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SIMPLIFIED LINEAR DYNAMIC MODEL FOR FIRST-CUT CONTROLLER DESIGN OF A SOLAR-POWERED ONCE-THROUGH BOILER

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ABSTRACT

A simplified linear dynamic thermal hydraulic model of a once-through steam generator is presented. The model is a first-order transfer function with pure transport delay and with explicit analytical expressions for the model parameters. The intended use for the model is the initial design of an outlet steam temperature controller using inlet flow rate valve adjustment, where final controller gains can then be determined through a tuning process of detailed simulation, test, and operation. Model validation is accomplished by several approaches. First, a numerically derived higher order linear model frequency response is obtained from a nonlinear mathematical dynamic description based on established first principles techniques. The frequency response of this higher order linear model is shown to compare favorably to that of the simplified model, thereby providing analytical credence to the simplified model. Next, the frequency response of the simplified model is validated by direct comparison with frequency response test results obtained at the Department of Energy/Sandia Laboratories Central Receiver Test Facility. Finally, a description is given of a simplified model frequency response validation based on step response test results. The modeling and validation techniques should be applicable to similar initial controller design of other once-through boilers and to other similar processes.

INTRODUCTION

The application of a once-through steam generator in a solar-powered central receiver concept poses an unusual controller design problem. The steam temperature controller must provide good performance (transient response, stability margin, and steady-state accuracy) in response to a continuously varying, uncontrolled solar heat input. This variability of solar energy is due to two principal causes: first, the sun angle varies throughout the day and from day to day throughout the year; and second, the usable solar energy varies due to intermittent cloud conditions. Because of this varying heat input rate, a necessary first step in the steam temperature controller design process is to model and validate the model for the boiler/receiver dynamics, which is the subject of this paper. The actual controller design and test validation of the controller performance is being done at the present time and will be the subject of future reporting.

BACKGROUND

The once-through steam generator considered in this paper is presently undergoing testing at the U. S. Department of Energy (DOE)/Sandia Laboratories Central Receiver Test Facility (CRTF) at Albuquerque, New Mexico. This receiver is being designed for the DOE 10 MWe (10^7 J/S) solar thermal pilot plant which is being built at Barstow, California. The receiver controller is conceptually described by Rountree, et. al. (1). The pilot plant concept is shown in Figure 1. It consists of a field of tracking heliostats (mirrors) that redirect and focus the sun's energy onto a central receiver mounted atop a tower. In the receiver, the solar energy is absorbed, water is converted into steam, and the steam is then used to power a conventional turbine/generator and/or to charge a thermal storage unit for subsequent use by the steam turbine (e.g., nighttime operation). The steam loop is closed by pumping feedwater back to the receiver from the condenser.

The receiver consists of 24 individually fabricated vertical flow panels, six panels used as preheaters and eighteen used as boiler panels, distributed circumferentially around the top of the tower. A sketch of an individual panel is shown in Figure 2. Each panel contains 70 individual tubes of 1/2-inch outside diameter with an approximate panel area of 3 feet (0.9144 m) in width by 45 feet (13.72 m) high. Each boiler panel has an outlet steam temperature controller which adjusts the inlet control valve in order to maintain an outlet steam temperature close to a reference set point value.

Modeling and Validation Overview

The modeling of the receiver portion of the CRTF and associated validation effort proceeded along several paths, and an overview of the effort is shown in Figure 3. Some brief comments concerning this figure are made at this point to indicate the nature of the more detailed discussion in the ensuing sections of the paper.

The detailed nonlinear modeling, which is the basis for the ensuing linearizations, is described first. This nonlinear modeling is based on established first principles lumped approximation techniques for once-through boilers and has been previously reported (2, 3, 4, 5).

With a nonlinear model available, the next step in the modeling effort is the simple model linearization. The first-order explicit analytic linearization is the result of numerous assumptions and averaging applied to the basic nonlinear boiler model. This simple model for the heated section of the boiler is a first-order transfer function with transport delay and explicit expressions for the transfer function parameters. Additional first-order models are derived for other components associated with the receiver test setup. The frequency response of the overall receiver model is readily obtained for comparison in the validation effort.

The validation effort is then discussed, first, in terms of a higher order numerical linearization, which was done using the Time And Frequency (TAF) Domain Analysis Program (6, 7). This computer program accepts the nonlinear model equations and a nominal operating condition as input and computationally performs the linearization. One resulting output is a numerical frequency response - gain and phase shift as a function of frequency. This frequency response is compared to that of the simplified overall receiver model to demonstrate analytical correspondence of the simplified model.

Second, the direct validation test effort is discussed. Frequency responses were obtained from testing at the CRTF by performing a sinusoidal variation of the flow rate about a nominal value and measuring the corresponding outlet steam temperature response. These test points were determined at two different operating power levels and are directly compared to the frequency responses obtained for the simplified model.

A third validation technique using flow rate step response tests was also performed. The flow rate step input and steam temperature outlet time histories were digitized and used by a Fourier transform program to produce a numerically-derived frequency response, which is also compared to the frequency response test points.

A supplemental computational procedure was also performed, as shown to the right of Figure 3. This involved fitting the computed frequency response to a user-supplied transfer function form, and then the time response, which resulted from the step input corresponding to the test, was determined. This linearized step response is then compared to the test step response in the paper.

The appendices describe the nonlinear model equations, the derivation of the simplified linear transfer function, and the Fourier transform equations based on the convolution integral.

NONLINEAR MODELING

In order to predict the response of a boiler panel to either flux or control valve disturbances, a complete set of equations which describe the process must be considered, and these equations should be based on first principles. The corresponding model should be as simple as possible while still bearing a close resemblance to the actual physical process and still possessing reasonable dynamic accuracy over the system operating range. The primary assumption used in the development of such a model is that a distributed parameter process can be represented by a lumped parameter model using the concept of control volumes. A set of nonlinear differential and algebraic equations are then developed by sectioning the receiver (boiler) into appropriate control volumes and applying fundamental equations, well-known semiempirical formulae for fluid flow and heat transfer and steady-state design data.

A schematic of the boiler panel test setup at CRTF is shown in Figure 4. The heated section is analytically divided into three variable length sections. Due to nonuniform heliostat aiming, there can exist an unheated section of tubes which receives negligible heat flux. The 70 tubes converge into a steam header, which has a single outlet pipe. The temperature sensor (thermocouple) is located several feet downstream of the steam header within the outlet pipe.

The basic modeling approach is the formulation of a tube model by use of the concept of time-varying phase boundaries. The tube is partitioned into three sections, i.e., subcooled (or compressed) water, saturated two-phase mixture, and superheated steam. This results in six control volumes, or two for each section - one enclosing working fluid and one enclosing metal tube mass. The length of each control volume is allowed to vary with time. Consequently, the other process variables (e.g., pressure, temperature, enthalpy) at these phase boundaries are also time varying. This model formulation is based on the established techniques of Adams, et. al. (2) and Ray and Bowman (3). The implementation is patterned after the techniques used by Ray, et. al. (4) and Zondervan (5). The convective heat transfer coefficients used in the subcooled water and superheated steam control volumes are based on a slightly modified form of the Dittus-Boelter correlation. Heat transfer in the saturated two-phase region takes place by nucleate boiling and film boiling. The effective two-phase heat transfer coefficient between the tube wall and the saturated two-phase liquid is an average value obtained by integrating the nucleate (8) and film (9) boiling coefficients over the entire length of the two-phase control volume surface.

A block diagram model of the test setup is shown in Figure 5. The corresponding nonlinear model equations for each block are given in Appendix A and are based on the nonlinear modeling and simulation previously mentioned (5). While the detailed nonlinear modeling and simulation studies included the external radiative and convective losses of the boiler, the equations used for the linearization neglected the losses. Even though good agreement of the linearized models with test data was exhibited, the effect of the neglect of these losses on the validity of the models is the subject of ongoing study. Both the steam header and the outlet pipe are insulated, and thus, an adiabatic assumption was used for these components for both linear and nonlinear models, with heat transfer occurring between the steam and the metal.

FIRST-ORDER EXPLICIT ANALYTIC LINEARIZATION

The model described herein is an analytical expression for any operating condition, with explicit formulae given for each of the model parameters in terms of the physical properties of the boiler. The model is based on a single dynamic energy balance for all the boiler metal and a steady-state energy balance for the fluid. Pressure is assumed to be uniform and constant through the tubes. The heated boiler model discussion is followed by consideration of models for other unheated components corresponding to those of Figure 5. Charts are presented to allow the control designer to quickly estimate the gain, poles, and zeroes of the transfer functions of the applicable test setup components.

Heated Portion of Boiler

The primary modeling objective was to represent the boiler outlet steam temperature dynamics as simply as possible; hence, a first-order boiler model was the objective and is derived here. A first-order boiler model has several advantages:

1. It requires less effort than more complex models.

2. It can be used to design a "first cut" analytical controller.

3. It can serve as an approximate model for checkout of more detailed, higher-order, and more accurate linearized model computer programs.

4. It can be used as an approximate model for the debugging and checkout of complex nonlinear dynamic simulations.

5. In overall plant simulations where knowledge of internal boiler variables is not essential, this model could be used as an approximation, especially when other plant component models are being simulated and debugged in a closed fluid flow loop.

The conjecture that a reasonable first-order model exists is consistent with engineering intuition on the behavior of time lag types of processes. In particular, Ray and Berkowitz (10) have indicated that the transfer function of steam temperature to flow rate for commercial size power plant once-through boilers can be approximated by order two or less. Although the boiler described in this paper does not scale exactly with the boiler in Reference 8, the conclusion is still considered applicable since the dynamic processes involved are the same. The nonlinear model (Appendix A) simulation results also support this hypothesis (11).

<u>Phase Boundary Levels:</u> The relative locations of the phase boundaries are dependent upon the power level input, the flow rate, and the inlet temperature and pressure in the steady state. For any operating condition (inlet temperature, flow rate, power level, outlet temperature set point, and pressure), if outlet temperature is controlled by means of a flow rate adjustment, then for a heat input change, the flow rate will change accordingly in order to maintain outlet steam temperature at the setpoint value in the steady state. This process amounts to maintaining a constant power/flow rate ratio, and the consequence on the phase boundaries is that they return to the same levels after the transient has died. This character was mentioned by Ray and Berkowitz (10), and in addition, they indicated that although "the rate of change of these boundary locations may be high under transient conditions, the range of variation is relatively narrow". Similar corroboration of this character has been observed in the outputs of the detailed nonlinear simulations using the computer program of Reference 5.

These phase boundary levels may be estimated from performance data by the following steady state heat balances. With reference to Figure 4, if $Q_{1\ell}$* is the estimated averaged absorbed heat rate input per foot of boiler in the subcooled region, then a steady state heat balance shows

$$Q_{1\ell}\, L_1 = W_o\, (h_{f\ sat} - h_{IN}) \qquad (1)$$

or

$$L_{1\ell} = \frac{W_o}{Q_{1\ell}}\, (h_{f\ sat} - h_{IN}) \qquad (2)$$

Similar reasoning shows

$$L_2 = \frac{W_o}{Q_{2\ell}}\, (h_{v\ sat} - h_{f\ sat}) \qquad (3)$$

and

$$L_3 = \frac{W_o}{Q_{3\ell}}\, (h_{OUT} - h_{v\ sat}) \qquad (4)$$

For a nominal pressure in the boiler, the fluid and vapor saturation enthalpies are known from the steam tables. Knowledge of the inlet and outlet temperatures can be used to obtain the corresponding enthalpies. In practice, Equations (2), (3), (4) are not completely independent,

*See Nomenclature for explanation of symbols.

since the lengths must sum to the total boiler length, L_T, i.e.,

$$L_T = L_1 + L_2 + L_3 \quad (5)$$

In order to satisfy this constraint, the estimates of Q_1, Q_2, Q_3 are adjusted rather than the enthalpies or flow rate, since the test data for heat rate contains the greatest uncertainty.

Heat Transfer Coefficients of Boiler: The principal barrier to obtaining a first-order model was the problem of how to lump and average the convection heat transfer characteristics of a dynamic process involving a moving fluid undergoing one transformation from a liquid state to a two-phase mixture, followed by another transformation to a gaseous state. As a first step, the lumped heat transfer coefficients were defined for each of the three regions U_{b1}, U_{b2}, U_{b3}. Modified forms of the Dittus-Boelter correlation were used for U_{b1} and U_{b3}, the subcooled water and superheated steam coefficients, which assumed a dependency on flow rate to the 0.8 power.

The effective heat transfer coefficient in the two-phase region U_{b2} was a combination of the correlation proposed by Thom, et. al. (8) for nucleate boiling and the correlation proposed by Rockwell (9) for the film boiling. With average convective heat transfer coefficients for each region in hand, a single effective convective heat transfer coefficient for the entire boiler is defined as

$$U_b \equiv \frac{A_1}{A_T} U_{b1} + \frac{A_2}{A_T} U_{b2} + \frac{A_3}{A_T} U_{b3} \quad (6)$$

where A_T is the total boiler heat transfer surface area. The areas A_1, A_2, A_3 are the inside surface areas of the tubes of the three fluid sections, and their sum is the total surface area, i.e.,

$$A_1 + A_2 + A_3 = A_T \quad (7)$$

Because the lengths of the three different fluid state sections define the boundaries of the different heat transfer regimes, these areas are found to be

$$A_1 = A_T\left(\frac{L_1}{L_T}\right) ; \; A_2 = A_T\left(\frac{L_2}{L_T}\right) ; \; A_3 = A_T\left(\frac{L_3}{L_T}\right) (8)$$

Introducing (8) into (6) shows the approximate lumped average heat transfer coefficient is given by the expression

$$U_b = \frac{U_{b1} L_1 + U_{b2} L_2 + U_{b3} L_3}{L_T} \quad (9)$$

Fluid Temperature/Enthalpy Relations: Outlet steam temperature perturbations are related to outlet enthalpy perturbations through the inverse specific heat at constant pressure for steam:

$$\delta T_{OUT} = C_{p_s}^{-1} \, \delta h_{OUT} \quad (10)$$

Similarly, inlet water temperature and enthalpy perturbations are related by the inverse specific heat at constant pressure for water:

$$\delta T_{IN} = C_{p_w}^{-1} \, \delta h_{IN} \quad (11)$$

For given nominal operating conditions at the boiler outlet and inlet respectively, these specific heats may be determined from steam tables (12) or from the graph of Figure 6.

