE SHARE OF THE LOAD: 25.5 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LHV-FUEL/HP-HR):  
 GT ONLY: 0.221 COGAS: 0.395 GT AT SYSTEM HP: 0.479  
 FUEL CONSUMPTION (LHV-FUEL/HP-HR):  
 GT ONLY: 443.1 COGAS: 431.1 GT AT SYSTEM HP: 5371.5  
 TURBINE EFFICIENCY:  
 GT ONLY: 0.261 COGAS: 0.350 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FM HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #12

WASTE HEAT RECOVERY UNIT DESIGN RLN

GAS TURBINE

BRASE DISSEPERMENT: 1694.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
 EXHAUST GAS TEMPERATURE: 680.0 F  
 EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 15.0 FT.  
 HEIGHT: 3.9 FT.

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 2.0 IN.  
 INSIDE TUBE DIAMETER: 1.9 IN.  
 TUBE/FIN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 5.94 FIN/IN.  
 FIN HEIGHT: 1.0 IN.  
 FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.  
 LONGITUDINAL TUBE SPACING: 3.00 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 32.  
 TUBE LENGTH: 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.  
 INSIDE AREA/PASS: 187.5 SQ. FT.  
 FRONTAL AREA: 143.5 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)  
 HEATING SECTION: 3  
 COOLING SECTION: 3  
 SUPERHEATING SECTION: 6  
 (HEATING LENGTH= 4.9 FT.)  
 (COOLING LENGTH= 2.1 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	504.1	492.4	200.0	466.3	5427.1
COOLING	643.2	508.1	466.3	486.3	47057.9
SUPERHEATING	580.3	643.2	486.3	642.5	

STEAM PRESSURE: 600.0 PSIA SATURATION TEMPERATURE= 486.3 F  
 STEAM FLOW RATE: 8286.4 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 0.8 IN H2O  
 PINCH POINT: 41.3 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 1660.4  
 STEAM TURBINE HORSEPOWER: 1072.9  
 TOTAL SYSTEM HORSEPOWER: 2733.3  
 STEAM TURBINE SHARE OF THE LOAD: 39.3 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 1.064 COGAS: 0.646 GT AT SYSTEM MPI: 0.873  
 FULL LOAD SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 1.762 C COGAS: 1.766.0 GT AT SYSTEM MPI: 2385.9  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.131 COGAS: 0.214 GT AT SYSTEM MPI: 0.158

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 COOLING WATER FLOW RATE: 1000 GPM  
 COOLING WATER TEMPERATURE: 60 F  
 EXHAUST GAS PRESSURE: 5.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #13

WASTE HEAT RECOVERY UNIT DESIGN RUN

08/22/75 11:40:51

GAS TURBINE

RPM: 16821.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
 EXHAUST GAS TEMPERATURE: 849.0 F  
 EXHAUST GAS FLOW RATE: 437589.0 LB/HR (1113.2 LB/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:

LENGTH: 12.0 FT.  
 WIDTH: 12.1 FT.  
 HEIGHT: 3.7 FT.

HEAT EXCHANGER SURFACE

FINNED TUBE DIAMETER: 1.5 IN.  
 FINNED TUBE LENGTH: 1.4 IN.  
 TUBE/ROW SPACING: 1.4 IN.  
 FIN TYPE: CONVOLUTED  
 FIN SPACING: 7.92 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.28 IN.

LONGITUDINAL TUBE SPACING: 2.52 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 43.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 3290.5 SQ.FT.  
 INSIDE AREA/PASS: 189.0 SQ. FT.  
 FPCNTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 15 (TOTAL)  
 HEATING SECTION: 6  
 ROLLING SECTION: 7  
 SUPERHEATING SECTION: 2

(HEATING LENGTH= 9.2 FT.)  
 (ROLLING LENGTH= 4.1 FT.)

HEAT EXCHANGE PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	924.5	407.5	200.0	493.8	26226.9
ROLLING	743.6	524.5	483.8	483.8	
SUPERHEATING	849.0	743.6	486.3	642.5	223123.8

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 39239.4 LB/HR.

GAS-SIDE PRESSURE DROP: 5.6 IN H2O

PIPE PAINT: 90.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 10031.2

STEAM TURBINE HORSEPOWER: 5080.8

TOTAL SYSTEM HORSEPOWER: 21112.0

STEAM TURBINE SHARE OF THE LOAD: 24.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LHV-FUEL/HP-HR):

GT ONLY: 0.436 COGAS: 0.351 GT AT SYSTEM HPI: 0.391

FULL COMBUSTION (LHV-FUEL/HP-HR):

GT ONLY: 0.394.7 COGAS: 0.294.6 GT AT SYSTEM HPI: 0.257.6

THERMAL EFFICIENCY:

GT ONLY: 0.317 COGAS: 0.417 GT AT SYSTEM HPI: 0.354

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 Btu/LHV

RUN #14

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 6526.01 APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 EXHAUST GAS TEMPERATURE: 742.0 F  
 EXHAUST GAS FLOW RATE: 320641.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.1 FT.  
 HEIGHT: 3.2 FT.  
 HEAT TRANSFER SURFACE:  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE LENGTH: 12.0 FT.  
 FIN TYPE: TOE ELEMENT  
 FIN THICKNESS: 7.92 FINS/IN.  
 FIN SPACING: 0.8 IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.  
 TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 43.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 3250.5 SQ.FT.  
 INSIDE AREA/PASS: 189.0 SQ. FT.  
 FRONTAL AREA: 144.8 SQ. FT.  
 NUMBER OF PASSES: 13 (TOTAL)  
 HEATING SECTION: 7  
 BOILING SECTION: 2  
 SUPERHEATING SECTION: 2 (HEATING LENGTH= 3.5 FT.)  
 (BOILING LENGTH= 2.1 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	512.1	433.5	200.0	475.0	14511.6
BOILING	512.1	512.1	475.0	482.3	
SUPERHEATING	741.2	687.4	486.3	637.3	122511.0

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM FLOW RATE: 21557.0 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 3.3 IN H2O  
 PINCH POINT: 37.1 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 8363.3  
 STEAM TURBINE HORSEPOWER: 2837.8  
 TOTAL SYSTEM HORSEPOWER: 11201.1  
 STEAM TURBINE SHARE OF THE LOAD: 25.3 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LHM-FUEL/HP-HR):  
 GT TURB: 0.533 CORRS: 0.396 GT AT SYSTEM HP: 0.475  
 FUEL CONSUMPTION (LHM-FUEL/HR.):  
 GT TURB: 4432.6 CORRS: 4432.6 GT AT SYSTEM HP: 5368.1  
 THERMAL EFFICIENCY:  
 GT TURB: 0.261 CORRS: 0.349 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:  
 CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FWH HEATER PRESSURE: 15.0 PSIA  
 LHM FCF FUEL: 18400 BTU/LHM

RUN #15

06/22/75 13.C1.14

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

NET HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
 EXHAUST TEMPERATURE: 1480.0 F  
 EXHAUST GAS FLOW RATE: 15973.0 LB/HR (44.4 LB/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.3 FT.  
 WIDTH: 12.1 FT.  
 HEIGHT: 2.2 FT.

HEAT TRANSFER SURFACE:  
 CONDENSER TUBE DIAMETER: 1.5 IN.  
 CONDENSER TUBE LENGTH: 1.4 IN.  
 CONDENSER TUBE QUANTITY: 43  
 FIN TYPE: UNIFORM  
 FIN SPACING: 7.92 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 43.  
 TUBE LENGTH: 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.  
 INSIDE AREA/PASS: 189.0 SQ. FT.  
 FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)  
 HEATING SECTION: 2  
 ROLLING SECTION: 5  
 SUPERHEATING SECTION: 2 (HEATING LENGTH= 4.7 FT.)  
 (ROLLING LENGTH= 6.5 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	511.2	456.5	200.0	456.3	5146.9
ROLLING	259.2	259.2	428.3	428.3	44097.8
SUPERHEATING	687.9	654.5	486.3	486.3	

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 6043.7 LB/HR.

GAS-SIDE PRESSURE DROP: 0.6 IN H2O

PINCH POINT: 54.5 F

SYSTEM PERFORMANCE

GT CORRECTION REVERSE: 1661.0

STEAM TURBINE HORSEPOWER: 1039.6

TOTAL SYSTEM HORSEPOWER: 2700.5

STEAM TURBINE SHARE OF THE LTAC: 38.5 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):

GT ONLY: 1.063  
 CO2 GAS: 0.654  
 GT AT SYSTEM HP: 0.878

FUEL CONSUMPTION (LBM-FUEL/HR):

GT ONLY: 1728.1  
 CO2 GAS: 1166.1  
 GT AT SYSTEM HP: 2370.0

THERMAL EFFICIENCY:

GT ONLY: 0.133  
 CO2 GAS: 0.211  
 GT AT SYSTEM HP: 0.158

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FM HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

08/22/79 13.16.58

WASTE HEAT RECOVERY UNIT DESIGN RUN

CAS TURBINE

BRAKE HORSEPOWER: 1421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
 EXHAUST GAS TEMPERATURE: 849.0 F  
 EXHAUST GAS FLOW RATE: 437589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.0 FT.  
 HEIGHT: 2.0 FT.

HEAT TRANSFER SURFACE:  
 OUTSIDE TUBE DIAMETER: 1.0 IN.  
 INSIDE TUBE DIAMETER: 0.9 IN.  
 TUBE LENGTH: 12.0 FT.  
 TUBE TO TUBE SPACING: 0.5 IN.  
 FIN SPACING: 1.0 IN.  
 FIN HEIGHT: 0.5 IN.  
 FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.  
 LONGITUDINAL TUBE SPACING: 1.05 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 64.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 3264.9 SQ.FT.  
 INSIDE AREA/PASS: 187.5 SQ. FT.  
 FRONTAL AREA: 143.6 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)  
 HEATING SECTION: 4  
 BOILING SECTION: 4  
 SUPERHEATING SECTION: 2 (HEATING LENGTH= 5.7 FT.)  
 (BOILING LENGTH= 5.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	510.9	401.5	200.0	462.5	25925.0
BOILING	707.6	510.9	462.5	486.3	230765.6
SUPERHEATING	854.1	707.6	486.3	665.0	

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 39759.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.9 IN H<sub>2</sub>O

PINCH POINT: 48.6 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 16053.3  
 STEAM TURBINE HORSEPOWER: 5232.3  
 TOTAL SYSTEM HORSEPOWER: 21285.7  
 STEAM TURBINE SHARE OF THE LOAD: 24.6 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.436 COGAS: 0.329 GT AT SYSTEM HP: 0.387  
 FUEL CONSUMPTION (LBM-FUEL/HR):  
 GT ONLY: 6997.7 COGAS: 6997.7 GT AT SYSTEM HP: 8235.2  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.317 COGAS: 0.421 GT AT SYSTEM HP: 0.357

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LHM

CG/22/75 14.12.23

RUN #17

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

NET HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
EXHAUST GAS FLOW RATE: 742.0 LBM/HR  
EXHAUST GAS FLOW RATE: 32864.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
LENGTH: 12.0 FT.  
WIDTH: 12.0 FT.  
HEIGHT: 1.6 FT.

HEAT TRANSFER SURFACE:  
OUTSIDE TUBE DIAMETER: 1.3 IN.  
INSIDE TUBE DIAMETER: 0.9 IN.  
TUBE LENGTH: 12.0 FT.  
FIN SPACING: 0.118 IN.  
FIN HEIGHT: 0.2 IN.  
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.  
LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.  
NUMBER OF TUBES PER ROW: 64.

TUBE LENGTH: 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ. FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 10 (TOTAL)

HEATING SECTION: 3

BOILING SECTION: 5

SUPERHEATING SECTION: 2

(HEATING LENGTH= 2.5 FT.)  
(BOILING LENGTH= 4.9 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	512.9	436.0	200.0	416.3	14632.2
BOILING	242.9	212.0	488.3	488.3	
SUPERHEATING	740.4	644.5	488.3	835.0	126956.9

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
STEAM FLOW RATE: 21564.0 LBM/HR.  
GAS-SIDE PRESSURE DROP: 2.8 IN H2O  
PINPOINT: 36.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 8372.4  
STEAM TURBINE HORSEPOWER: 2828.4  
TOTAL SYSTEM HORSEPOWER: 11200.7  
STEAM TURBINE SHARE OF THE LOAD: 25.3 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
GT ONLY: 0.533 CGAS: 0.396 GT AT SYSTEM HP: 0.475

FUEL CONSUMPTION (LBM-FUEL/HR.):  
GT ONLY: 4433.5 CGAS: 4433.5 GT AT SYSTEM HP: 5368.0

THERMAL EFFICIENCY:  
GT ONLY: 0.261 CGAS: 0.349 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
STEAM TURBINE EFFICIENCY: 0.85  
FW HEATER PRESSURE: 15.0 PSIA  
LHV OF FUEL: 18400 BTU/LBM

08/22/79 14:21:00

RUN #18  
WASTE HEAT RECOVERY UNIT DESIGN RUN

G S TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
EXHAUST GAS TEMPERATURE: 689.0  
EXHAUST GAS FLOW RATE: 15931.0 LBM/HR ( 44.4 LBM/SEC)

HEA EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
LENGTH: 12.0 FT.  
WIDTH: 12.0 FT.  
HEIGHT: 1.1 FT.

HEAT TRANSFER SURFACE:  
OUTSIDE TUBE CLAVES: 1.0 IN.  
INSIDE TUBE CLAVES: 0.9 IN.  
TUBE/FIN ARRANGEMENT:  
FIN TYPE: SEGMENTED  
FIN SPACING: 11.88 FINS/IN.  
FIN HEIGHT: 0.5 IN.  
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.  
LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.  
NUMBER OF TUBES PER ROW: 64.  
TUBE LENGTH: 12. FT.  
OUTSIDE AREA/PASS: 3264.9 SQ.FT.  
INSIDE AREA/PASS: 187.5 SQ. FT.  
FRONTAL AREA: 143.8 SQ. FT.  
NUMBER OF PASSES: 7 (TOTAL)  
HEATING SECTION: 2  
BOILING SECTION: 3  
SUPERHEATING SECTION: 2 (HEATING LENGTH= 0.2 FT.,  
BOILING LENGTH= 4.4 FT.)

HEAT EXCHANGER PERFORMANCE

REC RUN GAS TEMP. IN G.S TEMP. OUT FLUID TEMP. IN FLUID TEMP. OUT REYNOLDS NUMBER (AVG.)  
HEATING: 519.2 458.0 200.0 486.3 5465.2  
BOILING: 605.8 519.2 486.3 486.3  
SUPERHEATING: 687.4 605.8 486.3 633.8 45654.2

STEAM PRESSURE: 600.0 PSI (SATURATION TEMPERATURE = 486.3 F)

STEAM FLOW RATE: 7792.5 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.5 IN H<sub>2</sub>O

PINCH POINT: 33.1 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 1661.4

STEAM TURBINE HOR EPICER: 1028.3

TOTAL SYSTEM HOR EPICER: 2689.7

STEAM TURBINE SHARE OF LOAD: 38.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):

GT ONLY: 1.663 COGAS: 0.857 GT AT SYSTEM MP: 0.879

GT ONLY: 1.766.2 COGAS: 1.765.2 GT AT SYSTEM MP: 2364.6

HEAT EXCHANGER EFFICIENCY:

GT ONLY: 0.130 COGAS: 0.211 GT AT SYSTEM MP: 0.157

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN HG  
STEAM TURBINE EFFICIENCY: 0.85  
FW HEATER PRESSURE: 15.0 PSIA  
LHV OF FUEL: 18400 BTU/LBM

RUN #19

WASTE HEAT RECOVERY UNIT DESIGN RUN

08/22/79 14.35.21

GAS TURBINE

FRAME HIPSER WEE: 14421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 MTS  
 EXHAUST GAS TEMPERATURE: 899.0 F/WHR  
 EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (1113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.0 FT.  
 HEIGHT: 4.0 FT.

HEAT TRANSFER SURFACE:  
 TUBE DIAMETER: 2.0 IN.  
 TUBE LENGTH: 12.0 FT.  
 TUBE/FIN ARRANGEMENT: 1-9 IN.  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 5.94 FINS/IN.  
 FIN HEIGHT: 1.0 IN.  
 FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.00 IN.  
 LONGITUDINAL TUBE SPACING: 3.99 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 32.  
 TUBE LENGTH: 12.0 FT.  
 OUTSIDE AREA/PASS: 3264.9 SQ. FT.  
 INSIDE AREA/PASS: 187.5 SQ. FT.  
 FRONTAL AREA: 143.5 SQ. FT.  
 NUMBER OF PASSES: 15 (TOTAL)  
 HEATING SECTION: 5  
 BOILING SECTION: 8  
 SUPERHEATING SECTION: 2

(HEATING LENGTH = 4.3 FT.)  
 (BOILING LENGTH = 1.1 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	599.0	405.5	200.0	427.1	23808.5
BOILING	787.7	499.3	427.1	444.6	
SUPERHEAT	849.9	787.7	444.6	640.0	227181.1

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE = 444.6 F)  
 STEAM FLOW RATE: 38942.0 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 5.3 IN H2O  
 FLOW RATE: 71.9 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 16039.5  
 STEAM TURBINE HORSEPOWER: 4821.6  
 TOTAL SYSTEM HORSEPOWER: 20861.1  
 STEAM TURBINE SHARE OF THE LOAD: 23.1 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.433 COGAS: 0.2335 GT AT SYSTEM MPI: 0.396  
 FUEL CONSUMPTION (LBM-FUEL/HR):  
 GT ONLY: 6995.8 COGAS: 6995.8 GT AT SYSTEM MPI: 0.271-2  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.317 COGAS: 0.412 GT AT SYSTEM MPI: 0.345

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #20

08/22/79 14.56.50

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSE POWER: 8524.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 EXHAUST GAS TEMPERATURE: 742.0  
 EXHAUST GAS FLOW RATE: 378641.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.0 FT.  
 HEIGHT: 5.2 FT.

HEAT RAN FER SURFACE  
 OUTSIDE TUBE DIAMETER: 2.0 IN.  
 INSIDE TUBE DIAMETER: 1.9 IN.  
 TUBE WALL THICKNESS: 0.048 IN.  
 FIN TYPE: UNLIMITED  
 FIN SPACING: 5.94 FINS/IN.  
 FIN HEIGHT: 1.0 IN.  
 FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.  
 LONGITUDINAL TUBE PACING: 3.93 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 32.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 3264.9 SQ.FT.  
 INSIDE AREA/PASS: 187.5 SQ. FT.  
 FRONTAL AREA: 143.5 SQ. FT.

NUMBER OF PASSES: 16 (TOTAL)  
 HEATING SECTION: 8  
 BOILING SECTION: 8  
 SUPERHEATING SECTION: 3  
 (HEATING LENGTH = 3.3 FT.)  
 (BOILING LENGTH = 3.2 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	676.9	403.5	200.0	434.6	14730.3
BOILING	672.2	476.9	434.6	444.6	
SUPERHEATING	741.3	672.2	444.6	637.5	143729.1

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE = 444.6 F)

STEAM FLOW RATE: 23807.4 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.8 IN H<sub>2</sub>O

PINCH POINT: 42.4 F

SYSTEM PERFORMANCE

GT HP/SEHPMER (REVISED): 8354.6

STEAM TURBINE HORSEPOWER: 2942.6

TOTAL SYSTEM HORSEPOWER: 11297.3

STEAM TURBINE SHARE OF THE LOAD: 26.0 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):

GT ONLY: 0.230 COGAS: 0.352 GT AT SYSTEM HP: 0.478

FUEL CONSUMPTION (LBM-FUEL/HR):

GT ONLY: 4431.7 COGAS: 4431.7 GT AT SYSTEM HP: 5399.8

THERMAL EFFICIENCY:

GT: 0.281 COGAS: 0.353 GT AT SYSTEM HP: 0.285

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FWH HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #21

08/22/79 15.19.43

WASTE HEAT RECOVERY UNIT DESIGN RUN

G/S TURBINE

BRAKE HOR EPWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
 EXHAUST GAS TEMPERATURE: 689.0 F  
 EXHAUST GAS FLOW RATE: 15931.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.0 FT.  
 HEIGHT: 4.2 FT.

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 2.0 IN.  
 INSIDE TUBE DIAMETER: 1.9 IN.  
 TUBE/FIN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN PITCH: 5.9% FINS/IN.  
 FIN HEIGHT: 1.0 IN.  
 FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.  
 LONGITUDINAL TUBE PACING: 3.9) IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 32.  
 TUBE LENGTH 12. FT.  
 OUTSIDE AREA/PASS: 3264.9 SQ.FT.  
 INSIDE AREA/PASS: 187.5 SQ. FT.  
 FRONTAL AREA: 143.5 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)  
 HEATING SECTION: 4  
 BOILING SECTION: 4  
 SUPERHEATING SECTION: 5

(HEATING LENGTH = 0.7 FT.)  
 (BOILING LENGTH = 1.8 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	G/S TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	472.8	410.5	200.0	442.7	5951.7
BOILING	639.5	412.8	442.7	444.6	
SUPERHEATING	687.8	636.5	444.6	635.0	56273.6

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE = 444.6 F)  
 STEAM FLOW RATE: 9494.3 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 0.8 IN 120  
 PINCH PCIN: 30.1 F

SYSTEM PERFORMANCE

GT WORK POWER (REVISED): 1660.3  
 STEAM TURBINE HOR EPWER: 1171.5  
 TOTAL SYSTEM HOR EPWER: 2831.8  
 STEAM TURBINE SHARE OF THE LOAD: 41.4 PERCENT

PUMP FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 1.06% COGAS: 0.52% GT A SYSTEM HP: 0.859  
 FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 1706.0 COGAS: 1766.0 GT A SYSTEM HP: 2432.8

THERMAL EFFICIENCY:  
 GT ONLY: 0.13) COGA: 0.222 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:  
 CONDENSER PRESSURE: 4.08 IN HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 PUMP HEATER PRESSURE: 13.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #22

08/22/79 16.39.47

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
 EXHAUST GAS TEMPERATURE: 849.0  
 EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSION:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.8 FT.  
 HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE:  
 TUBE/INCH DIAMETER: 1.5 IN.  
 TUBE/INCH DIAMETER: 1.4 IN.  
 TUBE/FIN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 7.92 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE PACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 43.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 3290.5 SQ. FT.  
 INSIDE AREA/PASS: 189.0 SQ. FT.  
 FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)  
 HEATING SECTION: 4  
 BOILING SECTION: 6  
 SUPERHEATING SECTION: 2

(HEATING LENGTH: 3.4 FT.)  
 (BOILING LENGTH: 3.5 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	499.2	405.5	200.0	427.7	23652.1
BOILING	744.9	499.2	427.7	444.6	444.6
SUPERHEATING	848.6	744.9	444.6	635.0	231167.1

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 38942.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.4 IN. H<sub>2</sub>O

PINCH POINT: 71.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 16068.7

STEAM TURBINE HORSEPOWER: 4804.9

TOTAL SYSTEM HORSEPOWER: 20873.6

STEAM TURBINE SHARE OF THE LOAD: 23.0 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):

GT ONLY: 0.436 COGAS: 0.335 GT AT SYSTEM HP: 0.396

FUEL CONSUMPTION (LBM-FUEL/HR.):

GT ONLY: 6949.8 COGAS: 6999.8 GT AT SYSTEM HP: 8270.7

THEMPL EFFICIENCY:

GT ONLY: 0.317 COGAS: 0.412 GT AT SYSTEM HP: 0.345

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 EXHAUST GAS PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #23

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 EXHAUST TEMPERATURE: 742.0 F  
 EXHAUST GAS FLOW RATE: 32000.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.1 FT.  
 HEIGHT: 3.2 FT.  
 HEAT EXCHANGER SURFACE:  
 TUBE DIAMETER: 1.5 IN.  
 TUBE LENGTH: 12.0 FT.  
 TUBE TYPE: DIRECT  
 FIN TYPE: COMBINED  
 FIN SPACING: 0.92 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.  
 TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 43.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 3290.5 SQ.FT.  
 INSIDE AREA/PASS: 189.0 SQ. FT.  
 FRONTAL AREA: 144.8 SQ. FT.  
 NUMBER OF PASSES: 13 (TOTAL)  
 HEATING SECTION: 4  
 BOILING SECTION: 7  
 SUPERHEATING SECTION: 2 (HEATING LENGTH= 3.2 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
FEEDING	474.8	401.5	200.0	433.3	14658.9
BOILING	681.3	474.8	433.3	443.6	
SUPERHEATING	739.2	681.3	443.6	623.8	139551.1

STEAM PRESSURE: 430.0 PSIA (SATURATION TEMPERATURE= 444.6 F)  
 STEAM FLOW RATE: 23545.2 LBM/HR.  
 GAS - IDE PRESSURE DROP: 3.2 IN H2O  
 PUMP POINT: 41.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 8365.0  
 STEAM TURBINE HORSEPOWER: 2931.5  
 TOTAL SYSTEM HORSEPOWER: 11296.5  
 STEAM TURBINE SHARE OF THE LOAD: 26.0 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 G ONLY: 0.530  
 FUEL CONSUMPTION (LBM-FUEL/HR.): 4432.7  
 G ONLY: 4432.8  
 THERMAL EFFICIENCY: 0.461  
 C/D GAS: 0.352  
 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #24

WASTE HEAT RECOVERY UNIT DESIGN RUN

G S TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
 EXHAUST GAS TEMPERATURE: 489.0  
 EXHAUST GAS FLOW RATE: 159751.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.1 FT.  
 HEIGHT: 2.4 FT.