In order to solve the one-lump approximate model equations, a relationship is needed for the temperature perturbations of the fictitious lumped fluid in the boiler in terms of outlet enthalpy perturbations. This relationship is developed by defining the lumped fictitious temperature to be an average of the actual fluid temperatures, weighted by the heat transfer areas (or equivalently the lengths) of the three fluid phase regions, i.e.,

$$T_f = \frac{L_1}{L_T}\left(\frac{T_{IN} + T_{SAT}}{2}\right) + \frac{L_2}{L_T}(T_{SAT}) + \frac{L_3}{L_T}\left(\frac{T_{SAT} + T_{OUT}}{2}\right) \quad (12)$$

Taking perturbations shows

$$\delta T_f = \frac{L_1}{2L_T} \, \delta T_{IN} + \frac{L_3}{2L_T} \, \delta T_{OUT} \quad (13)$$

where the perturbation in T_{SAT} is zero for constant pressure. Equations (10) and (11) can be combined with (13) to yield

$$\delta T_F = 1/2\left[\left(\frac{L_1}{L_T}\right) C_{p_w}^{-1} \, \delta h_{IN} + \left(\frac{L_3}{L_T}\right) C_{p_s}^{-1} \, \delta h_{OUT}\right] \quad (14)$$

If flow rate perturbations are of interest, then assuming $\delta h_{IN} = 0$ furnishes the desired approximate relation

$$\delta T_f = \bar{C}_p^{-1} \, \delta h_{OUT} \quad (15)$$

where

$$\bar{C}_p^{-1} = \frac{L_3}{2L_T} C_{p_s}^{-1} \quad (16)$$

Transfer Functions: The detailed derivation of the transfer functions is given in Appendix B. It is shown that outlet steam temperature with respect to flow rate transfer function has the form

$$\frac{\Delta T_s}{\Delta w}(s) = -K_w \frac{(1 + \tau_a s)}{(1 + \tau_b s)} e^{-\frac{\tau_{Db}}{2} s} \quad (17)$$

where

$$K_w = \left(\frac{Q_o}{W_o}\right)\left(\frac{1}{C_{ps}}\right)\left(\frac{1}{W_o}\right)\left(\frac{{}^oF}{lb/sec}\right) or \left(\frac{{}^oC}{Kg/sec}\right) \quad (18)$$

$$\tau_a = 0.2\ \tau_{mb} \quad (sec) \quad (19)$$

$$\tau_{mb} = \frac{M_{mb}\ C_{mb}}{U_{bo}\ A_b} \quad (sec) \quad (20)$$

$$\tau_b = (1 + \beta)\ \tau_{mb} \quad (sec) \quad (21)$$

$$\beta_b = \frac{U_{bo}\ A_b}{\bar{C}_p\ W_o} \quad (dimensionless) \quad (22)$$

$$\tau_{Db} = \tau_{D1} + \tau_{D2} + \tau_{D3} \quad (sec) \quad (23)$$

$$U_{bo} = U_{REF}\left(\frac{W_o}{W_{REF}}\right)^{0.8} \quad (24)$$

The negative sign on K_w in Equation (17) indicates that a positive change in flow rate produces a negative change in steam temperature. Equation (18) indicates that the steady state gain K_w is proportional to the absorbed power to flow rate ratio at the operating condition, which is identical to the enthalpy change from fluid inlet to outlet. The inverse specific heat, C_{ps}^{-1}, has a value consistent with the operating pressure and the nominal outlet steam temperature. The last term in (18) shows that the gain is inversely proportional to the nominal mass flow rate.

The boiler metal time constant, τ_{mb}, includes the total mass of the boiler metal, the metal specific heat, C_{mb}, the total heat transfer area of the boiler, A_b, and the lumped averaged boiler convection heat transfer coefficient, U_{bo}. The dimensionless parameter β_b was numerically on the order of 6 to 10, and thus, β_b is a significant contributor to the effective boiler time constant τ_b. The boiler time delay τ_{Db} is simply the sum of the individual transport delays in the subcooled, saturated, and superheated sections. In any one section, the time delay is

$$\tau_D = \frac{A_c L}{\bar{v} W_o} \quad (25)$$

where A_c and L are the cross-sectional area and length of the section, respectively, $\bar{v}$ is the average specific volume, and W_o is the nominal mass flow rate.

Overall Receiver Model

The transfer function described in the previous section corresponds to the boiler or heated section of the receiver panel. To validate this transfer function, additional linear models were formulated, corresponding to the CRTF hardware indicated in Figure 5. A general first-order linear model was derived for each of these unheated components. The transfer function was derived using the heated boiler section modeling equations with the heat input set to zero. The metal in all these unheated components is INCOLOY 800. The models for each of these sections assume that all average heat transfer coefficients vary proportionately to $(W_o)^{0.8}$. The individual component transport delays were summed and are represented by one lump, τ_D, which is inversely proportional to W_o. The derivation of the transfer function for a general unheated component is indicated in Appendix B.

The temperature sensor was assumed to possess a first-order time lag. Its time constant was obtained from the manufacturer's specification and is assumed to be 12 sec (future studies will consider varying this time constant as a function of flow rate).

Parameter Values for the Transfer Functions: The transfer functions for all the components of Figure 5 are shown in the block diagram of Figure 7, where it is noted that the individual transport delays are lumped into a single one. With the exception of the sensor time constant, all parameters are flow rate dependent.

The steady state gain of the heated panel transfer function, K_w, is given by Equation (18). This gain is completely independent of any boiler parameters and is only a function of mass flow rate (W_o), specific heat of outlet steam (C_{ps}) and the absorbed power to flow rate ratio (Q_o/W_o). For any operating condition, W_o is known. The specific heat at constant pressure can be obtained either from steam tables or from Figure 6. The ratio (Q_o/W_o) can also be obtained from steam tables for any operating condition of inlet and outlet temperatures, and Figure 8 shows a plot of this ratio for a specific operating pressure of 1500 psia (10.34×10^6 Pa). Thus, the gain K_w can quickly be determined for any operating condition. The numerical values for the components of Figure 7 were inserted into Equations (19) through (24). The resulting time constants and time delay for each component are listed in Table I as a function of nominal mass flow rate. The reciprocals of the time constants are the corresponding zero and pole locations in radians per second, and these zeroes and poles are plotted as a function of flow rate in Figure 9. Thus, for any given CRTF test flow rate, the zeroes and poles for this simple representation can be quickly determined from the figure. The calculated transport time delay as a function of flow rate is shown in Figure 10. The average heat transfer coefficient for the steam header was much lower than in the other sections, since the velocity was much lower. Accordingly, the transfer function showed a nearly cancelling dipole (pole and zero very close together) at a very large time constant value. As a result, only the transport delay was retained for this transfer function.

VALIDATION EFFORT

The linear transfer function relating measured outlet steam temperature to inlet flow rate to the receiver panel was selected to be the primary transfer function used in the evaluation. The transfer function validation was performed using three approaches, each based on frequency response as indicated in Figure 11:

1. Comparison with higher order linearization based on first principles nonlinear modeling to determine the analytical validity of the lower order approximation.
2. Direct comparison to experimental points obtained by frequency response testing at CRTF.
3. Indirect comparison to frequency responses derived from experimental step response testing at CRTF.

Figures 12 and 13 show the comparisons of the frequency responses obtained by all techniques for the 1- and 2-MW test cases, respectively. The remainder of this section discusses more fully each validation technique, in addition to a supplemental test step response comparison.

Numerical Linearized Frequency Response

The linearization of the overall process model and the determination of both the eigenvalues and frequency responses were performed automatically by means of the Time And Frequency Domain Analysis Program, TAF (6,7). Use of the TAF Program significantly reduces the time required to linearize the system equations, since the linearization is performed numerically and provides a direct correlation with the nonlinear process model equations which are input to the TAF Program. Both linear stability analysis and linear and nonlinear transient analysis can be performed using the same computer source code. This source code is a FORTRAN subroutine which contains the nonlinear differential and algebraic equations which define the mathematical model of the process dynamics. The nonlinear equations (Appendix A) which describe the process were linearized about steady state operating points, the eigenvalues were calculated to determine the dominant time constants, and the critical transfer functions of the process were evaluated in terms of frequency responses.

These frequency responses were evaluated at the 1- and 2-MW test conditions and are shown on Figures 12 and 13, respectively. Comparison with the simplified model shows very good agreement for the gain or amplitude ratio for both power levels. The phase shift for the 2-MW case agrees closely for frequencies below about 0.1 rad/sec. The phase shifts for the 1-MW case parallel each other below 0.1 rad/sec with offsets ranging from 5 to 20 degrees, still representing reasonable agreement. The differences in transport delay times and the low order approximation are believed to be the cause of the divergence of phase shift at higher frequencies.

Frequency Response Testing at CRTF

Having obtained analytical validation of the simplified model, frequency response tests were specified and performed at CRTF for the direct experimental validation. A brief description of the CRTF, the test procedure, and the results follows.

Figure 14 shows the receiver (boiler) panel on top of the concrete tower being illuminated by the mirror field at CRTF. The tests are directed from the control center which contains the data acquisition system. The controls for the facility water input and boiler output pressure are located at the base of the concrete tower. The electronics for controlling the boiler are located two floors down from the top of the tower. From this electronics station, the boiler inlet flow rate control valve was commanded to a small sinusoidal variation about a nominal value, and measurements were taken of the outlet steam temperature response. An example of the results of the input and output time histories of one such test is shown in Figure 15. This procedure was followed for sinusoidal periods ranging from 1-min to 4-min periods, at two nominal power levels of approximately 1 and 2 MW.

The amplitude and phase shift of the steam temperature variations relative to the flow rate variations correspond to the individual data points on Figures 12 and 13. It is observed that the amplitude ratio (gain) of the simplified model has close agreement to the test points at frequencies below 0.1 rad/sec. The phase shifts reasonably agree in the mid-frequency range where test points were available, although better agreement was accomplished at the higher input power case. A divergence is noted at the higher frequencies (the 2-MW or higher flow case shows phase agreement for a wider frequency range). This divergence is again believed to be due to the choice of the numerical value of the transport delay time, which dominates the phase shift at the higher frequencies. The choice of this transport delay time warrants further study. The lowest frequency magnitude points were determined from step response tests performed on different test days, but at similar operating conditions.

From the demonstrated agreement with test data, the simplified model appears to be an adequate representation for initial controller design purposes. Additional frequency response and step response testing is planned at the CRTF to further refine the simplified model, especially in the choices of transport delay and thermocouple sensor time responses as a function of flow rate.

Frequency Response Derived from CRTF Step Response

An indirect comparison with the simplified model was accomplished by generating numerical frequency responses from CRTF step responses. These step responses pertained to steam temperature responses to inlet valve step decreases at similar test conditions performed in different test days. The frequency responses were derived using a computer program that solves the convolution technique described in Appendix C. The frequency responses obtained for the 1- and 2-MW cases with operating conditions similar to the direct frequency response tests are shown on Figures 12 and 13. The gain characteristic matches that of the simplified model very closely for the 1-MW case, while the agreement is not as close for the 2-MW case. The phase shift closely agrees with the simple model for the 1-MW case below a frequency of 0.05 rad/sec, and reasonably agrees for the 2-MW case up to the same frequency. The dominance of the transport delay time has been mentioned as one reason for the phase discrepancy. Another possible explanation for this discrepancy is that the granularity acquired by digitizing the time response inputs to the program serves to limit the accuracy of the computed frequency responses at the higher frequencies. Even though these step response tests were not performed on the same test day and at the same operating conditions as the direct frequency response tests, the general closeness of the frequency response results lends further support to the use of the simplified model.

Supplemental Step Response Validation

A supplemental validation of the derived frequency response technique was also performed. The previously derived frequency responses were input to a second computer program that produced linear numerical transfer functions. A third program used these transfer functions and the test step input time history to compute an output transient step response. This linear transient response was compared to the test output step response, and the difference between the two is a measure of the degree of nonlinearity of the physical process and of the error introduced by digitizing the continuous test responses. As seen in Figure 16, close correspondence is observed.

Refinement of this technique for numerically deriving frequency response from test step response appears promising, especially from the consideration of reducing test time for boiler model characterization. A single step response test can furnish nearly as much frequency response information as the direct sinusoidal testing, which requires tests at multiple frequencies. The lowest frequency of the direct tests corresponded to a 4-min period (≈ 0.004 Hz), during which time all operating conditions were required to remain stable, especially the solar heat input. The presence of moving clouds severely restricts the time for long periods of testing.

CONCLUSIONS

A first-order analytical model of a once-through steam generator is derived that includes the important interactions and dynamics affecting the outlet steam temperature. This model was derived using engineering approximations applied to established "first principles" once-through boiler nonlinear mathematical descriptions. The model was validated using several approaches, including testing, and is an adequate representation for initial steam temperature-inlet flow rate controller design purposes. The model validation techniques described resulted in high confidence of the result and have general applicability to dynamic processes. The simplified modeling technique may be applicable to other once-through steam generators and to other similar processes. The model can be used as an approximate description for debugging the dynamics of more highly complex nonlinear computer simulations, as a check on higher order, more exact linear analyses, and in larger overall plant simulations involving other major dynamic components where a knowledge of internal boiler variables is not essential.

Due to the demonstrated validity of the simplified model, it appears the model structure is adequate, but the choices of numerical values needed in the model can be improved. Additional open-control-loop testing is planned at the Barstow site for this purpose.

The technique of numerically deriving frequency response from step response tests shows promise as an expeditious and efficient method of boiler characterization by means of step response tests. Further effort is warranted for this technique.

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(11) Zondervan, K. L., et. al., "Dynamic Computer Simulation of the DOE 10 MWe Solar Thermal Pilot Plant", AIAA/ASERC Conference on Solar Energy: Technology Status, November 24 - 29, 1978.

(12) Meyer, C. A., et. al., ASME Steam Tables, Third Edition, American Society of Mechanical Engineers, New York, N.Y., 1977.

(13) Saucedo, R., Schiring, E. E., "Classical Characterization of Control Systems", Introduction to Continuous and Digital Control Systems, Macmillan Co., New York, N.Y., 1968.

NOMENCLATURE

	Variables and Constants	English Units	SI Units
A	Area	ft^2	m^2
C	Specific heat	Btu/ lb_m-°F	J/Kg-°C
F	Fluid flow friction coefficient per unit length	psi-sec^2/ lb_m-ft^2	Pa-sec^2/ Kg-m^2
h	Enthalpy	Btu/lb_m	J/Kg
L	Length	ft	m
$\bar{M}$	Mass per unit length	lb_m/ft	Kg/m
M	Mass	lb_m	Kg
P	Pressure	psia	N/m^2(Pa)
$\bar{Q}$	Heat flux	Btu/ft^2-sec	J/m^2-sec
Q	Heat flow rate	Btu/sec	J/sec
S	Area per unit length	ft^2/ft	m^2/m
s	LaPlace variable	sec^{-1}	sec^{-1}
T	Temperature	°F	°C
t	Time	sec	sec
U	Heat transfer coefficient	Btu/ ft^2-°F-sec	J/m^2-°C-sec
V	Volume	ft^3	m^3
v	Specific volume	ft^3/lb_m	m^3/Kg
W	Flow rate	lb_m/sec	Kg/sec
δ	Perturbation operator	---	---
ϵ	Emissivity	---	---
σ	Stefan-Boeltzmann constant	Btu/ ft^2-°R^4-sec	J/ m^2-°K^4-sec
τ	Time constant	sec	sec

Subscripts

b	boiler
c	Cross-sectional
D	Delay
f	Fluid
fb	Film boiling
h	Header
i	General index
IN	Inlet
L	Length, Loss
ℓ	Length
m	Metal
nb	Nucleate boiling
o	Operating point
OUT	Outlet
p	Pipe or pressure
R	Degrees Rankine
REF	Reference value
q	Pertaining to solar heat input
s	Steam
sat	Saturation
SENS	Sensor
T	Total
t	Thermocouple
u	Unheated boiler section
v	Vapor
w	Flow rate perturbation or water

APPENDIX A. NONLINEAR RECEIVER DYNAMIC MODEL EQUATIONS

The information in this appendix is from References 2, 3, 4, 5 of the main text.

The receiver subsystem thermal/hydraulic models are formulated from the following basic sets of equations:

1. Fundamental equations of mass, momentum, and energy conservation
2. Semiempirical relationships for fluid flow and heat transfer
3. State relations for thermodynamic properties of working fluids

The primary assumption in this study is that an infinite-dimensional distributed parameter process can be represented by a finite-dimensional lumped parameter model using the concept of control volumes. Additional assumptions are:

1. The boiler contains all three fluid states - subcooled water, two-phase mixture and superheated steam.
2. Uniform flow distribution in multitube devices
3. Steady, fully-developed, turbulent, single-phase fluid flow
4. Insignificant temporal acceleration and momentum transport contributions to fluid flow dynamics
5. Insignificant potential and kinetic energy contributions to fluid flow dynamics
6. Insignificant heat transfer by conduction

The following equations define the mathematical models used for the nonlinear model and correspond to the schematic diagram of Figure 4. The explanation of the symbols used is given in the Nomenclature Section.

Subcooled Section

$$L_1 \overline{M}_{ml} C_m \dot{T}_{ml} = \overline{Q} S_q L_1 - U_1 SL_1 (T_{ml} - T_{fl}) - Q_{L1} \qquad \text{(A-1)}$$

$$\dot{L}_1 = - \frac{v_1 v_{f_{sat}} \left[W(h_{1IN} - h_{f_{sat}}) + U_1 S L_1 (T_{ml} - T_{fl})\right]}{A_c \left[v_1 (h_{f_{sat}} - u_2) - v_{f_{sat}} (u_{f_{sat}} - u_2)\right]} \qquad \text{(A-2)}$$

Two-Phase Section

$$L_2 \overline{M}_{m2} C_m \dot{T}_{m2} = \overline{Q} S_q L_2 - U_2 SL_2 (T_{m2} - T_{sat}) - Q_{L2} \qquad \text{(A-3)}$$

$$L_2 = W(h_{v_{sat}} - h_{f_{sat}}) / U_2 S (T_{m2} - T_{sat}) \qquad \text{(A-4)}$$

Superheated Section

$$L_3 \overline{M}_{m3} C_m \dot{T}_{m3} = \overline{Q} S_q L_3 - U_3 SL_3 (T_{m3} - T_{f3}) - Q_{L3} \qquad \text{(A-5)}$$

$$L_3 = L_T - L_1 - L_2 \qquad \text{(A-6)}$$

$$\frac{A_c L_3}{v_3} \dot{h}_{3_{OUT}} = U_3 \, SL_3 \, (T_{m3} - T_{f3}) - W(h_{3_{OUT}} - h_{v_{sat}}) \quad \text{(A-7)}$$

Unheated Section of Boiler

$$L_u \, \overline{M}_{mu} \, C_{mu} \, \dot{T}_{mu} = -U_u \, SL_u \, (T_{mu} - T_{fu}) - Q_{Lu} \quad \text{(A-8)}$$

$$\frac{A_c L_u}{v_u} \dot{h}_u = U_u \, SL_u \, (T_{mu} - T_{fu}) - W \, (h_u - h_{3_{OUT}}) \quad \text{(A-9)}$$

Steam Header

$$M_{mh} \, C_m \, \dot{T}_{mh} = -U_h \, A_h \, (T_{mh} - T_{fh}) \quad \text{(A-10)}$$

$$\frac{V_{fh}}{v_h} \dot{h}_h = U_h \, A_h \, (T_{mh} - T_{fh}) - W \, (h_h - h_u) \quad \text{(A-11)}$$

Outlet Pipe

$$M_{mp} \, C_p \, \dot{T}_{mp} = -U_p \, A_p \, (T_{mp} - T_{fp}) \quad \text{(A-12)}$$

$$\frac{V_{fp}}{v_p} \dot{h}_p = U_p \, A_p \, (T_{mp} - T_{fp}) - W \, (h_p - h_h) \quad \text{(A-13)}$$

Temperature Sensor

$$\tau_t \, \dot{T}_{SENS} = T_{P_{OUT}} - T_{SENS} \quad \text{(A-14)}$$

Steam and Water Properties

Standard tables or equation curve fits

Heat Transfer Coefficients

Single-Phase

$$U_i = U_{i_{REF}} \left(\frac{W}{W_{REF}}\right)^{0.8} \quad \text{(A-15)}$$

Two-Phase

$$U = 0.76 \, U_{nbref} \exp \, (P/630) \frac{(T_m - T_f)}{(T_m - T_f)_{ref}} + 0.24 \, U_{fbref} \left(\frac{W}{W_{ref}}\right)^{0.8} \quad \text{(A-16)}$$

Heat Losses

$$Q_{Li} = U_i \, S_q \, L_i \, (T_{mi} - T_a) + \sigma \, \epsilon \, S_q \, L_i \, (T^4_{mi_R} - T^4_{a_R}) \quad \text{(A-17)}$$

Fluid Flow

$$P_{OUT_i} = P_{IN_i} - F_i \, L_i \, v_i \, W^2 \quad \text{(A-18)}$$

APPENDIX B. DERIVATION OF SIMPLE TRANSFER FUNCTIONS

Boiler Transfer Functions

The equation for the lumped metal derivative is

$$M_m \, C_m \, \dot{T}_m = Q - U_b \, [W] \, A_b \, (T_m - T_f) \quad \text{(B-1)}$$

The heat balance for the fictitious fluid is

$$0 = U_b \, [W] \, A_b \, (T_m - T_f) - W \, (h_{OUT} - h_{IN}) \quad \text{(B-2)}$$

The relation between h_{OUT} and the fictitious fluid temperature change is

$$\frac{\partial T_f}{\partial h_o} = \frac{1}{C_p} \quad \text{(B-3)}$$

The relation between outlet steam temperature and h_{OUT} change is

$$\frac{\partial T_s}{\partial h_o} = \frac{1}{C_{ps}} \quad \text{(B-4)}$$

In order to derive the steam temperature with respect to flow rate transfer function, the variables are expressed as perturbations about nominal operating values:

$$\left.\begin{aligned} Q &= Q_o \\ T_m &= T_{mo} + \delta T_m \\ W &= W_o + w \\ T_f &= T_{fo} + \delta T_f \\ h_{OUT} &= H_o + \delta h_{OUT} \\ h_{IN} &= h_{INo} \end{aligned}\right\} \quad \text{(B-5)}$$

Since the average heat transfer coefficient is assumed to vary as $(W_o)^{0.8}$, the perturbation for U_b is written as

$$U_b = U_{ob}\left[1 + 0.8\frac{W}{W_o}\right] \quad \text{(B-6)}$$

where U_{ob} is the average for the nominal operating condition. In terms of some reference flow rate W_{REF} for which U_{REF} is known, then

$$U_{ob} = U_{REF}\left(\frac{W_o}{W_{REF}}\right)^{0.8}$$

Introducing the perturbations (B-5), (B-6) into (B-1) - (A-4) and performing algebraic manipulation results in the perturbation equations

$$\delta\dot{T}_m = -\frac{1}{\tau_{mb}}(\delta T_m - \delta T_f) - \frac{0.8}{M_m C_m}\left(\frac{Q_o}{W_o}\right) w \quad \text{(B-7)}$$

$$\delta h_{OUT} = \frac{1}{W_o} U_{ob} A_b (\delta T_m - \delta T_f) - 0.2\left(\frac{Q_o}{W_o}\right) w \quad \text{(B-8)}$$

$$\delta T_f = \frac{1}{\overline{C}_p}\,\delta h_{OUT} \quad \text{(B-9)}$$

$$\delta T_{OUT} = \frac{1}{C_{ps}}\,\delta h_{OUT} \quad \text{(B-10)}$$

where

$$\tau_{mb} = \frac{M_m C_m}{U_{ob} A_b} \quad \text{(B-11)}$$

The LaPlace transform is applied to (B-7) through (B-11) resulting in algebraic equations in the LaPlace variables. Any of several techniques could be used to develop the desired transfer function. The method used in this case was the construction of a signal flow graph, followed by the application of Mason's flow graph quick reduction technique as described in most control system texts (13). The resulting transfer function multiplied by the transport delay exponential is

$$\frac{\delta T_s}{w}(s) = -K_w \frac{(1 + \tau_a s)}{(1 + \tau_b s)} e^{-\frac{\tau_{Db}}{2} s} \quad \text{(B-12)}$$

where

$$K_w = \left(\frac{Q_o}{W_o}\right)\frac{1}{C_{ps}}\left(\frac{1}{W_o}\right)$$

$$\tau_a = 0.2\,\tau_{mb}$$

$$\tau_b = (1 + \beta_b)\,\tau_{mb}$$

$$\beta_b = \frac{U_{ob} A_b}{\overline{C}_p W_o}$$

$$\tau_{Db} = \tau_{D1} + \tau_{D2} + \tau_{D3} \quad \text{(B-13)}$$

and for any section,

$$\tau_D = \frac{A_c L}{\overline{v} W_o}$$

A similar derivation for outlet steam temperature with respect to heat input is

$$\frac{\delta T_s}{\delta Q}(s) = \frac{1}{C_{ps} W_o}\,\frac{1}{1 + \tau_b s}\, e^{-\frac{\tau_{Db}}{2} s} \quad \text{(B-14)}$$

where the absence of a zero is noted, and the pole is the same one as in (B-12). The transfer function for inlet temperature perturbations is

$$\frac{\delta T_s}{\delta T_{IN}}(s) = \left(\frac{C_{pw}}{C_{ps}}\right)\frac{(1 + \tau_{mb} s)}{(1 + \tau_b s)} e^{-\tau_{Db} s} \quad \text{(B-15)}$$

where the complete transport delay is used in this case, and the gain is the ratio of the water and steam specific heats evaluated at the nominal inlet and outlet conditions, respectively.

Unheated Component Transfer Function

The derivation for these functions is similar to that of the boiler, with zero heat input to the metal. Again, the dominant dynamic effect is the interaction of the steam on the metal and vice-versa. The steam header and outlet pipe are insulated, so the adiabatic assumption was used, i.e., no external heat input and no losses. The upper unheated boiler section is not insulated, but the adiabatic assumption was used anyway (the adequacy of this assumption will be the subject of future effort). The average heat transfer coefficient was again assumed to vary as $(W_o)^{0.8}$ from values calculated for some W_{REF} and velocity reference for each unheated component. The general transfer function relating inlet and outlet temperatures for these sections has the same form as (B-15), with the absence of the specific heat ratio since inlet and outlet are both superheated steam,

$$\frac{\delta T_{s\ OUT}}{\delta T_{s\ IN}}(s) = \frac{(1 + \tau_m' s)}{(1 + \tau_b')} e^{-\tau_D' s} \qquad \text{(B-16)}$$

and where the prime (') is used to indicate the time constants are different from those of the boiler.

APPENDIX C. USE OF CONVOLUTION INTEGRAL TO GENERATE FREQUENCY RESPONSE

Let y(t) be the response of a linear network to an input function f(t), and let M represent a value of time such that F(M) is approximately equal to $F(\infty)$. Then, the frequency response of the network is given by

$$G(j\omega) = \frac{y(0^+) + \int_0^M e^{-j\omega t}\, y'(t)\, dt}{f(0^+) + \int_0^M e^{-j\omega t}\, f'(t)\, dt} \qquad \text{(C-1)}$$

Usually, y and f are known only at a finite number of points

$$0 = t_1 < t_2 < \ldots < t_N = M$$

So, the convolution program evaluates expression (1) by assuming

$$y'(t) = \frac{y(t_{k+1}) - y(t_k)}{t_{k+1} - t_k} \qquad \text{(C-2)}$$

in the interval t_k to t_{k+1}. Therefore, in each subinterval, Δt_k ($\Delta t_k = t_{k+1} - t_k$), of time we have

$$\int_{t_k}^{t_{k+1}} e^{-j\omega t}\, y'(t)\, dt =$$

$$\int_{t_k}^{t_{k+1}} \left[\frac{y(t_{k+1}) - y(t_k)}{\Delta t_k}\right] e^{-j\omega t}\, dt \qquad \text{(C-3)}$$

$$= \frac{y(t_{k+1}) - y(t_k)}{\Delta t_k}\left[\frac{j}{\omega} e^{-j\omega t_{k+1}} - \frac{j}{\omega} e^{-j\omega t_k}\right] \qquad \text{(C-4)}$$

so that

$$\int_0^M e^{-j\omega t}\, y'(t)\, dt$$

$$= \frac{j}{\omega}\sum_{k=0}^{N-1} \frac{y(t_{k+1}) - y(t_k)}{\Delta t_k}\left[e^{-j\omega t_{k+1}} - e^{-j\omega t_k}\right] \qquad \text{(C-5)}$$

Likewise

$$\int_0^M e^{-j\omega t}\, f'(t)\, dt$$

$$= \frac{j}{\omega}\sum_{k=0}^{N-1} \frac{f(t_{k+1}) - f(t_k)}{t_k}\left[e^{-j\omega t_{k+1}} - e^{-j\omega t_k}\right] \qquad \text{(C-6)}$$