HEAT TRANSFER SURFACE  
 INSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE LENGTH: 1.4 IN.  
 TUBE FIN RANGE PERCENT:  
 FIN SPACING: 7.92 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 10 (TOTAL)

HEATING SECTION: 3

BOILING SECTION: 5

SUPERHEATING SECTION: 2

{ HEATING LENGTH= 1.2 FT. }  
 { BOILING LENGTH= 0.1 FT. }

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	473.8	412.4	200.0	440.2	5841.8
BOILING	658.9	475.8	440.2	440.2	53585.1
SUPERHEATING	688.5	658.9	444.6	632.9	

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)  
 STEAM FLOW RATE: 9425.4 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 0.7 IN H<sub>2</sub>O  
 PINCH POINT: 33.6 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 1660.9

STEAM TURBINE HORSEPOWER: 1161.0

TOTAL SYSTEM HORSEPOWER: 2821.9

STEAM TURBINE SHARE OF THE LOAD: 41.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):

GT ONLY: 1.063 COGAS: 0.626 GT AT SYSTEM HP: 0.860

FUEL CONSUMPTION (LBM-FUEL/HR.):

GT ONLY: 1766.1 COGAS: 1766.1 GT AT SYSTEM HP: 2420.1

THERMAL EFFICIENCY:

GT ONLY: 0.130 COGAS: 0.221 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #25

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
 EXHAUST GAS TEMPERATURE: 849.0 F  
 EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.0 FT.  
 HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.1 IN.  
 INSIDE TUBE DIAMETER: 0.9 IN.  
 TUBE/FIN ARRANGEMENT:  
 FIN TYPE: SEGMENTED FINS/IN.  
 FIN LENGTH: 11.88 IN.  
 FIN SPACING: 0.5 IN.  
 FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE PACING: 2.25 IN.  
 LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 64.  
 TUBE LENGTH: 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.  
 INSIDE AREA/PASS: 187.5 SQ. FT.  
 FRONTAL AREA: 143.8. SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)  
 HEATING SECTION: 3  
 BOILING SECTION: 3  
 SUPERHEATING SECTION: 1

(HEATING LENGTH= 8.3 FT.)  
 (BOILING LENGTH= 8.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	506.0	409.0	200.0	432.1	23810.6
BOILING	498.6	306.0	432.1	444.6	
SUPERHEATING	848.4	798.6	444.6	624.3	213343.7

STEAM FLOW RATE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)  
 STEAM FLOW RATE: 38643.0 LRM/HR.  
 GAS-SIDE PRESSURE DROP: 3.5 IN H2O  
 PINCH POINT: 71.9 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 16098.5  
 STEAM TURBINE HORSEPOWER: 4732.7  
 TOTAL SYSTEM HORSEPOWER: 20831.3  
 STEAM TURBINE SHARE OF THE LOAD: 22.7 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.435 COGAS: 0.336 GT AT SYSTEM HP: 0.397  
 FUEL CHG/IMP RPM (LBM-FUEL/HR.):  
 GT ONLY: 7003.9 COGAS: 7003.9 GT AT SYSTEM HP: 8271.2  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.313 COGAS: 0.411 GT AT SYSTEM HP: 0.346

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 CYCLE RATIO EFFICIENCY: 0.85  
 FUEL HEATER PRESSURE: 1.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #26

WASTE HEAT RECOVERY UNIT DESIGN RUN

625 TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 EXHAUST GAS TEMPERATURE: 742.0 F  
 EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.0 FT.  
 HEIGHT: 1.6 FT.  
 HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.0 IN.  
 INSIDE TUBE DIAMETER: 0.9 IN.  
 TUBES/FIN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 11.88 FINS/IN.  
 FIN HEIGHT: 0.5 IN.  
 FIN THICKNESS: 0.024 IN.  
 TRANSVERSE TUBE SPACING: 2.25 IN.  
 LONGITUDINAL TUBE PITCH: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 64.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 3264.9 SQ.FT.  
 INSIDE AREA/PASS: 187.5 SQ. FT.  
 FRONTAL AREA: 143.8 SQ. FT.  
 NUMBER OF PASSES: 10 (TOTAL)  
 HEATING SECTION: 3  
 HEATING SECTION: 2  
 SUPERHEATING SECTION: 2  
 (HEATING LENGTH= 3.8 FT.)  
 (BOILING LENGTH= 3.8 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	475.1	401.5	200.0	434.0	14789.1
BOILING	643.7	475.1	434.0	444.6	143151.9
SUPERHEATING	740.8	643.7	444.6	444.6	

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)  
 STEAM FLOW RATE: 23945.2 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 2.7 IN H2O  
 PINCH POINT: 41.1 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 8373.8  
 STEAM TURBINE HORSEPOWER: 2954.5  
 TOTAL SYSTEM HORSEPOWER: 11328.3  
 STEAM TURBINE SHARE OF THE LOAD: 26.1 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.529  
 COGAS: 0.391  
 GT AT SYSTEM HP: 0.478  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 4433.6  
 COGAS: 4433.6  
 GT AT SYSTEM HP: 5410.0  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.261  
 COGAS: 0.353  
 GT AT SYSTEM HP: 0.290

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #27

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
 EXHAUST GAS TEMPERATURE: 689.0 F  
 EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (444.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS: FT.  
 LENGTH: 12.0 FT.  
 WIDTH: 11.0 FT.  
 HEIGHT: 11.3 FT.

HEAT RANFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.0 IN.  
 INSIDE TUBE DIAMETER: 0.9 IN.  
 TUBE/FIN ARRANGEMENT:  
 FIN TYPE: SEGMENTED FINS/IN.  
 FIN SPACING: 11.88 IN.  
 FIN HEIGHT: 0.5 IN.  
 FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.  
 LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 64.  
 TUBE LENGTH 12. FT.  
 OUTSIDE AREA/PASS: 3264.9 SQ.FT.  
 INSIDE AREA/PASS: 187.5 SQ. FT.  
 FRONTAL AREA: 143.8 SQ. FT.  
 NUMBER OF PASSES: 8 (TOTAL)  
 HEATING SECTION: 2  
 CONDENSING SECTION: 2  
 SUPERHEATING SECTION: 2 (HEATING LENGTH= 3.0 FT.)  
 (BOILING LENGTH= 2.8 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMMR (AVG.)
HEATING	468.2	409.6	200.0	428.3	5831.0
BOILING	611.7	468.2	428.3	544.6	
SUPERHEATING	688.2	611.7	444.6	637.5	55609.7

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)  
 STEAM FLOW RATE: 9526.0 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 0.6 IN H2O  
 PUMP FCIN: 39.9 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 1661.2  
 STEAP TURBINE HORSEPOWER: 1177.4  
 TOTAL SYSTEM HORSEPOWER: 2838.5  
 STEAM TURBINE SHARE OF THE LOAD: 41.5 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 1.063 COGAS: 0.522 GT AT SYSTEM HP: 0.858  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 1766.2 COGAS: 1766.2 GT AT SYSTEM HP: 2436.0  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.133 COGAS: 0.222 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.00 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 PUMP HEATER PRESSURE: 10.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #28

08/15/79 15-09-46

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16621.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
 EXHAUST GAS TEMPERATURE: 849.0 F  
 EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 15.3 FT.  
 HEIGHT: 5.9 FT.

HEAT TRANSFER SURFACE  
 TUBE DIAMETER: 2.0 IN.  
 TUBE LENGTH: 12.0 FT.  
 TUBE SPACING: 1.9 IN.  
 FIN TYPE: UNFINISHED  
 FIN SPACING: 0.4 IN.  
 FIN HEIGHT: 1.0 IN.  
 FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.  
 LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 40.  
 TUBE LENGTH: 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.  
 INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.5 SQ. FT.  
 NUMBER OF PASS SECTIONS (TOTAL): 18  
 HEATING SECTION: 8  
 BOILING SECTION: 8  
 SUPERHEATING SECTION: 2

(HEATING LENGTH= 3.4 FT.)  
 (BOILING LENGTH= 3.4 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	549.0	419.0	200.0	516.4	22076.2
BOILING	766.0	749.0	518.3	518.3	
SUPERHEATING	849.2	769.6	518.3	643.8	170747.6

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)  
 STEAM FLOW RATE: 38770.5 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 4.3 IN H2O  
 PINCH POINT: 32.5 F

SYSTEM PERFORMANCE

CF FUEL CONSUMPTION REVISITED: 16072.2

STEAM TURBINE HORSEPOWER: 5132.8

TOTAL SYSTEM HORSEPOWER: 21205.0

STEAM TURBINE SHARE OF THE LOAD: 24.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.436  
 COGAS: 0.330  
 GT AT SYSTEM HP: 0.305

FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 7060.3  
 COGAS: 7000.3  
 GT AT SYSTEM HP: 8246.9

THERMAL EFFICIENCY:  
 GT ONLY: 0.317  
 COGAS: 0.419  
 GT AT SYSTEM HP: 0.356

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FUEL TURBINE EFFICIENCY: 0.85  
 LHV OF FUEL: 18400 Btu/Lbm

08/11/75 15.45.59

RUN #29

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
EXHAUST GAS TEMPERATURE: 742.0 F  
EXHAUST GAS FLOW RATE: 328641.0 LBW/HR ( 91.3 LBM/SEC )

HEAT EXCHANGER GEOMETRY

OVERALL CIRCUMFERENCE  
LENGTH: 12.0 FT.  
WIDTH: 15.0 FT.  
HEIGHT: 4.6 FT.

HEAT TRANSFER SURFACE  
OUTSIDE TUBE DIAMETER: 2.9 IN.  
INSIDE TUBE DIAMETER: 1.9 IN.  
TUBE WALL THICKNESS: 0.075 IN.  
FIN TYPE: SEGMENTED FINS/IN.  
FIN SPACING: 3.94 IN.  
FIN HEIGHT: 1.0 IN.  
FIN THICKNESS: 0.008 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.  
LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF RCMS PER PASS: 1.  
NUMBER OF TUBES PER ROW: 40.  
TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.  
INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.5 SQ. FT.

NUMBER OF PASSES: 14 (TOTAL)  
HEATING SECTION: 7 (HEATING LENGTH= 1.6 FT.)  
BOILING SECTION: 2 (BOILING LENGTH= 1.0 FT.)  
SUPERHEATING SECTION: 2

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	546.3	462.9	200.0	515.2	11488.2
BOILING	706.9	546.3	515.2	518.3	
SUPERHEATING	740.5	706.9	518.3	641.3	87717.6

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)  
STEAM FLOW RATE: 20212.2 LBW/HR.  
CAS-SIDE PRESSURE DROP: 2.4 IN H2O  
PINCH POINT: 31.2 F

SYSTEM PERFORMANCE

GT FUEL/CHP (REVISED): 8378.9  
STEAM TURBINE HORSEPOWER: 2670.5  
TOTAL SYSTEM HORSEPOWER: 11049.4  
STEAM TURBINE SHARE OF THE LOAD: 24.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
GT ONLY: 0.527 COGAS: 0.401 GT AT SYSTEM HP: 0.481  
FUEL CONSUMPTION (LBM-FUEL/HR):  
GT ONLY: 4434.2 COGAS: 4434.2 GT AT SYSTEM HP: 5318.0

THERMAL EFFICIENCY:  
GT ONLY: 0.261 COGAS: 0.345 GT AT SYSTEM HP: 0.287

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
STEAM TURBINE EFFICIENCY: 0.85  
FW HEATER PRESSURE: 15.0 PSIA  
LHV OF FUEL: 18400 BTU/LBM

RUN #30

WASTE HEAT RECOVERY UNIT DESIGN RUN

08/15/75 15.54.15

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
 EXHAUST GAS TEMPERATURE: 689.0 F  
 EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 15.0 FT.  
 HEIGHT: 3.3 FT.

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 2.3 IN.  
 INSIDE TUBE DIAMETER: 1.9 IN.  
 TUBE LENGTH: 12.0 FT.  
 TUBE AREA: 4081.2 SQ. FT.  
 FIN SPACING: 0.4 IN.  
 FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.  
 LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 40.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4081.2 SQ. FT.  
 INSIDE AREA/PASS: 234.4 SQ. FT.  
 FIN AREA: 179.5 SQ. FT.  
 NUMBER OF PASSES: 10 (TOTAL)  
 HEATING SECTION: 4  
 BOILING SECTION: 3  
 SUPERHEATING SECTION: 3 (HEATING LENGTH= 3.8 FT.)  
 (BOILING LENGTH= 3.8 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	245.1	485.5	200.0	510.3	4033.4
BOILING	628.9	628.9	218.2	218.2	
SUPERHEATING	628.6	628.6	518.3	647.3	31670.3

STEAM FLOW RATE: 810.0 PSIA (SATURATION TEMPERATURE= 518.3 F)  
 STEAM FLOW RATE: 7149.0 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 0.5 IN H2O  
 PINCH POINT: 35.0 F

SYSTEM PERFORMANCE

GT WORKFLOW (REVISED): 1661.6  
 STEAM TURBINE HORSEPOWER: 949.3  
 TOTAL SYSTEM HORSEPOWER: 2610.9  
 STEAM TURBINE SHARE OF THE LOAD: 36.4 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 1.763 CGAS: 0.677  
 GT AT SYSTEM MP: 0.891

FUEL CONSUMPTION (LBM-FUEL/HR):  
 GT ONLY: 1766.3 CGAS: 1766.3  
 GT AT SYSTEM HP: 2325.5

THERMAL EFFICIENCY:  
 GT ONLY: 0.132 CGAS: 0.204  
 GT AT SYSTEM HP: 0.155

ASSUMED SYSTEM CHARACTERISTICS:  
 CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FM HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #31

08/15/75 20.50.10

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
EXHAUST GAS TEMPERATURE: 849.0 F  
EXHAUST GAS FLOW RATE: 407509.0 LHM/HR (1113.2 LHM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
LENGTH: 12.0 FT.  
WIDTH: 15.0 FT.  
HEIGHT: 13.5 FT.

HEAT TRANSFER SURFACE  
OUTSIDE TUBE DIAMETER: 1.5 IN.  
INSIDE TUBE DIAMETER: 1.4 IN.  
TUBE WALL THICKNESS: 0.036 IN.  
FIN TYPE: SEGMENTED  
FIN SPACING: 7.92 FINS/IN.  
FIN HEIGHT: 0.8 IN.  
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
NUMBER OF TUBES PER ROW: 54.  
TUBE LENGTH: 12. FT.  
OUTSIDE AREA/PASS: 4132.2 SQ.FT.  
INSIDE AREA/PASS: 237.3 SQ. FT.  
FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 15 (TOTAL)  
HEATING SECTION: 6  
BOILING SECTION: 7  
SUPERHEATING SECTION: 2

(HEATING LENGTH= 5.4 FT.)  
(BOILING LENGTH= 5.1 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	540.9	415.0	200.0	504.5	21620.1
BOILING	730.7	540.9	504.5	518.3	
SUPERHEATING	849.8	730.7	518.3	647.5	172417.9

STEAM PRESSURE: 830.0 PSIA (SATURATION TEMPERATURE= 518.3 F)  
STEAM FLOW RATE: 39123.8 LHM/HR.  
GAS-SIDE PRESSURE DROP: 3.7 IN H2O  
PINCH POINT: 36.4 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 16092.0  
STEAM TURBINE HORSEPOWER: 5154.9  
TOTAL SYSTEM HORSEPOWER: 21287.0  
STEAM TURBINE SHARE OF THE LOAD: 24.4 PERCENT  
SPECIFIC FUEL CONSUMPTION (LHM-FUEL/HP-HR):  
GT ONLY: 0.435  
COGAS: 0.329  
GT AT SYSTEM HP: 0.387  
FULL CONSUMPTION (LHM-FUEL/HR.):  
GT ONLY: 7003.0  
COGAS: 7003.0  
GT AT SYSTEM HP: 8235.5  
THERMAL EFFICIENCY:  
GT ONLY: 0.513  
COGAS: 0.420  
GT AT SYSTEM HP: 0.357

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
STEAM TURBINE EFFICIENCY: 0.85  
HEATING SECTION PRESSURE: 15.0 PSIA  
LHM OF FUEL: 18400 R10/LBM

RUN #32

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 EXHAUST GAS TEMPERATURE: 742.0 F  
 EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.0 FT.  
 HEIGHT: 2.5 FT.

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.4 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE FIN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 7.92 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 54.  
 TUBE LENGTH 12. FT.  
 OUTSIDE AREA/PASS: 4132.2 SQ.FT.  
 INSIDE AREA/PASS: 237.3 SQ. FT.  
 FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 11 (TOTAL)  
 HEATING SECTION: 4  
 BOILING SECTION: 5  
 SUPERHEATING SECTION: 2

(HEATING LENGTH= 9.5 FT.)  
 (BOILING LENGTH= 3.8 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	548.8	465.1	200.0	518.3	11317.2
BOILING	675.4	548.8	518.3	637.5	
SUPERHEATING	743.6	675.4	518.3	637.5	87322.8

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE = 516.3 F)  
 STEAM FLOW RATE: 20052.2 LBM/HR.  
 GAS-SIDE PPESSURE DROP: 1.9 IN H2O  
 PINCH POINT: 30.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 8387.7  
 STEAM TURBINE HORSEPOWER: 2641.5  
 TOTAL SYSTEM HORSEPOWER: 11029.2  
 STEAM TURBINE SHARE OF THE LOAD: 23.9 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 (G. CALY): 0.527  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 4435.1 COGAS: 4435.1 GT AT SYSTEM HP: 5311.3  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.262 COGAS: 0.344 GT AT SYSTEM HP: 0.287

ASSUMED SYSTEM CHARACTERISTICS:  
 CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #33

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE FCSPEWPER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
 EXHAUST GAS TEMPERATURE: 689.0 F  
 EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS: FT.  
 LENGTH: 12.0 FT.  
 WIDTH: 15.2 FT.  
 HEIGHT: 2.0 FT.

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE/FIN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 7.92 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 54.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4132.2 SQ.FT.  
 INSIDE AREA/PASS: 237.3 SQ. FT.  
 FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 8 (TOTAL)  
 HEATING SECTION: 2  
 BOILING SECTION: 2  
 SUPERHEATING SECTION: 2 (HEATING LENGTH= 4.4 FT.)  
 (BOILING LENGTH= 1.6 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	540.4	584.0	200.0	492.7	3901.9
BOILING	652.7	540.4	492.7	518.3	
SUPERHEATING	688.7	652.7	518.3	647.5	30667.8

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)  
 STEAM FLOW RATE: 7201.1 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 0.4 IN H2O  
 PINCH POINT: 47.7 F

SYSTEM PERFORMANCE

GT HIGH-SPEED (REVISED): 1661.9  
 STEAM TURBINE HORSEPOWER: 956.2  
 TOTAL SYSTEM HORSEPOWER: 2618.1  
 STEAM TURBINE SHARE OF THE LOAD: 36.5 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 1.061 COGAS: 0.675 GT AT SYSTEM HP: 0.890  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 1766.3 COGAS: 1756.3 GT AT SYSTEM HP: 2329.1  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.133 COGAS: 0.205 GT AT SYSTEM HP: 0.155

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.895  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #34

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
 EXHAUST GAS TEMPERATURE: 849.0 F  
 EXHAUST GAS FLOW RATE: 47589.0 LB/HR (113.2 LB/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 15.0 FT.  
 HEIGHT: 2.0 FT.

HEAT TRANSFER SURFACE:  
 CUTTING TUBE DIAMETER: 1.3 IN.  
 TUBE LENGTH: 12.0 FT.  
 TUBE WALL THICKNESS: 0.3 IN.  
 TUBE FIN TYPE: SEGMENTED  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 11.88 FINS/IN.  
 FIN HEIGHT: 0.5 IN.  
 FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.  
 LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 80.  
 TUBE LENGTH 12. FT.  
 OUTSIDE AREA/PASS: 4081.2 SQ.FT.  
 INSIDE AREA/PASS: 234.4 SQ. FT.  
 FCENTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)  
 HEATING SECTION: 5  
 BOILING SECTION: 4  
 SUPERHEATING SECTION: 3  
 { HEATING LENGTH= 1.9 FT.:  
 { BOILING LENGTH= 0.7 FT.:

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	544.6	414.2	200.0	513.9	22250.0
BOILING	797.0	544.6	513.9	513.9	
SUPERHEATING	851.1	797.0	518.3	649.3	163175.6

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 39189.5 LB/HR.