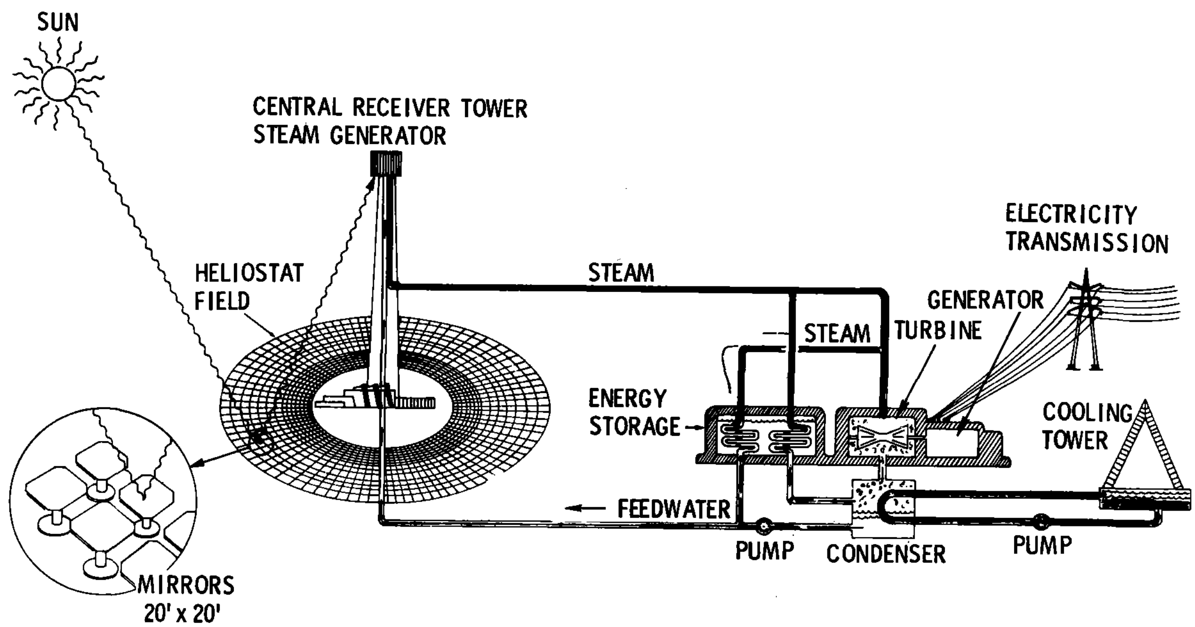

Figure 1. Central Receiver Concept

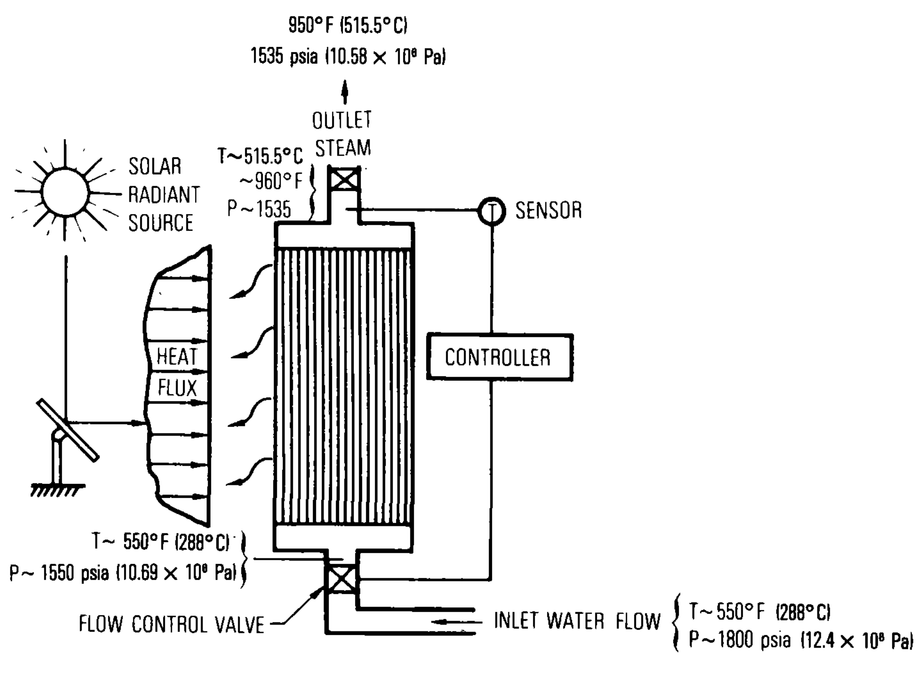

Figure 2. Single Panel Sketch

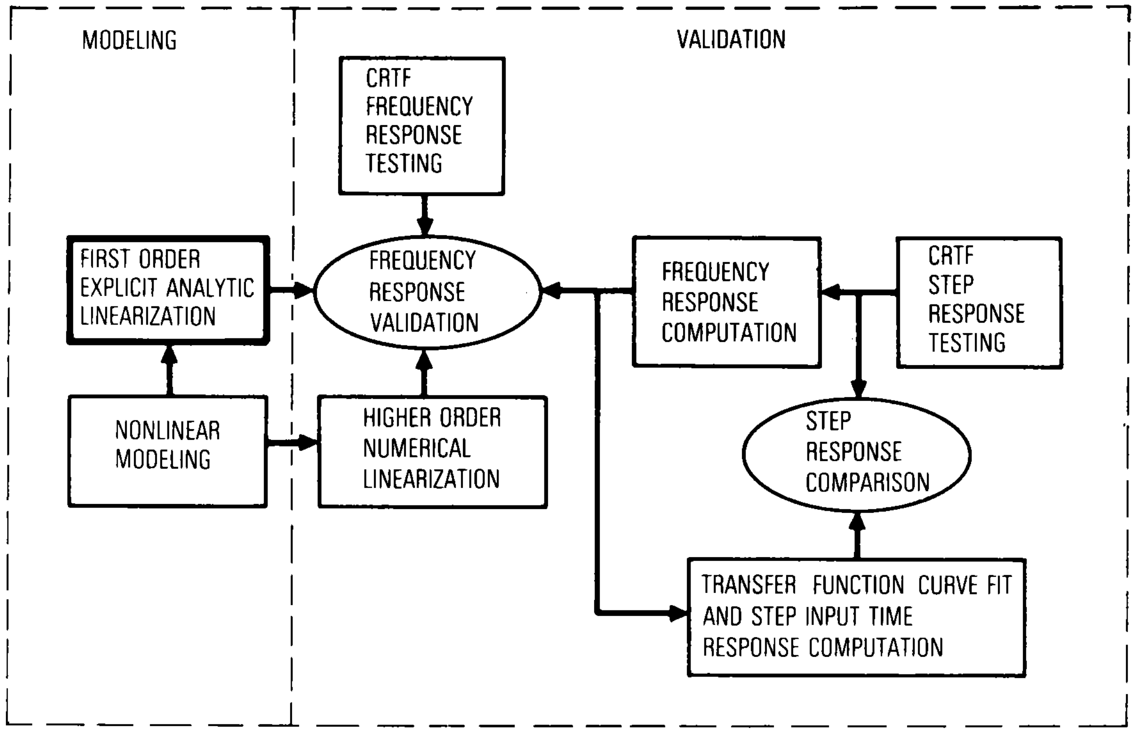

Figure 3. Modeling and Validation Effort

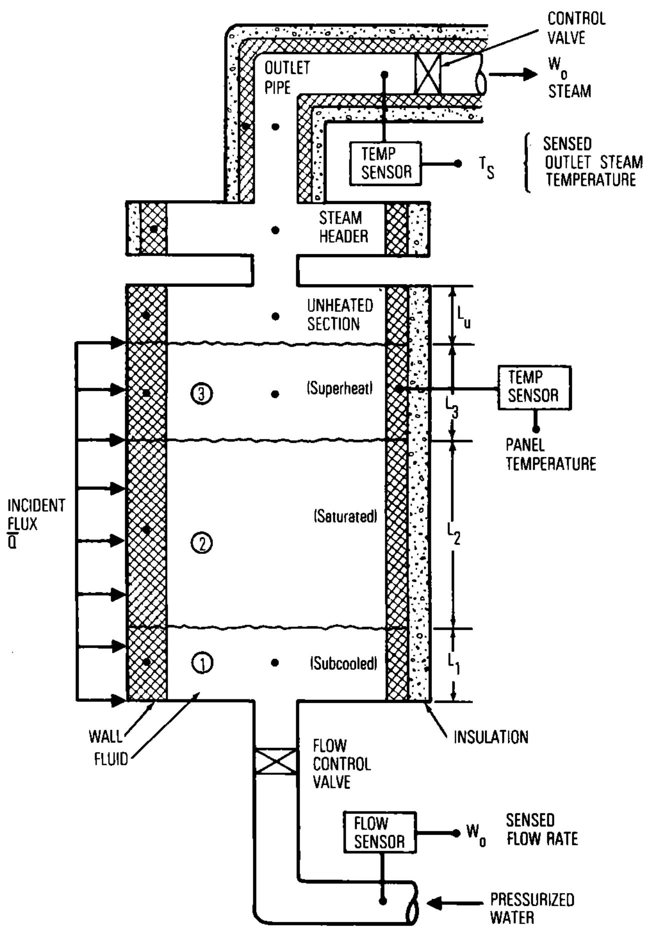

Figure 4. Receiver Panel Model Schematic

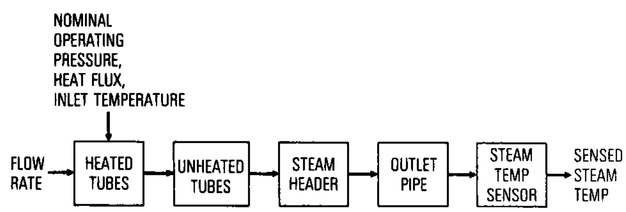

Figure 5. Receiver Analytical Block Diagram

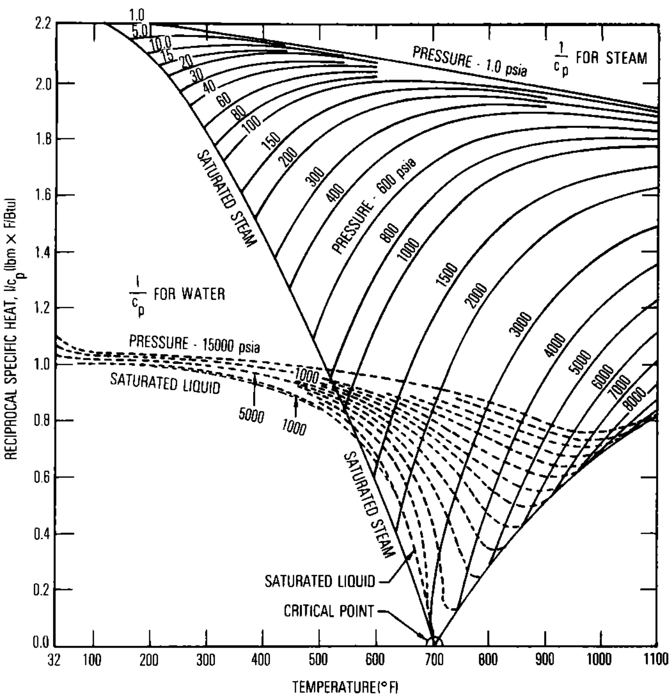

Figure 6. Reciprocal Constant Pressure Specific Heat

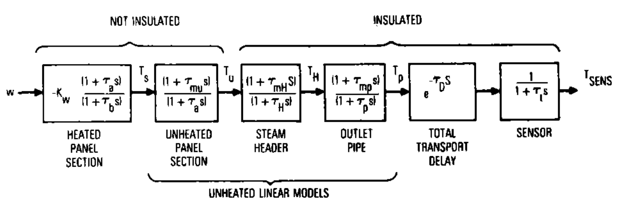

Figure 7. Simplified CRTF Linear Heat Transfer Model

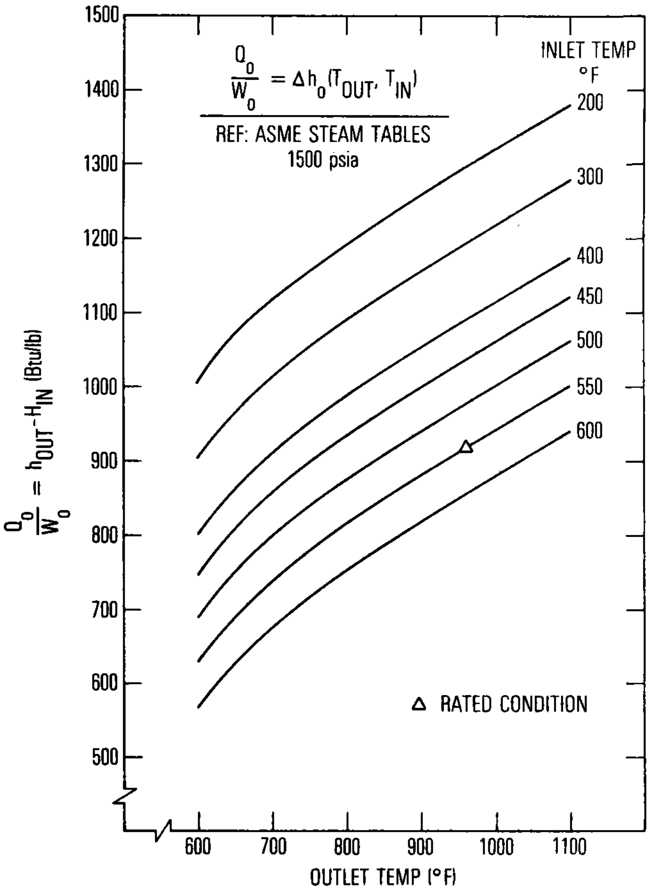

Figure 8. Gain Proportionality Factor

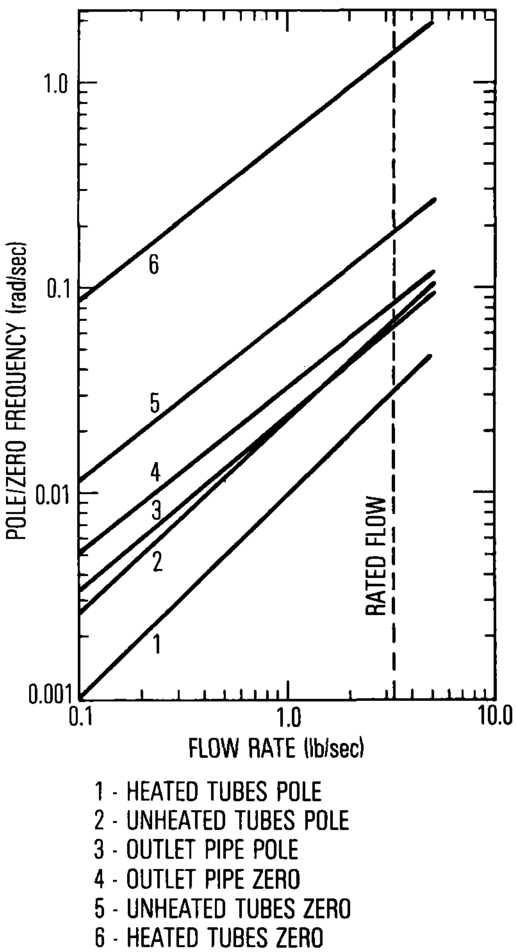

Figure 9. Zeros and Poles of CRTF Receiver Test Setup vs Flow Rate

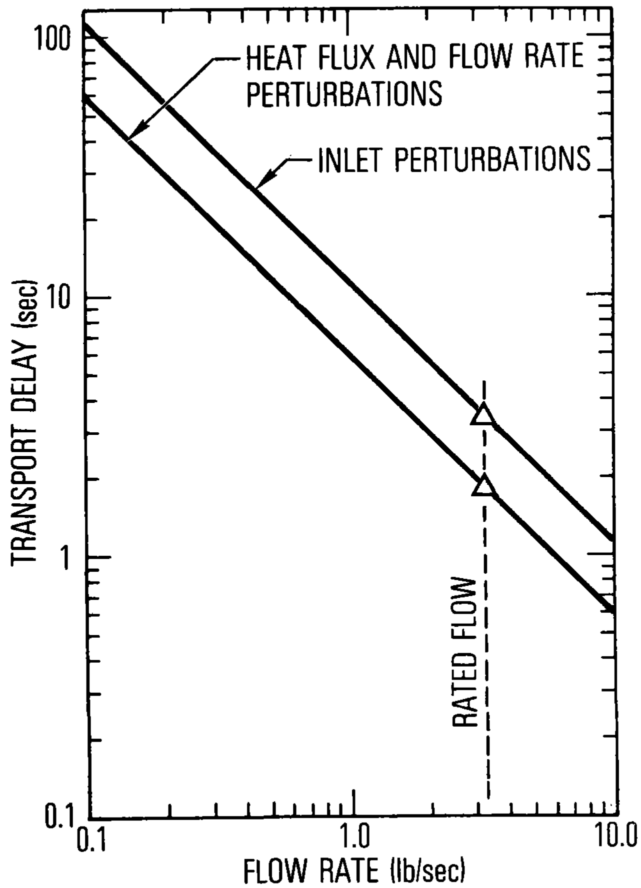

Figure 10. Transport Delay for CRTF Test Receiver Setup vs Flow Rate

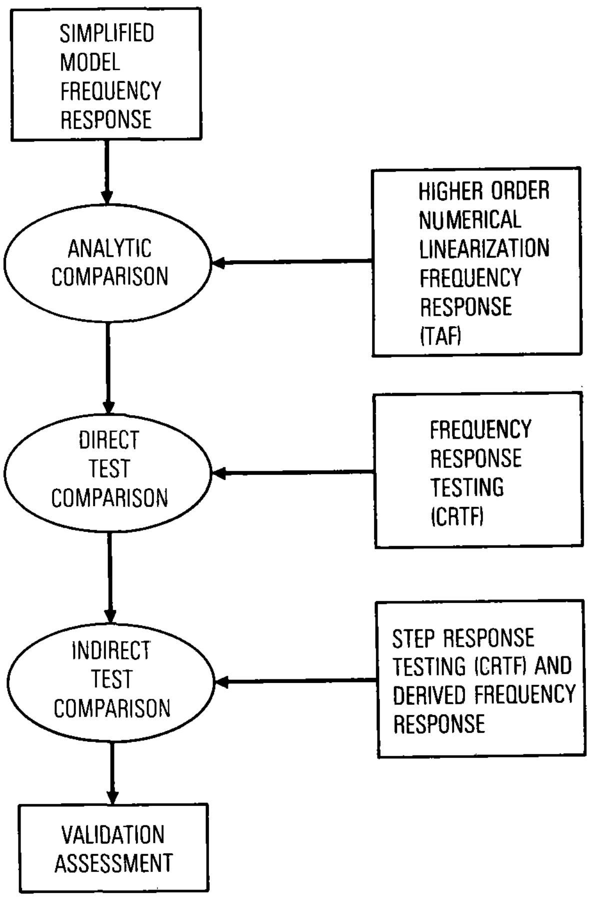

Figure 11. Validation Effort

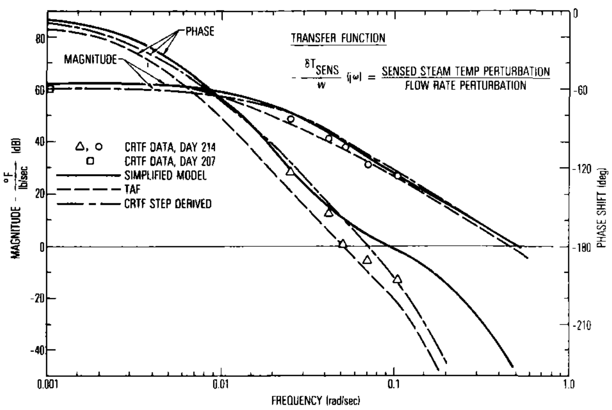

Figure 12. Frequency Response Results for 1-MW Power Level

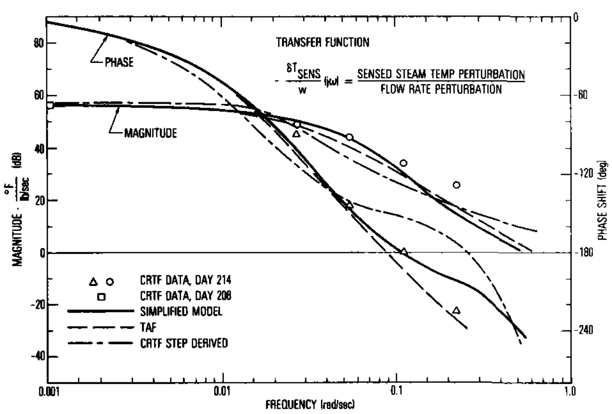

Figure 13. Frequency Response Results for 2-MW Power Level

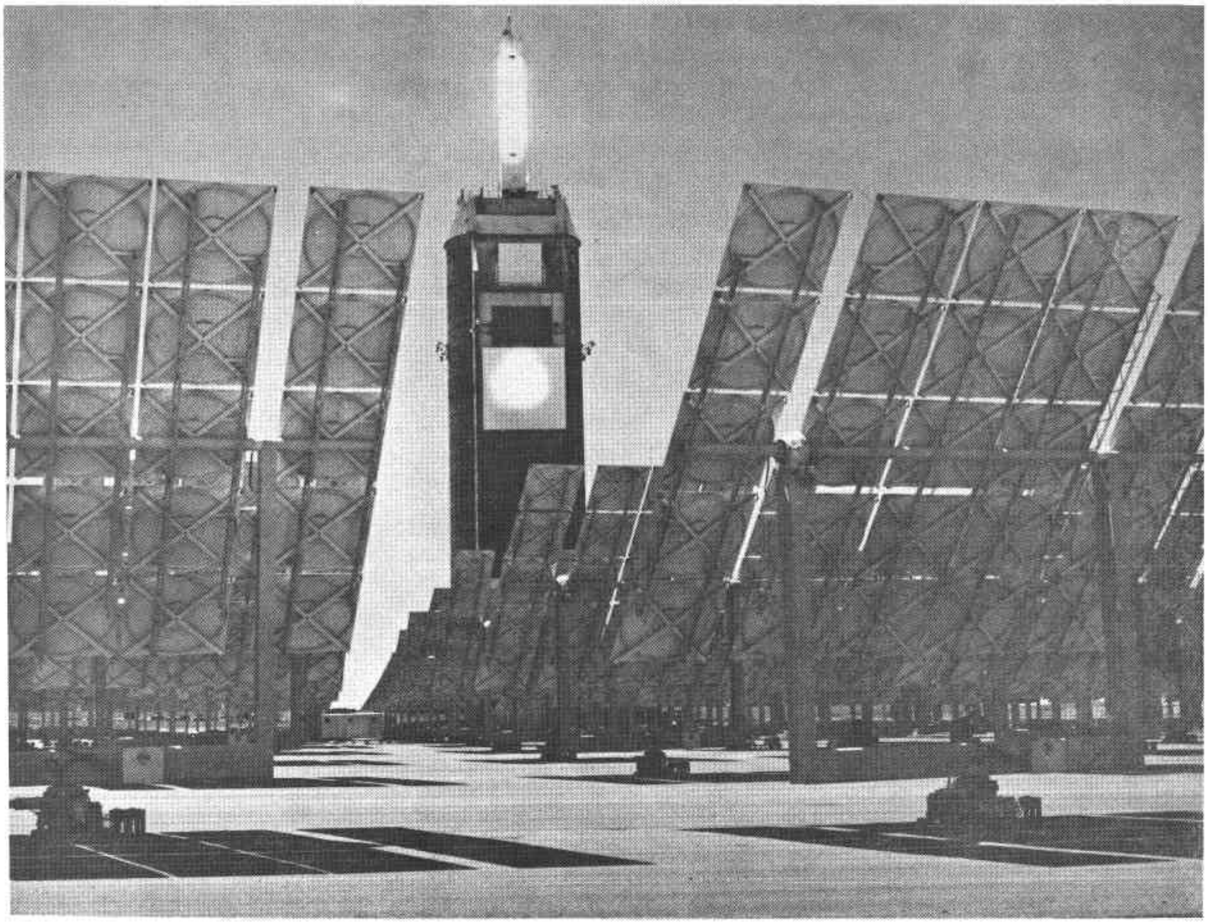

Figure 14. Receiver Test Panel Atop Tower at DOE/Sandia Central Receiver Test Facility

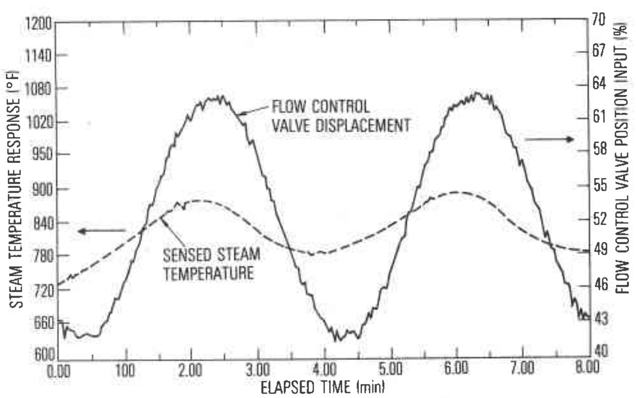

Figure 15. Typical Open Loop Frequency Response Test Data

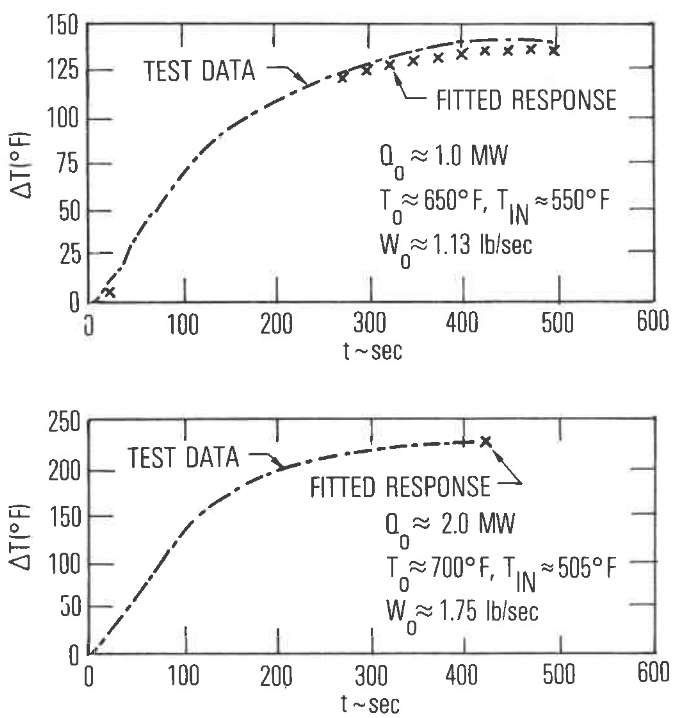

Figure 16. Comparison of Step Response Test Data and Linearized Fitted Response

Department of Energy
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Solar Ten Megawatt Project Office
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STMPO-039

November 29, 1979

Ms. Frances A. Brady D6/125D
Office of Technical Relations
The Aerospace Corporation
P.O. Box 92957
Los Angeles, California 90009

SUBJECT: Professional Paper "Simplified Linear Dynamic Model for a Solar-Powered Once-Through Boiler", authors - E.E. Schiring, R.O. Rogers, E.J. Riel, A.J. Welch

Dear Ms. Brady:

The subject paper has been reviewed, and is approved for presentation and publication at the ISA Power Industry Division Symposium, Chicago, Illinois, May 14-16, 1980.

Sincerely,

James C. Corcoran, Contracting Officer