GAS-SIDE PRESSURE DROP: 3.3 IN H2O

PINCH POINT: 30.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16107.1

STEAM TURBINE HORSEPOWER: 5211.1

TOTAL SYSTEM HORSEPOWER: 21318.2

STEAM TURBINE SHARE OF THE LOAD: 24.4 PERCENT

SPECIFIC FUEL CONSUMPTION (LB4-FUEL/HP-HR.):

GT ONLY: 0.435 COGAS: 0.329 GT AT SYSTEM HP: 0.386

\* FUEL CONSUMPTION (LB4-FUEL/HR.):

GT ONLY: 7005.1 COGAS: 7005.1 GT AT SYSTEM HP: 8230.2

THERMAL EFFICIENCY:

GT ONLY: 0.313 COGAS: 0.421 GT AT SYSTEM HP: 0.358

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBW

RUN #35

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8520.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 EXHAUST GAS TEMPERATURE: 742.0 F  
 EXHAUST GAS FLOW RATE: 328641.0 LB/HR ( 91.3 LB/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 15.0 FT.  
 HEIGHT: 11.5 FT.  
 HEAT TRANSFER SURFACE:  
 OUTSIDE TUBE DIAMETER: 1.0 IN.  
 INSIDE TUBE DIAMETER: 0.9 IN.  
 TUBE/FIN ARRANGEMENT:  
 IN SPACED SEGMENTED FINS/IN.  
 FIN HEIGHT: 0.300 IN.  
 FIN THICKNESS: 0.024 IN.  
 TRANSVERSE TUBE SPACING: 2.25 IN.  
 LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF RCMS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 80.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4081.2 SQ.FT.  
 INSIDE AREA/PASS: 234.4 SQ. FT.  
 FRONTAL AREA: 179.8 SQ. FT.  
 NUMBER OF PASSES: 9 (TOTAL)  
 HEATING SECTION: 3  
 BOILING SECTION: 2  
 SUPERHEATING SECTION: 2 (HEATING LENGTH= 1.6 FT.)  
 (BOILING LENGTH= 5.5 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	543.7	209.0	513.3	513.3	11569.7
BOILING	743.5	518.3	518.3	518.3	91410.0
SUPERHEATING	741.8	518.3	518.3	518.3	

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)  
 STEAM FLOW RATE: 20426.0 LB/HR.  
 GAS-SIDE PRESSURE DROP: 1.7 IN H2O  
 PINCH POINT: 30.4 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 8391.1  
 STEAM TURBINE HORSEPOWER: 2706.8  
 TOTAL SYSTEM HORSEPOWER: 11098.0  
 STEAM TURBINE SHARE OF THE LOAD: 24.4 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.529  
 COGAS: 0.400  
 GT AT SYSTEM HP: 0.981  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 4335.4  
 COGAS: 4435.4  
 GT AT SYSTEM HP: 5334.1  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.262  
 COGAS: 0.346  
 GT AT SYSTEM HP: 0.286

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FWH HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #36

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1084.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
 EXHAUST GAS TEMPERATURE: 999.0 F  
 EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 15.0 FT.  
 HEIGHT: 1.0 FT.

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.7 IN.  
 INSIDE TUBE DIAMETER: 0.9 IN.  
 TUBE LENGTH: 12.0 FT.  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 0.508 FINS/IN.  
 FIN HEIGHT: 0.5 IN.  
 FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.  
 LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF RCWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 80.  
 TUBE LENGTH: 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ. FT.  
 INSIDE AREA/PASS: 234.4 SQ. FT.  
 FPCNTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 4 (TOTAL)  
 HEATING SECTION: 1  
 BOILING SECTION: 3  
 SUPERHEATING SECTION: 2

(HEATING LENGTH= 5.7 FT.)  
 (BOILING LENGTH= 4.4 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	532.5	485.5	200.0	448.3	3656.6
BOILING	672.2	672.2	518.3	518.3	
SUPERHEATING	689.0	616.2	518.3	646.3	31476.1

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)  
 STEAM FLOW RATE: 7149.0 LHM/HR.  
 GAS-SIDE PRESSURE DROP: 0.3 IN H2O  
 PINCH POINT: 84.2 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 1662.2  
 STEAM TURBINE HORSEPOWER: 948.3  
 TOTAL SYSTEM HORSEPOWER: 2610.5  
 STEAM TURBINE SHARE OF THE LOAD: 36.3 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 1.063 COGAS: 0.677 GT AT SYSTEM HP: 0.691  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 1762.4 COGAS: 1766.4 GT AT SYSTEM HP: 2325.3

THERMAL EFFICIENCY:  
 GT ONLY: 0.130 COGAS: 0.204 GT AT SYSTEM HP: 0.155

ASSUMED SYSTEM CHARACTERISTICS:  
 CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

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RUN #37

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16621.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
EXHAUST GAS TEMPERATURE: 848.0  
EXHAUST GAS FLOW RATE: 407588.0 LBM/HR (1113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
LENGTH: 12.0 FT.  
WIDTH: 15.0 FT.  
HEIGHT: 5.5 FT.

HEAT TRANSFER SURFACE  
OUTSIDE TUBE DIAMETER: 2.3 IN.  
INSIDE TUBE DIAMETER: 1.9 IN.  
TUBE/FAN ARRANGEMENT:  
FIN TYPE: SEGMENTED  
FIN SPACING: 5.94 FINS/IN.  
FIN HEIGHT: 1.0 IN.  
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.  
LONGITUDINAL TUBE SPACING: 3.93 IN.

NUMBER OF ROWS PER PASS: 1.  
NUMBER OF TUBES PER ROW: 40.  
TUBE LENGTH: 12. FT.  
OUTSIDE AREA/PASS: 4081.2 SQ.FT.  
INSIDE AREA/PASS: 234.4 SQ. FT.  
FRONTAL AREA: 179.5 SQ. FT.

NUMBER OF PASSES: 17 (TOTAL)  
HEATING SECTION: 7  
BOILING SECTION: 8  
SUPERHEATING SECTION: 2  
(HEATING LENGTH= 1.3 FT.)  
(BOILING LENGTH= 2.6 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	522.5	405.0	200.0	482.8	21261.9
BOILING	769.5	522.5	483.8	486.3	
SUPERHEATING	848.0	769.5	486.3	640.0	178832.9

STEAM PRESSURE: 630.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 39455.5 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.0 IN H2O

PINCH POINTS: 38.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 16081.9

STEAM TURBINE HORSEPOWER: 5099.4

TOTAL SYSTEM HORSEPOWER: 21181.4

STEAM TURBINE SHARE OF THE LOAD: 24.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):

GT ONLY: 0.435 COGAS: 0.331 GT AT SYSTEM HP: 0.385

FUEL CONSUMPTION (LBM-FUEL/HR.):

GT ONLY: 7001.2 COGAS: 7001.6 GT AT SYSTEM HP: 8249.9

THERMAL EFFICIENCY:

GT ONLY: 0.318 COGAS: 0.418 GT AT SYSTEM HP: 0.355

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG

STEAM TURBINE EFFICIENCY: 0.85

FW HEATER PRESSURE: 15.0 PSIA

LHV CF FUEL: 18400 BTU/LBM

RUN #38

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 6526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 EXHAUST GAS TEMPERATURE: 742.0  
 EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 15.0 FT.  
 HEIGHT: 4.5 FT.

HEAT TRANSFER SURFACE AREA: 23 SQ. FT.  
 INSIDE TUBE DIAMETER: 1.9 IN.  
 TUBE FIN ARRANGEMENT: FIN TYPE: SEGMENTED  
 FIN SPACING: 5.94 FINS/IN.  
 FIN HEIGHT: 1.0 IN.  
 FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.  
 LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 40.  
 TUBE LENGTH 12. FT.  
 OUTSIDE AREA/PASS: 4081.2 SQ. FT.  
 INSIDE AREA/PASS: 234.4 SQ. FT.  
 FRONTAL AREA: 179.5 SQ. FT.

NUMBER OF PASSES: 15 (TOTAL)  
 HEATING SECTION: 8  
 BOILING SECTION: 2  
 SUPERHEATING SECTION: 5  
 (HEATING LENGTH= 3.3 FT.)  
 (BOILING LENGTH= 0.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
PREHEATING	511.5	431.0	200.0	478.8	11871.0
BOILING	709.7	511.5	478.8	486.3	
SUPERHEATING	741.7	709.7	486.3	637.5	98751.3

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE = 486.3 F)  
 STEAM FLOW RATE: 22173.9 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 2.4 IN H2O  
 PINCH POINT: 32.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 8378.6  
 STEAM TURBINE HORSEPOWER: 2860.6  
 TOTAL SYSTEM HORSEPOWER: 11239.2  
 STEAM TURBINE SHARE OF LOAD: 25.5 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.529 CGAS: 0.395  
 FUEL CONSUMPTION (LBM-FUEL/HR):  
 GT ONLY: 4434.1 CGAS: 4434.1  
 GT AT SYSTEM HP: 5380.7  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.261 CGAS: 0.351  
 GT AT SYSTEM HP: 0.285

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #39

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
 EXHAUST GAS TEMPERATURE: 689.0  
 EXHAUST GAS FLOW RATE: 15931.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 15.0 FT.  
 HEIGHT: 3.6 FT.

HEAT TRANSFER SURFACE AREA: 2.3 IN.  
 INSIDE TUBE DIAMETER: 1.9 IN.  
 TUBE/FLUE IN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 5.94 FINS/IN.  
 FIN HEIGHT: 1.0 IN.  
 FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.  
 LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 40.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4081.2 SQ. FT.  
 INSIDE AREA/PASS: 234.4 SQ. FT.  
 FIN TAIL AREA: 179.5 SQ. FT.

NUMBER OF PASSES: 11 (TOTAL)  
 HEATING SECTION: 3  
 BOILING SECTION: 3  
 SUPERHEATING SECTION: 5

(HEATING LENGTH= 3.5 FT.)  
 (BOILING LENGTH= 4.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	511.0	450.9	200.0	473.8	4370.5
BOILING	622.1	511.0	473.8	486.3	
SUPERHEATING	687.9	622.1	486.3	637.5	37903.1

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 8234.7 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.5 IN H<sub>2</sub>O

PINCH POINT: 37.3 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 1661.5

STEAM TURBINE HORSEPOWER: 1062.4

TOTAL SYSTEM HORSEPOWER: 2723.9

STEAM TURBINE SHARE OF THE LOAD: 39.0 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):

GT ONLY: 1.063 COGAS: 0.648 GT AT SYSTEM HP: 0.874

FUEL CONSUMPTION (LBM-FUEL/HR.):

GT ONLY: 1766.2 COGAS: 1766.2 GT AT SYSTEM HP: 2381.3

THERMAL EFFICIENCY:

GT ONLY: 0.133 COGAS: 0.213 GT AT SYSTEM HP: 0.158

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.00 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 F.A. HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #40

WASTE HEAT RECOVERY UNIT DESIGN RUN

C/S TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
 FANAL GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)  
 EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.2 FT.  
 HEIGHT: 3.4 FT.

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.3 IN.  
 INSIDE TUBE DIAMETER: 1.45 IN.  
 TUBE FIN ARRANGEMENT:  
 FIN SPACING: 7.02 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 54.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4132.2 SQ. FT.  
 INSIDE AREA/PASS: 237.3 SQ. FT.  
 FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 14 (TOTAL)  
 HEATING SECTION: 2  
 BOILING SECTION: 2  
 SUPERHEATING SECTION: 2  
 (HEATING LENGTH= 5.7 FT.)  
 (BOILING LENGTH= 4.1 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	513.5	402.3	200.0	447.5	20576.3
BOILING	513.5	467.5	467.5	486.3	179758.6
SUPERHEATING	850.5	737.5	467.5	650.0	

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM FLOW RATE: 39693.2 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 3.5 IN H2O  
 PINCH POINT: 45.8 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 16101.5  
 STEAM TURBINE HORSEPOWER: 5167.7  
 TOTAL SYSTEM HORSEPOWER: 21265.2  
 STEAM TURBINE SHARE OF THE LOAD: 24.3 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.435 COGAS: 0.329 GT AT SYSTEM HP: 0.387  
 FUEL CONSUMPTION (LBM-FUEL/HR):  
 GT ONLY: 7004.3 COGAS: 7004.3 GT AT SYSTEM HP: 8237.9  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.310 COGAS: 0.420 GT AT SYSTEM HP: 0.351

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FAN HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #41

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 EXHAUST GAS TEMPERATURE: 742.0 F  
 EXHAUST GAS FLOW RATE: 328691.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 15.2 FT.  
 HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE:  
 CONDENSER TUBE DIAMETER: 1.5 IN.  
 TUBES PER TUBE DIAMETER: 1.5 IN.  
 TUBE TYPE: VIGORANT  
 FIN TYPE: SEGMENTED FINS/IN.  
 FIN SPACING: 0.8 IN.  
 FIN HEIGHT: 0.076 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF RCMS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 54.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4132.2 SQ.FT.  
 INSIDE AREA/PASS: 237.3 SQ. FT.  
 FRONTAL AREA: 181.9 SQ. FT.  
 NUMBER OF PASSES: 12 (TOTAL)  
 HEATING SECTION: 4  
 BOILING SECTION: 4  
 SUPERHEATING SECTION: 2 (HEATING LENGTH= 0.9 FT.)  
 (BOILING LENGTH= 2.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	516.5	435.0	200.0	486.4	11664.0
BOILING	683.2	516.0	486.4	486.4	97271.8
SUPERHEATING	741.7	683.2	486.3	486.3	

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM FLOW RATE: 21894.0 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 2.0 IN H2O  
 PINCH POINT: 31.6 F

SYSTEM PERFORMANCE

GT FUEL/CHARGE (REVISED): 8385.5  
 STEAM TURBINE HORSEPOWER: 2832.3  
 TOTAL SYSTEM HORSEPOWER: 11217.8  
 STEAM TURBINE SHARE OF THE LOAD: 25.2 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.527  
 COGAS: 0.395  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 4424.8  
 COGAS: 4434.8  
 GT AT SYSTEM HP: 0.475  
 GT AT SYSTEM HP: 5373.6  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.261  
 COGAS: 0.350  
 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:  
 CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #42

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

SHAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
 EXHAUST GAS TEMPERATURE: 689.0 F  
 EXHAUST GAS FLOW RATE: 155731.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 13.2 FT.  
 HEIGHT: 2.2 FT.

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE/FIN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 7.92 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 54.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4132.2 SQ.FT.  
 INSIDE AREA/PASS: 237.3 SQ. FT.  
 FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)  
 HEATING SECTION: 2  
 BOILING SECTION: 5  
 SUPERHEATING SECTION: 2

(HEATING LENGTH= 5.2 FT.)  
 (BOILING LENGTH= 0.9 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	505.6	449.4	200.0	455.0	4212.0
BOILING	653.8	505.6	455.0	486.3	
SUPERHEATING	687.9	653.8	486.3	641.3	36232.5

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 8285.8 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.4 IN H2O

FAN FCMT: 50.6 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 1661.7

STEAM TURBINE HORSEPOWER: 1071.9

TOTAL SYSTEM HORSEPOWER: 2733.6

STEAM TURBINE SHARE OF THE LOAD: 39.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):

GT ONLY: 1.223 COGAS: 0.646 GT AT SYSTEM MPI: 0.873

FUEL CONSUMPTION (LBM-FUEL/HR.):

GT ONLY: 1766.3 COGAS: 1766.3 GT AT SYSTEM MPI: 2386.0

THERMAL EFFICIENCY:

GT ONLY: 0.133 COGAS: 0.214 GT AT SYSTEM MPI: 0.158

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #43

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
 EXHAUST GASES TEMPERATURE: 845.0  
 EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.0 FT.  
 HEIGHT: 1.8 FT.  
 HEAT TRANSFER SURFACE:  
 OUTSIDE TUBE DIAMETER: 1.3 IN.  
 INSIDE TUBE DIAMETER: 0.9 IN.  
 TUBE IN TUBE DIAMETER:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 0.5 IN  
 FIN HEIGHT: 0.5 IN  
 FIN THICKNESS: 0.024 IN.  
 TRANSVERSE TUBE SPACING: 2.25 IN.  
 LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 80.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4081.2 SQ.FT.  
 INSIDE AREA/PASS: 234.4 SQ. FT.  
 FRONTAL AREA: 179.8 SQ. FT.  
 NUMBER OF PASSES: 11 (TOTAL)  
 HEATING SECTION: 4  
 BOILING SECTION: 6  
 SUPERHEATING SECTION: 1 (BOILING LENGTH= 3.6 FT.,  
 SUPERHEATING LENGTH= 0.6 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION GAS TEMP. IN GAS TEMP. OUT FLUID TEMP. IN FLUID TEMP. OUT REYNOLDS NUMBER (AVG.)  
 HEATING 535.5 400.8 299.0 21083.2  
 BOILING 600.0 500.0 486.3 169625.8  
 SUPERHEATING 849.7 792.6 486.3  
 STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM FLOW RATE: 35818.5 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 3.0 IN H2O  
 PINCH POINT: 42.0 F

SYSTEM PERFORMANCE

GT HP/REFORMER(REVERSE): 16117.5  
 STEAM TURBINE HORSEPOWER: 5154.2  
 TOTAL SYSTEM HORSEPOWER: 21271.7  
 STEAM TURBINE SHARE OF THE LOAD: 24.2 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.435 COGAS: 0.329  
 FUEL CONSUMPTION (LBM-FUEL/HR.): 7006.5 GT AT SYSTEM HP: 8237.5  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.318 COGAS: 0.420 GT AT SYSTEM HP: 0.357

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FM HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #44

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 EXHAUST GAS TEMPERATURE: 742.0 F  
 EXHAUST GAS FLOW RATE: 32843.0 LB/MHR ( 91.3 LB/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS: FT.  
 LENGTH: 15.0  
 WIDTH: 15.0  
 HEIGHT: 15.0  
 HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.3 IN.  
 INSIDE TUBE DIAMETER: 0.9 IN.  
 TUBE/FIN ARRANGEMENT:  
 FIN TYPE: SEMI-HEATED  
 FIN SPACING: 11.88 FINS/IN.  
 FIN HEIGHT: 0.5 IN.  
 FIN THICKNESS: 0.024 IN.  
 TRANSVERSE TUBE SPACING: 2.25 IN.  
 LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 80.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4081.2 SQ.FT.  
 INSIDE AREA/PASS: 234.4 SQ. FT.  
 FRONTAL AREA: 179.8 SQ. FT.  
 NUMBER OF PASSES: 9 (TOTAL)  
 HEATING SECTIONS: 3  
 BOILING SECTIONS: 4  
 SUPERHEATING SECTIONS: 2 (HEATING LENGTH= 0.2 FT.,  
 BOILING LENGTH= 5.2 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	517.8	436.5	200.0	486.3	11788.4
BOILING	635.8	517.8	486.3	486.3	
SUPERHEAT	740.9	635.8	486.3	638.8	100947.2

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM FLOW RATE: 21789.0 LB/MHR.  
 GAS-SIDE PRESSURE DROP: 1.6 IN H<sub>2</sub>O  
 FINCP POINT: 31.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 8391.7  
 STEAM TURBINE HORSEPOWER: 2813.6  
 TOTAL SYSTEM HORSEPOWER: 11205.3  
 STEAM TURBINE SHARE OF THE LOAD: 25.1 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.529  
 COGAS: 0.396  
 FUEL CONSUMPTION (LBM-FUEL/HR):  
 GT ONLY: 4435.5  
 COGAS: 4435.5  
 GT AT SYSTEM HP: 5369.5  
 COGAS AT SYSTEM HP: 5369.5  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.262  
 COGAS AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FM HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #45

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
 EXHAUST GAS TEMPERATURE: 689.0  
 EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 15.0 FT.  
 HEIGHT: 1.1 FT.

HEAT TRANSFER SURFACE METERS: 1.0 IN.  
 NUMBER OF TUBES PER PASS: 1  
 NUMBER OF TUBES PER ROW: 80  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4081.2 SQ. FT.  
 INSIDE AREA/PASS: 234.4 SQ. FT.  
 FFONTAL AREA: 179.8 SQ. FT.  
 NUMBER OF PASSES: 7 (TOTAL)  
 HEATING SECTION: 2  
 BOILING SECTION: 3  
 SUPERHEATING SECTION: 2

TRANSVERSE TUBE SPACING: 2.25 IN.  
 LONGITUDINAL TUBE SPACING: 1.95 IN.

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	514.8	552.6	200.0	485.0	4418.5
BOILING	201.8	485.0	485.0	485.0	37418.6
SUPERHEATING	681.7	601.8	486.3	636.3	

STEAM PRESSURE: 600.0 PSIA ISATURATION TEMPERATURE= 486.3 F

STEAM FLOW RATE: 8183.6 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.3 IN H2O

PINCH POINT: 29.8 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVERSED): 1662.0

STEAM TURBINE HP/SEPOWER: 1054.8

TOTAL SYSTEM HP/SEPOWER: 2716.8

STEAM TURBINE SHARE OF THE LOAD: 38.8 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR) F

GT ONLY: 1.063 COGAS: 0.650

FUEL CONSUMPTION (LBM-FUEL/HR.): 1766.3 GT AT SYSTEM HP: 2377.5

THERMAL EFFICIENCY: GT ONLY: 0.130 COGAS: 0.213 GT AT SYSTEM HP: 0.158

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.65  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV CF FUEL: 18400 BTU/LBM

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RUN #46

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16521.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
EXHAUST GAS TEMPERATURE: 869.0 F  
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
LENGTH: 12.0 FT.  
HEIGHT: 15.0 FT.  
WIDTH: 4.6 FT.

HEAT TRANSFER SURFACE  
OUTSIDE TUBE DIAMETER: 2.0 IN.  
INSIDE TUBE DIAMETER: 1.9 IN.  
TUBE IN ARRANGEMENT:  
FIN TYPE: SEGMENTED  
FIN SPACING: 5.94 FINS/IN.  
FIN HEIGHT: 1.0 IN.  
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.  
LONGITUDINAL TUBE SPACING: 3.93 IN.

NUMBER OF ROWS PER PASS: 1.  
NUMBER OF TUBES PER ROW: 40.  
TUBE LENGTH: 12. FT.  
OUTSIDE AREA/PASS: 4081.2 SQ.FT.  
INSIDE AREA/PASS: 234.4 SQ. FT.  
FRONTAL AREA: 179.5 SQ. FT.

NUMBER OF PASSES: 14 (TOTAL)  
HEATING SECTION: 5  
COOLING SECTION: 5  
SUPERHEATING SECTION: 2  
{ HEATING LENGTH= 3.0 FT.:  
{ COOLING LENGTH= 3.2 FT.:

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	597.8	400.5	200.0	433.3	19452.2
COOLING	766.2	497.8	433.3	444.6	
SUPERHEATING	867.5	766.2	444.6	632.5	186080.6

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)  
STEAM FLOW RATE: 39368.9 LBM/HR.  
GAS-SIDE PRESSURE DROP: 3.3 IN H2O  
PINCH POINT: 64.6 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 16106.7  
STEAM TURBINE HORSEPOWER: 4849.2  
TOTAL SYSTEM HORSEPOWER: 20955.9  
STEAM TURBINE SHARE OF THE LOAD: 23.1 PERCENT  
SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
GT ONLY: 0.435  
GT ONLY: 0.334  
GT AT SYSTEM HP: 0.395  
FUEL CONSUMPTION (LBM-FUEL/HR.):  
GT ONLY: 7005.0  
GT AT SYSTEM HP: 8268.1  
THERMAL EFFICIENCY:  
GT ONLY: 0.318  
GT AT SYSTEM HP: 0.350

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.208 IN. HG  
STEAM TURBINE EFFICIENCY: 0.85  
P.M. HEATER PRESSURE: 15.0 PSIA  
LHV OF FUEL: 18400 BTU/LHM

RUN #47

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 EXHAUST GAS TEMPERATURE: 742.0 F  
 EXHAUST GAS FLOW RATE: 32864.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 15.0 FT.  
 HEIGHT: 4.5 FT.

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 2.1 IN.  
 INSIDE TUBE DIAMETER: 1.9 IN.  
 TUBE SHEET ARRANGEMENT:  
 #1 (2) 11 SEQUENTIAL  
 #2 (2) 11 IN. SPACING  
 #3 THICKNESS: 1.0 IN.  
 #4 THICKNESS: 3.0 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.  
 LONGITUDINAL TUBE SPACING: 3.70 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 40.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4081.2 SQ.FT.  
 INSIDE AREA/PASS: 234.4 SQ. FT.  
 FRONTAL AREA: 179.5 SQ. FT.  
 NUMBER OF PASSES: 15 (TOTAL)  
 HEATING SECTION: 7  
 ROLLING SECTION: 3  
 SUPERHEATING SECTION: 5  
 (HEATING LENGTH= 1.9 FT.)  
 (ROLLING LENGTH= 4.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION GAS TEMP. IN GAS TEMP. OUT FLUID TEMP. IN FLUID TEMP. OUT REYNOLDS NUMBER (AVG.)  
 HEATING 477.4 401.5 200.0 440.2 11965.7  
 ROLLING 457.4 427.1 440.2 448.9  
 SUPERHEATING 740.9 631.4 448.9 636.3  
 STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)  
 STRAP FLOW RATE: 23945.2 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 2.4 IN H2O  
 FLOW POINT: 30.3 F

SYSTEM EFFICIENCIES

GT HORSEPOWER (REVISED): 8379.3  
 STEAM TURBINE HORSEPOWER: 2957.1  
 TOTAL SYSTEM HORSEPOWER: 11336.4  
 STEAM TURBINE SHARE OF THE LOAD: 26.1 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.522 C3GAS: 0.391 GT AT SYSTEM HP: 0.477  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 4434.2 C3GAS: 4434.2 GT AT SYSTEM HP: 5412.6  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.261 C3GAS: 0.354 GT AT SYSTEM HP: 0.290

ASSUMED SYSTEM CHARACTERISTICS

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW FEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #48

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
 EXHAUST GAS TEMPERATURE: 689.0 F  
 EXHAUST GAS FLOW RATE: 159731.0 LB/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.0 FT.  
 HEIGHT: 3.9 FT.

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 2.1 IN.  
 INSIDE TUBE DIAMETER: 1.9 IN.  
 TUBE FIN AREA PER FT. OF TUBE:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 5.94 FINS/IN.  
 FIN HEIGHT: 1.0 IN.  
 FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.  
 LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 40.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4081.2 SQ.FT.  
 INSIDE AREA/PASS: 234.4 SQ. FT.  
 FRONTAL AREA: 179.5 SQ. FT.  
 NUMBER OF PASSES: 12 (TOTAL)  
 HEATING SECTION: 3  
 COOLING SECTION: 3  
 SUPERHEATING SECTION: 3

(HEATING LENGTH= 6.7 FT.)  
 (BOILING LENGTH= 0.5 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	467.2 F	409.6 F	200.0 F	424.6 F	4636.8
BOILING	651.4 F	467.2 F	424.6 F	444.6 F	
SUPERHEATING	688.5 F	651.4 F	444.6 F	646.3 F	44609.7

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)  
 STEAM FLOW RATE: 9524.5 LB/HR.  
 GAS-SIDE PRESSURE DROP: 0.5 IN H2O  
 FLOW RATE: 42.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 1661.4  
 STEAM TURBINE HORSEPOWER: 1184.4  
 TOTAL SYSTEM HORSEPOWER: 2845.7  
 STEAM TURBINE SHARE OF THE LOAD: 41.6 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 1.063 CO2AS: 0.621 GT AT SYSTEM HP: 0.857  
 FUEL CONSUMPTION (LBM-FUEL/HR-J):  
 GT ONLY: 1766.2 CO2AS: 1766.2 GT AT SYSTEM HP: 2439.3  
 THERMAL EFFICIENCY:  
 GT ONLY: 3.13 CO2AS: 0.223 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 CYCLE EFFICIENCY: 0.89  
 STEAM HEATER PRESSURE: 110 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

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08/16/79 15.46.35

RUN #49

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

NAME: GEPERCHRE; 16721.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
 EXHAUST TEMPERATURE: 840.0  
 EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 15.2 FT.  
 HEIGHT: 2.7 FT.  
 HEAT TRANSFER SURFACE:  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE IN EXCHANGER:  
 FIN IN EXCHANGER:  
 FIN SPACING: 0.92 IN.  
 FIN THICKNESS: 0.036 IN.  
 TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 54.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4132.2 SQ. FT.  
 INSIDE AREA/PASS: 237.3 SQ. FT.  
 FRONTAL AREA: 181.9 SQ. FT.  
 NUMBER OF PASSES: 11 (TOTAL)  
 HEATING SECTION: 5  
 BOILING SECTION: 5  
 SUPERHEATING SECTION: 2  
 HEATING LENGTH: 3.0 FT.  
 BOILING LENGTH: 3.0 FT.

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	505.5	405.5	200.0	439.6	19154.8
BOILING	329.9	304.6	439.6	444.6	
SUPERHEATING	349.2	299.8	444.6	640.0	184657.6

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE = 444.6 F)  
 STEAM FLOW RATE: 38942.0 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 2.7 IN H2O  
 PUMP POINT: 64.8 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 16127.1  
 STEAM TURBINE HORSEPOWER: 4821.6  
 TOTAL SYSTEM HORSEPOWER: 20948.7  
 STEAM TURBINE SHARE OF THE LOAD: 24.0 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.435  
 CO-GAS: 0.335  
 GT AT SYSTEM HPI: 0.395  
 FUEL CONSUMPTION (LBM-FUEL/HR-HR):  
 GT ONLY: 7007.8  
 CO-GAS: 7707.8  
 GT AT SYSTEM HPI: 8268.1  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.315  
 CO-GAS: 0.413  
 GT AT SYSTEM HPI: 0.350

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.00 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FUEL HEATER PRESSURE: 10.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #50

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 6526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 EXHAUST GAS TEMPERATURE: 742.0 F  
 EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS: FT.  
 LENGTH: 12.6 FT.  
 WIDTH: 15.2 FT.  
 HEIGHT: 2.9 FT.  
 HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE/FIN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 7.92 FIMS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.  
 TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 54.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4132.2 SQ.FT.  
 INSIDE AREA/PASS: 237.3 SQ. FT.  
 FRONTAL AREA: 181.9 SQ. FT.  
 NUMBER OF PASSES: 12 (TOTAL)  
 HEATING SECTIONS: 4  
 COOLING SECTIONS: 4  
 SUPERHEATING SECTIONS: 2 (HEATING LENGTH= 1.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	471.3	401.5	200.0	440.8	11817.9
BOILING	587.0	477.3	440.8	444.6	
SUPERHEATING	741.8	687.0	444.6	640.0	109744.9

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)  
 STEAM FLOW RATE: 23945.2 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 1.9 IN H2O  
 PINCH POINT: 36.4 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 8286.5  
 STEAM TURBINE HORSEPOWER: 2964.8  
 TOTAL SYSTEM HORSEPOWER: 11351.3  
 STEAM TURBINE SHARE OF THE LOAD: 26.1 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.529 COGAS: 0.391 GT AT SYSTEM HP: 0.477  
 FUEL CONSUMPTION (LBM-FUEL/HR):  
 GT ONLY: 444.9 COGAS: 434.9 GT AT SYSTEM HP: 5417.5  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.262 COGAS: 0.354 GT AT SYSTEM HP: 0.290

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FM HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LHM

WASTE HEAT RECOVERY UNIT DESIGN RUN  
 RUN #51

GAS TURBINE

INAKE DUCT DIAMETER: 1884.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
 EXHAUST GAS TEMPERATURE: 689.0 F  
 EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 15.2 FT.  
 HEIGHT: 2.4 FT.

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.3 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE/IN ARRANGEMENT:  
 IN TUBE/IN SEQUENTIAL FINS/IN.  
 FIN SPACING: 7.92 IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 54.  
 TUBE LENGTH 12. FT.  
 OUTSIDE AREA/PASS: 4132.2 SQ.FT.  
 INSIDE AREA/PASS: 237.3 SQ. FT.  
 FRONTAL AREA: 181.9 SQ. FT.  
 NUMBER OF PASSES: 10 (TOTAL)  
 HEATING SECTION: 3  
 BOILING SECTION: 2  
 SUPERHEATING SECTION: 3 (HEATING LENGTH= 0.7 FT.)  
 (BOILING LENGTH= 4.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	472.0	409.6	200.0	442.1	4712.4
BOILING	588.2	472.0	442.1	444.6	45957.4
SUPERHEATING	588.2	588.2	444.6	642.5	

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)  
 STEAM FLOW RATE: 9524.5 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 0.4 IN H2O  
 PRESSURE POINT: 29.7 F

SYSTEM PERFORMANCE

GT CORRECTION (REVISED): 1661.7  
 STEAM TURBINE WORKPERCENT: 1181.3  
 TOTAL SYSTEM WORKPERCENT: 2843.0  
 STEAM TURBINE SHARE OF THE LOAD: 41.6 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 1.063 COGAS: 0.621 GT AT SYSTEM MPI: 0.858  
 FUEL CONSUMPTION (LBM-FUEL/HR):  
 GT ONLY: 1766.3 COGAS: 1766.3 GT AT SYSTEM MPI: 2438.0  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.130 COGAS: 0.223 GT AT SYSTEM MPI: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 MAX HEAT RECOVERY: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT DESIGN RUN  
 RUN #52

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
 EXHAUST GAS TEMPERATURE: 849.0 F  
 EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 15.0 FT.  
 HEIGHT: 1.3 FT.

HEAT TRANSFER SURFACE AREA: 1.3 IN.  
 BASIC TUBE DIAMETER: 0.9 IN.  
 TUBE/FLANGE WEIGHT:  
 FIN TYPE: SERRATED  
 FIN SPACING: 11.88  
 FIN HEIGHT: 0.5 IN.  
 FIN THICKNESS: 1.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.  
 LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 80.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4081.2 SQ.FT.  
 INSIDE AREA/PASS: 234.4 SQ. FT.  
 FRONTAL AREA: 179.8 SQ. FT.  
 NUMBER OF PASSES: 8 (TOTAL)  
 HEATING SECTION: 4  
 BOILING SECTION: 2  
 SUPERHEATING SECTION: 2 (BOILING LENGTH= 5.5 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	488.5	410.2	200.0	394.6	17739.5
BOILING	488.7	488.5	394.6	444.6	
SUPERHEATING	351.8	351.7	444.6	651.5	190071.5

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 38544.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.2 IN H<sub>2</sub>O

PINCH POINT: 93.3 F

SYSTEM PERFORMANCE

GT HP SEPT 74 (REVISED): 16143.9  
 STEAM TURBINE HORSEPOWER: 4830.4  
 TOTAL SYSTEM HORSEPOWER: 20974.3  
 STEAM TURBINE SHARE OF THE LOAD: 23.0 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.434 COGAS: 0.334  
 GT AT SYSTEM HP: 0.394  
 FUEL CONSUMPTION (LBM-FUEL/HR):  
 GT ONLY: 7010.1 COGAS: 7010.1  
 GT AT SYSTEM HP: 8267.0  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.318 COGAS: 0.414  
 GT AT SYSTEM HP: 0.351

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM BOILING EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #53

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 EXHAUST GAS TEMPERATURE: 742.0 F  
 EXHAUST GAS FLOW RATE: 32864.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.0 FT.  
 HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE  
 (OUTSIDE TUBE DIAMETER: 1.1 IN.)  
 TUBE DIAMETER: 0.9 IN.  
 TUBE WALL THICKNESS: 0.024 IN.  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 11.88 FINS/IN.  
 FIN HEIGHT: 0.5 IN.  
 FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.  
 LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 80.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4081.2 SQ. FT.  
 INSIDE AREA/PASS: 234.4 SQ. FT.  
 FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)  
 HEATING SECTION: 3  
 BOILING SECTION: 4  
 SUPERHEATING SECTION: 2 (HEATING LENGTH= 0.2 FT.)  
 (BOILING LENGTH= 4.7 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	781.5	405.1	200.0	444.6	11921.6
BOILING	921.7	481.5	444.6	444.6	115150.3
SUPERHEATING	739.6	621.7	444.6	630.0	

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)  
 STEAM FLOW RATE: 23698.0 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 1.6 IN H2O  
 PINCH POINT: 36.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 8392.6  
 STEAM TURBINE HORSEPOWER: 2913.9  
 TOTAL SYSTEM HORSEPOWER: 11306.5  
 STEAM TURBINE SHARE OF THE LOAD: 25.8 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.529 COGAS: 0.392 GT AT SYSTEM HP: 0.47E  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 4435.6 COGAS: 435.6 GT AT SYSTEM HP: 5402.8  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.262 COGAS: 0.352 GT AT SYSTEM HP: 0.285

ASSUMED SYSTEM CHARACTERISTICS:  
 CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 PW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #54

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HP/SECTIONS: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
 EXHAUST GAS TEMPERATURE: 689.0 F  
 EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 15.0 FT.  
 HEIGHT: 11.1 FT.

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.0 IN.  
 INSIDE TUBE DIAMETER: 0.9 IN.  
 TUBE/FIN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 11.88 FINS/IN.  
 FIN HEIGHT: 0.5 IN.  
 FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.  
 LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 80.  
 TUBE LENGTH: 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 7 (TOTAL)  
 HEATING SECTION: 2  
 SUPERHEATING SECTION: 2  
 REHEATING SECTION: 3

(HEATING LENGTH= 9.0 FT.)  
 (BOILING LENGTH= 3.6 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	400.0	420.0	200.0	444.6	4615.9
BOILING	594.7	580.9	444.6	444.6	
SUPERHEATING	687.9	594.7	444.6	637.5	43360.5

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)  
 STEAM FLOW RATE: 9175.6 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 0.3 IN H2O  
 PINCH POINT: 30.2 F

SYSTEM PERFORMANCE

GT HP/SEPOWER (REVISED): 1662.0  
 STEAM TURBINE HP/SEPOWER: 1134.1  
 TOTAL SYSTEM HP/SEPOWER: 2796.2  
 STEAM TURBINE SHARE OF THE LOAD: 40.6 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 1.053 COGAS: 0.832 GT AT SYSTEM HP: 0.864  
 FUEL CONSUMPTION (LBM-FUEL/HR):  
 GT ONLY: 1760.4 COGAS: 1766.4 GT AT SYSTEM HP: 2416.0  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.133 COGAS: 0.219 GT AT SYSTEM HP: 0.160

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW PUMP PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

APPENDIX D

RUN #4(o)  
WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
EXHAUST GAS TEMPERATURE: 980.0 F  
EXHAUST GAS FLOW RATE: 15971.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
LENGTH: 12.0 FT.  
WIDTH: 12.1 FT.  
HEIGHT: 2.9 FT.  
HEAT TRANSFER SURFACE:  
OUTSIDE TUBE DIAMETER: 1.5 IN.  
INSIDE TUBE DIAMETER: 1.4 IN.  
TUBE LENGTH: 12.0 FT.  
NUMBER OF ROWS PER PASS: 1.  
NUMBER OF TUBES PER ROW: 43.  
TUBE LENGTH: 12.0 FT.  
OUTSIDE AREA/PASS: 3250.5 SQ.FT.  
INSIDE AREA/PASS: 189.0 SQ. FT.  
FRONTAL AREA: 144.8 SQ. FT.  
NUMBER OF PASSES: 12 (TOTAL)  
HEATING SECTION: 3  
BOILING SECTION: 3  
SUPERHEATING SECTION: 3 (HEATING LENGTH= 3.7 FT.;  
BOILING LENGTH= 0.4 FT.)

HEAT EXCHANGE PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	532.0	470.0	209.0	507.0	5281.1
BOILING	662.0	532.0	209.0	268.0	
SUPERHEATING	688.3	662.0	518.3	688.8	40471.1

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)  
STEAM FLOW RATE: 7577.0 LBM/HR.  
GAS-SIDE PRESSURE UNCP: 0.9 IN H2O  
PINCH POINT: 25.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1660.2  
STEAM TURBINE HORSEPOWER: 1022.8  
TOTAL SYSTEM HORSEPOWER: 2683.0  
STEAM TURBINE SHARE OF THE LOAD: 38.1 PERCENT  
SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
GT ONLY: 1.68 COGAS: 0.658 GT AT SYSTEM HP: 0.880  
FULL CONSUMPTION (LBM-FUEL/HP-HR):  
GT ONLY: 1765.9 COGAS: 1765.9 GT AT SYSTEM HP: 2361.4  
THERMAL EFFICIENCY:  
GT ONLY: 0.13 COGAS: 0.210 GT AT SYSTEM HP: 0.157

ASSUMED SYSTEM CHARACTERISTICS:  
CONDENSER PRESSURE: 4.08 IN. HG  
STEAM TURBINE EFFICIENCY: 0.85  
FW HEATER PRESSURE: 15.0 PSIA  
LHV OF FUEL: 18400 BTU/LBM

RUN #5

WASTE HEAT RECOVERY UNIT DESIGN RLN

GAS TURBINE

BRAKE HPS/HPM: 6520.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 EXHAUST GAS TEMPERATURE: 742.0 F  
 EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS: IN. FT.  
 LENGTH: 15.1 FT.  
 WIDTH: 15.9 FT.  
 HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE/FIN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 7.92 FINS/IN.  
 FIN HEIGHT: 0.4 IN.  
 FIN THICKNESS: J-036 IN.

TRANSVERSE TUBE SPACING: 3.31 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 43.  
 TUBE LENGTH: 12. FT.

OUTSIDE AREA/PASS: 3250.5 SQ.FT.  
 INSIDE AREA/PASS: 189.0 SQ. FT.  
 FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)  
 HEATING SECTION: 4  
 BOILING SECTION: 6  
 SUPERHEATING SECTION: 2  
 (HEATING LENGTH= 2.1 FT.)  
 (BOILING LENGTH= 3.4 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	547.5	565.9	200.0	511.4	14023.8
BOILING	682.5	547.5	511.4	635.0	
SUPERHEATING	740.6	682.5	518.3	635.0	109056.4

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)  
 STEAM FLOW RATE: 1998.0 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 3.1 IN H2O  
 FINCF PTIME: 30.1 F

SYSTEM PERFORMANCE

GT WGT/SEP THE (REVISED): 8366.4  
 STEAM TURBINE WORK/HP/HR: 2629.1  
 TOTAL SYSTEM HPS/HPM: 10955.6  
 STEAM TURBINE SHARE OF THE LOAD: 23.9 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: J.530 CO-GEN: 0.403 GT AT SYSTEM HPI: 0.482  
 FUEL CONSUMPTION (LBM-FUEL/HR):  
 GT ONLY: 4432.5 CO-GEN: 4432.5 GT AT SYSTEM HPI: 5300.1  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.261 CO-GEN: 0.343 GT AT SYSTEM HPI: 0.287

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #6(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
 EXHAUST GAS TEMPERATURE: 849.0 F  
 EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.3 FT.  
 HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE:  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE WALL THICKNESS: 0.036 IN.  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 7.52 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 43.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 3290.5 SQ.FT.  
 INSIDE AREA/PASS: 189.0 SQ. FT.  
 FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)  
 HEATING SECTION: 5  
 BOILING SECTION: 1  
 SUPERHEATING SECTION: 6  
 (HEATING LENGTH= 0.3 FT.:)  
 (BOILING LENGTH= 0.1 FT.:)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	572.0	451.5	200.0	517.0	25426.2
BOILING	814.7	572.0	518.3	518.3	
SUPERHEATING	847.7	814.7	518.3	630.2	187516.3

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 35912.3 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.5 IN H<sub>2</sub>O

PINCH POINT: 55.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 16066.0

STEAM TURBINE HORSEPOWER: 4703.0

TOTAL SYSTEM HORSEPOWER: 20769.1

STEAM TURBINE SHARE OF THE LOAD: 22.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):

GT ONLY: 0.436 COGAS: 0.337 GT AT SYSTEM HP: 0.390

FUEL CONSUMPTION (LBM-FUEL/HR):

GT ONLY: 6999.4 COGAS: 6999.4 GT AT SYSTEM HP: 8271.3

THERMAL EFFICIENCY:

GT ONLY: 0.317 COGAS: 0.410 GT AT SYSTEM HP: 0.347

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FM HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT DESIGN RUN  
 RUN #14

GAS TURBINE

3RAKE HORSEPOWER: 6526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 EXHAUST GAS TEMPERATURE: 742.0 F  
 EXHAUST GAS FLOW RATE: 328641.3 LB/HR ( 91.3 LPM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.1 FT.  
 HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE:  
 OUTSIDE TOTAL DIAMETER: 1.5 IN.  
 INSIDE TUBS DIAMETER: 1.6 IN.  
 TUBE/FT. TUBS DIAMETER:  
 FIN TYPE: SCREWED  
 FIN PITCH: 0.4 IN. FIN/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 FT.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 43.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 3290.5 SQ. FT.  
 INSIDE AREA/PASS: 189.0 SQ. FT.  
 FRONTAL AREA: 144.8 SQ. FT.  
 NUMBER OF PASSES: 13 (TOTAL)  
 HEATING SECTION: 7  
 BOILING SECTION: 2  
 SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.5 FT.,  
 SUPERHEATING LENGTH= 2.1 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	517.1	433.5	200.0	475.0	14511.6
BOILING	581.2	517.1	475.0	486.3	122511.0
SUPERHEATING	741.2	687.4	486.3	637.5	

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM FLOW RATE: 21557.0 LHM/HR.  
 GAS-SIDE PRESSURE DROP: 3.3 IN H<sub>2</sub>O  
 PITCH DUE: 37.1 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 8363.3  
 STEAM TURBINE HORSEPOWER: 2837.8  
 TOTAL SYSTEM HORSEPOWER: 11201.1  
 STEAM TURBINE SHARE OF THE LOAD: 25.3 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT TURBINE: 0.233  
 COGAS: 0.396  
 GT AT SYSTEM HP: 0.475

FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT TURBINE: 4922.6  
 COGAS: 4322.6  
 GT AT SYSTEM HP: 5368.1

THERMAL EFFICIENCY:  
 GT TURBINE: 0.221  
 COGAS: 0.349  
 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHM CF FUEL: 18400 RTU/LRM

RUN #13(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16621.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
 EXHAUST GAS TEMPERATURE: 1860.0 F  
 EXHAUST GAS FLOW RATE: 407589.0 LB/MHR (1113.2 LB/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.1 FT.  
 HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE/IN. TRANSFER SURFACE  
 IN SQUARE FEET  
 FIN SPACING: 1.95 IN  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 43.  
 TUBE LENGTH: 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.  
 INSIDE AREA/PASS: 189.0 SQ. FT.  
 FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)  
 HEATING SECTION: 5  
 BOILING SECTION: 6  
 SUPERHEATING SECTION: 2  
 (HEATING LENGTH= 1.5 FT.)  
 (BOILING LENGTH= 4.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	536.1	422.3	200.0	480.6	25259.9
BOILING	442.0	325.1	480.6	486.3	
SUPERHEATING	848.4	742.8	486.3	638.8	216614.1

STEAM FLOW RATE: 600.0 P/LA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM PRESSURE: 37562.9 LB/MHR.  
 GAS-SIDE PRESSURE DROP: 4.9 IN H2O  
 PINCH POINT: 53.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 16053.9  
 STEAM TURBINE EFFICIENCY: 4902.1  
 TOTAL SYSTEM HORSEPOWER: 20955.9  
 STEAM TURBINE SHARE OF THE LOAD: 23.4 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.436 COGAS: 0.334 GT AT SYSTEM HP: 0.395  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 6997.8 COGAS: 6997.8 GT AT SYSTEM HP: 8268.2  
 THERMAL EFFICIENCY:  
 COGAS: 0.311 GT AT SYSTEM HP: 0.350

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FUEL FEEDER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18450 BTU/LBM

CO/27775 15.48.33

RUN #15(6)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1689.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
EXHAUST GAS TEMPERATURE: 689.0 F  
EXHAUST GAS FLOW RATE: 15731.0 LB/HR (44.4 LB/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
LENGTH: 12.1 FT.  
WIDTH: 12.1 FT.  
HEIGHT: 3.2 FT.