Solar Ten Megawatt Pilot Plant Project Office
U.S. Department of Energy

11-79-434

File 1.7.5

bcc: Schweinberg
Slaminski
Eden
Rogers
E. Schiring, Aerospace
H. Bernstein, Aerospace

HEden:hl 11/29/79

OFFICE ➤	STMPO Out	STMPO				
SURNAME ➤	Eden	Corcoran				
DATE ➤		11/29/79				

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Mr. Harry D. Eden
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The Aerospace Corporation
Post Office Box 92957
Los Angeles, CA 90009

MAR 13 1984

Subj.: Identification and Clearance for DOE Technical Information Center of Aerospace Documents Related to 10-MWe Solar Thermal Pilot Plant (Solar One)

Dear Harry:

We are finalizing the current edition (covering the period through mid-1982) of the Solar One Project Bibliography; a proof copy is provided for your reference (publication by the Electric Power Research Institute is expected at the end of March). While we are in the process of establishing a reference library at the Plant site, which will include all of the 555 documents identified in the Bibliography, we would like to be able to refer inquiries from recipients of this document for individual copies of reports cited to the DOE Technical Information Center (DOE contractors) or the National Technical Information Service. In order to do this, we must insure that proper TIC/NTIS stock numbers are provided, and that all reports in the Bibliography have been properly patent cleared and sent to TIC and NTIS for preparation of microfiche. Unfortunately, this is the case at present for only about 300 of the documents listed; specifically, those for which the "Other Recipients" (line 10 of the document identification block) includes these agencies. We propose to issue an update to the Bibliography following completion of the Experimental Testing and Evaluation phase of Plant Operation (currently scheduled for the end of July, 1984). This update, in addition to providing documents produced by the Project since mid-1982, will include proper TIC/NTIS citation for all documents listed; it will also include a small number of documents from the earlier period which are omitted from the initial edition, but may be of interest to users of the Bibliography.