HEAT EXCHANGER SURFACE AREA: 144.8 SQ. FT.  
TUBE LENGTH: 12. FT.  
TUBE TYPE: SMOOTH  
TUBE DIAMETER: 1.5 IN.  
TUBE WALL THICKNESS: 0.036 IN.  
FIN TYPE: SEGMENTED  
FIN SPACING: 7.92 FINS/IN.  
FIN HEIGHT: 0.8 IN.  
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
NUMBER OF TUBES PER ROW: 43.  
TUBE LENGTH: 12. FT.  
OUTSIDE AREA/PASS: 3290.5 SQ. FT.  
INSIDE AREA/PASS: 189.0 SQ. FT.  
FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)  
HEATING SECTION: 3  
BOILING SECTION: 6  
SUPERHEATING SECTION: 4

(HEATING LENGTH= 4.8 FT.)  
(BOILING LENGTH= 4.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION GAS TEMP. IN GAS TEMP. OUT FLUID TEMP. IN FLUID TEMP. OUT REYNOLDS NUMBER (AVG.)  
HEATING 498.9 436.5 200.0 5643.0  
BOILING 611.5 498.9 471.3 4863.3  
SUPERHEATING 688.6 611.5 486.3 667.5  
STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE = 486.3 F)  
STEAM FLOW RATE: 8012.9 LB/HR.  
GAS-GAS PRESSURE DROP: 0.9 IN H2O  
PINCH POINT: 21.6 F

SYSTEM PERFORMANCE

GT FUEL CONSUMPTION (LBM-FUEL/HP-HR): 1660.1  
STEAM FUEL CONSUMPTION (LBM-FUEL/HP-HR): 1135.5  
TOTAL SYSTEM HORSEPOWER: 2795.6  
STEAM TURBINE SHARE OF THE LOAD: 40.6 PERCENT  
SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR): 0.864  
GT FUEL: 1.064  
GT FUEL: 1725.9  
GT FUEL: 1765.9  
GT AT SYSTEM HP: 0.864  
GT AT SYSTEM HP: 2415.7  
GT AT SYSTEM HP: 0.160  
GT AT SYSTEM HP: 0.160  
GT AT SYSTEM HP: 0.160  
GT AT SYSTEM HP: 0.160

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
STEAM TURBINE EFFICIENCY: 0.85  
FW HEATER PRESSURE: 15.0 PSIA  
LHV OF FUEL: 18400 BTU/LBM

RUN #18(o)

08/25/79 13.13.56

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1084.0, APPROXIMATE CORRESPONDING SHIP SPEED: 5.0 KTS  
EXHAUST GAS TEMPERATURE: 689.0 F  
EXHAUST GAS FLOW RATE: 15931.0 LB/MHR ( 44.4 LBP/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
LENGTH: 12.0 FT.  
WIDTH: 12.0 FT.  
HEIGHT: 2.0 FT.

HEAT TRANSFER SURFACE:  
OUTSIDE TUBE DIAMETER: 1.0 IN.  
INSIDE TUBE DIAMETER: 0.9 IN.  
TUBE IN ARRANGEMENT:  
FIN TYPE: SCHEMATED  
FIN SPACING: 11.88 FINS/IN.  
FIN HEIGHT: 0.5 IN.  
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.  
LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.  
NUMBER OF TUBES PER ROW: 64.  
TUBE LENGTH 12. FT.  
OUTSIDE AREA/PASS: 3264.9 SQ.FT.  
INSIDE AREA/PASS: 187.5 SQ. FT.  
FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)  
HEATING SECTION: 3  
BOILING SECTION: 6  
SUPERHEATING SECTION: 3 (HEATING LENGTH= 3.7 FT.:  
BOILING LENGTH= 4.0 FT.:)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	493.7	427.0	200.0	478.8	5965.5
BOILING	605.4	493.7	478.8	486.3	
SUPERHEATING	688.5	605.4	486.3	667.5	50891.9

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
STEAM FLOW RATE: 8931.9 LB/MHR.  
GAS-SIDE PRESSURE DROP: 0.9 IN H2O  
PINCH POINT: 15.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 1660.1  
STEAM TURBINE HORSEPOWER: 1177.6  
TOTAL SYSTEM HORSEPOWER: 2837.7  
STEAM TURBINE SHARE OF THE LOAD: 41.5 PERCENT  
SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
GT ONLY: 1.024 COGAS: 0.822 GT AT SYSTEM HP: 0.858  
GT ONLY: 1765.9 COGAS: 1765.9 GT AT SYSTEM HP: 2435.6  
THERMAL EFFICIENCY:  
GT ONLY: 0.130 COGAS: 0.222 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
STEAM TURBINE EFFICIENCY: 0.85  
FW HEATER PRESSURE: 15.0 PSIA  
LHV OF FUEL: 18400 BTU/LBM

RUN #17(0)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN  
 APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 LAUNCH GAS TEMPERATURE: 742.0 F  
 LAUNCH GAS FLOW RATE: 22664.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL HEIGHT: 17.0 FT.  
 LENGTH: 17.0 FT.  
 WIDTH: 2.0 FT.

HEAT TRANSFER SURFACE  
 COOLING TUBE DIAMETER: 1.0 IN.  
 HEATING TUBE DIAMETER: 0.9 IN.  
 TUBE ZEPHRAZING: 0.001 IN.  
 FIN TYPE: STRIP  
 FIN SPACING: 11.00 FIN/IN.  
 FIN HEIGHT: 0.5 IN.  
 FIN PITCH: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.  
 LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 64.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 3264.9 SQ.FT.  
 INSIDE AREA/PASS: 187.5 SQ. FT.  
 FRONTAL AREA: 143.8 SQ. FT.  
 NUMBER OF PASSES: 12 (TOTAL)  
 HEATING SECTION: 4  
 COOLING SECTION: 8  
 SUPERHEATING SECTION: 0

(HEATING LENGTH= 0.5 FT.)  
 (BOILING LENGTH= 3.8 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	200.3	421.5	200.0	435.0	15413.7
BOILING	450.1	506.3	485.0	486.3	
SUPERHEATING	442.5	656.1	486.3	647.5	125580.6

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE = 486.3 F)

STEAM FLOW RATE: 22638.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.3 IN H2O

PITCH POINT: 21.0 F

SYSTEM PERFORMANCE

GT HEAT RECOVERY EFFICIENCY: 8363.5  
 SEALED TURBINE EFFICIENCY: 2367.9  
 TOTAL SYSTEM EFFICIENCY: 11331.4  
 STEAM FLOW RATE SHARE OF THE LOAD: 26.2 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT HEAT: 0.530 COOLING: 0.391 GT AT SYSTEM HP: 0.478  
 FUEL CONSUMPTION (LBM-FUEL/HR):  
 GT HEAT: 4432.0 COOLING: 4432.0 GT AT SYSTEM HP: 5411.0  
 THERMAL EFFICIENCY:  
 GT HEAT: 0.281 COOLING: 0.254 GT AT SYSTEM HP: 0.250

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.09 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FUEL HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #16

WASTE HEAT RECOVERY UNIT DESIGN RUN

08/22/79 13.16.58

GAS TURBINE

BRAKE HORSEPOWER: 16621.0, 849.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
 FAN INLET GAS TEMPERATURE: 407589.0 LBWHR (1113.2 LBM/SEC)  
 EXHAUST GAS FLOW RATE: 407589.0 LBWHR (1113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

SMALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.0 FT.  
 HEIGHT: 2.0 FT.

HEAT TRANSFER SURFACE:  
 POSTHEATER DIAMETER: 1.0 IN.  
 PREHEATER DIAMETER: 0.9 IN.  
 HEATING SURFACE:  
 HEATING SURFACE:  
 FIN SPACING: 1.5 IN. FIMS/IN.  
 FIN HEIGHT: 0.5 IN.  
 FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.  
 LONGITUDINAL TUBE SPACING: 1.05 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 64.  
 TUBE LENGTH 12. FT.  
 OUTSIDE AREA/PASS: 3264.9 SQ.FT.  
 INSIDE AREA/PASS: 167.5 SQ. FT.  
 FRONTAL AREA: 143.6 SQ. FT.  
 NUMBER OF PASSES: 12 (TOTAL)  
 HEATING SECTIONS: 4  
 ROLLING SECTIONS: 6  
 SUPERHEATING SECTIONS: 2 (HEATING LENGTH= 5.7 FT.)  
 (ROLLING LENGTH= 5.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	510.9	401.5	200.0	462.5	25925.0
ROLLING	707.6	510.9	489.5	489.5	230765.6
SUPERHEATING	854.1	707.6	486.3	689.0	

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM FLOW RATE: 39459.0 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 4.9 IN H2O  
 PITCH POINT: 48.4 F

SYSTEM PERFORMANCE

GT HP/SEPTHEK(REVISED): 16053.3  
 STEAM TURBINE HORSEPOWER: 5232.3  
 TOTAL SYSTEM HORSEPOWER: 21285.7  
 STEAM TURBINE SHARE OF THE LOAD: 24.6 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.436 CGAS: 0.329 GT AT SYSTEM HP: 0.387  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 6997.7 CGAS: 6997.7 GT AT SYSTEM HP: 8235.2  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.317 CGAS: 0.421 GT AT SYSTEM HP: 0.357

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 F.W. HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #24(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
 EXHAUST GAS TEMPERATURE: 689.0 F  
 EXHAUST GAS FLOW RATE: 15973.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.0 FT.  
 HEIGHT: 2.5 FT.

HEAT TRANSFER SURFACE:  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE/FIN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 7.92 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 43.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 3290.5 SQ.FT.  
 INSIDE AREA/PASS: 189.0 SQ. FT.  
 FRONTAL AREA: 144.8 SQ. FT.  
 NUMBER OF PASSES: 12 (TOTAL)  
 HEATING SECTION: 3  
 BOILING SECTION: 5  
 SUPERHEATING SECTION: 4

(HEATING LENGTH= 1.9 FT.)  
 (BOILING LENGTH= 1.9 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	410.0	200.0	437.7	437.7	5779.9
BOILING	630.3	437.7	444.6	444.6	
SUPERHEATING	688.9	444.6	672.5	672.5	54546.6

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)  
 STEAM FLOW RATE: 9377.8 LBM/HR.  
 CAS-SIDE PRESSURE DROP: 0.8 IN H2O  
 PINCH POINT: 32.4 F

SYSTEM PERFORMANCE

GT HCFSEPOWER(REVISIED): 1660.4  
 STEAM TURBINE HORSEPOWER: 1187.4  
 TOTAL SYSTEM HORSEPOWER: 2847.8  
 STEAM TURBINE SHARE OF THE LOAD: 41.7 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 1.364  
 COGAS: 0.620  
 GT AT SYSTEM HP: 0.857  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 1766.0  
 COGAS: 1766.0  
 GT AT SYSTEM HP: 2440.3  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.130  
 COGAS: 0.223  
 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #23(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

08/25/79 13-57-41

GAS TURBINE

BRAKE HORSEPOWER: 8526.0 APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 FUEL CONSUMPTION RATE: 742.0  
 EXHAUST GAS TEMPERATURE: 142.0  
 EXHAUST GAS FLOW RATE: 32864.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.1 FT.  
 HEIGHT: 2.4 FT.

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE LENGTH: 12.0 FT.  
 TUBE WALL THICKNESS: 0.036 IN.  
 FIN SPACING: 0.8 IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 43.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 3290.5 SQ.FT.  
 INSIDE AREA/PASS: 189.0 SQ. FT.  
 FRONTAL AREA: 144.8 SQ. FT.  
 NUMBER OF PASSES: 10 (TOTAL)  
 HEATING SECTION: 3  
 BOILING SECTION: 2  
 SUPERHEATING SECTION: 2 (HEATING LENGTH= 1.5 FT.)

HEAT EXCHANGE PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	789.9	431.5	200.0	438.3	13513.8
BOILING	789.9	438.3	438.3	438.3	
SUPERHEATING	741.2	684.7	444.6	633.8	126450.5

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)  
 STEAM FLOW RATE: 21974.8 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 2.5 IN H2O  
 PINCH POINT: 61.6 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 8376.7  
 STEAM TURBINE HORSEPOWER: 2696.7  
 TOTAL SYSTEM HORSEPOWER: 11073.4  
 STEAM TURBINE SHARE OF THE LOAD: 24.4 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.529  
 CGAS: 0.400  
 GT AT SYSTEM HP: 0.481  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 4433.5  
 CGAS: 4433.9  
 GT AT SYSTEM HP: 5326.0  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.221  
 CGAS: 0.345  
 GT AT SYSTEM HP: 0.288

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FUEL HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #22(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
 EXHAUST GAS TEMPERATURE: 845.0  
 EXHAUST GAS FLOW RATE: 40388.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.1 FT.  
 HEIGHT: 2.4 FT.  
 HEAT TRANSFER SURFACE:  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE IN MANAGER LENGTH: 12.0 FT.  
 FIN SPACING: 0.970 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.  
 TRANSVERSE TUBE SPACING: 3.34 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 43.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 3290.5 SQ.FT.  
 INSIDE AREA/PASS: 189.0 SQ. FT.  
 FRONTAL AREA: 144.8 SQ. FT.  
 NUMBER OF PASSES: 10 (TOTAL)  
 HEATING SECTION: 3  
 BOILING SECTION: 2  
 SUPERHEATING SECTION: 2 (HEATING LENGTH= 3.7 FT.)  
 (BOILING LENGTH= 4.0 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	515.6	431.0	200.0	419.0	21962.6
BOILING	738.2	419.0	419.0	419.0	219577.9
SUPERHEATING	897.5	738.2	444.6	631.3	

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)  
 STEAM FLOW RATE: 36760.7 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 3.8 IN H2O  
 FINCH POINT: 96.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 16090.9  
 STEAM TURBINE HORSEPOWER: 4524.0  
 TOTAL SYSTEM HORSEPOWER: 20614.9  
 STEAM TURBINE SHARE OF THE LOAD: 21.9 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.435 COGAS: 0.340 GT AT SYSTEM HP: 0.401  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 7002.8 COGAS: 7002.8 GT AT SYSTEM HP: 8266.2  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.313 COGAS: 0.407 GT AT SYSTEM HP: 0.345

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 EXHAUST GAS HEATER PRESSURE: 1.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #24

WASTE HEAT RECOVERY UNIT DESIGN RUN

G.S. TURBINE

SHAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
 EXHAUST GAS TEMPERATURE: 689.0 F  
 EXHAUST GAS FLOW RATE: 15931.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 15.0 FT.  
 WIDTH: 15.1 FT.  
 HEIGHT: 2.4 FT.

HEAT TRANSFER SURFACE:  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE TO TUBE ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 7.92 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 43.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 3290.5 SQ. FT.  
 INSIDE AREA/PASS: 189.0 SQ. FT.  
 FRONTAL AREA: 144.8 SQ. FT.  
 NUMBER OF PASSES: 10 (TOTAL)  
 HEATING SECTION: 3  
 BOILING SECTION: 3  
 SUPERHEATING SECTION: 2

{ HEATING LENGTH= 1.2 FT. }  
 { BOILING LENGTH= 0.1 FT. }

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	473.8	412.6	200.0	440.2	5841.8
BOILING	658.9	473.8	440.2	444.6	53585.1
SUPERHEATING	688.5	658.9	444.6	632.5	

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)  
 STEAM FLOW RATE: 9425.4 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 0.7 IN H<sub>2</sub>O  
 PINCH POINT: 33.6 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 1660.9  
 STEAM TURBINE HORSEPOWER: 1161.0  
 TOTAL SYSTEM HORSEPOWER: 2821.9  
 STEAM TURBINE SHARE OF THE LOAD: 41.1 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 1.063 COGAS: 0.826 GT AT SYSTEM HP: 0.860  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 1766.1 COGAS: 1766.1 GT AT SYSTEM HP: 2428.1  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.130 COGAS: 0.221 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:  
 CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 F.W. HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

08/25/79 13.47.43

RUN #23(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 6526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
EXHAUST GAS TEMPERATURE: 742.0 F  
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
LENGTH: 12.1 FT.  
WIDTH: 12.1 FT.  
HEIGHT: 2.9 FT.  
HEAT TRANSFER SURFACE  
OUTSIDE TUBE DIAMETER: 1.5 IN.  
INSIDE TUBE DIAMETER: 1.4 IN.  
TUBE/FIN ARRANGEMENT:  
FIN TYPE: SEGMENTED  
FIN SPACING: 7.92 FINS/IN.  
FIN HEIGHT: 0.8 IN.  
FIN THICKNESS: 0.036 IN.  
TRANSVERSE TUBE SPACING: 3.38 IN.  
LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
NUMBER OF TUBES PER ROW: 43.  
TUBE LENGTH 12. FT.  
OUTSIDE AREA/PASS: 3290.5 SQ.FT.  
INSIDE AREA/PASS: 189.0 SQ. FT.  
FRONTAL AREA: 144.8 SQ. FT.  
NUMBER OF PASSES: 12 (TOTAL)  
HEATING SECTION: 4  
COILING SECTION: 4  
SUPERHEATING SECTION: 2 (BOILING LENGTH= 0.0 FT.)  
(BOILING LENGTH= 1.0 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION GAS TEMP. IN GAS TEMP. OUT FLUID TEMP. IN FLUID TEMP. OUT REYNOLDS NUMBER (AVG.)  
HEATING 486.3 411.5 200.0 444.6 14510.6  
BOILING 694.1 486.3 444.6 444.6  
SUPERHEATING 741.5 694.1 444.6 637.5 133818.8  
STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)  
STEAM FLOW RATE: 23255.8 LBM/HR.  
GAS-SIDE PRESSURE DRCP: 3.0 IN H2O  
PINCH POINT: 41.8 F

SYSTEM PERFORMANCE

GT HCRSEFCWR (REVISED): 8368.8  
STEAM TURBINE HTRSEFCWR: 2874.4  
TOTAL SYSTEM HTRSEFCWR: 11243.3  
STEAM TURBINE SHARE OF THE LOAD: 25.6 PERCENT  
SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
GT ONLY: 0.530 COGAS: 0.394 GT AT SYSTEM HP: 0.479  
FUEL CONSUMPTION (LBM-FUEL/HR.):  
GT ONLY: 4433.1 COGAS: 4433.1 GT AT SYSTEM HP: 5382.0  
THERMAL EFFICIENCY:  
GT ONLY: 0.261 COGAS: 0.351 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
STEAM TURBINE EFFICIENCY: 0.85  
FW HEATER PRESSURE: 15.0 PSIA  
LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
EXHAUST GAS TEMPERATURE: 845.0 F  
EXHAUST GAS FLOW RATE: 407589.0 LB/HR (1113.2 LBW/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
LENGTH: 12.0 FT.  
WIDTH: 12.0 FT.  
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE  
OUTSIDE TUBE DIAMETER: 1.5 IN.  
INSIDE TUBE DIAMETER: 1.4 IN.  
TUBE/FIN ARRANGEMENT:  
FIN TYPE: SEGMENTED  
FIN SPACING: 7.92 FINS/IN.  
FIN HEIGHT: 0.8 IN.  
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
LONGITUDINAL TUBE PACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
NUMBER OF TUBES PER ROW: 43.  
TUBE LENGTH: 12. FT.  
OUTSIDE AREA/PASS: 3290.5 SQ.FT.  
INSIDE AREA/PASS: 189.0 SQ. FT.  
FRONTAL AREA: 144.8 SQ. FT.  
NUMBER OF PASSES: 12 (TOTAL)  
HEATING SECTION: 4  
BOILING SECTION: 6  
SUPERHEATING SECTION: 2 (HEATING LENGTH= 3.4 FT.; BOILING LENGTH= 3.5 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	599.2	405.2	200.0	427.7	23652.1
BOILING	744.9	495.2	427.7	444.6	
SUPERHEATING	848.4	744.9	444.6	635.0	231167.1

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)  
STEAM FLOW RATE: 38942.0 LBW/HR.  
GAS-SIDE PRESSURE DROP: 4.4 IN H2O  
PINCH POINT: 71.5 F

SYSTEM PERFORMANCE

GT HP (REPOWERED/REVISED): 16068.7  
STEAM TURBINE HORSEPOWER: 4804.9  
TOTAL SYSTEM HORSEPOWER: 20873.6  
STEAM TURBINE SHARE OF THE LOAD: 23.0 PERCENT  
SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
GT ONLY: 0.436  
COGAS: 0.335  
GT AT SYSTEM HP: 0.396  
FUEL CONSUMPTION (LBM-FUEL/HR.):  
GT ONLY: 6959.8  
COGAS: 6999.8  
GT AT SYSTEM HP: 8270.7  
THERMAL EFFICIENCY:  
GT ONLY: 0.317  
COGAS: 0.412  
GT AT SYSTEM HP: 0.345

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
STEAM TURBINE EFFICIENCY: 0.85  
FW HEATER PRESSURE: 15.0 PSIA  
LHV OF FUEL: 18400 BTU/LBM

RUN #36(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1884.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
 EXHAUST TEMPERATURE: 899.0  
 EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 15.0 FT.  
 HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE:  
 OUTSIDE TUBE DIAMETER: 1.0 IN.  
 INSIDE TUBE DIAMETER: 0.9 IN.  
 TUBE LENGTH: 12.0 FT.  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 0.188 FINS/IN.  
 FIN HEIGHT: 0.5 IN.  
 FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.  
 LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 80.  
 TUBE LENGTH: 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.  
 INSIDE AREA/PASS: 234.4 SQ. FT.  
 FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)  
 HEATING SECTION: 2  
 BOILING SECTION: 3  
 SUPERHEATING SECTION: 2

(HEATING LENGTH= 4.7 FT.)  
 (BOILING LENGTH= 1.4 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	527.3	465.0	200.0	458.9	4305.7
BOILING	648.2	527.3	298.0	279.3	
SUPERHEATING	688.0	648.2	518.3	662.3	33219.9

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 7769.6 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.5 IN H2O

PINCH POINT: 28.4 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 1661.6

STEAM TURBINE HORSEPOWER: 1043.8

TOTAL SYSTEM HORSEPOWER: 2705.4

STEAM TURBINE SHARE OF THE LOAD: 38.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):

GT ONLY: 1.023 COGAS: 0.853 GT AT SYSTEM HP: 0.877

GT ONLY: 1.766.3 COGAS: 1.766.3 GT AT SYSTEM HP: 2372.3

GT ONLY: 0.130 COGAS: 0.212 GT AT SYSTEM HP: 0.156

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.00 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 1.50 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #35

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 EXHAUST GAS TEMPERATURE: 742.0 F  
 EXHAUST GAS FLOW RATE: 328641.0 LBM/HR ( 91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS: FT.  
 LENGTH: 12.0 FT.  
 WIDTH: 12.0 FT.  
 HEIGHT: 1.5 FT.