STMDO, -019, -021, -022, -027, -028, -034, -035, -038, -039 or will be included in the update
(NEW) -563, -564, -565

We have identified twelve Aerospace documents which are listed, but for which no TIC-approved citation has been located; most of these appear not to have been submitted in the first place, apparently having been treated as "working papers", while others are conference reports or journal articles. In addition, we have three NSF- and ERDA-era documents which, we feel sure, are "somewhere in the system", but which we have been unable to identify in the periodic reports lists issued by TIC, or - thus far - by inquiries to the data base. The latter three documents are described in the attached memorandum to Don Holz, the DOE/SAN Technical Information Officer; if, however, Aerospace records indicate the TIC/NTIS identifiers assigned (most likely "PB-" followed by six or eight digits), we would be most appreciative if you could pass them to us.

STMDO -013, -015 -018

For the twelve documents in the first group, I have provided copies for your reference; I have also prepared SAN Form 70 for completion by your staff for each of them (unless you have copies of previous patent clearances from SAN/OPC). While

I appreciate that Aerospace is no longer formally involved in the Project, and thus cannot assign a very high priority to dealing with these materials, I anticipate that you would be as eager as we are to get them cleaned up and on the way to TIC. (The "routine" on line 3 of the Form 70 is addressed to SAN/OPC.)

In preparing these documents and the Form 70's, I have assigned two identification numbers to each. The primary number is the normal TIC identifier: an ATR-series number, where such is provided on the document, or a number derived from the DOE contract number, where it is not. (Three Aerospace contracts are involved: DE-AT03-76CS51101 - formerly EY-76-C-03-1101/PA#2 -, DE-AT03-76ET21060 - formerly -1101/PA#14 - and the STMPO contract, DE-AC03-78ET20517; I have tried to assign the reports to the proper contract, where it is not cited in the document itself, using date or subject matter). If you know of appropriate ATR-nummer assignments, or if you wish to make such assignments, please do so and so advise me.

The secondary number (STMPO-xxx) is for convenience in filing and tracking Project documents; it will probably occur to you fairly promptly that it is connected with the Bibliography listing, and, in fact, it is the Bibliography page number. Aerospace documents comprise the first thirty-nine listings (STMPO-001 to STMPO-039), as well as the first three in the prospective update (STMPO-563 to STMPO-565) to the Bibliography. In any discussions with the Project Office, communication will be enhanced by using these numbers, and they should be preserved in the event your staff wishes to alter or re-type the relevant Form 70's.

I need, in order to track progress on a total of some 300 reports in processing, to have the Form 70's, together with the reference copies provided, <u>returned to me at the Project Office</u>, and <u>not</u> to SAN/OPC or TIC; I have made special <u>arrangements with Roger Gaither</u> at SAN and Bill Matheny at TIC, and the process seems to be working well at this point.

The advice of your patent/copyright staff on how best to deal with conference reports and journal articles (STMPO-28, -34, -38 and -39) and specifications including manufacturers' data sheets (STMPO-564, -565) would be welcomed. If copyright issues arise with these items, we can request TIC to limit further distribution as appropriate.

If you do wish copies of any of the documents provided, or cited in the Aerospace section of the Bibliography, I shall be happy to provide them. Thank you for your assistance.

Sincerely yours,

S. D. Elliott, Jr., Director,
DOE Solar One Project Office

Attch.: memo dtd. 3/12/84

Encls.: 12 Aerospace documents, w/ SAN Form 70

Proof copy of Solar One Project Bibliography

SAN FORM 70 10/80

DEPARTMENT OF ENERGY
SAN FRANCISCO OPERATIONS OFFICE

CONTRACTOR REQUEST FOR PATENT CLEARANCE FOR RELEASE OF UNCLASSIFIED DOCUMENT

Prime Contract No.	DE-AC03-78ET20517
Subcontract No.	(N/A)
Report No.	DOE/ET/20517-6 (STMPO-039)
Date of Report	(no date given)
Name & Phone No. of DOE Technical Representative	S. D. Elliott, Jr. (619) 254-2672

TO: Roger S. Gaither, Asst. Chief for Prosecution
Office of Patent Counsel/Livermore Office
P.O. Box 808, L-376
Livermore, California 94550

FROM: DOE Solar One Project Office
Post Office Box 366
Daggett, CA 92327

1. Document Title: "SIMPLIFIED LINEAR DYNAMIC MODEL FOR FIRST-CUT CONTROLLER DESIGN OF A SOLAR-POWERED ONCE-THROUGH BOILER"

2. Type of Document: ☐ Technical Report, ☐ Conference Paper, ☒ Journal Article, ☐ Abstract or Summary, ☐ Copy of Oral Presentation, ☐ Other (please specify): ______

3. In order to meet a publication schedule or submission deadline, patent clearance by (Routine) would be desired.

SENDER IS TO CHECK BOX #4 OR #5 BELOW.

☐ 4. I have reviewed (or have had reviewed by technically knowledgeable personnel) this document for possible inventive subject matter (Subject Inventions) and that no inventions or discoveries (Subject Inventions) are deemed to be disclosed in this document except as stated below:

a. Attention should be directed to pages ______ of this document.

b. This document describes matter relating to an invention:

i. Contractor Invention Docket No. ______.
ii. A disclosure of the invention was submitted to DOE on ______ (date)
iii. A disclosure of the invention will be submitted shortly ______ (approximate date)
iv. A waiver of DOE's patent rights to the contractor:
☐ has been granted, ☐ has been applied for; or ☐ will be applied for ______ (date)

☐ 5. This document is being submitted, but no review has been made of this document for possible inventive subject matter.

6. Remarks: Return clearance to Project Office; document may be destroyed

Reviewing/Submitting Official: Name (Print/Type) ______
Title ______
Signature ______ Date ______

TO: INITIATOR OF REQUEST

FROM: ASSISTANT CHIEF FOR PROSECUTION
Office of Patent Counsel/Livermore Office

☐ No patent objection to above-identified release.

☐ Please defer release until advised by this office.

Signed ______ Date Mailed ______

DOE OFFICE OF PATENT COUNSEL (OPC)

THE AEROSPACE CORPORATION

Post Office Box 92957, Los Angeles, California 90009, Telephone: (213) 648-5000

9 April 1984

Mr. Doug Elliott
Dept. of Energy Field Office
P.O. Box 366
Daggett, CA 92327

Dear Doug:

Enclosed with this letter I am returning some of the Aerospace reports and letters which you left with me relative to your desire to have them listed in the TIC. In the case of the three documents listed below, discussed herin, permission to place these in the TIC must be obtained from the technical associations listed with the documents. Aerospace has no authority in these matters other than to affirm that we previously obtained permission from DOE to have these published and therefore have no objection to your request. The particular documents referred to are:

1. (STMPO-028) "Dynmamic Computer Simulation of the DOE 10-MW Solar Thermal Pilot Plant" (AIAA/ASERC Conference on Solar Energy; November 1978).

2. (STMPO-034) "Preventing Eye Hazards at the 10MW Solar Thermal Pilot Plant" (American Conference of Governmental - Industrial Hygienists; November 27, 1979).

3. (STMPO-039) "Simplified Linear Dynamic Model for First-Cut Controller Design of a Solar-Powered Once-Through Boiler" (ISA Power Industry Division Symposium; May 1980).

For the case of the document which is the preliminary specification for the Infrared Monitor System (STMPO-565), this was to be a part of a DOE procurement package, and as such, does not fall into the category of a report. This specification is DOE property and doesn't even have Aerospace's name on it. DOE did not release the procurement package at the time because of funding problems, however we feel you may do with it as you wish.

The following two reports are parts of Aerospace proposals to DOE and definitely <u>should not</u> be in the TIC files. They are a part of the STMPO/DOE files only. These are:

1. (STMPO-563) "Barstow Insolation Variation Measurements; Experiment Description". This material is covered in the Aerospace report ATR-79(7747-2) entitled "Measurements of Insolation Variation Over a Solar Collector Field".

2. (STMPO-564) "Experiment Description, Low Cost Infrared Monitor System for the 10-MW_e Pilot Plant". This technical material is covered in the Aerospace report ATR-81(7747)-4 entitled "An Infrared Sensor for Remote Temperature Monitoring of Solar Thermal Central Receiver".

One additional paper is enclosed which you may wish to consider for the TIC. It is entitled "Regulation of a System with Variable Structure" and was written by Dave Sworder. It was presented at the IEEE Conference on Decision and Control in December 1981.

I'm still working on the rest of the documents you left with me and will get back to you with further comments and recommendations at a later date.

Best wishes,

Harry D. Eden
Project Engineer
Energy and Resources Division

HDE:d

cc: H. Bernstein
M. Watson

Enclosures

DOE/ET/20517-6
(STMPO-039)

SIMPLIFIED LINEAR DYNAMIC MODEL FOR FIRST-CUT CONTROLLER DESIGN OF A SOLAR-POWERED ONCE-THROUGH BOILER

E. E. Schiring
R. O. Rogers
The Aerospace Corp.
El Segundo, CA

E. J. Riel
McDonnell Douglas
Astronautics Co.
Huntington Beach, CA

A. J. Welch
Rockwell International
Rocketdyne Division
Canoga Park, CA

ABSTRACT

A simplified linear dynamic thermal hydra... model of a once-through steam gener... sented. The model is a first-or... tion with pure transport de... analytical expressio... The intended u... of an outlet ... inlet flow r... troller gain... tuning proce... operation. M... several appro... higher order li... obtained from a ... description base... techniques. The ... order linear mod... to that of the simp... analytical credence ... the frequency respo... validated by direct c... response test results ... Energy/Sandia Labor... Facility. Finally, a d... plified model frequency ... on step response test re... validation techniques sh... lar initial controller desi... boilers and to other simil...

INTRODUCTION

The application of a once-th... in a solar-powered central r... an unusual controller design p... temperature controller must p... mance (transient response, sta... steady-state accuracy) in respo... ously varying, uncontrolled sola... variability of solar energy is due ... causes: first, the sun angle varie... day and from day to day throughou... second, the usable solar energy va... intermittent cloud conditions. Beca... varying heat input rate, a necessary ... the steam temperature controller des... is to model and validate the model for ... receiver dynamics, which is the subje... ...nis paper. The actual controller design and test ... the controller performance is being ... resent time and will be the subject ... ...rting.

...h steam generator considered in ... sently undergoing testing at the ... of Energy (DOE)/Sandia ... ral Receiver Test Facility ... ...rque, New Mexico. This ... ...signed for the DOE 10 MWe ... ...nal pilot plant which is being ... ...ifornia. The receiver con... ...r described by Rountree, ...nt concept is shown in ... ...f a field of tracking helio... ...irect and focus the sun's ... ...ceiver mounted atop a ... ...he solar energy is ... ...ted into steam, and the ... ...r a conventional ... ...o charge a thermal ... ...use by the steam tur... ...ion). The steam loop ... ...er back to the ...

...ividually fabricated ... used as preheaters ... ...s, distributed ... ...of the tower. A ... ...own in Figure 2. ... ...ubes of 1/2-inch ... ...te panel area ... ...eet (13.72 m) ... ...t steam tem... ... inlet control ... ...eam tem... ... value.

...eiver portion of the CRTF ... ...idation effort proceeded along ... ...us, and an overview of the effort is ... ...n Figure 3. Some brief comments concerning this figure are made at this point to indicate the nature of the more detailed discussion in the ensuing sections of the paper.

Doug – this paper was given at the ISA Power Industry Division Symposium in the May 1980 & appears in Volume 23 document in "Instrumentation in the Power Industry". Permission to copy must be obtained from them. The Symposium was May 14-16, 1980 in Chicago. HE

HARRY D. EDEN
M3/372 EXT. 87262

DOE F 1325.8
(7-79)

U.S. DEPARTMENT OF ENERGY

memorandum

DATE APR 2 3 1984

REPLY TO ATTN OF S. D. Elliott, Jr., Director, DOE Solar One Project Office

SUBJECT Transmission of Three Conference/Symposium Papers on 10-MWe Pilot Plant Topics by Aerospace (and other) Project Participants

TO William D. Matheny, DOE/TIC Document Control

Enclosed are three conference papers prepared and presented by Aerospace Corporation staff (with co-authorship by McDonnell Douglas personnel in two cases and by Rockwell/Rocketdyne in one) on topics related to work performed for the Solar One Project. Document numbers have been assigned based upon the current DOE contracts with Aerospace Corporation:

Primary Document No.	Secondary No.	Title
DOE-CS/51101-4	STMPO-028	"Dynamic Computer Simulation of the DOE 10 MW Solar Thermal Pilot Plant" (AIAA/ASERC)
DOE/ET/20517-4	STMPO-034	"Preventing Eye Hazards at the 10MW Solar Thermal Pilot Plant (ACGIH & DOE)
DOE/ET/20517-6	STMPO-039	"Simplified Linear Dynamic Model for First-Cut Controller Design of a Solar-Powered Once-Through Boiler" (ISA)

Although the copy of the second paper provided refers to presentation at a DOE Environmental Control Symposium March 15-17, 1980, Aerospace informs me it was originally presented November 27, 1979 to the American Conference of Industrial -Government Hygeinists.

I am not familiar with the processes and copyright restrictions associated with the release of such documents; however, we have cited them in our Project bib liography, and would like to be able to direct inquirers properly, if they wish to obtain copies. Although I do not have any documentation on these, I do know that Aerospace has in the past been meticulous in seeking prior DOE approval for presenting such materials, and assume this was the case here. I am forwarding copies of these documents to SAN Office of Patent Counsel for their information and for any appropriate action.

Please advise me of proper procedures for handling conference reports of this sort; we have a few more old ones to cover, and some are being planned in the near future.