FEET TRANSVERSE SURFACE  
 OUTSIDE TUBE DIAMETER: 1.3 IN.  
 INSIDE TUBE DIAMETER: 0.9 IN.  
 TUBE FIN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 11.88 FMS/IN.  
 FIN HEIGHT: 0.5 IN.  
 FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.  
 LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 80.  
 TUBE LENGTH 12. FT.  
 OUTSIDE AREA/PASS: 4081.2 SQ.FT.  
 INSIDE AREA/PASS: 234.4 SQ. FT.  
 FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)  
 HEATING SECTION: 3  
 BOILING SECTION: 4  
 SUPERHEATING SECTION: 2

(HEATING LENGTH= 1.6 FT.)  
 (BOILING LENGTH= 5.5 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	543.7	559.9	200.0	513.3	11569.7
BOILING	643.5	643.7	518.3	518.3	
SUPERHEATING	741.8	643.5	518.3	645.0	91410.0

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)  
 STEAM FLOW RATE: 20426.0 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 1.7 IN H2O  
 PINCH POINT: 30.6 F

SYSTEM PERFORMANCE

GT HP/SEPOWER(REVISED): 8391.1  
 STEAM TURBINE HORSEPOWER: 2706.8  
 TOTAL SYSTEM HORSEPOWER: 11098.0  
 STEAM TURBINE SHARE OF THE LOAD: 24.4 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR.):  
 GT ONLY: 0.522 COGAS: 0.400 GT AT SYSTEM HP: 0.401  
 FUEL GT ONLY: 4.35.4 COGAS: 4435.4 GT AT SYSTEM HP: 5334.1  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.262 COGAS: 0.346 GT AT SYSTEM HP: 0.28E

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FM HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #34(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

08/25/75 15.07.21

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
 EXHAUST GAS TEMPERATURE: 849.0 F  
 EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 15.0 FT.  
 HEIGHT: 11.5 FT.

HEAT TRANSFER SURFACE:  
 OUTSIDE TUBE DIAMETER: 1.0 IN.  
 INSIDE TUBE DIAMETER: 0.9 IN.  
 TUBE/FIN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 11.88 FINS/IN.  
 FIN HEIGHT: 0.3 IN.  
 FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.  
 LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 80.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4081.2 SQ.FT.  
 INSIDE AREA/PASS: 234.4 SQ. FT.  
 FRONTAL AREA: 179.8 SQ. FT.  
 NUMBER OF PASSES: 9 (TOTAL)  
 HEATING SECTION: 3  
 BOILING SECTION: 2  
 SUPERHEATING SECTION: 1 (HEATING LENGTH= 1.9 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	552.1	441.0	200.0	481.7	20064.0
BOILING	779.1	525.1	487.7	518.3	154754.6
SUPERHEATING	847.1	778.1	518.3	613.8	

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)  
 STEAM FLOW RATE: 36836.9 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 2.5 IN H2O  
 FINCH POINT: 64.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 16132.9  
 STEAM TURBINE HORSEPOWER: 4838.2  
 TOTAL SYSTEM HORSEPOWER: 20971.1  
 STEAM TURBINE SHARE OF THE LOAD: 23.1 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.434  
 COGAS: 0.334  
 GT AT SYSTEM HP: 0.394  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 708.6  
 COGAS: 7008.6  
 GT AT SYSTEM HP: 8267.6  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.318  
 COGAS: 0.414  
 GT AT SYSTEM HP: 0.351

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.06 IN. HG  
 SYSTEM THERMAL EFFICIENCY: 0.35  
 F.W. HEATER PRESSURE: 0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #42(0)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

08/25/79 15.51.44

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
 EXHAUST GAS TEMPERATURE: 689.0 F  
 EXHAUST GAS FLOW RATE: 159731.0 LB/MHR (44.4 LB/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 15.2 FT.  
 HEIGHT: 3.4 FT.

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE/FLUID ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 7.92 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 54.  
 TUBE LENGTH: 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.  
 INSIDE AREA/PASS: 237.3 SQ. FT.  
 FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 14 (TOTAL)  
 HEATING SECTIONS: 4  
 COOLING SECTIONS: 4  
 SUPERHEATING SECTION: 6

(HEATING LENGTH= 0.8 FT.)  
 (COOLING LENGTH= 4.5 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	497.9	430.5	200.0	485.0	4760.4
COOLING	606.8	497.9	485.0	486.3	
SUPERHEATING	688.8	606.8	486.3	670.0	40168.4

STEAM PRESSURE: 600.0 PSIA SATURATION TEMPERATURE= 486.3 F

STEAM FLOW RATE: 8814.4 LB/MHR.

GAS-SIDE PRESSURE DROP: 0.6 IN H2O

FINCH POINT: 14.9 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 1661.0  
 STEAM TURBINE HORSEPOWER: 1164.2  
 TOTAL SYSTEM HORSEPOWER: 2825.2  
 STEAM TURBINE SHARE OF THE LOAD: 41.2 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 1.063 COGAS: 0.625 GT AT SYSTEM HP: 0.860  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 1766.1 COGAS: 1766.1 GT AT SYSTEM HP: 2429.7  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.130 COGAS: 0.221 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 F.W. HEATER PRESSURE: 13.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #41 (o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

66/22/75 15-06-16

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 EXHAUST GAS TEMPERATURE: 742.0 F  
 EXHAUST GAS FLOW RATE: 32864.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:

LENGTH: 12.0 FT.  
 WIDTH: 15.2 FT.  
 HEIGHT: 3.4 FT.

HEAT TRANSFER SURFACE DIMETERS: 1.5 IN.  
 CIRCULAR TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.5 IN.  
 TUBE BUNDLE ARRANGEMENT: U  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 7.92 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.33 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF RCMS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 54.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4132.2 SQ.FT.  
 INSIDE AREA/PASS: 237.3 SQ. FT.  
 FFCTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 14 (TOTAL)  
 HEATING SECTION: 4  
 BOILING SECTION: 7  
 SUPERHEATING SECTION: 3  
 (HEATING LENGTH= 3.7 FT.)  
 (BOILING LENGTH= 1.9 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	506.1	428.0	200.0	475.6	11462.9
BOILING	680.4	506.1	475.6	487.3	96788.1
SUPERHEATING	741.2	680.4	486.3	687.5	

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 21620.8 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.4 IN H2O

PINCH POINT: 30.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 8379.2  
 STEAM TURBINE HORSEPOWER: 2918.0  
 TOTAL SYSTEM HORSEPOWER: 11297.2  
 STEAM TURBINE SHARE OF THE LOAD: 25.8 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.529  
 CGAS: 0.393  
 GT AT SYSTEM HP: 0.476  
 FUEL CONSUMPTION (LBM-FUEL/HR):  
 GT ONLY: 4434.2  
 CGAS: 4434.2  
 GT AT SYSTEM HP: 5399.6  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.261  
 CGAS: 0.352  
 GT AT SYSTEM HP: 0.285

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FM HEATER PRESSURE: 15.0 PSIA  
 LHV CF FUEL: 18400 BTU/LBM

RUN #40

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1621.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
 EXHAUST GAS TEMPERATURE: 840.0 F/LBM/HR (1113.2 LBM/SEC)  
 EXHAUST GAS FLOW RATE: 407589.0 LBM/HR

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 15.2 FT.  
 HEIGHT: 3.4 FT.

HEAT TRANSFER SURFACE  
 INSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE LENGTH: 1.4 IN.  
 TUBE RANGE PER FT.:  
 TUBE IN RANGE PER FT.:  
 FIN SPACING: 7.92 FINS/IN.  
 FIN PITCH: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 54.  
 TUBE LENGTH 12. FT.  
 OUTSIDE AREA/PASS: 4132.2 SQ.FT.  
 INSIDE AREA/PASS: 237.3 SQ. FT.  
 FRONTAL AREA: 181.9 SQ. FT.  
 NUMBER OF PASSES: 14 (TOTAL)  
 HEATING SECTION: 5  
 BOILING SECTION: 7  
 SUPERHEATING SECTION: 2 (HEATING LENGTH= 5.7 FT.)  
 (BOILING LENGTH= 4.1 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	213.5	402.3	200.0	467.5	20574.3
BOILING	737.5	517.2	486.3	486.3	
SUPERHEAT ING	850.0	737.5	486.3	650.0	179758.6

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM FLOW RATE: 39693.2 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 3.5 IN H2O  
 PINCH POINT: 45.8 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 16101.5  
 STEAM TURBINE HORSEPOWER: 5167.7  
 TOTAL SYSTEM HORSEPOWER: 21268.2  
 STEAM TURBINE SHARE OF THE LOAD: 24.3 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.435 COGAS: 0.329 GT AT SYSTEM HP: 0.387  
 FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 7004.3 COGAS: 7004.3 GT AT SYSTEM HP: 0.237.9  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.310 COGAS: 0.420 GT AT SYSTEM HP: 0.357

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #42(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
 EXHAUST GAS TEMPERATURE: 689.0 F  
 EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBP/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS: FT.  
 LENGTH: 12.0 FT.  
 WIDTH: 15.2 FT.  
 HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE/FIN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 7.92 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 3.036 IN.

TRANSVERSE TUBE SPACING: 3.36 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 54.  
 TUBE LENGTH: 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.5 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)  
 HEATING SECTION: 3  
 BOILING SECTION: 3  
 SUPERHEATING SECTION: 3

(HEATING LENGTH= 4.1 FT.)  
 (BOILING LENGTH= 1.8 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	498.7	435.0	200.0	474.4	4552.9
BOILING	639.4	498.7	474.4	486.3	
SUPERHEATING	687.9	639.4	486.3	661.3	38478.7

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 885.4 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.6 IN H2O

PINCH POINT: 24.3 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.3

STEAM TURBINE HORSEPOWER: 1140.0

TOTAL SYSTEM HORSEPOWER: 2801.3

STEAM TURBINE SHARE OF THE LOAD: 40.7 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 1.063 COGAS: 0.630 GT AT SYSTEM MP: 0.863

FUEL CONSUMPTION (LBM-FUEL/HR):  
 GT ONLY: 11766.2 COGAS: 1766.2 GT AT SYSTEM MP: 2418.4

THERMAL EFFICIENCY:  
 GT ONLY: 0.130 COGAS: 0.219 GT AT SYSTEM MP: 0.160

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.855  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #41

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 3526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 EXHAUST GAS TEMPERATURE: 742.0 F  
 EXHAUST GAS FLOW RATE: 320691.0 LBM/HR ( 91.3 LBM/SEC )

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.3 FT.  
 WIDTH: 15.2 FT.  
 HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE:  
 CONDENSER TUBE DIAMETER: 1.5 IN.  
 CONDENSER TUBE LENGTH: 1.4 IN.  
 CONDENSER TUBE SPACING: 1.5 IN.  
 CONDENSER TUBE WEIGHT: 1.5 LBS  
 HEATING SECTION:  
 FIN SPACING: 0.8 IN.  
 FIN WEIGHT: 0.9 LBS  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF RCMS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 54.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4132.2 SQ.FT.  
 INSIDE AREA/PASS: 237.3 SQ. FT.  
 FRONTAL AREA: 181.9 SQ. FT.  
 NUMBER OF PASSES: 12 (TOTAL)  
 HEATING SECTION: 4  
 BOILING SECTION: 4  
 SUPERHEATING SECTION: 2 (HEATING LENGTH= 9.3 FT.; BOILING LENGTH= 2.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	516.5	435.0	200.0	486.3	11664.0
BOILING	281.5	281.5	486.3	486.3	97271.8
SUPERHEATING	741.7	683.2	486.3	486.3	

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM FLOW RATE: 21894.0 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 2.0 IN H2O  
 PINCH POINT: 31.6 F

SYSTEM PERFORMANCE

GT FUEL/CFM (REVISED): 0.385.5  
 STEAM TURBINE HORSEPOWER: 2032.3  
 TOTAL SYSTEM HORSEPOWER: 11217.8  
 STEAM TURBINE SHARE OF THE LOAD: 25.2 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.522 COGAS: 0.395 GT AT SYSTEM HP: 0.475  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 4434.8 COGAS: 4434.8 GT AT SYSTEM HP: 5373.6  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.261 CO-ASE: 0.350 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:  
 CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #40(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
 EXHAUST GAS TEMPERATURE: 849.0 F  
 EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBP/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 15.2 FT.  
 HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE  
 GLT SIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE/FIN ARRANGEMENT:  
 FIN TYPE: SEGMENTED FINS/IN.  
 FIN SPACING: 7.92 IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.032 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 54.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4132.2 SQ.FT.  
 INSIDE AREA/PASS: 237.3 SQ. FT.  
 FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)  
 HEATING SECTION: 4  
 BOILING SECTION: 4  
 SUPERHEATING SECTION: 2 (HEATING LENGTH= 5.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	522.8	418.8	200.0	460.6	19625.8
BOILING	730.7	522.8	460.6	486.3	
SUPERHEATING	850.0	730.7	486.3	647.3	173776.7

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM FLOW RATE: 38266.0 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 3.0 IN H2O  
 FINCT FCINT: 62.2 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16116.8  
 STEAM TURBINE HORSEPOWER: 4972.8  
 TOTAL SYSTEM HORSEPOWER: 21089.7  
 STEAM TURBINE SHARE OF THE LOAD: 23.6 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/MP-HR):  
 GT ONLY: 0.435 COGAS: 0.332 GT AT SYSTEM MP: 0.392  
 FUEL CONSUMPTION (LBM-FUEL/HR-1):  
 GT ONLY: 7006.4 COGAS: 7006.4 GT AT SYSTEM MP: 8259.7  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.318 COGAS: 0.416 GT AT SYSTEM MP: 0.353

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.0 CF IN. HG  
 HEATING EFFICIENCY: 0.85  
 TUBE SURFACE AREA: 5.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #54(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

SHAKE COMPRESSOR: 1084.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
 EXHAUST GAS TEMPERATURE: 689.0 F  
 EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS: FT.  
 LENGTH: 15.0 FT.  
 WIDTH: 15.0 FT.  
 HEIGHT: 1.5 FT.  
 HEAT TRANSFER SURFACE  
 INSIDE TUBE DIAMETER: 1.0 IN.  
 INSIDE TUBE DIAMETER: 0.9 IN.  
 TUBE/FIN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 11.88 FINS/IN.  
 FIN HEIGHT: 0.5 IN.  
 FIN THICKNESS: 0.024 IN.  
 TRANSVERSE TUBE SPACING: 2.25 IN.  
 LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 80.  
 TUBE LENGTH 12. FT.  
 OUTSIDE AREA/PASS: 4081.2 SQ.FT.  
 INSIDE AREA/PASS: 234.4 SQ. FT.  
 FRONTAL AREA: 179.8 SQ. FT.  
 NUMBER OF PASSES: 9 (TOTAL)  
 HEATING SECTION: 2  
 BOILING SECTION: 4  
 SUPERHEATING SECTION: 3 (HEATING LENGTH= 3.9 FT.)  
 (BOILING LENGTH= 3.9 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	501.6	403.0	200.0	425.8	4683.4
BOILING	527.7	461.6	425.8	444.6	
SUPERHEATING	607.9	587.7	444.6	667.5	45829.2

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)  
 STEAM FLOW RATE: 9609.1 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 0.4 IN H2O  
 FINCH FCINT: 35.8 F

SYSTEM PERFORMANCE

GT HOPSEPOWER (REVISED): 1661.7  
 STEAP TURBINE HOPSEPOWER: 1212.5  
 TOTAL SYSTEM HOPSEPOWER: 2874.2  
 STEAM TURBINE SHARE OF THE LOAD: 42.2 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 ST ONLY: 1.061 COGAS: 0.615 GT AT SYSTEM HP: 0.853  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 1766.3 COGAS: 1766.3 GT AT SYSTEM HP: 2452.6  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.133 COGAS: 0.225 GT AT SYSTEM HP: 0.162

ASSUMED SYSTEM CHARACTERISTICS:  
 CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #53

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 EXHAUST GAS TEMPERATURE: 747.0 °F  
 EXHAUST GAS FLOW RATE: 32864.0 LBM/HR ( 91.3 LBM/SEC )

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 15.0 FT.  
 HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE:  
 TUBESIDE TUBE DIAMETER: 1.1 IN.  
 EXHAUST TUBE DIAMETER: 0.9 IN.  
 TUBE/FIN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 11.88 FINS/IN.  
 FIN HEIGHT: 0.5 IN.  
 FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.  
 LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 80.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4081.2 SQ.FT.  
 INSIDE AREA/PASS: 234.4 SQ. FT.  
 FRONTAL AREA: 179.8 SQ. FT.  
 NUMBER OF PASSES: 9 (TOTAL)  
 HEATING SECTION: 3  
 BOILING SECTION: 4  
 SUPERHEATING SECTION: 2 (HEATING LENGTH= 0.2 FT.; BOILING LENGTH= 4.7 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	WAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	781.2	405.1	200.0	444.6	11921.6
BOILING	621.7	481.5	444.6	444.6	115150.3
SUPERHEATING	739.8	621.7	444.6	630.0	

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)  
 STEAM FLOW RATE: 23098.0 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 1.6 IN H2O  
 PINCH POINT: 36.9 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 8392.6  
 STEAM TURBINE HORSEPOWER: 2913.9  
 TOTAL SYSTEM HORSEPOWER: 11306.5  
 STEAM TURBINE SHARE OF THE LOAD: 25.8 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.523 COGAS: 0.3392 GT AT SYSTEM HP: 0.47E  
 FUEL CONSUMPTION (LBM-FUEL/HR):  
 GT ONLY: 4435.6 COGAS: 4435.6 GT AT SYSTEM HP: 5402.8  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.263 COGAS: 0.352 GT AT SYSTEM HP: 0.285

ASSUMED SYSTEM CHARACTERISTICS:  
 CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

RUN #52(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16621.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
 EXHAUST GAS TEMPERATURE: 849.0 F  
 EXHAUST GAS FLOW RATE: 40759.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 15.0 FT.  
 HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE:  
 TUBE DIAMETER: 1.0 IN.  
 TUBE LENGTH: 12.0 FT.  
 TUBE WALL THICKNESS: 0.024 IN.  
 TUBE FIN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 11.88 FINS/IN.  
 FIN HEIGHT: 0.5 IN.  
 FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.  
 LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 80.  
 TUBE LENGTH: 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.  
 INSIDE AREA/PASS: 234.4 SQ. FT.  
 FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)  
 HEATING SECTION: 3  
 ROLLING SECTION: 2  
 SUPERHEATING SECTION: 2

(HEATING LENGTH= 0.9 FT.)  
 (ROLLING LENGTH= 3.9 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	501.4	405.0	200.0	439.0	18992.1
ROLLING	706.8	501.4	439.0	444.6	
SUPERHEATING	848.8	706.8	444.6	690.0	180690.5

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 38086.5 LBM/HR.

GAS-SIDE FRESHURE DROP: 2.5 IN H2O

PINCH POINT: 62.4 F

SYSTEM PERFORMANCE

GT FCRSEFCMR(REVISED): 16135.3

STEAM TURBINE HORSEPOWER: 4880.7

TOTAL SYSTEM HORSEPOWER: 21016.0

STEAM TURBINE SHARE OF THE LOAD: 23.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.438 C0GAS: 0.334 GT AT SYSTEM HP: 0.393

FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 7008.9 C0GAS: 7008.9 GT AT SYSTEM HP: 8265.1

THERMAL EFFICIENCY:  
 GT ONLY: 0.318 C0GAS: 0.415 GT AT SYSTEM HP: 0.352

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

APPENDIX E

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

CAS TURBINE

BRAKE HORSEPOWER: 1684.01 APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
 EXHAUST GAS TEMPERATURE: 689.0 F  
 EXHAUST GAS FLOW RATE: 159731.0 LBM/HR ( 44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 15.2 FT.  
 HEIGHT: 2.9 FT.  
 HEAT TRANSFER SURFACE:  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE/FLY AREA: 10.4 SQ. FT.  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 0.792 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.  
 TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 54.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4132.2 SQ. FT.  
 INSIDE AREA/PASS: 237.3 SQ. FT.  
 FRONTAL AREA: 181.9 SQ. FT.  
 NUMBER OF PASSES: 12 (TOTAL)  
 HEATING SECTION: 3  
 BOILING SECTION: 6  
 SUPERHEATING SECTION: 3 (HEATING LENGTH= 4.1 FT.)  
 (BOILING LENGTH= 1.7 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	498.7	435.0	200.0	474.4	4552.9
BOILING	639.4	498.7	474.4	484.3	
SUPERHEATING	688.1	639.4	486.3	662.5	38336.8

STEAM PRESSURE: 630.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM FLOW RATE: 6685.4 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 0.6 IN H2O  
 PINCH POINT: 24.3 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 1661.3  
 STEAM TURBINE HORSEPOWER: 1141.0  
 TOTAL SYSTEM HORSEPOWER: 2802.3  
 STEAM TURBINE SHARE OF THE LOAD: 40.7 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 1.063 CONCAS: 0.830 GT AT SYSTEM HP: 0.863  
 FUEL CONSUMPTION (LBM-FUEL/HR):  
 GT ONLY: 1766.2 CONCAS: 1766.2 GT AT SYSTEM HP: 2418.9  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.133 CONCAS: 0.219 GT AT SYSTEM HP: 0.16C

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

18716/79 14-34.30

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

INLET FURSTROMPERI 1895.0, APPROXIMATE CORRESPONDING SHIP SPEED: 10.0 KTS  
EXHAUST GAS TEMPERATURE: 689.0  
EXHAUST GAS FLOW RATE: 167075.0 LBM/HR ( 46.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
LENGTH: 12.0 FT.  
WIDTH: 15.2 FT.  
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE  
OUTSIDE TUBE DIAMETER: 1.5 IN.  
INSIDE TUBE DIAMETER: 1.4 IN.  
TUBE/FIN ARRANGEMENT:  
FIN TYPE: SEGMENTED  
FIN SPACING: 7.92 FINS/IN.  
FIN HEIGHT: 0.8 IN.  
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
NUMBER OF TUBES PER ROW: 54.  
TUBE LENGTH 12. FT.  
OUTSIDE AREA/PASS: 4132.2 SQ.FT.  
INSIDE AREA/PASS: 237.3 SQ. FT.  
FRONTAL AREA: 181.9 SQ. FT.  
NUMBER OF PASSES: 12 (TOTAL)  
HEATING SECTION: 3  
COOLING SECTION: 3  
SUPERHEATING SECTION: 6

{ HEATING LENGTH= 2.4 FT. }  
{ BOILING LENGTH= 2.4 FT. }

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	498.5	435.0	200.0	473.1	4757.0
BOILING	631.5	498.5	473.1	486.3	
SUPERHEATING	687.6	631.5	486.3	660.0	40389.8

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 9084.8 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.6 IN H2O

FINCH PITCH: 25.3 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 1864.2  
 STEAM TURBINE HORSEPOWER: 1191.3  
 TOTAL SYSTEM HORSEPOWER: 3060.6  
 STEAM TURBINE SHARE OF THE LOAD: 38.9 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 1.022 COGAS: 0.624 GT AT SYSTEM HP: 0.829  
 FUEL CONSUMPT FOR LBM-FUEL/HR.:  
 GT ONLY: 1910.7 COGAS: 1910.7 GT AT SYSTEM HP: 2536.6  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.135 COGAS: 0.222 GT AT SYSTEM HP: 0.167

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
STEAM TURBINE EFFICIENCY: 0.85  
FW HEATER PRESSURE: 15.0 PSIA  
LHV OF FUEL: 18400 BTU/LBM

08/16/79 12-50-27

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 3150.0, APPROXIMATE CORRESPONDING SHIP SPEED: 12.0 KTS  
EXHAUST TEMPERATURE: 689.0 F  
EXHAUST GAS FLOW RATE: 22390.0 LBM/HR ( 62.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
LENGTH: 12.0 FT.  
WIDTH: 15.2 FT.  
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE  
OUTSIDE TUBE DIAMETER: 1.5 IN.  
INSIDE TUBE DIAMETER: 1.4 IN.  
TUBE LENGTH: 12.0 FT.  
FIN TYPE: UNLIMITED  
FIN SPACING: 7.92 FINS/IN.  
FIN PITCH: 0.8 IN.  
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.36 IN.  
LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
NUMBER OF TUBES PER ROW: 54.  
TUBE LENGTH: 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.  
INSIDE AREA/PASS: 237.3 SQ. FT.  
FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)  
HEAT EXG SECTION: 3  
BOILING SECTION: 3  
SUPERHEATING SECTION: 3 (BOILING LENGTH= 4.3 FT.)  
(HEATING LENGTH= 3.1 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	501.8	439.5	200.0	471.9	6282.8
BOILING	627.0	607.9	471.9	469.3	54035.3
SUPERHEATING	687.9	627.0	486.3	486.3	

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 12028.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.0 IN H2O

PINCH POINT: 29.9 F

SYSTEM PERFORMANCE

GT FUSEPOWER/REVERSE	3112.1	GT AT SYSTEM MP:	0.672
GT FUSEPOWER/REVERSE	3112.1	GT AT SYSTEM MP:	0.672
STEAM TURBINE HORSEPOWER	1568.9	GT AT SYSTEM MP:	3143.8
TOTAL SYSTEM HORSEPOWER	4681.2	GT AT SYSTEM MP:	0.251
STEAM TURBINE SHARE OF THE LOAD	33.5 PERCENT	GT AT SYSTEM MP:	0.206
SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):			
GT ONLY: 0.829			
COGAS: 0.551			
FUEL CONSUMPTION (LBM-FUEL/HR.):			
GT ONLY: 2577.1			
COGAS: 2577.1			
THERMAL EFFICIENCY:			
GT ONLY: 0.167			
COGAS: 0.251			
GT AT SYSTEM MP:			
GT AT SYSTEM MP:			

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
STEAM TURBINE EFFICIENCY: 0.85  
FW HEATER PRESSURE: 15.0 PSIA  
LHV OF FUEL: 18400 BTU/LBM

CG/16/75 15:47.C7

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

HPAKE HORSEPOWER: 4316.0, APPROXIMATE CORRESPONDING SHIP SPEED: 13.0 KTS  
EXHAUST GAS TEMPERATURE: 699.0 F  
EXHAUST GAS FLOW RATE: 262546.0 LBM/HR ( 72.9 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:

LENGTH: 12.0 FT.  
WIDTH: 15.2 FT.  
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE

OUTSIDE TUBE DIAMETER: 1.5 IN.  
INSIDE TUBE DIAMETER: 1.4 IN.  
TUBE WALL THICKNESS: 0.036 IN.  
FIN TYPE: SEGMENTED  
FIN SPACING: 0.8 IN  
FIN HEIGHT: 0.8 IN  
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 4.92 IN.

NUMBER OF ROWS PER PASS: 1.  
NUMBER OF TUBES PER ROW: 54.  
TUBE LENGTH: 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)  
HEATING SECTION: 3  
BOILING SECTION: 6  
SUPERHEATING SECTION: 3

(HEATING LENGTH= 5.1 FT.)  
(BOILING LENGTH= 4.8 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	527.7	439.5	209.0	467.5	7675.4
BOILING	506.9	502.7	467.5	467.5	67796.6
SUPERHEATING	699.3	620.6	486.3	647.5	

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 14806.4 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.3 IN H2O

PINCH POINT: 35.2 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 4250.8

STEAM TURBINE HORSEPOWER: 1924.2

TOTAL SYSTEM HORSEPOWER: 6175.0

STEAM TURBINE SHARE OF THE LOAD: 31.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):

GT ONLY: 0.710 COGAS: 0.489 GT AT SYSTEM HP: 0.589

FUEL CONSUMPTION (LBM-FUEL/HR-J):

GT ONLY: 3018.3 COGAS: 3018.3 GT AT SYSTEM HP: 3639.4

THERMAL EFFICIENCY:

GT ONLY: 0.195 COGAS: 0.283 GT AT SYSTEM HP: 0.235

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
STEAM TURBINE EFFICIENCY: 0.85  
FW HEATER PRESSURE: 15.0 PSIA  
LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

HPAKE HORSEPOWER: 5474.0, APPROXIMATE CORRESPONDING SHIP SPEED: 14.0 KTS  
 EXHAUST GAS TEMPERATURE: 709.0 F  
 EXHAUST GAS FLOW RATE: 279070.0 LB/HR (177.5 LBW/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 15.3 FT.  
 HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE/FLY ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 1.92 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.30 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 54.  
 TUBE LENGTH: 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.  
 INSIDE AREA/PASS: 237.3 SQ. FT.  
 FRONTAL AREA: 181.5 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)  
 HEATING SECTION: 3  
 BOILING SECTION: 3  
 SUPERHEATING SECTION: 3

(HEATING LENGTH= 5.2 FT.)  
 (BOILING LENGTH= 4.6 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	504.3	438.0	200.0	465.6	8467.9
BOILING	930.1	504.3	465.6	486.3	74819.9
SUPERHEATING	710.3	630.1	486.3	655.0	

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 16381.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.5 IN H2O

PINCH POINT: 36.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 5389.5

STEAM TURBINE HORSEPOWER: 2140.5

TOTAL SYSTEM HORSEPOWER: 7530.0

STEAM TURBINE SHARE OF THE LOAD: 28.4 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):

GT ONLY: 0.632 COGAS: 0.452 GT AT SYSTEM HP: 0.545

FUEL CONSUMPTION (LBM-FUEL/HR):

GT ONLY: 3404.5 COGAS: 3404.5 GT AT SYSTEM HP: 4100.7

THERMAL EFFICIENCY:

GT ONLY: 0.219 COGAS: 0.306 GT AT SYSTEM HP: 0.254

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 6947.0, APPROXIMATE CORRESPONDING SHIP SPEED: 15.0 KTS  
 EXHAUST GAS TEMPERATURE: 733.0  
 EXHAUST GAS FLOW RATE: 31218.0 LBM/HR ( 86.7 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 15.2 FT.  
 HEIGHT: 2.5 FT.

HEAT TRANSFER SURFACE  
 (OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.)  
 TUBE LENGTH: 12.0 FT.  
 FIN TYPE: ANGLE CUT  
 FIN SPACING: 7.92 IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 54.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4132.2 SQ.FT.  
 INSIDE AREA/PASS: 237.3 SQ. FT.  
 FRONTAL AREA: 181.5 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)  
 HEATING SECTION: 4  
 BOILING SECTION: 4  
 SUPERHEATING SECTION: 2 (HEATING LENGTH= 0.5 FT.,  
 BOILING LENGTH= 2.4 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	513.8	435.0	200.0	485.0	10757.3
BOILING	473.8	482.0	482.0	498.3	
SUPERHEATING	732.1	673.4	486.3	698.8	89617.3

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM FLOW RATE: 20172.7 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 1.8 IN H<sub>2</sub>O  
 PINCH POINT: 28.8 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 6835.2  
 STEAM TURBINE HORSEPOWER: 2604.9  
 TOTAL SYSTEM HORSEPOWER: 9440.0  
 STEAM TURBINE SHARE OF THE LOAD: 27.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.559  
 COGAS: 0.412

FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 3852.0  
 COGAS: 3892.0  
 GT AT SYSTEM HP: 4769.3  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.243  
 COGAS: 0.335  
 GT AT SYSTEM HP: 0.274

ASSUMED SYSTEM CHARACTERISTICS:  
 CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FM HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 EXHAUST GAS TEMPERATURE: 742.0  
 EXHAUST GAS FLOW RATE: 328641.0 LBM/HR I 91.3 LBM/SEC

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.2 FT.  
 HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE  
 CIRCULAR TUBE DIAMETER: 1.5 IN.  
 SQUARE TUBE DIAMETER: 1.4 IN.  
 TUBE FIN TYPE: UNFINISHED  
 FIN TYPE: UNFINISHED  
 FIN SPACING: 7.92 IN FINS/IN.  
 FIN HEIGHT: 3.8 IN  
 FIN THICKNESS: 3.036 IN.

TRANSVERSE TUBE SPACING: 3.36 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 54.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4132.2 SQ.FT.  
 INSIDE AREA/PASS: 237.3 SQ. FT.  
 FRONTAL AREA: 181.9 SQ. FT.  
 NUMBER OF PASSES: 12 (TOTAL)  
 HEATING SECTION: 4  
 BOILING SECTION: 6  
 SUPERHEATING SECTION: 2 (HEATING LENGTH= 9.6 FT.)  
 (BOILING LENGTH= 2.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	516.0	435.0	200.0	484.4	11664.0
BOILING	489.0	289.0	484.4	486.3	
SUPERHEATING	741.7	683.2	484.4	486.3	97271.8

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM FLOW RATE: 21894.0 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 2.0 IN H2O  
 PINCH POINT: 31.6 F

SYSTEM PERFORMANCE

GT HP/SEC (REVISED): 8385.5  
 STEAM TURBINE HORSEPOWER: 2832.3  
 TOTAL SYSTEM HORSEPOWER: 11217.8  
 STEAM TURBINE SHARE OF THE LOAD: 25.2 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.527 CGAS: 0.395 GT AT SYSTEM HP: 0.475  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 4434.8 CGAS: 4434.8 GT AT SYSTEM HP: 5373.6  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.261 CGAS: 0.350 GT AT SYSTEM HP: 0.285

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 PW HEATER PRESSURE: 15.0 PSIA  
 LHV CF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 10421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 17.0 KTS  
 EXHAUST GAS TEMPERATURE: 786.0 F  
 EXHAUST GAS FLOW RATE: 350673.0 LBM/HR ( 97.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 16.9 FT.  
 WIDTH: 12.0 FT.  
 HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE/IN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 7.92 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 54.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4132.2 SQ.FT.  
 INSIDE AREA/PASS: 237.3 SQ. FT.  
 FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)  
 HEATING SECTION: 4  
 BOILING SECTION: 4  
 SUPERHEATING SECTION: 2  
 (HEATING LENGTH= 3.5 FT.)  
 (BOILING LENGTH= 3.6 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	516.6	525.0	200.0	473.1	14414.3
BOILING	696.5	516.6	473.1	486.3	
SUPERHEATING	786.0	696.5	486.3	642.5	123750.3

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM FLOW RATE: 27527.7 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 2.3 IN H2O  
 PINCH POINT: 43.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 10243.8  
 STEAM TURBINE HORSEPOWER: 3564.3  
 TOTAL SYSTEM HORSEPOWER: 13808.1  
 STEAM TURBINE SHARE OF THE LOAD: 25.8 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.449  
 COGAS: 0.369  
 GT AT SYSTEM HP: 0.449  
 FUEL CONSUMPTION (LBM-FUEL/HR):  
 GT ONLY: 5066.5  
 COGAS: 5088.5  
 GT AT SYSTEM HP: 6195.5  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.278  
 COGAS: 0.375  
 GT AT SYSTEM HP: 0.308

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 12105.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 EXHAUST GAS TEMPERATURE: 809.0 F  
 EXHAUST GAS FLOW RATE: 381885.0 LBM/HR (106.1 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.6 FT.  
 WIDTH: 15.2 FT.  
 HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE FIN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 7.92 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 54.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 4132.2 SQ.FT.  
 INSIDE AREA/PASS: 237.3 SQ. FT.  
 FRONTAL AREA: 181.9 SQ. FT.  
 NUMBER OF PASSES: 12 (TOTAL)  
 HEATING SECTION: 4  
 HOILING SECTION: 6  
 SUPERHEATING SECTION: 2 (HEATING LENGTH= 4.5 FT.)  
 (HOILING LENGTH= 4.2 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	519.1	423.0	200.0	468.1	16677.8
HOILING	705.8	519.1	468.1	468.1	
SUPERHEATING	808.4	705.8	486.3	640.0	145423.7

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM FLOW RATE: 32094.9 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 2.6 IN H2O  
 PINCH POINT: 51.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 11889.6  
 STEAM TURBINE HORSEPOWER: 4148.1  
 TOTAL SYSTEM HORSEPOWER: 16037.7  
 STEAM TURBINE SHARE OF THE LOAD: 25.9 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.474 C/GAS: 0.352  
 GT ONLY: 5640.5 C/GAS: 5640.5  
 GT AT SYSTEM HP: 6916.9  
 GT AT SYSTEM HP: 0.431

THERMAL EFFICIENCY:  
 GT ONLY: 0.251  
 C/GAS: 0.393  
 GT AT SYSTEM HP: 0.321

ASSUMED SYSTEM CHARACTERISTICS:  
 CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FW HEATER PRESSURE: 15.0 PSIA  
 LHV CF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

EXAKE HORSEPOWER: 1790.0, APPROXIMATE CORRESPONDING SHIP SPEED: 15.0 KTS  
 EXHAUST GAS TEMPERATURE: 820.0 F  
 EXHAUST GAS FLOW RATE: 307393.0 LBM/HR (107.6 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 17.0 FT.  
 WIDTH: 15.2 FT.  
 HEIGHT: 12.9 FT.  
 WEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE FIN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 7.92 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 54.  
 TUBE LENGTH 12. FT.  
 OUTSIDE AREA/PASS: 4132.2 SQ.FT.  
 INSIDE AREA/PASS: 237.3 SQ. FT.  
 FRONTAL AREA: 181.9 SQ. FT.  
 NUMBER OF PASSES: 12 (TOTAL)  
 HEATING SECTION: 4  
 BOILING SECTION: 6  
 SUPERHEATING SECTION: 2

(HEATING LENGTH= 4.7 FT.)  
 (BOILING LENGTH= 4.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	519.9	421.5	200.0	466.3	17400.5
BOILING	712.1	519.9	466.3	466.3	
SUPERHEATING	819.2	712.1	486.3	640.0	152656.3

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM FLOW RATE: 33631.7 LBM/HR.  
 GAS-SIZE PRESSURE DROP: 2.7 IN H2O  
 FINCH POINT: 53.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 13542.5  
 STEAM TURBINE HORSEPOWER: 4346.7  
 TOTAL SYSTEM HORSEPOWER: 17889.2  
 STEAM TURBINE SHARE OF THE LOAD: 24.3 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.455  
 COGAS: 0.345  
 GT AT SYSTEM HP: 0.423  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 6165.9  
 COGAS: 6165.9  
 GT AT SYSTEM HP: 7566.7  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.304  
 COGAS: 0.401  
 GT AT SYSTEM HP: 0.327

ASSUMED SYSTEM CHARACTERISTICS:  
 CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 P.W. HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RLM

GAS TURBINE

BRAKE HORSEPOWER: 14421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
 EXHAUST GAS TEMPERATURE: 849.0 F  
 EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.2 FT.  
 WIDTH: 15.3 FT.  
 HEIGHT: 2.6 FT.

HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE IN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 7.52 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 54.  
 TUBE LENGTH: 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.  
 INSIDE AREA/PASS: 237.3 SQ. FT.  
 FFCNTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)  
 HEATING SECTION: 4  
 COOLING SECTION: 4  
 SUPERHEATING SECTION: 2

HEATING LENGTH= 5.5 FT.  
 COOLING LENGTH= 4.5 FT.

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	522.8	419.8	200.0	460.6	19625.8
COOLING	730.7	522.8	460.6	486.3	173910.7
SUPERHEATING	849.8	730.7	486.3	486.3	

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM FLOW RATE: 38266.0 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 3.0 IN H2O  
 FINCF POINT: 62.2 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 16116.8  
 STEAM TURBINE HORSEPOWER: 4968.3  
 TOTAL SYSTEM HORSEPOWER: 21085.1  
 STEAM TURBINE SHARE OF THE LCAD: 23.6 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.435 COGAS: 0.332 GT AT SYSTEM HP: 0.392  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 7306.4 COGAS: 7006.4 GT AT SYSTEM HP: 8259.5  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.318 COGAS: 0.416 GT AT SYSTEM HP: 0.353

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 42.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.87  
 HEATER PRESSURE: 0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM



CB/2776 15.48.33

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1685.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS  
EXHAUST GAS TEMPERATURE: 689.0 F  
EXHAUST GAS FLOW RATE: 15731.0 LB/HR (44.4 LB/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
LENGTH: 12.1 FT.  
WIDTH: 12.1 FT.  
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE  
CIRCULAR TUBE DIAMETER: 1.5 IN.  
INSIDE TUBE DIAMETER: 1.4 IN.  
TUBE WALL THICKNESS: 0.036 IN.  
FIN TYPE: SEGMENTED  
FIN SPACING: 7.92 FINS/IN.  
FIN HEIGHT: 0.8 IN.  
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF RCWS PER PASS: 1.  
NUMBER OF TUBES PER ROW: 43.  
TUBE LENGTH: 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.  
INSIDE AREA/PASS: 189.0 SQ. FT.  
FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)  
HEATING SECTION: 3  
BOILING SECTION: 6  
SUPERHEATING SECTION: 4  
(HEATING LENGTH= 4.8 FT.)  
(BOILING LENGTH= 4.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	498.9	436.5	200.0	271.3	5643.0
BOILING	611.5	498.9	471.3	467.3	
SUPERHEATING	688.6	611.5	486.3	667.3	49203.8

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 8612.9 LB/HR.

CAS-SIDE PRESSURE DROP: 0.9 IN H2O

PINCH POINT: 27.6 F

SYSTEM PERFORMANCE

GT FUEL EFFICIENCY (REVISED): 1600.1

STEAM TURBINE HORSEPOWER: 1135.5

INITIAL SYSTEM HORSEPOWER: 2795.6

STEAM TURBINE SHARE OF THE LOAD: 40.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):

GT ONLY: 1.004 (LBM-FUEL/HP-HR) | GT AT SYSTEM HP: 0.864

GT ONLY: 1741.9 (LBM-FUEL/HP-HR) | GT AT SYSTEM HP: 2415.7

INITIAL SYSTEM HORSEPOWER: 2795.6

GT ONLY: 1741.9 (LBM-FUEL/HP-HR) | GT AT SYSTEM HP: 2415.7

INITIAL SYSTEM HORSEPOWER: 2795.6

GT ONLY: 1741.9 (LBM-FUEL/HP-HR) | GT AT SYSTEM HP: 2415.7

INITIAL SYSTEM HORSEPOWER: 2795.6

GT ONLY: 1741.9 (LBM-FUEL/HP-HR) | GT AT SYSTEM HP: 2415.7

INITIAL SYSTEM HORSEPOWER: 2795.6

GT ONLY: 1741.9 (LBM-FUEL/HP-HR) | GT AT SYSTEM HP: 2415.7

INITIAL SYSTEM HORSEPOWER: 2795.6

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
STEAM TURBINE EFFICIENCY: 0.85  
FW HEATER PRESSURE: 15.0 PSIA  
LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1895.0, APPROXIMATE CORRESPONDING SHIP SPEED: 10.0 KTS  
 EXHAUST GAS TEMPERATURE: 483.0  
 EXHAUST GAS FLOW RATE: 167075.0 LBM/HR ( 46.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:

LENGTH: 12.0 FT.  
 WIDTH: 12.1 FT.  
 HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE AREA: 1.5 I.A.  
 OUTSIDE TUBE SURFACE AREA: 3290.5 SQ. FT.  
 INSIDE TUBE SURFACE AREA: 189.0 SQ. FT.  
 TUBE LENGTH: 12. FT.  
 FIN TYPE: SEMI-EMERGED  
 FIN SPACING: 7.92 IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 43.  
 TUBE LENGTH: 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ. FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)

HEATING SECTION: 3

BOILING SECTION: 6

SUPERHEATING SECTION: 4

(HEATING LENGTH= 5.0 FT.)  
 (BOILING LENGTH= 4.8 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	699.0	436.5	200.0	470.0	5922.7
BOILING	608.6	499.0	470.0	486.3	
SUPERHEATING	609.8	608.6	486.3	667.5	52032.4

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 9055.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.0 IN H<sub>2</sub>O

FINCH FCIN: 29.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 1867.8

STEAM TURBINE HORSEPOWER: 1193.8

TOTAL SYSTEM HORSEPOWER: 3061.7

STEAM TURBINE SHARE OF THE LOAD: 39.0 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):

GT ONLY: 1.023 COGAS: 0.624 GT AT SYSTEM HP: 0.829

FUEL CONSUMPTION (LBM-FUEL/HR.):

GT ONLY: 1910.4 COGAS: 1910.4 GT AT SYSTEM HP: 2537.0

THERMAL EFFICIENCY:

GT ONLY: 0.135 COGAS: 0.222 GT AT SYSTEM HP: 0.167

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG

STEAM TURBINE EFFICIENCY: 0.85

FW HEATER PRESSURE: 15.0 PSIA

LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HHPSEPTIMENTS: 2105.0, APPROXIMATE CORRESPONDING SHIP SPEED: 11.0 KTS  
 EXHAUST GAS TEMPERATURE: 689.0 F  
 EXHAUST GAS FLOW RATE: 170747.0 LBM/HR ( 47.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.1 FT.  
 HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE  
 INSIDE TUBE DIAMETER: 1.5 IN.  
 TUBE WALL THICKNESS: 1.4 IN.  
 TUBE LENGTH: 12.0 FT.  
 FIN TYPE: CEMENTED  
 FIN SPACING: 7.92 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 4.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 43.  
 TUBE LENGTH: 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.  
 INSIDE AREA/PASS: 189.0 SQ. FT.  
 FRONTAL AREA: 144.0 SQ. FT.