Encls.: 3 Documents w/DOE Forms RA-426

S. D. Elliott, Jr.

cc: M. Lopez, DOE/SAN (FGS)
D. Holz, DOE/SAN (ISEA)
R. Gaither, DOE/SAN (OPC) w/copies
M. Soderstrum, Burns & McDonnell

DOE Form RA-426
(10/80)

U.S. DEPARTMENT OF ENERGY

OMB NO. 038-R0190

DOE AND MAJOR CONTRACTOR RECOMMENDATIONS FOR ANNOUNCEMENT AND DISTRIBUTION OF DOCUMENTS

See Instructions on Reverse Side

1. DOE Report No.	2. Contract No.	3. Subject Category No.
DOE/ET/20517-6 (STMPO-039)	DE-AC03-78ET20517	UC-62

4. Title "SIMPLIFIED LINEAR DYNAMIC MODEL FOR FIRST-CUT CONTROLLER DESIGN OF A SOLAR-POWERED ONCE-THROUGH BOILER"

5. Type of Document ("x" one)
   - ☐ a. Scientific and technical report
   - ☒ b. Conference paper: Title of conference ISA Power Division Symposium (See Symposium Report in ISA Volume 23, "Instrumentation in the Power Industry", May 1980 Date of conference 5/14-16/80

     Exact location of conference Chicago Sponsoring organization Instrument Society of America
   - ☐ c. Other (specify planning, educational, impact, market, social, economic, thesis, translations, journal article manuscript, etc.)

6. Copies Transmitted ("x" one or more)
   - ☐ a. Copies being transmitted for standard distribution by DOE–TIC.
   - ☐ b. Copies being transmitted for special distribution per attached complete address list.
   - ☒ c. Two completely legible, reproducible copies being transmitted to DOE–TIC. (Classified documents, see instructions)
   - ☐ d. Twenty-seven copies being transmitted to DOE–TIC for TIC processing and NTIS sales.

7. Recommended Distribution ("x" one)
   - ☐ a. Normal handling (after patent clearance): no restraints on distribution except as may be required by the security classification.
   - Make available only ☐ b. To U.S. Government agencies and their contractors. ☐ c. within DOE and to DOE contractors.
   - ☐ d. within DOE. ☐ e. to those listed in item 13 below.
   - ☒ f. Other (Specify) Archive

8. Recommended Announcement ("x" one)
   - ☒ a. Normal procedure may be followed. ☐ b. Recommend the following announcement limitations:

9. Reason for Restrictions Recommended in 7 or 8 above.
   - ☐ a. Preliminary information. ☐ b. Prepared primarily for internal use. ☐ c. Other (Explain)

10. Patent, Copyright and Proprietary Information Conference paper; no information on this item

    Does this information product disclose any new equipment, process or material? ☐ No ☐ Yes If so, identify page nos. ____

    Has an invention disclosure been submitted to DOE covering any aspect of this information product? ☐ No ☐ Yes

    If so, identify the DOE (or other) disclosure number and to whom the disclosure was submitted.

    Are there any patent-related objections to the release of this information product? ☐ No ☐ Yes If so, state these objections.

    Does this information product contain copyrighted material? ☐ No ☐ Yes

    If so, identify the page number ____ and attach the license or other authority for the government to reproduce.

    Does this information product contain proprietary information? ☐ No ☐ Yes If so, identify the page numbers ____.

    ("x" one ☐ a. DOE patent clearance has been granted by responsible DOE patent group.

    ☒ b. Document has been sent to responsible DOE patent group for ~~clearance.~~ XXXXXXX information

11. National Security Information (For classified document only; "x" one)

    Document ☐ a. does ☐ b. does not contain national security information

12. Copy Reproduction and Distribution

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13. Additional Information or Remarks (Continue on separate sheet, if necessary)

    Assume this was cleared by the Project Office

14. Submitted by (Name and Position) (Please print or type)

    S. D. Elliott, Jr., Director, DOE Solar One Project Office

Organization

Post Office Box 366, Daggett, CA 92327 (619) 254-2672

Signature [signature] Date APR 23 1984

DOE/ET/20517-6
(STMPO-039)

SIMPLIFIED LINEAR DYNAMIC MODEL FOR FIRST-CUT CONTROLLER DESIGN OF A SOLAR-POWERED ONCE-THROUGH BOILER

E. E. Schiring
R. O. Rogers
The Aerospace Corp.
El Segundo, CA

E. J. Riel
McDonnell Douglas
Astronautics Co.
Huntington Beach, CA

A. J. Welch
Rockwell International
Rocketdyne Division
Canoga Park, CA

ABSTRACT

A simplified linear dynamic thermal hydraulic model of a once-through steam generator is presented. The model is a first-order transfer function with pure transport delay and with explicit analytical expressions for the model parameters. The intended use for the model is the initial design of an outlet steam temperature controller using inlet flow rate valve adjustment, where final controller gains can then be determined through a tuning process of detailed simulation, test, and operation. Model validation is accomplished by several approaches. First, a numerically derived higher order linear model frequency response is obtained from a nonlinear mathematical dynamic description based on established first principles techniques. The frequency response of this higher order linear model is shown to compare favorably to that of the simplified model, thereby providing analytical credence to the simplified model. Next, the frequency response of the simplified model is validated by direct comparison with frequency response test results obtained at the Department of Energy/Sandia Laboratories Central Receiver Test Facility. Finally, a description is given of a simplified model frequency response validation based on step response test results. The modeling and validation techniques should be applicable to similar initial controller design of other once-through boilers and to other similar processes.

INTRODUCTION

The application of a once-through steam generator in a solar-powered central receiver concept poses an unusual controller design problem. The steam temperature controller must provide good performance (transient response, stability margin, and steady-state accuracy) in response to a continuously varying, uncontrolled solar heat input. This variability of solar energy is due to two principal causes: first, the sun angle varies throughout the day and from day to day throughout the year; and second, the usable solar energy varies due to intermittent cloud conditions. Because of this varying heat input rate, a necessary first step in the steam temperature controller design process is to model and validate the model for the boiler/receiver dynamics, which is the subject of this paper. The actual controller design and test validation of the controller performance is being done at the present time and will be the subject of future reporting.

BACKGROUND

The once-through steam generator considered in this paper is presently undergoing testing at the U. S. Department of Energy (DOE)/Sandia Laboratories Central Receiver Test Facility (CRTF) at Albuquerque, New Mexico. This receiver is being designed for the DOE 10 MWe (10^7 J/S) solar thermal pilot plant which is being built at Barstow, California. The receiver controller is conceptually described by Rountree, et. al. (1). The pilot plant concept is shown in Figure 1. It consists of a field of tracking heliostats (mirrors) that redirect and focus the sun's energy onto a central receiver mounted atop a tower. In the receiver, the solar energy is absorbed, water is converted into steam, and the steam is then used to power a conventional turbine/generator and/or to charge a thermal storage unit for subsequent use by the steam turbine (e.g., nighttime operation). The steam loop is closed by pumping feedwater back to the receiver from the condenser.

The receiver consists of 24 individually fabricated vertical flow panels, six panels used as preheaters and eighteen used as boiler panels, distributed circumferentially around the top of the tower. A sketch of an individual panel is shown in Figure 2. Each panel contains 70 individual tubes of 1/2-inch outside diameter with an approximate panel area of 3 feet (0.9144 m) in width by 45 feet (13.72 m) high. Each boiler panel has an outlet steam temperature controller which adjusts the inlet control valve in order to maintain an outlet steam temperature close to a reference set point value.

Modeling and Validation Overview

The modeling of the receiver portion of the CRTF and associated validation effort proceeded along several paths, and an overview of the effort is shown in Figure 3. Some brief comments concerning this figure are made at this point to indicate the nature of the more detailed discussion in the ensuing sections of the paper.

DOE F 1325.8
(7-79)

U.S. DEPARTMENT OF ENERGY

memorandum

DATE: APR 30 1984

REPLY TO ATTN OF: Doug Elliott, DOE/Barstow

SUBJECT: Transmission of Three Conference/Symposium Papers on 10-MWe Pilot Plant Topics by Aerospace Corp. (and others) for SAN/OPC Information/Action

TO: Roger S. Gaither, SAN/OPC

The three enclosed documents have been sent to the DOE Technical Information Center for archiving, announcement and forwarding to NTIS, as part of our Project documentation activity:

Primary Document No.	Secondary No.	Title (abbreviated)	Sponsor
DOE/CS/51101-4	STMPO-028	"Dynamic Computer Simulation."	(AIAA/ASERC)
DOE/ET/20517-4	STMPO-034	"Preventing Eye Hazards..."	(ACGIH & DOE)
DOE/ET/20517-6	STMPO-039	"Simplified Linear Dynamic..."	(ISA)

I am not acquainted fully with the requirements for announcement and/or archiving of such materials, which are subsequently published in symposium or conference proceedings published by the sponsors, and - presumably - copyrighted by the latter; nor do I have records indicating prior clearance for presentation by the Project Office or OPC. Nevertheless, since in my experience Aerospace has been meticulous in obtaining the proper releases for such materials under other contracts, I presume this was done in the case of these papers as well.

I am providing copies of these papers for OPC information and any action as required to permit TIC/NTIS archiving and announcement; I have also prepared copies of the corresponding SAN Form 70's for OPC use as appropriate.

Please advise me of the proper procedures to be followed in the future for (a) other conference/symposium papers and journal articles already issued (and presumably cleared through STMPO) which we wish to have so archived and announced, and cited in future editions of our Project Bibliography; and (b) papers and articles prepared as part of current and future Project activities.

Doug Elliott

S. D. Elliott, Jr., Director,
DOE Solar One Project Office

Encls.: 3 Conference/Symposium papers
w/ SAN Form 70's
Copy of TIC Transmittal Memo

cc: M. Lopez, DOE/SAN (FGS)
D. Holz, DOE/SAN (ISEA)
M. Soderstrum, Burns & McDonnell
W. D. Matheny, DOE/TIC Document Control

DEPARTMENT OF ENERGY
SAN FRANCISCO OPERATIONS OFFICE

CONTRACTOR REQUEST FOR PATENT CLEARANCE FOR RELEASE OF UNCLASSIFIED DOCUMENT

Prime Contract No.
DE-AC03-78ET20517
Subcontract No.
(N/A)
Report No.
DOE/ET/20517-6 (STMPO-039)
Date of Report
May, 1980
Name & Phone No. of DOE Technical Representative
S. D. Elliott, Jr. (619) 254-2672

TO: Roger S. Gaither, Asst. Chief for Prosecution
Office of Patent Counsel/Livermore Office
P.O. Box 808, L-376
Livermore, California 94550

FROM: DOE Solar One Project Office
Post Office Box 366
Daggett, CA 92327

1. Document Title:

2. Type of Document: ☐ Technical Report, XX Conference Paper, ☐ Journal Article, ☐ Abstract or Summary, ☐ Copy of Oral Presentation, ☐ Other (please specify): ____________

3. In order to meet a publication schedule or submission deadline, patent clearance by (routine) would be desired.

SENDER IS TO CHECK BOX #4 OR #5 BELOW.

☐ 4. I have reviewed (or have had reviewed by technically knowledgeable personnel) this document for possible inventive subject matter (Subject Inventions) and that no inventions or discoveries (Subject Inventions) are deemed to be disclosed in this document except as stated below:

a. Attention should be directed to pages ____________ of this document.

b. This document describes matter relating to an invention:

i. Contractor Invention Docket No. ____________.
ii. A disclosure of the invention was submitted to DOE on ____________ (date)
iii. A disclosure of the invention will be submitted shortly ____________ (approximate date)
iv. A waiver of DOE's patent rights to the contractor:
☐ has been granted, ☐ has been applied for; or ☐ will be applied for ____________ (date)

XX 5. This document is being submitted, but no review has been made by me of this document for possible inventive subject matter.

6. Remarks: Return clearance to Project Office; original to Mike Lopez, (SAN/FGS)
Report presented to Instrument Society of America, Chicago, May 14-16, 1980

Reviewing/Submitting Official: Name (Print/Type) S. D. Elliott, Jr., Director
Title DOE Solar One Project Office
Signature [signature] Date April 30, 1984

TO: INITIATOR OF REQUEST

FROM: ASSISTANT CHIEF FOR PROSECUTION
Office of Patent Counsel/Livermore Office

☐ No patent objection to above-identified release.

☐ Please defer release until advised by this office.

Signed ____________ Date Mailed ____________

OPC - 11VFO

DOE/ET/20517-6
(STMPO-039)

SIMPLIFIED LINEAR DYNAMIC MODEL FOR FIRST-CUT CONTROLLER DESIGN OF A SOLAR-POWERED ONCE-THROUGH BOILER

E. E. Schiring
R. O. Rogers
The Aerospace Corp.
El Segundo, CA

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Huntington Beach, CA

A. J. Welch
Rockwell International
Rocketdyne Division
Canoga Park, CA

ABSTRACT

A simplified linear dynamic thermal hydraulic model of a once-through steam generator is presented. The model is a first-order transfer function with pure transport delay and with explicit analytical expressions for the model parameters. The intended use for the model is the initial design of an outlet steam temperature controller using inlet flow rate valve adjustment, where final controller gains can then be determined through a tuning process of detailed simulation, test, and operation. Model validation is accomplished by several approaches. First, a numerically derived higher order linear model frequency response is obtained from a nonlinear mathematical dynamic description based on established first principles techniques. The frequency response of this higher order linear model is shown to compare favorably to that of the simplified model, thereby providing analytical credence to the simplified model. Next, the frequency response of the simplified model is validated by direct comparison with frequency response test results obtained at the Department of Energy/Sandia Laboratories Central Receiver Test Facility. Finally, a description is given of a simplified model frequency response validation based on step response test results. The modeling and validation techniques should be applicable to similar initial controller design of other once-through boilers and to other similar processes.

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STMPO-039

Department of Energy
San Francisco Operations Office
1333 Broadway
Oakland, California 94612

Reply to:

DOE Solar One Project Office
Post Office Box 366
Daggett, CA 92327

(619) 254-2672

MAY 0 3 1984

Mr. William D. Matheny
Chief, Control Branch
Document Control & Evaluation Division
DOE Technical Information Center
Post Office Box 62
Oak Ridge, TN 37830

Subj.: Ten-Megawatt Solar Thermal Central Receiver Pilot Plant ("Solar One") Documentation Activities

Dear Mr. Matheny:

I am sorry to have missed the opportunity to have met with you at SAN last week. Mike Lopez, SAN/FGS (who has been designated as my SAN support resource, and as the SAN Project Director following my departure at the end of this fiscal year) tells me, however, that you feel that our coordination with respect to Project documentation has been successful. As I have said previously, to you and to others, I am very glad to have the resources of TIC available to assist us in developing what I regard as one of the most valuable products of our effort: information. Any comments or suggestions (please be frank!) regarding how we might be able to further expedite the process will be most welcome. With the resources available to me over the next five months (Mike Lopez and Don Holz at SAN, Mary Soderstrum of Burns & McDonnell, and our EPRI-published bibliography - see the enclosed flyer - now summarized on the on-site computer), I am in a good position to fulfil my self-imposed goal of having all Project documentation to date fully catalogued, and distributed as appropriate to TIC and NTIS, by the end of FY84.