NUMBER OF PASSES: 13. (TOTAL)  
 HEATING SECTION: 4  
 BOILING SECTION: 4  
 SUPERHEATING SECTION: 5

(HEATING LENGTH= 0.3 FT.)  
 (BOILING LENGTH= 4.2 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	505.0	435.0	200.0	486.3	6262.5
BOILING	615.7	502.0	486.3	486.3	53330.6
SUPERHEATING	687.5	615.7	486.3	645.0	

STEAM FLOW RATE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM FLOW RATE: 9332.5 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 1.0 IN H2O  
 PINCH POINT: 15.8 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REV. LEC): 2074.7  
 STEAM TURBINE HORSEPOWER: 1210.6  
 TOTAL SYSTEM HORSEPOWER: 3285.3  
 STEAM TURBINE SHARE OF THE LOAD: 36.8 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.985  
 COGAS: 0.622  
 GT AT SYSTEM HP: 0.801  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 2042.8  
 COGAS: 2042.8  
 GT AT SYSTEM HP: 2632.4  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.143  
 COGAS: 0.222  
 GT AT SYSTEM HP: 0.173

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 HEATER PRESSURE: 0.85 PSIA  
 HEATER PRESSURE: 0.85 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

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NAVAL POSTGRADUATE SCHOOL MONTEREY CA  
WASTE HEAT RECOVERY UNIT DESIGN FOR GAS TURBINE PROPULSION SYST--ETC(U)  
SEP 79 R M COMBS

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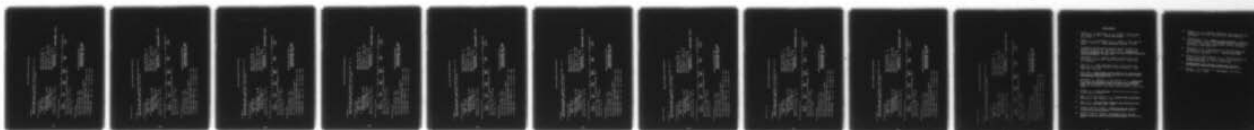
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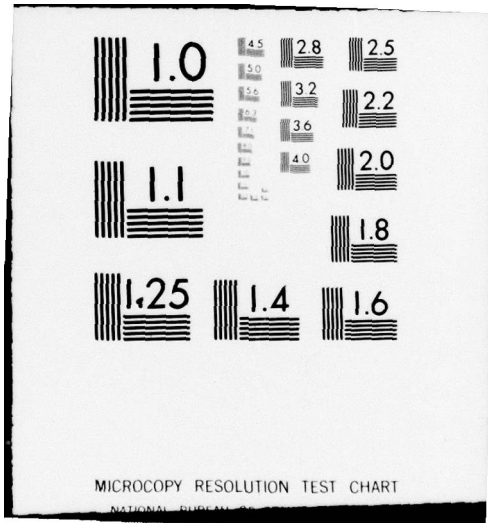


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WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

CAS TURBINE

BRAKE POWER: 3158.0, APPROXIMATE CORRESPONDING SHIP SPEED: 12.0 KTS  
 EXHAUST GAS TEMPERATURE: 683.0 F  
 EXHAUST GAS FLOW RATE: 22390.0 LB/HR ( 62.2 LB/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 HEIGHT: 12.1 FT.  
 HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE:  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE/IN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 7.92 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.78 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 43.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 3290.5 SQ.FT.  
 INSIDE AREA/PASS: 189.0 SQ. FT.  
 FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)  
 HEATING SECTION: 7  
 ROLLING SECTION: 3  
 SUPERHEATING SECTION: 3

(HEATING LENGTH= 5.5 FT.)  
 (ROLLING LENGTH= 1.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	500.9	440.0	200.0	466.9	7809.7
ROLLING	650.0	500.9	466.9	466.9	
SUPERHEATING	688.9	650.0	486.3	486.3	66615.3

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM FLOW RATE: 12005.2 LB/HR.  
 GAS-SIDE PRESSURE DROP: 1.7 IN H2O  
 FINCH POINT: 34.7 F

SYSTEM PERFORMANCE

GT CORRECTOR (REVISED): 3100.0  
 STEAM TURBINE CORRECTOR: 1572.9  
 TOTAL SYSTEM CORRECTOR: 4680.8  
 STEAM TURBINE SHARE OF THE LOAD: 33.6 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 AT INLET: 0.82 COGAS: 0.551 GT AT SYSTEM HP: 0.672  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 AT INLET: 2572.9 COGAS: 2576.9 GT AT SYSTEM HP: 3143.6  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.167 COGAS: 0.251 GT AT SYSTEM HP: 0.206

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 STEAM HEATER PRESSURE: 5.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

CG/27/75 14.10.13

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 4310.0, APPROXIMATE CORRESPONDING SHIP SPEED: 13.0 KTS  
EXHAUST GAS TEMPERATURE: 699.0 F  
EXHAUST GAS FLOW RATE: 202546.0 LBM/HR ( 72.9 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
LENGTH: 15.0 FT.  
WIDTH: 15.0 FT.  
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE  
OUTSIDE TUBE DIAMETER: 1.5 IN.  
INSIDE TUBE DIAMETER: 1.4 IN.  
TUBE/TUBE SPACING:  
FIN TYPE: SEGMENTED  
FIN SPACING: 7.92 FINS/IN.  
FIN HEIGHT: 0.8 IN.  
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.30 IN.  
LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
NUMBER OF TUBES PER ROW: 43.  
TUBE LENGTH: 12. FT.  
OUTSIDE AREA/PASS: 3290.5 SQ.FT.  
INSIDE AREA/PASS: 189.0 SQ. FT.  
FRONTAL AREA: 144.0 SQ. FT.  
NUMBER OF PASSES: 13 (TOTAL)  
HEATING SECTION: 3  
BOILING SECTION: 3  
SUPERHEATING SECTION: 3

(HEATING LENGTH= 5.2 FT.)  
(BOILING LENGTH= 0.4 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	505.0	443.0	200.0	465.6	9350.0
BOILING	667.1	505.0	465.6	486.3	
SUPERHEATING	658.7	607.1	486.3	607.5	79304.0

STEAM PRESSURE: 600.0 PSIA SATURATION TEMPERATURE= 486.3 F

STEAM FLOW RATE: 14403.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.3 IN H2O

PUMP HEAD: 59.3 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 4242.5  
 STEAM TURBINE HORSEPOWER: 1899.0  
 TOTAL SYSTEM HORSEPOWER: 6141.5  
 STEAM TURBINE SHARE OF THE LOAD: 30.9 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.711 (CORRECTED: 0.45) AT SYSTEM HP: 0.591  
 FUEL CONSUMPTION (LBM-FUEL/HR):  
 GT ONLY: 3018.1 COGAS: 3018.1 GT AT SYSTEM HP: 3628.2  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.194 COGAS: 0.281 GT AT SYSTEM HP: 0.234

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
STEAM TURBINE EFFICIENCY: 0.83  
FW WATER PRESSURE: 15.0 PSIA  
LHV OF FUEL: 18500 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 5474.0, APPROXIMATE CORRESPONDING SHIP SPEED: 14.0 KTS  
 EXHAUST GAS TEMPERATURE: 709.0 F  
 EXHAUST GAS FLOW RATE: 279070.0 LBM/HR ( 77.5 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS: FT.  
 LENGTH: 12.0 FT.  
 WIDTH: 12.1 FT.  
 HEIGHT: 3.2 FT.  
 HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE/FIN ARRANGEMENT:  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 7.52 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.  
 TRANSVERSE TUBE SPACING: 3.36 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.  
 NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 43.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 3290.5 SQ.FT.  
 INSIDE AREA/PASS: 189.0 SQ. FT.  
 FRONTAL AREA: 144.8 SQ. FT.  
 NUMBER OF PASSES: 13 (TOTAL)  
 HEATING SECTION: 4  
 BOILING SECTION: 6  
 SUPERHEATING SECTION: 3 (HEATING LENGTH= 0.0 FT.,  
 BOILING LENGTH= 4.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	512.1	441.5	200.0	486.3	10796.5
BOILING	636.0	512.1	486.3	486.3	92072.9
SUPERHEATING	708.4	636.0	486.3	486.3	

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM FLOW RATE: 16089.2 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 2.4 IN H2O  
 PINCH POINT: 25.9 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 5378.9  
 STEAM TURBINE HORSEPOWER: 2096.5  
 TOTAL SYSTEM HORSEPOWER: 7475.4  
 STEAM TURBINE SHARE OF THE LOAD: 28.0 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.633 COGAS: 0.455  
 GT AT SYSTEM MP: 0.546  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 GT ONLY: 3404.2 COGAS: 3404.2  
 GT AT SYSTEM MP: 4081.8  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.219 COGAS: 0.304  
 GT AT SYSTEM MP: 0.253

ASSUMED SYSTEM CHARACTERISTICS:  
 CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FWH HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 6947.0, APPROXIMATE CORRESPONDING SHIP SPEED: 15.0 KTS  
 EXHAUST GAS TEMPERATURE: 733.0 F  
 EXHAUST GAS FLOW RATE: 31218.0 LBM/HR ( 86.7 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS: 1.0  
 LENGTH: 12.0 FT.  
 WIDTH: 12.1 FT.  
 HEIGHT: 3.2 FT.  
 HEAT TRANSFER SURFACE: 3290.5 SQ.FT.  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE/FIN ARRANGEMENT: U  
 FIN TYPE: SEGMENTED  
 FIN SPACING: 7.92 FINS/IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.39 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 43.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 189.0 SQ. FT.  
 INSIDE AREA/PASS: 144.8 SQ. FT.  
 FRONTAL AREA: 144.8 SQ. FT.  
 NUMBER OF PASSES: 13 (TOTAL)  
 HEATING SECTION: 7  
 BOILING SECTION: 2  
 SUPERHEATING SECTION: 2 (HEATING LENGTH= 2.3 FT.)  
 (BOILING LENGTH= 0.4 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	512.9	436.5	200.0	479.4	13299.6
BOILING	998.4	512.9	479.4	486.3	109833.1
SUPERHEATING	732.5	698.4	486.3	486.3	

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM FLOW RATE: 19968.0 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 3.0 IN H2O  
 PINCH POINT: 33.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 6918.4  
 STEAM TURBINE HORSEPOWER: 2594.9  
 TOTAL SYSTEM HORSEPOWER: 9413.3  
 STEAM TURBINE SHARE OF THE LOAD: 27.6 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.571  
 COGAS: 0.413  
 GT AT SYSTEM HP: 0.506  
 FUEL CONSUMPTION (LBM-FUEL/HR):  
 GT ONLY: 3890.8  
 COGAS: 3890.8  
 GT AT SYSTEM HP: 4760.0  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.242  
 COGAS: 0.335  
 GT AT SYSTEM HP: 0.273

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FM HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LM

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 6526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS  
 EXHAUST GAS TEMPERATURE: 743.0 F/LBM/HR (91.3 LBM/SEC)  
 EXHAUST GAS FLOW RATE: 32864.0 LBM/HR

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS: FT.  
 LENGTH: 12.0  
 WIDTH: 12.1  
 HEIGHT: 3.2  
 HEAT TRANSFER SURFACE  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE/FIN ARRANGEMENT:  
 FIN TYPE: SCREWED  
 FIN SPACING: 0.8 IN.  
 FIN HEIGHT: 7.92 IN.  
 FIN THICKNESS: 0.036 IN.  
 TRANSVERSE TUBE SPACING: 3.39 IN.  
 LONGITUDINAL TUBE SPACING: 2.02 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 43.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 3290.5 SQ. FT.  
 INSIDE AREA/PASS: 189.0 SQ. FT.  
 FRONTAL AREA: 144.8 SQ. FT.  
 NUMBER OF PASSES: 13 (TOTAL)  
 HEATING SECTION: 4  
 ROLLING SECTION: 7  
 SUPERHEATING SECTION: 2  
 (HEATING LENGTH= 3.5 FT.)  
 (ROLLING LENGTH= 2.1 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	512.1	433.5	200.0	475.9	14512.9
ROLLING	687.2	423.0	423.0	483.3	122660.3
SUPERHEATING	741.2	486.3	486.3	486.3	

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE = 486.3 F)  
 STEAM FLOW RATE: 21999.0 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 3.3 IN H2O  
 PEACH POINT: 37.1 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 8363.3  
 STEAM TURBINE HORSEPOWER: 2838.1  
 TOTAL SYSTEM HORSEPOWER: 11201.3  
 STEAM TURBINE SHARE OF THE LOAD: 25.3 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.530  
 COGAS: 0.396  
 GT AT SYSTEM MP: 0.479  
 FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 4632.6  
 COGAS: 432.6  
 GT AT SYSTEM MP: 5368.2  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.261  
 COGAS: 0.349  
 GT AT SYSTEM MP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 FM HEATER PRESSURE: 15.0 PSIA  
 LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 10621.0, APPROXIMATE CORRESPONDING SHIP SPEED: 17.0 KTS  
 EXHAUST GAS TEMPERATURE: 266.0 F  
 EXHAUST GAS FLOW RATE: 35083.0 LB/HR ( 97.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

CYCLICAL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.1 FT.  
 HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE:  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE IN ARRANGEMENT: 1-1  
 TUBE SPACING: 0.92 IN.  
 FIN HEIGHT: 0.036 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 43.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 3250.5 SQ.FT.  
 INSIDE AREA/PASS: 189.0 SQ. FT.  
 FRONTAL AREA: 144.8 SQ. FT.  
 NUMBER OF PASSES: 13 (TOTAL)  
 HEATING SECTION: 7  
 COOLING SECTION: 2  
 SUPERHEATING SECTION: 2  
 (HEATING LENGTH= 5.7 FT.)  
 (COOLING LENGTH= 3.5 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	513.2	425.0	200.0	463.8	17825.6
COOLING	703.2	713.2	483.9	496.3	155577.3
SUPERHEAT IN:	784.8	703.2	486.3	639.0	

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM FLOW RATE: 27527.7 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 3.7 IN H2O  
 PLANT PUMP: 49.4 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 10213.1  
 STEAM TURBINE HORSEPOWER: 3544.8  
 TOTAL SYSTEM HORSEPOWER: 13757.9  
 STEAM TURBINE SHARE OF THE LOAD: 25.8 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 0.493  
 COGAS: 0.370  
 GT AT SYSTEM HP: 0.449  
 FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 GT ONLY: 5085.2  
 COGAS: 5085.2  
 GT AT SYSTEM HP: 6179.8  
 THERMAL EFFICIENCY:  
 GT ONLY: 0.278  
 COGAS: 0.374  
 GT AT SYSTEM HP: 0.308

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 HEATER PRESSURE: 10.985  
 LHV OF FUEL: 18400 BTU/LBM

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WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

HPAKE HORSEPOWER: 1205.3, APPROXIMATE CORRESPONDING SHIP SPEED: 18.0 KTS  
EXHAUST GAS TEMPERATURE: 809.0 F  
EXHAUST GAS FLOW RATE: 381885.0 LBM/HR (106.1 LBM/SEC)

HEAT EXCHANGE GEOMETRY

OVERALL DIMENSIONS: FT.  
LENGTH: 12.0 FT.  
WIDTH: 12.1 FT.  
HEIGHT: 3.2 FT.  
HEAT TRANSFER SURFACE  
OUTSIDE TUBE TOTAL DIAMETER: 1.5 IN.  
INSIDE TUBE DIAMETER: 1.4 IN.  
TUBE/FIN ARRANGEMENT: I  
FIN TYPE: SEVENTHED  
FIN SPACING: 7.92 FINS/IN.  
FIN HEIGHT: 0.8 IN.  
FIN THICKNESS: 0.036 IN.  
TRANSVERSE TUBE SPACING: 3.38 IN.  
LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
NUMBER OF TUBES PER ROW: 43.  
TUBE LENGTH: 12. FT.  
OUTSIDE AREA/PASS: 3290.5 SQ.FT.  
INSIDE AREA/PASS: 189.0 SQ. FT.  
FPYNTAL AREA: 144.8 SQ. FT.  
NUMBER OF PASSES: 13 (TOTAL)  
HEATING SECTION: 2  
COOLING SECTION: 1  
SUPERHEATING SECTION: 2 (HEATING LENGTH= 0.3 FT.)  
(BOILING LENGTH= 4.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION WAS TEMP. IN GAS TEMP. OUT FLUID TEMP. IN FLUID TEMP. OUT REYNOLDS NUMBER (AVG.)  
HEATING 528.5 526.2 200.0 486.3 21363.3  
BOILING 715.6 528.5 486.3 486.3  
SUPERHEATING 807.1 715.6 486.3 632.5  
STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
STEAM FLOW RATE: 31836.1 LBM/HR.  
WAS-TEMP PRESSURE DRCP: 4.3 IN H2O  
PINCH POINT: 42.2 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 11848.5  
STEAM TURBINE EFFICIENCY: 4052.1  
TOTAL SYSTEM HORSEPOWER: 15940.5  
STEAM TURBINE SHARE OF THE LOAD: 25.7 PERCENT  
SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
GT ONLY: 0.475 COGAS: 0.356  
FUEL CONSUMPTION (LBM-FUEL/HR.):  
GT ONLY: 5036.4 COGAS: 5636.4 GT AT SYSTEM HP: 6884.0  
THERMAL EFFICIENCY:  
GT ONLY: 0.251 COGAS: 0.391 GT AT SYSTEM HP: 0.322

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
STEAM TURBINE EFFICIENCY: 0.40  
FW HEAT EXCH PRESS: 300 PSIA  
LHV OF FUEL: 18400 BTU/LBM

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WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 13790.0, APPROXIMATE CORRESPONDING SHIP SPEED: 19.0 KTS  
EXHAUST GAS TEMPERATURE: 820.0 F/LBM/HR  
EXHAUST GAS FLOW RATE: 307393.0 LBM/HR (107.6 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
LENGTH: 12.0 FT.  
WIDTH: 12.1 FT.  
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE  
OUTSIDE TUBE DIAMETER: 1.5 IN.  
INSIDE TUBE DIAMETER: 1.4 IN.  
TUBE WALL THICKNESS: 0.015 IN.  
FIN SPACING: 0.015 IN.  
FIN THICKNESS: 0.006 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.  
LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF PMS PER PASS: 1.  
NUMBER OF TUBES PER ROW: 43.  
TUBE LENGTH: 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.  
INSIDE AREA/PASS: 189.0 SQ. FT.  
TOTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)  
HEATING SECTION: 5  
COOLING SECTION: 2  
SUPERHEATING SECTION: 2

(HEATING LENGTH= 9.2 FT.)  
(BOILING LENGTH= 3.8 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	730.9	526.1	200.0	486.3	22156.0
BOILING	728.1	530.9	486.3	486.3	
SUPERHEATING	818.0	728.1	486.3	641.3	187362.6

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
STEAM FLOW RATE: 33076.9 LBM/HR.  
GAS-SIDE PRESSURE DROP: 4.4 IN H2O  
PUMP POWER: 44.6 F

SYSTEM PERFORMANCE

GT HOT SECTOR (REVISED): 13494.2  
STEAM TURBINE HORSEPOWER: 4279.0  
TOTAL SYSTEM HORSEPOWER: 17773.1  
STEAM TURBINE SHARE OF THE LOAD: 24.1 PERCENT  
SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
GT ONLY: 0.45 / COGAS: 0.347  
GT AT SYSTEM MP: 0.423  
FUEL CONSUMPTION (LBM-FUEL/HR):  
GT ONLY: 6161.2  
COGAS: 6161.2  
GT AT SYSTEM MP: 7525.7  
THERMAL EFFICIENCY:  
GT ONLY: 0.303  
COGAS: 0.399  
GT AT SYSTEM MP: 0.327

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
STEAM TURBINE EFFICIENCY: 0.85  
HEATING SECTION PRESSURE: 600.0 PSIA  
LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16621.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS  
 EXHAUST GAS TEMPERATURE: 849.0 °F  
 EXHAUST GAS FLOW RATE: 47589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:  
 LENGTH: 12.0 FT.  
 WIDTH: 12.1 FT.  
 HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE:  
 OUTSIDE TUBE DIAMETER: 1.5 IN.  
 INSIDE TUBE DIAMETER: 1.4 IN.  
 TUBE WALL THICKNESS: 0.036 IN.  
 FIN SPACING: 0.9 IN.  
 FIN HEIGHT: 0.8 IN.  
 FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE PACING: 3.38 IN.  
 LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
 NUMBER OF TUBES PER ROW: 43.  
 TUBE LENGTH: 12. FT.  
 OUTSIDE AREA/PASS: 3290.5 SQ.FT.  
 INSIDE AREA/PASS: 189.0 SQ. FT.  
 FRONTAL AREA: 144.8 SQ. FT.  
 NUMBER OF PASSES: 13 (TOTAL)  
 HEATING SECTION: 5  
 ROLLING SECTION: 2  
 SUPERHEATING SECTION: 6  
 (HEATING LENGTH= 1.5 FT.)  
 (ROLLING LENGTH= 4.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	525.1	422.3	200.0	480.6	25259.9
ROLLING	442.8	335.1	480.9	480.3	216614.1
SUPERHEATING	648.4	742.8	480.3	638.8	

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)  
 STEAM FLOW RATE: 37562.9 LBM/HR.  
 GAS-SIDE PRESSURE DROP: 4.9 IN H2O  
 PINCH POINT: 53.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER (NET): 16053.9  
 STEAM TURBINE HORSEPOWER: 4902.1  
 TOTAL SYSTEM HORSEPOWER: 20955.9  
 STEAM TURBINE SHARE OF THE LOAD: 23.4 PERCENT  
 SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
 ST CALY: 0.435 COGAS: 0.336 GT AT SYSTEM HP: 0.395  
 FUEL CONSUMPTION (LBM-FUEL/HR.):  
 ST CALY: 6997.8 COGAS: 6997.8 GT AT SYSTEM HP: 8268.2  
 THERMAL EFFICIENCY:  
 ST ONLY: 0.317 COGAS: 0.414 GT AT SYSTEM HP: 0.350

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
 STEAM TURBINE EFFICIENCY: 0.85  
 EXHAUST GAS PRESSURE: 1.0 PSIA  
 LHV OF FUEL: 18450 BTU/LBM

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WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

EXHAUST TEMPERATURE: 600.00 F, APPROXIMATE CORRESPONDING SHIP SPEED: 21.5 KTS  
EXHAUST GAS TEMPERATURE: 897.0 F  
EXHAUST GAS FLOW RATE: 416836.0 LBM/HR (122.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

EXCHANGE AREA: 1200 FT.  
LENGTH: 12.5 FT.  
HEIGHT: 3.5 FT.  
HEAT TRANSFER SURFACE: 1.5 IN.  
OUTSIDE DIAMETER: 1.4 IN.  
TUBE WALL THICKNESS: 0.036 IN.  
TUBE SPACING: 7.92 FT./IN.  
FIN SPACING: 0.4 IN.  
FIN HEIGHT: 0.036 IN.  
TRANSVERSE TUBE SPACING: 3.34 IN.  
LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.  
NUMBER OF TUBES PER ROW: 43.  
TUBE LENGTH: 12. FT.  
OUTSIDE AREA/PASS: 3290.5 SQ.FT.  
INSIDE AREA/PASS: 165.0 SQ. FT.  
FRONTAL AREA: 144.8 SQ. FT.  
NUMBER OF PASSES: 14 (TOTAL)  
HEATING SECTION: 5  
COOLING SECTION: 2  
SUPERHEATING SECTION: 2 (HEATING LENGTH= 2.6 FT.)  
(COOLING LENGTH= 5.5 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION GAS TEMP. IN GAS TEMP. OUT FLUID TEMP. IN FLUID TEMP. OUT REYNOLDS NUMBER (AVG.)  
HEATING 543.0 420.5 200.0 475.0 30216.1  
COOLING 700.5 543.0 475.0 490.3  
SUPERHEATING 373.7 700.5 480.3 265866.2  
STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 480.3 F)  
STEAM FLOW RATE: 45957.0 LBM/HR.  
GAS-SIDE VELOCITY: 5.7 IN/SEC  
FINCH COUNT: 60.0 F

SYSTEM PERFORMANCE

GE DISPLACEMENT VOLUME: 19520.0  
STEAM TURBINE HORSEPOWER: 5085.3  
TOTAL SYSTEM HORSEPOWER: 25405.9  
STEAM TURBINE SHARE OF THE LOAD: 23.2 PERCENT  
SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):  
AT LOAD: 0.415 CGR/HP-HR AT SYSTEM HP: 0.045  
FUEL CONSUMPTION (LBM-FUEL/HR):  
AT LOAD: 11178.4 CGR/HR AT SYSTEM HP: 1132.8  
FUEL COST (LBM-FUEL/HR):  
AT LOAD: 1.430 CGR/HR AT SYSTEM HP: 3.102

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG  
STEAM TURBINE EFFICIENCY: 0.85  
FW HEATER PRESSURE: 15.0 PSIA  
LHV OF FUEL: 18400 BTU/LBM

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