A couple of questions have arisen, largely drawn from the "feedback" I receive through the "Solar Thermal" Current Awareness Bulletin and the "reports Holdings File" printouts for SAN contracts Don Holtz forwards to me:

1. I note that a number of our "STMPO" reports, submitted to TIC with UC-62 distribution recommended on our Form RA-426's, appear in the "Holdings File" under UC-58c instead. While the reports so listed, for example, under Cooperative Agreement SF10501 (see enclosure) do, in fact, reflect "education, training and information dissemination...", I feel that my primary audience for these reports is the Solar Thermal community, and would appreciate it if all "STMPO-xxx" reports submitted by this office (including those already logged) could also appear under UC-62. This is especially valuable since the advent of the Solar Thermal Current Awareness Bulletin, which, I presume, is made up from the UC-62 listings. I have been "bragging this up" as a way of tracking incorporation of items from our bibliography into the TIC data base.

2. On the same subject, I am wondering whether I ought to be citing UC-62c or -d rather than UC-62. I had assumed that UC-62 was the more extensive addressee listing but Don Holz forwarded to me an extract from DOE/TIC-4500(Rev. 71) which shows 209 addressees for UC-62d (Central Receivers) and 195 for UC-62c (Large-Scale Systems), versus only 179 for UC-62 (Solar Thermal). I'd really like to reach

all these addressees; is there a better way to do so (like, "UC-62x")?

3. I also note, in the Report Holdings File, that some documents show "NTIS", "PC" and a price code on the right under "Source". All of the documents on the enclosed list for SF10501 have been patent cleared, and it was our intention that they all go to NTIS. Is there some policy reason why they have not? I can provide verification of patent clearance for all of these if you need it. Also, I note that the documents that have been cleared and forwarded to NTIS show "04" under "DS" and "EDB;ERA" and (usually) "NTS" under "Announcement", while those that have not show "09" and "HLO", respectively. Can you translate these for me?

4. Did you receive the re-submission of the "missing" reports DOE-SF/10501--22-VC through --33-VC I sent off February 20? (I'll bet they turn up on the next Report Holdings File Don sends me, just as soon as I put this in the mail!). I note you show only one copy for DOE/SF/10501--137 (which did get forwarded to NTIS), and --304 (which did not). I meant to send two; did I goof up, or are these typos?

5. Can you advise me as to which contract number you elected to list ERDA RFP 75-124 (STMPO-046) under? (I offered you several choices in my letter of transmittal of February 6, inst. - see enclosure) I'd like to enter the official report number in our next bibligraphy update.

6. I am still feeling my way on how to handle conference/symposium reports and journal articles, old and new. Am I on the right track with the three old Aerospace papers cited in my memo to you of April 23 and the enclosed April 30 memo to SAN/OPC? And, can you advise me of the report number assignments for these, if the primary document numbers I have suggested are not appropriate? STMPO-039

Thank you for your patience and support. If you should have another opportunity to come to the West Coast before the end of September, please plan to stop by Solar One (Las Vegas and Ontario airports are both convenient; Los Angeles is less so) and look over our operation; I'll be happy to give you the "VIP tour" as partial recompense for your help.

Encls.: EPRI Report Summary/Announcement
Report Holdings File extract: SF10501
Ltr. Project Office to TIC, 2/6/84
Memo, Project Office to SAN/OPC, 4/30/84

Sincerely yours,

Doug Elliott

S. D. Elliott, Jr., Director,
DOE Solar One Project Office

cc: Mike Lopez, DOE/SAN (FGS)
Don Holz, DOE/SAN (ISEA)
Mary Soderstrum, B&McD

SAN FORM 70 10/80

DEPARTMENT OF ENERGY
SAN FRANCISCO OPERATIONS OFFICE

CONTRACTOR REQUEST FOR PATENT CLEARANCE
FOR RELEASE OF UNCLASSIFIED DOCUMENT

Prime Contract No.	DE-AC03-78ET20517
Subcontract No.	(N/A)
Report No.	DOE/ET/20517-6 (STMPO-039)
Date of Report	May, 1980
Name & Phone No. of DOE Technical Representative	S. D. Elliott, Jr. (619) 254-2672

TO: Roger S. Gaither, Asst. Chief for Prosecution
Office of Patent Counsel/Livermore Office
P.O. Box 808, L-376
Livermore, California 94550

FROM: DOE Solar One Project Office
Post Office Box 366
Daggett, CA 92327

1. Document Title: "SIMPLIFIED LINEAR DYNAMIC MODEL FOR FIRST-CUT CONTROLLER DESIGN OF A SOLAR-POWERED ONCE-THROUGH BOILER"

2. Type of Document: ☐ Technical Report, ☒ Conference Paper, ☐ Journal Article, ☐ Abstract or Summary, ☐ Copy of Oral Presentation, ☐ Other (please specify): ________

3. In order to meet a publication schedule or submission deadline, patent clearance by (routine) would be desired.

SENDER IS TO CHECK BOX #4 OR #5 BELOW.

☐ 4. I have reviewed (or have had reviewed by technically knowledgeable personnel) this document for possible inventive subject matter (Subject Inventions) and that no inventions or discoveries (Subject Inventions) are deemed to be disclosed in this document except as stated below:

a. Attention should be directed to pages ________ of this document.

b. This document describes matter relating to an invention:

i. Contractor Invention Docket No. ________.
ii. A disclosure of the invention was submitted to DOE on ________ (date)
iii. A disclosure of the invention will be submitted shortly ________ (approximate date)
iv. A waiver of DOE's patent rights to the contractor:
☐ has been granted, ☐ has been applied for; or ☐ will be applied for ________ (date)

☒ 5. This document is being submitted, but no review has been made by me of this document for possible inventive subject matter.

6. Remarks: Return clearance to Project Office; original to Mike Lopez, (SAN/FGS)
Report presented to Instrument Society of America, Chicago, May 14-16, 1980

Reviewing/Submitting Official: Name (Print/Type) S. D. Elliott, Jr., Director
Title DOE Solar One Project Office
Signature S D Elliott Date April 30, 1984

TO: INITIATOR OF REQUEST

FROM: ASSISTANT CHIEF FOR PROSECUTION
Office of Patent Counsel/Livermore Office

M. Lopez, SAN

☒ No patent objection to above-identified release.

☐ Please defer release until advised by this office.

5/3/84

Signed L. E. Carnahan Date Mailed 5/8/84

2

COPY FOR CONTRACTOR'S (SENDER'S) FILES AFTER OPC RELEASE

Department of Energy
Office of Scientific and Technical Information
Post Office Box 62
Oak Ridge, Tennessee 37831

Technical Information Center

June 14, 1984

Mr. S. D. Elliott, Jr., Director
DOE Solar One Project Office
Post Office Box 366
Daggett, CA 92327

Dear Doug:

Sorry I have taken so long to answer your May 3, 1984 letter on Solar One Documentation Activities, but after the SAN visit I have had a week in Las Vegas, a trip to Bonneville Power Administration, a trip to Idaho Operations Office, an appraisal of the Oak Ridge Gaseous Diffusion Plant, and a Department-wide technical information meeting at the Office of Scientific and Technical Information (OSTI). I appreciate the kind words about OSTI and also your attitude about the importance of information management. If more people took a similar approach it would certainly make the job of managing the Department's technical information program a lot easier.

I will attempt to answer your questions in the order asked:

1. Some of the STMPO reports were selected for category UC-58c because in the opinion of the evaluator they fit there better. One contributing factor is that we have several evaluators and this sort of thing which is a judgment call, will be made differently by different evaluators. As you may know we select only one UC category for the RHF and microfiche distribution even though we can make hard copy distribution in several categories. In the future if you will indicate UC-62 on the form 426 the evaluators will usually go along with this. The "Solar Thermal Awareness Bulletin" is not driven by the UC-categories but rather by the EDB categories assigned by our Science and Technology Division.

2. To reach all addresses in UC-62, 62c, and 62d you should indicate all three categories on the report cover and the form 426. That way when we do make hard copy distribution we send to all addresses.

3. All reports that are unlimited are <u>considered</u> for NTIS but only those with significant saleable information are selected for NTIS. This is a judgment call and even though a report is not selected for NTIS the implied alternative is that OSTI will make the report available to any requestor. The reports showing DS=09 and HLO were the non-selected for NTIS and no microfiche distribution (09).

4. We did receive the missing reports DOE/SF/10501-22VC through 33VC. The one copy thing was a typo.

5. We decided to list the report ERDA RFP 75-124 (STMPO-046) under both AC03-76ET20417 and AC03-76ET20422. The primary number assigned was DOE/ET/20417-T8 (secondary STMPO-046).

6. In your handling of conference papers and journal articles, treat conference papers just like reports, i.e. send them to OSTI with a form 426 with patent clearance, journal articles should cite the DOE contract number and sponsoring DOE program office as a footnote and should be sent to OSTI if they are submitted to an obscure journal. If the journals are mainstream science or engineering journals OSTI will pick up the citation from the open literature. OSTI's processing policy for conference papers is to treat them like reports until such time as the full proceedings are available then process no more individual papers from that conference since the papers are then available as part of the proceedings. In the case of the 3 Aerospace papers; DOE/CS/51101-4 was processed as a report with availability at AIAA, DOE/ET/20517-4 is included in the full proceedings at NTIS as STMPO-039 CONF-800334--Vol.2, DOE/ET/20517-6 has not been made available anywhere (could you send a complete copy of this one).

I will be coming back to Las Vegas this fall and if it is in September I will try to get in touch with you beforehand and see if we will have time to tour Solar One.

Sincerely,

Bill Matheny

William D. Matheny
Chief, Control Branch
Document Control & Evaluation Division

cc: Mike Lopez, DOE/SAN (FGS)
Don Holz, DOE/SAN (ISEA)
Mary Soderstrum, B&McD

Department of Energy
San Francisco Operations Office
1333 Broadway
Oakland, California 94612

Reply to:

DOE Solar One Project Office
Post Office Box 366
Daggett, CA 92327

(619) 254-2672

AUG 03 1984

Mr. William D. Matheny
Chief, Control Branch
Document Control & Evaluation Div.
DOE Office of Scientific
and Technical Information
Post Office Box 62
Oak Ridge, TN 37831

Subj.: Submission of Two Reports by Aerospace Corporation in Support of Solar One Pilot Plant Project; Comments Concerning Three Additional Reports

Dear Mr. Matheny:

Enclosed are two copies each of two reports prepared by the Aerospace Corporation (under two separate contracts with ERDA/DOE) in support of the Solar One Ten-Megawatt (electric) Central Receiver Solar Thermal Pilot Plant project:

DOE Document No.	Secondary No.	Contract	Title
DOE/CS/51101-3	STMPO-027	DE-AT03-76CS51101	Barstow Daily Insolation Plots, Calendar Year 1976
ATR-80(7747)-2	STMPO-035	DE-AC03-78ET20517	Number of Thermal Cycles Estimated for the 10 MWatt Pilot Plant over its 30-Year Lifetime

Each report is accompanied by a completed DOE Form RA-426. Through a misunderstanding, compounded by the passage of time and the dispersal of former Project participants, both reports were submitted to - and cleared by - SAN/OPC under a single SAN Form 70, as shown by the attached correspondence. (It appears that the data plotted in STMPO-027 were assumed to have provided the background for the analysis of STMPO-035; in fact, the latter was based upon data acquired later, and reported under STMPO-32 and -33; Aerospace ATR -80(7747)-1, Vols. 1 & 2.) By copy of this letter, SAN/OPC and Aerospace will be advised of this correction. Please process the two attached reports as indicated on the respective RA-426's.

In your letter of June 14, 1984, responding to several inquiries of mine, you asked whether I could obtain for you a complete copy of the Instrument Society of America Proceedings in which STMPO-039 (DOE/ET/20517-6) was included. Unfortunately, I have been unable to do so. Can you advise me whether this report and STMPO-034 (DOE/ET/20517-4, listed by you as at NTIS in the proceedings CONF-800334, Vol. 2) will be filed by OSTI as individual reports? They have not as yet shown up on the Reports Holdings File under contract ET20517 (my most recent copy of the RHF is the May 29, 1984 printout), and I'd like to be able to check them off on my "Punch list". A copy of your letter and Xeroxes of the report covers are provided as Attachment 2.

Last April, we resubmitted an old Aerospace report, ATR-77(8523-22)-3 (STMPO-015), which had somehow gone astray in the system. It has turned up on the RHF printout (under Contract DE-AT03-76CS51101), but does not show a "PC" (nor did I get a SAN Form 70 feedback from SAN/OPC); did the clearance ever get to you, or should I go back to Roger Gaither? (See Attachment 3).

Please let me know if your Las Vegas trip is still on for September; I will be in the Solar One Project Office through September 28. If you can't come West until after that date, however, a call to the Visitors' Center in advance, at (619) 254 -2810, will provide a tour, if you identify yourself as a "high DOE official" and /or my guest.

Encls.: 2 reports, w/DOE Forms RA-426

Attchs.: 3, as stated

Sincerely yours,

Doug Elliott

S. D. Elliott, Jr., Dorector,
DOE Solar One Project Office

cc: H. Eden/C. Randall, Aerospace
R. Gaither, DOE/SAN (OPC)
M. Lopez, DOE/SAN (ISEA)
D. Holz, DOE/SAN (ISEA)
M. Soderstrum, B&McD

DOE F 1325.8
(7-79)

U.S. DEPARTMENT OF ENERGY

memorandum

DATE [illegible] 8 1984

REPLY TO ATTN OF Doug Elliott, DOE/Barstow

SUBJECT Assorted Aerospace Reports; Closure

TO Harry Eden, Aerospace

I think we've spent all the time on this topic any of us can afford. The only loose end I can think of is that you may want to get these two reports back into the Aerospace "system" as separate documents, which they were originally. I've got all I need at this end, and OSTI (nèe TIC) should be all set once Bill Matheny has digested my letter.

Please thank Dr. Randall for the rewrite on the "Thermal Cycles " paper; it's a most pertinent reference for future designers, and I'm also submitting the companion paper by John Raetz (Ref. 2) to OSTI/NTIS.

Please call me if you have any need for further follow-up; and let me know if you should have a cahance to come to (or past) Solar One before I leave in September.

Doug

S. D. Elliott, Jr.